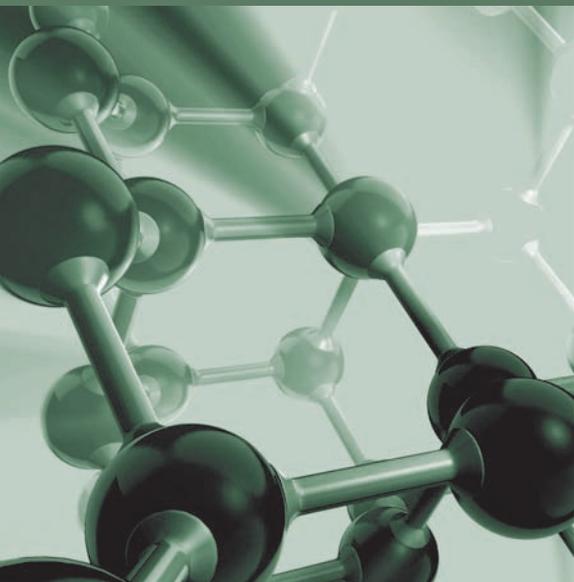


Formulating Strategies in Cosmetic Science



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Introduction

Cosmetic science is a constantly evolving, ever-changing world. Changes come from consumer preferences, but they are always flavored by chemistry, formulating, regulatory and legal disciplines. The formulation of consumer acceptable high performance personal care products is one of the most challenging undertakings for a chemist. There are many reasons why the challenge is so great and becoming more acute. The industry has undergone a metamorphosis in recent years. Every year new technology, formulation techniques and raw materials come into existence. Along with these, new regulations, registrations, patent pressures and ever-changing consumers' preferences are a daily event. In addition, the number of chemists formulating has been reduced and the product life cycle is compressing.

Chemists have a need to keep up to date with the available technology to respond to the new market needs. This includes not only formulating techniques, but basic science. *Formulating Strategies in Cosmetic Science* presents the work of a variety of individuals that have been published in *Cosmetics and Toiletries* magazine that is timely and valuable to formulators in addressing the science and art of personal care. It is not intended to be all-inclusive and the reader is encouraged to look at the various references in each work to expand their knowledge.

Armed with the proper knowledge raw materials become formulator friendly and formulations become multi-functional.

Happy reading!

SECTION I

Preservatives

The ability to prevent degradation of personal care products by microbial growth is the challenge of preservation. The frequency of use of preservatives is covered in this section. Testing and the special needs of specific product groups are also presented in various articles. Finally the concept of “natural preservatives” is discussed.

- 1 The Safety Factor in Preservative Efficacy Testing
- 2 The Labeling of Fragrance Allergens in the European Union
- 3 Natural Preservatives
- 4 Frequency of Use of Preservatives 2003
- 5 The “Period After Opening” in the Jungle of EU Product Labeling
- 6 Water Activity
- 7 Natural Preservation from Concepts in Nature

The Safety Factor in Preservative Efficacy Testing

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KEY WORDS: *preservative system, regulations, efficacy testing, microbial contamination, compliance*

ABSTRACT: *The authors explain how preservative efficacy testing is done to determine whether a formula is adequately preserved. Product contamination problems are frequently caused by inadequate preservation.*

Aqueous consumer products in multiple-use containers need a preservative system to prevent microbial contamination during manufacturing and consumer use, and to comply with governmental regulations. Preservative efficacy testing is performed to determine the type and minimum effective concentration of preservative(s) required for satisfactory preservation of these products.¹

In its *Cosmetics Handbook* under “Adequacy of Preservation,” the FDA recommends that: (a) each batch of a cosmetic which is not self-preserving be tested for microbial contamination before it is released for interstate shipment; and (b) each cosmetic, particularly each eye area cosmetic, be tested during product development for adequacy of preservation against microbial contamination that may occur under reasonably foreseeable conditions of consumer use.²

The European Union's Cosmetic Directive states that all cosmetics must have in their product information package ("dossier") the microbiological specifications of the raw materials and the finished product; the dossier must also disclose the purity and the microbiological control criteria of the cosmetic product.³

Preservative efficacy test methods include the following:

- Compendial methods, such as the United States Pharmacopoeia (USP) and European Pharmacopoeia (EP) methods;
- Trade association methods, such as the Cosmetic, Toiletry, and Fragrance Association (CTFA) method; and
- Rapid methods, such as the linear regression method.

Several articles have discussed similarities and differences in these test methods. Orth, Delgadillo and Dumatol⁴ reported that the slower rates of death allowed by both the USP and CTFA methods may be too lenient.

It is believed that reliance on lenient acceptance criteria may result in products that are inadequately preserved. This can result in sporadic contamination problems and tends to make cosmetic microbiology seem perplexing and governed by factors that we are unable to control. Actually, products that are well preserved kill microorganisms quickly and meet USP and CTFA criteria. Products that are marginally preserved may still meet USP and CTFA criteria, but they may kill Gram negative bacteria so slowly that these bacteria are able to adapt, survive and/or grow.^{4,5} This results in product contamination.

Preservative efficacy testing is part of the safety testing of a product. Although aqueous cosmetics and drugs in multiple-use containers are not intended to be sterile, as they are not applied to sterile surfaces, adequately preserved products have a preservative system that renders them self-sterilizing. Such products kill contaminating bacteria quickly enough so that they do not become a health hazard or undergo unacceptable physical changes (color, odor, viscosity, pH, and other factors).

Toxicologists often apply a safety factor, which may be 10-fold or 100-fold greater than toxicity test endpoints observed in animal

studies or in vitro test models when extrapolating the data to humans. Although preservative efficacy testing is performed to determine whether the product preservative system can kill microorganisms fast enough to pass test criteria, there is little published information on how to determine whether a preservative system has a satisfactory margin of safety to insure adequate preservation. The goal of this work was to determine the risk factor for bacteria provided by the acceptance criteria of current methods of preservative efficacy testing and to use this factor to determine the preservation safety factor for cosmetic and drug products.

Acceptance Criteria of Test Methods

USP method: The USP acceptance criteria for topical aqueous products is “not less than 2.0 log reduction from the initial count at 14 days, and no increase from the 14 days’ count at 28 days.”⁶

Although a product that kills microorganisms quickly (e.g., complete kill of 10^6 cfu/g within 24 h) passes USP acceptance criteria, the criteria also allow slow killing. Thus, a 2-log (99%) reduction of bacteria by 14 days actually means that the number of viable bacteria decreases from the initial level of about 10^6 cfu/g to 10^4 cfu/g living organisms at 14 days (and thereafter).

It is evident that these criteria do not require complete kill of the test organisms in 28 days, and it is possible that the survivors will be able to adapt and grow if given the right circumstances.

EP method: The acceptance criteria for topical products using the EP method is a 2-log reduction of bacteria in 48 h and a 3-log reduction by 7 days, with no increase afterwards.⁷ This method does not require killing all the bacteria during the 28 day test.

CTFA method: The acceptance criteria of the CTFA method states that there should be greater than 99.9% (3-log) reduction of vegetative bacteria within 7 days following each challenge and continued reduction for the duration of the [28 day] test.⁸ This actually means that the number of viable bacteria decreases from the initial level of about 10^6 cfu/g to $<10^3$ cfu/g living organisms at 7 days (and thereafter). Although more stringent than the USP criteria, the CTFA method does not require killing all the bacteria during the 28 day test.

Linear regression method: The rate of inactivation of test organisms in the linear regression method is given by the decimal reduction time (D-value), which is the time required for killing 90% (1-log) of the population of test organisms.

The D-value is calculated by taking the negative reciprocal of the slope of the survival curve, plotted using the log number of surviving microorganisms as a function of the time at which samples were taken, for each test organism. Smaller D-values indicate faster rates of death, and larger D-values indicate slower rates of death.

The target acceptance criteria are a D-value ≤ 4 h [a ≥ 6 -log reduction in 24 h] for pathogens; a D-value of ≤ 28 h [a ≥ 6 -log reduction in 7 days] for nonpathogenic vegetative bacteria, yeasts and molds; and bacteriostatic or bactericidal for *Bacillus* spp. spores.⁹ Adequacy of preservation is indicated by complete kill of at least 10^6 cfu/g pathogens in 24 h, and at least 10^6 cfu/g nonpathogens by 7 days.

Comparison of Test Methods

Figure 1.1 is a plot of the slowest rates of death allowed by the USP, CTFA and linear regression methods. Although the target criteria of the linear regression method require a complete kill of at least 10^6 cfu/g pathogens in 24 h and at least 10^6 cfu/g nonpathogens by 7 days, the other methods do not require a complete kill of the test organisms during the 28 day test.

Figure 1.1 shows that the USP and CTFA methods allow microorganisms to persist in products after a 2- or 3-log reduction in viable cell counts. This figure differs from a similar figure in an earlier publication in which the USP criteria then required a ≥ 3 -log reduction by 14 days¹⁰ and initial rates of death were extrapolated to the X-axis.

Orth and co-workers⁴ reported the maximum allowable D-value (MA D-value) for Gram negative bacteria routinely used in preservative efficacy testing was < 30 h. *Pseudomonas aeruginosa*, *Burkholderia (Pseudomonas) cepacia* and *Escherichia coli* did not die and/or began to grow after an initial decline if D-values were not < 30 h.

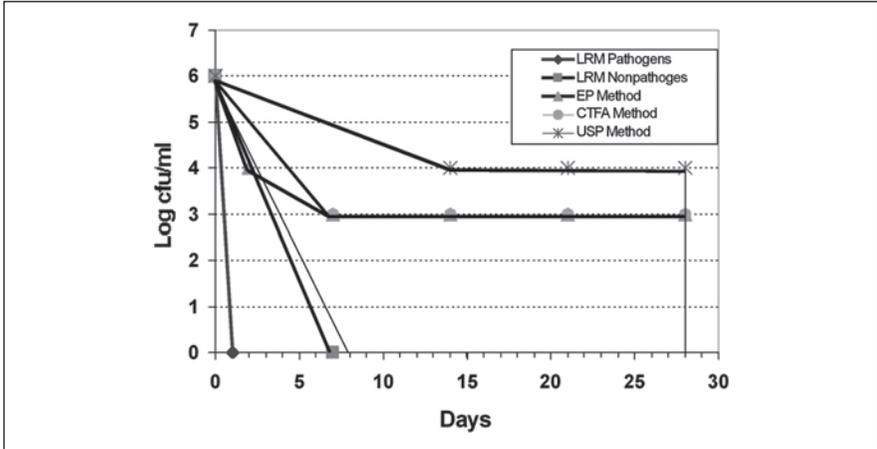


Figure 1.1. Comparison of slowest rates of death allowed by the USP, EP, CTFA and linear regression methods of preservative efficacy testing. The region where preservative systems may fail (shaded area) shows where the formula risk factor is >1 because the rates of death of bacteria are ≥ 30 h.

Although similar studies have not been reported for Gram positive bacteria, these findings indicate that Gram negative bacteria introduced into products may survive and/or grow unless the preservative system kills them with a D-value of <30 h. This is indicated as the “Region where preservative system may fail” in the shaded area of **Figure 1.1**. Here, the survival curves show the slowest rates of death allowed by the USP, EP, CTFA and linear regression methods of preservative efficacy testing. The Region where preservative system may fail (shaded area) shows where the formula risk factor is >1 because the rates of death of bacteria are ≥ 30 h. The type of contaminating microorganism(s), their physiological state, the nutrients provided by the product, and storage conditions (time, temperature, oxidation/reduction potential, and other factors) determine whether Gram positive or Gram negative bacteria will survive and grow in any given situation.

When discussing rates of bacterial death using %-reductions or log-reductions, a time interval must be included (such as, a 3-log reduction in 7 days). D-values are used in all areas of microbiology to describe rates of death of microorganisms. Conversion of USP, EP and CTFA challenge test acceptance criteria to D-values

enables direct comparison of the slowest rates of death allowed by these methods.

The log-reductions (initial rates of death) allowed by the different methods are given in **Table 1.1**. Conversion of these log-reductions to D-values gives values of <156 h, ≤24 h, and ≤56 h for USP, EP and CTFA methods, respectively. These D-values give the rates of death without stating the number of hours or days required for a given number of log-reductions.

Table 1.1. Comparison of acceptance criteria and risk factors provided by the USP, EP, CTFA and linear regression methods

Test Method	Log-Reductions	D-value	MA D-value	Risk Factor*
USP	>2 by 14 days	<156 h	30 h	5.6
EP	≥2 by 2 days	≤24 h	30 h	0.8
CTFA	>3 by 7 days	<56 h	30 h	1.87
LRM-Path.**	≥6 by 1 day	≤4 h	30 h	0.13
LRM-Nonpath.**	≥6 by 7 days	≤28 h	30 h	0.93

* D-value determined from the initial rate of death in USP, EP and CTFA methods
 * MA D-value determined for Gram negative bacteria⁴
 * Risk Factor = D-value/MA D-value
 ** LRM-Path. = Linear regression method for pathogens
 ** LRM-Nonpath. = linear regression method for nonpathogens

Required D-Value

It is possible to specify the rate of death required for test organisms in a product depending on the type of packaging and consumer use. Orth, Barlow and Gregory⁵ reported that the preservative efficacy of the formula, the protection provided by packaging (the packaging factor), and the conditions of use (the consumer use/abuse factor) must be considered when determining the adequacy of preservation of a product. Criteria for determining packaging and consumer use/abuse factors are given in **Tables 1.2** and **1.3**.

Table 1.2. Criteria for risk assessment of packaging to allow microbial contamination of a product

Packaging Factor	Type of Packaging Closure
1 (low risk)	Single use product/applicator Unit-dose container Hermetically sealed container
5 (moderate risk)	Multiple-use container intended for use where contact with water or wet/soiled fingers is likely <ul style="list-style-type: none"> • Lotion in pump dispenser • Cream in tube with screw cap or flip-top
10 (high risk)	Multiple-use container intended for use where repeated contact with water or wet/soiled fingers may occur <ul style="list-style-type: none"> • Shampoo/conditioner in pump dispenser or tube with screw cap or flip-top • Toothpaste tube with screw cap or flip-top • Jar of cream with removable lid • Eye shadow/mascara with reusable applicator (brush/wand)

Table adapted from Orth et. al⁵

Orth and co-workers related D-values of a formula with packaging and consumer use/abuse factors in the required D-value (RDV) by the following expression:

$$RDV = D\text{-value}_t / (F_p * F_{cua})$$

where

D-value_t is the D-value of a target organism,

F_p is the packaging factor of the product, and

F_{cua} is the consumer use/abuse factor.

Application of the RDV enables one to determine what D-value is required by specific (target) organisms when the type of packaging and consumer use are known. The consumer use of a product generally cannot be changed because consumers use shampoos in the shower, apply pressed powders using a pad, and dispense lotions from a tube or bottle. However, the preservative system may need to

be improved or packaging modified to achieve the desired RDV and have a product that will be microbiologically safe and stable during consumer use.

Table 1.3. Criteria for risk assessment of consumer use/abuse that may allow microbial contamination of a product

Consumer Factor	Type of Consumer Use/Abuse
1 (low risk)	Using single-use product/applicator <ul style="list-style-type: none"> • Shampoo in unit-dose container • Lotion in tear-open packet
5 (moderate risk)	Using multiple-use product where touching product with wet/soiled fingers may occur occasionally <ul style="list-style-type: none"> • Touching outlet of lotion pump as product is dispensed • Touching tip of tube when dispensing sunscreen onto fingers
10 (high risk)	Using multiple-use product where repeated product touching with wet/soiled fingers occurs or where contact with water occurs <ul style="list-style-type: none"> • Removing cap from bottle of shampoo while showering • Moistening mascara applicator (wand) and reintroducing it into product • Adding water to the bottle of liquid soap or bath gel to get all of the product out of the bottle, and re-using this diluted product over a period of days

Table adapted from Orth et. al⁵

Risk Factor of the Preservative System

Experience has shown that Gram negative bacteria generally are more capable of adapting and causing problems in aqueous cosmetic and drug products than are Gram positive bacteria, so use of the MA D-value for Gram negative bacteria in aqueous products provides a more conservative approach to safety assessment than using similar data for Gram positive bacteria.

The contamination risk factor is an expression of the ability of the formulation to prevent growth based on the rate of death of specific test organisms, relative to the rate of death at which bacteria die so slowly that they may adapt and grow (or persist) in the formula.

The risk factor for the preservative system may be determined by dividing the D-value for a specific bacterium in that product by the MA D-value for Gram negative bacteria (30 h). For example, a formula with a D-value of 30 h for Gram negative bacteria would have a risk factor of $30 \text{ h}/30 \text{ h} = 1$ for these microorganisms. This formula would be expected to prevent growth by unadapted bacteria, but may have no margin of safety. A formula with a D-value of 15 h for *E. coli* or *B. cepacia* would have a risk factor of $15 \text{ h}/30 \text{ h} = 0.5$ for these bacteria. If *S. aureus* had a D-value of 20 h in the same formula, the risk factor for *S. aureus* would be $20 \text{ h}/30 \text{ h} = 0.67$.

Risk factors were calculated using the maximum acceptance criteria for the USP, EP, CTFA and linear regression methods (**Table 1.1**). It is believed that products with risk factors >1 may not be adequately preserved, and their preservative system may fail. Formulas that meet EP and linear regression method criteria would be adequately preserved for Gram negative bacteria because all have risk factors ≤ 1 . Note that formulas that just meet the linear regression method acceptance criteria for pathogens (4 h) would have a risk factor of $4 \text{ h}/30 \text{ h} = 0.13$. It is very important that products be adequately preserved against pathogens that could cause skin or eye infections.

Aqueous formulations that allow microbial growth without the addition of preservatives [i.e., they are not self-preserving due to low water activity (a_w)] should have D-values $\leq 4 \text{ h}$ for opportunistic pathogens such as *P. aeruginosa*. Self-preserving formulas with low a_w should be tested and shown to be bacteriostatic/slowly bactericidal. Although a_w -based formulas may not provide killing of bacteria with D-values of $\leq 30 \text{ h}$, they are inherently self-preserving, they do not permit microbial growth, and the formula risk factors discussed here do not apply.

Determining the Microbial Safety Factor for a Product

The preservative system of the formula is very important; however, other parameters are required for determining the microbiological safety factor of a product. The microbial safety factor for a product may be calculated by dividing the RDV in hours by the risk factor for a formula, as follows:

Microbial Safety Factor = RDV (in hours) / Risk Factor

Criteria for risk assessment of packaging and consumer use/abuse are presented in Tables 2 and 3.

It is desirable to have a topical lotion with an RDV of 4 h for *P. aeruginosa*. If we have a product with a formula that meets acceptance criteria of the linear regression method (D-value ≤ 4 h), protective packaging (i.e., a lotion in a small tube that minimizes contamination; packaging risk factor = 1) and good protection from consumer contamination (consumer use/abuse risk factor = 1), we can determine the RDV and microbial safety factor as follows:

$$\text{RDV} = 4 \text{ h} / (1) * (1) = 4 \text{ h}$$

$$\text{Microbial Safety Factor} = 4 / 0.13 = 30$$

In this example, this product has a 30-fold safety factor, so it is unlikely that it would become contaminated by *P. aeruginosa* during consumer use. If the same formula were to be used as a shower treatment product (consumer use/abuse factor = 10), it would probably have different packaging (i.e., a bottle with a flip-top cap; packaging risk factor = 5). This would change the RDV and microbial safety factors as follows:

$$\text{RDV} = 4 \text{ h} / (5) * (10) = 0.08 \text{ h}$$

$$\text{Microbial Safety Factor} = 0.08 / 0.13 = 0.62$$

Here, the formula still has a D-value of 4 h for *P. aeruginosa*, but the packaging allows contamination during use in the shower. This illustrates that the same formula may have a safety factor of 30 when used as lotions are commonly used and that it may have a safety factor of 0.62 when used as a shower product. A product with a safety factor < 1 has no margin of safety.

Even though the formula may be adequately preserved for *P. aeruginosa*, it is possible that the use as a shower product will result in contamination because the product will be touched with wet fingers during repeated use in the shower over a period of weeks/months. If the packaging cannot be changed to reduce the packaging

factor, it may be necessary to increase the type/concentration of preservatives to decrease the risk factor of the preservative system. This illustrates the necessity for evaluation of both consumer use and the type of packaging prior to final selection of the packaging for any product.

Examples illustrate that the risk factor of the formula and the RDV may be used to determine the safety factor for a product. A formula that just meets USP criteria has a risk factor of 5.6 and a safety factor for *P. aeruginosa* of $4/5.6 = 0.71$. There is no margin of safety with a safety factor of <1 . Bacterial contamination during consumer use is possible unless the packaging and the manner in which it is used restrict human and environmental contamination. The likelihood of contamination could be reduced by use of small tubes (perhaps 1 oz.) so that the product would be used up in a few weeks. This would reduce repeated exposure and the possibility of microbial adaptation (a consumer use/abuse factor = 1). If the tube had a small orifice to help prevent consumer contamination, the product would have a packaging factor = 1.

A formula that just meets CTFA criteria would need packaging that provides two-times the protection in a formula that just meets linear regression criteria for nonpathogens. When selecting criteria that result in acceptance of formulas in the “Region where preservative systems may fail to prevent bacterial growth” (**Figure 1**), it is quite possible that the greatest consumer protection would be obtained with unit-dose packaging, or small tubes with narrow orifices (as mentioned earlier).

The linear regression method acceptance criteria provide a product safety factor of just greater than one for nonpathogens and substantially greater than one for pathogens. It appears that this safety factor is adequate for aqueous cosmetic and drug products because to the best of our knowledge, formulas that meet the acceptance criteria of the linear regression method have never been contaminated with unadapted microorganisms.

On the other hand, USP and CTFA criteria have acceptance criteria that allow microbial safety factors of <1 , and it is known that products that are considered to be satisfactorily preserved by these

methods may allow microbial growth.¹⁰ Although a safety factor of >1 does not guarantee that a product cannot become contaminated during manufacturing or consumer use, it provides a rational basis for predicting the likelihood of product contamination. Obviously, a product with a safety factor of 10 is much less likely to become contaminated than a formula with a safety factor of <1 , if all other conditions remain constant. It is believed that use of microbial safety factor in product development will help take some of the mystery out of cosmetic microbiology.

Conclusions

Preservative efficacy testing is carried out to determine whether a formula is adequately preserved. Product contamination problems seem perplexing, yet they frequently are caused by inadequate preservation—the products do not have a large enough microbial safety factor.

- Lenient acceptance criteria may result in inadequately preserved products.
- Different methods have different acceptance criteria for determining adequacy of preservation. These criteria generally do not consider packaging or consumer use.
- The RDV may be used to determine preservative requirements of a product when the type of packaging and consumer use are known.
- Contamination risk factors for preservative efficacy testing methods may be determined from the slowest rate of death allowed by the acceptance criteria (i.e., the maximum allowable D-value) and the MA D-value for Gram negative bacteria.
- The microbial safety factor for a product may be determined by dividing the RDV by the risk factor.
- Aqueous products with a microbial safety factor of >1 have an excellent history being satisfactorily preserved in manufacturing and during use by consumers.

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The Labeling of Fragrance Allergens in the European Union

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KEY WORDS: *allergen, fragrance, essential oil, 7th Amendment, labeling*

ABSTRACT: *The 7th Amendment to the Cosmetic Directive of the European Union (EU) has added 26 new contact allergens that the EU states must be listed on the ingredient declaration if they exceed certain minimum levels.*

The 7th Amendment to the Cosmetic Directive of the European Union (EU) has added 26 new ingredients to the “Annex III List of Substances Which Cosmetic Products Must Not Contain Except Subject to Restrictions and Conditions Laid Down.” These 26 ingredients are all contact allergens found in fragrances. Under comments 15 and 16,¹ the EU states that in order to inform consumers who are allergic to these ingredients, it will mandate that these be listed on the ingredient declaration if they exceed certain minimum levels. These levels are 0.001% in leave-on products and 0.01% in rinse-off products. **Table 2.1** lists the 26 ingredients with their EU Reference number, names as listed, INCI designation if different, their CAS number and the Frequency of Use as reported by the FDA.

The current North American Contact Dermatitis Group (NACDG) tray used by dermatologists to check for allergic reactions has a fragrance mixture that includes these eight ingredients: cinnamic alcohol (EU-68), cinnamic aldehyde (EU-76), hydroxycitronellal (EU-72), amylcinnamaldehyde (EU-67), geraniol (EU-78),

eugenol (EU-71), isoeugenol (EU-73) and oakmoss (EU-91).² I wonder if the NACDG tray might be expanded to include all of the 26 EU allergens.

Table 2.1. The European Union 26 fragrance allergens

Chemical Name	INCI Designation	CAS Number	Use
Amyl cinnamal		122-40-7	
Benzyl alcohol		100-51-6	380
Cinnamyl alcohol		104-54-1	
Citral		5392-40-5	3
Eugenol		97-53-0	
Hydroxy-citronellal	Hydroxycitronellal	107-75-5	
Isoeugenol		97-54-1	
Amylcinnamyl alcohol	Amylcinnamyl alcohol	101-85-9	
Benzyl salicylate		118-58-1	
Cinnamal		104-55-2	15
Coumarin		91-64-5	
Geraniol		106-24-1	
Hydroxy-methylpentyl-cyclohexenecarboxaldehyde	Hydroxyisohexyl 3-cyclohexone carboxaldehyde	31906-04-4	
Anisyl alcohol	Anise alcohol	105-13-5	
Benzyl cinnamate		103-41-3	
Farnesol		4602-84-0	16
2-(4-tert-Butylbenzyl)propionaldehyde	Butylphenyl methylpropional	80-54-6	
Linalool		78-70-6	
Benzyl benzoate		120-51-4	45
Citronellol		106-22-9	
Hexyl cinnam-aldehyde	Hexyl cinnamal	101-86-0	
d-Limonene	Dipentene (CAS 138-86-3)	5989-27-5	7
Methyl heptin carbonate	Methyl 2-octynoate	111-12-6	
3-Methyl-4-(2,6,6-trimethyl-2-cyclohexene-1-yl)-3-buten-2-one	Alpha-isomethyl ionone	127-51-5	
Oakmoss extract	<i>Evernia prunastri</i> (oakmoss) extract	90028-68-5	
Treemoss extract	<i>Evernia fururacea</i> (treemoss) extract	90028-67-4	

Cosmetic manufacturers have been contacting their fragrance suppliers and are asking about the levels of these 26 components. At a meeting held in October 2002 in England, Kristi Holt (Firmenich, UK) gave the following statistics based on a survey of 347 leave-on cosmetics in the UK:

- 3% of the products on the market contain more than 15 allergens;
- 24% contain 11–15 allergens;
- 50% contain 6–10 allergens;
- 22% contain 1–5 allergens;
- 1% contain no allergens.

In a similar survey, rinse-off products fared only slightly better.³

I have heard that some companies are asking their fragrance vendors to re-formulate and remove all of these 26 ingredients. That doesn't make sense for two reasons. The first is the enormous expense in replacing these commonly used, inexpensive compounds. The second is if you removed all 26 from all use, whatever replaces them will become the next 26 common allergens. It is far easier just to change your label.

The real problem arises when cosmetic companies discover that their products may contain some of these allergens from sources other than the intentionally added fragrance. This EU regulation is based on the total present in the formulation—regardless of the source or origin.

What other sources are there? Benzyl alcohol is used as a preservative and as an external analgesic. It is found in these mixtures as listed in the latest International Nomenclature Cosmetic Ingredient (INCI) Dictionary: Covafix 123 (LCW), Euxyl 100 (Schülke & Mayr), Jambu Oleoresin (Takasago), Microcare CB (Acti-Chem) and Nipaguard CMB (Clariant). d-Limonene is found as the INCI name dipentene as a solvent. Farnesol is used in deodorants and as a preservative—“booster.”^a Eugenol is listed as a permitted denaturant in SD Alcohol 38-B. Many of these compounds appear as components in essential oils.

Essential Oils

These are the real nightmare. As naturally occurring compounds, essential oils have a composition that varies. Also, the definition of essential oils is subject to debate. The most common definition is that they are volatile oils produced by steam, steam and water or water distillation of vegetable plant matter. The vapors are condensed to yield a water condensate and the essential oil that can be separated off usually by gravity.

Please note: Essential oils are not soluble or compatible with water. Citrus peel oils are still referred to as essential oils although they are mechanically cold pressed from the rinds of the citrus fruit. Finally certain “essential oils” are also produced by the distillation of oleo-resins and absolutes.⁴

Please also note the following facts about what an essential oil is *not*.

- It is not solvent extracted.
- It is not a product of dry (destructive) distillation.
- It is not a molecular distilled product.
- It is not natural. The steam distillation causes chemical reactions, so the composition is not the same as found in nature.

Table 2.2 lists the 45 essential oils that are being used in cosmetics in the U.S., according to findings of the U.S. Food and Drug Administration (FDA). Allergens used at a concentration of 1% or more are listed. I would caution everyone that these are approximates and you should confirm the levels in your final formulation. This table is meant to be used only as a guide.

It is interesting to note that five essential oils (benzoin, cedarwood, myrrh, patchouli and sandalwood) do not show measurable presence of any of the allergens (i.e., the allergens are present at levels less than 1%). The others do. So much for “natural” being safe.

Table 2.2. Allergens typically found in levels of greater than 1% in essential oils found in cosmetics, as reported to the FDA

Essential Oil	INCI Name	FOU	Allergens
Anise	<i>Illicium verum</i> (anise) oil	6	Limonene
Basil	<i>Ocimum basilicum</i> (basil) oil	15	Eugenol, Limonene, Linalool
Benzoin	<i>Styrax benzoin</i>	7	
Bergamot	<i>Citrus aurantium bergamia</i> (bergamot) fruit oil	16	Limonene, Linalool
Cajuput	<i>Melaleuca leucadendron cajuputi</i> oil	7	Limonene, Linalool
Camphor	<i>Cinnamomum camphora</i> (camphor) bark oil	5	Limonene
Cardamom	<i>Elettaria cardamomum</i> seed oil	24	Geraniol, Limonene, Linalool
Carrot	<i>Daucus carota sativa</i> (carrot) seed oil	31	Geraniol, Limonene, Linalool
Cedarwood	<i>Cedrus atlantica</i> (cedarwood) bark oil	9	
Chamomile	<i>Anthemis nobilis</i> flower oil	55	Limonene
Cinnamon leaf	<i>Cinnamomum cassia</i> leaf oil	5	Cinnamyl alcohol, Cinnamal, Eugenol, Benzyl Benzoate, Linalool
Clary sage	<i>Salvia sclarea</i> (clary) oil	10	Geraniol, Limonene, Linalool
Clove	<i>Eugenia caryophyllus</i> (clove) flower oil	49	Eugenol
Coriander fruit	<i>Coriandrum sativum</i> (coriander) fruit oil	22	Geraniol, Limonene, Linalool
Cypress	<i>Callitris intratropica</i> wood oil	49	Limonene
Eucalyptus	<i>Eucalyptus globus</i> leaf oil	73	Limonene
Geranium	<i>Geranium maculatum</i> oil	72	Citral, Geraniol, Citronellol, Limonene, Linalool
Ginger	<i>Zingiber officinale</i> (ginger) root oil	5	Limonene
Grapefruit	<i>Citrus grandis</i> (grapefruit) peel oil	17	Limonene
Juniper berry	<i>Juniperus communis</i> fruit oil	4	Limonene
Lavandin	<i>Lavandula hybrida</i> oil	7	Limonene, Linalool
Lavender	<i>Lavandula angustifolia</i> (lavender) oil	156	Limonene, Linalool
Lemongrass	<i>Cymbogon schoenthus</i> oil	24	Citral, Geraniol, itronellol, Limonene, Linalool

continues

Table 2.2. continued

Essential Oil	INCI Name	FOU	Allergens
Lemon	<i>Citrus medica limonum</i> (lemon) peel oil	100	Citral, Limonene
Lime	<i>Citrus aurantifolia</i> (lime) oil	14	Citral, Limonene
Mandarin	<i>Citrus nobilis</i> (mandarin orange) peel oil	16	Limonene
Marjoram	<i>Origanum majorana</i> leaf oil	11	Limonene, Linalool
Myrrh	<i>Commiphora myrrha</i> oil	7	
Orange	<i>Citrus aurantium dulcis</i> (orange) flower oil	63	Limonene
Palmarosa	<i>Cymbogon martini</i> oil	8	Geraniol, Farnesol, Limonene, Linalool
Parsley	<i>Carum petroselinum</i> (parsley) seed oil	5	Limonene
Patchouli	<i>Pogostemon cablin</i> oil	4	
Peppermint	<i>Mentha piperita</i> (peppermint) oil	105	Limonene
Petitgrain	<i>Citrus aurantium</i> (bitter orange) oil	14	Geraniol, Limonene, Linalool
Pine	<i>Pinus palustris</i> oil	10	Limonene
Rose	<i>Rosa damascena</i> flower oil	39	Citral, Eugenol, Geraniol, Citronellol, Farnesol, Linalool
Rosemary	<i>Rosmarinus officinalis</i> (rosemary) leaf oil	108	Limonene
Sage	<i>Salvia officinalis</i> (sage) oil	46	Limonene, Linalool
Sandalwood	<i>Santalum album</i> (sandalwood) oil	39	
Spearmint	<i>Mentha viridis</i> (spearmint) leaf oil	26	Limonene
Tangerine	<i>Citrus tangerina</i> (tangerine) peel oil	6	Limonene
Tea tree	<i>Melaleuca alternifolia</i> (tea tree) leaf oil	31	Limonene
Thyme	<i>Thymus vulgaris</i> (thyme) oil	54	Limonene, Linalool
Tonka	<i>Diperyx odorata</i> seed oil	3	Coumarin
Ylang	<i>Cananga odorata</i> flower oil	27	Benzyl Salicylate, Benzyl Benzoate, Farnesol, Linalool

FOU=Frequency of Use

Labeling

The first step in complying with this new regulation is to determine which of the 26 allergens are in your product. The best way is to analyze your final formulation. If you lack the methodology or equipment to do this, you are left relying on your suppliers and then totaling everything up to see if you exceed the threshold that requires you to label them.

If you do have these allergens present in your formulation and you wish to dual label your product for sale in the U.S. and the EU, you may face another dilemma. In the U.S., you are required to list all of your ingredients in descending order of predominance to 1%, and then any order after this. The FDA allows you to use the term “fragrance” or “flavor” instead of listing the components. The other option is to list all of the components.

In order to comply with the EU allergen listing, you will have to list the term fragrance (parfum) or flavor (aroma) and then list the allergens. The FDA has not committed on whether this hybrid listing will be acceptable to them. Let’s look at an old label and how you would list it with the new EU requirements.

For this body lotion I do not know the quantitative composition and have made some modifications for illustrative purposes only.

Old label:

Water, Octyl Palmitate, Butylene Glycol, Hyaluronic Acid, Cetyl Alcohol, Glycol Stearate, Polysorbate-20, Orange Oil, Lavender Oil, Petitgrain Oil, Rosemary Oil, Benzyl Alcohol, Methylparaben, Fragrance.

New EU label:

Water (Aqua), Ethylhexyl Palmitate, Butylene Glycol, Hyaluronic Acid, Cetyl Alcohol, Glycol Stearate, Polysorbate-20, Citrus Aurantium Dulcis (Orange) Flower Oil, Lavandula Angustifolia (Lavender) Oil, Citrus Aurantium (Bitter Orange) Oil, Rosmarinus Officinalis (Rosemary) Leaf Oil, Benzyl Alcohol, Methylparaben, Fragrance (Parfum), Citral, Eugenol, Limonene, Linalool.

The key point is not listing benzyl alcohol twice. I have also assumed the only allergens in the fragrance are benzyl alcohol, citral, eugenol, limonene and linalool.

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Natural Preservatives

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KEY WORDS: *preservatives, natural preservatives, regulatory status, packaging, self-preservation*

ABSTRACT: *Traditional methods of preservation, such as those used in the food industry and some available from natural plants, suggest a natural preservative system whose components are already available to the formulator.*

The subject of natural preservatives probably has more academic interest than practical or economic virtue. However, it does have a wonderful marketing angle that may justify the higher raw material costs.

This chapter looks at the most commonly used methods of preservation that are already available to the formulator. It also conceptualizes the theoretical development of a natural preservative system using a database on medicinal plants as a source of reference. The legal aspects of this concept in Europe are considered. The traditional methods of preservation—many taken from the food industry—are summarized. The use of alcohol, glycerine, sugar, salt, dessication, anhydrous systems and temperature are amongst examples considered. The commercial solutions are examined.

Regulatory Position: Annex VI

According to European regulation, the only permitted preservatives are those that appear in Annex VI Part 1 or 2 of the EEC Cosmetic Directive 76/768/EEC, including the 7th amending Commission Directive 94/32/EC.

However, there is no legislation for those natural materials, which, when used for their beneficial effect on the skin, may coincidentally have a positive effect on the total preservative requirement of the formulation. Of course, no material appearing in Annex II may be considered for use.

The food industry often uses a preservation technique known as the “hurdle approach,” where there are a number of different methods that might eliminate organisms on their own if used at a high level, but which in a food might make the product unpalatable. The idea of using a whole variety of these “hurdles” to slowly weaken each organism, but at individual levels that would be ineffective, is an almost alien concept to the cosmetic and toiletry industry.

Natural Ingredients

Sugar: High levels of sugar can preserve against spoilage organisms. This may be seen in jams, preserves, certain sweet pickles and marmalades. This is also an important factor in the preservation of boiled sweets and chocolates.

Increasingly, it will be noticed that many products now have to be kept in the refrigerator or freezer once opened because sugar has been replaced by artificial sweetener, which is cheaper and healthier to eat but compromises the self-preservation of the product.

Honey: Honey, in its undiluted form, is also a natural preservative and, indeed, there are many scholarly papers citing honey as a viscous barrier to bacteria and infection.

Salt: The use of extreme levels of salt is effective. This technique was used by the ancient mariners to preserve their meat. It very likely that the preservation of the Egyptian mummies was, in part, achieved by the 40-day treatment in natron (a concentrated brine solution that osmotically drained the tissues of water). Sugar, honey and salt all work as preservatives by lowering the water activity.

Alcohol: Not all organisms are bad! The production of alcohol from sugar by yeast is an industry in its own right. A wine that is carefully produced using sterilized equipment and fermented to 13% by volume will just about resist further infection from external organisms once the ferment has completed. It is during the

fermentation process that the fermenting new wine is vulnerable to infection.

The naturally produced fermentation grade alcohol can be concentrated by distillation and used as a natural preservative in toners, aftershaves and colognes. The purist would argue that the denaturant present in the alcohol is not “natural,” and they would be right. The need to return to quassin, the bitter substance present in quassia (*Picraena excelsa*), might be a solution; however, the Customs & Excise officials might not see your antique solution to denaturing with quite the same enthusiasm.

Acid pH and chelating agents: The preservative activity can be boosted by operating at as low a pH as possible. Natural acidity could be obtained from one of the many alpha hydroxy acids (AHAs) that are obtained from citrus species, where the major components are citric and malic acids.

Chelating agents, such as ferulic acid extracted from rice bran, could be added to enhance the activity of the natural preservative.

Antioxidants: Antioxidants, such as natural tocopherol and ascorbic acid, will aid in preservation. They will also help in reducing the potential rancidity.

Glycerine: High levels (15–20%) of vegetable glycerine will also have a preservative effect, similar to that effect obtained by the use of high levels of sugar.

Emulsion form: It has been argued that the formula comprised of a water-in-oil emulsion, where the oil is the continuous phase, is far less likely to be subject of attack by spoilage organisms, compared to an oil-in-water emulsion. This might be true, but it certainly does not exclude the use of a preservative system. It does, however, form another link in the hurdle approach to preservation.

Emulsifier type: Many years ago someone marketed a material called Lauricidin, which was glyceryl laurate. It was said to mimic the sterile and protective action found in a mother’s milk (as well as in bovine milk). It had been found that the properties that determine the anti-infective action of lipids are related to their structure: free fatty acids and monoglycerides.

The monoglycerides are active; diglycerides and triglycerides are inactive. Of the saturated fatty acids, lauric acid has greater antiviral

activity than caprylic acid (C_8), capric acid (C_{10}) or myristic acid (C_{14}). Lauric acid is one of the best “inactivating” fatty acids, and its monoglyceride is even more effective than the fatty acid alone.

Once again the system has been shown to work, but the formulating is difficult and highly unpredictable. It might be a good solution for those with a large research department and plenty of human resources.

Natural Processes

Heat: Heating, cooking and pasteurization is another natural form of preservation that will sterilize a product, especially when that product is designed for one-shot use, such as a vial or a sachet. Alternatively, once opened, the product can be stored in the refrigerator or freezer to prevent microbiological degradation.

Cold: Placing a product in the cold merely “stops the clock” on microbiological growth. This is perfectly fine, provided the product was sterile when it was placed in the cold and/or had sufficient preservative “mass” to counter any new organisms subsequently introduced.

Dessication: Removing water from a product or making it totally dehydrated will greatly reduce the possibility of spoilage. However, it must be noted that any spore-bearing organisms could become active once that water is reintroduced.

Anhydrous: In a similar vein, one could make products with materials that do not contain any traces of water, and in this way deliberately design and formulate a totally anhydrous product. However, creams that can be finished by the consumer—by introducing water to the blend of oils, fats and waxes—are prone to the same restrictions as the dessicated products.

Self-Preservation of Plants

Plants in the wild do not go moldy, yet they are in an environment that predisposes them to suffer from infestation from all manners of spoilage organisms. Yeasts, molds and bacteria abound in the soil, all working to decompose dead plant material and provide fresh humus

for those plants living in the soil. Living plants resist the natural forces of disintegration.

The chemicals present in all parts of the plant protect it from the environment. However, examples can be seen where tampering with the plant leads to a reduction in the efficacy of this natural mechanism.

It is concluded that the chemical constituents within each plant clearly differ in composition. Furthermore, in certain plant species there may be a chemical or group of chemicals capable of killing microorganisms. This chemical composition varies according to whether the plant is alive or dead, and in most plants will vary according to season.

In many cases, when these plants are extracted, it is found that the extracts are capable of resisting certain spoilage organisms, and in some cases can act to destroy them. The time and speed of extraction of the fresh plant is often critical if the preservative activity is to be retained.

Commercial Products

On the market are a number of natural preservatives that are not legal, strictly speaking, because they are not listed in Annex VI as a permitted preservative. However, the use of a plant for its marketing claim or for other functional benefits smudges the issue. One may use a number of plant derivatives as fragrance components and coincidentally achieve a lower overall preservative requirement for the product in which they are used.

There are many cases where plants may contain paraben-type compounds in addition to other functional actives and the difficulty is to decide whether the botanical is being used as a preservative or for other legitimate and perfectly legal benefits.

Silver chloride: In days of old, wine and water were stored in silver vessels because it had been observed that the keeping time was vastly improved over using earthenware jugs and pots. This is somewhat surprising because one might have expected that the glazes (often rich in lead) on those earthenware pots might have further aided preservation.

The modern preservative is comprised of silver chloride (20%) deposited on a substrate of titanium dioxide. It does appear in Annex VI, but is prohibited for use in products for children under three years of age. It is not allowed in oral products and those products intended for application around the eyes and lips. It is limited to 0.004% when calculated as silver chloride.

Nature identicals: A number of materials already allowed in the legislation occur naturally in nature. Among these are benzoic acid (limit 0.5% as the acid) and benzyl alcohol (limit 1%). They can be obtained naturally from natural sources such as balsamic resins, but the price is ludicrously expensive. Benzoic acid is moderately good against Gram-positive bacteria, yeast and molds, but moderately poor against Gram-negative bacteria. Benzyl alcohol is good to very good against Gram-positive, moderately poor against Gram-negative, poor versus fungi and moderately poor against yeast.

Sorbic acid (and perhaps its salt, potassium sorbate) is found in nature (originally from *Sorbus aucuparia* or rowanberry). A synthetic version is also available. Sorbic acid can be used up to 0.6%. It is moderately effective against all bacteria and good against fungi and yeasts.

A two-pack system consisting of lactoperoxidase, glucose oxidase and glucose does not appear in Annex VI but has found a good following amongst the green brigade. It is very awkward to work with and has to be premixed just prior to addition to the finished batch. Its mechanism is said to mimic the conditions that keep a cow's udder free of infection while the cow is suckling its calf.

The "Illegal" Preservatives

Citrus seed extracts: There are other dodges used by the "green" formulators in their quest for preservatives that are both listed in Annex VI and occurring in nature. Citrus fruits have always been a useful source of alpha hydroxy acids, fragrant essential oils and useful astringents.

Everything in the fruit is useful: the juice for its vitamin C claims; the peel gives a fragrant essential oil and enables a "zest" claim; the

flowers yield an exquisite and very expensive essential oil called neroli; and the seeds yield an antibacterial that is either hesperidin (**Figure 3.1a**) or naringenin (**Figure 3.1b**) depending on the citrus species chosen.

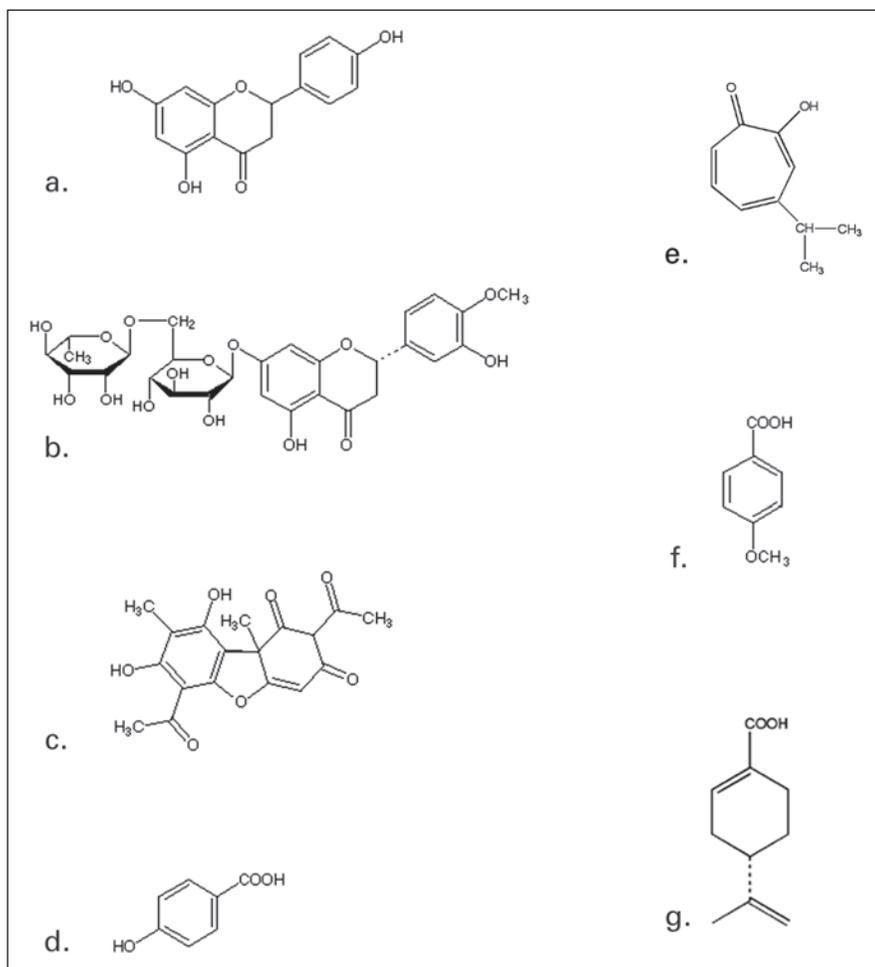


Figure 3.1. Structures of “illegal” preservatives

a Naringenin

b Hesperidin

c Usnic acid

d p-Hydroxy benzoic acid

e Hinokitiol

f Anisic acid

g Perillic acid

This can be slipped in with other citrus components and is conveniently lost amongst the myriad of exotic ingredients. As if by magic, the need for a preservative has disappeared.

It is not simple to formulate with these types of materials and you have to do a lot of experiments because not all systems are compatible. Nevertheless, success can be achieved.

Tree lichen extracts: The tree lichen (*Usnea barbata*) contains usnic acid (**Figure 3.1c**), which is a fairly powerful agent against yeast and molds. It comes as no surprise, therefore, that when this extract is used at a reasonable concentration these spoilage organisms are not able to grow. The traditional use of this material for infections of the feet is well justified.

Japanese honeysuckle extracts: A plant preservative that is based on the Japanese honeysuckle (*Lonicera japonica*) is described as being a complex mixture of esters of lonicerin and natural p-hydroxy benzoic acid (**Figure 3.1d**). Clearly this is a naturally occurring paraben, and we would expect this material to have antimicrobial properties.

Formosan hinoki tree: Hinokitiol (**Figure 3.1e**) is a white crystalline acidic substance first isolated from the essential oil of Formosan hinoki (*Chamaecyparis taiwanensis* Masamune et Suzuki) by Nozoe in 1936. This substance was also found in the essential oil of aomori hiba tree (*Thujopsis dolabrata* SIEB et ZUCC) at a later date.

Though the natural form of hinokitiol is no longer available, the nature-identical form is still made. It may be a surprise to learn that this material is listed as a hair conditioning agent in the CTFA Ingredient Dictionary. If one were looking for a conditioning effect with this ingredient, it might be annoying to discover that the anticipated preservative system was superfluous to requirement. It is also unusual in that it has a 7-membered ring and is quite unlike any other preservative one normally encounters.

The parfum (fragrance): Another clever idea is to look at essential oils and then isolate one or two of the components that coincidentally have antimicrobial activity. Since these components came from an essential oil, they must be perfumery-based materials and can be listed as parfum or fragrance.

The two largest commercial players at this time are anisic acid (**Figure 3.1f**) or 4-methoxy benzoic acid (the similarity to a paraben is outstanding) and levulinic acid or 4-oxopentanoic acid. Anisic acid is found in aniseed (*Pimpinella anisum*) amongst many sources, and levulinic acid has been found as a by-product in the production of diosgenin from wild yam (*Dioscorea villosa*).

This area could be exploited far more, because there are many other essential oil components that have anti-bacterial properties.

Perillic acid: A material that was presumably first found in *Perilla frutescens* or the Japanese shiso oil is perillic acid (**Figure 3.1g**). The perillaldehyde present has already been found effective against *Acnes propionibacterium* and *Staphylococcus aureus*.

This material is made commercially by the conversion from limonene using a biotechnology process. It has been found to have good activity against Gram-positive and Gram-negative bacteria.

Packaging Considerations

We have considered the base. We have also considered the additives that could be added in order to reduce or eliminate spoilage organisms in our products. The last piece of the jigsaw is the packaging.

Wide-neck jars with shives (the plastic discs that cover the neck) are probably the worst news for the microbiological integrity of a product. Those covers allow water to condense on the surface and then enrich the organisms. The cardboard seal in the lid is another microbial sponge just waiting to act as a growth medium.

Tubes are far better (which is why they are more widely used in the pharmaceutical industry). The nozzle offers a smaller and more discrete surface for contamination. There are now tubes that have non-return valves so that, once pressed, the tube cannot relax to permit the ingress of air. Notice how tubes for eye products have long tapering nozzles with a small pinhole for delivery of product. This is good microbiological sense.

The new generation of pots does not allow the consumer to insert fingers that may be highly contaminated. There are pots with nozzles and sealed flat surfaces that have airless pistons that follow the product to completion. The product is offered to the consumer at a push.

The days of scooping out are over, especially with the 7th Amendment demanding declaration of a “use after opening” period.

It could be argued that in these sealed and hygienic environments, the need for a microbial challenge test is over because the consumer and the air will never enter the product during its active life. The preservative requirement will be a fraction of that required for a wide-necked cream jar.

The most secure pack is a single-application pack, the sachet, the blister pack and the single-shot capsule. These are technologies that come to us from the fast food and pharmaceutical industries. You use it all or throw away the residue. It is the perfect preservative-free environment and the worst example of wastefulness.

Conclusions

A move toward “preservative-free” is being achieved by many means. It is hoped that this overview has provided an insight into some of the techniques available. Any means used to preserve cosmetic formulations must be verified by appropriate challenge test or in-use test methods. Simply adding ingredients without testing for effectiveness and safety is a “natural” road to disaster.

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Frequency of Use of Preservatives 2003

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KEY WORDS: *preservatives, frequency of use, voluntary registration program, electronic filing, Cosmetic Ingredient Review (CIR), Food and Drug Administration (FDA)*

ABSTRACT: *The importance of participating in the FDA's Voluntary Registration of Cosmetics Formulations program is reviewed, and that program's data on the frequency of use of preservatives is presented.*

Although the data on frequency of use of preservatives has not changed much in recent years, there are additional reasons to support the voluntary program that collects that data. This chapter reviews those reasons and presents the latest data on preservative use.

Voluntary Registration with the FDA

Nearly two years have passed since my last report¹ on the frequency of use of preservatives in cosmetic formulations sold in the U.S. and voluntarily registered with the Food and Drug Administration (FDA) by cosmetics manufacturers. Although the number of registered formulations has increased by approximately 10% since then, this difference in numbers is not significant. The real reason to publish now (as opposed to every three years, as I intended) is the FDA's movement to encourage cosmetic companies to file their forms electronically. The new system will allow companies to fill out forms online and hit the "send" button—making registration and updating a snap. There should be no reason for not participating.

Why participate? There are some very important reasons why every company should participate.

Active participation: One of the best “defenses” against new regulations to our industry is to show that we actively participate in the voluntary programs run by the FDA. This shows that self-regulation works. New FDA regulations would be mandatory. How long would it take to submit the necessary information and wait for the FDA to send their okay before you can put a product on the market?

The EU last year strongly considered the pre-submission of their product information packages (PIP) (dossiers) as a requirement before a product could be placed on the market. Fortunately for all of us, as an alternative to this pre-approval step they agreed to allow public access to the PIP with the exception of the quantitative formulation.

The CIR priority list: The Cosmetic Ingredient Review (CIR) uses the data collected to determine its priority list, which leads to an even more important function of this data. If the CIR reaches a verdict of “insufficient data” because there has not been enough documentation submitted to support a conclusion of safety for a given ingredient, the FDA (which again is actively attending the CIR meetings) may require any cosmetic containing that ingredient to have the 740.10 label. This is the label that says, “WARNING the safety of this product has not been determined.” According to the Code of Federal Regulations,² that warning is required when any cosmetic or any ingredient in the cosmetic that has not been found to be safe. So a CIR finding of “insufficient data” can trigger this warning.

Who would buy a cosmetic with this warning besides lawyers? When the CIR faces this problem, the CTFA tries to contact all known users to advise them of how important it is to submit safety data for this ingredient to the CIR. How does the CTFA know who uses this ingredient? From these filings! So a second reason to participate is to be notified of this potential danger to your business.

Proof of use: The European Union requires that all ingredients used in cosmetics sold in the EU must be on its inventory list. The original list was an old edition of the CTFA Dictionary. It quickly

became obvious that many ingredients listed in the dictionary were not used, so the EU started to remove them from its inventory.

How does an ingredient get on the inventory if it is not already there? The manufacturer must submit a government report showing proof of the ingredient's use. The only such U.S. report that is available to the EU officials is the FDA's report based on these voluntary filings of Form 2512a. Hence any U.S. company that wants to sell its formulations in the EU really needs to submit Form 2512a for each formulation. Even many EU companies that do not sell products in the U.S. understand this, and as a result, many EU formulations are registered with the FDA.

It recently became clear to me that the FDA does not know the database contained registrations from EU countries. At a recent CIR meeting, an FDA spokesman remarked that the database contained some formulations that use a preservative that the CIR had found to be "unsafe." I explained to him how the registrations were filed and that the formulations in question were from the EU and, as far as I knew, not imported into the U.S.

Lawsuit defense: If I had been asked two years ago why companies should participate, the above list would be my reasons. However, in the last two years I have used this data obtained from the FDA database in defense of companies who were being sued for injuries allegedly sustained by consumers who used the companies' products. The lawyers claimed that the cosmetics involved were "defective" and were not typical of the type of product found in the industry. I was able to show where each ingredient was very frequently found in cosmetics registered under the FDA's voluntary registration program. By the use of these statistics, those parts of the complaints were dropped.

The data used in those trials was available because companies participated. Lack of participation results in very poor statistics. So just in case you are ever involved in these types of lawsuits, you really need this data for your defense. Finally, from a purely personal standpoint, without active participation the report you are now reading would be useless, so please take part so we all can see what is being used!

Preservatives Frequency of Use

Clearly, parabens and imidazolidinyl urea remain our most popular preservatives, along with phenoxyethanol, frequently used as a solvent for parabens.

There are no striking changes in this report. Some preservatives remain the same, which may be a result of inactive registration in the case of a preservative that hasn't been removed or has limited activity. These include: paraformaldehyde/formalin, sodium bisulfite, benzethonium chloride, chloroacet-mide (found to be unsafe by the CIR and probably only has EU filings), methenamine, 5-bromo-5-nitro-1,3-dioxane (probably EU filings), o-phenylphenol/sodium o-phenylphenol, grapefruit seed extract (a fraudulent preservative), triclocarban, glutaral, polymethoxy bicyclic oxazolidine, chlorhexidine, dihydrochloride, escin, dichlorobenzyl alcohol, phenyl mercuric acetate (probably obsolete and in formulations that were never deleted), chlorhexidine acetate, dimethoxane (probably obsolete and in formulations that were never deleted as the manufacturer has withdrawn its use as a cosmetic preservative), domiphen bromide, dichlorophene, hinokitiol, phenoxyisopropanol, thimersol (probably obsolete and in formulations that were never deleted), sodium propylparaben and benzylparaben (probably obsolete and in formulations that were never deleted). Complete lists of the frequency of use of preservatives can be found in **Tables 4.1** and **4.2**.

A review of old reports indicates that the declines in use of quaternium-15 and the mixture of methylchloroisothiazolinone and methylisothiazolinone have been reversed and these preservatives are again growing in use. This report will be the last time methylchloroisothiazolinone and methylisothiazolinone are reported as one entry. The U.S. producer has introduced methylisothiazolinone as a "pure" preservative and I will report it that way in the future.

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Table 4.1. Frequency of use of preservatives in cosmetic formulations reported in 2003 vs. 2001 (by amount of use); the data and report was written in 2001 and published in 2002

Preservative	2003	2001
Methylparaben	7161	6893
Propylparaben	5809	5621
Butylparaben	2326	2174
Imidazolidinyl urea	2038	2025
Ethylparaben	1725	1451
Phenoxyethanol	1670	1480
Sodium sulfite	1177	933
DMDM Hydantoin	993	943
Diazolidinyl urea	725	701
Methylchloroisothiazolinone/Methylisothiazolinone	699	595
Quaternium-15	516	505
Benzoic acid/Sodium benzoate	500	462
Sorbic acid/Potassium sorbate	479	432
Triclosan	451	443
Dehydroacetic acid/Sodium dehydroacetate	445	396
Benzyl alcohol	380	321
Sodium borate	280	273
Isobutylparaben	227	187
Iodopropynyl butylcarbamate	172	170
2-Bromo-2-nitro-1,3-diol	168	164
paraformaldehyde/formalin	139	139
Salicylic acid	125	127
formaldehyde	118	118
Methyldibromo glutaronitrile	95	88
Benzalkonium chloride	85	83
Boric acid	78	77
Chlorhexidine digluconate	60	57
Sodium bisulfite	58	58
Chloroxylonol	43	42
Hexamidine isethionate	43	37
Sodium methylparaben	42	38

continues

Preservative	2003	2001
Isopropylparaben	41	33
Benzethonium chloride	39	39
Chloroacetamide	37	37
Methenamine	32	32
Phenethyl alcohol	31	30
5-Bromo-5-nitro-1,3-dioxane	30	30
o-Phenylphenol/sodium o-phenylphenol	28	28
Sodium hydroxymethylglycinate	24	23
Grapefruit Seed Extract	22	22
Triclocarban	22	22
Glutaraldehyde (Glutaral)	20	20
Polymethoxy bicyclic oxazolidine	19	19
Chlorhexidine dihydrochloride	18	18
Chlorphenesin	17	12
Escin	15	15
Dichlorobenzyl alcohol	11	11
Phenyl mercuric acetate	11	11
Chlorhexidine acetate	9	9
Dimethoxane	9	9
Domiphen bromide	6	6
Captan	5	7
Dichlorophene	5	5
Hinokitiol	5	5
p-Chloro-m-cresol	5	2
Phenoxyisopropanol	5	5
Thimerosal	5	5
Sodium propylparaben	4	4
Benzylparaben	3	3
Chlorbutanol	0	0
Polyaminopropyl biguanide	<u>0</u>	<u>1</u>
Total formulations reported	17907	16687

Table 4.2. Frequency of use of preservatives in cosmetic formulations reported in 2003 vs. 2001 (in alphabetical order)

Preservative	2003	2001
2-Bromo-2-nitro-1,3-diol	168	164
5-Bromo-5-nitro-1,3-dioxane	30	30
Benzalkonium chloride	85	83
Benzethonium chloride	39	39
Benzoic acid/Sodium benzoate	500	462
Benzyl alcohol	380	321
Benzylparaben	3	3
Boric acid	78	77
Butylparaben	2326	2174
Captan	5	7
Chlorbutanol	0	0
Chlorhexidine acetate	9	9
Chlorhexidine digluconate	60	57
Chlorhexidine dihydrochloride	18	18
Chloroacetamide	37	37
Chloroxylenol	43	42
Chlorphenesin	17	12
Dehydroacetic acid/Sodium dehydroacetate	445	396
Diazolidinyl urea	725	701
Dichlorobenzyl alcohol	11	11
Dichlorophene	5	5
Dimethoxane	9	9
DMDM Hydantoin	993	943
Domiphen bromide	6	6
Escin	15	15
Ethylparaben	1725	1451
Glutaraldehyde (Glutaral)	20	20
Grapefruit Seed Extract	22	22
Hexamidine isethionate	43	37
Hinokitiol	5	5
Imidazolidinyl urea	2038	2025
Iodopropynyl butylcarbamate	172	170

continues

Preservative	2003	2001
Isobutylparaben	227	187
Isopropylparaben	41	33
Methenamine	32	32
Methylchloroisothiazolinone/Methylisothiazolinone	699	595
Methyldibromo glutaronitrile	95	88
Methylparaben	7161	6893
o-Phenylphenol/sodium o-phenylphenol	28	28
paraformaldehyde/formalin	139	139
p-Chloro-m-cresol	5	2
Phenethyl alcohol	31	30
Phenoxyethanol	1670	1480
Phenoxyisopropanol	5	5
Phenyl mercuric acetate	11	11
Polyaminopropyl biguanide	0	1
Polymethoxy bicyclic oxazolidine	19	19
Propylparaben	5809	5621
Quaternium-15	516	505
Salicylic acid	125	127
Sodium bisulfite	58	58
Sodium borate	280	273
Sodium hydroxymethylglycinate	24	23
Sodium methylparaben	42	38
Sodium propylparaben	4	4
Sodium sulfite	1177	933
Sorbic acid/Potassium sorbate	479	432
Thimerosal	5	5
Triclocarban	22	22
Triclosan	451	443

The “Period After Opening” in the Jungle of EU Product Labeling

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KEY WORDS: *regulatory affairs, product labeling, product durability, safety testing, testing and instrumentation, 2003/15/CE, microbial spoilage*

ABSTRACT: *In the EU, a newly required “Period After Opening” designation on product labels has re-focused consumer information to address both a product’s safety and its functional performance over time. This has implications for consumers and for product testers.*

Cosmetics durability has always been a burning issue. Because cosmetics are multifunctional products, their durability should be somehow bound to the fading of their complex of aesthetic, skin compatibility and functionality. This approach would be perfect, if simple and unambiguous testing methods for each set of functions were generally agreed between industries and authorities.

Lacking that agreement thus far, we find that the adopted definition of stability has been vague and precise at the same time, since the date of the first European law on cosmetics.¹ “Durability” meant the period during which the product was able to perform its main functions without causing either physiological or microbial harm to the consumer.² In other words, it referred to durability in terms of both safety and ability to perform. Indeed, it was a very clear and unquestionable definition. Therefore, irrespective of the changing product appearance or a fading scent, a shampoo could be

considered stable if it kept its hair detergent activity over time and did not either induce unexpected irritating effects or became micro-biologically spoiled or dangerous.

Labeling Issues

Problems arose when applying the labeling directives concerning the indication “Best used before the end of...” for products with a minimum durability of less than 30 months. Indeed, this directive is compulsory and applies only to products that are durable up to 30 months, while there is no obligation to give details for products with longer durability. As a result, in order to prevent the return of unsold products from the market, most cosmetics labels (approximately 90% in Europe) did not bear any durability indication. In fact, it seemed that cosmetic products had acquired a sort of immortality irrespective of their composition, use conditions, active ingredients and packaging characteristics.

In certain retail markets, such as pharmacies, where cosmetics are usually regarded as products with higher ethical characteristics than products in other sales outlets, customers requested a more detailed expiry indication in addition to adherence to the strict requirements for short-lasting products. The grant of such a request has so far been very reassuring, because the most frequent indications claim durability of four to five years, at least in these selling points.

However, a number of factors led the European Commission to decree a new norm within the European Union (EU) with the apparent intent to shed light into the jungle of cosmetics labeling. This new norm is the Period after Opening (PAO) statement, which was a response to consumer incredulity, technological advancements, the search for increasing safety, and consumers’ complaints about the lack of transparency on this aspect of cosmetics.³ The term “Period after Opening” is intended to disclose the period of time after opening a product during which the product can be used without any harm to the consumer. “Functionality” is not even mentioned. “Safety” seems to be paramount.

Why are stability studies a hurdle-race? There are many reasons why cosmetic formulations are prone to modify their composition as

time goes by.⁴ Firstly, being a linear combination of different categories of substances, all cosmetics are a potential reaction pot. In theory, many chemical reactions could potentially take place without being easily foreseen.

Moreover, the concentration scales of components are spread over a wide range (i.e., from 10¹% to 10⁻⁴%), so the consequences of reactions might be striking or hidden.

Furthermore, while some ingredients are pure substances and have clearly defined compositions, some others are simply blends comprising large amounts of co-products. Others have mostly unknown compositions (e.g., many vegetal extracts, perfumes) at least for the formulator of finished cosmetics. In this last example, many labile chemical classes are included (e.g., aldehydes, esters, phenols). It must also be added that impurities may play a frequently hidden role in chemical reactions and skin compatibility.⁵⁻⁷ Additional elements of interaction are packaging materials that are prone to release or absorb chemicals to and from the formulation.

Finally, most formulations are accompanied throughout their life by four unpredictable traveling companions: oxygen, light, water and microbes.

- Oxygen is more or less efficiently kept under control by packaging materials during shelf life, but like a wave it surrounds and invades the product at opening and periodically during use by the consumer.
- Light provides the activation energy for decomposition and cross-reactions, mainly when it crosses over the weak “fence” of transparent containers.
- Water, which is an ideal vehicle for many products, is both a reagent and a fast carrier of reagents. Its action is bound to the concentration of the hydrogen cation, to metallic impurities (e.g., calcium, iron) and to additional solvents. Water reactivity is strongly influenced by its usually high concentration or chemical activity in most formulations. Its concentration may be changed waywardly by the continuous delivery of water vapor through the container’s walls or by evaporation during use.

- Last but not least, the “jungle” of a cosmetic environment is populated by living organisms, that are mostly kept under control by the preservative system. Nevertheless, they might be re-strengthened and flourish when new fresh microbial supplies from outside reach the product and the action of the antibacterial system fades. Because bacteria, molds and yeasts are biological reactors, this extra driving force may lead to unwanted by-products in the original composition.

A reliable monitoring would require complex analytical (and micro-analytical) methods, huge investments and a long time. All of them are very difficult to combine. Moreover, all this would be too expensive for products with the quick development time and very short market life of most cosmetics. Frequently, accelerated temperature cycles that are applied in order to take a perspective view over the future of the formula represent only cloudy image of this complex universe. For all these reasons, the chemical approach is hardly provided for in norms and in practical methods related to products' stability, except for specific additives (e.g., fluorides) or a few substances (e.g., bactericides). What to do then?

The physical approach: Because the number of implied variables is so huge, the most traditional and common approach to stability testing is to measure the physical parameters that are in some way averaging a wide group of small or big composition changes.⁸

For example, pH measures are regarded as indicative of hydrolysis and oxidative reactions, both chemically or microbiologically induced; rheology behavior as an indicator of reactions or molecule rearrangements able to induce structural changes; density changes as a signal of gas production or uncontrolled evaporation. All this is jointly carried out with the organoleptic evaluation, which is the type of analysis consumers do with their senses during the product use.

Indeed, many individual changes—small or large—contribute to affecting both a formula's physical parameters and our comprehension of what is really happening inside the formula. Therefore, because its indications regarding use safety may remain largely unclear, we regard the physical approach more as a comparative indicator rather than a stability detector.

The safety approach: The 2003/15/CE Directive of the European Parliament and Council, which modified the Council Directive 76/768/CEE, introduced new requirements for product labeling concerning consumer's safety (see sidebar).⁹ Safety is indeed considered more important than chemical or physical stability. Currently, the main problem seems to be the "Period after opening" (PAO) definition and the list of 26 allergens from perfumes. We will deal only with the PAO issue, which many cosmetic formulators seem to find more puzzling than the other requirements of this directive.

Some Product Labeling Issues Addressed in the EU's 2003/15/CE Directive

- Period After Opening
- A list of 26 allergens from perfumes
- Substances that are considered carcinogenic, mutagenic or toxic for human reproduction
- The setting of animal testing prohibition
- Providing consumers with information on products' composition and unwanted effects
- Specific safety evaluations for baby products as well as for those intended to go into contact with the mucous membranes

Period after Opening

The 2003/15/CE Directive establishes that labels on containers must bear the date of minimum durability and the period of time (months, years) after opening for which the product can be used without any negative effect to the consumer, for products with a minimum durability of more than 30 months after production. This information is indicated by a special symbol¹⁰ representing an open cream jar. In other words, the new law says: "When an expiry date after production is not mentioned, it is believed that your products are permanently stable if they are tightly closed; yet, make sure they resist environmental attacks, the hands of the user and the microflora once they have been opened!"

Adverse effects: The current problem for technicians and researchers is how to determine the PAO period. Indeed, if we look

backwards, we may realize that the existing rules in EU cosmetics had already required the absence of adverse effects during product (shelf and use) life. Nowadays, the novelty lies in understanding the difference of stability behavior that could take place after simply opening a container and partially using its contents.

Let's imagine an ideal formulator, who would be a wise scientist of high ethical standards, with plenty of time to carry out tests by means of instrumental equipment in the laboratory. Let's picture this formulator encountering the PAO problem. In order to guarantee durability of longer than 30 months, this person will have to repeat the same set of trials that were carried out in the first phase of product development. These tests are usually performed during selected periods (e.g., six months) at temperatures higher than ambient temperature in order to artificially induce product aging. Indeed, temperature higher than ambient conditions is a side reactions accelerator, but high temperature accelerates all reactions in the same way, while time (at room temperature) favors only reactions with a low activation energy barrier. Anyway, because time cannot be accelerated, elevated temperatures are taken as the best possible model of long-term phenomena. Our ideal formulator will repeat the Challenge Test, and compare the results with the ones carried out on fresh samples to be convinced that the microbial stability with time is guaranteed and the antimicrobials in the formula continue to be active.

Which modifications are brought to this already clear picture by a more or less continuous jar opening/closing and the partial intermittent use of the cosmetic itself? In other words, which product elements could be dangerously modified by the mixture of air, the passing of time, light, temperature and the input of skin/environment bacteria?

Current interpretation: The evaluation of microbiological stability after opening represents what most companies and industry associations in Europe interpret today as an expression of a product's safety for consumers.¹⁰ In other words, microbial spoilage during use is considered the main risk for consumers. Indeed, this is obvious. However, a standard test design must still be prepared. This could mean repeating

the challenge test after a product use simulation, including opening, repeatedly touching (with soiled hands!), and using it as an average consumer would do, without special storage and hygiene precautions, for long periods (from six months up to one year).

Chemical stability/potential inactivation of preservatives and the ease of their uptake by the packaging materials should also be taken into account. The profile of results from the challenge tests that were carried out on the fresh product should thus be carefully reconsidered.

Sometimes, this common interpretation could lead to puzzling suggestions. For example, since most lipsticks do not contain water, their average stability after first opening might be considered to be longer than 36 months (**Table 5.1**). But, has anybody ever seen a two-year-old lipstick? It frequently looks like a piece of rubber with a rancid smell! On top of that, it will probably have a very high peroxide number and some decomposed lipids. No apparent bacterial harm but certainly some irritation or sensitization risks will lay in ambush.

Table 5.1. Approximate duration of selected product categories¹¹

Product Category	Duration (months)
Toothpaste	12
Lipsticks	36
Eye contour products	6
Emulsions/sunscreens	12
Perfumes	36
Aqueous detergents	12
Solid detergents	12

Other safety elements: Besides microbial safety as the main issue, there are certainly others (see sidebar on efficacy issues). Skin safety has more complex aspects. Which other safety elements should be taken into account when determining durability after opening? **Table 5.2** is a list obtained from a view taken through a virtual magnifying lens

suggested by both professional experience and logic. Even if not necessary in all cases, these elements can help to prepare a checklist for the model product that can be described as 90% emptied and forgotten for 12 months in the bathroom.

Table 5.2. Suggested possible check-list of non-microbial evaluations for determining product durability. Tests should be carried out on a model product that is both used and aged and still in its market container.

Evaluation	Reasons
Repeating the patch tests	Comparison with results of fresh products helps understanding formation of irritant-sensitizing by-products.
Analytical data (e.g., peroxide number, gas chromatography, preservatives, etc.)	Identification of newly formed molecules, decomposition products, volatile by-products.
Considering existing stability data, also for similar formulations. Temperature fastness.	Records of product behavior at several temperature conditions, and frequent opening operations. It gives guidelines of expected duration, and provides information about overall unstable product characteristics.
Packaging characteristics (e.g., oxygen fastness, tightness, ease of bacterial contamination, ease of humidity and product dusts uptake, light transparency, release of monomers and plasticizers). Chemical nature of packaging materials is also important. Ease of recapping. Tightness after recapping.	Even if packaging protects the product from the start of its shelf-life, repeatedly opening the container submits the product and packaging system to environmental influences. Oxygen and product concentration/dilution could induce corrosion and pitting, reduced antibacterial effect and rancidity.
Consumer’s habits during use, multiple use, and professional product	Information about hygiene, mishandling, dilution risks, opening frequency, light exposure, environment
Physico-chemical and sensory characteristics of the formula	Identify key control parameters and evident alterations. Parallels consumer’s ‘instrument’ of product evaluation.
Product technology quality, materials, temperature cycles, vacuum efficiency, bulk storage and filling operations	Provides support to standard reproduction of the formula and identifies production variables that may strongly influence long-term stability. Environmental pollution/trace metals (Fe, Ni) uptake.

Evaluation	Reasons
Chemical composition (reactive chemical groups, type/amount of impurities, structure and number of ingredients)	Identifies chemical interactions/ decomposition risk hydrolysis potential, cross-reaction probability, catalysts, allergens.
Light/oxygen fastness	Rancidity development potential
Shelf-life behavior (for existing similarities with new products) during years	Picture of potential troubles during storage and transport
Design and suggest use precautions.	Warnings on label (about re-capping after use, keeping the product in a cool place, out of light) help reduce consumers' mistakes (and complaints)
Logic and company insurance	Message understood by consumer. Safety margin.
Consumer's complaints	Give the historical record of most frequently perceived problems.

All these elements from **Table 5.2** could be applied to the approximate duration dates in **Table 5.1**, and used as semi-quantitative correction elements to increase or decrease the figures. For instance, a five-point scale (+++, +, ==, -, --) could be drawn up for each item. Then, according to the results of the evaluation, for example, the 12-month figure could be either decreased, kept constant or increased by an arbitrary amount (e.g., 1 month for each + or -).

What's new: In practice, almost all these considerations were generally taken into account during the development phase of the product by wise chemists. Indeed, the only new difference is that now an indication concerning stability will have to appear on the label (replacement of the previous "non-indication" issue). What will then be the consumer's interpretation of such acquired transparency? The first answer could be: the absence of adverse reactions. But other expectations will involve also the continuity of a pleasant use, acceptable appearance, a nice smell and perceivably good performance. They are all elements of expected quality that an indication of duration on the label could imply in consumers' reasoning.

Efficacy Issues Affecting Product Safety of Sunscreens

Besides microbial spoilage, other elements could influence product acceptability over time with risks for consumers. Could also efficacy issues intervene to transform an originally safe product into a harmful one? In the case of sunscreens, their reduced efficacy would influence consumers’ safety against sunburn (in the EU sunscreens are standard cosmetics). Moreover, this category of products is generally used at high ambient temperatures, with increased risks of impaired functionality.

Indeed, some worries about sunscreens have risen. In Italy, the Head Laboratories of the Ministry for Health (Istituto Superiore di Sanità) admitted planning to test sunscreens SPF for stability just for the sake of consumers’ safety. Luckily enough, the actual agreement between labeled SPF and real SPF will necessarily be tested at the same time. Perhaps sensational findings will be made. It has been recently announced by UNIPRO (Italian Cosmetic Industry Association) that approximately half of the SPF values in European sunscreens are incorrect and thus modifications to the testing methods are suggested.

However, if inaccuracies concerning the SPF values are discovered, they should not be attributed solely to instability factors or an inadequate in vivo testing method. Inaccuracies could also arise due to the approximate values that resulted from the in vitro measures and were adopted as definitive instead of the official in vivo measurements. Furthermore, inaccuracies could be due to making assumptions about SPF values based only on concentrations of sun filters concentrations without any further testing!

Involved communication elements are also important. For example, if too short a period would induce anxiety in consumers, too long a period would reduce credibility and manufactures may incur serious risks in case of consumers’ problems. Will the consumer misinterpret the PAO symbol and take it as an absolute stability indicator? Should cosmetic companies take an adequate safety margin in order to avoid surprises? What will competitors do?

In general, one could recommend differentiating the products on the basis of three main risk categories (low, medium and high) related to the previously mentioned technical elements, as well as to a consumer’s category (such as age) and to involved parts of the skin (such as the eye area or mucosa).

Conclusion: The Dark Side and Bright Side of PAO

The dark side: EU Directive 2003/15/CE gives rise to controversy and poses serious questions:

- In case of dispute, how to check if a reclaimed product has received adequate use and storage conditions?
- Who will establish the real opening date for a protested product?
- How can one be sure about an appropriate consumer's handling of the cosmetic product under discussion?

Indeed, the PAO evaluation bears the features of an expert's evaluation, that is typically subjective and not easily reproducible. Moreover, even if no penalty is inflicted for a wrong PAO indication, the law provides for the manufacturer's liability for the damage induced to consumers using unsafe cosmetics.

The bright side: Good advice on this matter is:

- To be prudent
- To have a practical mind
- To indicate short-term date when storage instructions are not well defined.

If one wishes (or is required by market laws) to indicate long-term dates, adequate and defined storage instructions should be reported on the label, as a form of insurance for marketing companies. Scientific support, in the form of a written expertise, should be prepared in advance, taking into account the results from the entire set of tests carried out on the products. This could be accomplished with the cooperation of all scientists who are involved in the "childhood" of the product and who are also called upon in its "maturity" to cast the product in a bright light.

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Water Activity

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KEY WORDS: *preservation, water activity, glycols, HACCP, CCP*

ABSTRACT: *Water activity is a key consideration in preserving cosmetics. As this chapter discusses, there is an important difference between the amount of water present in a product and availability of this water for microorganism growth.*

All microorganisms need sufficient water and nutrients to grow. The concept of controlling water activity to prevent this growth is as old as time, and the practice of using water activity to prevent spoilage began with honey. Honey would appear to be the ideal growth medium for microorganisms—it contains water and sugar—but it is in fact an excellent example of a self-preserving product because the sugar ties up the water molecules, making the water unavailable for microorganism growth. This is a simple example of the very important difference between water content and available water, also known as water activity.

Water activity is written as a_w and is defined as the ratio of the water vapor pressure of the product compared to pure water at the same temperature, where P is the vapor pressure of the product, P_o is the vapor pressure of pure water, n_1 is the number of moles of solute, and n_2 is the number of moles of water:

$$a_w = P/P_o = (n_2/(n_1 + n_2)) \quad \text{Equation 6.1}$$

Pure water has an activity of 1.00 while something considered “bone dry” is 0.00. It is numerically equivalent to 1/100 of the relative humidity (RH) generated by the product in a closed system. RH can

be calculated from the direct measurements of partial vapor pressure or dew point, or indirect measurements by sensors that are altered by being exposed to RH. Thus, the relationship between water activity and the equilibrium relative humidity (ERH) is:

$$\text{ERH (100\%)} = a_w \times 100 \quad \text{Equation 6.2}$$

Although it is possible to calculate water activity, measurements are significantly more accurate when taken instrumentally. The food industry has used water activity for many years to determine the need for preservatives.

Measuring Water Activity

There are several ways to measure water activity, including: vapor pressure manometry, electric hygrometry, hair hygrometry and dew point. The Association of Analytical Communities (AOAC) officially recognizes the dew-point/chilled mirror method.

The approximate water activity needed for growth of various micro-organisms has been published and these amounts are generally recognized as the minimums needed for growth (see **Table 6.1**). The specific water activity needed for growth of the five common test organisms is shown in **Table 6.2**. It should be noted that some molds can grow with water activities as low as 0.7; therefore, it is a good rule of thumb that water activity be kept below 0.7.

Robert Friedel published one of the earliest papers on the use of water activity to determine the requirements for preserving topical products.¹ This work showed how water activity could be measured using a dew-point/chilled mirror instrument to obtain accurate and reproducible results^a. Among the examples given were creams, gels, anhydrous lip balms and ointments.

Water activity has become a valuable tool to determine the potential for growth in raw materials. Since microbiological specifications are required by the European Union for all cosmetic ingredients, assuring whether the water activity of a product is below

^a Aqua Lab CX-2 is a device from Decagon Devices; A2101 is available from Rontronic

Table 6.1. The approximate a_w needed for growth of various microorganisms

Bacteria	0.94-0.99
Yeast	>0.7
Mold	>0.6

Table 6.2. The specific a_w needed for growth of the five common test organisms

<i>Aspergillus niger</i>	0.77
<i>Staphylococcus aureus</i>	0.86
<i>Escherichia coli</i>	0.95
<i>Pseudomonas aeruginosa</i>	0.97
<i>Candida albicans</i>	0.87

0.7 determines the need for micro-testing of ingredients. Equally of value is determining the activity of the finished formulation before adding preservatives. If it is found that only mold or yeast can grow in the product, there is no need to add preservatives that are active only against bacteria.

There are certain ingredients that have been shown to lower water activity—salts, such as Dead Sea salts; glycols and polyols, such as glycerin, propylene glycol and polyethylene glycol; a series of commercial mixtures^b that, at 15–20%, may make a product self-preserving—however, there appears to be no linear relationship between specific levels of these ingredients and water activity. Models have been published to predict the effects of adding water-binding ingredients to lower water activity, but due to the complex nature of cosmetic formulations, these models do not predict the outcome accurately. Measurement by instrumentation is the best way to achieve accurate results.

^b The Osmicide line is a product of Croda Inc.

Attempts have also been made using high amounts of glycols to lower activity so that no additional chemical preservative is needed; however, the esthetics of the resulting products were unacceptable.

Measuring water activity is especially useful for formulations that are atypical, such as: w/o emulsions, low-water content products, anhydrous products such as lipsticks and powders, and water extracts where the addition of high levels of glycols, even as extracting solvents, can be used to lower the water activity below 0.7 to avoid the need for additional preservatives. Some typical water activities of various personal care products are shown in **Table 6.3**.

Shampoos	0.97
Conditioners	0.96
Liquid soap	0.91
Hand cream	0.86
Hand lotion	0.98

It is critical to understand that water activity is not cidal, meaning it does not kill microbes; it only prevents growth. Therefore, it can only be applied to products that are already free of contamination. As water activity can only be determined by measurement, hazard analysis critical control point (HACCP) is an important concept applicable to both raw materials and finished formulations.

HACCP

The concept of HACCP was originally developed for the space industry to assist in producing food for astronauts. The purpose was to provide a high degree of quality and microbiologically safe foods. Hazard analysis identifies critical control points (CCP) and relates to contamination. HACCP is currently mandatory in the food industry; the US Food and Drug Administration (FDA) is also encouraging its use for the drug industry. It is very useful for the production of cosmetics.

Basic Principles of HACCP

The seven basic principles of HACCP are as follows:

1. Identify microbial hazards and preventive measures.
2. Determine CCPs as related to the identified hazards.
3. Establish the critical limits that must be met at each CCP.
4. Establish procedures to monitor the critical limits.
5. Establish corrective active plans to be implemented when critical limits are exceeded.
6. Establish recordkeeping systems that document the HACCP plan.
7. Establish procedures for verification that HACCP system is working correctly with documentation.

For more information on HACCP, see Borovian's³ and Easter's⁴ papers as well as the International Life Sciences Institute's Web site⁵ and Technical Consultancy Services in-house training software.⁶

CCP can be used in every process and design during the manufacture of cosmetics. It is used to identify locations where contamination could occur. If manufacturers choose not to incorporate traditional active preservatives or rely on water activity or other non-preservative methods, HACCP is a valuable tool to ensure quality.

It has been a general belief that the purpose of preservatives is to make a cosmetic remain in its "clean" condition under normal consumer use and to protect products from consumer contamination. In reality, preservatives or preservative systems should prevent contamination from occurring during production. Formulators never know for certain if the production of a clean cosmetic was achieved by strict adherence to current good manufacturing practices (cGMP), or whether the preservative system prevented incidental contamination.

To illustrate the point, consider the following: When a batch is produced and found to be contaminated, this is referred to as a "preservative failure." The FDA does not permit post-manufacturing treatment by external means like radiation, heat sterilization or pressure to reduce contamination to acceptable levels. When products

are challenge-tested to determine their adequacy of preservation, they are usually challenged with pure cultures. Also strongly recommended is the introduction of house isolates to be certain that the system is strong enough. But how could a consumer possibly contaminate a cosmetic with a manufacturer's house "bugs"? Or with a pure strain of bacteria? The focus needs to be on controlling and preventing microbial contamination during manufacture, thereby removing the onus of enforcing regulations from the formulator.

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Natural Preservation from Concepts in Nature

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KEY WORDS: *preservation, natural antimicrobials, organic acids, glyceryl monoesters, microorganisms*

ABSTRACT: *Chemical defense mechanisms used in the plant kingdom are the basis of natural antimicrobials with multifunctionality for preservation of cosmetic formulations. Two examples are organic acids and glyceryl monoesters.*

Nature demonstrates various protective strategies in the animal and plant kingdom. At the macroscopic scale, mobility (i.e., the ability to run) is the first and most obvious example, but slow or immobile creatures have evolved other fascinating ways to protect themselves. Chemical strategies can play an important role in this context.

Strong odors and bright colors are often employed to point out that an attack may bring more harm to the aggressor than to the prey.

This strategy depends on the large variety of naturally toxic materials produced by animals and plants in their “natural laboratories” in which some of the world’s most effective poisons are developed.

Figure 7.1 gives the structures of some exemplary natural poisons.

Somewhat more hidden and therefore less known are the activities in the microscopic world. The strategy for chemical defense against microorganisms will normally differ from that against larger invaders due, in part, to differences in the metabolism. While large alkaloids or polypeptides may successfully harm animals, it is sometimes small and simple molecules that are effective against bacteria

or fungi. Chemical defense against microbes is normally found in plants or other competing microorganisms, while animals rely on their biological immune response.

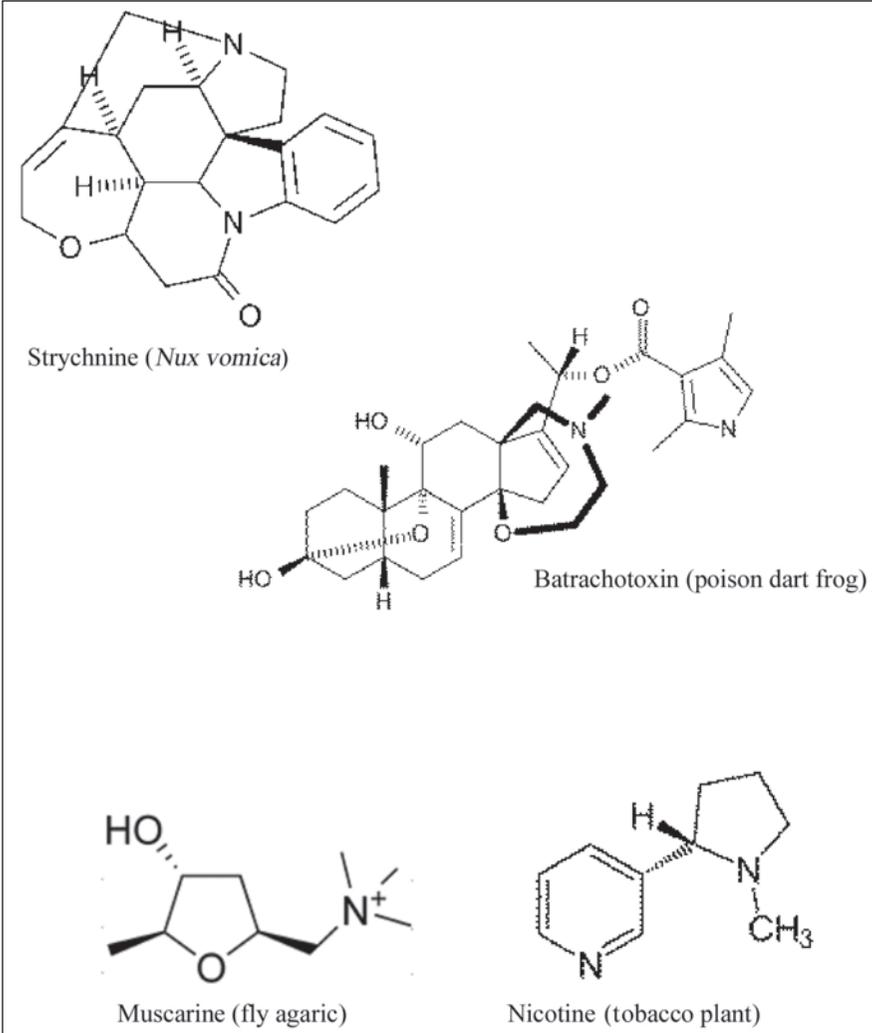


Figure 7.1. Structures of some exemplary naturally occurring poisons

The following discussion will focus solely on the chemical defenses against microorganisms. It will define some general principles that can be exploited to determine metabolic weaknesses for the control of target organisms. It also will point out how natural

systems protect themselves*i.e.*, which chemical compounds are best against the permanent pressures of harmful microbes. Finally, it will demonstrate the concepts that currently are available to the industry to achieve natural and sustainable—yet efficient—preservation of cosmetic products.

Throughout this discussion, the term *natural* is used to describe preservatives and will have a meaning as clarified by the relevant European certification bodies—BDIH (the Federation of German Industries and Trading), EcoCert (France) and the Organic Soil Association (UK) (see **Petrochemical Preservatives and the Term *Natural* sidebar**).

Natural Strategies Against Microorganisms

With the discovery of penicillin in 1928, the Scottish biologist Alexander Fleming identified one of the most prominent examples of a potent biologically active agent. This historic event has served as the foundation from which to consider different concepts in the control of microorganisms. Penicillin is an antibiotic agent and must be distinguished from active compounds for use in preservation or disinfection. The major difference is the selectivity against the target organism and as a result thereof, the possibility for the bacteria to build up a resistance. Because of their selectivity, antibiotics can be used within the human body to fight bacteria.

Active compounds for preservation are not selective, nor should they be. Ideally their mission is to fight all microbes present—bacteria, yeasts and fungi.

The desired antimicrobial effect is directed by some general principles:

- denaturation of membrane proteins and enzymes (alcohols);
- chemical alteration of enzymes and DNA (aldehydes);
- oxidation of membrane proteins and enzymes (ozone, H₂O₂, halogen compounds);
- disturbance of membrane function (organic acids); and
- disruption of the cell membrane (surfactants, alcohols).

Petrochemical Preservatives and the Term *Natural*

There is no official legal definition of the term *natural* as it applies to cosmetic ingredients in the United States or Europe. However, Ecocert, BDIH and the Soil Association agree that the term implies restricted use of petrochemical-derived ingredients, silicones, ethoxylated raw materials and halogenorganic compounds.

In regard to preservation, some exemptions are allowed in the general rule to ban petrochemical-based raw materials. Benzoic acid, sorbic acid and benzyl alcohol may be used as preservatives in certified natural cosmetic products. In addition, salicylic acid (Ecocert, BDIH), propionic acid, formic acid (Ecocert) and phenoxyethanol (Soil Association) are permitted as additional petrochemical preservatives. In most cases, certified natural cosmetic products utilizing those preservatives must carry the information “preserved with...” on the package.

It is of course permitted to use alternative multifunctional antimicrobial actives to avoid the “preserved with...” statement on the package. For example, antimicrobial actives that also have activity for fragrance, refatting or moisturizing can be listed on the package under their alternative function. Those ingredients still have to comply with the general requirements of the *natural* standards in terms of the source and manufacturing method of the raw material. Therefore only materials extracted from nature with permitted solvents/methods or raw materials assembled from natural building blocks by accepted chemical conversione.g., hydrolysis, condensation (esterification), hydration, oxidation and fermentationare suitable. Petrochemical-derived antimicrobials, e.g., glycols and ethylhexylglycerine, are not an option for certified natural cosmetic products.

These definitions have no legal character. The above-mentioned organizations have created them as a self-imposed commitment for those companies that want to be granted the respective label. The compliance of raw materials and cosmetics with the criteria is thoroughly assessed by authorized certification bodies.

Plants, animals and microorganisms employ these principles and produce the respective compounds to combat microbes. Often, mixtures or synergistic systems are in place to fight the imminent invasion.

Phytoalexins are antimicrobial phytochemicals produced by plants under attack by bacteria and fungi. Numerous phytoalexins

have been identified, including hydrogen peroxide, terpenoids, aromatic acids, oxygenated fatty acids, aliphatic alcohols and polyols. Many of these compounds are not suitable for use in cosmetics. Therefore, the question remains: *Can natural systems be used to gently, safely and effectively preserve cosmetics?*

Among the decisive criteria for the use of natural preservative concepts in cosmetics are the availability, effectiveness and the toxicological profile of the actives. Another factor to consider is whether the conversion of naturally occurring building blocks offers a possibility to produce either nature-identical compounds or even more effective analogues thereof. Here is where a thorough understanding of natural concepts becomes decisive for the development of active agents that are new and potent, yet mild and sustainable.

The consumer's perception that natural raw materials are often better tolerated than non-naturally occurring ones in cosmetic applications follows a simple, comprehensible philosophy: the human organism is the product of an evolutionary process lasting millions of years. As is true for all other creatures on earth, human metabolism has adapted to the surrounding chemical environment. As a consequence it is concluded by many consumers that the human body is far more adapted to cope with naturally occurring compounds than with synthetic ones. For example, although both mineral oils and oils of plant origin may be excellent sources of energy if burned, the human body is able to metabolize only oils of plant origin.^{1,2}

This philosophy about the link between human metabolism and the chemical environment is the basis for the trend for *natural* cosmetics, but for preserving agents it has to be judged very carefully. It would be misleading or even dangerous to assume that antimicrobials from nature are free from any risks to the consumers. Because an intrinsic property of antimicrobial structures is that they can affect living cells, the toxicological evaluation of antimicrobial substances from nature has to be as thorough as for synthetic ones. However, there is little dispute that raw materials from natural origin have significant benefits over synthetic materials with respect to their impact on the environment and the maintenance of resources.

Identifying preserving agents derived from nature is a complex task. Efficacy and safety have to be the first priority because

microbiological contamination of cosmetic products can pose substantial threat to the consumer's health. It is the art of the researcher to identify adequate structures in nature or build them from natural building blocks.

The same may be true for cosmetic applications: although both synthetic and naturally occurring ingredients may have an excellent cosmetic performance, the synthetic ones often exhibiting a better performance the skin will more easily deal with naturally occurring compounds than with synthetic compounds that cannot be degraded or built into biological structures. Although the biochemical inertness of mineral oils is well known and most of these compounds will not enter the human metabolism, the intake and accumulation of hydrocarbons are regarded as undesirable.^{1,2} Natural oil components that are identical to the constituents of human cell membranes can be integrated into living cells. Mineral oils, although having a cosmetic function, preferably will be washed away with the next shower.

For the illustration of antimicrobial actives for natural preservation, two examples from organic acids and glyceryl monoesters will show how these concepts apply to cosmetic formulations.

Organic Acids

The widely accepted principle of antimicrobial action of organic acids is illustrated in **Figure 7.2** and explained here. The cell incorporates molecules of the protonated acid through the membrane. Within the cell plasma the acid dissociates and thus changes the pH within the cell.³ The bacterium has to pump out protons permanently and take in sodium ions to maintain the physiological pH of the cell. This energy-consuming process as well as the decreased pH level inside the cell will lead to a decreased rate of reproduction. Because it also lowers the pH outside the cell to a favorable acidic level, the cell makes things worse by favoring the protonated acid side of the acid-base-equilibrium, enabling the membrane to be penetrated by the protonated acid, which is the active species. Finally the process will end with the death of the microorganism.

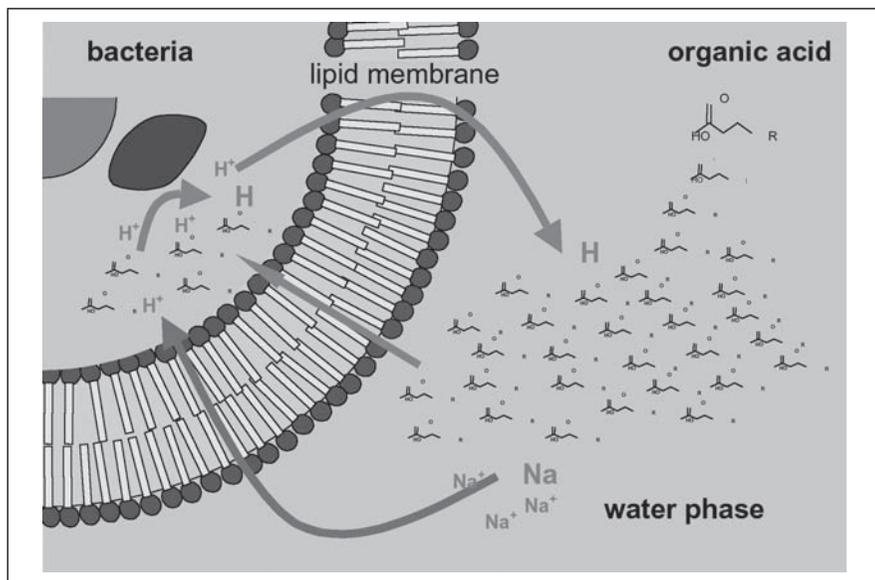


Figure 7.2. Antimicrobial mode of action of organic acids

The nature of the acid is of utmost importance to end up with an efficient active compound. The right compound will be one that ensures biological availability, penetrates the cell membrane and deprotonates within the cell.

If suitable organic acids are available in sufficient amount they will effectively control the growth of microbes in the product. The chosen active compounds should have the following properties:

- Sufficient solubility in the water phase;
- Availability in the protonated form at a given pH in a formulation;
- A structure that permits passage through the membrane; and
- Ready dissociation of the acid within the cell plasma.

For use in self-preserving formulations or in cosmetics making *natural* claims, there are various compounds, also found in nature, that are in accordance with the requirements of the BDIH, EcoCert and the Organic Soil Association. One commercial product line^a of

^a Dermosoft is a product line and registered trade name of Dr. Straetmans Chemische Produkte GmbH, Germany.

multifunctional additives has, alone or in combination with others, a demonstrated performance against bacteria, yeast and fungi.⁴ Among the active species within this product line are levulinic acid and anisic acid, which are well-known for their antimicrobial activity and are found in many natural sources.^{5,6} According to their primary function as very light perfumes they are declared as “fragrance (*parfum*)” on the ingredients list shown in **Formula 7.1**, an exemplary formulation with biological stabilization by organic acids. The function of the glyceryl caprylate, the only other ingredient with an antimicrobial function in **Formula 7.1**, will be described next.

Formula 7.1. Moisture cream preserved with organic acids

A. Water (<i>aqua</i>)	73.30% w/w
Sodium phytate and water (<i>aqua</i>) (Dermofeel PA-3, Dr. Straetmans)	0.10
Glycerin	3.00
Glyceryl caprylate (Dermosoft GMCY, Dr. Straetmans)	0.50
Fragrance (<i>parfum</i>) (Dermosoft 700 B, Dr. Straetmans)	0.30
Fragrance (<i>parfum</i>) (Dermosoft 688, Dr. Straetmans)	0.20
Sodium hydroxide, 10%	0.75
B. Xanthan gum (Keltrol RD, Kelco)	0.20
Galactoarabinan (Lara Care, Rahn)	0.50
C. Glyceryl stearate citrate (Dermofeel GSC, Dr. Straetmans)	3.50
Decyl cocoate (Tegosoft DC, Goldschmidt)	3.00
<i>Olea europaea</i> (olive) fruit oil	2.00
Squalane (Phytosqualan, NRC/Sophim)	6.00
Cetearyl alcohol (Lanette O, Cognis)	2.00
Caprylic/capric triglyceride (Miglyol 812, Sasol)	4.00
Tocopherol (and) <i>Helianthus annuus</i> (sunflower) seed oil (Dermofeel Toco 70 non-GMO, Dr. Straetmans)	0.15
D. Fragrance (<i>parfum</i>) (Parfum Baby Cotton 449264, Symrise)	<u>0.20</u>
	100.00

Procedure: Heat A and B to 78°C. Disperse B in A. Heat C to 78°C. Emulsify C to AB under stirring. Homogenize for 1–2 min using a homogenizer-disperser. Start to cool to 30°C under stirring. Add D and adjust pH. *Specification values:* Appearance: Soft white emulsion; pH: 5.0–5.4; Viscosity (Brookfield: Helipath TF; Speed 10):

~ 40,000 mPas; Centrifuge (15 min, 4000 rpm): No separation; *Stability:* More than 3 months stable at 20°C, 40°C, 4°C; *Microbiological stability:* Proven.

Figure 7.3 shows the results of a challenge test on **Formula 7.1** conducted according to the European Pharmacopoeia (EP). The EP's criteria regarding the death rate are somewhat stricter than those of the US Pharmacopoeia and the Personal Care Products Council (formerly the Cosmetic, Toiletry, and Fragrance Association).⁷

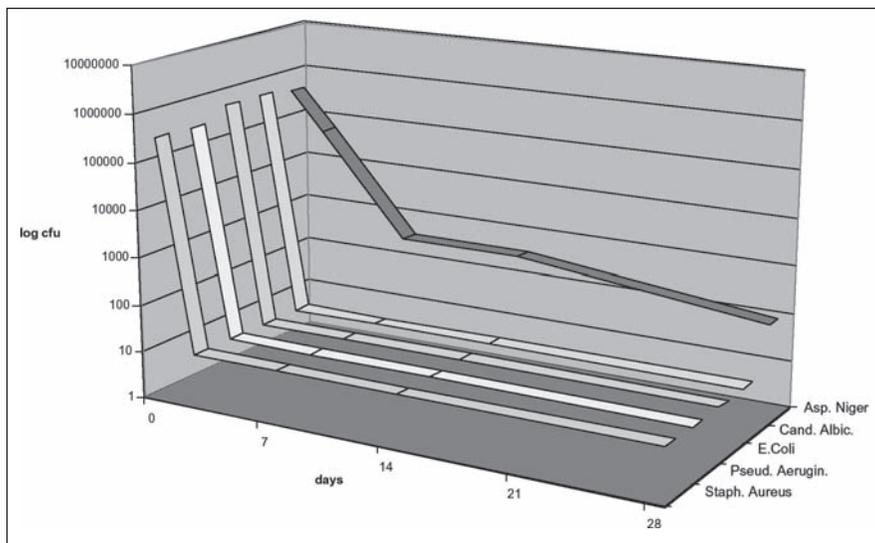


Figure 7.3. Results of challenge test on the moisture cream in Formula 1. Preservation is based solely on glyceryl caprylate, anisic acid and levulinic acid.

Glyceryl Monoesters

A different mode of action is found in another prominent group of multifunctional molecules, the glyceryl monoesters. Some of these multifunctional surfactants have amphiphilic properties and an excellent microbiological performance. The design of the molecules is optimized to bring them into the cell membrane of microbes and destabilize that membrane because of the presence of an incompatible structure such as an incompatible chain length (**Figure 7.4**).^{8,9}

The key is to find molecules with suitable structures.¹⁰ In addition, the molecules must be soluble and therefore available in the water phase or in the interface between water and oil, and they must be able to penetrate the outer layer of the membrane. Once there, the molecules will deteriorate the stability of the membrane and finally

disrupt it completely.¹¹ To enhance the activity against fungi, a faster-acting agent like certain organic acids can be added.

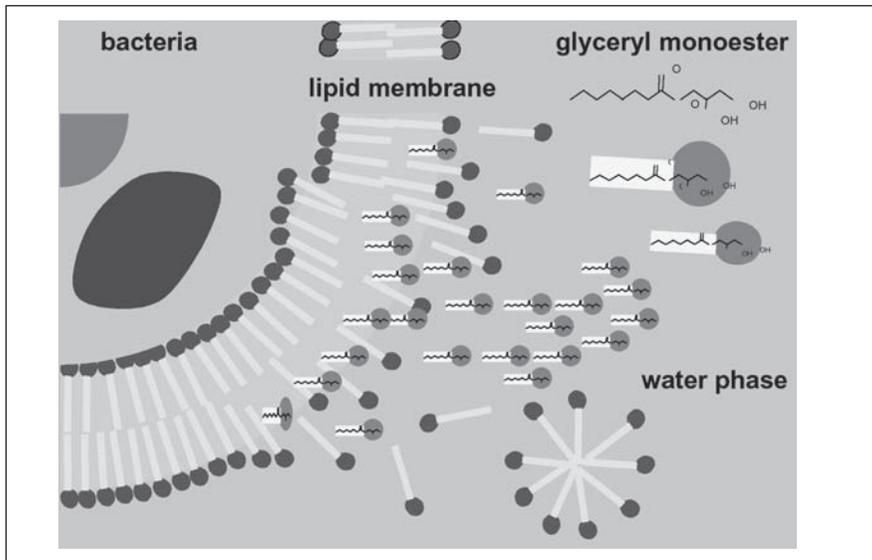


Figure 7.4. Disruption of the cell membrane of a bacterium by the action of glyceryl monoesters. The stability of the membrane is corrupted by the incompatible chain length and finally destroyed.

The primary function of these glyceryl monoesters is moisturizing and refatting of the skin. To avoid the need for altering an existing basic formulation, the formulator and the supplier should discuss the additional functions of these raw materials and their possible impact on the formulation.

Formulations for cosmetics making *natural* claims can be preserved effectively with glyceryl monoesters. As long as they are produced from naturally occurring, sustainable sources, they are in accordance with the requirements of the relevant European certification bodies (BDIH, EcoCert and Organic Soil Association).

These active compounds are not declared as preservatives due to their primary function as moisturizing and refatting agents. With optimum activity is in the pH range of 4.5 to 7, the field of application is very broad. **Formula 7.2** shows a body spray with biological stabilization using glycerol monoesters as the only antimicrobial agent for preservation in the formula. **Figure 7.5** shows the results of a challenge test on this formulation.

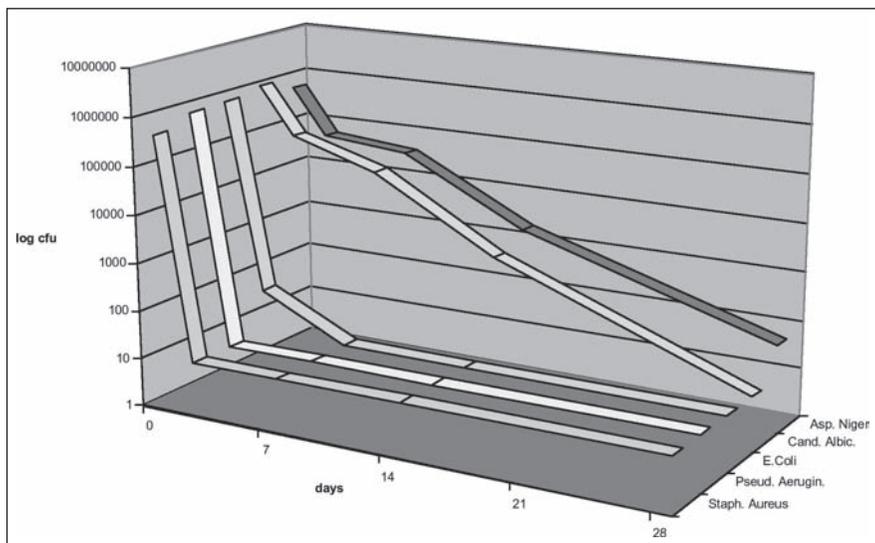


Figure 7.5. Results of challenge test on the body spray in Formula 2. Preservation is based solely on glyceryl caprylate.

Formula 7.2. Body spray preserved with glyceryl monoesters

A. Water (<i>aqua</i>)	80.05% w/w
<i>Rosa centifolia</i> flower water (Rose Flower Water, Sanoflore)	3.00
Glycerin	3.00
Glyceryl caprylate (Dermosoft GMCY, Dr. Straetmans)	1.00
B. Sclerotium gum (Amigel Granulat, Alban Muller)	0.25
C. Tocopheryl acetate (and) <i>Helianthus annuus</i> (sunflower) seed oil (Dermofeel E 74 A non-GMO, Dr. Straetmans)	0.50
<i>Prunus armeniaca</i> (apricot) kernel oil (Apricot Kernel Oil, Henry Lamotte)	1.00
Tricaprylin (Dermofeel MCT, Dr. Straetmans)	4.00
Lecithin (and) glycerin (and) alcohol (Pro-Lipo Duo, Lucas Meyer)	7.00
Fragrance (<i>parfum</i>) (Parfum Baby Cotton 449264, Symrise)	<u>0.20</u>
	100.00

Procedures: Mix A and B under stirring until B dissolves. Mix C at RT and add to AB while stirring. Homogenize ABC at medium speed for ~3 min using a homogenizer-disperser. Adjust pH if necessary. **Specification Values:** Appearance: Creamy sprayable lotion; pH: 5.5–6.5; Viscosity (Brookfield: LV 4; 10 rpm): ~2,000–3,000 mPas; Centrifugation (4000 rpm, 20 min): No separation; **Microbiological stability:** Proven.

Evaluation of Preservatives

For the formulator it is sometimes difficult to determine which preservative system will work best. There are dozens of antimicrobial actives and hundreds of commercial products. There are single compounds and more or less complex blends. The formulator should select from among the ones that are efficient antimicrobials, toxicologically unobjectionable and accepted by consumers.

If certain traditional preservatives cannot be used, there are many alternative and natural antimicrobial compounds. A closer look into microbiological data and challenge tests will reveal the usefulness or unreliability of alternative preservatives. The evaluation and comparison of, for example, MIC data can only be a first and rather unreliable step, because this generalized approach takes into account neither the influence of the various raw materials present in a formulation nor chemo-physical hurdles such as solubility and migration of preservatives into the oil phase. The MIC values of some exemplary traditional products are compared to a multifunctional microbial agent in **Table 7.1**. Even after studying the MIC or other generalized data, the formulator still must test the preservative system in the targeted cosmetic formulation.

Table 7.1. Comparison of MIC values of different commercial products. All data is taken from technical information provided by the manufacturers.

Preservative	<i>P. aeruginosa</i>	<i>S. aureus</i>	<i>A. niger</i>
Glyceryl caprylate (Dermosoft GMCY, Dr. Straetmans)	0.05%	0.03%	0.1%
Methylparaben (Nipagin M, Clariant/Nipa)	0.2	0.15	0.1
Phenoxyethanol (and) methylparaben (and) ethylparaben (and) butylparaben (and) propylparaben (and) isobutylparaben (Phenonip, Clariant/Nipa)	0.225	0.2	0.125
Benzyl alcohol (and) methylchloroisothiazolinone (and) methylthiazolinone (Euxyl K 100, Schülke & Mayr)	0.06	0.25	0.03
Methyldibromo glutaronitrile (Euxyl K 135, Schülke & Mayr)	0.5	0.13	0.25

Summary

To meet the growing demand for alternative preservation concepts in cosmetic products making “natural” claims, there is a broad range of active compounds already available to the cosmetic industry. Examples from among organic acids and glyceryl monoesters were described here.

Due to the compounds’ primary properties there is no need to declare them as preservatives, although results of microbiological testing indicate that they provide excellent biological stability. They also allow for a new set of benefits and marketing claims, such as “reduced allergenic load” and “ingredients from sustainable resources.” Indeed, it is difficult to ignore the fact that certain preservatives have suffered from bad press, and more and more cosmetic manufacturers are introducing alternative and natural preservatives in their formulations.¹²

Natural, sustainable and efficient preservation of cosmetic products can be achieved from the chemical defense mechanisms of nature.

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SECTION II

Emulsions

Emulsions are systems composed of two (or more) immiscible materials (usually liquids) in which one material (the dispersed/internal phase) is suspended or dispersed throughout another material (the continuous/external phase) in separate droplets. All emulsions are inherently unstable (with the exception of spontaneously forming micro emulsions). All we can do is delay the day when the instability will arrive.

Despite the fact emulsions are found in almost every category of cosmetic product, the preparation of stable, cosmetically elegant emulsions remains one of the most daunting tasks undertaken by the cosmetic chemist. No wonder there has been so much published on emulsions in the pages of Cosmetics and Toiletries!

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Soap: Our Old Friend and Great Emulsifier

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KEY WORDS: *soap, emulsifier, stearic acid, sodium stearate, polyvalent soaps*

ABSTRACT: *This chapter examines the history and many uses of soaps and their role as an emulsifier in formulating.*

Cosmetic chemists are being constantly bombarded by raw material suppliers promising the latest and greatest new chemistry. As each and every supplier greets us, they inform us that they have the answer to our formulation needs. A good formulator will listen intently, ask the right questions, try to understand the chemistry of the material and its benefits and drawbacks (a material will always have both), see if it really offers something they can use, and ultimately integrate it into their existing bag of tricks. All too often we are swayed by the “cuteness” and glamour of a new material and forget our old friends. What I urge you to do is not forget those materials that have worked for you in the past.

Before we take a step backward to explore the positives (and negatives) of “soap emulsifiers,” let me encourage you once again to explore new raw materials; only by exploration can we raise our fine art and science of cosmetic formulation to new heights.

Soap has been around for a very long time and was being made in Babylon as early as 2800BC, but probably used only for washing garments. Pliny the Elder (7BC–53AD) mentioned that soap was produced from tallow and beech ashes by the Phoenicians in 600BC.¹

What exactly is soap? It is the reaction product of an alkali with a fatty acid. Interestingly enough, actual soaps (generally bars) are exempt from labeling as cosmetics (by the FDA). Because they have a strong negative charge, soaps are, by definition, anionic in nature. This charge gives them a very large effective size and can thus act as effective emulsifiers. As I am fond of saying: size doesn't matter, but effective size ("electric size" through space) does. Stearic acid and sodium stearate have (essentially) the same physical size but the negatively charged stearate anion causes the polar head to occupy a much greater effective size.

Soaps as Emulsifiers

For a material to act as an emulsifier it must have some solubility in both the water and oil phases. Soap accomplishes this task quite well. The long 18-Carbons fatty tail is quite soluble in most cosmetic oil phase ingredients while the polar/charged carboxylate anion wants to associate with the water phase.

The fatty acid that is typically used to make soap emulsifiers is stearic acid, which is a mixture of several carbon chain lengths (C12, 14, 16 and 18). It would be expected that because it is called stearic acid that the predominant chain length would be C18, but that is incorrect. Palmitic (C16) is the most prevalent chain length in stearic acid. While we can use other chain lengths (behenic, lauric, myristic, etc.), stearic is most used. This is probably due to its low cost and efficiency as an emulsifier. As a general rule, we don't see the use of branched (isostearic) or unsaturated (oleic) acids. The branching and unsaturation promote liquidity and also inhibit the formation of a well-defined and tightly packed interface, and thus emulsion stability suffers.

Neutralizing Stearic Acid

In order to neutralize stearic acid with an appropriate alkali, the molecular weight of stearic acid (284) and the number of possible neutralizable "acid" groups (one) must be considered (**Figure 8.1**). The molecular weight of possible neutralizers must then be the next consideration. Two of the most popular are triethanolamine

(molecular weight = 149) and sodium hydroxide (molecular weight = 40). Since these alkalis react mole for mole with stearic acid, it can be shown that if 10 grams of stearic acid are being used, approximately 5.2 grams of triethanolamine (assuming that triethanolamine is 100% and not its normal 99%) would be needed. When using sodium hydroxide, 1.4 grams (of 100% NaOH) would be needed. If this is done, then the pH would be quite high (along with a greater potential for irritation) and the emulsion would be less stable than it could be. That is to say that if the stearic acid is under-neutralized, then the free stearic acid complexes with the soap (sodium or TEA stearate) to form an emulsifier complex that is very efficient (see **Figure 8.2** for an illustration of sodium stearate).

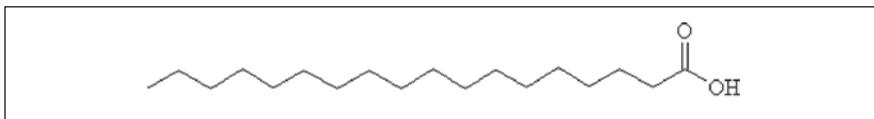


Figure 8.1. Stearic acid

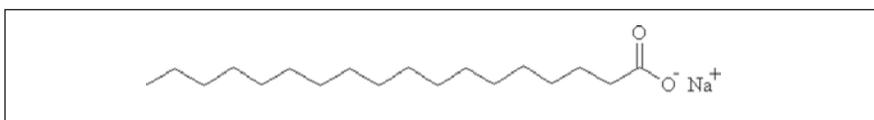


Figure 8.2. Sodium stearate

In addition to forming an excellent interfacial complex and coherent electrical double layer, there is a real tendency to form some lamellar liquid crystals that extend from the surface of the oil droplet out into the bulk, which acts as a further barrier to coalescence. A dry bar of soap is draggy. But when it is wet, it becomes very slippery. This slipperiness is caused by the formation of a lamellar liquid crystalline phase with the layers sliding over each other. If we let the soap bar stand in the soap dish wet for a few days, we can see the slimy soap mush, which are really just liquid crystals.

As a general rule, I recommend neutralizing one-half to one-third of the stearic acid. This will typically provide optimal emulsion stability. You can then add low levels of secondary emulsifier to insure a robust emulsion has been achieved. A good choice for the secondary

emulsifier is one of the ethoxylated fatty materials based on cetyl or stearyl alcohol. The addition of Glyceryl stearate can also be a big help in difficult-to-emulsify systems; such as high levels of difficult-to-emulsify oils (dimethicone gums) or high oil phase systems.

You can purchase sodium stearate, but my experience has shown that forming it in-situ is a better alternative. The stearic acid is added to the oil phase (heating to 75°C) and the neutralizer is added after the oil and water phases are combined. This method works if there is a secondary emulsifier. However, if no secondary emulsifier is present, then some neutralizer should be added to the water phase—this way, the emulsion will be formed as the phases are combined. You can then add the remaining neutralizer after the phases are combined and cool with mixing.

Many people have noticed that emulsions (o/w) based on soap emulsifiers have a great tendency to thicken over time, which can cause significant problems and grief. More than likely, this is caused by the formation of lamellar liquid crystals over time. One way to speed up this thickening process is to cool the emulsion slowly and then reheat it (leaving out temperature-sensitive materials such as preservative and fragrance). This technique will insure maximum opportunity for the soap emulsifier to get to the interface and form liquid crystals, and thereby achieve its final viscosity quickly. Triethanolamine (TEA) stearate is a very effective emulsifier at lower pH levels than sodium (or potassium) stearate and forms the emulsion with more flexible interfacial films and, as a result, more stable emulsions.

Additionally, TEA stearate emulsions are easier to control in viscosity. The soap emulsifier systems have numerous advantages (they are inexpensive, efficient, easy to manufacture and scale-up, etc). Because they do not change their character as a function of temperature (as do the ethoxylated emulsifiers), you do not have to be careful of phase inversion temperature (PIT) effects. They do, however, have several disadvantages associated with them: they must be formulated at a pH above 7.2 (TEA stearate) and, sometimes, above 7.8 (sodium or potassium stearate). Some irritation and eye sting can be seen at this high pH, which is considerably above the “normal” skin pH (5.5). These systems can also mobilize the lipid bilayer

Formula 8.1. Skin moisturizer

A. Water (<i>aqua</i>)	qs to 100
Propylene glycol	2.5
Tetrasodium EDTA	0.1
Carbomer	0.15
B. Stearic acid	4.0
Cetearyl alcohol	0.25
Dimethicone 100CS	1.0
Octyl Palmitate	6.0
Steareth-21	1.0
C. Water (<i>aqua</i>)	5.0
Triethanolamine, 99%	0.9
D. Fragrance (<i>parfum</i>)	0.25
E. Propylene glycol (and) diazolidinyl urea (and) methylparaben (and) propylparaben	1.0

Procedure: Separately combine A and B at 75°C. Add B to A with vigorous mixing. Add C. Mix for 20 min and cool to 40°C. Add remaining phases and package. Adjust pH to 7.2–7.5 as needed.

between the skin cells and cause an increase transepidermal water loss (TEWL).

With this in mind, soap systems are not suggested for emulsions designed for use on damaged or dry skin. Soap systems should also not be used in sunscreen systems designed to be very water resistant, since the residual soap emulsifier will promote wash off of the sunscreen when exposed to water.

While the major use of soap as an emulsifier is found in the oil-in-water emulsions, there has been some limited use of polyvalent soaps (primarily aluminum or calcium stearate) as water-in-oil (w/o) emulsifiers. As always we must go back to Bancroft's Rule, which tells us that where the emulsifier is most soluble will become the external phase. Since polyvalent soaps contain two or three fatty chains and only one polar head, the molecule will become more soluble in the oil phase, and a water-in-oil emulsion will be formed. It should be pointed out that these w/o emulsifiers are not

nearly as efficient as their o/w counterparts—w/o emulsifiers will always need a good secondary emulsifier and high shear mixing to insure emulsion stability.

As you can see soap emulsifiers can be very effective and should be considered when developing your next emulsion. **Formula 8.1** is a simple o/w emulsion illustrating some of the covered principles.

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Refractive Index Matching: Principles and Cosmetic Applications

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KEY WORDS: *refractive index matching, clear emulsion, formulation strategies, skin care, hair care*

ABSTRACT: *Clear emulsion formulas can be achieved by matching refractive indexes (RI) of water phase and oil phase. The match is achieved by varying the ratio of water and glycols, as shown in several skin and hair care formulas.*

Current consumer trends favor clear products in the cosmetic market. To meet this requirement, chemists have developed two ways to make clear emulsions: by micro emulsion¹ and by refractive index matching.² The former has been widely explored, leading to many microemulsion-conditioning products in the market. In contrast, the latter has not been widely explored because the physical principle is not well explained and there has been no practical methodology to follow to realize many different applications.

In our exploration of refractive index matching in formulation of cosmetics, a practical method has been developed and leads to many unique formulations. Refractive index matching enables chemists to make many unique formulas that cannot be achieved by other methods. Refractive index matching should become a common technique for formulation chemists.

Physical Principle of Index Matching

Optical refraction: Consider a beam of light transmitted through air and directed onto the surface of a body of water. Some of the light is reflected at the interface between the air and water; the remainder enters the water and is transmitted through it. Every transparent material has a property called optical density, which is an inverse measure of the speed of light through the material. Because water has a higher optical density than air, the speed of light is reduced as the light enters the water. The beam of light changes direction abruptly as it enters the water because of the change in speed. This bending of the light ray is called optical refraction.

Index of refraction: The ratio of the speed of light in a vacuum to its speed in a substance is called the index of refraction for that substance or the refractive index (RI). The index of refraction of a homogeneous substance is a constant quantity that is a definite physical property of the substance. Consequently, the identity of such a substance can be determined by measuring its index of refraction with an instrument known as a refractometer. Some indexes of refraction for common cosmetic ingredients are listed in **Table 9.1**.

What cosmetic chemists want to know is how to calculate the refractive index of a solution and how to design a formula with the refractive index of each ingredient in solution. Experimentally, it turns out that if one mixes several miscible ingredients together to form a clear homogeneous liquid phase, the refractive index of the mixture can be calculated from each individual component's refractive index in the composition. The calculated value of refractive index normally is very close to the value measured instrumentally.

For example if one mixes glycerin (RI = 1.468) and water (RI = 1.330) at 50:50 (weight ratio) compositions, the final refractive index of mixture is calculated by taking average of refractive index of these two components (RI = $[1.468+1.330]/2 = 1.399$). A plot of refractive indexes versus the percentage concentration of glycerin in aqueous solution is given in **Figure 9.1**. The measured RI values of solutions at different concentrations also compare to the values calculated from two components. It is apparent that experimental values deviate only very slightly from calculated values.

Table 9.1. Selected refractive index values of some common cosmetic ingredients

Ingredient	RI value
Water, deionized	1.3300
Glycerin	1.4680
Hexylene glycol	1.4276
Butylene glycol	1.4401
Propylene glycol	1.4355
Glycereth-7 (Liponic EG-7, Lipo Chemicals)	1.4720
PEG-4 (Carbowax PEG 200, Union Carbide)	1.4582
PEG-6 (Carbowax PEG 300, Union Carbide)	1.4615
VP/VA Copolymer (Luviskol VA 73W, BASF AG)	1.4275
PVP (Luviskol K30, BASF AG)	1.3805
Cyclomethicone (and) dimethicone (DC 1501, Dow Corning)	1.3972
Cyclomethicone (Rhodorsil 45V5, Rhodia)	1.3960
Cyclomethicone (and) phenyltrimethicone (and) dimethicone (Gelaïd 5565, Chemsil)	1.4015
Cyclomethicone (and) dimethicone copolyol (DC 5225, Dow Corning)	1.3975
Polyacrylamide (and) C13-14 isoparaffin (and) laureth-7 (Sepigel 305, Seppic)	1.4460
Sodium acrylate/acryloyldimethyl taurate copolymer (and) isohexadecane (and) polysorbate 80 (Simugel EG, Seppic)	1.4450
Hydroxyethylacrylate/sodium acryloyldimethyl taurate copolymer (and) squalane (and) polysorbate 60 (Simugel NS, Seppic)	1.4475
C13-14 Isoparaffin (Isopar M, Exxon Mobil Chemical)	1.4380
C11-13 Isoparaffin (Isopar L, Exxon Mobil Chemical)	1.4255

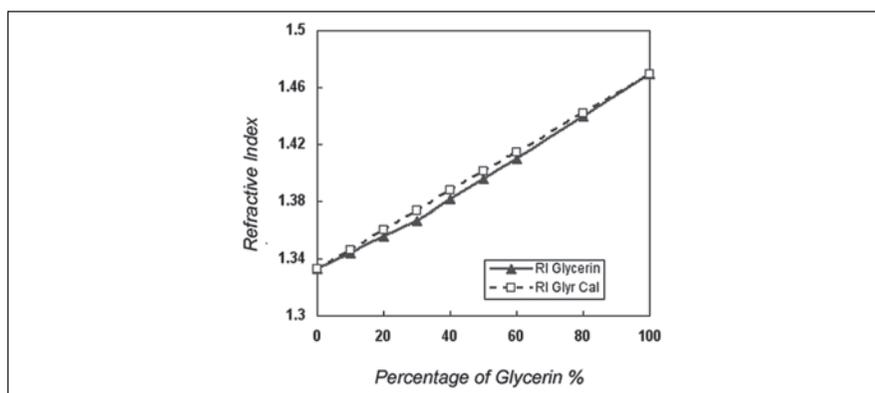


Figure 9.1. RI values—measured and calculated—of glycerin aqueous solution

One can generalize a universal equation for calculating RI_{mix} , the refractive index of a clear homogeneous liquid mixture (**Figure 9.2**). If W represents the weight of each component and RI represents the refractive index of each component, then the RI of the mixture will be determined by equation 1 and 2, which simplifies to equation 3 (all shown in **Figure 9.2**).

$$RI_{\text{mix}} = [W_1 \times RI_1 + W_2 \times RI_2 + W_3 \times RI_3 + \dots + W_n \times RI_n] / W_T \quad (1)$$

where

$$W_T = W_1 + W_2 + W_3 + \dots + W_n \quad (2)$$

We can simplify this equation as:

$$RI_{\text{mix}} = [SW_i \times RI_i] / W_T \quad (3)$$

Figure 9.2. A universal equation for calculating the refractive index of clear homogeneous liquid mixtures

Refractive index matching: By using equation 3, one can calculate RI clear water solutions containing several functional cosmetic ingredients and also clear oil phase solutions containing several functional cosmetic ingredients. It is possible to match the refractive index of the water phase to that of the oil phase. Furthermore, it is possible to make a clear or opalescent emulsion by combining a water phase and an oil phase that have equal refractive indexes. In order to directly use equation 3 for refractive index matching in an emulsion, equation 3 could be modified as shown (**Figure 9.3**) in equation 4 for RI_{oil} and equation 5 for RI_{water} (all found in **Figure 9.3**).

In reality, emulsifiers have to be dissolved in either oil phase or water phase, so it is necessary that either phase has to be clear or close to clear.

There are some limitations for using equations 4 and 5.

Firstly, there should be no reactions between ingredients in either the water phase or the oil phase. Even neutralization will change the refractive index of ingredients. For example, 10.0% glycolic acid at

pH = 3 has RI = 1.3450; at pH = 4, RI = 1.3555. Glycolic acid and glycolate anion (neutralized by triethanolamine) have different refractive indexes.

$$RI_{oil} = [\Sigma(W_i \times RI_i)] / [\Sigma W_i] \quad (4)$$

where W_i is a weight of each component in oil phase and RI_i is refractive index for each component in the oil phase;

$$RI_{water} = [\Sigma(W_i \times RI_i)] / [\Sigma W_i] \quad (5)$$

where W_i is a weight of each component in water phase and RI_i is refractive index for each component in the water phase

Figure 9.3. Refractive index matching for an emulsion

Secondly, the ingredients in the oil phase should be physically insoluble in the water phase, and vice versa. In other words, the ingredients chosen for use in the formula should not have dual distribution in both the water phase and the oil phase. Any emulsifier (or blended emulsifier ingredients) should stay only at the interface of their original phase and cannot be allowed to permeate into the other phase.

Thirdly, it is necessary to produce the emulsions at room temperature because RI values are temperature-dependent, and normally the oil phase and the water phase differ in their temperature dependency. If the clear emulsion were made at elevated temperature, the emulsion most likely would be cloudy or hazy at room temperature.

Choosing an emulsifier is also a crucial step to get a clear emulsion. Based on the nature of the emulsions, some recommended emulsifiers are shown in **Table 9.2**.

Chemists can take advantage of these equations to design their formula to meet the specific requirement of appearance and performance. After the RI of the two phases has been matched (become equal) and the two phases have been mixed together, the emulsion could be slightly cloudy at first. Longer mixing time is needed to make the emulsion homogeneous and clear. It is worth noting that water-in-silicone oil emulsions perform the best in skin care products and oil-in-water emulsions perform best for hair care products.

Table 9.2. Recommended emulsifiers for obtaining clear emulsions

Emulsifier	Emulsion type
Cyclomethicone (and) dimethicone copolyol (Dow Corning 5225, Dow Corning)	water-in-silicone
Polyacrylamide (and) C13-14 isoparaffin (and) laureth-7 (Sepigel 305, Seppic)	silicone- or isoparaffin-in-water
Sodium acrylate/acryloyldimethyl taurate copolymer (and) isohexadecane (and) polysorbate 80 (Simugel EG, Seppic)	silicone- or isoparaffin-in-water
Hydroxyethylacrylate/sodium acryloyldimethyl taurate copolymer (and) squalane (and) polysorbate 60 (Simugel NS, Seppic)	silicone- or isoparaffin-in-water

Example applications: The following examples show RI applications in cosmetic formulations based on the principles previously described. Two formulas for skin care and two formulas for hair care are illustrated. To illustrate the formulation designing process, only simplified formulas are used. They are by no means the formulas with the best performance.

The applications are not limited to the examples shown. The chemist can design many different formulas with many different ingredients by using the principles already described. This method could also be used for designing general dual-phase products with two different colors in two phases.

RI Matching in Skin Care Products

Clear AHA gel: Alpha hydroxy acids (AHAs) have been determined to have antiaging and antiwrinkle effects. AHAs have been widely used in skin care formulations.^{3,4} However, AHAs are also skin irritants. By incorporating an AHA complex (glycolic acid and arginine) to form a water-in-silicone oil emulsion, we are able to obtain a clear eye gel product with AHAs that are much less irritating.

Formula 9.1 shows the preliminary formula with the corresponding RI. The related RI calculation is also given for RI_{oil} (1.3966) and RI_{water} (1.3964) as an example for using equations 4 and 5.

Formula 9.1. Clear eye-moisturizing gel

Ingredient	Weight %	RI value
<i>Silicone oil phase</i>		
Cyclomethicone and dimethicone (DC 1501, Dow Corning)	10.0	1.3971
Cyclomethicone and dimethicone copolyol (DC 5225, Dow Corning)	10.0	1.3975
Cyclomethicone (DC 344, Dow Corning)	5.0	1.3942
<i>AHA water phase</i>		
Water, deionized	35.5	1.333
Glycerin	27.0	1.468
Glycolic acid and arginine (AHCare G-60, Cognis)	<u>12.5</u>	1.428
	100.0	

$$RI_{oil} = (10 \times 1.397 + 10 \times 1.398 + 5 \times 1.394) / 25 = 1.3966$$

$$RI_{water} = (35.5 \times 1.333 + 27 \times 1.468 + 12.5 \times 1.428) / 75 = 1.3964$$

Antiaging gel containing ascorbic acid or sodium ascorbyl phosphate: Ascorbic acid (vitamin C) has a confirmed ability to stimulate collagen synthesis in human dermal fibroblasts by increasing the rate of transcription of the collagen genes.^{5,6} It has also been found to act as a major antioxidant, anti-inflammatory and inhibitor of the enzyme tyrosinase.⁷ However, ascorbic acid has been found to be easily oxidized in aqueous solution. Therefore a gel-like product is recommended to prevent oxidation of ascorbic acid.

The alternative form of ascorbic acid is sodium (or magnesium) ascorbyl phosphate.^{8,9} Sodium ascorbyl phosphate is a stable form of ascorbic acid and will deliver ascorbic acid after applied on skin. **Formula 9.2** gives the preliminary formula with corresponding RI for an antiaging gel. The related RI calculation yields 1.3971 for RI_{oil} and 1.3970 for RI_{water} .

This is an interesting example because it shows that one can incorporate solid ingredients to get an RI match to achieve clear or opalescent products. Magnesium ascorbyl phosphate could also be used in the same way to make clear gel.

Formula 9.2. Clear W/O gel containing sodium ascorbyl phosphate

Ingredient	Weight %	RI value
<i>Silicone oil phase</i>		
Cyclomethicone and dimethicone (DC 1501, Dow Corning)	4.00	1.3972
Cyclomethicone and dimethicone copolyol (DC 5225, Dow Corning)	10.00	1.3975
Cyclomethicone (Rhodorsil 45V5, Rhone Poulenc)	11.00	1.3942
<i>Sodium ascorbyl phosphate water phase</i>		
Water, deionized	8.25	1.3330
Glycereth-7 (Liponic EG-7, Lipo)	28.60	1.4720
Sodium ascorbyl phosphate, 13.16% soln	38.00	1.3550
DMDM hydantoin (Glydant, Lonza Group)	<u>0.15</u>	1.4250
	100.00	

$$RI_{oil} = (4 \times 1.3972 + 10 \times 1.3975 + 11 \times 1.3942)/25 = 1.3971$$

$$RI_{water} = (8.25 \times 1.3330 + 28.6 \times 1.4720 + 38 \times 1.3550 + 0.15 \times 1.425)/75 = 1.3970$$

RI Matching in Hair Care Products

O/W hair silicone styling gel: Silicone oil has been widely used to deliver shine, luxurious feel, anti-frizz and manageability in hair care products. Hair fixative ingredients (such as PVP/VA or PVP) have also been widely used in carbopol gels, giving styling effects for hair. The interesting point here is that if one can combine silicone oil and hair fixatives into a clear gel-like product, the new product will have impart hold and give the aforementioned properties of silicone. At the same time, the product will also have styling function from the fixative resins. As shown in **Formula 9.3**, the principle of RI matching can be used to make the clear silicone styling gel with a value of 1.4060 calculated for both the RI_{oil} and the RI_{water} .

O/W isoparaffin glossing styling gel: It is general knowledge that an oil ingredient with higher refractive index usually will give more shine to hair. The isoparaffins often have higher RI than silicones. This suggests the possibility of incorporating both isoparaffin and PVP/VA in a clear glossing gel, such as **Formula 9.4**. For this

Formula 9.3. Clear O/W silicone gel containing PVP/VA

Ingredient	Weight %	RI value
<i>Silicone oil phase</i>		
Cyclomethicone (Rhodorsil 45V5, Rhodia)	4.00	1.396
Polyacrylamide, C13-14 isoparaffin, laureth-7 (Sepigel 305, Seppic)	3.00	1.446
Cyclomethicone (and) phenyltrimethicone (and) dimethicone (Gelaidd 5565, Chemsil)	20.00	1.402
<i>PVP/VA water phase</i>		
Water, deionized	26.50	1.333
Glycereth-7 (Liponic EG-7, Lipo)	21.35	1.472
PVP/VA copolymer soln (50% active) (Luviskol VA 73W, BASF)	25.00	1.427
DMDM hydantoin (Glydant, Lonza Group)	<u>0.15</u>	1.425
	100.00	

$$RI_{oil} = (4 \times 1.396 + 3 \times 1.446 + 20 \times 1.402)/27 = 1.4060$$

$$RI_{water} = (26.5 \times 1.333 + 21.35 \times 1.472 + 25 \times 1.427 + 0.15 \times 1.425)/73 = 1.4060$$

Formula 9.4. Clear O/W isoparaffin gel containing PVP/VA

Ingredient	Weight %	RI value
<i>Isoparaffin oil phase</i>		
C11-13 Isoparaffin (Isopar L, Exxon Mobil)	4.00	1.425
Polyacrylamide, C13-14 isoparaffin, laureth-7 (Sepigel 305, Seppic)	3.00	1.446
C13-14 Isoparaffin (Isopar M, Exxon Mobil)	20.00	1.438
<i>PVP/VA water phase</i>		
Water, deionized	10.25	1.333
Glycereth-7 (Liponic EG-7, Lipo)	37.60	1.472
PVP/VA copolymer soln (50% active) (Luviskol VA 73W, BASF)	25.00	1.427
DMDM hydantoin (Glydant, Lonza Group)	<u>0.15</u>	1.425
	100.00	

$$RI_{oil} = (4 \times 1.425 + 3 \times 1.446 + 20 \times 1.438)/27 = 1.4369$$

$$RI_{water} = (10.25 \times 1.333 + 37.6 \times 1.472 + 25 \times 1.427 + 0.15 \times 1.425)/73 = 1.4369$$

formula a value of 1.4369 was calculated for both the RI_{oil} and the RI_{water} .

Deviations and Practical RI Adjustment

The calculation of refractive index for solutions only applies for the ideal solutions or ideally dilute solutions. In ideal solutions, the molecules of the various species are so similar to one another that molecules of one component can replace molecules of another component in the solution without changing the solution's energy or spatial structure. In ideally dilute solutions, all solutes are present in very low concentrations and the solvent weight percentage approaches 100%.

In cosmetic formulations, the solutions are neither ideal nor ideally dilute solutions because the solvent and solutes can not be very similar, and the concentrations of solutes can not be impractically low. They are nonideal solutions containing both electrolytes and nonelectrolytes. The precise calculations will need to use chemical potential (m_i), solutes activities (a_i) and activity coefficients (g_i). The calculation will become very complicated and impractical for cosmetic chemists. Fortunately, a simplified calculation is sufficient to serve the purpose of designing the formulation.

In the process of making the oil phase and water phase for **Formulas 9.1** through **9.4**, the RI will deviate slightly from the calculated value. The deviation in the oil phase is usually very small because all the RI values of the oil phase ingredients are very close. Consistent RI readings of oil fluids result from similarity in both molecular structure and interaction between these molecules.

However, there is a noticeable RI deviation in the water phase preparation because water has a very low RI value and glycols have very high RI values. In addition, the molecular interaction between glycol and water is different than the interaction between glycol molecules or the interaction between water molecules. Therefore the formula needs further refinements to assure index matching of oil phase and water phase.

Various glycols are used to raise the refractive index of the aqueous phase to match the silicone oil ($RI \sim 1.4$) or isoparaffin ($RI \sim 1.43$). The refractive index values for several glycols as a function of

concentration are shown in **Figure 9.4** for a two-components system. The glycol aqueous concentrations are varied from 10% to 80%. Different deviations are seen in the plot. Glycerin has slightly negative deviation and all others show positive deviation. Hexylene glycol shows the biggest positive deviation. The deviation is also concentration dependent.

To demonstrate the positive and negative deviation, we plotted the refractive index values of hexylene glycol and glycerin aqueous solution versus percentage concentration in **Figure 9.5**.

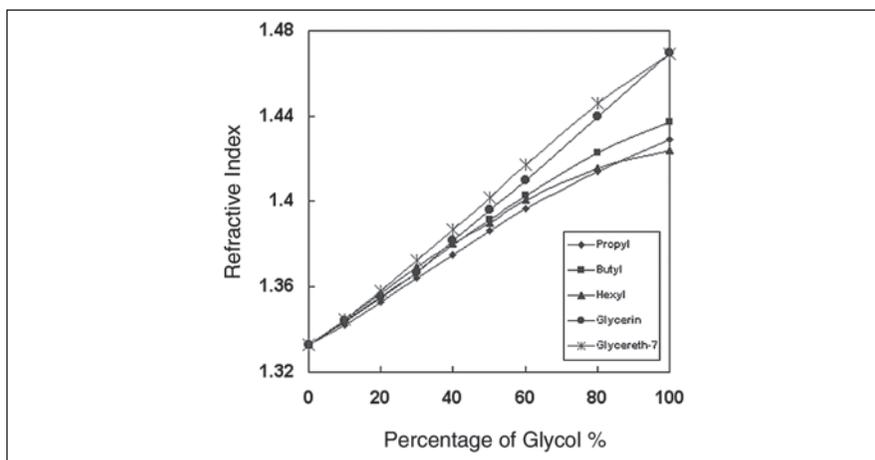


Figure 9.4. RI values of glycol aqueous solutions

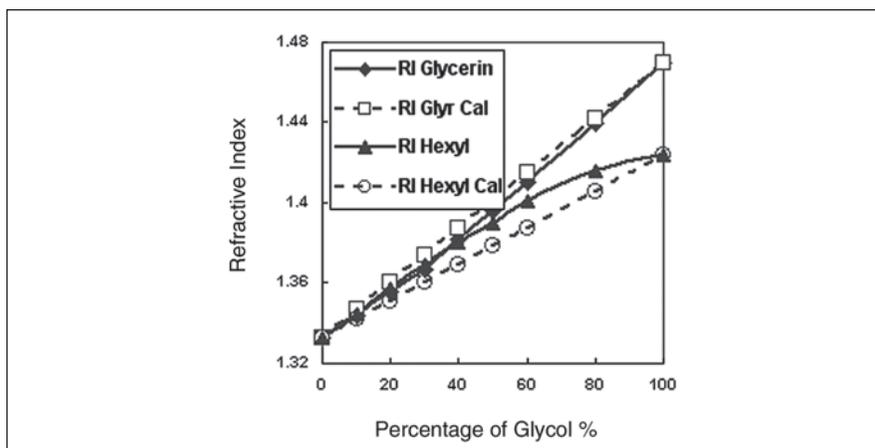


Figure 9.5. RI deviation of glycerin and hexylene glycol aqueous solutions

In **Figure 9.5**, the largest negative deviation is seen for glycerin at the concentration of 30%, where there is a -0.51% deviation ($1.367 - 1.37395 = -0.00695$) from the calculated value.

Hexylene glycol shows the largest positive deviation among all the studied glycols (**Figure 9.4**). The experimental RI value of hexylene glycol is even larger than the value of glycerin solution (**Figure 9.5**) at concentrations in the range of 10–35%. The largest deviation of refractive index for hexylene glycol is at the concentration of 60%, where it deviated 0.97% from the calculated value.

Propylene glycol, butylene glycol and hexylene glycol all show positive deviation (**Figure 9.4**). However, propylene glycol has least deviation and hexylene glycol has largest deviation. The nature of the deviation may be related to the molecular interaction between water molecules and between glycol molecules as well as between water and glycol molecules. These three glycols have the same diol (dihydroxy) function groups on two carbon atoms. The more carbon the molecule has, the more difference there will be in the molecular interaction between glycol and water molecules. The more difference there is in the molecular interaction between glycol and water molecules, the more positive is the observed deviation (**Figure 9.4**).

It is apparent that the most efficient way to raise the refractive index of the aqueous phase is use a combination of hexylene glycol in the range of 20–30% with either glycerin, glycereth-7 or butylene glycol. Propylene glycol is less efficient at raising the RI of the water phase because it has the least positive deviation and the lowest refractive index value in the group.

In the formulation process, one has to consider, among other factors, the formulation performance, ingredient cost and ease of operation. Although the examples presented here are not the best performers or the best formulas, they do illustrate the use of refractive index matching to design new formulas by combining equations 4 and 5 and **Figure 9.4**.

Refractive index matching enables chemists to make unique formulas that are unachievable by other methods. Refractive index matching could become a common means for developing the next generation of cosmetic formulas.

Summary

A simple calculation scheme has been developed for designing clear emulsion formulas by matching the refractive indexes of the water phase and the oil phase. The RI value of the water phase was adjusted by varying the ratio of water and glycols. Some positive deviations and negative deviations were observed for water-glycol two-component system. The use of index calculation and deviations leads to more precise formulation design.

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Choosing Thickening Agents For Emulsions: Water Phase Thickeners

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KEY WORDS: *emulsion, stabilization, viscosity, temperature stability, gums, thickeners, pH, electrolyte, skin feel, application, marketing claims*

ABSTRACT: *This chapter focuses on the thickening aspect of emulsion stabilization. By looking at application qualities and temperature stability, the author examines the many different aspects to consider in the choice of thickeners.*

Emulsion stabilization is a favorite topic of mine. A key component of every emulsion is the thickener or, more properly, a thickener system that is employed. We all remember the Stokes Law, which tells us that an important factor in stabilizing emulsions is the viscosity of the external phase. Interestingly enough, often the primary function of thickeners is not to increase the viscosity of the emulsion, but to stabilize the emulsion or to affect application qualities.

The choice of thickeners is almost limitless, with more being developed practically every day. This short column will discuss a few thickeners and things to keep in mind when choosing them. It is by no means comprehensive, and I'm fairly certain that I won't be discussing your favorite material.

There are a number of factors to be considered when choosing a thickening agent for emulsions, but the most important one is to remember your goal. To say it another way: Why are you using a

thickener? Is it to increase the viscosity, stabilize the emulsion, effect application qualities, or suspend some particulate material?

In regards to increasing the viscosity, we know that this can be accomplished in two ways: increasing the volume/size/percentage of the internal phase, or increasing the viscosity of the external phase (see previously mentioned Stokes Law).

Application Qualities

Few things are more important than an emulsion's application qualities. When discussing this parameter, there are some important elements to take into account.

Playtime: How long does it take for the emulsion to rub in? This can be (and usually is) dramatically affected by the inclusion of a gum/thickener. It is also affected by the type and concentration of the emollients in the internal and external phases. If you have, for example, a liquid makeup that contains high levels of particulates, you must have sufficient playtime to allow the product to be applied and cover the skin while also having a quick drying time. Otherwise, the liquid makeup will be considered oily. On the other hand, a sunscreen must not dry too quickly or it cannot be spread evenly to provide complete/uniform protection.

Cushion: "Cushion" is a difficult concept to put into words because it is a perceived quality, so it is quite subjective. Generally, cushion refers to the apparent thickness during the rubout of the emulsion. If the cushion is too little, then the emulsion will feel thin and not luxurious. Cushion can be affected by a thickener, the humectant used (for example, butylene glycol and hexylene glycol have less cushion than glycerin or propylene glycol) and the "oil" content and type.

Temperature Stability

Stabilizing the emulsion can be further subdivided: high temperature stability (40°C, 45°C and 50°C), low temperature stability (4°C, -10°C) or freeze/thaw stability. In terms of suspension, the formulator must consider the specific gravity of the material to be suspended along with its surface charge/modification (if any). Additionally, the particulate may change its effect based on pH. Zinc oxide is a good

example of this phenomenon—as the pH drops, zinc oxide becomes more soluble, this releases polyvalent “electrolyte” into the system which can have a deleterious effect on the thickening ability of the polymer.

When talking about stability and viscosity, a formulator should always measure the viscosity of the emulsion at room temperature and at high temperature as a predictor of emulsion stability. If, for example, the viscosity of the lotion is 10,000 cps at 20°C but drops to 100 cps at 45°C, then you should be concerned. If the viscosity only reduces to 5,000 cps at 45°C then the formulator can have a real measure of confidence of the long-term stability of the lotion.

Gums and Thickeners

Emulsion stabilization can also be accomplished through the use of hydrophobically modified gums. There are many such materials currently marketed, and I urge you to investigate these versatile materials. But, beware of using hydrophobically modified gums in formulations with high levels of emulsifiers—destabilization may result due to flocculation depletion (a competition at the interface between the emulsifier and the hydrophobically modified gum). There are specific things that govern which thickener to use and at what percentage.

pH: Many gums and thickeners will profoundly change their efficiency based on the pH of the system. For example, if you are formulating an AHA lotion with a pH of 3.5 and incorporating lactic acid at 5%, the use of carbomers is not a good idea because they are acrylic acid polymers and must be neutralized to a pH of at least 5.5 to exhibit functionality. You might consider a cellulose derivative combined with xanthan gum or magnesium aluminum silicate. Polyacrylamide or hydroxyethyl acrylate/sodium acryloyldimethyl taurate copolymer would also be a good choice, as these materials have good thickening characteristics at low pH. If a hair relaxer was formulated with a pH above 12 and a very high electrolyte load, acrylates/steareth-20 methacrylate copolymer might be used because it tolerates these conditions well.

Electrolyte: There are two things to consider when discussing electrolytes: type and concentration.

Is the electrolyte type monovalent (sodium or potassium) or polyvalent (calcium, magnesium, zinc, aluminum, etc.)? Some gums are more tolerant to electrolytes and specifically to the polyvalent type. Sometimes the neutralizer (when the polymeric thickener must be neutralized) can dramatically improve the electrolyte tolerance. You should also remember that neutralization can play a major role in the final stability of the formulation. Generally, the material should be neutralized before it “sees” the electrolyte.

Generally the “natural” thickeners have better electrolyte tolerance than the synthetic materials. However, as a general rule, the natural materials are not as good/efficient in building viscosity or stabilizing emulsions.

Viscosity desired: I would not recommend using gums/thickeners for significantly increasing viscosity of emulsions. In order to accomplish this, they must be used at levels that degrade the skin-feel qualities of the emulsion.

Ionic nature of the emulsifier: If the emulsifier system is non-ionic, you can readily employ any thickener. However, if you are making a skin cream based on cationic emulsifiers (baby or dry skin lotions, for instance), you should consider using a cationic thickener such as polyquaternium-37 or polyquaternium-32.

Cost: This is always an important consideration. In general, the thickeners we are discussing are used at a sufficiently low level, so cost contribution is not an issue. However, some exotic natural (sclerotium gum) and synthetic (acrylic acid/acrylonitrogens copolymer) gums, which offer excellent skin feel and stabilization, can be quite expensive. They can often be utilized in combination with other materials at low use levels while still applying their significant benefits.

Skin feel: This cannot be ignored! The natural materials generally provide great lubricity but, if used at concentrations that are too high, they can get sticky and negatively affect playtime. Using particulates (nylon, hydrophobically modified starches, PTFE, polymethylmethacrylate, etc.) can dramatically improve skin feel.

Stability/compatibility with key materials: If you have developed an emulsion that contains reactive materials such as hydrogen

peroxide, hydroquinone or dihydroxyacetone, then you must determine the compatibility of your chosen gum with these materials.

Application characteristics: The rheology of the emulsion is very important. A cream should shear thin during application and then thicken up (thixotropy) after rubbing to give a rich skinfeel. This can be controlled/influenced by your choice of gum/thickener.

Marketing claims/issues: With the move toward “natural” cosmetics (which has been going on for several decades), we’re seeing the use of natural thickeners expanding. I suggest combining them with newer synthetic thickeners in order to get real synergism and performance.

The thickener category changed dramatically several decades ago with the introduction of the carbomer materials by the B.F. Goodrich (now Noveon) Company. These synthetic polymers can be loosely described as a homopolymer of acrylic acid that has been crosslinked. As supplied, this off-white powder is in its acid form. When neutralized with an appropriate base (triethanolamine, sodium hydroxide, potassium hydroxide, etc.), the acrylic acid groups become acrylate anions (negatively charged) and repel each other. This repulsion opens up the polymeric backbone, and thickening is the result.

Since the carbomers depend on electrostatic repulsion to thicken, it is not surprising that they exhibit a poor tolerance to high electrolyte (sodium chloride) levels. They are even less forgiving of polyvalent electrolytes (zinc oxide, calcium chloride, magnesium sulfate, etc.). Thus, if you are formulating a sunscreen containing zinc oxide and need to use a good suspending agent, these materials are to be avoided. In this case, you might consider using a more robust polymer such as acrylates/acrylamide copolymer or polyacrylamide.

Many people have had success using a natural thickener such as xanthan gum in combination with a mineral thickener (magnesium aluminum silicate). The carbomers became popular for a number of reasons, but they had three major benefits when compared to other thickeners of the time: they increased viscosity at low concentrations, they were excellent suspending agents, and they maintained

most of their viscosity at high temperatures. There are now numerous materials available that have similar (and sometimes better) performance, but carbomers is where it started.

Let me end with one of my favorite rants—we don't combine thickening agents often enough. It is more typical for us to use a single material and, if it doesn't seem to work, we just increase its usage level until price or skin feel considerations force us to abandon it for another material. Remember that it is difficult to sell an emulsion that feels like wallpaper paste! Combine thickeners...save money, improve skin feel and improve stability.

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New Emulsion Technology Makes Formulation Easy

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KEY WORDS: *cold mixing, emulsions, HIP, emollients, particle size, dispersion*

ABSTRACT: *This chapter describes the use of a novel process technology to prepare high internal phase (HIP) emulsions, which can provide solutions to a number of formulating issues.*

Developing a successful formulation in today's competitive personal care industry presents many challenges. The formulation must fulfill the expectations of consumers with respect to performance as well as esthetics. It must meet a number of physical stability criteria including the ability to withstand various aging conditions such as high temperature, freeze-thaw cycling and vibration. Often, formulations must be developed under a tight schedule that can include adjustments driven by consumer testing of prototypes developed in the initial stages of the project. Given these factors, it is no surprise that so many commercialized products are variations of formulations that were developed years ago. This is especially true of products based on emulsions because formulators work against the laws of thermodynamics, which dictate that emulsions are fundamentally unstable systems.

This chapter describes the use of a novel process technology to prepare high internal phase (HIP) emulsions, which can provide solutions to a number of formulating issues. HIP emulsions have

been used as a basis for pre-emulsified concentrates of emollients, moisturizers and sunscreens. The small particle size and size-distribution control provided by the new technology allow formulators to create skin care products with distinctive aesthetics. The emulsion concentrates allow simple cold mixing and, because of their excellent stability, formulators can easily adjust emollient levels to obtain the desired skin feel. The result can be greater speed in formulation and scale-up of new skin care products.

Background

Despite the inherent instability of emulsions, formulators are usually required to work with these systems because so many ingredients are hydrophobic and water-insoluble. An emulsion is defined as a stabilized mixture of two or more insoluble materials. In most cases, personal care emulsion formulations consist of water mixed with a variety of water-insoluble ingredients such as emollient oils, moisturizers and sunscreen oils. The term “water phase” is used to refer to the water and all the water-soluble ingredients in the formula. The water-insoluble ingredients are dispersed in the water phase in the form of tiny droplets that are stabilized by a layer of emulsifiers that prevent the oil droplets from coalescing. Coalescence must be prevented because it leads to changes in the texture and appearance of the formulation, eventually causing separation as the oil droplets continue to grow in size.

To produce the tiny droplets of oil, the formulation is typically subjected to some form of high shear mixing that causes the oils to break up into droplets with the desired particle size. (The droplet size is customarily referred to as particle size, even though the oils are usually liquid droplets instead of solid particles.) The particle size of an emulsion formulation must be small enough to produce a smooth texture, which requires droplets with an average diameter less than about 30 or 40mm (1mm is 0.001 millimeter).

Because of a phenomenon called “creaming,” it is usually desirable to have a particle size even smaller than that needed to give a smooth texture. Creaming is the tendency of the oil droplets to float to the top of the formulation, and is driven by the fact that the oils usually have a

lower density than the water phase. The movement of the oil droplets will lead to a nonuniform product if the movement is not controlled. Stokes Law predicts the rate of movement of droplets in a formulation as a function of the difference in density between the droplets and the water phase, the droplet diameter and the viscosity of the water phase. The relationship between Stokes Law and emulsion stability has been reviewed in some detail.¹ The equation says that the rate of movement can be reduced by reducing the particle size of the droplets or by increasing the viscosity of the water phase. In practice, formulators usually do both to minimize the rate of movement.

A variety of thickeners for the water phase are available and widely used to reduce the rate of particle movement and to adjust the consistency of the formulation. For some product types, such as sprays, there are limitations on the formula viscosity because systems that are too thick will not spray properly. In these cases, particle size reduction is the most important technique for making formulations with the required stability against creaming.

Particle size reduction in emulsion formulations has advantages beyond stability considerations because the objective for a good formulation is to deliver a uniform coating of active ingredient onto the application surface. For example, in a moisturizer that is based on petrolatum, the efficacy of the product depends on delivering a thin, uniform coating of petrolatum onto the skin. This is best achieved by a petrolatum emulsion with a small, uniform particle size distribution.

Sunscreen is another product type where the delivery of a uniform coating of active ingredient is critical. The sun protection factor (SPF) for a sunscreen depends on the consumer's ability to apply a uniform film. A film of sunscreen with areas of low concentration provides less protection from UV radiation in those areas that, in turn, produces a lower SPF value. One way to help ensure a uniform film of sunscreen is to make a formulation with a small, uniform particle size distribution. In addition to performance considerations, aesthetics are improved by dispersing the oil ingredients in the form of small, uniform droplets. Formulations of this type will have a whiter, more shiny appearance and will apply more evenly.

New Dispersion Technology

The traditional process for making emulsions involves combining the oil phase and the aqueous phase, often at high temperatures and shear rates, to form the emulsion using a “shear rupture” mechanism. Traditional batch processes are usually energy intensive, requiring long processing times and resulting in batch-to-batch inconsistencies. The heat cycle also reduces the efficacy of many actives. These traditional batch processes are limited in their ability to incorporate highly viscous materials and to control and minimize particle size, and they typically require higher levels of surfactant to create stable emulsions.

Unlike traditional batch emulsions that use multiple passes through the shear field to generate particles, new proprietary HIP technology^a uses a process that utilizes a dispersion technology^b that uses a single-pass “droplet elongation” mechanism² to spontaneously form the desired particles as shown in **Figure 11.1**. This continuous process involves stretching the oil droplets under minimal shear to the point where they “pinch” off, forming a series of uniform oil droplets. The droplet elongation mechanism allows for reliable control of particle size from submicron to several microns in size. Because the process does not require high temperature, special surfactants or high shear, it can incorporate materials that are heat sensitive (e.g., actives, botanicals, etc.) as well as materials over a wide range of viscosities (1 to 500,000cP have been demonstrated).

In general, the process can be used to create high solids (75–95% oil phase) HIP emulsions with particle sizes less than 1 μm and with half the surfactant typically required in traditional processes.

Particle Size Profiles in Finished Formulas

One of the most significant differences between using HIP emulsions versus conventional means of emulsifying oils is the small and uniform particle size distribution that can be achieved with HIP emulsions. **Figure 11.2** shows the particle size distribution for a

^a The technology referenced is offered through Dow Dispersion Sciences, a new business within The Dow Chemical Company (Dow).

^b The dispersion technology was created by Dow Chemical. Patent application pending

commercial hand and body lotion. Most of the particles in this product are larger than 10 μm , and the emulsion has particles ranging from about 6 μm to more than 70 μm .

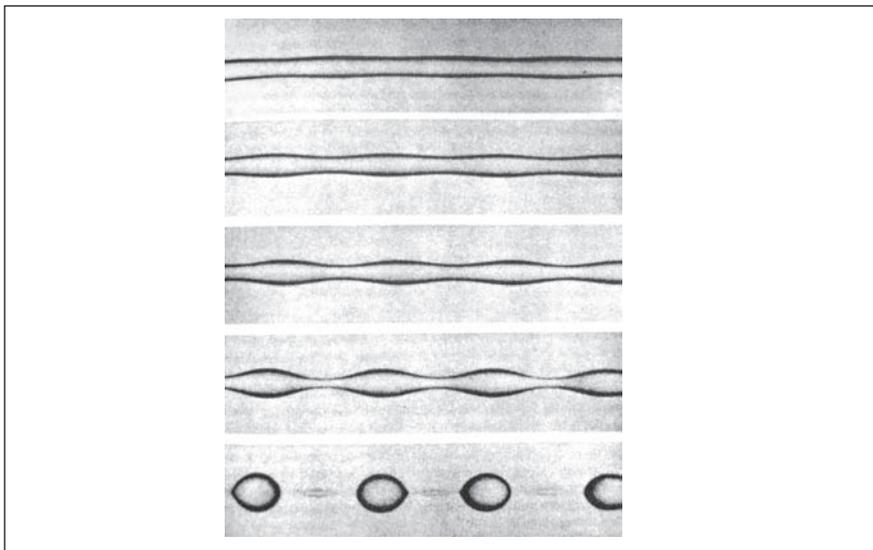


Figure 11.1. Breakup of a stationary liquid thread by capillary waves^c

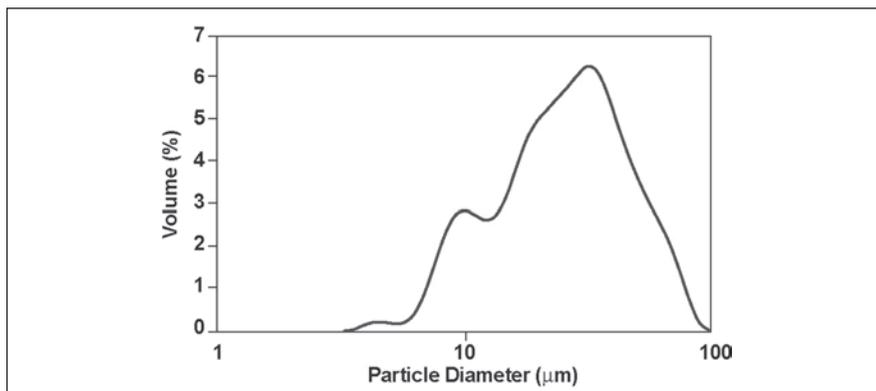


Figure 11.2. Particle size distribution in a commercial hand and body lotion. Particles range in size from approximately 6 μm to greater than 70 μm . The majority of particles are larger than 10 μm .

^c Photo in Figure 1 reprinted from The Journal of Colloid and Interface Science, Vol. 17, FD Rumscheidt, SG Mason, Break-up of stationary liquid threads, pages 260-269 Copyright 1962"

In contrast, **Figure 11.3** shows the particle size distribution for an HIP emulsion of a 50:50 mixture of petrolatum and dimethicone prepared via the dispersion technology. The particle size distribution for the HIP emulsion (red line) shows that most of the particles are less than 1 μm in diameter. The blue line in **Figure 11.3** shows the particle size distribution for a formulation made with the same HIP emulsion after it was aged at 50°C for four weeks. The formulation was made by diluting the HIP emulsion to 15% oil in water that was thickened with 0.3% carbomer neutralized with triethanolamine.

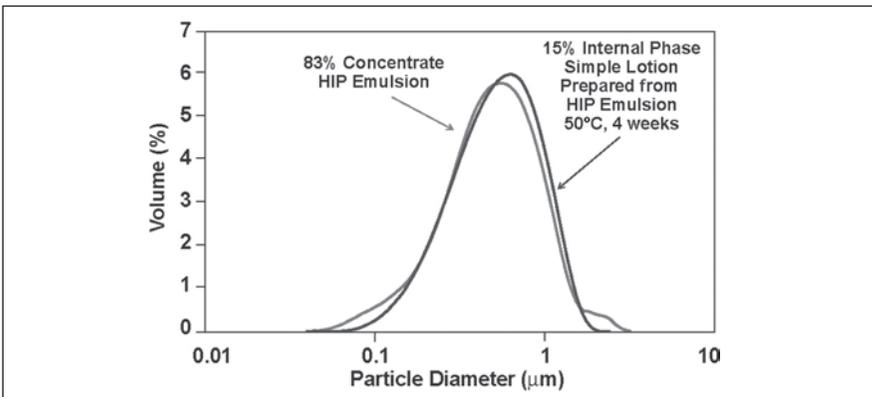


Figure 11.3. Particle size distribution for an HIP emulsion of a 50:50 mixture of petrolatum and dimethicone. Most particles are less than 1 μm in diameter.

HIP emulsions are especially useful for emollients that can be difficult to emulsify. For example, mixtures of silicone gums and fluids can be difficult to emulsify because of their relatively high viscosity and the tendency for the silicone gum to separate from the fluid.

Figure 11.4 shows the particle size distribution for two emulsion formulations that contain a 15% dimethiconol/cyclopentasiloxane blend. The red line shows the particle size distribution for the formulation made with an HIP emulsion of the silicone gum blend, while the blue is for a similar formulation made using a conventional emulsification technique. The formulation made by the conventional method has a very broad particle size distribution with particles larger than 50 μm .

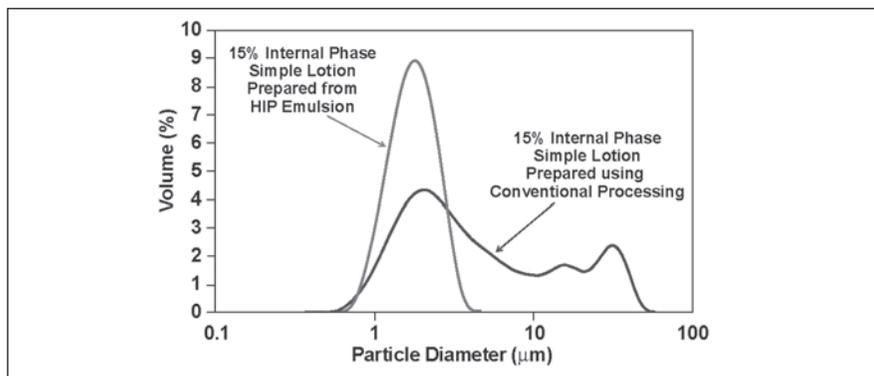


Figure 11.4. Particle size distribution for two emulsion formulations (conventional and HIP) that contain 15% dimethiconol/cyclopentasiloxane blend.

Sunscreen oils such as octinoxate (also known as ethylhexyl methoxy-cinnamate or octyl methoxycinnamate) can be introduced into formulations using an HIP emulsion, which also produces a formulation with a better particle size profile compared to conventional emulsification techniques. **Figure 11.5** shows particle size distributions for two formulations that contain 7.5% octinoxate. The red line is the distribution for the formulation made with the HIP emulsion, and the blue line shows the distribution for the conventional emulsion formulation. **Figure 11.6** shows that the particle size distribution is maintained from the HIP emulsion (blue line) to the formulation (red line) and to the formulation that was aged at 45°C for three months (green line).

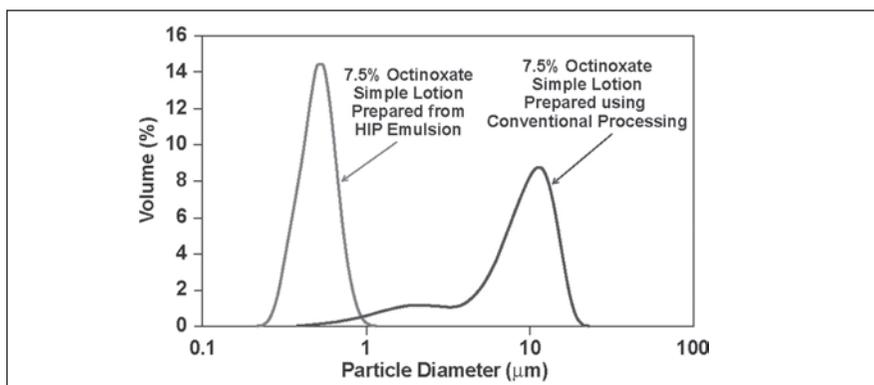


Figure 11.5. Particle size distributions for two formulations (conventional and HIP) that contain 7.5% octinoxate.

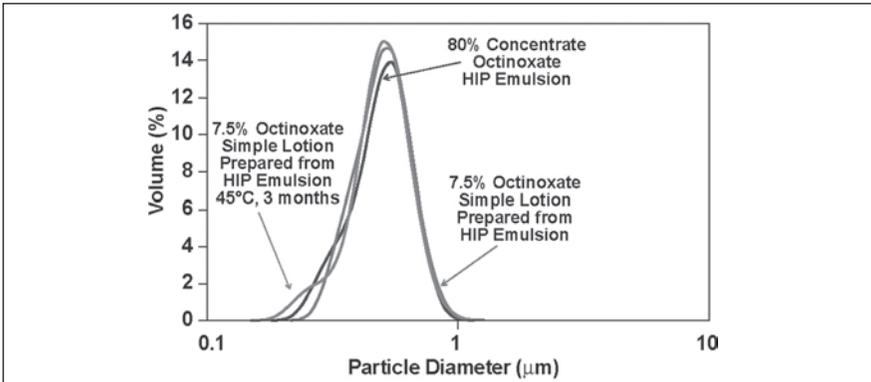


Figure 11.6. Stability of particle size distribution from HIP emulsion through formulation and aging (45 °C/3mos.)

Better Performance with HIP Emulsions

The small particle size and narrow particle size distribution for formulations made using HIP emulsions can improve formulation quality and stability, especially for low viscosity formulations. Many formulations have a high enough viscosity that creaming or settling is not a significant problem. However, formulations that are stabilized with emulsifying waxes such as fatty alcohols and fatty alcohol ethoxylates can become unstable if they are stored above the melting point of these waxes.

Formulations made with HIP emulsions do not have this problem, and their consistency can be adjusted by the use of thickening agents without any effect on emulsion stability. But formulation stability is only one benefit of using HIP emulsions. The aesthetics and performance of the formulation can be improved as a consequence of the small particle size that is produced with an HIP emulsion.

Petrolatum is often used as an emollient and occlusive moisturizing agent in skin care formulations, although it can be difficult to emulsify and can have undesirable sensory properties. To determine if a formulation based on a petrolatum HIP emulsion might have better sensory properties, two simple lotions were evaluated by a trained sensory panel. One formulation was made with 16% petrolatum that was emulsified using conventional means. The other was made with an HIP emulsion of petrolatum. The lotions were

evaluated during rubout, immediately after rubout, and again after 20 minutes.

The greatest differences were found at the evaluation done 20 minutes after rubout. **Figure 11.7** shows the results for two attributes where statistically significant differences were found by the trained panel. The lotion made with the HIP emulsion was less sticky and had a less waxy feel compared to the lotion made by conventional means. Evaluations of other pairs of lotions that contained silicone emollients did not show differences as large as those for the petrolatum lotions, which suggest that the esthetics of silicones are not as dependent on particle size in the formulation.

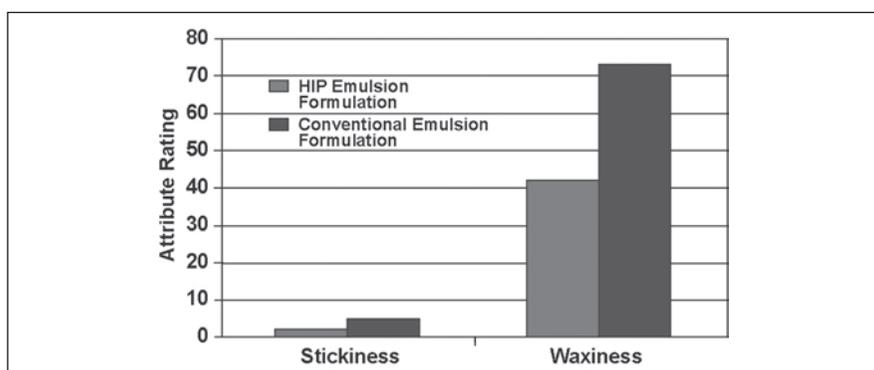


Figure 11.7. Results of paired comparisons of stickiness and waxiness between HIP and conventional emulsions.

The efficacy of sunscreen oils is increased by the use of HIP emulsions. This effect was demonstrated for simple lotions based on octinoxate as well as other sunscreens. **Figure 11.8** shows both in vitro and in vivo SPF results for a lotion that contains 7.5% octinoxate. The lotion made with an octinoxate HIP emulsion produced almost twice the SPF value compared to the lotion with octinoxate that was emulsified by a conventional method. Similar results were found with octisalate (also known as ethylhexyl salicylate or octyl salicylate), a mixture of octinoxate and octisalate, and a mixture of octinoxate, octisalate and oxybenzone. These results, based on in vitro testing, are given in **Figure 11.9**. The increase in SPF for the formulations made with HIP emulsions is thought to be due to more even coverage produced by the smaller droplets when they are applied to the skin.

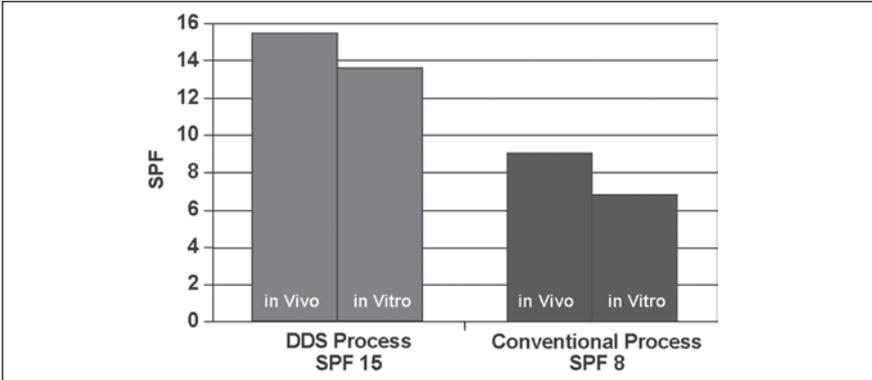


Figure 11.8. In vitro and in vivo SPF results in conventional and HIP emulsions for a lotion containing 7.5% octinoxate.

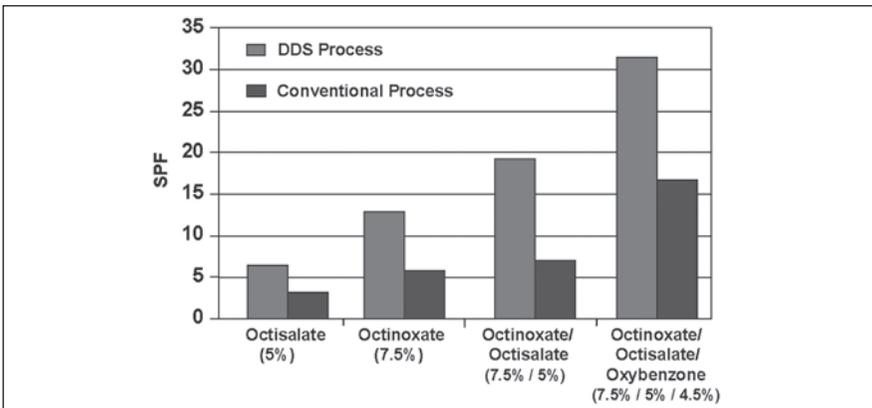


Figure 11.9. In vitro comparisons of SPF values in conventional and HIP emulsions using combinations of several organic sunscreens.

Recommended Applications for HIP Emulsions

HIP emulsions have many potential uses in personal care formulations. They can be used to make very simple products where the concentrated emulsions are simply added to a water phase that contains a thickener to give the desired consistency. The water phase could contain water-soluble ingredients such as humectants (e.g., glycerin or sorbitol), botanical extracts, thickeners and preservatives.

The small particle size of the HIP emulsions makes them well suited for the preparation of clear moisturizing or skin treatment gels. Clarity is achieved by matching the refractive index of the water phase to the refractive index of the oil(s) in the concentrated emulsion. One

way to do this is by adding glycerin to the water phase to increase its refractive index. Once the correct water phase refractive index is found, the concentrated emulsion can be added in any proportion to produce the desired aesthetics. The formulation can be thickened by the use of carbomer or other rheology modifiers. The small particle size of the HIP emulsion contributes to the clarity of the resulting gels.

Sprays are another product form that can be easily prepared using HIP emulsions. Because these products must be relatively low in viscosity to spray properly, creaming can be a serious problem. With the new low particle size HIP emulsions, only a minimal amount of an associative thickener such as acrylates/C10-30 alkyl acrylate crosspolymer is needed to prevent creaming. To determine the minimum amount of thickener needed, the HIP emulsion is dispersed in the water phase along with a low concentration of a thickener such as acrylates/C10-30 alkyl acrylate crosspolymer that has been neutralized. The formulation can then be centrifuged to quickly determine if the concentration of thickener is high enough. If so, a second formulation with a lower concentration can be made and centrifuged. This process can be continued until the formulation exhibits creaming after centrifuging, an indication that the thickener has been reduced too much.

An HIP emulsion with a high concentration of emollient can be useful for solid moisturizers such as body butters. To make an aqueous body butter, the HIP emulsion concentration is adjusted to give the desired emolliency and skin feel. The proper consistency can be achieved by a combination of thickeners and water-soluble waxes in the water phase. One water-soluble wax that works well for this purpose is bis-PEG-18 methyl ether silane.

Conclusions

The new HIP emulsion technology allows formulators to develop emulsion systems that deliver ingredients with a potentially greater functionality and better aesthetics. With broader formulating options for pre-emulsified emollients and moisturizers, formulators can create highly differentiated products that have an edge in today's competitive personal care market.

Acknowledgements

The authors would like to thank Dale Schmidt and David Malotky for their efforts to develop many of the HIP emulsions described here. Thanks also to Letha Gatz and Craig Laszlo for preparing and characterizing the emulsions.

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Correlation of Long-term Physical Stability of Emulsions with the Short-term Rheological Measurements

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KEY WORDS: *emulsion, rheology, stability, life span, coalescence*

ABSTRACT: *Three short-term rheological measurements on some personal care emulsions showed good correlation with long-term physical instability of the emulsions. Use of these rheological measurements can shorten the time to test the stability of new formulations.*

Emulsions used in personal care and cosmetic formulations—both oil-in-water (o/w) and water-in-oil (w/o) types—need to satisfy a number of criteria. They must demonstrate physical stability over 2–3 years under various conditions, such as temperature variation and stress induced by vibration during transportation. They must also maintain the proper consistency (rheology) to achieve good skin-feel, spreading and delivery of actives. Finally, the safety of the ingredients used must be assured to avoid any skin irritation or adverse effects on contact with the skin.¹ Since the life-span of most personal care and cosmetic formulations is only 3–5 years, development of the product should be fast. For this reason, accelerated

storage testing is needed for the prediction of the long-term physical stability of the formulation as well as the change of consistency with time. These represent challenging tasks for formulation chemists.

Of the several processes by which emulsions break down,² the most important are creaming or sedimentation, flocculation, coalescence, Ostwald ripening (disproportionation) and phase inversion. The physical phenomena involved in these breakdown processes have been discussed in detail in several review articles.^{3,4} The aim of the formulation chemist is to use short-term measurements (within the first few weeks after preparation of the formulation) to predict the long-term physical stability (more than one year) of the emulsion system.

To date, most predictive tests are based on accelerated storage such as subjecting the formulation to temperature changes (cycling), centrifugation and vibration. However, most of these methods do not provide an accurate predictive test. For example, by subjecting the formulation to high temperature, the assumption is made that if a formulation stores for 3 months at 50°C, it would stay for 2 years at ambient temperature. The problem with this approach is the phase changes that may occur at a critical temperature, which means a breakdown may not occur at an ambient temperature for several years. Centrifugation tests can also be misleading, since subjecting the formulation to a high gravity force may cause coalescence that may not occur at normal gravity forces.

Recently, it was found that rheological measurements carried out within the first few weeks proved to be the most useful and predictive tests. Three different types of rheological measurements—steady state, constant stress and dynamic or oscillatory techniques—have been applied and these have been described in detail in a recent review.⁵ To test these methods, the study begins with model emulsions representative of many personal care formulations. The correlations obtained between the long-term breakdown process with the short-term measured rheological parameters will be given in the hope to prove the validity of these prediction tests. In some cases, optical microscopic investigations are carried out to give direct observation of some of the breakdown processes.

Experiment

Materials: The oil phase used for the preparation of the emulsion consisted of 10 parts isohexadecane^a, 2 parts of caprylic/capric triglyceride^b, 1 part *Helianthus annuus* (sunflower) oil^c and 1 part *Persea gratissima* (avocado) oil.

Two emulsifier systems were used for the preparation of o/w emulsions. The first emulsifier was poloxamer 407^d, an A-B-A block copolymer of polyethylene oxide (PEO with A chains of approximately 100 EO (ethylene oxide) units each) and polypropylene oxide (PPO with B chains of approximately 55 PO (propylene oxide) units each). The second emulsifier system was a biopolymer surfactant blend^e that is a nonionic polymeric emulsifying system made of a blend of steareth-100 (stearyl alcohol with 100 EO units), steareth-2 (stearyl alcohol with 2 EO units), glyceryl stearate citrate, sucrose and a mixture of two polysaccharides, namely mannan and xanthan gum. In some emulsions, one specific xanthan gum^f was used as a thickener. All emulsions contained a preservative blend, namely phenoxyethanol, methylparaben, propylparaben and 2-bromo-2-nitropropane-1,3-diol^g.

Preparation of the emulsions: Emulsions prepared using poloxamer 407 were prepared by direct addition of the oil phase to an aqueous solution of the emulsifier, followed by homogenization using a high speed stirrer^h to obtain an average droplet diameter of 2–3 μm . Emulsions prepared using the biopolymer surfactant blend were prepared using a special procedure referred to as hot-cold process. The emulsifier powder is dispersed into water at room temperature while stirring at 200 rpm. The temperature of the solution was then raised to 80°C and the oil phase was added while stirring at 600 rpm, followed by homogenization for 2 minutes at 9500 rpm

^a Arlamol HD is a product of Uniqema, Redcar, UK. Arlamol is a trademark of Uniqema.

^b Estasan 3575 is a product of Uniqema, Redcar, UK. Estasan is a trademark of Uniqema.

^c Sunflower Oil Florasun 90 is a product of Floratech, Gilbert, AZ, USA

^d Synperonic PEF 127 is a product of Uniqema, Redcar, UK. Synperonic is a trademark of Uniqema.

^e Arlatone V-100 is a product of Uniqema, Redcar, UK. Arlatone is a trademark of Uniqema.

^f Keltrol F is a product of Kelco, Liverpool,

^g Nipaguard BPX is a product of Clariant, Leeds, UK

^h Ultra Turrax Ika-werk Janke and Kunkel, Hamburg, Germany

using an homogenizer (Ultra Turrax type stirrer). The temperature of homogenization was kept at 60°C and the final emulsion was cooled to room temperature while stirring at 600 rpm. The average droplet diameter of the final emulsion was also 2–3 μm .

Investigation Procedures for the Emulsion Stability

Measurement of creaming: A master 50/50 o/w emulsion was prepared using poloxamer 407 and the emulsifier concentration was kept at 5% (based on the oil). This master emulsion was diluted with deionized water to obtain o/w emulsions of 40/60, 30/70 and 20/80.

The 30/70 emulsion was also prepared using xanthan gum in the continuous phase. This was prepared by diluting the 50/50 emulsion water and a master gel of 1% xanthan gum to obtain different concentrations of xanthan gum in the continuous phase (0.1, 0.15, 0.2 and 0.3%).

With the biopolymer surfactant blend, the oil volume fraction was kept constant at 20/80, while the blend concentration was varied at 0.5, 0.6, 0.7, 0.8, 0.9 and 1%.

All emulsions were placed in 100-ml cylinders and kept at constant temperatures of -4°C , RT (room temperature), 40°C and 50°C . The creaming rate was measured at 1-day intervals for a period of 1 month.

Samples kept at RT were also investigated using rheological techniques and optical microscopy after preparation, 1 week, 2 weeks and 1 month. These techniques will be described later.

Measurement of flocculation: To induce flocculation, the emulsions were prepared in NaCl solutions. o/w emulsions were prepared using poloxamer 407 and NaCl at 55/45, and the concentration of NaCl in the aqueous phase was adjusted to 0.1, 0.2, 0.5, 0.75 and 1 mol dm^{-3} .

Flocculation was qualitatively investigated using optical microscopy. For this purpose, a drop of the emulsion was placed on a glass slide and another drop of water was carefully placed on the slide in the vicinity of the emulsion drop. When the glass cover was placed on the top of the two drops, mixing occurred and the flocs could be easily observed under the microscope. If the emulsion was weakly

flocculated, one could observe the rapid breakup of the emulsion flocs to single drops in the aqueous phase. If the emulsion was strongly flocculated, the flocs could be dispersed in the aqueous phase without significant breakup into single droplets.

Measurement of coalescence: To induce coalescence of the emulsion, the poloxamer 407 was gradually reduced; 50/50 emulsions were prepared at 5, 4, 3, 2, 1 and 0.5%. The emulsions containing less than 1% emulsifier started to coalesce, which could easily be observed by microscopy. These emulsions were also investigated using rheology.

Microscopic investigation: An optical microscope with bright field illumination module was used. The images were obtained each time a rheological measurement (1 day, 1 week, 2 weeks and 1 month) was made to assess any change in droplet size distribution.

Rheological measurements: These were carried out at 25°C using a rheometerⁱ. A cone and plate geometry was used with a plate diameter of 25 mm and a cone angle of 2 degrees. The gap between the cone and plate was 50 µm, which was significantly higher than the average diameter of the emulsion droplets. Temperature control of $\pm 0.1^\circ\text{C}$ was achieved using a Peltier device. A solvent trap was used to prevent any evaporation of the sample during measurement.

Three rheological measurements were carried out:

- Steady state covering the range 0–500 s⁻¹;
- Oscillatory measurement covering the strain amplitude range 0.1–400% (at a frequency of 0.5 Hz) and the frequency range 0.1–20 Hz;
- Creep measurements starting from the lowest possible stress (0.1–0.3 Pa depending on the sample) to a stress value where the strain suddenly increases with time (the point at which the structure starts to “break down”).

All rheological parameters were analyzed using the equation described in reference.⁵ The reproducibility of the rheological results

ⁱ Olympus BX 60 – CCD, Hamburg, Germany

^j Physica UDS 200 – Universal Dynamic Spectrometer, Physica Par, Hamburg, Germany

was checked by carrying out measurements on three chosen emulsion systems, namely a 50/50 emulsion prepared using poloxamer 407, a 50/50 emulsion prepared using poloxamer 407 and containing 0.2% xanthan gum, and a 50/50 emulsion prepared using the 1% biopolymer surfactant blend. Reproducibility was in most cases better than $\pm 5\%$.

Results and Discussion

Investigation of creaming and correlation with rheology: The creaming rate was assessed by comparing the creamed volume V_c with that of the maximum value V_∞ obtained when the emulsion was stored at 55°C .⁶ Thus, we calculated the time $t_{0.3}$ taken to reach a value of $V_c/V_\infty = 0.3$ (i.e., 30% of the maximum rate). As an illustration, **Figure 12.1** shows the results obtained at various temperatures for a 20/80 emulsion prepared using poloxamer 407. Clearly, $t_{0.3}$ decreases with the increasing temperatures.

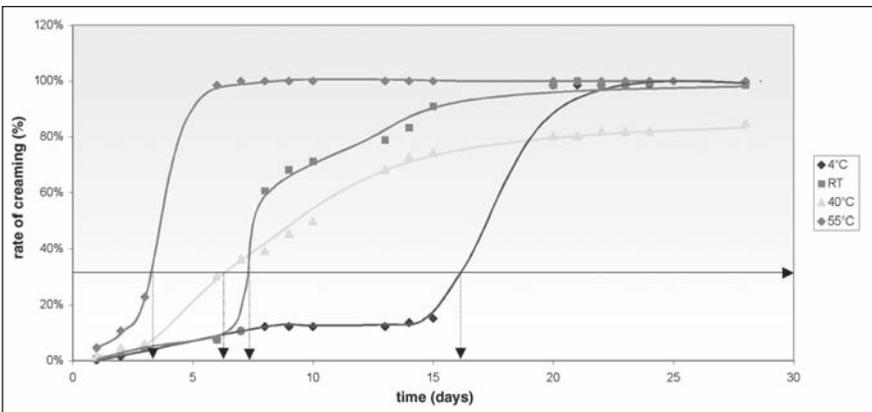


Figure 12.1. Creaming rate versus time at various temperatures

The creaming rate was found to decrease with increasing oil volume fraction, when the latter was increased above 40% oil. The average droplet size of the emulsions as determined by microscopy did not show a significant change with storage time, indicating the absence of coalescence.

The reduction of creaming rate with increase in oil volume fraction could be correlated with the viscosity obtained from steady state

measurements and application of a power law fluid model⁵ and the viscosity was calculated at three different shear rates (10, 100 and 500 s⁻¹). The variation of creaming rate with viscosity is shown in **Figure 12.2**. This figure shows non-linear correlation of creaming rate with viscosity. This behavior is commonly observed with concentrated dispersions, which show a rapid reduction in creaming or sedimentation rate when the volume fraction of the disperse phase increases above a critical value.

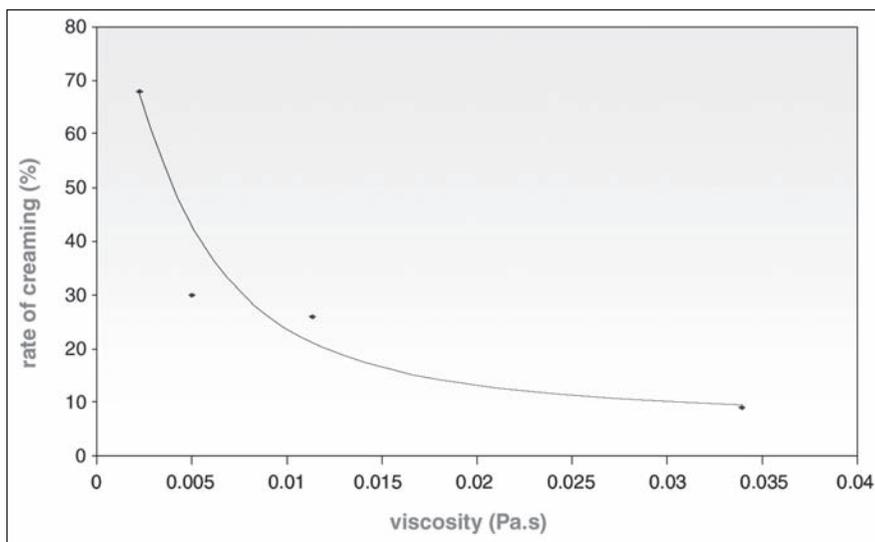


Figure 12.2. Creaming rate versus emulsion viscosity

The most useful way to predict creaming or sedimentation of emulsions is to use low shear measurements, namely constant stress (creep) and oscillatory techniques. This allows one to obtain the residual (zero shear rate) viscosity $\eta(0)$. Plots of residual viscosity versus the biopolymer surfactant blend concentration for 20/80 emulsions are given in **Figure 12.3** at various storage times. Initially there was a reduction in the value of $\eta(0)$ after one week of storage, after which the reduction became much smaller. The creaming rate of the emulsion decreased with increase in blend concentration and there was a sharp reduction in cream rate when the concentration of the blend was greater than 0.8%.

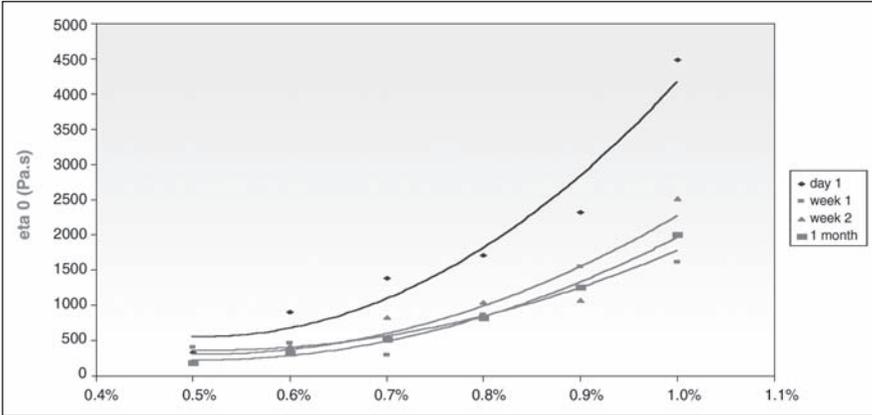


Figure 12.3. Effect of biopolymer surfactant blend concentration on residual viscosity at various storage times

Another useful rheological study for investigation of creaming is oscillatory measurements. **Figure 12.4** shows the variation of storage modulus (obtained in the linear viscoelastic region and at a frequency of 1 Hz) as a function of the biopolymer surfactant blend concentration for a 20/80 emulsion at various storage times. The results in **Figure 12.4** show a linear increase in G' with the increase in the blend concentration. G' increased with increase in storage time due to emulsion flocculation. There was no coalescence, as demonstrated by optical microscopy.

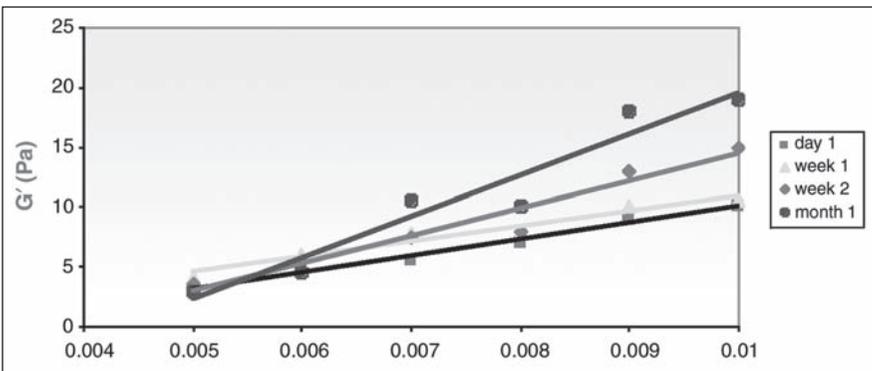


Figure 12.4. Effect of biopolymer surfactant blend concentration on G' for a 20/80 emulsion

From G' and γ_{cr} the cohesive energy of the structure, E_c , can be calculated.⁵ Plots of E_c versus the biopolymer surfactant blend concentration are given in **Figure 12.5** at various storage temperatures. Again, E_c showed a rapid increase when the blend concentration was increased above 0.7%. E_c also increased with increase in storage time indicating flocculation of the emulsion. The results showed rapid reduction in creaming rate when E_c exceeded 0.0003 Jm^{-3} (which is the value obtained above 0.7% biopolymer surfactant blend).

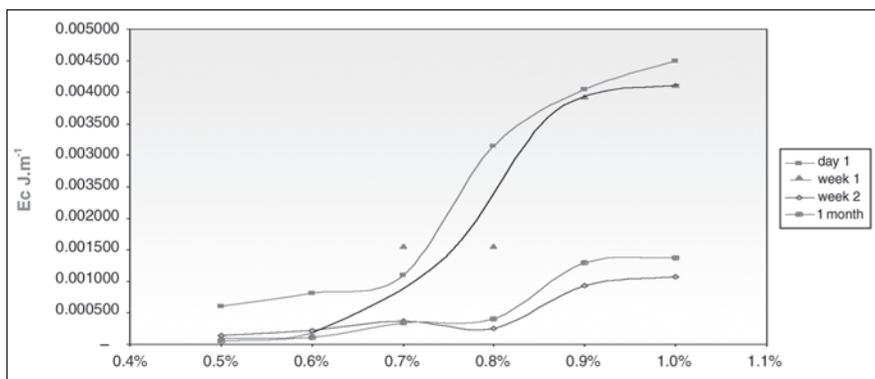


Figure 12.5. Effect of biopolymer surfactant blend concentration on E_c at various storage times

These rheological results show a nonlinear correlation between the creaming rate and various rheological parameters. Indeed, one can identify certain critical rheological parameters for which the creaming rate will be zero when the parameter reaches a certain value:

$$G' > 12 \text{ Pa}$$

$$\gamma > 0.03$$

$$E_c > 0.0034$$

$$\eta_0 > 521 \text{ Pas}$$

All the above values are obtained at the biopolymer surfactant blend concentration above 0.8%, which is indeed the recommended concentration for preparation of a stable emulsion with virtually no creaming.

Flocculation results: Flocculation investigations were carried out using a 55/45 emulsion, using Poloxamer 407 at 5% (based on the oil phase) while varying the NaCl concentration from 0 to 1 mol dm⁻³. **Figure 12.6** shows the variation of the yield value calculated using the Herschel-Bulkley model⁵ as a function of NaCl concentration at various storage times. In the absence of salt, the yield value did not change with storage time over a period of 1 month, indicating absence of flocculation. In the presence of NaCl, the yield value increased with increase in storage time and the increase was very significant when the NaCl concentration was increased above 0.8 mol dm⁻³. This increase in yield value indicates flocculation of the emulsion and this was confirmed by microscopic investigation, which showed the appearance of large flocs. The droplet size of the emulsion droplets showed only a small increase with storage time, indicating that coalescence was insignificant.

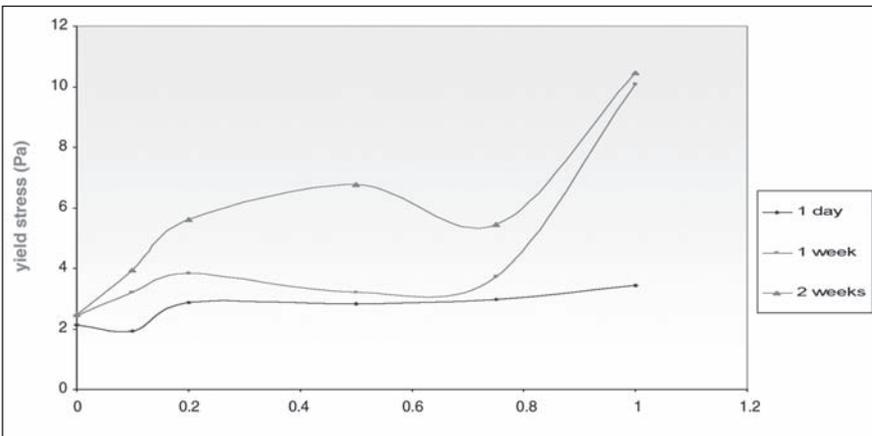


Figure 12.6. Effect of NaCl concentration on yield value at various storage times for a 55/45 emulsion stabilized with poloxamer 407

Further evidence of flocculation was obtained using oscillatory measurements. **Figure 12.7** shows the variation of G' with NaCl concentration at several storage times. Again below 0.8 mol dm⁻³ NaCl, G' showed a modest increase with increase of storage time over a period of two weeks, indicating some “weak” flocculation. However, above 0.8 mol dm⁻³ NaCl, G' showed rapid increase with increase of storage time.

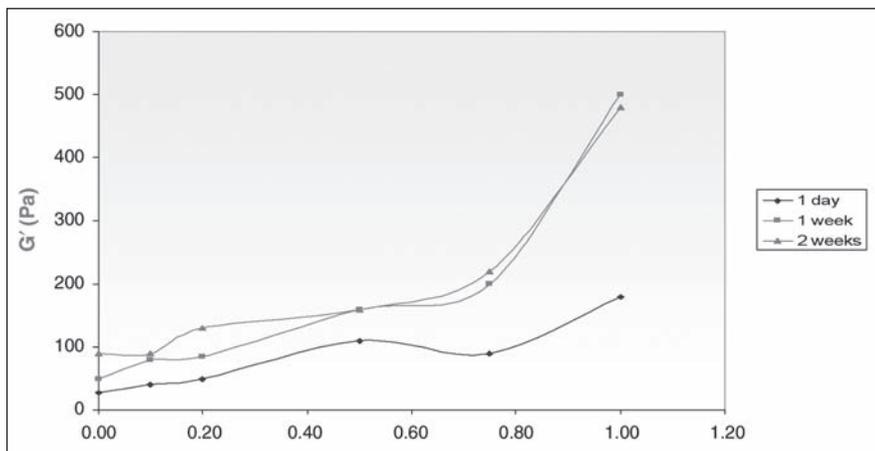


Figure 12.7. Effect of NaCl concentration on G' at various storage times for a 55/45 emulsion stabilized with poloxamer 407

The observed weak flocculation at NaCl concentrations below 0.8 mol dm^{-3} can be attributed to the reduction of solvency for the PEO chains on addition of salt. This results in deeper minimum in the energy-distance curve, resulting in weak flocculation.⁷ However, above 0.8 mol dm^{-3} NaCl, the solvency of the medium for the chains becomes poor. In this case, the mixing interaction of the chains becomes negative, resulting in a very deep minimum in the energy-distance curve and this causes strong flocculation.

Coalescence results: To induce coalescence, the emulsifier poloxamer 407 concentration was gradually reduced from 5 to 0.5% and coalescence was directly investigated using optical microscopy. The variation of droplet size was followed with time for 60/40 emulsion at various poloxamer 407 concentrations. When the emulsifier concentration was greater than 2%, there was no significant increase of droplet size with time over 14 days, indicating absence of coalescence. At 2% emulsifier concentration, the droplet size showed a small increase over 14 days, indicating the beginning of coalescence. The rate of increase of droplet size with time became larger at 1 and 0.5% poloxamer 407, indicating significant coalescence.

Figure 12.8 shows the variation of yield stress (calculated using the Herschel-Bulkley model) for a 60/40 emulsion versus poloxamer 407 concentration at various storage times. Below 2% emulsifier, the

yield value was very small and could not be estimated. At such emulsifier concentrations, the droplet size was quite large and hence one could not measure a yield value. Above 2% emulsifier concentration, the yield stress increased with increase in poloxamer 407 concentration. There was also a small decrease of yield stress with storage time during the period of storage. Thus, these results using steady state measurements are not sensitive enough to give an accurate estimate of coalescence.

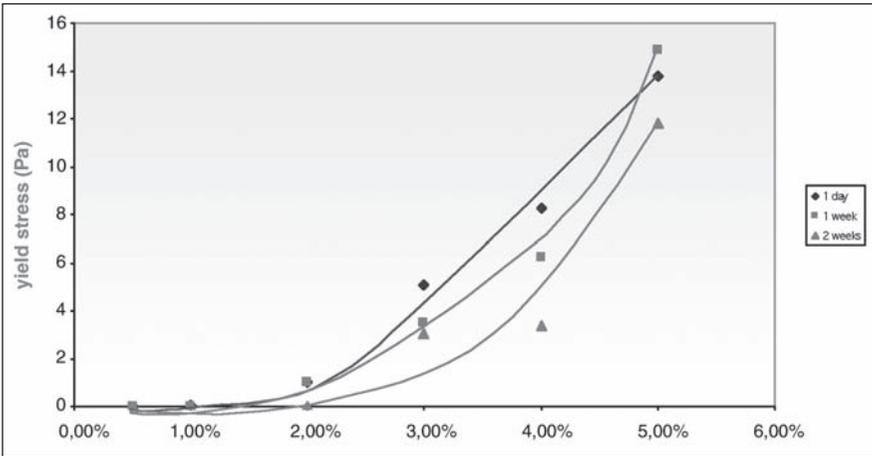


Figure 12.8. Effect of the variation of storage modulus with poloxamer 407 concentration at various storage times

The dynamic (oscillatory) measurements could give a more sensitive method for assessment of coalescence. This is given in **Figure 12.9**, which shows the variation of storage modulus with poloxamer 407 concentration at various storage times. It can be seen that below 2% emulsifier, there is a rapid reduction of G_2 with storage time. Such reduction becomes less significant when the emulsifier concentration is between 2% and 3%. However, above 3% emulsifier concentration, G_2 showed little dependence on storage time. These results correlate very well with the droplets size measurements.

The correlation between the emulsion elastic modulus with coalescence could be easily represented if one calculates the relative decrease in G' after 2 weeks, i.e.:

$$\text{Relative decrease} = \left[\frac{(G'_{\text{initial}} - G'_{\text{after 2 weeks}})}{G'_{\text{initial}}} \right] \times 100$$

Below 2% emulsifier concentration, the relative decrease in G' increases very sharply. This is explained by a large increase in droplet size, showing the correlation between coalescence and the rheological parameter G' .

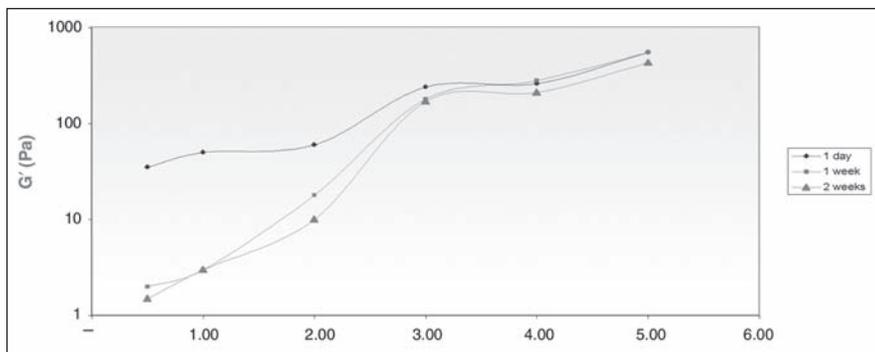


Figure 12.9. Effect of poloxamer 407 concentration on G' for a 60/40 emulsion at various storage times

Another good correlation between coalescence and rheology is shown when the relative decrease in cohesive energy and droplet size are plotted as a function of poloxamer 407 concentration. Below 2% emulsifier concentration, the relative decrease in E_c increases very sharply and the droplet size increases rapidly, indicating coalescence. The cohesive energy is related to the “structure” of the system, which in turn depends on the number of contact points between the droplets. For an emulsion that does not show much coalescence, E_c shows much smaller reduction when compared with emulsions that are rapidly coalescing. Indeed E_c seems to correlate well with the droplet size.

Conclusions

The results obtained in this chapter showed good correlation between the long-term physical instability (creaming, flocculation and coalescence) and some rheological parameters measured over much shorter periods of time.

For prediction of creaming, the low shear or residual viscosity $\eta(o)$ is the most important parameter to obtain (using constant stress creep measurements). Emulsions that gave a value of $\eta(o)$ in excess of 1000 Pas showed very little or no creaming.

For prediction of flocculation, measurement of the storage modulus G' as a function of time in the initial periods of storage gave the best correlation. If flocculation occurs, the droplets may form discrete or continuous gel networks in the continuous phase and are accompanied by an increase in G' . The cohesive energy E_c could also be used to predict flocculation.

These viscoelastic measurements could also be used to predict coalescence. When the emulsifier concentration is reduced below a certain level, coalescence occurs and this could be estimated from droplet size measurements as a function of time. The increase in droplet size on coalescence was accompanied by a decrease in G' and E_c as a result of the reduction in the number of contact points between the droplets.

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Hydrophobically Modified Inulin: A Novel Polymeric Surfactant and Emulsion Stabilizer

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KEY WORDS: *surfactant, polymer, hydrophobically modified inulin, emulsion stabilizer, emulsions, suspensions*

ABSTRACT: *After a short introduction illustrating the basic principles for steric stabilization by polymeric surfactants, the authors describe a novel polymeric surfactant that consists of hydrophobically modified inulin and demonstrate that it is an effective stabilizer for o/w emulsions, suspensions, nanoemulsions and multiple emulsions.*

Many personal care and cosmetic formulations consist of suspensions or emulsions. Their stabilization against flocculation and/or coalescence requires the presence of an energy barrier between the particles or droplets to prevent their close approach where the van der Waals attraction is large.

Two general mechanisms of stabilization can be applied. The first, referred to as electrostatic stabilization, is based on the formation of an electrical double layer (e.g., by the use of ionic surfactants). When two particles or droplets approach to a distance of separation where the double layers begin to overlap, strong repulsion occurs provided

the surface or zeta potential is sufficiently high and the electrolyte concentration and valency of the ions is low.¹ This stabilization mechanism is seldom used in practice because it is difficult in most cases to maintain low electrolyte concentrations.

An alternative and more effective stabilization is produced when using nonionic surfactants or polymers, usually referred to as steric stabilization.² When two particles or droplets approach each other to a separation distance such that the adsorbed layers begin to overlap, repulsion occurs as a result of two mechanisms: (i) Unfavorable mixing of the surfactant or polymer layers when these are in good solvent conditions; and (ii) Reduction in configurational entropy on significant overlap.

In this chapter, we will describe the criteria for effective steric stabilization, particularly when using block and graft copolymers.³ This will be followed by a section describing a novel polymeric surfactant that was based on inulin (polyfructose). Examples will be given to illustrate the effectiveness of this polymeric surfactant in stabilization of emulsions, suspensions, nano-emulsions and multiple emulsions.

Criteria for Effective Steric Stabilization

One can cite at least four criteria for effective steric stabilization.

1. Complete coverage of the particles or droplets by the polymer chains. This will prevent any attraction between the bare patches of the particles or droplets. It will also prevent bridging flocculation resulting from simultaneous adsorption of the polymer on two or more particles or droplets.
2. Strong adsorption or anchoring of the chains to the particle or droplet surface. This requires chains that are insoluble in the medium and have strong affinity to the surface. For A-B, A-B-A block and BA_n graft copolymers, B represents the anchor chain. For adsorption on a hydrophobic surface such as polystyrene or hydrophobically modified pigments of TiO_2 or ZnO (that are used in sunscreen formulations) or an oil droplet, the anchor chain can be simply an alkyl chain. To ensure strong anchoring, multiplicity of these alkyl chains

is required (multiple anchor points) as we will show later for hydrophobically modified inulin.

3. The stabilizing chain(s) “A” should be highly soluble in the medium and strongly solvated by its molecules under all practical conditions, such as in the presence of electrolytes in the aqueous medium and also at high temperatures. As we will see below, this condition is satisfied by inulin (polyfructose) that remains hydrated in high electrolyte concentrations and at high temperatures. This condition can be tested by measuring the cloud point of the A chain(s) as a function of electrolyte type and concentrations.
4. The hydrodynamic thickness of the A chain(s) should be greater than 5 nm to prevent close approach of the particles or droplets, thus preventing any weak flocculation. This is particularly important for sunscreens where the TiO_2 should remain dispersed on application.

Hydrophobically Modified Inulin as a Stearic Stabilizer

Recently, a novel graft copolymer based on a naturally occurring polysaccharide, namely inulin (polyfructose), has been synthesized.⁴ Inulin is a polydisperse polysaccharide, consisting mainly, if not exclusively, of $\beta(2\rightarrow1)$ fructosyl fructose units (F_n) with normally, but not necessarily, one glucopyranose unit at the reducing end (GF_n).^{5,6} To produce the amphiphatic graft copolymer, the chains were hydrophobically modified by introduction of alkyl groups ($C_4 - C_{22}$) on the polyfructose backbone. The structure of this hydrophobically modified inulin molecule^a is illustrated in **Figure 13.1**. In this chapter we will refer to this material as HMI.

This copolymer can be represented as AB_n graft, with the backbone A being the hydrophilic (linear) polyfructose chain and B representing the hydrophobic “anchor” (alkyl) chains. On a hydrophobic particle the alkyl groups become adsorbed on the surface producing strong adsorption due to the multipoint attachment,

^a INUTEK SP1, (INCI: not yet assigned), is a product of Orafit Non-Food, Tienen, Belgium. INUTEK is a registered trade name.

whereas the polyfructose chain forms several loops in between each anchor point. With oil-in-water (o/w) emulsions the alkyl groups reside inside the oil droplets (due to their solubility in the oil) and the hydrophilic loops reside in the aqueous phase.

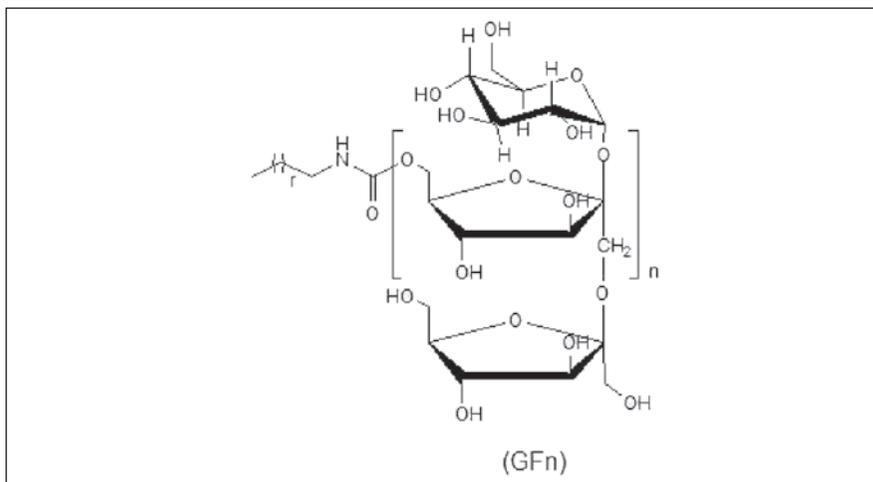


Figure 13.1. Structure of hydrophobically modified inulin

This graft copolymer forms an ideal steric stabilizer for hydrophobic particles and emulsion droplets in aqueous solution. As discussed by Napper,² the multipoint attachment by several alkyl chains produces enhanced steric stabilization. The hydrophilic loops are strongly solvated by water molecules (strong hydrogen bonding with the fructose units) and the layer thickness in the region of 7 nm.⁷ The polyfructose chains remain strongly hydrated in water as well as in high electrolyte concentrations. This can be demonstrated by measuring the cloud point of inulin^b (unmodified chain) as a function of its concentration in water as well as in electrolyte solutions.

In water, inulin showed no cloudiness up to 100°C. The same result was obtained in NaCl at concentrations reaching 4 mol dm⁻³ (**Figure 13.2**). With MgSO₄, the same behavior was obtained up to 1 mol dm⁻³, but in 1.5 mol dm⁻³ the cloud point reached 60°C at 1% inulin and it decreased further with increase in inulin concentration (**Figure 13.2**).

^b INUTEC N25, (INCI: not yet assigned), is a product of Orafti Non-Food, Tienen, Belgium.

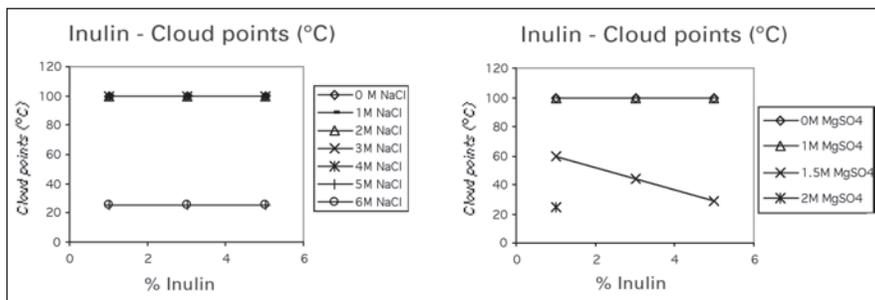


Figure 13.2. Cloud points of inulin (unmodified chain) at various NaCl and MgSO₄ concentrations as a function of inulin concentration (Cloud point of 100°C means that no cloud point could be noticed up to 100°C.)

From the above results, one would expect the suspension or emulsion stabilized with the HIM to remain stable against flocculation and coalescence up to 4 mol dm⁻³ NaCl and up to 1 mol dm⁻³ MgSO₄. This is illustrated next.

Using HMI to Stabilize Emulsions

Two oils^c were used to prepare o/w emulsions.³ Most emulsions consisted of 50/50 (v/v) ratio oil in water and the HMI was changed from 0.25% to 2% (w/v), based on the oil phase, for example up to 1% (w/v) in the total formulation.

The emulsion quality was assessed by optical microscopy. Samples of the emulsion were stored at room temperature and 50°C. The emulsions prepared using HMI alone were fairly coarse with droplets ranging from 1 to 10 μm in diameter. Addition of a small amount of Span 20 in the oil phase shows a significant reduction in droplet size with an average diameter less than 4 μm. No increase in droplet size during storage at 50°C was observed.

This high stability at such low emulsifier concentration is remarkable and it shows the effectiveness of the polymeric surfactant in stabilizing the emulsion when compared with classical nonionic surfactants that require concentrations in the region of 5% w/v. This low polymeric surfactant concentration is very important for personal care and cosmetic formulations because skin irritation that may be caused by high emulsifier concentration is prevented. In addition,

^c Isopar M supplied by Exxon, Belgium, and cyclomethicone supplied by Dow Corning, also in Belgium.

the high molecular weight of the polymeric surfactant (few thousand daltons) prevents these molecules from penetrating through the skin. Tests of primary skin irritation, acute ocular irritation and acute oral toxicity, sensitization and mutagenicity showed the safety of this HMI polymeric surfactant. In addition such surfactants are biodegradable and they do not show any aquatic toxicity.

Similar results were also obtained in high electrolyte concentrations, namely 2 mol dm^{-3} NaCl and 1 mol dm^{-3} MgSO_4 . As discussed above, the reason for this high stability against flocculation and coalescence is the strong hydration of the polyfructose chain in such high electrolyte concentration. This opens a potential use for these polymeric surfactants in antiperspirant formulations that require the presence of high electrolyte (aluminum chlorohydrate) concentrations.

Using HMI to Stabilize Suspensions

Recently we have studied the use of HMI surfactant for stabilization of suspensions using model polystyrene (PS) and polymethylmethacrylate (PMMA) suspensions.⁷ These latex suspensions were prepared using emulsion polymerization techniques.⁸ The stability of the latex particles in the presence and absence of polymeric surfactant was investigated by measuring the critical coagulation concentration (CCC) in the presence of three different electrolytes, namely NaCl, CaCl_2 and $\text{Al}_2(\text{SO}_4)_3$. The CCC was determined by direct microscopic investigation as well as using turbidity measurements. The effect of increasing the polymer concentration on the CCC was systematically investigated.

In the absence of the polymeric surfactant, the CCC was $0.375 \text{ mol dm}^{-3}$ for NaCl, $0.007 \text{ mol dm}^{-3}$ for CaCl_2 and $0.0004 \text{ mol dm}^{-3}$ for $\text{Al}_2(\text{SO}_4)_3$. On addition of HMI, the stability of the latex was significantly increased and the CCC became very high above a critical polymer concentration. For example for the PS latex, the CCC for NaCl was higher than 5.2 mol dm^{-3} and for CaCl_2 was higher than 4.3 mol dm^{-3} when the polymeric surfactant concentration was greater than 0.25% wt (based on 10% wt latex weight in the suspension, i.e. a ratio of HMI to latex of 0.025). Similar results were obtained using PMMA latex and this illustrates the general use of

HMI for stabilization of aqueous hydrophobic particles against flocculation by electrolyte.

This high stability using the HMI surfactant can be rationalized in terms of the possibility of enhanced steric stabilization suggested by Napper.² As mentioned earlier, the polymeric surfactant adsorbs with several alkyl chains on the particle surface (multipoint attachment) leaving polyfructose loops dangling and strongly hydrated in solution. It is surprising that the latex dispersion remained stable at NaCl concentrations higher than 5.2 mol dm^{-3} , because the cloud point results indicated that the cloud point in 5 mol dm^{-3} NaCl is $\sim 20^\circ\text{C}$. This means that under these conditions the polyfructose chains are now in poor solvent conditions and one would expect flocculation to occur at this electrolyte concentration. However, due to the multipoint attachment the loops produce an extra repulsion (at separation distance close to twice the layer thickness) arising from entropic or elastic repulsion. This phenomena has been discussed in detail by Napper² and the reader should refer to his text for more details.

The above results clearly indicate that HMI surfactant can be used to stabilize suspensions of hydrophobic particles in aqueous solution, such as hydrophobically modified titanium dioxide that is used in sunscreen formulations. This stability can be achieved at relatively low polymeric surfactant concentration, in the region of 0.25% wt for a 10% wt suspension. Such low stabilizer concentrations are not obtained with classical dispersants such as those based on polyethylene oxide. In addition, these ethoxylated surfactants cannot tolerate such high electrolyte concentrations.

Using HMI to Stabilize Nano-Emulsions

Nano-emulsions are transparent or translucent systems mostly covering the size range 50–200 nm (diameter). Unlike microemulsions (which are also transparent or translucent and thermodynamically stable), nano-emulsions are only kinetically stable.⁹ However, the long-term physical stability of nano-emulsions (with no apparent creaming or sedimentation, flocculation and coalescence) makes them unique and they are sometimes referred to as “Approaching Thermodynamic Stability.”

The high colloid stability of nano-emulsions can be understood from their size and steric stabilization. The small size of droplets results in significant reduction of the gravity force, such that the Brownian diffusion becomes sufficient to overcome gravity, resulting in no creaming or sedimentation. The high ratio of adsorbed layer thickness to droplet radius results in absence of flocculation and/or coalescence because the droplets cannot reach small distances and the liquid film between them stabilizes the droplets against coalescence.

The only instability problem with nano-emulsions is Ostwald ripening which results from the difference in solubility between different size droplets. When prepared, say, using high pressure homogenization, the droplets formed are not of equal size and they show a distribution. The smaller droplets will have a higher Laplace pressure (or higher solubility) when compared with the larger ones. Thus, on storage, oil molecules will diffuse from the smaller to the larger droplets and with time, the droplet size distribution shifts to larger values and the system may lose its transparency and some creaming or sedimentation may occur.

This problem of Ostwald ripening can be reduced by two main effects:

- Addition of a small portion (say 10%) of a second oil with much lower solubility than the major component. During Ostwald ripening, molecules of the more soluble oil (the major component) start to diffuse from the smaller to the larger droplets, resulting in more concentration of the less soluble oil in the smaller droplets. Equilibrium is established when the difference in chemical potential resulting from curvature effects is balanced by the difference in chemical potential due to the variation of the components in the two oil droplets.¹⁰
- Modification of the interfacial film at the o/w interface. Reduction in interfacial tension results in reduction of the rate of Ostwald ripening, but most important is the increase in surface dilational modulus.¹¹ This clearly shows the importance of using polymeric surfactants that are strongly adsorbed at the o/w interface.

The importance of the interfacial film was tested by using the HMI surfactant for preparation of nano-emulsions. The latter were prepared using a high pressure homogenizer^a and the stability of the nano-emulsion was investigated by following the droplet size as a function of time. The average droplet size was determined using dynamic light scattering or photon correlation spectroscopy.¹² A summary of the results is given in **Table 13.1**.

Table 13.1. Droplet size (in nm) of nano-emulsions stored at 50°C for various 2 weeks and 10 weeks

O/W ratio	Nano-Emulsion		Droplet size (nm) at selected times			
	Oil phase	Surfactant	Cosurfactant	Fresh	2 wks	10 wks
40:60	Silicone	8%* HMI	5% Glycerol	185	188	-
40:60	Hydrocarbon	8% HMI	5% Glycerol	180	173	-
20:80	Silicone/Squalane (9:1)	12% HMI	3% Span 20	199	208	207
20:80	Silicone/Squalane (9:1)	8% HMI	3% Span 20	240	203	217

* = HMI surfactant concentration (% based on oil)

It can be seen that the nano-emulsions are highly stable showing no significant increase in droplet size after storage for 10 weeks at 50°C. Most interesting is the production of stable nano-emulsions without the addition of highly insoluble oil and cosurfactant. This illustrates the highly elastic film of the HMI surfactant that is also strongly adsorbed at the o/w interface and hence the polymeric molecule has a long relaxation time, thus inhibiting Ostwald ripening.

The attraction of nano-emulsions for applications in cosmetics and personal care formulations stems from their long-term physical stability and possible transparency of the system. In addition, these nano-emulsions with very large surface areas are suitable for efficient delivery of actives, such as lipophilic vitamins (A and E). Due to their small size, nano-emulsions can penetrate through the “rough” skin surface and this enhances penetration of actives. The

transparent nature of the system and its fluidity (absence of any thickeners) may give them a pleasant aesthetic character and skin feel.

Using HMI in Multiple Emulsions

Multiple emulsions are complex systems of “emulsions of emulsions.” Two main types can be distinguished:

- Water-in-Oil-in-Water (w/o/w) multiple emulsions where the dispersed oil drops contained emulsified (and smaller) water droplets.
- Oil-in-Water-in-Oil (o/w/o) multiple emulsions in which the water drops contain emulsified oil droplets.

The most commonly used multiple emulsions are those of the w/o/w type, which has been used for the formulation of hand creams.

Several criteria must be satisfied for the preparation and stabilization of multiple emulsions:¹³

- Two emulsifiers with low and high HLB numbers. Emulsifier 1 should prevent coalescence of the internal water droplets, whereas emulsifier 2 should prevent flocculation and coalescence of the resulting multiple emulsion drops.
- Optimum osmotic balance to reduce water transfer from the inner water droplets to the outside continuous aqueous phase. This can be achieved by the use of electrolytes and non-electrolytes.

The most convenient method for preparation of multiple emulsions is to use a two-step process. For preparation of w/o/w multiple emulsion, a w/o emulsion is firstly prepared by emulsification of the aqueous phase into an oil solution of the low HLB emulsifier (using a high-speed mixer to produce droplets in the region of 1 μm). The primary emulsion is then emulsified into an aqueous solution containing the high HLB emulsifier (and any additives to control the osmotic balance).

Using the above principles, we have prepared w/o/w multiple emulsions as follows. A w/o emulsion was prepared using an oil^a and a low HLB polymeric emulsifier, namely an A-B-A block copolymer of polyhydroxystearic acid (PHS), the A chains, and polyethylene oxide, the B chain (i.e. PHS-PEO-PHS). This primary emulsion was emulsified into an aqueous solution containing HMI surfactant. The multiple emulsions were stored at room temperature and at 50°C. To date, these multiple emulsions are stable for several weeks.

An o/w/o multiple emulsion was also prepared as follows. An o/w nano-emulsion was prepared using HMI surfactant and this emulsion was further emulsified into an oil solution of the block copolymer of PHS-PEO-PHS. Again the resulting o/w/o multiple emulsion was stable for several weeks at 50°C.

Conclusion

A novel polymeric surfactant that exists as a trademarked ingredient and consists of hydrophobically modified inulin has been described as an effective stabilizer for o/w emulsions, suspensions, nano-emulsions and multiple emulsions. This polymeric surfactant achieves steric stabilization via multi-anchor attachment of the stabilizing chains to a hydrophobic surface. The polyfructose loops are strongly hydrated at high temperature and in the presence of high electrolyte concentrations. This ensures stabilization of many personal care and cosmetic formulations.

Several sections were devoted to discuss the application of this polymeric surfactant for stabilization of o/w emulsions, suspensions of polystyrene and polymethylmethacrylate latex, nano-emulsions of hydrocarbon and silicone oils as well as multiple emulsions of the w/o/w and o/w/o types.

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^a Isopar M, supplied by Exxon, Belgium

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Particle-Stabilized Emulsions: A Brief Overview

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KEY WORDS: *particle, emulsions, Pickering emulsion, wetting, surfactant-stabilized emulsion*

ABSTRACT: *The fundamentals of particle-stabilized emulsions are outlined here, and comparisons are made to surfactant-stabilized emulsions. Recent advances in Pickering emulsions for cosmetics are described in this chapter.*

Since the 1980s there has been a trend towards surfactant-free emulsions^{1,2,3,4} driven by products for sensitive skin and for improved sunscreens. In recent times there has been a flurry of research, development and intellectual property activity in the field of particle-stabilized emulsions. Tailored nanoparticles are desired for these applications. The purpose of this chapter is to briefly review the basic principles of the particle stabilization of emulsions.

Pickering Emulsions

Pickering reported the first recorded scientific study^{5,6} of particle-stabilized emulsions in 1907 when he stabilized water and paraffin with basic copper and iron sulfates, in which the particles were precipitated in situ. He noted, “Many other precipitated substances

*This work was submitted in partial fulfillment of the degree requirements of the Honors College at the University of Southern Mississippi. Shelly Corcorran graduated *Magna Cum Laude* in Chemistry and she intends to pursue graduate studies in Chemical Engineering at Tulane University.

act as emulsifiers but this property is destroyed as soon as they have been dried or have by any other means been deprived of their fine-grained structure.” These emulsions are now known as Pickering emulsions. In Pickering emulsions, small particles position themselves at the oil-water interface and form a mechanical barrier to coalescence.⁷ These emulsions were known as a problematic occurrence in the recovery of oil because stable water-in-oil emulsions were formed by minerals present in the system.⁸ Other examples of Pickering emulsions are the stabilization of whipping cream by fat particles and the stabilization of ice cream by ice crystals.⁹

In order for particles to stabilize emulsions, they must be of an appropriate size, wettability^{10,11,12} and concentration. Other factors contributing to the stability of the emulsion include the pH and presence of ions in the water phase as well as the presence of any other emulsifiers.¹³ These three factors can lead to an inversion in the type of the emulsion.⁸ The interactions of the particles with each other are also important.^{14,15}

Particle size: The size of particles is very important because the particles must be small enough to form a film around the droplets of the dispersed phase. Obviously, the particles must be much smaller than the droplets.⁷ Even when particles are smaller than the dispersed droplets, if they reach a critical size, they become too large to be held at the interface.⁸ The ratio of droplet size to particle size is important in determining the ease in emulsion formation. The larger this ratio is, the more easily a stable emulsion is formed.¹³ Generally the stability of an emulsion increases as particle size decreases.¹³ However, when particles approach the size of surfactant molecules, which is less than half a nanometer, they become easily removed from the interface, which leads to increased instability.⁹

There are two mechanisms that are discussed in the stabilization of emulsions by particles. The first is that the particles adsorb at the interface and form a rigid film that acts as a barrier between the droplets of the dispersed phase. The second is that interactions of particles form a three-dimensional network in the continuous phase that surrounds the droplets.¹³

The size of the droplets of the dispersed phase is also noteworthy in determining the stability of the emulsion. Although millimeter-sized droplets have been successfully stabilized using particles,⁹ in general it is advantageous to have very small droplets within the emulsion. As the concentration of particles in the system increases, the size of the droplets decreases. When the droplet size decreases, more particles can be arranged at the interface, which imparts added stability to the emulsion.¹³ However, particles that are too hydrophilic or hydrophobic create large, unstable droplets.⁹

Particle wettability: The wettability of the particles used to stabilize emulsions is of utmost importance. Because virtually all of these particles must lie at the interface between oil and water,¹³ they must be amphipathic in nature. If they are wet too strongly by either water or oil, they will remain in the phase that they prefer instead of contributing to the stability of the emulsion.¹⁶ However, it is expected that the particles will be more strongly wet by one of the liquids. This liquid will become the continuous phase of the emulsion⁹ (See **Figures 14.1** and **14.2**).

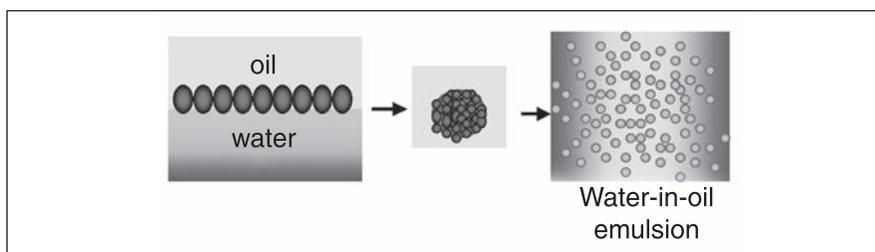


Figure 14.1. Emulsion stabilization with particles: if the particles are wetted more by water than by oil, then a water-in-oil emulsion will result.

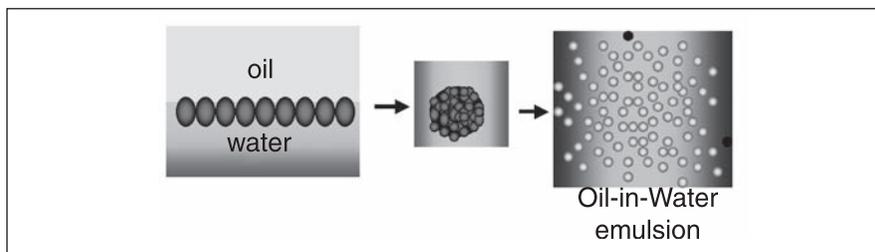


Figure 14.2. Emulsion stabilization with particles: if the particles are wetted more by oil than by water, then an oil-in-water emulsion will result.

The parameter used in determining particle wettability is the contact angle. For a particle to stabilize an emulsion, the contact angle of the liquid interface (measured through the water) at the particle surface must be near 90° . If a particle is slightly more hydrophilic, the contact angle will be less than 90° and the particle will have the potential to stabilize oil-in-water emulsions. If the particle is slightly more hydrophobic, the contact angle will be greater than 90° and the particle will have the potential to stabilize water-in-oil emulsions⁹ (See **Figures 14.3** and **14.4**).

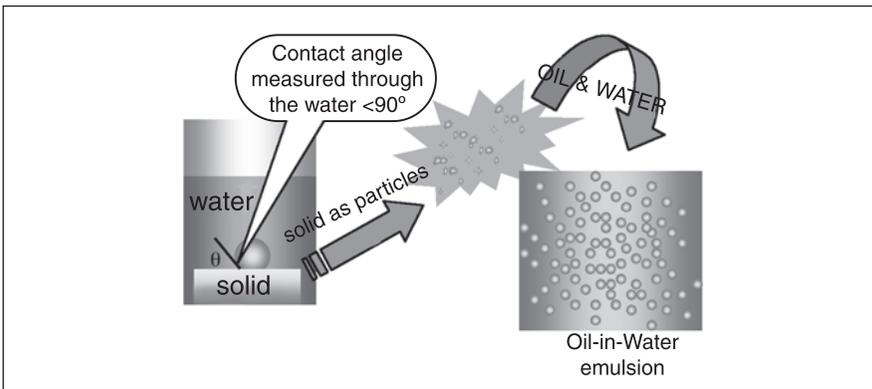


Figure 14.3. Particle wetting and emulsion stabilization: if the contact angle of the oil on the solid is greater than 90° , then an oil-in-water emulsion will result.

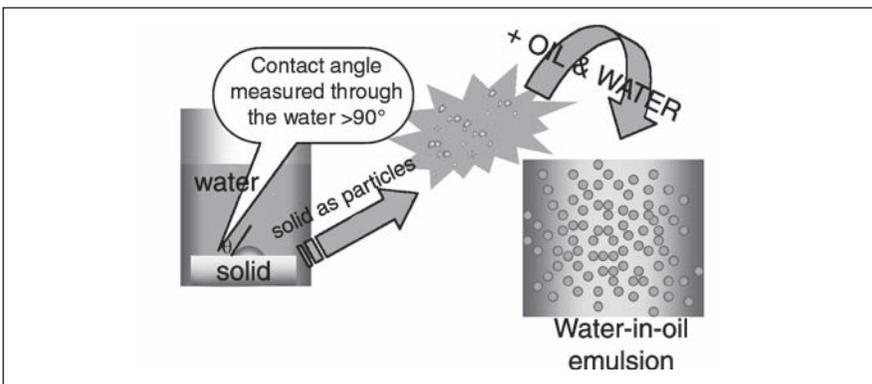


Figure 14.4. Particle wetting and emulsion stabilization: if the contact angle of the oil on the solid is less than 90° , then a water-in-oil emulsion will result.

If the particles are completely wetted by water, then they will reside in the aqueous phase and the emulsion will be unstable. Similarly, complete wetting by the oil phase will result in emulsion instability.¹⁷

There is a strong correlation between particle wettability and surface free energy. The interaction between particles and interfaces is strongest when the solid/liquid/oil contact angle is 90° from the interface. When the contact angle becomes less or greater than 90° , the interfacial interaction drops drastically. This extreme change in interaction is the reason that wettability is such an important factor in particle stabilization.⁹ Emulsions cannot be stabilized by particles at all if the free energy change that occurs when the particles are transferred from the continuous phase to the interface is not negative.⁸ However, the size of the particles allows Brownian motion to distribute the particles to the state with the lowest free energy. When the particles are of appropriate wettability, this state is between the two phases.⁹

One particular type of particle that has been developed to stabilize emulsions is known as a Janus particle. These particles are round glass beads that have been chemically treated to have one hydrophobic hemisphere and one hydrophilic hemisphere. This is accomplished by protecting half of the glass sphere with varnish and coating the other half with octadecyl trichlorosilane to impart a hydrophobic nature. The varnish is then removed to reveal the hydrophilic side of the bead. Janus particles range from 50 to 90 micrometers in size.¹⁸ The advantage they have over particles of intermediate wettability is that they can be up to three times more surface active which leads to greater emulsion stability.¹⁹

Particle concentration: The concentration of particles in the emulsion, along with the wettability of the particles, determines the quantity of particles at the oil-water interface.¹³ Closer packing of particles at the interface leads to an increase in the stability of the emulsion (See **Figures 14.5** and **14.6**).

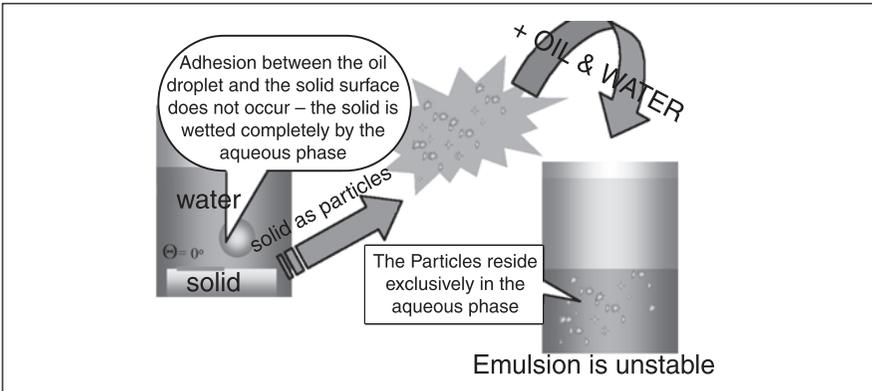


Figure 14.5. Particle wetting and emulsion stabilization: if the contact angle of the oil on the solid is 0° , then the particles will reside in the aqueous phase and the emulsion will be unstable.

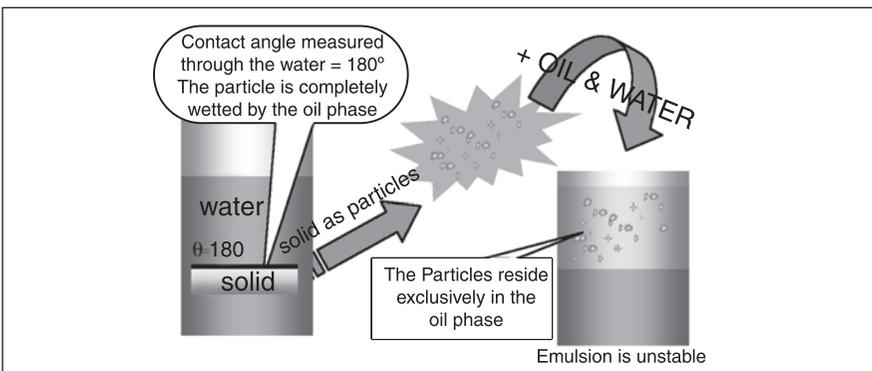


Figure 14.6. Particle wetting and emulsion stabilization: if the contact angle of the oil on the solid is 180° , then the particles will reside in the oil phase and the emulsion will be unstable.

Particle interactions: The interactions of particles at the interface also contribute to the stability or instability of the emulsion. In order to stabilize an emulsion, the particles at the interface may not form agglomerates.^{5,7} However, the particles must be partially flocculated in order to form the film between the phases. If they are completely flocculated or deflocculated, stabilization will not occur.¹³ In systems that are stabilized by clay particles, the particles actually form a three-dimensional network.²⁰ In other systems, where charged particles reside at the interface, the stability is enhanced because the particles create electrostatic repulsion between the

droplets of the dispersed phase.¹³ Finally, when a mixture of different particles is used, the interactions between these particles can greatly alter the character of the emulsion.

Comparison to Surfactant-Stabilized Emulsions

Although particles and surfactants are both able to stabilize emulsions, the characteristics of these emulsions are very different. To compare the two emulsifiers, it is important to see that for particle-stabilized emulsions, contact angle is an expression of wettability, just like HLB is an expression of surfactant hydrophobicity and hydrophilicity. Amphipathic particles can essentially be irreversibly adsorbed at the oil/water interface if they have appropriately constructed patterns of hydrophobicity and hydrophilicity on their surfaces.

Surfactants, on the other hand, tend to be more mobile at the interfaces and under appropriate conditions they can adsorb and desorb very quickly.⁹ Surfactants and polymers tend to form aggregates in ways that particles do not. Because of this, solubilization phenomena that are important in surfactant-stabilized emulsions are not an issue for particle-stabilized emulsions. Another difference is that for surfactants, the type of oil used is important in determining whether the emulsion will be oil-in-water or water-in-oil. The choice of oil does not affect emulsion type for particle-stabilized emulsions. However, for particle-stabilized emulsions, the initial particle location has an effect on emulsion type and stability.

The initial location of the particle determines which phase will be continuous. This is an advantage over surfactants because it allows both water-in-oil and oil-in-water emulsions to be formed depending on the oil-to-water ratio.⁹ In these systems, maximum stability can be achieved by changing the initial location of the particles. Any one surfactant or surfactant system is less versatile in this respect due to the speed at which surfactants are distributed and redistributed throughout the emulsion. A final difference between the two types of emulsifiers is that surfactant-stabilized emulsions are least stable at conditions near inversion, while particle-stabilized emulsions are most stable at those conditions.⁹

Recent Advances in Pickering Emulsions for Cosmetics

It has been revealed that “emulsifier free” oil-in-water Pickering emulsions can be formed in which the stabilizing particles are zinc oxide or titanium dioxide that has been coated with aluminum stearate or dimethicone, and aluminum hydroxide or silicon dioxide^{a,b}.^{21,22,23}

The ultrafine amphiphilic particles are defined as having particle sizes less than 200 nm. The specifications of these patents disclose that these formulated emulsions are characterized by excellent skin tolerability and exhibit higher effectiveness in sunscreen formulations.

It is interesting that these emulsifiers follow a modification of Bancroft’s rule. Bancroft states that the phase in which the emulsifier is soluble becomes the continuous phase of the emulsion. Gers-Barlag et al reveal that if the particles are first dissolved in the aqueous phase, then an oil-in-water emulsion results. On the other hand, if they are first dispersed in the oil phase, then a water-in-oil emulsion results. Water-in-oil emulsions preferably contain magnesium silicate particles as stabilizers.

The inventors also reveal that these particle-stabilized emulsions are remarkably stable in the presence of electrolytes²⁴ and this makes it possible to design systems containing both astringents and antimicrobials.²¹ One type of amphiphilic particle that is disclosed is hydrophobic latex rendered hydrophilic by saponification or by polymerizing acrylic acid on the particle surfaces.²⁵ Hydrocolloids may be added to the water-in-oil emulsions; a particularly advantageous hydrocolloid is hydroxypropylmethylcellulose^c.²⁶

In one manifestation, water-in-oil emulsions are claimed for relatively non-viscous oils²⁷ and in another, waxes and oil thickeners

^a Eusolex T2000 (INCI: Titanium dioxide (and) alumina (and) simethicone) and Eusolex.TA (INCI: Titanium dioxide (and) alumina (and) silica) are products of Merck KGAA, Darmstadt, Germany.

^b MT 100 T (INCI: Titanium dioxide (and) alumina (and) hydrated silica (and) stearic acid) is a product of TAYCA Corporation, Tokyo, Japan.

^c Methocel E4M (INCI: hydroxypropyl-methylcellulose) is a product of Dow Chemical Company, Midland, MI, USA.

may be included. These include natural waxes^d, chemically modified waxes^e and synthetic waxes^f. The preferred thickeners are aluminum stearate and magnesium stearate and stearylalkonium hectorite.²⁸ In one invention the modified phyllosilicate, stearylalkonium hectorite^g is combined with ultrafine boron nitride particles as the emulsion stabilizer.²⁹

In addition to the amphiphilic particles, it has been claimed that stable compositions can also contain non-amphiphilic pigments such as hydrophobically-modified titanium dioxide^h.^{30,31}

Polymeric moisturizers (such as chitosan and hyaluronic acid) can be included.³² The optional addition of cosmetic ingredients or pharmaceutical additives has been claimed.^{33,34,35} One drawback of particle-containing emulsions is that they can give a dry or dull impression on the skin. This is overcome in particle-stabilized emulsions containing cyclodextrin,³⁶ preferably beta-cyclodextrin and gamma-cyclodextrin^j.^{37,38}

Cyclodextrin functions as a molecular sheath on exposed hydrophobic groups. Once “sheathed” the moieties become hydrophilic but the cyclodextrin partitions away from the original hydrophobe when sufficiently high concentrations of surfactants or oils are introduced into the composition, and the original hydrophobes can be exposed for hydrophobic association.

It has been claimed that emulsifier-free cosmetic or dermatological emulsions can be obtained from compositions comprising an oil phase, an aqueous phase and an amphiphilic polysaccharide.³⁹ The amphiphilic polysaccharide is non-thickening^k.

^d Permulgin 1550 and Permulgin 4002 are products of Koster Keunen Holland BV, Bladel, Netherlands. Schellack Wachs 7302 L and Candellila Wachs 2039 L are products of Kahl & Co., Trittau, Germany.

^e BW Ester BW 67 and BW Ester BW 80 (INCI: Alkyl beeswax) are products of Koster Keunen Holland BV, Bladel, Netherlands.

^f Syncrowax AW1C (INCI: C16-36 fatty acids) is a product of Croda, Parsippany, NJ, USA.

^g Bentone 27 and Bentone 38 (INCI: stearylalkonium hectorite) are products of Elementis, Hightstown, NJ, USA.

^h T 805 (INCI: Titanium dioxide) is a product of Degussa AG, Hanau, Germany. UV Titan M160 (INCI: Titanium dioxide) is a product of Kemira Pigments OY, Pori, Finland)

^j Beta W7 (INCI: Gamma-cyclodextrin) is a product of Pharma, Düsseldorf, Germany. Gamma W8 (INCI: Gamma-cyclodextrin) is a product of Wacker Chemie GmbH, Burghausen, Germany.

^k Amiogum,²² Dry Flo Elite LL and Dry Flo PC (INCI: Aluminium starch octenyl succinate) are products of CERESTAR USA Inc., Hammond, IN USA.

It is interesting that it is claimed that these emulsions are characterized as being free of hydrocolloids, particularly carbomers.⁴⁰

Conclusion

Pickering emulsions have been somewhat of a laboratory curiosity since their discovery almost a century ago. Recent technological advances have resulted in the introduction of amphipathic nanoparticles that are enabling the production of surfactant-free particle-stabilized emulsions. Hydrophobic/ hydrophilic tailoring of nanoparticles holds the promise for formulators of novel stimuli-responsive surfactant free emulsions.

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“New” Emulsifier

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KEY WORDS: *new material, raw material, emulsification properties, stability profile, efficiency, transepidermal water loss (TEWL)*

ABSTRACT: *This chapter discusses the many different new materials that are available for use in new formulations and addresses the different questions formulators should be asking about these new materials.*

Cosmetic chemists are constantly being bombarded by “new” raw materials from suppliers. We welcome this “bombardment” as it gives us the opportunity to be more creative in our formulation efforts. I think it is worthwhile to step back and look at how a formulator should evaluate a new material before deciding whether or not to use it. Let’s focus our attention on emulsifiers (one of my favorite topics).

The Need

When a new material comes to me from a supplier who wants to introduce it into the cosmetic industry, I ask the following question: “What is the compelling reason a chemist should use this material?” If there is no such reason, then suppliers should seriously question whether or not they should spend the money to launch the material. Cosmetic chemists have literally thousands of materials from which to choose. Why should they look at an unproven, new material? Why take the risk?

When we look at a new chemical, which the supplier claims is an emulsifier, a myriad of questions immediately comes to mind (**Figure 15.1**). The first one I like to ask is why the supplier has brought this

material to us in the first place. Is this a new compound or have they been selling it into another industry? If it is being used in another industry what is its application (see sidebar)?

The Chemistry

The first thing to look at when exploring the possible applications of a new emulsifier is its chemistry. What is the nature of its polar head group? Is it charged (anionic or cationic)? Is it ethoxylated/propoxylated? Does it have hydroxyl groups? Does it have one or more head groups? What is the nature of the "tail/fatty" group? Is it straight or branched? Does it have double bonds? Sometimes having double bonds can degrade an emulsifier's performance/efficiency by not allowing it to line up as efficiently/tightly at the oil/water interface.

By understanding the chemistry of the emulsifier we can better predict its compatibility with often-used cosmetic materials. For example, if the emulsifier is cationic, one should not use (or at least be careful using) anionic thickeners or anionic emulsifiers. If the emulsifier has an ester linkage one must be careful not to use it in emulsions that have pH extremes (AHA or depilatories).

So, now that we have some information on the chemistry of the proposed emulsifier we need to perform some bench work to see what this new material "brings to the table."

Remembering a "New" Emulsifier

I remember, many years ago, a company came to me with a "new" emulsifier that was being used in the food industry to control the bubble size/uniformity in commercial cakes and breads. It was based on lactylate chemistry. It was quite interesting to explore why it functioned in this way and to discuss what applications it might have in our industry.

At the time we did not perform any testing on these materials and "forgot" about them. In fact, these anionic "surfactants" now find usage (more than 20 years later) as emulsifiers in creams and lotions and foam stabilizers in shampoos (where they form liquid crystals to slow the form bubble breakage by strengthening the bubble wall).

—Ken Klein

What is the compelling reason a chemist should use this material?

- Why did the supplier bring this material to me in the first place?
- Is this a new compound or has it been sold into another industry?
- If it is being used in another industry what is its application in that industry?

What is the chemistry of this new material?

- What is the nature of its polar head group?
- Is it charged (anionic or cationic)?
- Is it ethoxylated/propoxylated?
- Does it have hydroxyl groups?
- Does it have one or more head groups?
- What is the nature of the “tail/fatty” group?
- Is it straight or branched?
- Does it have double bonds?

What are its emulsification properties/issues?

- Is it an o/w or w/o emulsifier?
- What is its efficiency?
- What is the stability profile of the emulsion?
- Is it a primary or secondary emulsifier?
- Can this emulsifier produce emulsions that are water resistant?
- Can this emulsifier act as a pigment dispersion aid?
- Can this emulsifier stabilize the foam of shampoos and body washes?
- How successful is it at emulsifying hard-to-emulsify materials such as high-molecular-weight dimethicones?
- What is its electrolyte tolerance?

What effects does it demonstrate?

- What is the emulsifier’s effect on skin feel?
- What is the emulsifier’s effect on transepidermal water loss (TEWL)?
- What is the emulsifier’s effect on color and odor of the finished product?

What are the production and manufacturing considerations?

- Do we need to heat the emulsion to a very high temperature in order to incorporate this material?
- Can this emulsifier be used to make one-pot or low-energy emulsions?
- Is the performance of this emulsifier affected by high shear mixing?

Figure 15.1. Questions to ask when evaluating a “new” emulsifier

Emulsification Properties/Issues

Is it an o/w or w/o emulsifier? This question can most often be answered by just looking at the structure of the material by referring back to Bancroft's Rule (where the emulsifier that is most soluble will become the external phase). I'm not a big fan of the hydrophile-lipophile balance (HLB) system (for choosing emulsifiers), nevertheless understanding the science behind the HLB system can help you predict if the material will form o/w or w/o emulsions. If a greater portion of the molecule is water soluble (polar), more than likely it will form an o/w emulsion. As previously discussed, this system only really works for nonionic emulsifiers. If the head group is charged (most often anionic) then in reality most times it will be an o/w emulsifier. This is particularly true for monoalkyl emulsifiers.

What is its efficiency? This is a most important question because it relates to cost/performance issues. We need to prepare a simple emulsion and then determine its stability via high temperature storage testing. Once we have a "stable" emulsion we then titrate down the emulsifier level until we "achieve" an unstable emulsion. A good starting point for emulsifier concentration is 20% of the internal phase. A very efficient emulsifier can produce a stable emulsion at a use level of 5% (w/w) based on the size of the internal (usually oil) phase.

What is the stability profile of the emulsion? We can, if the supplier is in a hurry (and he always is), perform some centrifuge testing to also predict stability. We should also monitor the particle size and particle size distribution as a function of time/temperature. This is a great predictor of stability (or instability). Of course, if the emulsifier in question stabilizes emulsions by forming liquid crystals, then looking at particle size can be quite misleading. We also need to look at freeze/thaw stability.

Primary or secondary emulsifier? While the goal is to find a material that functions as a primary emulsifier, quite often this is not the case. Sometimes we evaluate an emulsifier and find while it is a somewhat weak o/w emulsifier, it can be added to w/o emulsions at a low level (typically less than 0.5%) and it can dramatically improve the stability and ease of manufacture of the emulsion. This has been shown

for some cationic emulsifiers (commonly found in hair conditioners) as well as alkyl polyglucosides (found in mild shampoos)!

Can this emulsifier produce emulsions that are water resistant?

Clearly this is a factor to be considered when developing sunscreen or insect repellent emulsions.

Can this emulsifier act as a pigment dispersion aid? This can suggest its usage in makeup applications or sunscreen products that incorporate particulate sunscreen actives (zinc oxide/titanium dioxide).

Can this emulsifier stabilize the foam of shampoos and body washes?

How successful is it at emulsifying hard-to-emulsify materials such as high-molecular-weight dimethicones?

What is its electrolyte tolerance?

Effect of the Emulsifier

What is the emulsifier's effect on skin feel? Evaluate the product's initial, middle, and final skin feel, as well as cushion.

What is the emulsifier's effect on transepidermal water loss (TEWL)? Emulsifiers with a “smaller” head group will generally not negatively affect the TEWL. More aggressive (bigger head group) emulsifiers will have a tendency to upset the lipid bilayer between the skin cells (mobilize the skin lipids) and thus promote (increase) TEWL. This is undesirable because it will make the skin more permeable to chemicals (higher irritation potential?) and detract from skin moisturization.

What is the emulsifier's effect on color and odor of the finished product?

Production/Manufacturing Considerations

Do we need to heat the emulsion to a very high temperature to incorporate this material? We all remember the anionic diethanolamine-cetyl phosphate. While it is a very potent anionic emulsifier (let's not discuss the DEA issue), it must be incorporated at a temperature of 85°C. This can present manufacturing problems and will increase the cost and time of manufacture.

Can this emulsifier be used to make one-pot or low-energy emulsions? These reduced time/energy manufacturing procedures can greatly reduce the cost needed to manufacture the finished product.

Is the performance of this emulsifier affected by high shear mixing? This is of particular concern if the emulsifier forms liquid crystals.

Conclusion

As you can see there are many questions to be addressed when we consider using a new emulsifier. While we have many hundreds of emulsifiers from which to choose, we are always on the lookout for another emulsifier, one that has one (or more) compelling reasons to use it.

Optimizing Your Emulsion to Meet Marketing Requirements

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KEY WORDS: *application, marketing, stability, silkier, drier, perfect*

ABSTRACT: *This chapter focuses on the communication between formulator and marketer in terms of marketing a product. Suggestions are made as to how they can communicate using terms that are understandable to both backgrounds of focus.*

Cosmetic formulators are given product briefs from our marketing friends and then we go off to the bench to create our masterpiece. After we submit our idea of what we think the brief really meant, someone from marketing gets back to us and tells us that it doesn't feel right. It's too "draggy," doesn't have enough "cushion" and doesn't feel "sophisticated."

Ideally, marketing and formulators can communicate with words whose definitions both parties can agree on, but still there is the problem of optimizing the emulsion to meet marketing requirements. This chapter illustrates that process.

The Request from Marketing

Marketing has requested that we develop a sunscreen facial moisturizer (SPF 15) that rubs in quickly but doesn't feel draggy. This product must leave the skin feeling moisturized but cannot be greasy. It is to be dispensed from a squeeze bottle.

Communicating with Marketing

One marketing person told me that the cream we made for her didn't feel as good as the target product. When I asked in what way the target product felt better, she said the following: "The target product feels delicious and your product doesn't." I told her that I don't know how to formulate "delicious" products.

Application and Stability

Formula 16.1 shows our first submission to the marketing people. They clearly were not happy. They had numerous complaints that had to be addressed:

- It took much too long for the lotion to rub in.
- During application it felt draggy and heavy.
- During application it whitened on the skin.
- The viscosity was too low.

In addition to the marketing complaints, we noticed several stability issues:

- It failed freeze/thaw stability testing after the second cycle.
- While the initial viscosity was 10,000 cps, we observed an increase in viscosity to 17,000 cps after two weeks at room temperature.
- Examining the emulsion under the microscope, we clearly could see that the particle size was changing with numerous large droplets being readily visible at a magnification of 200X.

Without a doubt, this formula needed some major revisions. Let's now look at each issue and offer some possible solutions.

Application: Marketing complained that it took much too long for the lotion to rub in, and during application it felt draggy and heavy. While stearic acid (when neutralized by the triethanolamine) and behenyl alcohol achieve good emulsion stabilization, they have a tendency to give a waxy or draggy skin feel during application. The

**Formula 16.1. Sunscreen facial moisturizer SPF 15
(Submission 1)**

Phase	Ingredient	
A.	Water (<i>aqua</i>)	qs to 100.00% wt/wt
	Glycerin	5.00
	Xanthan gum	0.50
B.	Stearic acid	4.00
	Behenyl alcohol	1.50
	Mineral (<i>paraffinum liquidum</i>) oil	5.00
	Petrolatum	5.00
	Ethylhexyl palmitate	7.50
	Octinoxate	7.50
	Oxybenzone	4.00
	Octisalate	3.50
	Glyceryl stearate	2.50
C.	Triethanolamine	1.00
D.	Fragrance (<i>parfum</i>)	0.25
E.	Preservative	qs

addition of 1% of a low molecular weight dimethicone will address this issue and at the same time will deal with the complaint that during application the formulation whitened on the skin. Whitening during rub-in is called soaping.

We now need to change the emollient system in order to allow the lotion to rub in more quickly. Mineral oil and petrolatum are excellent moisturizers and form an occlusive layer on the skin; however, because they do not spread well, they take a long time to rub in and this often is a major negative associated with their usage in lotion products. We need to design a more “sophisticated” emollient system. Reducing the mineral oil and petrolatum and adding lighter emollients such as cyclomethicone and short-chain esters or short-chain hydrocarbons is a good approach.

Another factor affecting time needed to rub-in this lotion is the use of a high level of xanthan gum. Xanthan gum is an excellent

stabilizer for emulsions—it maintains some viscosity when the emulsion is exposed to high temperatures—but it can impart stickiness during application as the emulsion begins to dry down on the skin.

We need to reduce the concentration of xanthan gum while adding another material to act synergistically with it to continue to provide good high-temperature stability. Magnesium aluminum silicate will do the trick. This “clay-type” thickener has been used for decades as a suspending agent in liquid makeup lotions where skin feel is of primary importance.

Stability: The other issues observed were related to stability. The humectant employed was 5% glycerin, which can be sticky during application and is not very effective in improving freeze/thaw stability. Why not replace it with a mixture of two humectants that will have several benefits: improve freeze/thaw stability, improve cushion (rich/thick skin feel during initial rub-in), and at the same time eliminate stickiness? Among such materials are butylene glycol, hexylene glycol, propylene glycol, and methylpropane diol (M, P diol).

We now must think about why this emulsion showed an increase in viscosity after two weeks. More than likely the increase was caused by the combination of the soap (triethanolamine stearate) and the high level of behenyl alcohol, resulting in the formation of some lamellar gel phase liquid crystals in the external phase. We need to address this issue. Additionally, whenever a single emulsifier is being used in an emulsion, stability concerns are justified.

Why not add a polar emulsifier? This hydrophilic material with a big head and small tail will complex at the interface with the soap, forming an emulsion that is more tightly packed and hence more stable. At the same time it will increase the curvature of any lamellar gel phase liquid crystals that form and thus stabilize the viscosity. We can consider highly ethoxylated fatty materials such as PEG-100 stearate. The addition of a secondary emulsifier will also help prevent the formation of large emulsion droplets over time.

Armed with these ideas, we go back to the bench for revisions and prepare **Formula 16.2**.

Formula 16.2. Sunscreen facial moisturizer SPF 15 (Submission 2)

Phase	Ingredient	
A.	Water (<i>aqua</i>)	qs to 100.00% wt/wt
	M, P diol	3.00
	Hexylene glycol	3.00
	Xanthan gum	0.15
	Magnesium aluminum silicate	1.00
B.	Stearic acid	4.00
	Behenyl alcohol	0.50
	PEG-100 stearate	1.00
	Mineral (<i>paraffinum liquidum</i>) oil	2.50
	Petrolatum	2.50
	Dimethicone, 50 cs	0.75
	Ethylhexyl palmitate	2.50
	Cyclopentasiloxane	5.00
	Octinoxate	7.50
	Oxybenzone	4.00
	Octisalate	3.50
Glyceryl stearate	2.00	
C.	Triethanolamine	1.00
D.	Fragrance (<i>parfum</i>)	0.25
E.	Preservative	qs

Silkier

We submit Formula 2 and our marketing buddies tell us we are very close, but the final skin feel is not quite silky enough. We know exactly what to do. A small addition of a powder will do the trick. We prepare **Formula 16.3**.

Drier

We submit **Formula 16.3** to marketing and are told that while it is better, we just need to make it feel drier because it is intended to be applied to the face. We study the formula and examine the oil phase.

Formula 16.3. Sunscreen facial moisturizer SPF 15 (Submission 3)

Phase	Ingredient	
A.	Water (<i>aqua</i>)	qs to 100.00% wt/wt
	Xanthan gum	0.15
	Magnesium aluminum silicate	1.00
B.	Stearic acid	4.00
	Behenyl alcohol	0.50
	PEG-100 stearate	1.00
	Mineral (<i>paraffinum liquidum</i>) oil	2.50
	Petrolatum	2.50
	Dimethicone, 50 cs	0.75
	Ethylhexyl palmitate	2.50
	Cyclopentasiloxane	5.00
	Octinoxate	7.50
	Oxybenzone	4.00
	Octisalate	3.50
	Glyceryl stearate	2.00
	C.	Triethanolamine
D.	M, P diol	3.00
	Hexylene glycol	3.00
	Aluminum starch octenyl succinate	1.00
E.	Fragrance (<i>parfum</i>)	0.25
F.	Preservative	qs

There is our problem. We need to decrease the oil phase to make it feel much drier. But if we decrease it too much we will cause the oxybenzone to crystallize out. Clearly this is something that cannot be tolerated.

Another idea comes to mind. Because this formula is designed for daily application to the face and must not be very water-resistant, let's change to a mixture of water-soluble sunscreen combined with oil-soluble sunscreens. In this way the overall skin feel will be less oily while the SPF will still be high. We prepare **Formula 16.4**.

Formula 16.4. Sunscreen facial moisturizer SPF 15 (Submission 4)

Phase	Ingredient	
A.	Water (<i>aqua</i>)	qs to 100.00% wt/wt
	Xanthan gum	0.20
	Magnesium aluminum silicate	1.00
B.	Stearic acid	4.00
	Behenyl alcohol	0.50
	PEG-100 stearate	1.00
	Mineral (<i>paraffinum liquidum</i>) oil	2.00
	Petrolatum	2.00
	Dimethicone, 50 cs	0.75
	Ethylhexyl palmitate	2.00
	Cyclopentasiloxane	5.00
	Octinoxate	7.50
	Oxybenzone	2.00
	Octisalate	3.00
	Glyceryl stearate	2.00
	C.	Triethanolamine
D.	Ensulizole, 30% aq soln, pH adjusted to 7.2 with triethanolamine	6.00
E.	M, P diol	3.00
	Hexylene glycol	3.00
	Aluminum starch octenyl succinate	1.00
F.	Fragrance (<i>parfum</i>)	0.25
G.	Preservative	qs

Perfect

Formula 16.4 is perfect. Marketing loves it. Stability looks fine and all is well with the world.

I wish all projects ended this well.

Rationalizing and Producing Nanoemulsions for Personal Care

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KEY WORDS: *nanoemulsions, personal care, droplet size, high-pressure homogenizers, phase inversion temperature (PIT) principle, Ostwald ripening*

ABSTRACT: *This review describes the principles of nanoemulsion formation and stability. Advantages of nanoemulsions for personal care and challenges with the lack of progress in nanoemulsions are discussed.*

Nanoemulsions, a class of emulsions with a very small and uniform droplet size typically in the range of 20 nm–500 nm, are becoming increasingly popular as vehicles for the controlled delivery and optimized dispersion of active ingredients. They often are referred to as mini-emulsions, submicrometer-sized emulsions, ultrafine emulsions, etc.¹

Their small droplet size makes some nanoemulsions transparent or translucent, resembling microemulsions; but if they are inadequately prepared to control droplet size distribution and stabilized against Ostwald ripening that occurs when the oil has some finite solubility in the continuous medium, nanoemulsions may lose their transparency with time as a result of an increase in droplet size.

Unlike microemulsions that are thermodynamically stable, nanoemulsions are only kinetically stable. However, the long-term physical stability of nanoemulsions with no apparent flocculation or coalescence makes them unique and they are sometimes referred to

as *approaching thermodynamic stability*.² The inherently high colloid stability of nanoemulsions can be well understood by considering their steric stabilization (when using non-ionic surfactants and/or polymers) and how this is affected by the ratio of the adsorbed layer thickness to droplet radius, as will be discussed.

The characteristic properties of nanoemulsions are of special interest for practical applications. They mainly are used in cosmetics as personal care formulations in sun care, in agrochemicals for pesticide delivery and sometimes in pharmaceuticals (see **Nanoemulsion Applications sidebar**).

Nanoemulsion formation requires energy input, generally from mechanical devices or from the chemical potential of the components.

The traditional method of preparing nanoemulsions using high-pressure homogenization requires high energy with limited practical applications. Mechanical methods of nanoemulsion production are designed for dispersion or high-energy emulsification and include high shear stirring, high-pressure homogenizers and ultrasound generators.

Producing a nanoemulsion from the chemical energy stored in its components is referred to as condensation or low-energy emulsification. A hydrophilic surfactant mixture can be adjusted by changing the surfactant ratio toward a lipophilic mixture, thus forming a w/o nanoemulsion by the stepwise addition of oil to a surfactant/water mixture.

If the nanoemulsion system components are considered bio-compatible—i.e., capable of being used in or on the human body without causing a rejection response—w/o nanoemulsions also can be used for pharmaceutical applications.

Nanoemulsion Applications

Nanoemulsions based on glycerol fatty esters are useful in cosmetics and dermatological fields, in particular for moisturizing the skin and mucose membranes, as well as for treating hair and in the ophthalmological field as an eye lotion. Nanoemulsions based on phosphoric acid fatty esters are used in cosmetics, dermatological applications and pharmaceuticals.

This review describes the principles of formation and stability of nanoemulsions. It begins with an introduction to advantages of nanoemulsions over macroemulsions for personal care and cosmetic formulations and describes challenges with the lack of progress in nanoemulsions. Methods of emulsification, including high- and low-energy emulsification; the principle of phase inversion temperature (PIT); and the role of surfactants are discussed; and steric stabilization and the role of the adsorbed layer thickness are covered. The problem of Ostwald ripening, which is the main instability process of nanoemulsions, is described in some detail and methods to reduce this effect are described. In summary, the review gives examples of nanoemulsions prepared by the PIT method as well as using a high-pressure homogenizer and a comparison of the two is made.

Nanoemulsions in Personal Care and Cosmetics

The use of nanoemulsions in personal care and cosmetics as well as in pharmaceutical applications is because of numerous advantages.

Small droplet size: Their very small droplet size causes a large reduction in the gravity force and the Brownian motion may be sufficient for overcoming gravity. This means that no creaming or sedimentation occurs on storage. This small droplet size also prevents any flocculation of the droplets. Weak flocculation is prevented and this enables the system to remain dispersed with no separation. The small droplets also prevent coalescence, since these droplets are non-deformable and hence surface fluctuations are prevented. In addition, the significant surfactant film thickness (relative to droplet radius) prevents any thinning or disruption of the liquid film between the droplets.

The small size of the droplets allows them to deposit uniformly on substrates. Wetting, spreading and penetration also may be enhanced as a result of the low surface tension of the whole system and the low interfacial tension of the o/w droplets.¹

In sun protection, microscale TiO_2 particles are brilliant white pigments that scatter all wavelengths of light. Nanoscale TiO_2 particles, however, no longer scatter visible light because they are transparent but they still block UV light. Hence, nanoscale TiO_2 particles provide excellent UV protection in sunscreen applications.

Examples of Nanoemulsions in Personal Care

Nanoemulsions are used mainly in the formulation of sunscreen creams. Below are example formulations incorporating TiO_2 and ZnO_2 nanoparticles.

Formula 1.⁵

A. Dimethicone (and) trimethylsiloxysilicate	5.00% w/w
<i>Paraffinum liquidum</i> (mineral) oil	5.00
Cyclomethicone pentamer	8.00
Laurylmethicone copolyol	3.00
B. Glycerol	4.00
Sodium chloride	1.00
Water (<i>aqua</i>)	58.60
C. Titanium dioxide (and) caprylic/capric triglyceride (and) 2-ethylhexyl palmitate (and) alumina (and) polyhydroxy stearic acid silica (TiO_2 dispersions, 40% solids)	15.00
D. Butylparaben (and) ethylparaben (and) isobutylparaben (and) phenoxyethanol (and) propylparaben	0.40
	<hr/> 100.00

Formula 2.⁶

A. Water (<i>aqua</i>)	65.10% w/w
Glycerin	7.00
Disodium EDTA	0.05
B. Xanthum gum	0.30
Magnesium aluminium silicate	0.50
C. Cetareth-25	0.35
Steareth-2	0.65
Potassium cethyl phosphate (and) hydrogenated palm glycerides	0.50
Cetearyl alcohol	1.00
Behenyl alcohol	0.75
Ethylhexyl methoxycinnamate	7.50
Zinc oxide (and) triethoxycaprylylsilane	3.00
Titanium dioxide (and) aluminium hydroxide (and) dimethicone/bithicone copolymer	3.00
Isohexadecane	4.00
Isononyl isononanoate	1.50
Polydimethylsiloxane (Dimethicone 200, Dow Corning)	1.00
Bisabolol, racemic	1.00

D. Hydroxyethyl acrylate/sodium acryloyldimethyl taurate copolymer (and) squalene (and) polysorbate 60	1.70
Acrylates/acrylamide copolymer, <i>Paraffinum liquidum</i> (mineral) oil (and) polysorbate 85	0.70
E. DMDM hydantoin idopropynyl butylcarbamate	0.40
	<hr/> 100.00

Skin penetration: Because of their small size, nanoemulsions can penetrate the skin's surface, enhancing the penetration of actives. Also, the large surface area of the emulsion system allows rapid and efficient penetration of actives through the skin.

Aesthetics: The transparent nature of the system, its fluidity (at reasonable oil concentrations), as well as the absence of any thickeners, give nanoemulsions a pleasant aesthetic character and skin feel.

Reduced surfactant need: Unlike microemulsions that require a high surfactant concentration, usually in the region of 20% and higher, nanoemulsions can be prepared using a more reasonable surfactant concentration. For a 20% o/w nanoemulsion, a surfactant concentration in the region of 5%–10% may be sufficient.²

Fragrance delivery: Nanoemulsions can be applied for delivery of fragrance that often is incorporated in personal care products. Additionally, fragrances such as esters, aldehydes and ketones, which are alcohol-free, can be used in nanoemulsion formulations.

Liposome substitution: Nanoemulsions may be applied as a substitute for liposomes and vesicles, which are much less stable, and it is possible in some cases to build lamellar liquid crystalline phases around the nanoemulsion droplets.³

In spite of the described advantages, nanoemulsions in personal care applications only have attracted interest in recent years. This may be for several reasons. The preparation of nanoemulsions in many cases requires special application techniques, such as the use of high pressure homogenizers as well as ultrasonics. Such equipment has become available only in recent years.

Nanoemulsions are more expensive to produce² and require specialized equipment as well as the use of high concentrations of emulsifiers.

A lack of understanding of the production mechanism of submicron droplets and the role of surfactants and cosurfactants also has slowed the progress of nanoemulsions;⁴ in addition to the lack of demonstration of the benefits from using nanoemulsions compared with the classical macroemulsion systems.²

On a fundamental level, difficulty in understanding the interfacial chemistry involved in production of nanoemulsions also has slowed the progress of nanoemulsions. For example, few formulation chemists are aware of the use of the PIT concept and how it can be usefully applied for the production of small emulsion droplets.²

Another challenge is understanding the mechanism of Ostwald ripening, which perhaps is the most serious instability problem found in nanoemulsions.² In relation to this, not knowing the ingredients to incorporate to overcome Ostwald ripening has slowed the industry's use of nanoemulsions. Adding a second oil phase with very low solubility, and/or incorporating polymeric surfactants that strongly adsorb at the o/w interface, which are also insoluble in the aqueous medium, are two solutions.²

Finally, the fear of introducing new systems without full evaluation of the cost and benefits inhibits the use of nanoemulsions in personal care applications.

Despite these difficulties, several companies have introduced nanoemulsions in the market and within the next few years, the benefits will be evaluated (see **Examples of Nanoemulsions in Personal Care sidebar**).

The acceptance of nanoemulsions depends on customer perception and acceptability. With the advent of new instruments for high pressure homogenizers and the competition between manufacturers, the cost of production of nanoemulsions will decrease, approaching that of classical macroemulsions. The importance of phase behavior in the preparation of nanoemulsions is also very crucial.

Preparation of Nanoemulsions

Three methods may be applied for the preparation of nanoemulsions in the 50nm–200 nm droplet range: the use of high pressure homogenizers, low energy emulsification methods at constant temperature, or application of the PIT concept.

High pressure homogenizers: The production of submicron-sized droplets requires the application of high energy. The process of emulsification generally is inefficient as illustrated in the **Inefficiencies in High-Pressure Emulsifiers sidebar**.

The intensity of the process or the effectiveness in making small droplets often is governed by the net power density ($\epsilon(t)$).²

$$\rho = \epsilon(t) dt \quad (1)$$

where t is the time during which emulsification occurs.

The break up of droplets will only occur at high ϵ values, which means that the energy dissipated at low ϵ levels is wasted. Batch processes generally are less efficient than continuous processes. This shows why, with a stirrer in a large vessel, most of the energy applied at low intensity is dissipated as heat. In a homogenizer, ρ simply is equal to the homogenizer pressure.

Several procedures may be applied to enhance the efficiency of emulsification when producing nanoemulsions.² The efficiency of agitation can be optimized by increasing ϵ and decreasing dissipation time. The emulsion preferably is prepared at high volume fraction of the disperse phase and diluted afterward. However, very high Φ values may result in coalescence during emulsification.² Adding more surfactant creates a smaller γ_{eff} and could possibly diminish recoalescence. Using a surfactant mixture reduces γ in the individual components. If possible, dissolving the surfactant in the disperse phase rather than the continuous phase often leads to smaller droplets.

Inefficiencies in High-Pressure Emulsifiers

Simple calculations show that the mechanical energy required for emulsification exceeds the interfacial energy by several orders of magnitude. For example, to produce an emulsion at $\Phi=0.1$ with a $d_{32}=0.6 \mu\text{m}$, using a surfactant that gives an interfacial tension $\gamma=10 \text{ m}\cdot\text{Nm}^{-1}$, the net increase in surface free energy is $A\gamma=6 \Phi \gamma/d_{32}=10^4 \text{ Jm}^{-3}$. The mechanical energy required in a homogenizer is 10^7 Jm^{-3} i.e., an efficiency of 0.1%. The rest of the energy (99.9%) is dissipated as heat.

It may be useful to emulsify in steps of increasing intensity, particularly with emulsions having highly a viscous disperse phase.

Low energy emulsification: A study of the phase behavior of water/oil/surfactant systems demonstrates that emulsification can be achieved by three different low energy emulsification methods: (a) stepwise addition of oil to a water surfactant mixture; (b) stepwise addition of water to a solution of the surfactant in oil; and (c) mixing all the components in the final composition, pre-equilibrating the samples before emulsification. It is important to remember that nanoemulsions with droplet sizes of 50 nm can be formed only when water is added to the mixtures of surfactant and oil, i.e., method (b).²

Phase inversion temperature principle: Phase inversion is a process whereby the internal and external phases of the emulsion suddenly invert (o/w changing to w/o or vice-versa). This phenomenon can be induced either by changing the volume fraction of one of the phases (catastrophic inversion) or by changing the affinity of the surfactants toward the two phases (transition inversion).⁵

In the first case, the increase of one fraction above a critical value induces a phase inversion; the latter accounts for certain nonionic surfactants, which in an o/w system can alter the phase affinity with temperature. The critical temperature at which a phase inversion may take place is referred to as the PIT and is an important parameter to be taken into account when preparing nanoemulsions.⁵

Among factors that affect the phase inversion of an o/w emulsion are the nature of the oil phase, the surfactant type and its concentration, the temperature of the system, the oil:water ratio, the presence of additives in the oil or water phase, the mixing conditions, and the rate and order of addition of the different components.

Phase inversions in nanoemulsions can be one of the following two types:

- Transitional inversion is induced by changing factors such as temperature and/or electrolyte concentration, which affect the HLB of the system. Transitional inversion also can be induced by changing the HLB number of the surfactant at constant temperature using surfactant mixtures.

- Catastrophic inversion is induced by increasing the volume fraction of the disperse phase.

The diameter decreases and the rate constant increases as inversion is approached. To apply the PIT, the transitional inversion method should be used utilizing non-ionic surfactants of the ethoxylate type. These surfactants are highly dependent on temperature, becoming lipophilic with increasing temperature because of the dehydration of the polyethyleneoxide chain.² When an o/w emulsion prepared using a non-ionic surfactant of the ethoxylate type is heated at a critical temperature (the PIT), the emulsion inverts to a w/o emulsion. At the PIT the droplet size and the interfacial tension also reach a minimum. However, the small droplets are unstable and they coalesce very rapidly. Stable and small emulsion droplets can be produced by rapid cooling of an emulsion prepared at a temperature near the PIT.

Ostwald Ripening

Ostwald ripening results from the difference in solubility between small and large droplets present in nanoemulsions. It is characterized by the increase of droplet size with time. Ostwald ripening may be reduced by increasing surfactant concentration beyond the critical micellar concentration (CMC) so that micelles are formed; these micelles are capable of solubilizing large amounts of oil as “swollen micelles,” decreasing the ripening rate.²

Surfactants incorporated into the dispersed phase strongly adsorb at the interface and have low solubility in the continuous phase, which may significantly reduce Ostwald ripening.⁶ In this case, significant partitioning between different droplets occurs, with the component having low solubility in the continuous phase expected to be concentrated in the smaller droplets. By modifying the interfacial film at the o/w interface with polymeric surfactants, which do not desorb during ripening, the rate can be significantly reduced.

Another method used to reduce Ostwald ripening is to add a second disperse phase component that is concentrated in smaller droplets and insoluble or less soluble than the first one in the continuous phase.⁷ During Ostwald ripening in two-component disperse

phase systems, equilibrium is established when the difference in chemical potential between different size droplets (resulting from curvature effects) is balanced by the difference in chemical potential resulting from the partitioning of the two components. This method is of limited application since it requires a highly insoluble oil as the second phase, which is miscible with the primary phase.

The less polydisperse the nanoemulsion is, the lower the Ostwald ripening rate.² Theoretically, Ostwald ripening should lead to condensation of all droplets into a single drop (i.e., phase separation). This does not occur in practice since the rate of growth decreases with increase of droplet size.

Conclusions

It can be concluded that the applications of nanoemulsions are burgeoning in the field of personal care. However, some aspects such as Ostwald ripening and coalescence result in the destabilization of nanoemulsions. These aspects should be well-studied in order to enhance the acceptability of nanoemulsions in the personal care industry. Formulations containing nanoparticles offer many benefits, from preventing the scattering of visible light in sunscreen formulations, to enhancing skin feel and delivery.

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Effect of Oil Type on Stability of w/o/w Emulsions

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KEY WORDS: *w/o/w multiple emulsion, stability, oil types, hydrocarbon, triglycerides, characterization*

ABSTRACT: *The behavior of the w/o/w emulsion system and the stability of the oil membrane depend on the type of oil used to make the emulsion. Conductimetric analysis of the release of entrapped marker magnesium sulfate showed that the highest release of the marker occurred in emulsions based on oils from the triglyceride group. Emulsions based on hydrocarbon oils showed the best stability.*

Water-in-oil-in-water (w/o/w) emulsions have a wide range of uses (see **Future of W/O/W Emulsions sidebar**), but numerous factors can affect their stability. Among these factors are the method of preparation, the type of entrapped material, the type of emulsifier, the type of oil, and the effects of electrolyte, phase volumes and concentration.^{1,2} Of particular interest in this chapter is the type of oil.

The oils most frequently used to form multiple emulsions are hydrocarbons, triglycerides and esters. Hydrocarbons are compounds with a carbon backbone and attached hydrogen atoms. Among the hydrocarbons, the most widely used is mineral oil, which also is called liquid paraffin; mineral oil is used in finished commercial preparations and for research in multiple emulsions.

Hexadecane, dodecane, octane and cyclohexane have principal applications in research, especially in theoretical studies to explain the structure and mechanisms of multiple emulsions. Squalane, which is a hydrogenated form of squalene, is used occasionally in the industry for preparation of multiple emulsions. Squalane is also called cosbiol and perhydrosqualene.

The Future of W/O/W Emulsions

W/O/W multiple emulsions are promising systems for various fields such as chemistry, pharmacy, cosmetics, and the food and nutrition industries.^{7,8} They can ensure complete protection of the entrapped material. They can dissolve incompatible substances in the internal and external phases of the same product and modulate the release of the entrapped substances.^{8,9,10,11} They also lead to formulations characterized by their efficient, light, nongreasy and nonsticky textures.

Triglycerides are compounds in which glycerol is esterified with three fatty acids. The main triglycerides used are the oils of peanut, olive, sesame, almond, maize, castor and soybean. They are used mainly for *in vivo* experiments because of their tolerability.

Esters are compounds in which an organic group replaces a hydrogen atom in an oxygen acid. Esters of long-chain fatty acids including isopropyl myristate or oleate also have been used to obtain stable multiple emulsions.

The different molecular structures of these types of oils mean they have different effects on the behavior of the emulsion system and the stability of the oil membrane against leakage of the entrapped material. If a rupture occurs in an oil layer, the compartments disappear instantly and the inner aqueous phase in the compartments is mixed with the aqueous suspending fluid.³ Therefore, the polarity, density, viscosity and other physicochemical properties of oils influence the behavior of emulsions.⁴

Researchers have reported that the entrapment yield of the multiple emulsions depends on the oil type.⁵ The type of oil also affects the characteristics of the interfacial film and these two factors are of crucial importance in determining the globule size and the stability.⁶

The aim of this study was to formulate w/o/w multiple emulsions using oils of different types and assess the effect of oil type on formulation stability.

Materials

Table 18.1 lists the oils used in this study. They were selected as commonly used representatives of the three oil types. The lipophilic surfactant was a cetyl dimethicone copolyol^a and the hydrophilic surfactant was an ethoxylated propylene oxide copolymer^b. Hydrated magnesium sulfate^c entrapped in the inner phase as a tracer was employed as an index of the entrapment yield of formation as well as the stability of the multiple emulsion.

W/O/W emulsions were prepared according to **Formula 18.1**. Except for the oil, the formulation components and amounts were kept constant to follow the effect of the oil on the characteristics of the multiple emulsions. W/O/W multiple emulsions were obtained at room temperature by a two-step process.¹²

Formula 18.1. W/O/W emulsion used to test the effect of oil on formulation stability

Oil	24.0% wt/wt
Cetyl dimethicone copolyol (Abil EM90, Degussa)	3.0
Ethoxylated propylene oxide copolymer (Synperonic PE/F127, ICI)	0.8
Magnesium sulfate	0.7
Water (<i>aqua</i>)	<u>71.5</u>
	100.0

Evaluation Techniques

Microscopy: Microscopy was used to determine the size of globules and to characterize the emulsion systems. W/O/W multiple emulsions were examined under an optical immersion microscope at magnifications of 100 and 40.

^a Abil EM90, Degussa, France. Abil is a registered trademark of Degussa.

^b Synperonic PE/F127, ICI, France. Synperonic is a registered trademark of ICI.

^c From E. Merck, Germany

Table 18.1. Oils used in this study and properties of freshly prepared multiple emulsions

Code	Oil Type	Oil Name	Macroscopic Analysis	Mean (n=3) Droplet Diameter ($\mu\text{m}\pm\text{SD}$)	Mean (n=3) pH ($\text{pH}\pm\text{SD}$)	Yield (%)
F1	triglyceride	almond oil ^a	white cream	2.0 \pm 0.1	3.1 \pm 0.2	95.4
F2	ester	isopropyl myristate ^a	white cream	2.0 \pm 0.1	3.1 \pm 0.2	94.9
F3	triglyceride	caprylic/capric acid ^b	white cream	2.0 \pm 0.2	3.2 \pm 0.2	93.3
F4	hydrocarbon	mineral oil ^c	white cream	2.2 \pm 0.2	4.1 \pm 0.2	99.9
F5	hydrocarbon	squalane ^d	white cream	2.1 \pm 0.2	3.5 \pm 0.2	98.7
F6	triglyceride	caprylic/capric acid ^e	white cream	2.0 \pm 0.0	4.6 \pm 0.1	96.1
F7	carboxylic acid	oleic acid ^f	beige cream	3.0 \pm 0.1	2.9 \pm 0.1	96.0
F8	triglyceride	soja oil ^g	white cream	2.5 \pm 0.1	3.2 \pm 0.2	98.3
F9	triglyceride	sesame oil ^a	white cream	2.2 \pm 0.2	3.0 \pm 0.1	98.5

^a Degussa, France
^b Myritol 318/GR, Degussa
^c Birpa laç Laboratuan, Turkey
^d Cosbiol, a perhydro-squalene from ICN Biomedicals GmbH, Germany
^e Miglyol 812N, ICN Biomedicals GmbH
^f From E. Merck, Germany
^g ICN Biomedicals

Release studies: The emulsions were diluted to a 1:20 ratio in distilled water to measure their conductivity at 20 \pm 1°C after magnetic stirring using a conductimeter^d. This measurement enabled the calculation of the weight fraction, $\beta(t)$, of the electrolyte released into the external aqueous phase at a given time according to the following equation:

$$\beta(t) = M(t)/M_0 \quad (1)$$

where M_0 is the initial amount of electrolyte incorporated and $M(t)$ is the amount of electrolyte present in the external phase at a

^d Model 4071, Jenway, UK

given time (t). Analyses were performed after the establishment of a calibration curve.¹³ The β value can lead to the calculation of the entrapment yield, Y , of the multiple emulsions:

$$Y = 1 - \beta \quad (2)$$

At the same time, it is possible to obtain information on the stability of the multiple emulsion by evaluating the release of the tracer from the internal phase.

pH studies: pH was monitored to see if it varied during the release and stability studies. Therefore, pH values were determined for freshly prepared and 45-day-old multiple emulsions.

Stability studies: Stability was followed by the test methods already mentioned. Accelerated stability studies were performed at $4\pm 1^\circ\text{C}$, $25\pm 1^\circ\text{C}$ and $40\pm 1^\circ\text{C}$ with measurements taken at equal time intervals. Centrifugation at 4,000 rpm for 15 min was performed on freshly prepared and 24-hr-old multiple systems to examine any phase separation.

Results and Discussion

Characteristics of multiple emulsions: When diluted with mineral oil for the primary emulsion and with water for the multiple systems, homogenous mixtures were obtained indicating that the external phases were oil and water, respectively. Microscopic analysis showed the presence of both the primary and the multiple emulsions. The macroscopic aspects and the properties of the formulations are given in **Table 18.1**.

Except for formulation F7 prepared using oleic acid, the multiple emulsions had a homogeneous appearance with good consistency (**Table 18.2**). The possible ionization of the magnesium sulfate marker regulates the pH value of the aqueous droplets. The release of this entrapped hydrophilic marker may change the pH value of the external aqueous phase. The apparent pH of a topical product may also change on storage. Although pH measurements of vehicles have no fundamental meaning, they could be measured to monitor formulations as they age.¹⁴ In this study the pH values of formulations

F4 and F6 prepared with mineral oil and caprylic/capric acid were found to be in a weak acidic range that was cutaneously tolerable.

Release mechanism studies: The type of the oil is of great importance because the permeability of the oil layer controls the release of drugs or markers from the internal aqueous phase. Multiple emulsion instability can be determined from the release of the aqueous marker toward the outer compartment. The amount of the internal marker included in the inner aqueous phase droplets that may migrate and fuse with the outer aqueous phase is taken as the measure of emulsion stability. Conductivity measurement in the external phase is one way to evaluate the release of the internal marker.¹⁵ Conductimetric measurements were performed after the establishment of a calibration curve. Plotting conductivity versus concentration showed the validity of the model ($r^2 = 0.9872$).

Introducing an internal electrolyte into the internal aqueous phase has several goals: to promote an osmolar balance between the internal and external aqueous phases, to work as the breakdown indicator, and to increase the stability of the system due to the

Table 18.2. Breakdown rates of multiple oil globules in w/o/w emulsions freshly prepared (t_0) and after storage at 20°C for 30 days (t_{30})

Code	Oil Type	Oil Name	Breakdown Rate	
			t_0 (%)	t_{30} (%)
F1	triglyceride	almond oil	4.6	6.8
F2	ester	isopropyl myristate	0.9	7.1
F3	triglyceride	caprylic/capric acid	3.6	8.3
F4	hydrocarbon	mineral oil	0.1	3.1
F5	hydrocarbon	squalane	1.3	5.8
F6	triglyceride	caprylic/capric acid	1.1	7.3
F7	carboxylic acid	oleic acid	1.7	6.3
F8	triglyceride	soja oil	1.7	3.6
F9	triglyceride	sesame oil	1.0	3.9

salting-out phenomenon. In the salting-out phenomenon, competition of the electrolyte and the lipophilic surfactant results in a more rigid interfacial layer and thus a more effective mechanical barrier.

Conductimetric measurements were taken at $20 \pm 1^\circ\text{C}$ on the multiple emulsions diluted (1:20) with glucose solution having the same osmolarity as the inner aqueous phase (50 micro osmoles per liter). This determination was made with the help of tables.¹⁶ As shown in **Figure 18.1**, conductimetric measurements did not show any change in the fraction of magnesium sulfate released. This indicates that there was no passive diffusion or facilitated transport of magnesium sulfate, confirming the results of previous studies.^{12,17,18}

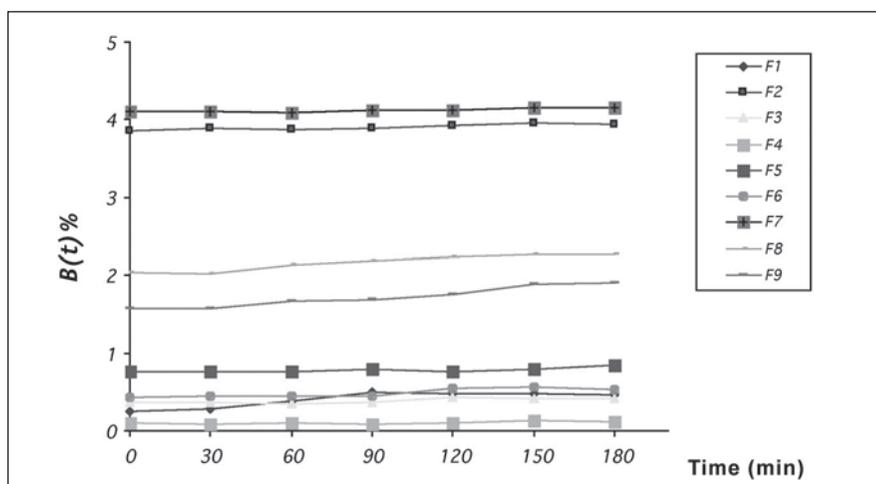


Figure 18.1. % β release values of the emulsions under iso-osmotic conditions (SD \pm 5)

Conductimetric measurements also were taken at $20 \pm 1^\circ\text{C}$ on the multiple emulsions diluted (1:20) with distilled water to produce a concentration gradient. In this case, the aqueous transport from the external phase to the internal phase leads to an increase in the size of the internal droplets, which increases the size of the multiple oil globules until they reach a critical size called a swelling step. Beyond this critical size, the globules split by breakdown of the oil membrane and release the entrapped salt; this is called the breakdown step. **Figure 18.2** shows magnesium sulfate release values from different formulations.

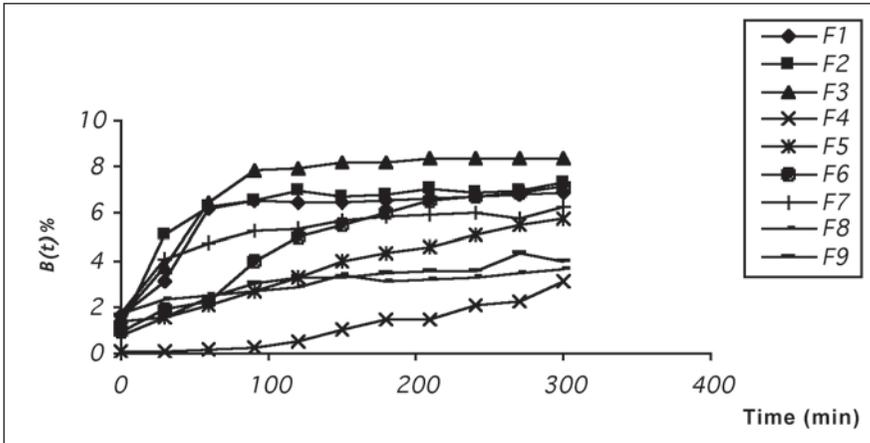


Figure 18.2. % β release values of the emulsions under hypo-osmotic conditions ($SD \pm 5$)

The yield was found to vary with the type of oil. It was concluded that the oil type can have a marked effect on the behavior of the system; furthermore, the stability of the oil membrane against leakage of the entrapped material will depend, among other factors, on the type of oil used in preparing the emulsion.¹⁹ The long-term stability of the emulsion was assessed by measuring the quantity of an internal marker remaining entrapped with time. According to results reported in **Figure 18.2**, release of magnesium sulfate was found to be highest from multiple emulsion formulated using the F3 caprylic/capric triglyceride, followed by the F2 isopropyl myristate and the F6 caprylic/capric triglyceride.

The initial values of $\beta(t)$, electrolyte release with time, was found to be different depending on the different properties of oils (**Figure 18.2**). While caprylic/capric acids belong to the triglyceride group, isopropyl myristate belongs to the ester group of oils. They are reported to be medium-polar oils. The interfacial tensions of caprylic/capric triglyceride-water and isopropyl myristate-water are 20.2 and 24.3 mN m^{-1} , respectively.²⁰ The mineral oil-water and squalane-water interfaces are 42.5 and 46.2 mN m^{-1} , respectively, and they are considered as nonpolar oils. The other oils used in this study were medium-polar vegetable oils with interfacial tensions between 11.5 and 14.73 mN m^{-1} .^{10,20,21}

The polarity of the oil phase has a great influence on the formulation and properties of emulsions. Tedajo et al. reported that

the higher the oil polarity (i.e., the lower the interfacial tension), the higher the transfer.²² Our findings were concordant with this study. Magnesium sulfate entrapment yields of w/o/w emulsions prepared with hydrocarbons that have the highest interfacial tension were found higher than the others. F3 and F2 showed the lowest entrapment yield while an intermediate entrapment yield was shown by F6. These results led to the conclusion that oil polarity plays a predominant role in the transport of materials.

Omotosho et al. reported that the release of marker was faster from multiple emulsions formulated with isopropyl myristate and slower from those prepared with hydrocarbons,¹⁰ a finding that is consistent with the current study. Swelling capacities of hydrocarbons are higher than the other oils. As explained in earlier studies, if the multiple oil globule swelling capacity increases, magnesium sulfate release is delayed.^{13,23} Therefore, stabilities of the systems prepared using hydrocarbons were found to be higher compared to the other systems. Release studies showed that the release of magnesium sulfate was faster from multiple emulsions formulated using caprylic/capric acids and isopropyl myristate because their smaller internal droplets lead to increased interfacial area. The absence of significant changes in the number of w/o/w oil droplets prepared with hydrocarbons was an indicator of stability.

Correlation with stability studies: Results of the swelling breakdown kinetic study can be correlated with the multiple emulsion stability. **Table 18.3** shows the results of the conductimetric analyses of the breakdown rate of the multiple oil globules, immediately after preparation and after 30 days of storage at 20°C. It can be seen that even if the formulation parameters are kept constant, the breakdown percentages vary with the type of oil. At the end of 30 days, the lowest breakdown rate was obtained with the F4 mineral oil, which also had the lowest release values in **Tables 18.1** and **18.2**. It was thus concluded that F4 was more resistant to degradation than the other preparations. This confirms the fact that higher stability may be predicted for a higher swelling capacity of the oils at all the interfaces of w/o and o/w emulsion formulations. The breakdown rate of formulation F6 caprylic/capric triglyceride after 30 days was higher than for the other formulations. Omotosho et al. studied the

effect of oil type on the release characteristics of multiple emulsions and concluded that the release and the stability could be affected by the type of oil.²⁴

Stability of the systems is of great concern with emulsions. When the freshly prepared and 24-hr-old emulsions were centrifuged to accelerate the effect of gravity, no phase separation could be observed except for formulations F7 and F8 made with oleic acid and soya oil, respectively.

Table 18.3 also shows the results of thermal stability tests performed at $4\pm 1^\circ\text{C}$, $25\pm 1^\circ\text{C}$ and $40\pm 1^\circ\text{C}$. It can be seen that the most stable formulation is F4, which was prepared using mineral oil, a hydrocarbon. In several studies it was reported that w/o/w multiple emulsions prepared with hydrocarbons are more stable than the emulsions containing triglycerides and other vegetable oils.^{25,26,27} Thermal stabilities of emulsions prepared with strongly polar and nonpolar oils were found to give emulsions with poor stability, which is generally experienced with vegetable oils. Compared to any of the hydrocarbons, the vegetable oils are more difficult to disperse in an aqueous medium.²² These results are in good accordance with the release results obtained in the current study.

Table 18.3. Results of thermal stability tests on w/o/w emulsions containing different oils

Code	Oil Type	Oil Name	40°C	25°C	4°C
F1	triglyceride	almond oil ^a	6 months	6 months	4 months
F2	ester	isopropyl myristate ^a	4 months	6 months	6 months
F3	triglyceride	caprylic/capric acid ^b	2 weeks	>6 months	>6 months
F4	hydrocarbon	mineral oil ^c	>6 months	>6 months	>6 months
F5	hydrocarbon	squalane ^d	6 months	6 months	6 months
F6	triglyceride	caprylic/capric acid ^e	>4 months	>6 months	4 months
F7	carboxylic acid	oleic acid ^f	2 weeks	3 months	3 months
F8	triglyceride	soja oil ^g	3 months	3 months	3 months
F9	triglyceride	sesame oil ^a	>6 months	>6 months	>6 months

See footnotes in Table 19.1.

Measurement of the multiple oil globule size is another parameter for monitoring stability of multiple emulsions. Regardless of the mechanism, destabilization leads to a change in the globule diameter; therefore, the globule mean size is an essential parameter in characterizing multiple emulsion stability. The average globule diameters of the freshly prepared samples were 2–3 μm . Globule size determination tests every 10 days revealed that globule size remained almost constant with time (**Figure 18.3**). The slight increase can be attributed to penetration of water into the internal phase from the external phase due to osmotic flux (higher magnesium sulfate concentration in the internal water droplets). Globule size of the F7 oleic acid formulation increased more, compared to other formulations. This may be due to the oil used, permitting much more water penetrating into the internal phase, which may have enhanced the enlargement of the internal droplets. At the end of 60 days, it was seen that the globule size of the F4 mineral oil formulation showed only a slight increase; F4 was also found stable in thermal stability tests and conductimetric studies.

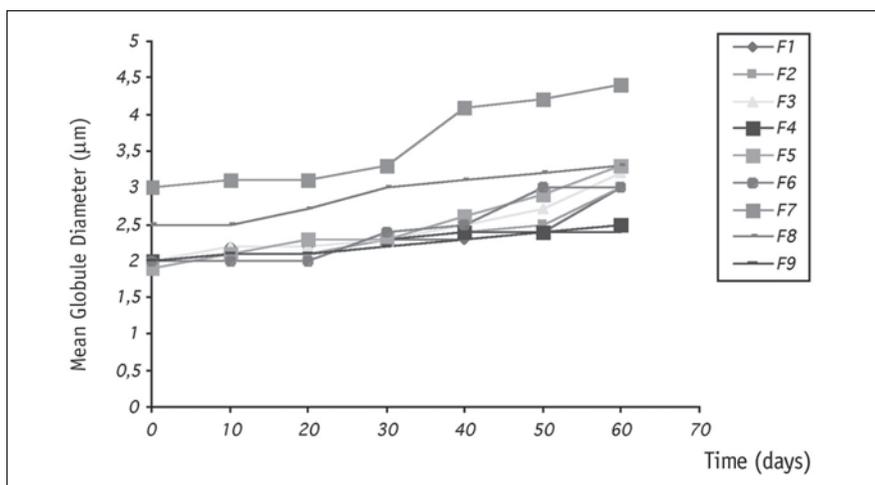


Figure 18.3. Change in the multiple droplet size of the formulations ($\text{SD}\pm 5$)

Conclusion

Because the oil phase in multiple emulsions is the main constituent of the membrane between the internal and external phases, it may influence the release pattern and stability in these emulsions. The basic characteristics of the oils greatly influence the colloidal, formulation and application characteristics of the emulsions prepared. The stability of the oil membrane against leakage of the entrapped material also depends on the type of oil. Therefore this study was performed on w/o/w multiple emulsions containing different oils. The main purpose was to prepare stable multiple emulsions and to assess the improvement of the stability versus the oil type. The dispersion of all vegetable oils in the aqueous phase was more difficult than dispersion of hydrocarbons.

This study found the highest magnesium sulfate entrapments from w/o/w emulsions prepared with hydrocarbons that have the highest interfacial tension, while the triglyceride group of cosmetic oils showed lower entrapment yield, indicating that the higher the oil polarity (i.e., the lower the interfacial tension), the higher the transfer. Compared to the triglyceride oil formulations, the hydrocarbon oil formulations had higher swelling capacities, delayed magnesium sulfate release, and better stability.

In conclusion, the type of oil was found to be responsible for the overall characteristics of the w/o/w emulsion system as well as the release conditions of the marker from the internal phase and the permeability characteristics of the oil layer. Mixtures of the oils may also be used to modulate the transfer rates of markers across the oil membrane and to improve the stability of the formulation.

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Preparing PIC Emulsions with a Very Fine Particle Size

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KEY WORDS: *o/w emulsions, fine particle size, cold processing, phase inversion concentration, wet wipes*

ABSTRACT: *A new technology has been developed for the production of o/w phase inversion concentration (PIC) emulsions with a very fine particle size and excellent storage stability. The concept is based on non-ethoxylated emulsifiers and can be easily used for the preparation of impregnating lotions for cosmetic wet wipes.*

Low viscous oil-in-water (o/w) emulsions are of interest for many cosmetic applications. Systems of particular interest are sprayable emulsions (see **Sprayable Emulsions sidebar**) and impregnating lotions for the preparation of cosmetic lotion wipes. In order to combine low-emulsion viscosity and good storage stability, a very fine droplet size is needed. This chapter describes a cold process using non-ethoxylated emulsifiers for preparing o/w emulsions with low viscosity, very fine droplet size and good storage stability.

Finely dispersed emulsion droplets do not undergo sedimentation or creaming because these processes are prevented by the Brownian motion of such small droplets. The submicroscopically small oil droplets cause a characteristic blue shining appearance of these emulsion systems.

Sprayable Emulsions

The term *sprayable emulsion* refers to an emulsion that can be directly sprayed, especially by means of a trigger pump, without using a pressurized propellant. Sprayable o/w emulsions typically are based on nonionic surfactants and prepared by the phase inversion method. Others are based on anionic emulsifiers, such as glyceryl stearate citrate or phosphoric acid derivatives, plus a thickener. Sprayable o/w emulsions are of great interest, particularly in the form of sunscreen products.

In a recent US patent application, Klaus Kwetkat and Gerd M. Dahms disclose sprayable low viscous o/w emulsions that can be prepared from at least two phases by using a hydrophobic phase consisting of gemini surfactants and a hydrophilic phase consisting of gemini surfactants with added solid particles, a foaming surfactant or an antitranspirant. The inventors claim that the composition is easy to use with a multitude of different solids and solids concentrations, as might be encountered in sunscreen formulations.

For more information, see US Patent Application 20050031653, Sprayable o/w emulsions of a low viscosity, available at www.freshpatents.com/Sprayable-o-w-emulsions-of-a-low-viscosity-dt20050210ptan20050031653.php (accessed Jul 20, 2006).

A common process for the preparation of such blue shining emulsions is the phase inversion temperature (PIT) method.^{1,2,3} The PIT method makes use of the low interfacial tension that is obtained in the region of phase inversion from a water-in-oil (w/o) emulsion to an o/w emulsion upon cooling; normally a microemulsion or a lamellar phase is passed in the phase inversion temperature region. This low interfacial tension in the phase inversion region allows the spontaneous formation of finely dispersed, blue shining o/w PIT emulsions. Nonionic ethoxylated emulsifiers are known for their strongly increasing hydrophobicity with increasing temperature, which is the reason why all practical applications of PIT emulsions are based on the use of ethoxylated emulsifiers.

Recently, personal care applications have shown a trend toward more natural ingredients. Therefore it was challenging to develop an alternative to the PIT technology based on emulsifiers that are

non-ethoxylated (PEG-free). Additionally, and especially with regard to the production of cosmetic lotion wipes, such a new technology should ideally be easy to process without the need to use a homogenizer or heating.

The new technology is illustrated by a recently developed oil phase mixture containing an emollient, a non-ethoxylated emulsifier mixture and a microemulsion booster system. Upon simple dilution with water, this system passes an intermediate microemulsion-like phase with minimized interfacial tension. Viscosity measurements are used to demonstrate that the same phase transitions occur as in the case of PIT emulsions. Because the phase inversion happens at a certain water concentration within the intermediate microemulsion-like phase, the resulting emulsions can be called phase inversion concentration (PIC) emulsions. Application properties and formulation flexibility of such PIC emulsion-based systems are demonstrated in a series of practical examples.

Surprising Findings

Developmental work on a new emulsifier system revealed several surprising findings. When a suitable PEG-free emulsifier combination was combined with preservatives based on phenoxyethanol at a certain oil-to-water ratio, microemulsion-like phases were obtained at room temperature. Simple dilution of these microemulsions with water led to blue shining o/w emulsions with a very fine particle size and excellent long-term stability.

Microemulsion boosters: Phenoxyethanol or commercially available combinations of phenoxyethanol and paraben esters are known for their interfacial activity in emulsion systems because this activity often causes stability problems in emulsions. However, this interfacial activity is essential when forming microemulsion-like phases at room temperature. Therefore, these compounds can be described as microemulsion boosters.

In colloid science, microemulsion boosters often are called cosurfactants. These substances integrate into interfacial films, but they are not surfactants and do not form micelles on their own. They also are not emulsifiers and do not stabilize emulsion droplets.

Classical cosurfactants in colloid science are molecules with a small polar head group and an alkyl chain of a suitable length, such as n-pentanol, n-hexanol or n-octanol. Surprisingly, it is the well-known and widely used preservative phenoxyethanol that proved to be a particularly efficient microemulsion boosting agent for the new emulsifying system.

Emollients and emulsifiers: Another surprise was the finding that suitable emollients and suitable emulsifier mixtures can be combined with the necessary amount of microemulsion boosters to obtain a clear liquid oil phase. When diluted with water and gently stirred at room temperature (no homogenization is needed), this oil phase passes through a microemulsion-like phase before yielding an o/w emulsion with extremely fine droplet size.

Suitable emulsifier combinations include mixtures of polyglyceryl esters and citric acid esters. Typical emollients are preferably ester and ether oils. Because this is a completely new technology, development work to expand mixture options and applications is ongoing. The best system examined so far is an oil phase combination based on the light emollient diethylhexyl carbonate.

Illustrating Technology and Performance

The technology platform of this patent-pending emulsion technology is depicted schematically in **Figure 19.1**. Its performance and backgrounds of this new technology are demonstrated using a system containing 20–25% of a suitable emulsifier mixture, 12% of microemulsion boosters and 65–70% of an emollient.

- The emulsifier mixture is at least 90% polyglyceryl-4 laurate and the remainder is dilauryl citrate.
- The microemulsion booster system is 72% phenoxyethanol and 28% alkylparaben esters whose main component is methylparaben.
- The main component of the total oil phase mixture is the emollient diethylhexyl carbonate. This mixture is a clear and easily pumpable system with a viscosity of 36 mPas (Hoepler

viscosimeter, 25°C). The mixture is a commercial product^a. In order to reduce complexity, this oil phase mixture will be discussed in this chapter using terms such as *DE system*, *DE mixture* and *DE oil phase*.

All percentages in the chapter are given in wt%. The term *water* refers to the use of demineralized water; using tap water might result in a different phase behavior.

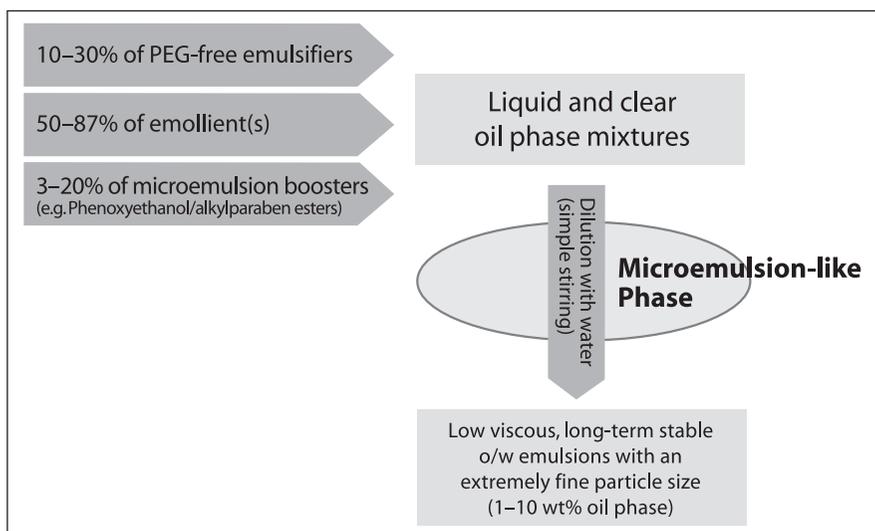


Figure 19.1. Schematic depiction of technology platform

Figure 19.2a shows the clear DE system. When the DE system is diluted with water at room temperature under simple stirring (e.g., magnet stirrer), at 32–72% water content, a translucent microemulsion-like phase is obtained, as in **Figure 19.2b**. Further dilution with water results in low viscous o/w emulsions with a very fine particle size. **Figure 19.2c**, with 94.3% water and 5.7% DE oil phase content, illustrates a blue shining o/w emulsion.

When using oil phase contents of 3–8%, the finely dispersed o/w emulsions can be used effectively as impregnating lotions for the

^a TEGO Wipe DE (INCI name: Diethylhexyl carbonate (and) polyglyceryl-4 laurate (and) phenoxyethanol (and) methylparaben (and) dilauryl citrate (and) ethylparaben (and) butylparaben (and) propylparaben (and) isobutylparaben) is a product of Degussa Care and Surface Specialties, Goldschmidt Personal Care. TEGO is a registered trade name of Degussa.

preparation of wet wipes. Because no heating or homogenizing is required, the production process is simple.

As an additional benefit, the microemulsion booster system consisting of phenoxyethanol and paraben esters is able to provide a significant part of the preservation needed to protect the impregnating lotions and the wipes against contamination with bacteria and microorganisms. A DE oil phase of 5.7% corresponds to a quantity of 0.7% phenoxyethanol and paraben esters in the impregnating lotion.



Figure 19.2. Images of: a) the DE oil phase, b) the intermediate microemulsion-like phase and c) a blue shining impregnating lotion

Droplet Size and Stability

Droplet size: Droplet sizes of the diluted o/w emulsions or impregnating lotions were determined using dynamic light scattering. Dynamic light scattering is a widely used method for the determination of the size of dispersed particles in diluted solutions. It is based on the measurement of intensity fluctuations of the light scattered by diffusing particles in solution. These intensity fluctuations enable the determination of the diffusion coefficient of the particles. In case of diluted systems where there is no interaction between the diffusing particles, the diffusion coefficient is correlated to the particle size via the Stokes-Einstein equation:

$$D = \frac{k_B T}{6\pi \cdot r_h \cdot \eta_0}$$

The particle size is given as hydrodynamic radius (k_B being the Boltzmann constant; T being the temperature and η_0 being the viscosity of the solvent).

All emulsions described in this chapter were diluted before the measurement to 0.5% total oil phase content and measured^a three times for 100 sec at 25°C. The resulting intensity-weighted size distributions are used in the further discussion.

Figure 19.3 shows the droplet size of impregnating lotions with 5.7% of the DE oil-phase system directly after production and after three months storage at -5°C, 25°C and 45°C.

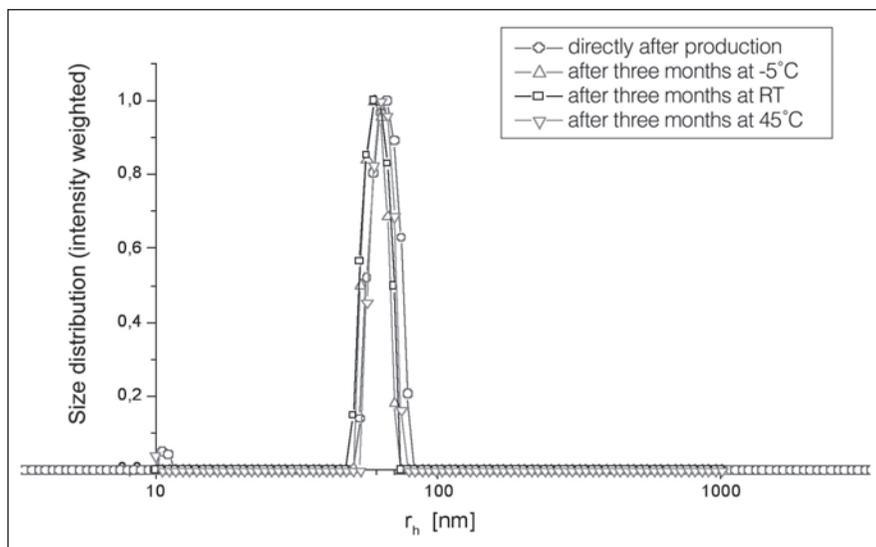


Figure 19.3. Droplet sizes of impregnating lotions containing 5.7% of the DE oil phase directly after production and after three months of storage

As already described, the impregnating lotions are prepared by the addition of water to the DE oil phase with simple stirring at room temperature. The measurements show that there is no change of the droplet size upon storage. Even after three months of storage at 45°C, the droplet size remains constant.

This finding corresponds with the visual observation of the stored samples: within three months no changes have been observed, indicating the excellent storage stability over a wide range of temperatures of these finely dispersed emulsions.

The storage stability is a result of the extremely fine particle size of the emulsion droplets. The droplets have radii r_h in the 50–80 nm range with an average droplet radius of approximately 65 nm.

Without the use of excessive shear forces, nanoemulsions of such a small particle sizes normally are known only from PIT systems using ethoxylated emulsifiers.

Comparing droplet sizes from different emulsion systems:

Particle sizes and storage stability of the impregnating lotion based on the DE mixture (the DE system) were compared to a market standard based on a PIT emulsion concentrate (the PIT comparison system, or PITCS) and also to an impregnating lotion prepared with a commercially available non-ethoxylated emulsifier comparison system (NEECS) used for such applications. Again, emulsions were prepared with a total oil phase ratio of 5.7%, consisting of 5.0% of a mixture of emollients and emulsifiers and 0.7% of a mixture of phenoxyethanol and paraben esters (to be comparable to the DE system).

The PITCS was a commercial product^a. It was diluted with water to 5.0% emollient/emulsifier/consistency enhancer mixture (plus 0.7% mixture of phenoxyethanol and paraben esters).

A PEG-free emulsifier system^b used for the NEECS was prepared in a two-step process. An emulsion concentrate was prepared in a hot process (75°C) using a homogenizer. This concentrate then was diluted with water at room temperature in a second step. The 5.0% oil phase of the NEECS consisted of 3.75% of diethylhexyl carbonate and 1.25% of the PEG-free emulsifier system and 0.7% of the mixture of phenoxyethanol and paraben esters.

Particle size distributions of the resulting impregnating lotions are depicted in **Figure 19.4**. The droplet distributions show clearly that particle sizes obtained with the DE system are in the same range as for the PITCS, and the DE system gives a narrower particle size distribution. PEG-free emulsions prepared with the NEECS have much larger droplets.

^a Emulgade CM (INCI: Cetearyl isononanoate (and) cetareth-20 (and) cetearyl alcohol (and) glyceryl stearate (and) glycerin (and) cetareth-12 (and) cetyl palmitate), a product of Cognis. Emulgade is a registered trade name of Cognis.

^b Arlatone V175 (INCI: Sucrose palmitate (and) glyceryl stearate (and) glyceryl stearate citrate (and) sucrose (and) mannan gum (and) xanthan gum) from Uniqema. Arlatone is a registered trade name of Uniqema.

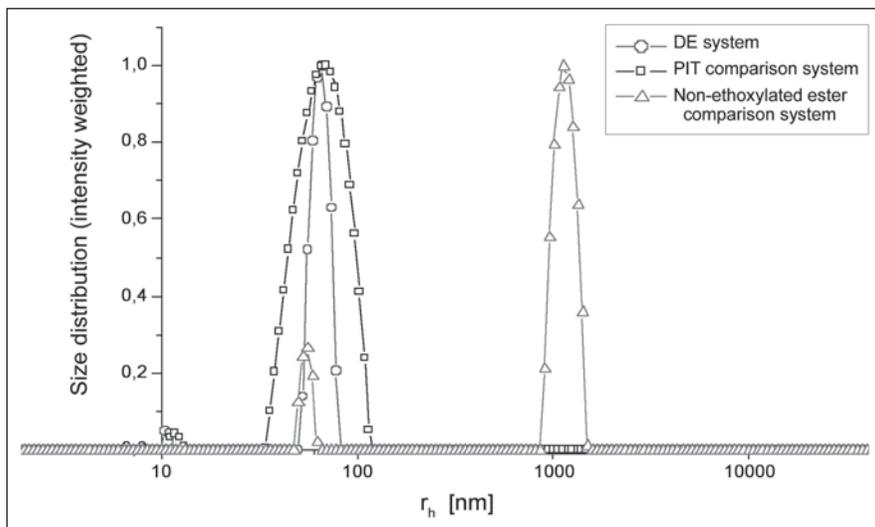


Figure 19.4. Droplet sizes of impregnating lotions containing 5.7% oil phase of the DE system compared to a PIT emulsion system and another PEG-free emulsifier system

Concerning storage stability, the NEECS dilution showed water separation at 25°C and at 40°C after one week. The PITCS showed deficiencies in heat stability (water separation at 40°C) after two weeks. As already mentioned, the DE system is stable for at least three months at temperatures from -5°C to 45°C.

Processing variations: Before discussing the reasons for the performance of the DE system, some comments on findings related to processing are appropriate. As already mentioned, impregnating lotions based on the DE system can be prepared by successively adding water to the DE oil phase at room temperature with gentle stirring. In this procedure, called *stepwise*, a microemulsion-like phase is passed before the impregnating lotions with a very fine particle size are obtained.

However, it also is possible to do two alternative types of fast one-step processing. The system also works when the dilution water is added in one step directly to the DE oil phase with gentle stirring. In this case, called *one-step: water addition*, no visually observable microemulsion-like phase is passed.

Moreover, the inverse way of fast processing is possible also. The DE oil phase can be added in one step with gentle stirring directly to

the necessary amount of dilution water in a process called *one-step: DE addition*. Again, by doing so, no microemulsion-like phase can be observed visually.

The resulting droplet size distributions are illustrated in **Figure 19.5**. It can be seen that there are no significant differences in the particle sizes obtained by applying the different production techniques. Also the storage stability data is comparable.

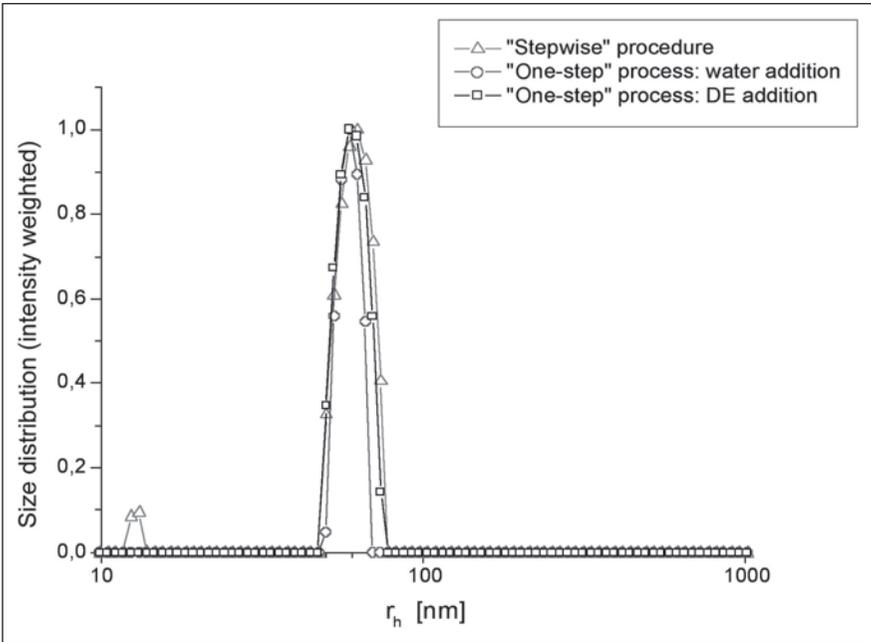


Figure 19.5. Droplet sizes of impregnating lotions containing 5.7% oil phase of the DE system prepared stepwise and in two types of one-step processing

This data illustrates the properties of the new technological approach of the DE system. What needs to be explained is why the system gives these results.

PIC Emulsion Systems

Phase behavior of varied mixtures of DE and water: The phase behavior was examined using simple measurement techniques as supporting tools. A series of samples was prepared by systematically varying the content of water and DE. Their appearance was

examined at 20°C. Additionally conductivity and viscosity measurements were carried out at 25°C. The results of these studies are summarized in **Figure 19.6**.

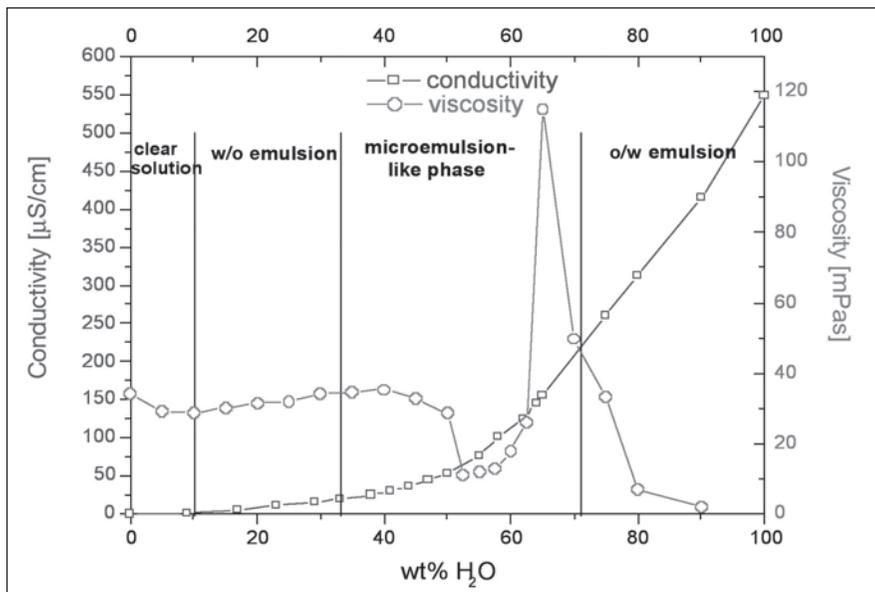


Figure 19.6. Phase behavior of mixtures of DE and water at 20°C and viscosity/ conductivity data of the mixtures at 25°C

Up to 10% of water can be incorporated into the DE oil phase system with the system remaining clear. Probably this amount of water is solubilized in a kind of inverse micelles. When water content is between 10% and 32%, a turbid w/o-emulsion-like system is obtained; it separates very quickly into two phases.

At water concentrations above 32%, translucent microemulsion-like systems are observed directly after preparation of the samples. At 32–45% water, these microemulsion-like systems separate after standing several days or weeks at room temperature; they form an upper translucent w/o microemulsion phase and a lower excess water phase. At 45–60% water, a one-phase microemulsion system was observed for one month without phase separation. At 60–72% water, samples with a microemulsion-like appearance after production tend to become more turbid after one month of storage without showing a real phase separation.

However, the samples within the microemulsion-like region differ in their transparency and turbidity. The most transparent samples are obtained directly after preparation in the range of 35–50% water content. At higher water concentrations, samples get more and more turbid while remaining translucent. A maximum of turbidity in systems still remaining translucent occurs in the range of 60–65% water content.

In mixtures with more than 72% water, the microemulsion-like region has been passed through and o/w emulsions are obtained. Typical systems used as impregnating lotions have a water content of more than 90%. As already mentioned, these systems are characterized by a very fine droplet size.

Conductivity and viscosity: After this general description of the phase behavior of the pseudobinary DE-water system, conductivity and viscosity data should be studied.

While conductivity data more or less shows the expected behavior with a steep increase as the systems change from w/o to o/w emulsions, the viscosity of the system—measured^a at 50 s⁻¹ with cylinder geometry—goes from a first viscosity maximum at around 40% water content through a surprising viscosity minimum at 50–55% water content to a steep second viscosity maximum at around 62% water content.

Similar viscosity behavior is known from PIT emulsion systems at temperatures close to the actual phase inversion temperature. Salager et al. reported such viscosity curves on a PIT emulsion system based on kerosene as oil and polysorbate 85 as emulsifier (see **Figure 19.7**).⁴

Comparison of the viscosity data from **Figures 19.6** and **19.7** show that the same phenomenon is observed when the system changes from a w/o emulsion to an o/w emulsion. Therefore most of Salager's explanations can be transferred to PIC emulsion systems.

On the w/o side, consider the first broad maximum in the DE-water system at approximately 40% water content in **Figure 19.6** and approximately 30°C in **Figure 19.7**. That peak probably corresponds to a w/o microemulsion-like system with a droplet character and a minimum droplet size at this point. Minimum size corresponds to a maximum of interface, which leads to a first viscosity maximum.

^a Reologica Stress Tech, Reologica Instruments AB, Sweden

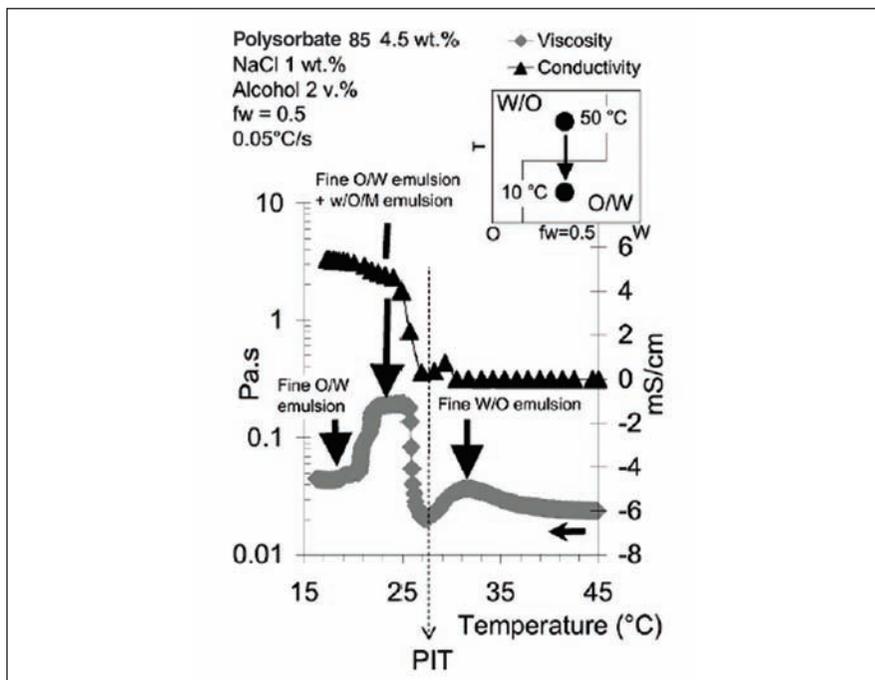


Figure 19.7. Viscosity and conductivity data of a PIT emulsion system close to the phase inversion temperature. The ratio of oil phase to water phase is 1:1. (Taken from Reference 4)

By further increasing the water content of the system, the curvature of the interfacial film continues to change from w/o to o/w. At a certain point a zero-curvature is obtained that corresponds to a system that is neither w/o nor o/w but something intermediate. Such systems are known as bicontinuous phases. In such systems water and oil domains are present, separated by a very flexible interfacial film. The flexibility of these structures is reflected by a minimum in the viscosity curve. Moreover, it is known that the interfacial tension of bicontinuous systems is extremely low.⁵

The steep second viscosity maximum at a water content around 62% in **Figure 19.6** probably can be attributed to the fact that water starts to be the outer phase when more water is added to the system. At the same time, water and oil domains are still present in the system. The relatively high viscosity can be explained by the relatively high amount of inner phase (water domains in oil domains) and the relatively low amount of external water phase at this point in the phase diagram.

The reason why the DE system results in such finely dispersed emulsion droplets upon simple dilution with water can be attributed to the fact that a region with extremely low interfacial tension has been passed. That region is the bicontinuous region characterized by a viscosity minimum. The whole process is comparable to the behavior of interfacial films of ethoxylated emulsifiers at the phase inversion temperature.

The main difference from PIT emulsions is the fact that in the DE system phase inversion does not occur at a certain temperature but at a certain concentration: the phase inversion concentration. Therefore, it seems appropriate to call such emulsions PIC emulsions. Because such PIC systems are not based on the temperature-dependent hydrophilicity of emulsifiers, ethoxylated emulsifiers are not needed to realize them.

The low interfacial tension known for bicontinuous microemulsion phases at the phase inversion concentration is the key point of this new technology. It explains why translucent phases with microemulsion-like appearance are obtained close to this phase inversion concentration. Whether these microemulsion-like phases are real microemulsions or whether they separate into a microemulsion with excess water or excess oil phase upon storage might not be the decisive point for the performance of such a PIC system. It is known from PIT systems that at the phase inversion temperature a bicontinuous microemulsion phase can be in coexistence with excess water and oil phases.⁶ The same might apply for PIC emulsions. More experiments are needed to answer that question.

Importance of the interfacial film: As already discussed regarding **Figure 19.5**, finely dispersed o/w emulsions with comparable final particle size can be prepared in the DE system by three different methods: a stepwise procedure, fast addition of the DE phase to the water phase, and fast addition of the water phase to the DE phase. While the stepwise procedure always displays an intermediate microemulsion-like phase, no intermediate microemulsion-like phase is observable in both ways of fast addition. This indicates that an inversion of the interfacial film from w/o to o/w takes place anytime the water concentration in a DE-water system is locally sufficient to provoke it. Therefore, the crucial parameter behind PIC

emulsions is an optimized design of an interfacial film that inverts smoothly from w/o to o/w at a certain water concentration.

By now, it is clear that such PIC emulsion systems can be formulated also for other cosmetic oils, preferably ester oils of medium polarity. The emulsifier combination and the microemulsion booster system have to be fine-tuned for each of the oils.

Application Properties

The aesthetics of impregnating lotions based on the pure DE system are mainly characterized by the properties of the cosmetic emollient diethylhexyl carbonate that is known for its low viscosity, good spreadability and quick absorption. It also is characterized by its light skin feel and its effectiveness at removing makeup.

Adding water-soluble or oil-soluble ingredients: The DE oil phase can be used as an emulsion base that allows adding certain amounts of water- or oil-soluble ingredients while maintaining a small droplet size and excellent storage stability.

Water-soluble ingredients can be added directly to the water phase. Impregnating lotions based on 5.7% of the DE system and, for example, 3% of ethanol or glycerin included in the water phase have been tested successfully for three months of stability at -5°C , 25°C , 40°C and 45°C . A formulation example of an impregnating lotion for facial care wipes is shown in **Formula 19.1**. It contains panthenol as a skin-soothing active and creatine as an antiaging active.⁷

Formula 19.1. Face care lotion

A.	Diethylhexyl carbonate (and) polyglyceryl-4 laurate (and) phenoxyethanol (and) methylparaben (and) dilauryl citrate (and) butylparaben (and) ethylparaben (and) propylparaben (and) isobutylparaben (TEGO Wipe DE, Degussa)	5.70% wt/wt
B.	Creatine	0.25
	Panthenol	0.50
	Water (<i>aqua</i>), demineralized	<u>93.55</u>
		100.00

Procedure: Charge the vessel with A and add B with simple stirring. Alternatively, it is possible to charge the vessel with B and add A with simple stirring.

The viscosity of impregnating lotions can be adjusted easily by adding carbomers or other ingredients to the water phase. Typical pH values in the DE systems are between 5 and 7, although a pH range of 4 to 8 is acceptable in some cases.

Oil-soluble ingredients preferably are added within the microemulsion-like region at a ratio of approximately 1:1, water to DE-phase. **Formula 19.2** shows the use of 1% isohexadecane in an impregnating lotion for makeup remover wipes based on the DE system.

Formula 19.2. Makeup remover

A. Diethylhexyl carbonate (and) polyglyceryl-4 laurate (and) phenoxyethanol (and) methylparaben (and) dilauryl citrate (and) butylparaben (and) ethylparaben (and) propylparaben (and) isobutylparaben (TEGO Wipe DE, Degussa)	4.2% wt/wt
B. Water (<i>aqua</i>)	4.2
C. Isohexadecane	1.0
D. Water (<i>aqua</i>), demineralized	<u>90.6</u> 100.0

Procedure: Charge vessel with A and add B with simple stirring; a microemulsion-like phase is obtained. Add C to the AB while stirring. Dilute with D while stirring.

In the microemulsion-like region at a DE-to-water ratio of 1:1, additional oil-soluble ingredients such as fragrance or oil-soluble preservatives can be added easily.

Adding secondary oil components: As already mentioned, a PIC emulsion system is optimized for a certain emollient or emollient mixture. However, these systems also have a certain flexibility concerning the addition of secondary oil components.

A series of test emulsions similar to **Formula 19.2** were prepared by adding 1% of secondary oils to impregnating lotions based on 5.7% of the DE system. As with the isohexadecane in **Formula 19.2**, the secondary oils were added at the intermediate microemulsion-like phase. The tested secondary oils were ethylhexyl palmitate, isopropyl palmitate, mineral oil, isohexadecane, caprylic/capric triglyceride and avocado oil.

The particle size distributions of these test emulsions are shown in **Figure 19.8**. The additional amount of isohexadecane and isopropyl palmitate leads to only a slight increase in droplet size. Also the addition of ethylhexyl palmitate and mineral oil still results in emulsions with a fine particle size. However, the addition of caprylic/capric triglyceride or especially the addition of avocado oil leads to a significant increase in the size of the oil droplets.

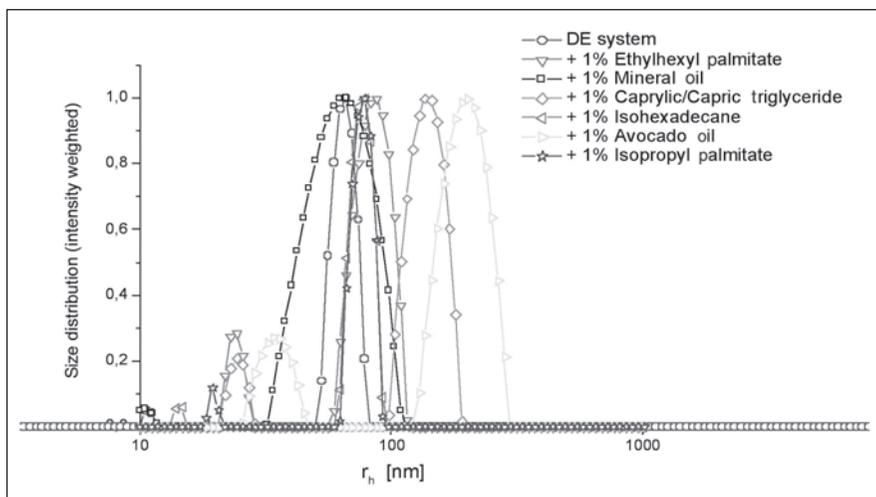


Figure 19.8. Droplet sizes of impregnating lotions based on 5.7% of the DE oil phase plus 1% of additional oils

These findings are reflected also in the observed stability data. The formulations containing additional 1% of isohexadecane, isopropyl palmitate, ethylhexyl palmitate or mineral oil are stable for at least two months at -5°C , 25°C , 40°C and 45°C . The formulations containing additional 1% of the more polar oils caprylic/capric triglyceride and avocado oil showed phase separation after some weeks of storage.

Summary: The results show that the DE system allows the addition of water-soluble and oil-soluble ingredients. Especially when adding a significant amount of secondary oils, the type of oil added (e.g., its polarity) and the stability requirements of the formula define the critical concentration of such secondary oils.

Conclusions

It has been demonstrated that low viscous o/w emulsions with an extremely fine particle size can be produced in a low-energy emulsification process with simple stirring at room temperature using non-ethoxylated emulsifiers. The key parameter of this new technology is the design of interfacial films that transfer at a certain water concentration from a w/o curvature to an o/w curvature. At this phase inversion concentration a minimum in viscosity is observed that can be linked to a bicontinuous structure with zero curvature and minimized interfacial tension.

The whole phase inversion process is very similar to PIT emulsions. In contrast to PIT emulsions, no heating or cooling steps are needed because phase inversion happens at a specific phase inversion concentration, or PIC, at room temperature. Suitable interfacial films for PIC emulsions can be formed by combination of non-ethoxylated emulsifiers such as polyglycerin esters and citric acid esters and suitable microemulsion boosters. Surprisingly, a combination of phenoxyethanol and alkyl paraben esters proved to be an excellent microemulsion booster system that additionally provides the well-known preservation benefits of such a combination in the final emulsion systems.

Finely dispersed emulsions obtained with this new technology can be used easily as impregnating lotions for the manufacturing of cosmetic wipes. Development work making use of this technology is ongoing. Innovative formulation solutions seem possible for many cosmetic emulsion formulation challenges where a combination of low emulsion viscosity, good storage stability and easy processing is needed.

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SECTION III

Sunscreen

This section includes the following chapters:

- 20** Pigments as Photoprotectants
- 21** Improved Delivery and Efficacy with Dimethyl Isosorbide
- 22** Film-Formers Enhance Water Resistance and SPF in Sun Care Products
- 23** Preservation of Sunscreen Products
- 24** Photostability: The Back Story of UV Filters
- 25** Stopping the Sun

Pigments as Photoprotectants

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KEY WORDS: *pigments, UV radiation, sun products, ZnO, TiO₂, benzotriazol*

ABSTRACT: *This chapter gives an overview of two pigments (TiO₂ and ZnO), their use in photoprotection, their mechanism of action and their ability to attenuate UV radiation. Finally, the organic pigments, the dominant members of a new family of photoprotectors, are described.*

Pigments are solid particles and are insoluble in water and fatty matter. They may be classified into two groups, depending on their origin: mineral pigments, which are of mineral origin, and organic pigments, which are produced by organic synthesis.

Mineral pigments are inert and opaque powders that reflect and diffuse UV radiation and part of the visible light (**Figure 20.1**). Consequently, they provide broad-spectrum protection. The mineral pigments most often used for photoprotection are titanium dioxide (TiO₂) and zinc oxide (ZnO). Other elements such as zirconium, cerium, talc and kaolin are less used because their capacity to attenuate UV radiation is low. This chapter will focus on the protectant properties of TiO₂ and ZnO.

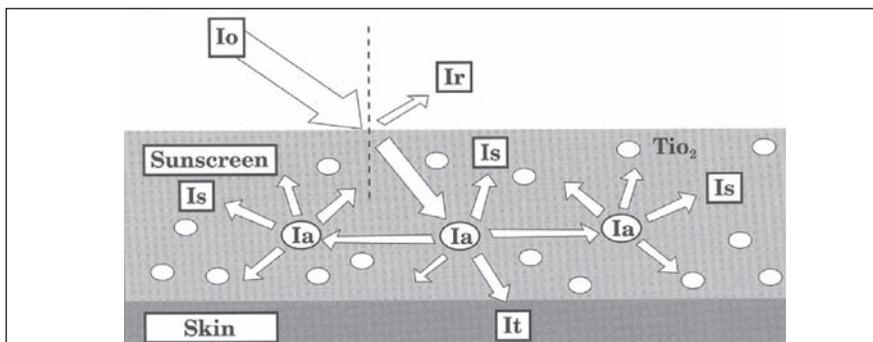


Figure 20.1. Attenuation of UV radiation by titanium dioxide¹

TiO_2 and ZnO

Titanium is one of the 10 most abundant elements on earth. It can be found as mineral rutile (93–97% titanium dioxide) or in conjunction with iron oxides in the ores such as ilmenite (45–75% titanium dioxide).² It makes up 0.6% of the earth's crust and can be found either in its pure state or combined with ferrous oxide.

Zinc is also found in large quantities on earth, although it is less abundant than titanium. Its principal ores are blend (sulfide), smithsonite (carbonate), calamine (silicate) and franklinite (zinc, manganese and iron oxide).³ It can be found as zinc salt (carbonate, silica) or combined with other metals such as manganese or ferrous oxide.

The industrial sector consumes 3 million metric tons of TiO_2 annually. TiO_2 is used for its pigment properties and its whitening capacity (opacity in the visible light range). These properties present a real interest in application and are used in the pharmaceutical industry⁴ as well as in the food, cosmetic and paint industries.

ZnO is used in the same industrial fields as TiO_2 and is conventionally used as a topical antiseptic in the pharmaceutical industry.¹

As pigments, TiO_2 and ZnO are opaque to UVB and UVA radiation. Their use has nevertheless been limited in sun care products for cosmetic reasons: they make the skin look excessively white. In order for TiO_2 and ZnO to be used as photoprotectors in cosmetic products, they must be opaque to UVB radiation and UVA radiation, but they must also be as transparent as possible to visible light so they

limit the appearance of whitening. Extra-fine mineral pigments with UV attenuation qualities (Figures 20.2 and 20.3) have been developed for this purpose.

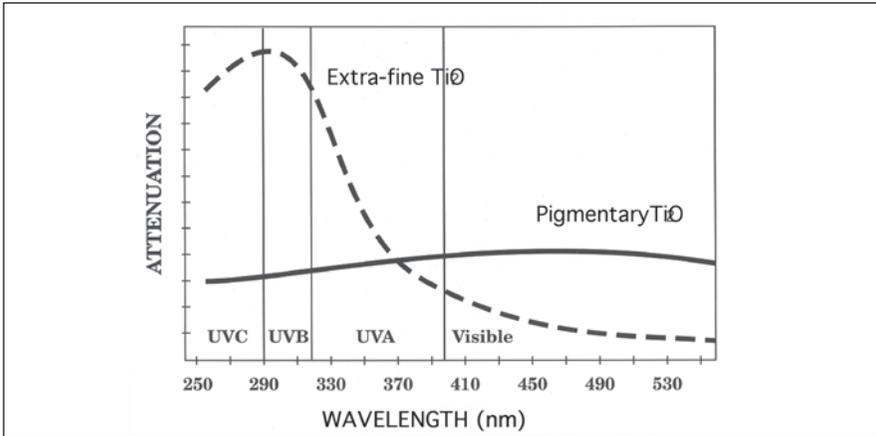


Figure 20.2. Attenuation of UV radiation and visible light by pigmentary and extra-fine titanium dioxide⁵

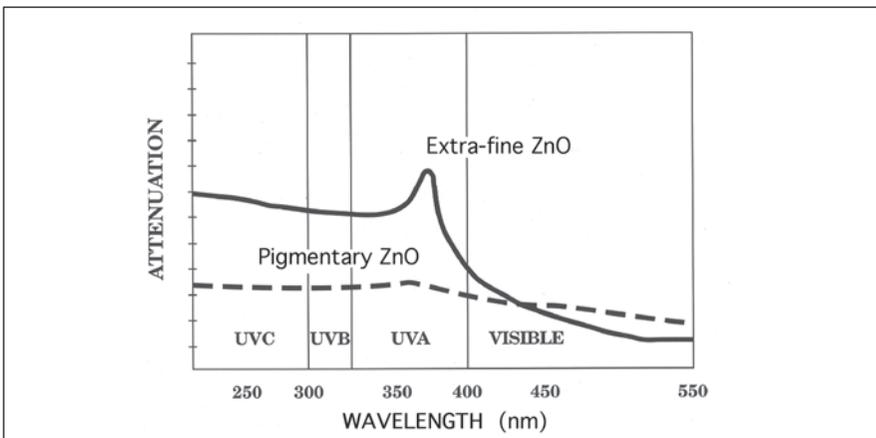


Figure 20.3. Attenuation of UV radiation and visible light by pigmentary and extra-fine zinc oxide⁵

Extra-fine TiO_2 may be obtained from hydrated titanium oxide by various methods. After a crystallization and washing phase, calcination and grinding (micronization) are performed, thus producing a micronized TiO_2 whose surface may eventually be treated.⁶ The UV radiation attenuation qualities of mineral pigments depend on

certain parameters that will directly impact their optical properties and thus affect their photoprotecting efficacy. Among these parameters are:

- The crystalline size and form;
- The refractive index;
- Coating and dispersion.

Crystalline Size and Form

For a mineral pigment, the crystal's size is a fundamental element in determining filtration efficacy. The crystalline size of pigmentary TiO_2 is greater than 250 nm. The particle size of extra-fine TiO_2 ranges from 15 to 60 nm. This nanometric size allows maximum absorption spectrum in the region of short UVA and UVB rays (Figure 20.4). The efficacy of UV attenuation in proportion to the crystal's size may be determined by spectroscopy. With this tool, the crystalline size best adapted to each need may be chosen.

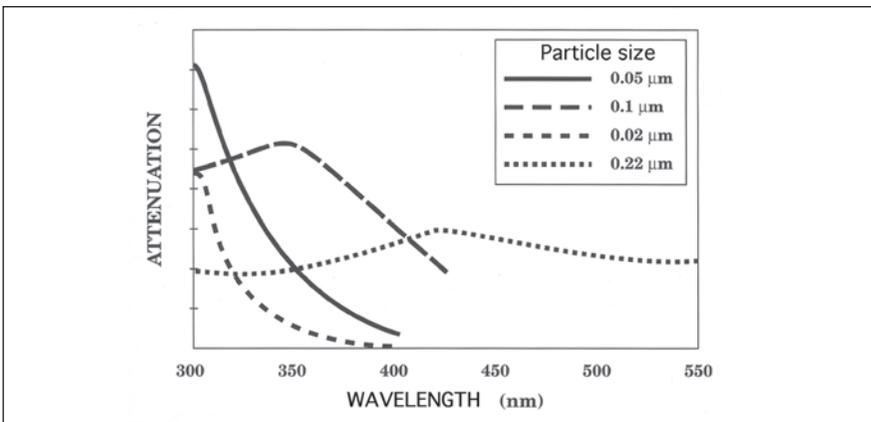


Figure 20.4. Attenuation of UV radiation according to the crystalline size of titanium dioxide⁵

A smaller crystalline size means shorter attenuated wavelength (toward UVB) and greater transmittance of visible light (transparency). The larger the crystalline size is, the nearer the attenuated wavelength is to that of visible light, and the greater is the opacity and the appearance of whiteness on the skin.

Titanium has various crystalline forms: brookite (very rare), anatase and rutile. Anatase and rutile crystals are used the most in photoprotection and have a tetragonal structure. The rutile form is the most abundant form and is very stable. Its refractive index and specific density are higher than those of anatase.

The industry has developed procedures similar to those used with TiO_2 to obtain extra-fine ZnO and optimize its filtration efficacy. Micronized ZnO has particle sizes that range from 40 to 100 nm. The highest efficacy of ZnO against UVA radiation is situated within this range (**Figure 20.5**). ZnO essentially attenuates short and long UVA radiation and complements TiO_2 attenuation, thus generating products with broad-spectrum protection.

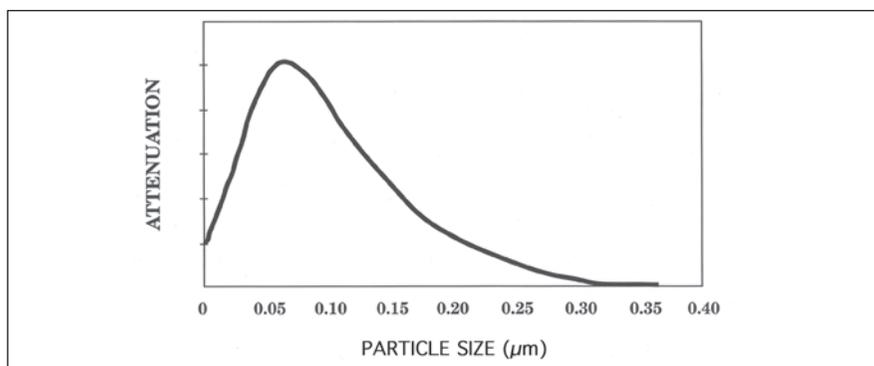


Figure 20.5. Attenuation of UVA radiation at 360 nm according to the particle size of zinc oxide⁵

Refractive Index

TiO_2 and ZnO have a refractive index of 2.7 and 2.01, respectively. A higher refractive index means a higher reflection of visible light. This explains why TiO_2 , though its particle size is identical to that of ZnO, is more opaque (whitening) and photoprotective.

Coating and Dispersion

The quality of pigment dispersion within the sun care products affects not only their cosmetic properties, but also their efficacy and performance as sun protectants (**Figure 20.6**). Proper pigment dispersion makes it easier to obtain the desired sun protection factor and does not whiten the skin as much.

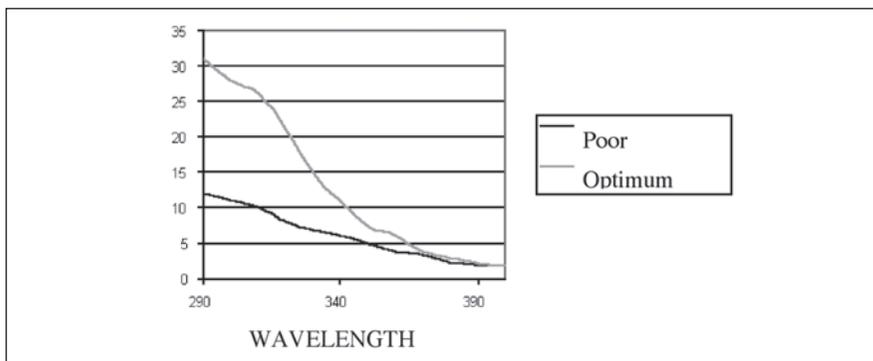


Figure 20.6. Attenuation of UV radiation depending on the quality of TiO_2 dispersion⁷

The aim of proper TiO_2 and/or ZnO dispersion is to reach stable particle distribution over time and avoid particle re-agglomeration, which is mainly due to absorption phenomena and electric charges at the pigment's surface (zeta potential), which tend to attract pigments to each other and, consequently, form aggregates.

In order to avoid aggregation phenomena, the pigment's surface is coated. The primary particles of TiO_2 and ZnO are treated with organic and inorganic materials such as silicone, alumina, silica and stearic acid derivatives.

Surface treatments cancel surface charges and optimize pigment dispersion. It is then possible to choose the coating best adapted to the desired formula, thus offering the formulator a wider range of excipients. The excellent quality of mineral pigment coatings should guarantee the perfect photostability of the formulated products (**Figure 20.7**).

Toxicological Aspects

The excellent toxicological profile of TiO_2 and ZnO is due to their insignificant—considered by some to be nonexistent—transcutaneous passage.¹⁰ Mineral pigments that do not dissolve in aqueous and organic solvents do not qualify for transcutaneous passage. In vivo studies on penetration have indeed shown that TiO_2 penetration is not detected in living skin tissues.¹¹

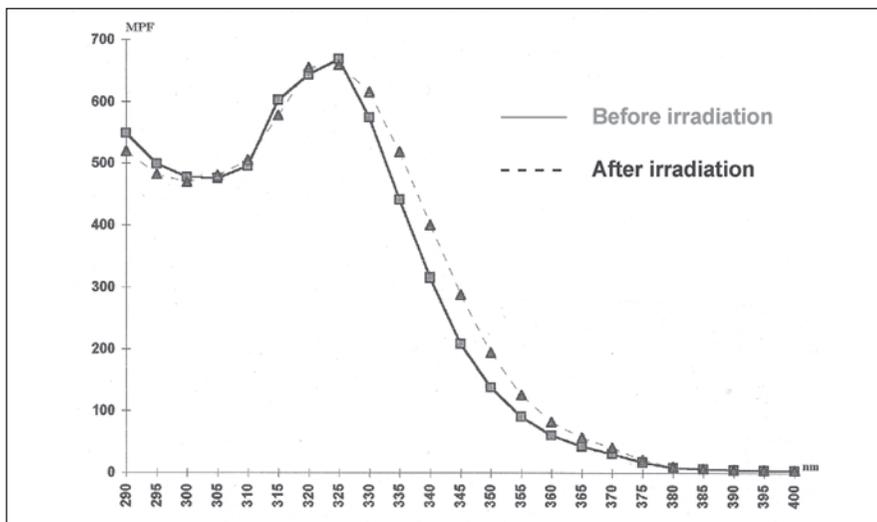


Figure 20.7. Absorption spectrum of a formula containing TiO_2 and ZnO before and after irradiation, 5 DEM (DEM=Minimal Erythral Dose related to photostability)⁸

Moreover, *ex vivo* studies with Franz cells have shown that TiO_2 is found in the upper layers of the stratum corneum.^{9,12} Its localization was demonstrated by assaying TiO_2 in the stratum corneum using a stripping method associated with spectrophotometry. Its localization was also demonstrated by observations with a transmission electron microscope (**Figure 20.8**).

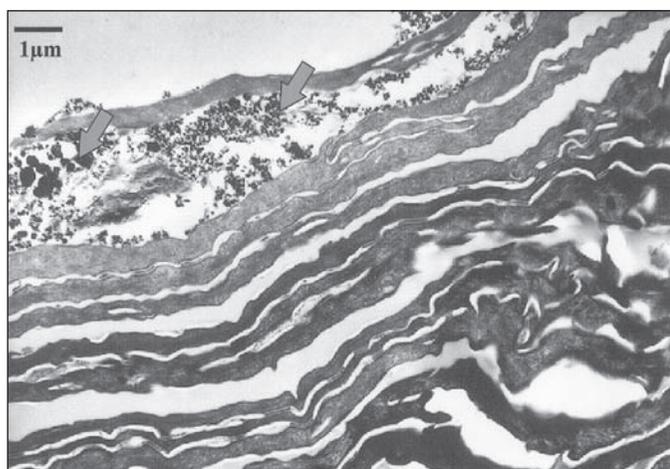


Figure 20.8. TEM image of TiO_2 localization in the upper layers of the stratum corneum⁹

Broad-Spectrum Protection from an Organic Pigment

Among the organic pigments is a new micronized organic pigment belonging to the benzotriazol family. This pigment is of great interest to photoprotection because it covers the whole UV spectrum (see **Broad-Spectrum Protection form an Organic Pigement sidebar**).

Methylene bis-benzotriazolyl tetramethylbutyl-phenol is the INCI name of this new organic UV filter that acts by absorbing radiation as soluble organic filters do, and by diffusing radiation as mineral pigments do. Like mineral pigments, it has high photostability. It also has some of the mineral pigment properties, such as its particle size (approximately 200 nm), and it offers maximum filtration efficacy (**Figure 20.9**).

Methylene bis-benzotriazolyl tetramethylbutyl-phenol disperses within the sun care product, and its toxicological profile is excellent.

This new pigment from the benzotriazol family opens the way for a new generation of photoprotective agents.

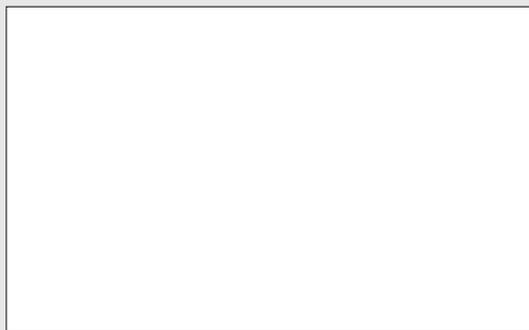
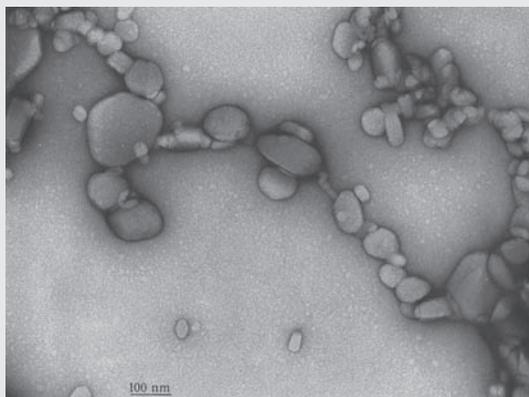


Figure 20.9. TEM image (top) and absorption spectrum (bottom) of methylene bis-benzotriazolyl tetramethylbutylphenol

Studies on skin localization and eye tolerance after repeated applications (45 days) and on oral or parenteral toxicity did not show any anomaly.¹³

Lastly, epidemiological studies on workers in the titanium industry showed the safety of this substance with regard to respiratory diseases or skin intolerance.¹⁴

One can conclude that mineral pigments (TiO₂ and ZnO) are the most appropriate means of photoprotection for children and persons with sensitive skin. They are also reported to be the most effective means of reducing photosensitization risks.^{15,16}

The qualities described in the chapter lead to the conclusion that TiO₂ and ZnO are seemingly the best way to obtain a safe and broad spectrum UV protective product.

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Improved Delivery and Efficacy with Dimethyl Isosorbide

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KEY WORDS: *dihydroxyacetone, dimethyl isosorbide, self-tanning, skin delivery, spreading, color intensity, color uniformity*

ABSTRACT: *The solvent dimethyl isosorbide improves the delivery of hydrophilic actives, enabling it to enhance the color intensity and color uniformity of self-tanning formulations in tests reported here.*

Improved spreading and enhanced delivery of actives into the deeper layers of the epidermis and the dermis are useful properties in applications such as anti-acne, skin whitening and scalp treatment. One way to achieve these improvements is with a skin adjuvant such as dimethyl isosorbide, as this chapter demonstrates in the case of hydrophilic actives delivered from formulations for self-tanning.

Dimethyl Isosorbide

Many cosmetic formulations and over-the-counter products contain ingredients that need to be delivered into the skin to produce their unique and/or therapeutic effects. These active ingredients are

either oil- or water-soluble or dispersible and can be delivered out of a variety of systems such as emulsions, gels or ointments. The target site for delivery is very often the epidermis and/or around the hair follicle.

Sufficiently high concentrations can be difficult to achieve due to the skin's natural barrier function, the stratum corneum. When the active ingredient to be delivered is water-soluble, such as hyaluronic acid or dihydroxyacetone, delivery becomes an even greater challenge due to the hydrophobic nature of the stratum corneum on the one hand and the rapid evaporation of the carrier (water) upon application of the product to the skin on the other hand. The latter results in precipitation of the ingredient, rendering it unavailable for skin penetration.

The use of skin adjuvants can greatly improve the skin delivery and consequently the efficacy of such active ingredients for reasons to be discussed later. One skin adjuvant of particular interest is dimethyl isosorbide^a (DMI), which has been used for many years in both the pharmaceutical and the cosmetic industries for its unique solvent and delivery properties

DMI is particularly effective for the delivery of water-soluble ingredients thanks to its high evaporation point, its complete miscibility with water, its miscibility with many cosmetic oils and its solvent properties for a wide variety of ingredients. Some recent unpublished in vitro skin delivery studies have shown that DMI greatly improves the delivery of water-soluble ingredients to the epidermis. These data also suggest that DMI has the unique advantage of not promoting delivery of the active ingredient beyond the epidermis.

DMI has the additional benefit of improving the spreading of viscous materials, which allows for a more even distribution of the active on the skin. In self-tanning applications, for instance, this results in a more uniform color development.

DMI is an ether with the empirical formula $C_8H_{14}O_4$ (see **Figure 21.1** for its chemical formula). It is a water-white liquid that feels dry

^a Arlasolve DMI (INCI: Dimethyl Isosorbide) is the trade name under which dimethyl isosorbide is available from Uniqema.

to the touch, with an odor and taste similar to isopropanol. Its melting point is below -50°C , its boiling point approximately 234°C (760 torr) and its flash point is 120°C . It is miscible with water (in all proportions), most organic solvents and nonionic surfactants and is pH stable. This mild, innocuous solvent is extraordinary in its ability to improve the delivery of water-soluble materials such as active ingredients to the upper layers of the epidermis.

It has therefore been used in products such as anti-acne preparations, toothpastes, transdermal pharmaceuticals, antiperspirants, scalp treatments, vitamin eye creams and anti-aging formulations where the delivery of the active ingredient can be the limiting factor in achieving excellent performance. An additional interesting use for DMI in cosmetic formulations is as a color-uniformity enhancer in self-tanning products.

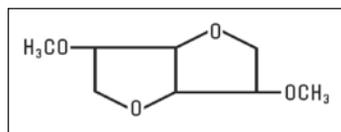


Figure 21.1. Chemical formula of dimethyl isosorbide

Effect of DMI on the Delivery of Hydrophilic Actives

The effect of DMI on the skin delivery of actives was assessed using a Franz glass diffusion cell system, an *in vitro* skin delivery measurement method used to assess the percutaneous absorption of industrial chemicals, drugs and cosmetic ingredients.

We used two oil-in-water test formulations (**Formula 21.1a** and **21.1b**) based on a classic nonionic emulsifier combination of steareth-2^a and steareth-21^b. The active ingredient was propagermanium^c, a slightly water-soluble immuno-stimulant ingredient used in cosmetic formulations for its free radical scavenging, skin whitening and photo-damage protection properties. The two test formulations were identical except for the addition of 10% DMI to **Formula 21.1b**.

^a Brij72, Uniqema

^b Brij721, Uniqema

^c Arlamol GEO, Uniqema

Formula 21.1. O/W test emulsion with and without dimethyl isosorbide

	1a	1b
Propylene glycol isostearate (Prisorine 2034, Uniqema)	15.0 %w/w	15.0 %w/w
Triethylhexanoin (Estol 3609, Uniqema)	3.0	3.0
Steareth-21 (Brij721, Uniqema)	5.0	5.0
Steareth-2 (Brij72, Uniqema)	1.0	1.0
Propagermanium (Arlamol GEO, Uniqema)	0.5	0.5
Dimethyl isosorbide (Arlasolve DMI, Uniqema)	-	10.0
Glycerin (Pricerine 9091, Uniqema)	4.0	4.0
Xanthan gum (Keltrol, Kelco)	0.4	0.4
Phenoxyethanol (and) methylparaben (and) propylparaben (and) 2-bromo-2-nitropropane-1,3-diol (Nipaguard BPX, Nipa)	0.7	0.7
Water (<i>aqua</i>)	qs	qs

The formulations were applied on 2.5 cm² disks of pig skin, which were clamped into the diffusion cell. The formulations were applied to the epidermal side of the skin while the dermal side was in contact with a receptor fluid (DMPBS pH 7.4) that was stirred continuously underneath the skin for a period of 20 hours.

After the excess formulation was wiped off the skin, the epidermal side of the skin was tape-stripped five times and the strips analyzed for propagermanium. The remainder of the skin and the receptor fluid were also analyzed for propagermanium. This analysis was done by means of Inductively-Coupled-Plasma Mass Spectroscopy (ICP-MS). These analyses reflect the amounts of propagermanium that penetrated into the superficial layers of the skin (tapes), the deeper layers of the stratum corneum, viable epidermis and dermis (skin fraction) and the bloodstream (receptor fluid).

Figure 21.2 illustrates that the addition of 10% DMI to a formulation resulted in a two-fold increase of the amount of propagermanium delivered to the skin fraction, whereas the amount of active delivered transdermally (receptor fluid) was not increased.

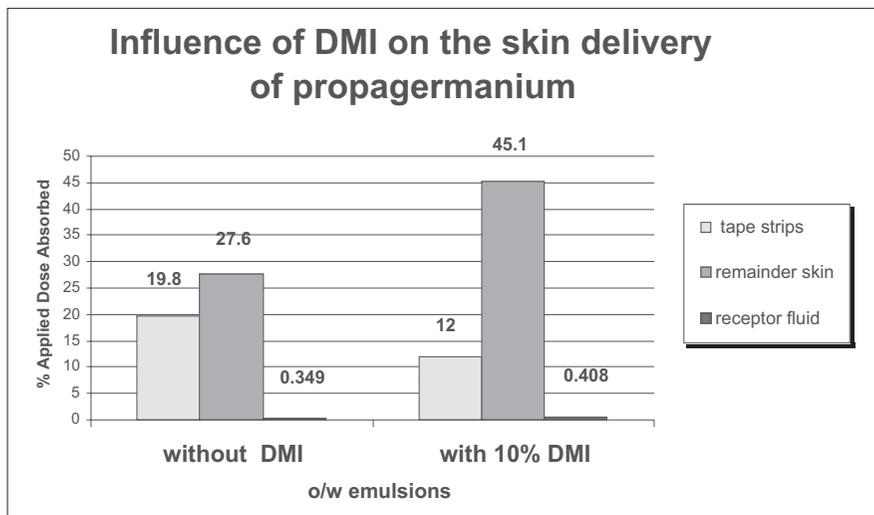


Figure 21.2. Topical delivery efficacy of propagermanium, a hydrophilic active, from two similar o/w formulations

The effect of DMI can be explained from its penetration into the stratum corneum where it increases the solubility of the active ingredient, which favorably influences the partition coefficient and hence its skin delivery.¹ Because the lipophilic stratum corneum has effectively become more polar, this enhanced delivery will be much more apparent for hydrophilic active ingredients (such as benzoyl peroxide and dihydroxyacetone) than lipophilic ingredients.

Effect of DMI Added to Self-Tanning Formulations

Most self-tanning formulations are based on dihydroxyacetone (DHA), which reacts with the amino acids and amino groups of the skin keratin (skin protein) to form brown-colored compounds. This process takes place in the outer layers of the epidermis. The brown coloration appears after a reaction time of about two hours and cannot be washed off but fades as the upper layers of the epidermis are shed.

The addition of DMI to self-tanning creams has been shown to increase skin color intensity and uniformity.² This increase in skin color intensity and uniformity is due to DMI's effect on DHA solubility in the stratum corneum (DHA is already fully soluble in water)

and consequent skin delivery enhancement discussed above. The improved color uniformity results in part from the effect of DMI on the spreading properties of especially viscous materials.

Figure 21.3 illustrates the ability of the water and oil-soluble DMI to greatly reduce the contact angle of some cosmetic oils, in particular that of dilinoleic acid^a. This reduction in contact angle shows that the spreading of this very viscous cosmetic oil is increased. For less viscous and more polar oils like glyceryl isostearate^b and propylene glycol isostearate^c, this reduction in contact angle is smaller in absolute terms but still substantial, yielding even lower values than that of dilinoleic acid.

These enhancing properties of DMI on skin color intensity and uniformity of self-tanning products were investigated in a clinical study using two DHA-based self-tanning formulations. Thirty-six female subjects participated in the study. The intensity, uniformity and longevity of skin color development (sunless tanning) resulting from the topical application of the test formulations was monitored. In the clinic, visual scoring scales were used to evaluate the intensity and uniformity of color development relative to untreated skin. The intensity of color development was also evaluated by chromametric measurements in a bioengineering technique.

The test formulations were applied in accordance with a randomization schedule on the leg of the subjects after equilibration for 30 minutes under ambient conditions. Subjects underwent a series of visual and chromametric evaluations before application of the test formulations and at 1, 3 and 8–10 hours post-application on day 1, followed by evaluations on days 2 (24 hours), 3 (48 hours), 5 (96 hours), 7 (144 hours) and 10 (216 hours) post-application.

Application involved the delivery of 50 μL of the cream to the center of the test site via a micro-dispenser. Spray formulations were confined to the test site through the use of a silicone rubber well. Test materials were distributed across the entire test site using a finger cot. After application, the subjects waited 1 hour to allow the test material to dry.

^a Pripol 1009 (INCI: Dilinoleic Acid), Uniqema

^b Prisorine 2040 (INCI: Glyceryl Isostearate), Uniqema

^c Prisorine 2034 (INCI: Propylene Glycol Isostearate), ma

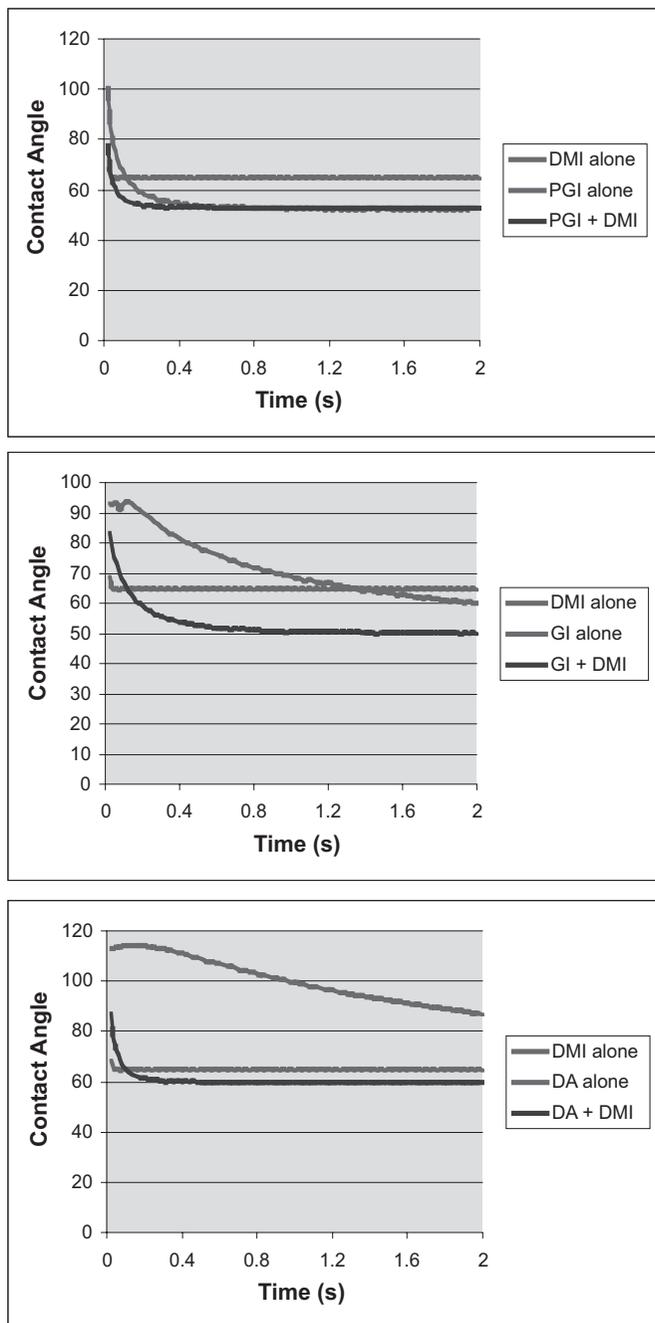


Figure 21.3. Effect of DMI on the spreading behavior of three cosmetic oils

PGI = propylene glycol isostearate

GI = glyceryl isostearate

DA = dilinoleic acid

In each case, the oil and DMI are in a 2:1 mixture by weight.

Clinical and chromametric evaluations both revealed that the addition of DMI to the cream base formulation containing DHA significantly altered the color development profile of the base formulation (see **Figure 21.4**). The cream with DMI also exhibited a significantly more uniform color than its counterpart without DMI within the plateau region of the color development profiles (see **Figure 21.5**). Finally it was noted that the inclusion of DMI appeared to have slowed the onset in the decline in color intensity (see **Figure 21.4**). As pointed out above, this improved color uniformity is likely to be caused by the improved spreading properties of the DMI-containing formulation, whereas the enhanced color intensity is likely due to the enhanced skin delivery of DHA as a result of the inclusion of DMI.

In another clinical study, the color intensity development obtained from two different formulation types (cream **Formula 21.2** and foam **Formula 21.3**) was captured with a digital camera. The cream was applied (0.3 g per 25 cm²) to the upper portion of the leg (above the knee cap). As in the first clinical trial, pictures were taken 24 hours after application. As illustrated in **Figure 21.6**, which is a side-by-side comparison of the DHA-containing cream formulation with and without 5% DMI, the addition of DMI to the formulation increases the color intensity and uniformity of the tan.

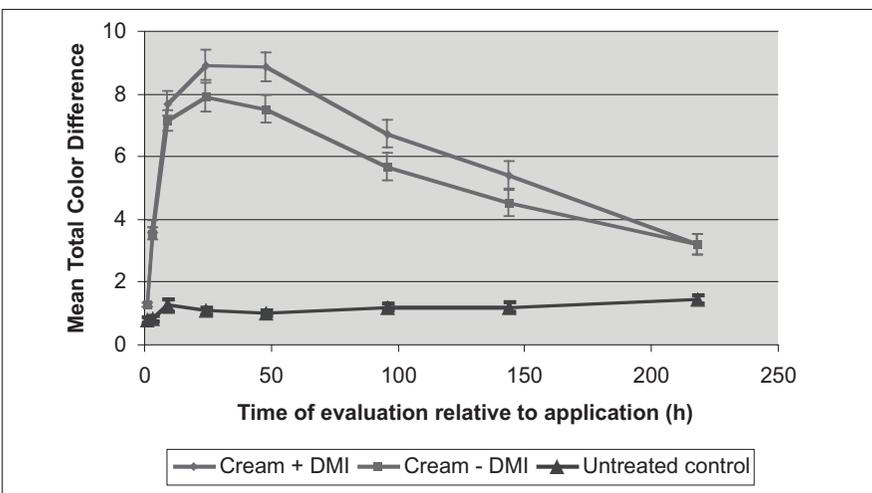


Figure 21.4. Mean total color differences (n=36) from skin color of skin treated once with a DHA-containing self-tanning cream with and without DMI

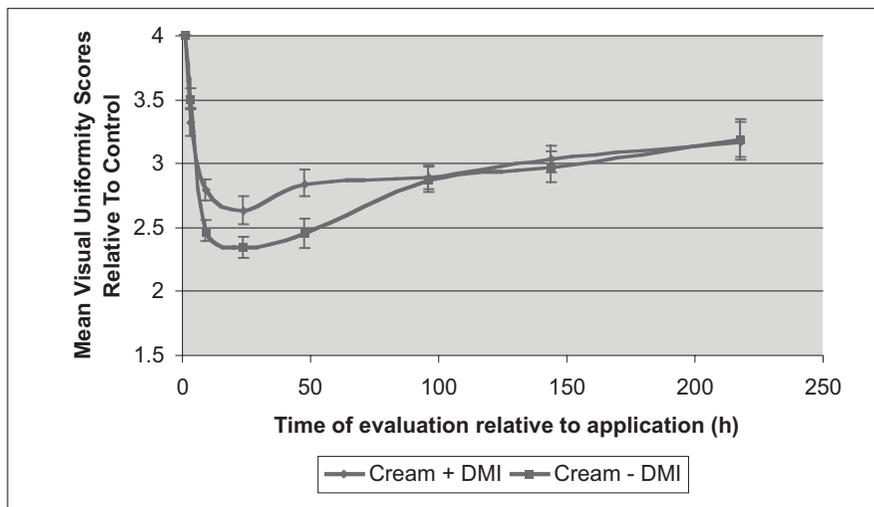


Figure 21.5. Mean color uniformity scores (n=36) on skin sites treated once with a DHA-containing self-tanning cream with and without DMI. (A score of 4 indicates uniformly colored skin. Lower scores indicate less uniformity.)

Formula 21.2. Cream used for photographic evaluation of skin color intensity and uniformity

	2a	2b
A. Water (<i>aqua</i>)	qs	qs
Glycerin (Pricerine 9088, Uniqema)	3.0% w/w	3.0% w/w
B. Glyceryl stearate (and) PEG-100 stearate (Arlacel 165 Veg, Uniqema)	4.0	4.0
Caprylic/Capric triglyceride (Estol 3603, Uniqema)	7.0	7.0
Dimethicone (Dow Corning 200, 350cs, Dow Corning)	3.0	3.0
Cetearyl alcohol (Lanette Wax O, Care Chemicals)	5.0	5.0
C. Dihydroxyacetone (Dihydroxyacetone, Rona)	4.0	4.0
Dimethyl isosorbide (Arlasolve DMI, Uniqema)	----	5.0
Phenoxyethanol (and) methylparaben (and) propylparaben (and) 2-bromo-2-nitropropane-1,3-diol (Nipaguard BPX, Nipa)	0.7	0.7
D. Citric acid	to pH 5	to pH 5

Formula 21.3. Foam used for photographic evaluation of skin color intensity and uniformity

	3a	3b
Water (<i>aqua</i>)	83.5% w/w	86.5% w/w
Dihydroxyacetone (Dihydroxyacetone, Rona)	4.0	4.0
Propylene glycol	2.0	2.0
Glycerin (Pricerine 9088, Uniqema)	2.0	2.0
Sorbeth-30 (Atlas G-2330, Uniqema)	2.0	2.0
PPG-2 hydroxyethyl cocamide (Promidium CO, Uniqema)	2.0	2.0
C9-C15 alkyl phosphate (Arlatone MAP 95, Uniqema)	1.0	1.0
Dimethyl isosorbide (Arlasolve DMI, Uniqema)	3.0	----
Propylene glycol (and) diazolidinyl urea (and) methylparaben (and) propylparaben (Germaben II, Nipa)	0.5	0.5
	100.0	100.0

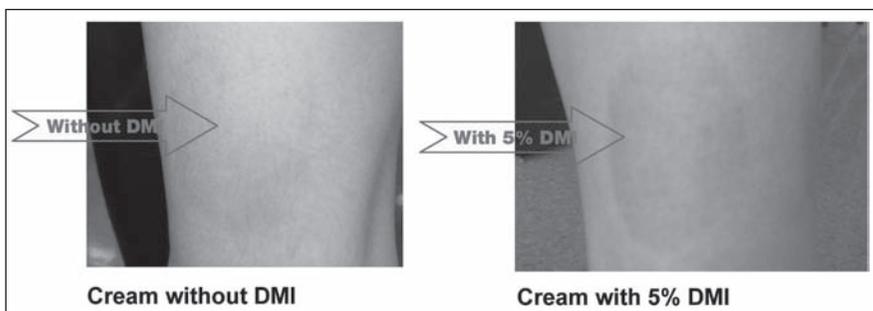


Figure 21.6. Enhanced color intensity development and skin color uniformity due to the inclusion of DMI in a DHA-containing cream formulation

The foam was applied on the inside of the arm (below the elbow) using the same dose (0.3 g per 25 cm²). Again, pictures were taken 24 hours after application. As shown in **Figure 21.7**, which is a side-by-side comparison of the DHA-containing foam formulation with and without 3% DMI, the addition of DMI to the formulation yielded a more intense and more uniform skin color development.

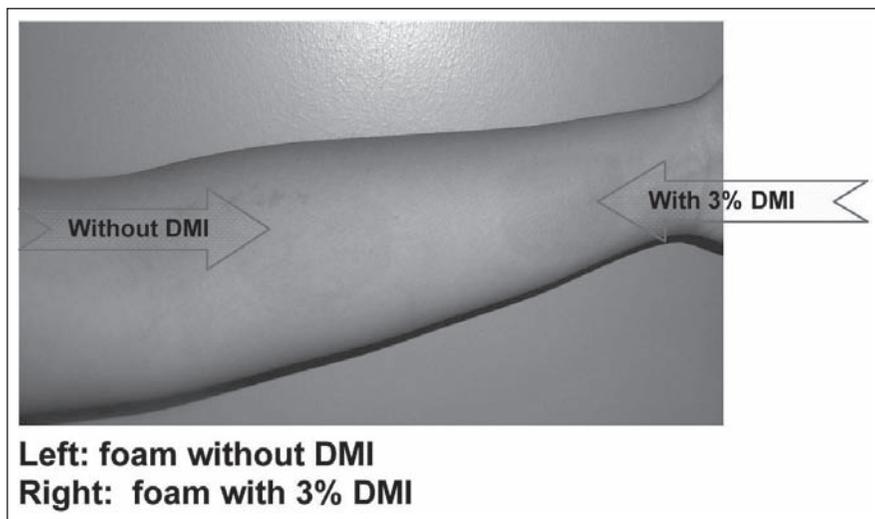


Figure 21.7. Enhanced skin color intensity and skin color uniformity due to the inclusion of 3% DMI in a DHA-containing foam formulation

The results from these three different sets of formulations, all with and without DMI, clearly illustrate that including DMI in self-tanning formulations has two benefits:

- Enhanced color intensity due to enhanced skin delivery of DHA as a consequence of improved solubility of DHA in the stratum corneum, and
- Improved color uniformity due to improved spreading of the formulation during application as a consequence of a reduction of the contact angle of the formulation with the stratum corneum.

Conclusions

Dimethyl isosorbide (DMI) is a unique cosmetic adjuvant with a non-toxic safety profile that extends its use into pharmaceutical formulations.

It is a good solvent for a variety of pharmaceutically and cosmetically active ingredients and is miscible with both water and organic esters. It has been proven to enhance the skin delivery—and consequently the skin efficacy—of water-soluble active ingredients in the epidermis. DMI also improves the spreading of oils in formulations.

DMI penetrates the stratum corneum and in doing so, increases the polarity of this skin layer. This change in polarity improves the partitioning of hydrophilic ingredients into the stratum corneum, resulting in an improved delivery of those ingredients and consequently greater activity.²

We demonstrated the usefulness of this approach in self-tanning applications where the change in polarity of the stratum corneum resulted in better solubilization of DHA. The better-solubilized DHA can also better diffuse within the stratum corneum and react more effectively with local amino acids. This enhanced efficacy results in deeper color development and color uniformity.

The improved spreading and enhanced delivery of actives into the deeper layers of the epidermis and the dermis are properties useful in applications such as anti-acne, skin whitening, scalp-treatment and self-tanning. Improving the delivery improves the clinical efficacy, which in turn presents the possibility of reducing the amount of active ingredient needed to achieve a desired effect. For some actives, reducing the level is not only an economical benefit, but also a safety benefit because it can result in improved mildness of the formulation.

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Film-Formers Enhance Water Resistance and SPF in Sun Care Products

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KEY WORDS: *SPF, sunscreen, water resistance, film formers, polyethylene*

ABSTRACT: *At low formulating levels, film-forming polymers can increase water resistance and enhance SPF in sun care formulations, while also imparting improved aesthetics. In the case of C30-38 olefin/isopropyl maleate/MA copolymer, a synergistic SPF effect can be achieved with PVP/eicosene copolymer.*

With ever higher levels of awareness, consumers are putting greater demand on sun care products. Performance is a key issue: products are expected to remain on skin for an extended time without the need for reapplication, even in the presence of water. Good aesthetics also are a must: consumers want lotions and creams that leave the skin feeling soft and moisturized, without the greasy, oily feel traditionally associated with sun care products.

By capitalizing on new technologies for improved aesthetics, greater resistance to wash-off and enhanced SPF, formulators can create innovative sun care products to meet specialized global requirements and the needs of individual skin types.

Polymers That Enhance Water Resistance and SPF

Among materials that impart water resistance, C30-38 olefin/isopropyl maleate/MA copolymer^a is a low molecular weight, hydrophobic material that ensures a light feel. The MA in this INCI name refers to maleic anhydride. For convenience, we will refer to this polymer as the olefin/MA copolymer.

The maleic functionality of the olefin/MA copolymer makes it easy to disperse and helps it adhere to the skin. It does need to be neutralized for oil-in-water dispersions, but when neutralized, it disperses readily into water and also acts as an anionic emulsifier. The olefin/MA copolymer forms a water-resistant film that also enhances SPF. Because of the copolymer's highly efficient film-forming properties, it may be possible to use lower levels of potentially irritating active ingredients in formulation.

Polyethylene^b and C20-40 alcohols^c also have hydrophobic properties that make them useful ingredients for offering water resistance to formulations. As with the olefin/MA copolymer, the low molecular weight of these ingredients imparts a light feel on the skin. The linear polymer backbone of the polyethylene provides a foundation for thickening and structuring the oil phase of formulations, while giving a matte appearance and a dry, non-oily feel. In the case of long-chain linear alcohols, the alcohol functionality offers compatibility with silicones, while helping to stabilize these ingredients in sun care formulations.

The film-forming properties of the polyethylene and alcohols improve the water resistance of formulations and minimize the levels of active ingredients. Their superior ability to thicken oils makes these ingredients especially useful for enhancing SPF.

^a PERFORMA V 1608 Polymer is a product of New Phase Technologies, Sugar Land, TX USA. PERFORMA V is a registered trademark of Baker Hughes Incorporated.

^b PERFORMALENE 400 Polyethylene is a product of New Phase Technologies. PERFORMALENE is a registered trademark of Baker Hughes Incorporated.

^c PERFORMACOL 350 Alcohol is a product of New Phase Technologies. PERFORMACOL is a registered trademark of Baker Hughes Incorporated.

In Vitro Tests Assess SPF

The studies described in this chapter involved in vitro evaluations of water resistance for several materials. They were developed based on several protocols.^{1,2} Water resistance was measured on the polymers at a use level of 2% by weight in an “easy-to-remove” prototype formula (**Formula 22.1**) that incorporates high levels of very hydrophilic surfactants.

Formula 22.1. Sunscreen test formula

A. Glyceryl stearate (and) PEG-100 stearate	4.00% w/w
Polysorbate-20	2.00
Octyl methoxycinnamate	7.50
Benzophenone 3	4.00
Octyl salicylate	5.00
Cetearyl alcohol	0.75
C12-15 alkyl benzoate	5.00
Polymer chosen for evaluation	2.00
B. Water (aqua)	52.15
Disodium EDTA	0.10
Carbomer, 2%	12.00
Butylene glycol	4.00
C. Triethanolamine, 99%	0.50
D. Propylene glycol (and) diazolidinyl urea (and) methylparaben (and) propylparaben	<u>1.00</u> 100.00

For the control condition, water was substituted for the polymer. Sunscreens were coated onto a clear substrate and analyzed with an SPF analyzer^a. This instrument measures the amount of ultraviolet light coming through the sample compared to an uncoated substrate, then calculates the SPF value. Samples were then placed in a heated water bath with agitation. After immersion, a final SPF value was measured. Specific test conditions were as indicated in **Table 22.1**.

^a The SPF-290S Analyzer System is a product of Optometrics LLC, Ayer, MA USA.

Table 22.1. In vitro SPF test conditions

Test parameter	Test condition or value
Substrate	Vitro-Skin Substrate ^e hydrated overnight in hydration chamber
Hydration chamber	Desiccator with 256 g water and 44 g glycerin in bottom of chamber
Amount of sunscreen on substrate	2 microliters/cm ²
Dry-down time	15 min
Measurements per sample	6 (at different positions on same piece of substrate)
Immersion time	80 min
Water bath temperature	37°C
Agitation rate	190 rpm
Delay time*	1 hr

* Interval between time of removal from bath to time of SPF measurement
^e Vitro-Skin Substrate is a product of Innovative Measurement Solutions (IMS) Inc., Milford, CT USA.

In vitro SPF measurements collected by this method appear to be higher than those obtained with in vivo tests, possibly because in vitro analyzers overestimate SPF by missing side scatter of UV rays.³ However, the approach used in this study is a useful screening tool for making relative comparisons among materials. **Figure 22.1** summarizes in vitro data for the test sunscreen containing 2% of some commercially available water-resistant polymers, before and after immersion.

Initial SPF was boosted versus the base formula for all the test polymers, particularly the polyethylene. However, results for olefin/MA copolymer show significantly better water resistance than the other polymers or the commercial benchmark, PVP/eicosene copolymer^b. Not only is initial SPF enhanced with the olefin/MA copolymer, but it remains significantly higher after immersion compared to samples formulated with the other materials.

^b Ganex V-220 alkylated polyvinylpyrrolidone is a product of International Specialty Products, Wayne, NJ USA.

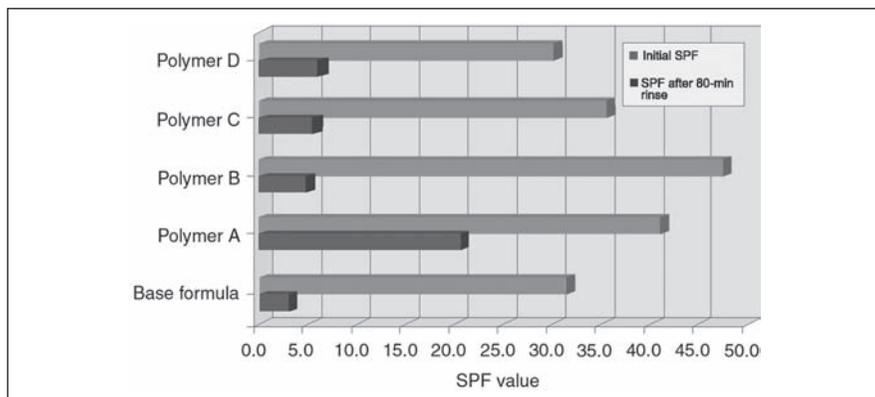


Figure 22.1. Comparison of water resistance and SPF; 2% polymer in test formula
 Polymer A = C30-38 olefin/isopropyl maleate/MA copolymer
 Polymer B = Polyethylene
 Polymer C = C20-40 alcohols
 Polymer D = PVP/eicosene copolymer

Although use levels of olefin/MA copolymer were 2% in the “easy to remove” prototype test formulation, lower levels may be sufficient in more optimized formulations. **Figure 22.2** illustrates the water resistance that can be attained using 1% olefin/MA copolymer. Data in **Figure 22.2** are based on **Formula 22.2**, a broad-spectrum sunscreen. This evaluation was based on a lower substrate coating level (1 microliter/cm²) than previous study conditions, to obtain SPF values closer to in vivo results.

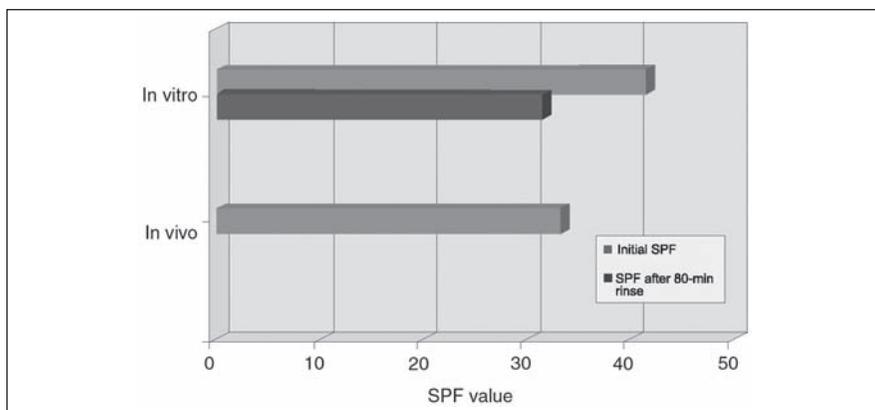


Figure 22.2. Water-resistant characteristics of prototype test formulation containing 1% C30-38 olefin/isopropyl maleate/MA copolymer

Formula 22.2. Water resistant sunscreen (SPF 32)

A. Ethylhexyl salicylate	5.00% w/w
C12-15 alkyl benzoate (Finsolv TN, Finetex)	4.50
Isopropyl myristate	4.00
Diethylhexyl 2,6-naphthalate (Corapan TQ, Symrise)	5.00
PPG-2 myristyl ether propionate (Crodamol PMP, Croda)	0.50
Benzophenone-3	4.00
B. Butyl methoxydibenzoylmethane	3.00
C. Stearyl alcohol	0.30
Polyglyceryl-3 methylglucose distearate (Tego Care 450, Degussa)	3.00
C30-80 olefin/isopropyl maleate/MA copolymer (PERFORMA V 1608, New Phase Technologies)	1.00
Disodium EDTA	0.05
D. Butylene glycol	2.00
Glycerin (Glycerin, Procter & Gamble)	4.00
Phenoxyethanol (and) methylparaben (and) propylparaben (and) butylparaben (Phenonip, Clariant)	0.70
E. Water (aqua)	qs
F. Carbomer (Carbopol Ultrez 10, Noveon)	0.20
G. Triethanolamine, 99%	0.15

Procedure: Combine A and heat to 80°C with stirring. Add B and stir to dissolve. Increase heat to 90°C. Add C to AB, stirring after each addition until homogeneous. Heat water (less than 50 g) to 85°C. Preblend D and add to E. Predisperse F in 50 g water and set aside. With homogenization, add ABC to DE. Add F to batch. Maintain heat and homogenize for 10 min. Remove from heat. Stir with propeller while cooling. When temperature is below 40°C, slowly add G. Continue stirring to smooth, homogeneous lotion.

The *in vivo* test was performed at a level of 2 mg/cm² according to the FDA Sunscreen Monograph.⁴ Note that an *in vivo* water resistance test was not conducted in this portion of the study.

The olefin/MA copolymer can be used in oil-in-water systems (which we discuss in this chapter) or water-in-oil systems. The polymer should be added to the oil phase of the formula, which must be heated to 85–90°C to melt the polymer. To ensure proper incorporation, the water phase should also be heated to 85–90°C. An appropriate amount of base, such as triethanolamine or sodium

hydroxide, must be added to oil-in-water formulations to neutralize the polymer.

The olefin/MA copolymer can be used alone or in combination with other polymers that impart water resistance. **Figure 22.3** shows the synergistic effect when olefin/MA copolymer and PVP/eicosene copolymer are used together in the test sunscreen formula (**Formula 22.1**). In this formula, 2% PVP/eicosene copolymer did not enhance SPF or provide good water resistance. The olefin/MA copolymer alone performed very well in SPF enhancement and water resistance. However, the combination of 1% of each copolymer outperformed 2% of either used alone. SPF was enhanced by more than 75% compared to the base formula. The combination also maintains a high SPF value even after an 80-minute warm water immersion. Doubling the level of each resulted in further improvement in both SPF enhancement and post-water immersion SPF value.

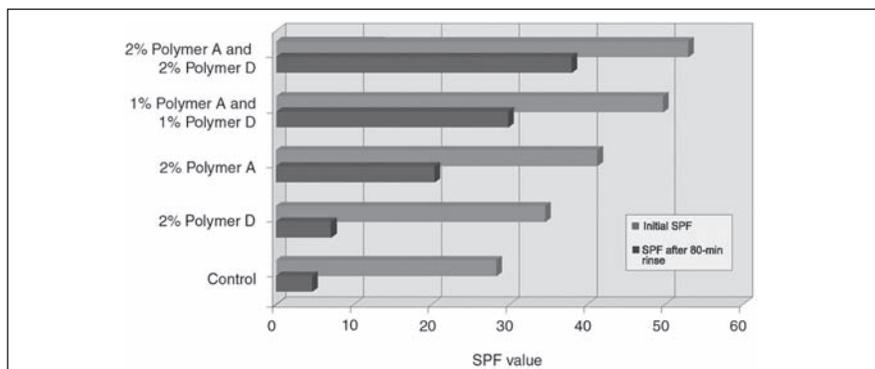


Figure 22.3. Synergistic water-resistance effect of C30-38 olefin/isopropyl maleate/MA copolymer (Polymer A) with PVP/eicosene copolymer (Polymer D)

The Link Between Viscosity and SPF

Polyethylene and C20-40 alcohols can significantly improve the SPF of sunscreen formulas. **Figure 22.4** shows that by adding 2.5% by weight—an amount selected so the oil phase will viscify, but not solidify as it does at around 3%—of these film-forming polymers, the SPF of a prototype base formula used in the test more than doubled. **Figure 22.4** also indicates the improvement in water resistance.

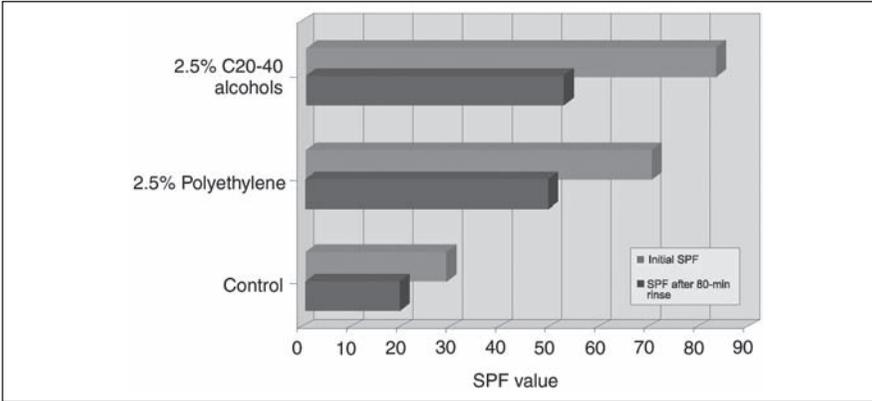


Figure 22.4. Water resistance of 2.5% polyethylene and 2.5% C20-40 alcohols

The property of enhanced SPF may be related to the viscosity-building properties of the material.⁵ When added to the oil phase, waxes or other viscosity-building materials can enhance SPF through their ability to act as good film formers and provide increased viscosity. Without their added benefit, the sunscreen formulation may flow downward into the wrinkles of the skin. The higher skin surface may be left without an adequate coating of sunscreen, and therefore more prone to damage from the sun. This proposed mechanism, illustrated in **Figure 22.5**, suggests why initial SPF may be higher with polyethylene and C20-40 alcohols, because they increase the viscosity of the oil phase.

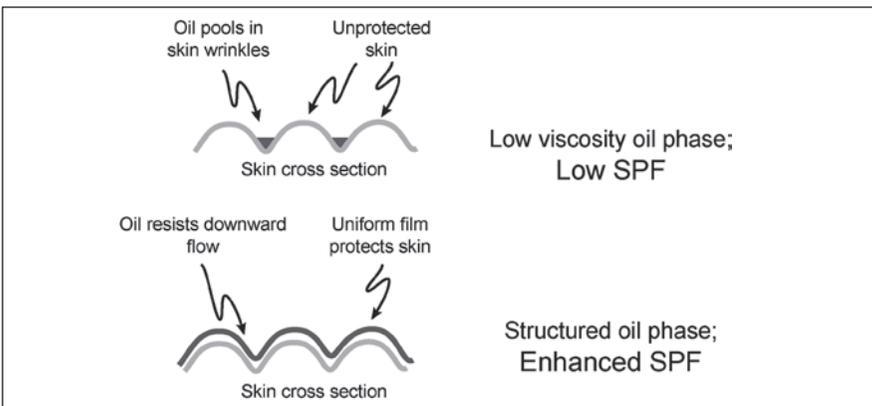


Figure 22.5. A structured oil phase of higher viscosity can optimize film formation to provide a uniform coating on the skin and enhanced SPF

Polyethylene and C20-40 alcohols can be used in oil-in-water or water-in-oil systems, and they should be added to the oil phase. Because these polymers are highly effective in building viscosity of the oil phase, use levels of 3% or less are recommended. The oil phase containing the polymers and the water phase should both be heated to 90–95°C to ensure complete incorporation.

If the resulting system appears grainy or if incompatibility is observed, addition of a small amount of C20-40 pareth-40^a is recommended. The optimal ratio, on a weight basis, is 1 part C20-40 pareth-40 to 10 parts polyethylene or C20-40 alcohols. A higher proportion of C20-40 pareth-40 negatively impacts water resistance.

Figure 22.6 compares SPF values and stability in a prototype sunscreen using concentrations of 0.25% and 1.0% C20-40 pareth-40 and the same formula without the polymer. Notice that in both cases, the control formulation was grainy (in the case of polyethylene) or separated (when formulated with C20-40 alcohols), while the addition of C20-40 pareth-40 produced stable formulations with varying SPF levels.

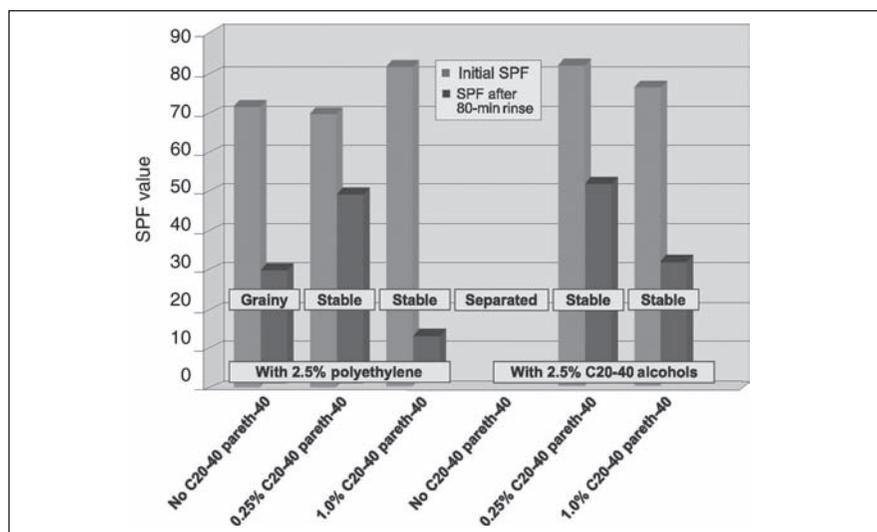


Figure 22.6. Optimal amount of C20-40 pareth-40 in sunscreen test formula with 2.5% polyethylene or 2.5% C20-40 alcohols

^a PERFORMATHOX 480 Ethoxylate is a product of New Phase Technologies. PERFORMATHOX is a registered trademark of Baker Hughes Incorporated.

As **Figure 22.6** indicates, just a small amount (0.25%) of C20-40 pareth-40 is effective in stabilizing the polyethylene and alcohols. Even though C20-40 pareth-40 is an emulsifier, which could be considered an ingredient that would encourage wash-off, at its optimum level in the formulation there is an increase in water resistance compared to a control formulation without this ingredient. By achieving a better emulsion at the optimal level, it is possible to get better SPF protection.

Formula 22.3 illustrates a nongreasy sport formula. Polyethylene provides water resistance, enhanced SPF and a dry feel. C20-40 pareth-40 acts as a secondary emulsifier to produce a smooth, creamy formula.

Formula 22.3. Water resistant sport lotion (SPF 30)

A. Polyethylene (PERFORMALENE 400 Polyethylene, New Phase Technologies)	2.50% w/w
C20-40 pareth-40 (PERFORMATHOX 480 Ethoxylate, New Phase Technologies)	0.25
Stearic acid	1.30
Cetearyl alcohol (Crodacol CS-50, Croda)	2.00
Diisodecyl adipate (DIDA, Trivent)	8.50
Triethanolamine, 99%	0.25
B. Benzophenone-3	6.00
C. Octocrylene	10.00
D. Ethylhexyl methoxycinnamate	7.50
E. Water (<i>aqua</i>)	qs
Carbomer, 2% (Carbopol 940, Noveon)	7.50
Acrylates C10-30 alkyl acrylate crosspolymer, 2% (Pemulen TR-1, Noveon)	7.50
Propylene glycol	1.00
F. Phenoxyethanol (and) methylparaben (and) propylparaben and butylparaben (Phenonip, Clariant)	1.00
Fragrance (<i>parfum</i>)	qs

Procedure: Heat A to 85–90°C while propeller mixing. When ingredients are fully dispersed, reduce heat to 80–85°C. Add B, C and D in order, dispersing each phase before adding next. Combine ingredients of E and heat to 80–85°C while propeller mixing. Emulsify, adding first mixture to E with high speed mixing. Continue mixing for 10–15 min. Remove from heat and continue propeller mixing until cooled to 70–75°C. Change to sweep mix and allow mixture to cool to 25–30°C. Add F with mixing.

Conclusions

Tests of water resistance showed that C30-38 olefin/isopropyl maleate/MA copolymer provided significantly better water resistance than the competitive benchmark or the polyethylene or C20-40 alcohol polymers evaluated in this study. However, combining PVP/eicosene copolymer with C30-38 olefin/isopropyl maleate/MA copolymer had a synergistic effect that provided much better water resistance than either polymer alone. Other products were evaluated together and no synergistic results were seen, so the phenomenon appears distinctive for this particular combination.

Because of their viscosity-building properties, polyethylenes and long-chain linear alcohols showed the best SPF enhancing characteristics in this study. These ingredients as well as the C30-38 olefin/isopropyl maleate/MA copolymer have highly efficient film-forming properties, which can allow formulators to use lower levels of potentially irritating active ingredients in sun care products.

These versatile and multifunctional properties, combined with excellent aesthetics, present formulators with broader choices for creating high performance, distinctive sun care products to meet the needs of today's global consumers.

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Preservation of Sunscreen Products

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KEY WORDS: *sunscreen product, sunscreen active, preservative, Avobenzene, aqueous product*

ABSTRACT: *Sunscreen products, even those formulated as anhydrous or powder formulations, may need preservative systems because of the high risk of microbial contamination or water intrusion, especially during consumer use around water.*

The primary purpose of sunscreen products is to prevent or minimize deleterious effects of solar and UV radiation on the skin. Among these effects are actinic aging and skin cancer. Secondary benefits include moisturization and reduction of UV-induced melanization on sun-exposed skin.

The purpose of this review is to consider what is necessary for adequate preservation of sunscreen products, including whether some ingredients present special challenges to preservation, what consumer use or abuse should be considered in product development and testing, and what protective packaging may be required to protect sunscreen products from excessive water intrusion and microbial contamination.

Sunscreen Active Ingredients

In the United States, the U.S. Food and Drug Administration (FDA) regulates sunscreen products as over-the-counter drugs. The official document regulating these products is the tentative final monograph (TFM) on Sunscreen Drug Products for Over-the-Counter Human

Use. It was published in the *Federal Register* on May 12, 1993. Although the final monograph on sunscreen drug products was published in the *Federal Register* on May 21, 1999, the effective date for this monograph has been stayed indefinitely. The TFM lists active ingredients that may be used singly or in combination to obtain desired levels of sun protection.

The sunscreen active agents approved by the FDA may be divided into two groups:

- Materials that absorb energy in the UV range (organic sunscreens); and
- Materials that block, scatter or absorb energy in the UV range (titanium dioxide and zinc oxide).

These ingredients are listed in **Table 23.1**.

These active ingredients are organic chemicals or inorganic salts that do not contain sufficient water to allow microorganisms to grow. Application of any of these materials from the neat state probably would not be appealing because they are predominantly oils or inorganic salts, some may be irritating, and they must be used within the concentrations specified in **Table 23.1** to meet monograph requirements.

Sunscreen active ingredients generally are formulated into an oil-in-water (o/w) emulsion to have an aesthetically pleasing product that provides the desired sun protection factor (SPF). The use of water, emulsifiers and other components in a sunscreen formulation provides substrates that may allow the growth of microorganisms. Consequently, these formulations need to have a preservative system to protect the product from microbial contamination and growth that could lead to changes in physical characteristics such as pH, color, odor and viscosity, and possibly make the products hazardous to use.

Preservation of Sunscreen Formulations

Emulsions are the most popular form of sunscreen products due to their efficacy, skin feel and cost. Other forms include oils, gels, ointments, sticks, pump sprays, creams or lotions, and mousses or

Table 23.1. Sunscreen active ingredients allowed for use in products marketed in the United States and their maximum use level

Current Designation	Max (%)
Aminobenzoic acid (PABA)	15
Avobenzene	3
Cinoxate	3
Dioxybenzone	3
Ensulizole ^a	4
Homosalate	15
Meradimate ^b	5
Octinoxate ^c	7.5
Octisalate ^d	5
Octocrylene	10
Oxybenzone	6
Padimate O	8
Sulisobenzene	10
Titanium dioxide	25
Trolamine salicylate	12
Zinc oxide	25

^a *Phenylbenzimidazole sulfonic acid*
^b *Menthyl anthranilate*
^c *Octyl methoxycinnamate*
^d *Octyl salicylate*

aerosols. In recent years, some powdered makeup products have included sunscreen active ingredients and have claimed SPF values.¹

Aqueous sunscreen formulations must be preserved as other aqueous consumer products. Sunscreen products in the form of anhydrous sticks, oils and powders may, at first thought, not require preservatives because these materials have insufficient moisture to support microbial growth. However, the product formula, product packaging and consumer use or abuse—for example, at the beach or pool where exposure to water is possible—may necessitate the inclusion of preservatives.

Aqueous formulations: Preservative efficacy testing, also called challenge testing, is performed on aqueous cosmetic and drug products to determine the minimum concentration of preservatives required for adequate preservation. Among the several methods of preservative efficacy testing are the compendial, trade association, in-house and rapid methods. These methods of preservative efficacy testing have a number of similarities including test organisms used, culture media and the method of performing aerobic plate counts (APCs); however, there may be differences in the growth temperatures, procedures for preparing inocula, times at which APCs are determined, use of rechallenge testing, and acceptance criteria. In-house and rapid methods may use miniaturized or more automated means of testing. Differences in methods may produce variations in test results that affect whether a product passes or fails the challenge test and whether it has microbiological problems in production or when used by consumers.

Many manufacturers are not using formaldehyde-donors in products distributed globally because of regulatory issues concerning these ingredients in some countries. Formaldehyde-donors are effective broad-spectrum preservatives, and their elimination has made it difficult for some manufacturers to achieve target kill rates for test organisms during preservative efficacy testing. Bacteria, yeasts and molds present in the manufacturing plant and in consumers' homes are opportunists that will take advantage of substrates available for their growth in warm, moist environments. Thus, it is up to product development scientists and microbiologists to work together to deliver formulas that meet product profiles *and* are satisfactorily preserved.

Hurdle technology using the principles of preservation (see **Principles of Preservation sidebar**) is a sound approach to developing effective preservative systems for many aqueous sunscreens.² Aqueous products in multiple-use containers are satisfactorily preserved if they meet appropriate acceptance criteria and have considered consumer use and abuse and the type of protective packaging.^{3,4,5} Experience has shown that aqueous emulsion products that have decimal reduction times (D-values) no greater than 4 h (≥ 6 -log reduction in 24 h) for pathogens and D-values no greater than 28 h

(≥ 6 -log reduction in seven days) for nonpathogens rarely, if ever, become contaminated during manufacturing and consumer use.

Anhydrous and powder formulations: Sunscreen active ingredients may be put into anhydrous products including sticks, oils and powders. These products often are considered to be atypical with respect to the type of challenge testing used; aqueous-based product challenge protocols may need to be modified to properly assess whether or not they are adequately preserved.⁶

For anhydrous sunscreen products, a reduction in the challenge inoculum size to 10^3 to 10^4 colony-forming units (CFU) per gram may be used instead of the inoculum concentration of around 10^6 CFU per gram that is recommended in aqueous product challenge test methods to make it easier to measure stasis or growth that may occur during testing. Although the recommended ratio of inoculum suspension for aqueous-based products is no more than 1.0% for a challenge sample, reduction of the ratio of inoculum suspension to product to 0.1% in anhydrous or atypical products may be needed to minimize changes in the physicochemical composition of the product.

For solid atypical products, such as anhydrous sticks that contain sunscreen active ingredients, inoculation and sampling of the product surface instead of the whole product more closely simulates potential consumer contamination. This modification also maintains the physical product integrity and more closely approximates in-use contamination because microorganisms are not able to penetrate into the interior and will always be found on the outermost layer of the product after consumer use. In some instances, it may be appropriate to use an oil-soluble carrier system, such as light mineral oil or other suitable oil carrier, when challenging anhydrous liquid atypical product formulations to form a homogeneous mixture.

Principles of Preservation

- Low or high pH
- Low water activity
- Multifunctional ingredients that have antimicrobial activity
- Protective packaging

The recovery procedure for determining the microbial counts from inoculated challenge samples of an atypical product may need to be modified to include an anhydrous product solubilizer such as Polysorbate 80 to help disperse microorganisms on or in anhydrous products. Acceptance criteria for anhydrous sunscreen products may include stasis or a slower rate of kill than generally considered to be acceptable for aqueous products. Pass/fail criteria should be set after a risk assessment considering product form, type of packaging, area of application, and other factors.⁶

Sunscreen Ingredients that Present Special Challenges

Most sunscreen actives are fairly stable and do not react readily with other chemicals in OTC-drug products. Avobenzone may require special attention because the formaldehyde released by formaldehyde-donor preservatives may react with avobenzone, with possible reduction in preservative efficacy. Use of this active with formaldehyde-donors should be avoided.

Protective Packaging Requirements

Many types of aqueous products are sold in bottles fitted with pumps, flip-tops, or screw caps, or in screw-cap tubes. All these delivery systems are subject to water and microbial contamination if caps are left open or off or if the product is immersed in water. Normal use of sunscreen products may expose them to water intrusion or microbial contamination (i.e., accidentally dropped into the swimming pool) that generally is not a consideration for most cosmetics and toiletries. Also, use of sunscreen products may result in occasional water contact with the orifice when the product is applied using wet hands. Product abuses would include leaving the closure off or open when the product is not in use and children playing with the product in swimming pools.

Consumer-use studies are helpful in determining how well the preservative system works during actual product use. Such studies may involve sampling of products and determining the APC following use of the product for a few weeks. A more robust preservative

system would be needed if products were found to be contaminated following consumer use. There may be opportunities for more fail-safe protective packaging for sunscreen products.

Conclusion

Normal use of sunscreen products may expose them to water intrusion or microbial contamination. Properly formulated sunscreen products—whether they are aqueous, anhydrous or atypical—need a preservative system to prevent microbial growth if the products might be contaminated during use. Hurdle technology is a sound approach to developing effective preservative systems. The formula, packaging and consumer use or abuse should be considered when determining the preservative requirements of sunscreen products.

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Photostability: The Back Story of UV Filters

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KEY WORDS: *organic UV filters, photostability, sunscreen, solvent polarity, complexation*

ABSTRACT: *This chapter focuses on the background behind UV filters. Also included are details about formulating and molecular strategies for sunscreens.*

Here's the story of organic UV filters. They absorb a packet of energy called a photon from incoming UV radiation and hold it briefly in an excited state before releasing it as heat or a lower-energy photon or both, and returning to the unexcited or ground state. The front story is absorption. Everybody knows that story. It's the functionality of these chemicals and their reason for being in sunscreen formulations. The back story is dissipation. That's the less familiar story of how, and if, the chemical returns to its ground state. The back story of UV filters is photostability.

“The Photostability of Organic Sunscreen Actives: A Review” is the title of a chapter in *Sunscreens: Regulations and Commercial Development*, published last year¹ as the third edition of a book on this topic in the Cosmetic Science and Technology Series (see **Defining “Sunscreen” sidebar**). Edited by Nadim A. Shaath, Ph.D., president of Alpha Research and Development Ltd. in White Plains, N.Y., USA, the book contains 48 articles by 72 authors and appears quite different in content from the 1997 second edition. Five chapters are devoted to UV filters. The one covering photostability is by Craig A. Bonda, director of R&D for personal care at CPH

Innovations, an affiliate of the C.P. Hall Company, Chicago. The industry knows this company through its sales and marketing arm, RTD*HallStar.

Bonda writes that a UV filter's fate is best understood as "a competition between the many pathways the molecule can take between its elevation to an excited state and its return to the ground state. All of the pathways result in the dissipation of excited state energy. Some of the pathways are destructive to the molecule (e.g., fragmentation, some types of isomerization, biomolecular reaction); others are nondestructive (e.g., fluorescence, phosphorescence, some types of isomerization, energy transfer to another molecule). Each pathway is associated with its own rate constant. If nondestructive pathways predominate, then, relatively speaking, the molecule will be photostable. Conversely, if destructive pathways predominate, then the molecule will be unstable."

This Bench & Beyond column relies heavily on Bonda's chapter, his patents and other publications, and his response to e-mailed questions. The column also draws on publications and patents from French and Italian researchers who have developed approaches different than Bonda's. The result is four strategies for improving the photostability of organic sunscreen actives. But first, a look at the UV filters themselves.

UV Filters

Dozens of UV filters have been approved variously for use in cosmetic products in different parts of the world, but often under different names and at different maximum percentages in formulations.^{2,3} **Table 24.1** shows the several UV filters that can be used in products marketed in the United States, Europe and Japan. They are listed by U.S. drug name and by UV filtering range. Some of the alternate names also are listed.

The UVB filters most widely used in the United States in commercial sunscreen compositions are paramethoxy-cinnamic acid esters, such as octyl methoxycinnamate (octinoxate). Other widely used UVB filters are octyl salicylate (octisalate) and benzophenone-3 (oxybenzone). The most commonly used UVA filters are the

Defining “Sunscreen”

If all you had was the contents page of the excellent new compilation titled *Sunscreens: Regulations and Commercial Development*, would you know what to expect in the 16 chapters whose title uses the word *sunscreen* without identifying it as either an ingredient or a formulated finished product? For that matter, if you had only the title of the book, would you expect it to be focused on consumer products or UV filters?

For example, are the following chapters about consumer products or UV filters?

- Sunscreen Evolution
- Safety Considerations for Sunscreens in the USA
- Regulation of Sunscreens in Australia
- Recreational Sunscreens
- Recent Sunscreen Market Trends

Again, are the following chapters about consumer products or UV filters?

- Regulatory Aspects of Sunscreens in Europe
- SPF Modulation: Optimizing the Efficacy of Sunscreens

In fact, the first group focuses on consumer products and the second on UV filters. This observation is not meant as a criticism. This excellent volume belongs in the formulator's library because sun protection is becoming a part of so many personal-care product forms. But the ambiguity in the use of the term *sunscreens* suggests that it has achieved a new status: multifunctionality.

dibenzoylmethane derivatives, particularly avobenzone. Methods to photostabilize avobenzone have been a particular interest of Bonda over a string of patents, some of which are cited in this chapter.

The Photochemistry of Photostability

The photochemistry of photostability has been described by Bonda in the Shaath book and elsewhere,⁴ so here it will suffice to say there are multiple routes by which a UV filter molecule can dissipate its energy and return from the excited state to the ground state. Some routes—such as fragmentation, biomolecular reaction and certain isomerizations—destroy the molecule. Others—such as fluorescence, phosphorescence, certain isomerizations, and energy transfer

Table 24.1. Universal UV filters for sunscreen products and their maximum usage levels (%) by region (NL = No Limit)

U.S. Drug name	Other name	U.S. (%)	Japan (%)	EU (%)
<u>UVB Absorbers</u>				
Octinoxate	INCI	Ethylhexyl methoxycinnamate	7.5	
	Old US	Octyl methoxycinnamate		
	Japan	2-Ethylhexyl 4-methoxycinnamate		20
	EU	Octyl methoxycinnamate		10
Homosalate	INCI	Homosalate	15	
	Japan	Homomethyl salicylate		10
	EU	Homosalate		10
Octisalate	INCI	Ethylhexyl salicylate	5	
	Old US	Octyl salicylate		
	Japan	Octyl salicylate		10
	EU	2-Ethylhexyl salicylate		5
Octocrylene	INCI	Octocrylene	10	
	Japan	Octocrylene		10
	EU	2-cyano-3,3-diphenyl acrylic acid, 2-ethylhexyl ester		10
Ensulizone	INCI	Phenylbenzimidazole sulfonic acid	4	
	Japan	Phenylbenzimidazole sulfonic acid		3
	EU	2-Phenylbenzimidazole-5-sulphonic acid and its potassium, sodium and triethanolamine salts		8
<u>UVA Absorbers</u>				
Oxybenzone	INCI	Benzophenone-3	6	
	Japan	Oxybenzone		5
	EU	Oxybenzone		10
Avobenzone	INCI	Butyl methoxydibenzoyl methane	3	
	Japan	4-tert-Butyl-4-methoxydibenzolymethane		10
	EU	1-(4-tert-Butylphenyl)-3-(4-methoxyphenyl)propane-1,3-dione		5

U.S. Drug name	Other name	U.S. (%)	Japan (%)	EU (%)
<u>Physical blockers</u>				
Zinc oxide		25	NL	NL
Titanium oxide		25	25	NL

to another molecule—preserve the molecule. Routes of the latter type are the photochemistry of photostability because the molecule survives and is ready to receive another photon.

While the molecule is in the triplet excited state, it behaves as a diradical, which means many chemical reactions are possible. Of particular importance to the sunscreen formulator are reactions between like or different UV filter molecules, those between UV filter molecules and sunscreen excipients, and isomerization or fragmentations of the UV filter molecules, any one of which may alter or destroy the UV absorption capacity of the sunscreen formulation, according to Bonda.⁵

The discussion turns now to several strategies for increasing the photostability of UV filters. They will be described here in terms of specific filters for simplicity, but please note that the source document describing these concepts probably talked in terms of families of filters. Thus, Bonda's U.S. Patent 6,962,692 discusses dibenzoylmethane derivatives, but this column will talk about only one of them, avobenzone.

Solvent Polarity

Several Bonda patents^{6,7,8} describe methods to optimize photostability by adjusting the polarity of the solvent system. This method is based on electron transfer theory, which holds that when a molecule absorbs or releases an electron, the rapid expansion and contraction of a molecule's electron cloud causes dislocation and rearrangement of the solvent molecules in the immediate vicinity. The energy required for the solvent molecules to accommodate these changes in dimension and charge distribution has a direct relationship to the rate at which electron transfer takes place.

Bonda's U.S. Patent 6,770,270 describes a method to prepare a sunscreen formulation by controlling the polarity of the solvent system to control the rate of photodecay of the filter system. It calls for these steps:

1. Select a UV filter or filter system.
2. Select a variety of solvent systems.
3. Prepare parallel mixtures of the filter system at constant concentration in the various solvent systems.
4. Determine a rate constant of photodecay of each of the mixtures at a selected wavelength.
5. Determine the polarity of each of the mixtures.
6. Select the final solvent system based on its polarity.
7. Mix the filter system and the solvent system.

Bonda's own studies documented a parabolic relationship between the dielectric constant of the oil phase and the photostability of several avobenzone-containing sunscreen formations.

Polarity of the solvent system plays a role in a Playtex patent from March 2006 in which Dueva and SaNogueira claim a method to optimize the polarity, photostability and other characteristics of sunscreen formulations by using optimizing agents selected from the group consisting of diol, alcohol, glycol, polyhydric alcohol and their derivatives or combinations.⁹

Formulation Strategies

The ideal formulation strategy removes ingredients known to be deleterious to UV filter photostability and includes ingredients that are known to improve photostability. For example, the combination of octinoxate and avobenzone is well known to be photo-unstable, according to Bonda. On the other hand, the combination of octocrylene and avobenzone improves the photostability of avobenzone.

Among other ingredients known to improve the photostability of avobenzone are the following:

- Diethylhexyl 2,6-naphthalate. This ingredient, invented by Bonda and disclosed in U.S. Patent 5,993,789 and others, is now marketed as Corapan TQ from Symrise. Bonda and Steinberg reported that this ingredient improves the performance of every sunscreen, regardless of the UV filter combination.¹⁰
- Polymers and compounds containing a diphenylmethylenes or a 9H-fluorene moiety.¹¹ A related patent uses the same idea but adds the possibility of synergistic combinations of the polymer with oxybenzone or diesters or polyesters of a naphthalene dicarboxylic acid.¹²
- Low levels of an α -cyano- β,β -diphenylacrylate compound with or without one or more diesters and polyesters of naphthalene dicarboxylic acid and a methoxy-substituted benzophenone.¹³ A related patent uses the same idea but specifies inclusion of octocrylene and diethylhexyl 2,6-naphthalate in the filter system.¹⁴
- Derivatives of fluorine, including diesters and polyesters of diphenyl-methylenemalononic acid and derivatives of cyano(9H-fluoren-9-ylidene) acetic acid.¹⁵

These are all Bonda patents from the last two years, all focused on the photostability of avobenzone. According to Bonda, these chemicals have two things in common: they quench the excited-state energy of avobenzone by an energy transfer mechanism, and they dissipate the excited-state energy harmlessly.¹⁶

Several researchers at L'Oréal have investigated the use of 4,4-diarylbuta-diene compounds to photostabilize avobenzone and other types of UV filters. Earlier this year Candau described sunscreen compositions containing a 4,4-diarylbutadiene compound in a weight ratio of at least 2.5 to avobenzone.¹⁷ In a patent application filed last year, Richard described the use of diarylbutadiene-substituted diorganopolysiloxanes to overcome avobenzone's disadvantages of photoinstability and solubility.¹⁸ Neither of these patent documents discloses the mechanism by which photostability is improved.

Bis-ethylhexyloxyphenol methoxyphenyl triazine^a (BEMT) prevented the photodegradation of avobenzone in a concentration-dependent way, according to a 2001 study by Chatelain and Gabard.¹⁹ This ingredient (**Figure 24.1**) also showed photoprotective properties toward octinoxate and can be used to improve the photostability of sunscreen products containing both avobenzone and octinoxate.

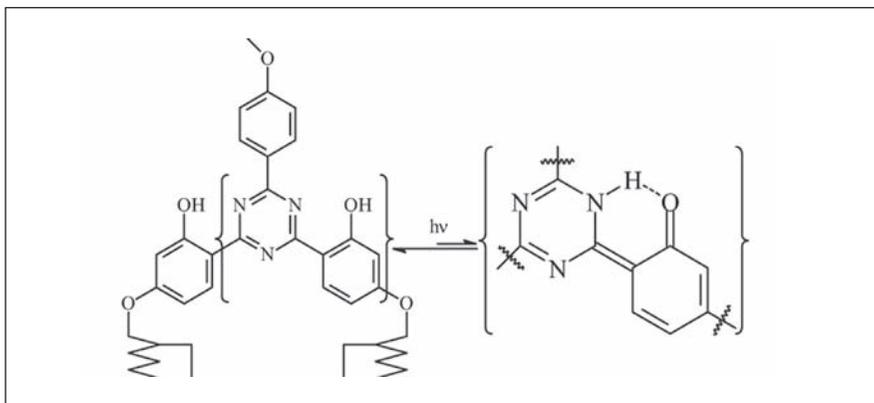


Figure 24.1. BEMT (Tinosorb S from Ciba)

Methylene bis-benzotriazolyl tetramethylbutylphenol^a (MBBT) is a new class of UV absorber based on microfine particle technology. This UVA filter at 7% active ingredient in aqueous suspension, 2 $\mu\text{L}/\text{cm}^2$ on a rough quartz plate, showed recovery of greater than 99% and 98% after irradiation by 10 MED and 50 MED, respectively. Efficient energy dissipation of the active ingredient, intramolecular hydrogen transfer in the excited state, followed by internal conversion and thermal deactivation may have accounted for the high photostability, according to Ciba.²⁰ MBBT (**Figure 24.2**) is compatible with other UV filters and may have a stabilizing effect on them. For example, after irradiation with 10 MED, 27% of octinoxate is lost when used alone versus 8% when used in the presence of MBBT.²⁰

^a MBBT is marketed as Tinosorb M from Ciba Specialty Chemicals. The U.S. drug name is bisoctrizole.

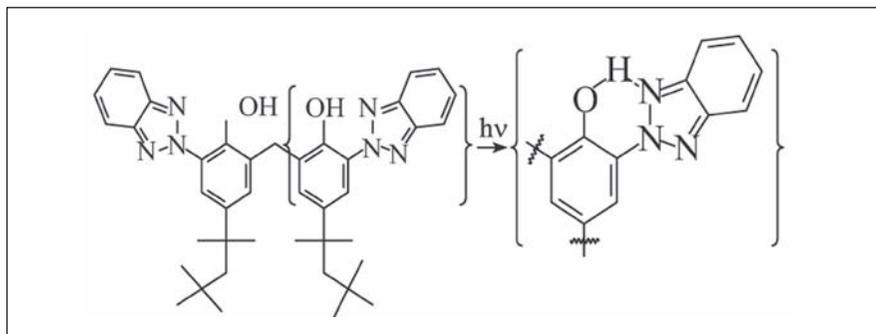


Figure 24.2. MBBT (Tinosorb M from Ciba)

Molecular Strategies

A UV filter in the ground state has its electrons in low-energy orbits and the directional spins of these electrons offset each other in pairs so there is no net spin. When the molecule absorbs a photon, one of a pair of electrons in a low-energy orbit is excited into an unoccupied higher-energy orbit and two spin states are possible. In the singlet excited state, the spins of the two electrons remain paired and there is no net spin. In the triplet excited state, the spins of the two electrons are unpaired and there is a net spin. The process by which an excited molecule moves from one of these states to the other is the basis of molecular strategies for photostabilization.

The process of moving from singlet state to ground state is called *internal conversion* because in both states the spins are paired. The process of moving from a paired state to an unpaired state is called *intersystem crossing*; this means the molecule is in the triplet state, where most chemical reactions occur. Therefore, the molecular strategy for photostabilization is to promote internal conversion and prevent intersystem crossing.

Isomerization and intramolecular hydrogen transfer are two techniques to promote rapid internal conversion.²¹ Examples are cited by Bonda in the Shaath book. Methylbenzylidene camphor^c and octocrylene photostabilize avobenzone by a process of isomerization.²² Octisalate, homosalate, oxybenzone, MBBT and BEMT are

^b The U.S. drug name is Enzacamene.

all very stable and contain a hydroxyphenyl group ortho to a carbonyl or a ring-bound nitrogen. This structure promotes rapid internal conversion.²²

Complexation or Encapsulation Strategy

Several Italian authors have reported that UV filter molecules can be protected by complexing or encapsulating them with certain substances. For example, Citernes reported that octinoxate, avobenzene or oxybenzone separately complexed in β -cyclodextrin showed “considerable” increases in photostability. He suggested that this increase might be due to the inclusion of the filter molecule in the molecular cavity of the β β -cyclodextrin where it is linked by quite stable chemical bonds and therefore poorly reactive to the action of possible free radicals.²³ He later suggested that the increase in photostability might be due to the particular combination of UV filters in the formulation independent of the inclusion structure.²⁴

Scalia et al. reported that the complex of β -cyclodextrin with octinoxate enhanced the filter’s chemical stability and photostability. Scalia recently told *C&T* magazine that “cyclodextrins are able to incorporate lipolytic molecules into their hydrophobic cavity, forming inclusion complexes. Because the included molecule is sterically constrained within the cyclodextrin cavity, it is difficult to fragment upon exposure to radiation and if it does, the fragments may not have the mobility needed to separate and react before a simple recombination takes place.”²⁵

Perugini et al. noted reduced photodegradation of octinoxate in emulsion vehicles when the filter was encapsulated in nanoparticles made of poly-D,L-lactide-co-glycolide.²⁶

Conclusion

The uniqueness of UV filters depends on their ability to reach an excited state after absorbing UV energy and then to return to ground state by dissipating the energy. Their functionality depends on their ability to do that process over and over again. Their photostability depends on their ability to dissipate the energy without self-destruction.

Bonda showed that non-self-destructive energy dissipation can be achieved by transferring the excited-state energy to the solvent molecules or to photostabilizers such as diethylhexyl 2,6-naphthalate, octocrylene and methylbenzylidene camphor. It also can be achieved within the molecule by promoting transfers from the triplet excited state to the singlet excited state, and discouraging transfers in the opposite direction.

Several Italian sources suggested inclusion complexes could improve UV filter photostability by slowing their reactivity or reducing their fragmentation.

The point of photostability is the safe return. As NASA knew long before *Apollo 13*, sending a man to the moon is good; if you can't bring him back, it's not good. As with *Apollo 13*, the story of photostability is the "back" story.

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Stopping the Sun

Leslie Lucchina, MD

KEY WORDS: *Ecamsule, Mexoryl SX, sun care, skin care, UVB rays, UVA rays*

ABSTRACT: *The following is a summarized interview with Leslie C. Lucchina, MD. She is a dermatologist at the Boston Center for Ambulatory Surgery in Boston. She currently focuses on clinical dermatology and has her own practice in laser, cosmetic and general dermatology.*

Ecamsule (INCI: Terephthalylidene dicamphor sulfonic acid), also known as Mexoryl SX, has been used in the formulation of sun care products in Europe, Canada and other parts of the world since 1993, but only recently did it appear in a US skin care product. Just this summer, Anthelios SX, a moisturizer containing the sunscreen ingredient, patented by L'Oréal, was approved by the US Food and Drug Administration for US distribution. Since that time, product manufacturers and skin care professionals have taken significant interest in the ingredient because of its full-spectrum protection. Although there may be excitement surrounding the ingredient, its formulation into skin care products other than the approved formulation remains prohibited.

Many dermatologists are excited that the ingredient formulation was approved, Leslie Lucchina, MD, being one of them. Lucchina is a dermatologist at the Boston Center and finds the new sunscreen ingredient to be innovative. "Mexoryl SX is the latest and greatest in sun protection," said Lucchina. "People have been waiting for this to be approved."

Mexoryl SX is an active that, when added to skin care products, filters out UVA rays. According to L'Oréal, ingredients available for formulation in sun products previously have filtered UVA rays; however, those ingredients were not photostable. "The thing that makes

[Mexoryl] unique is its photostability,” said Lucchina. “It doesn’t degrade when it is exposed to light and is incredibly stable when exposed to the sun.”

Although UVB rays cause sunburn, the UVA rays cause long-term damage such as wrinkles and some types of skin cancer. “Most people think about UVB rays as being the problem in terms of sun exposure. In reality, UVA accounts for more than 80% of the damage that occurs to the skin in terms of aging, DNA damage and ultimately skin cancer,” said Darrell Rigel, MD, in a L’Oréal press release. Therefore, the ability of the ingredient to protect against UVA rays while remaining photostable gives it the potential to provide products with full-spectrum protection.

This recent improvement in sun protection, according to Lucchina, will benefit her patients and people across the country. “A lot of the sunburns we see are due to a combination of things: not using the correct amount of sunscreen, not using the correct SPF and not reapplying often enough,” explained Lucchina. Although the benefits of the ingredient may not be seen immediately, the possibility of fewer wrinkles and decreased risk of skin cancer provides value for the future.

Lucchina finds the future of ecamsule to be promising. “I believe that a lot of companies will start to put the ingredient into other modes of use. For example, they will include it in face lotions and foundations,” said Lucchina. Currently, however, companies other than L’Oréal do not hold the rights to formulate with the ingredient.

Another benefit the ingredient could provide, according to Lucchina, is protection for those with photosensitivity. “This will be great for the individuals with a disease such as lupus that makes them sensitive to light. They often come back from being in the sun with a red, itchy rash; Mexoryl SX will be great for treating things like that,” said Lucchina.

L’Oréal intends to launch other products containing ecamsule or Mexoryl SX. The company reportedly plans to introduce other daily moisturizing products containing ecamsule in some of its other brands in addition to announcing more sunscreen formulations containing the ingredient.

With global warming ever-increasing the penetration of the sun, the emergence of sun care innovation is not only beneficial but vital. Many have high hopes for ecamsule, but as of now, its scope remains limited.

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SECTION IV

Hair Care

Hair care is one of the most important market segments for the personal care business. The market demands are ever changing and new benefits are always being proposed to the consumer. Inclusion of proteins and amino acids, pro-vitamins and a plethora of other additives is commonly encountered as one looks at ingredient listings. The number of articles published in *Cosmetic and Toiletries* and the level of sophistication of the authors speaks to the importance of this market segment.

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Shampoo Formulation: The Basics

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KEY WORDS: *formulation, shampoos, surfactant, pH, stabilizer, marketing*

ABSTRACT: *This chapter unveils the complexities inherent in shampoo formulation. While discussing the basics of primary and secondary surfactants, viscosity builders, marketing additives and many other properties of shampoo formulation, the author provides helpful tips for today's shampoo formulators.*

To the uninitiated, formulation of shampoos seems easy! It's a one-phase, water-based surfactant blend that foams! Simple, isn't it? While that may indeed be the case when compared to inherently unstable systems, many complications may arise that make it a more complex task than may first meet the eye. Let's start with the basics. **Table 26.1** presents an outline of a typical shampoo.

Getting Started

Now that we have a general overview of the raw materials that go into making a shampoo, let's discuss how to get started. The first thing we need to have is a discussion with our marketing friends, and yes they are (or should be) our friends. We need to determine who will be using the shampoo (men, babies, women, teenagers, etc.), hair type, the packaging, selling price/cost of raw material target and claims that will be made. Once we have this key information we can begin. Please recognize that this short chapter can only touch the surface of formulation intricacies.

Table 26.1. Shampoo components

Ingredient	Chemistry Options	% (Active)	Function
Primary surfactant	Sulfates, sulfonates, etc.	8-12	Foaming, cleansing
Secondary surfactant	Betaine, sarcosinate, sulfosuccinate, taurate, ether sulfate, glucoside, glutamates, etc.	2-5	Foaming, cleansing, reduce irritation
Viscosity builder	Alkanolamide, "salt", amine oxide, PEG-distearate, etc.	2-3	Control viscosity
Foam booster	Amine oxide, sarcosinate, lactylate, etc.	1-2	Boost foam
Foam stability	Lactylate, "gum", etc.	0.1-1	Stabilize foam
Active (when appropriate)	Zinc pyrithione, salicylic acid, etc.	As per FDA	Antidandruff agent
Suspending agent	Xanthan gum, carbomer, guar, etc.	0.1-1.0	Suspend zinc pyrithione or other materials
Conditioner	Polyquat., silicone, etc.	0.1-1.0	Hair conditioning
Opacifier	EGMS, EGDS, etc.	1.0-2.0	Pearlizer
Preservative	Paraben, etc.	0.1-0.5	Preservation
Fragrance	Fragrance	0.2-1.0	Fragrance
Humectant	Propylene glycol, glycerin, etc.	0.25-1.0	Improve clarity, reduce cloud point, modify viscosity
Color	Approved colorants	As needed	Color
Marketing additives	Vitamins, aloe, antioxidants, UV absorbers, etc.	As "dictated"	Marketing claims
Chelating agent	EDTA salt	0.05-0.15	Color/odor stability, preservative enhancer

Primary Surfactant

The primary surfactant is the key foaming/cleansing agent in the shampoo. When I first got started formulating shampoos the most popular primary surfactant was SLS (sodium lauryl sulfate). In more recent years it has been replaced by ALS (ammonium lauryl sulfate). I'm not really sure why this change was made, because they both foam and clean the same and their irritation potential is also the same. One possible reason is that ALS shampoos are formulated at a lower pH (to insure we don't get liberation of ammonia), and at this low pH (typically 4.5–6.0) we can add polyquaternium materials that are more substantive to hair at a low pH.

If the target users are babies, then the lauryl sulfates would not be used, but we would then find amphoteric surfactants such as propionates and highly ethoxylated sulfates and carboxylates being used.

Very often, cost plays a major role in the choice of a primary surfactant. Shampoos are, by far, the personal care category most sensitive to pricing. This must be kept in mind when choosing all ingredients and the percentages of those ingredients used.

Secondary Surfactant

Very often the secondary surfactant is used to reduce the drying effect of the primary surfactant and modify the aesthetic properties of the shampoo. The most popular secondary surfactant is the ether sulfate analogue of the primary surfactant (ALES). Most often we see the 1 and 2 mole (ethylene oxide) material being used. This is the case because if we chose a more highly ethoxylated version, viscosity building would be a problem. And who wants to buy a water-thin shampoo?

The second most popular secondary surfactant is the betaine. Betaines (most often cocamidopropyl) have a permanently quaternized nitrogen. Because of this they can be a good hair conditioning agent and also complex with the sulfate to build viscosity and improve clarity. While it was believed that they also reduce the irritation of anionics, more recent information (personal communication with Tom Schoenberg of McIntyre Chemical) disputes this and presents data to show quite the opposite is true. Other surfactants such

as sulfosuccinates, glutamate and sarcosinates can also have a very beneficial effect but will substantially increase the raw material cost.

Viscosity Builder

Few things are more important to consumers than seeing/using a thick (rich) shampoo. They equate it with value and “concentration.” Of course neither necessarily is true.

Alkanolamides have historically been used to increase the viscosity. Experienced shampoo formulators actually know that alkanolamides don't really boost viscosity but only change the position of the salt curve; in other words, less salt is required to build viscosity so it appears that they are boosting the viscosity. Alkanolamides have in recent years come under attack (particularly the DEA amides) and we now see the MEA amides being widely used.

Alkanolamides also improve shampoo clarity by acting as fragrance couplers while also improving foam stability (to a very limited extent when they are used at low use levels) and offering some hair conditioning (due most likely to their water insolubility).

Other more effective viscosity builders include betaines. They complex with the anionics to form an enlarged surfactant micelle that builds viscosity. Additionally, they contribute electrolyte (sodium chloride) that also builds viscosity. Electrolytes are almost always used to build viscosity of shampoos. They are inexpensive and effective. If too much is used, then a low cloud point will be the result.

While sodium chloride is most used, ammonium chloride is also widely used. Ammonium chloride is more efficient than sodium chloride and will also not raise the cloud point. When it is used, like ALS, the pH should be kept below 6.5 to insure that ammonia is not liberated.

Foam Booster/Stabilizer

Consumers equate foaming with cleansing and believe that unless copious amounts of foam are generated, their hair will not be cleaned. This, of course, is not true. All shampoos, even the low foaming baby shampoos, contain more than enough surfactant to clean the grimmest, dirtiest hair. Low levels of secondary surfactant

(lactylates, glutamates, taurates, sulfosuccinates, sarcosinates, amine oxides, etc.) can effectively boost foam at low concentrations (1–2%).

It is also crucial to deal with foam stabilizers. Having a voluminous quick breaking foam doesn't make sense. We need to add materials that slow the breakage of the foam bubbles. This can be accomplished by stabilizing the wall of the foam bubble. We have several materials that can play this role for us: gums (cellulose, guar, xanthan, etc., at 0.05–0.15%) and surfactants that form a liquid crystal layer at the bubble wall and thus slow the break and stabilize the foam.

Suspending Agents

When we have the need, based on marketing input, to incorporate materials that must be suspended, we need to incorporate a suspending agent. Most often we will use one or more of the following materials: xanthan gum, carbomer, magnesium aluminum silicate, cellulose gum. The choice will depend on factors such as cost, electrolyte content, pH, the desire for clarity and the feel of foam.

Conditioner

Practically all shampoos sold today will contain a hair conditioner of some type. This is even true for those shampoos that make no conditioning claim whatsoever. Consumers expect and demand that their hair is smooth and conditioned after shampooing. Conditioning agents are most often quaternary in nature because they possess a negative charge that makes them substantive to hair. They will also have at least one fatty group to improve wet comb and gloss. Most often polyquats are used in shampoos since they are (due to stearic hindrance) more compatible with the primary anionic surfactants. We also see wide usage of silicone and other “fatty” materials to provide conditioning and gloss to the hair. These materials plate out onto the hair during the rinsing process.

Opacifiers

To the consumer, a pearlescent shampoo connotes richness. Often it can be used to hide a cloudy shampoo, turning a negative into a

positive. EGDS (glycol distearate) and EGMS (glycol stearate), or a combination of both, are effective in this endeavor. Both crystallize out and form a lovely pearlescence. Be careful to slowly cool the shampoo to maximize this visual effect. Also, the addition of electrolyte can help.

Preservative, Chelating Agent, Color

Every shampoo must be preserved. Very often the primary surfactant will contain some preservative but additional must be added to insure a well protected product. Since shampoos are rinse off products, we have a wide range of preservatives from which to choose. The addition of a salt of EDTA will also help preservation and color stability. Speaking of color stability, we should consider the addition of a UV absorber to insure color stability on the shelf.

Fragrance

No fragrance-free shampoo has ever been successfully marketed, and I doubt one ever will! The fragrance adds to the shampoo experience and is thus a crucial part of the shampoo. It should be presolubilized into some surfactant to insure good product clarity.

Marketing Additives

While it's easy to make fun of the myriad of ingredients that marketing asks (demands?) we incorporate (such as vitamins, minerals, aloe, fruit, nuts, bark, twigs—just kidding here), they are important to the overall picture/image of the shampoo and must be added even though science tells us that they have no function whatsoever.

Conclusion

So you can see that formulating a shampoo offers us lots of opportunity for individual creativity. Just let your minds wander—**but keep in mind the cost of goods!**

Extending the Hair Care Line with Fragrance

Bud Brewster

Technical Editor, Cosmetics & Toiletries magazine

KEY WORDS: *hair, smell, fragrance, product extension, geographic extension*

ABSTRACT: *Fragrance is essential to hair care products. And, though often overlooked, it often is the factor consumers consider most thoughtfully when purchasing hair care products. Although the materials used to make hair care products do not provide an appealing aroma, every effort should be made by the formulator to achieve just that if they wish to attract consumers to their product.*

“Unlike any other cosmetic product form that you apply to the body, hair care products have to meet specific needs of specific consumers. And those consumers know they have genuinely different needs,” says Annette Toms, the London-based professional hair care expert with International Flavors and Fragrances (IFF).

“Hair has to smell fresh and clean. Unfortunately the ingredients in hair care products that make your hair look great do not smell great. What delivers the ‘fresh and clean message’ is the fragrance,” says Jayne Rodgers, New York-based global fragrance development manager for hair care at IFF.

Thus, fragrance is essential in hair care products. But how can it be selected to meet the differing needs of consumers in different parts of the world and products that perform different functions on the hair—especially when the goal is to extend that fragrance across

a range of geographies and product types? This chapter looks at work being done at IFF and at hair care product manufacturers to extend a hair care fragrance across regions and products.

Geographic Extension

In April 2003, IFF and Anderson French Salons opened Anderson French at IFF, a full-service hair salon in the IFF Building in Manhattan at 533 West 57th Street.

Traditionally, perfumers who created fragrances for hair care applications had to evaluate them out of a bottle, diluted in water or on swatches. But to create great fragrances for hair care products, IFF believes that fragrance must be evaluated in-use on real heads of hair. Having an on-site salon allows the perfumers to experiment and get useful feedback on how the fragrance performs on wet hair, during the drying process, and after styling.

“During our year at Anderson French, we have made some discoveries, all of which are now proprietary or confidential either for our clients or for IFF,” Rodgers said. “But we have also looked at the usage of hair care products in general and discovered how they behave on different cultural hair types, such as Latino, Asian, African American, or Caucasian. Experiencing those differences has helped us to better understand fragrancings for a brand and key into what type of fragrance notes are needed to support a brand benefit.”

IFF has gone beyond the salon in its Texture Awareness Program (TAP), which is led by Annette Toms. TAP is a sensory evaluation performed by a specially trained salon technologist working in areas such as Asia (Thailand) and Brazil (São Paulo and Recife) to understand the emerging market needs from within those markets.

“Our new approach in the TAP is we’re working with people in real life conditions, looking at it from a realistic viewpoint, as well as within a salon scene to make sure results in both settings correspond to the results obtained in a controlled setting,” Toms said.

Rodgers has accompanied Toms on TAP activities in Brazil. She feels that the ultimate goal for a good hair fragrance is that it performs the same on as many different types of hair as possible.

“Manufacturers, if they’re selling global megabrands, desire to have one fragrance profile for every single hair type out there. So you must develop a fragrance that is going to smell, within a window of acceptability, the same on every single head,” Rodgers said. “But we’ve learned that scalp odor can strongly affect fragrance performance. What people of different cultures eat, the environment in which they live and even the temperature and the odor of the water they use, can affect the way scalp odor is going to be covered. Scalp odor is a very important factor and TAP taught us that.”

There are regional differences in odor preferences. For example, in the Philippines, highly fragrant hair is a part of beauty. Strong hair fragrance residual that lasts for 24 hours would be desirable in the Philippines, but in the United States, that kind of substantivity would be way too much, according to Rodgers. “To develop a good hair care fragrance for a region, you must have a keen understanding of 1) consumer odor preferences, 2) hair types and textures and 3) the needs of a specific brand.”

You can’t take a single scent and expect it to perform the same in every country, Rodgers believes. “Years ago and somewhat still today, the industry tried to globalize fragrances. But we now see the trend clearly moving toward regional fragrances. When you’re talking about maximum hedonic preference, global is not the way to go, and I don’t think it is the trend of the future.”

Product Extension

Product types also present unique technical challenges, when attempting to extend a fragrance across a line of hair care products. These challenges were discussed three years ago in C&T by Carrubba et al.¹ Their observations are summarized in **Table 27.1**. Their conclusion was that fragrancing various hair care products presents a different set of technical issues for each product type.

Garnier Fructis: Earlier this year L’Oréal extended its Garnier Fructis shampoo and conditioner line to include Fructis Style, the brand’s first line of styling products in the United States. Fructis Style—consisting of five gels, a milk, two mousses and four sprays—is aimed at men and women aged 15 to 34.

Table 27.1. Technical considerations when adding fragrance (F) to hair care products. Primary fragrancing challenges are shown in bold.¹

Formulating Challenge	Shampoo	Conditioner	Styling Gel	Mousse	Hair Spray
F absorption	Surfactants (at ~20% solids) can absorb F.	Solids (at 7-8%) can absorb F.		Can be a problem if surfactants are added to solubilize F.	
F solubility			Up to 90% of product is water. To achieve F solubility, F must be added to product before gelling reaction occurs.	Hydrocarbon propellant gas can cause F insolubility.	
F alteration		Low pH of 3-4 means possible reaction between F and quats.	Gelling reaction can affect certain F ingredients.		
F suppression		Quats may reduce bloom.			
Masking function needed?	Fatty base notes must be masked.	Quats fatty base notes must be masked.		May be needed if alcohol is added to solubilize F.	Must mask alcohols and dimethyl ether propellant. Must mask resins after alcohols volatilize.

Formulating Challenge	Shampoo	Conditioner	Styling Gel	Mousse	Hair Spray
Product viscosity	Viscosity affected if F is added at wrong time in production process.				
Product clarity	Color stability in clear packages or clear formulations can be adversely affected by oxidation reactions between F and red/blue dyes.				
Typical level of F in finished product	0.5 - 1%	0.2%	0.1 - 0.3%	0.2%	~0.1%

The line is formulated with a fruit-based micro-wax technology using kernels of mango and apricot seeds to moisturize hair, according to the company. It is scented with notes of lemon, lime and green apple, with lemon fruit extract to add strength to hair and enhance shine.²

Nourishing Oasis: In March, Alberto VO5 launched a new line of restorative, heat-activated shampoos and conditioners called Nourishing Oasis. The line includes shampoos and conditioners in four scents. These scents contain synthetic fragrance compounds and are heat-activated to release top notes when the product is combined with warm or hot water, according to the company.³

“Nourishing Oasis shampoos and conditioners are designed to nourish hair with rich, patented conditioning ingredients while they ‘nourish’ the soul with aromatherapy fragrances,” said Shannon L. McKenzie, research scientist in fragrance, at the Alberto-Culver Company.

The fragrances are composed of 70–100 compounds to create an overall fragrance “effect” that fits the product concept as well as to provide optimal performance benefits, according to McKenzie.

These fragrance compounds can be classified into three categories based on their volatility. The most volatile compounds, known as top notes, are what the consumer smells first. The heavier, less volatile compounds (often referred to as middle and bottom notes) help fragrances “bloom” in the shower, provide substantivity to hair and help the smell to linger during and after use. Combined, these top, mid and bottom notes create an overall fragrance experience for the consumers using the products.

“We designed each pair of shampoos and conditioners to have the same fragrance,” McKenzie said. “These fragrances were developed in the shampoo base first because it is generally the more difficult base to cover due to the stronger fatty, surfactant odor. Once we identified the shampoo fragrance we experimented with the same fragrance in the conditioner. We optimized the fragrance level so it simultaneously complemented the shampoo while covering the conditioner base odor.”

McKenzie admits there could be a problem extending the line while maintaining the fragrance. “Although a fragrance used in a

shampoo typically works in a conditioner, this isn't always the case in styling or treatment products," she said. "These types of formulas generally contain propellants and solvents that can be very difficult to cover. If we wanted to carry these fragrances into other product forms we would need to work with the fragrance houses to develop appropriate modifications that would sufficiently cover the base as well as suitably match the current shampoo/conditioner fragrances."

Flawless: Now appearing in your local Walgreens stores is Ken Pavés celebrity hair care line called Flawless intended for use on dry, damaged hair. It includes a shampoo, two conditioners and five treatment and styling products. All of the products are formulated with a strengthening complex consisting of wheat and soy proteins, as well as polymers that lubricate and add shine, according to company sources.⁴

The Flawless products reject synthetic fragrances in favor of essential oils, both for benefits and for scent. The benefit ingredients include rose and chamomile oils combined with burdock and ginseng root extracts. The scent comes from a complex of essential oils from lavender, geranium, orange, clementine and lemon.

Alec Batis is head of product development and marketing for Pavés Products. He formulated and scented the line. Ken Pavés is a hair stylist to celebrities such as Celine Dion, Jennifer Lopez and Heather Locklear. They came together, the chemist and the stylist.

"We approached it from both angles," Batis said. "I, as a chemist wanted something that was very good for the hair. Ken wanted the same, but the smell was very important because he gives this to all his celebrity clientele, so it must not embarrass him. When the scent is naturally based, it's somehow more inviting. Ken liked that."

Also, essential oils are more "nutrient giving," according to Batis. So in spite of the fact that synthetic fragrances are cheaper and can provide exactly the scent you want, Batis and Pavés chose to use essential oils, even though they are very limited to what scents they can achieve and marketers rule them out because of cost.

"In this case, Ken didn't care about that," Batis said. "He just wanted the product to be as good as possible, and he wanted it to have a point of difference."

Noville Comments on Trends in Hair Care Fragrance

Trends in cologne and body products have a strong influence on hair care fragrances. The salon and upscale products are especially sensitive to these trends. We see tropical fruit notes in this category, apples taken to a new level (apple cider) and bright sophisticated citruses, like grapefruit.

Mass hair care follows closely on the heels of the salon, doing blends of fruits and citruses with floral, musky backgrounds, such as Fructis, FreshVive and Herbal Essence Fruit Fusion. Occasionally one finds wood notes with a retro balsamic feeling, but primarily the average hair care consumer loves apples, melons and citruses.

Another strong influence in hair care is the burgeoning men's market. L'Oréal Vive for Men, which has a fruity topnote with citrus, green and herbal notes, is gaining momentum. Fructis is simultaneously targeting male and female consumers, as well as GenY in its ad campaigns. We know that men are beginning to evolve as personal care consumers, and so will the male factor in hair care fragrances.

Most shampoo and conditioner bases are easily fragranced. Style and straightening products are a bit more challenging.

Betty Beighley, Senior Evaluator
Noville Inc, South Hackensack, New Jersey

Achieving the same scent from product to product in the line was not easy. Usually, with other clients and working with synthetic fragrances, Batis could just make adjustments in the concentrations. But Flawless has no synthetics, so the only thing he could do is cull out one or another of the essential oils in the complex.

“It was much harder, especially in the conditioner and then the shampoo, to achieve the scent; those bases were harder to cover. So what we did was we pushed up the citruses more,” Batis said. “And in the styling products, whose bases take the scent more easily, we brought the citruses down and pumped up the lavender. The result is that you don't get exactly the same scent throughout the whole line, but you get sort of variations on a theme.”

Batis recalls that extending the line presented the same challenge when he was formulating skin care and hair care products at L'Oréal. And it's the same for every brand. “But you work with the fragrance

chemists and they'll adjust the scent according to the base to achieve a similar scent. For instance, it's very difficult to use the same fragrance formula when going from a moisturizer to a cleanser. So the goal is to make them as close as possible. The scent is never the same, of course, but you get it as close as possible so the consumer feels that the two are similar. If this is a kiwi line, you definitely want the consumer to think there is a kiwi smell in each product."

Another point of difference in the Flawless line is that its products contain no sulfates. Instead, they use surfactants, such as sarcosinates, that are gentler, especially on the scalp.

"There was no goal to make Flawless an 'all natural' line. I'm a chemist. I'm not against chemistry," Batis said. "The goal was to make a good product. That means some things were coming from nature and some things were coming from chemistry. Both sulfates and sarcosinates come from chemistry, but sarcosinates are better for dry, damaged hair. Fragrance can be either synthetic or natural, but we think essential oils are better for dry, damaged hair. So we're not against technology and chemistry. We're just picking and choosing what we think will make a good product."

Conclusion

Extending the line in fragranced hair care products apparently runs into barriers that are regional and technical. Overcoming these barriers will take close cooperation between marketing, product development, R&D and the fragrance house. The fragrance chemist should be on the team early on.

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New Shampoo Technologies: Between the Shock Waves

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KEY WORDS: *shampoo, conditioner, cationic polymer, silicone, structured surfactant technology, multifunctionality, combinatorial chemistry*

ABSTRACT: *Though shampoo technology is not presently experiencing sudden and dramatic change, the author reviews several recent advances in materials, test methodology (combinatorial chemistry), and formulation approaches (structured surfactant technologies).*

In the past 30 years, only two innovations in shampoo technology have been of sufficient importance to have a major impact on formulation practices, ingredient supply, and consumer usage. These innovations are the incorporation of a cationic polymer into an anionic surfactant system¹ in the early 1970s and the functional incorporation of silicone in the late 1980s.²⁻⁴ In each case, the improvement served as a technological shock wave, causing a flurry of competitive patent activity and product emulation.

Today we are between shock waves. While the industry is currently not experiencing a period of major change, suppliers and marketers have nevertheless achieved significant advances in the development of new ingredients and the meaningful improvement of existing materials, formulation approaches and test methodology.

Cationic Polymers

Interestingly, in many cases today's efforts have direct application to the cited innovations of the 1970s and 80s. For example, more than 25 years after patents issued for the usage of cationic guar in anionic shampoo systems,⁵ work continues towards improving the functionality, selectivity, and aesthetics (e.g., clarity) of cationic guar when used in these applications.

Cationic guar as deposition aids: It has recently been determined that in addition to their inherent conditioning properties, certain cationic guar polymers also function as deposition aids for other non-substantive conditioning agents such as silicones. In one such case, Rhodia reported studies revealing a significant difference in the amount of silicone^a deposited onto hair from SLES^b/amphoacetate systems, with and without a cationic guar polymer^c.

These test results demonstrate that Rhodia's cationic guar polymers improve deposition of the tested silicone up to three times. This deposition is attributed to the liberation of the silicone from a complex that it forms with cationic guar upon dilution with water.

Anionic polymers and cationic buildup: Related to improving the resultant performance of cationic polymer-containing shampoos, National Starch has recently demonstrated that a high molecular weight sodium polystyrene sulfonate^d with high anionic charge density and excellent surfactant compatibility can be effective in removing cationic polymeric residue from hair. This material reportedly achieves removal through the formation of a complex with the cationic polymeric buildup.

In studies at National Starch, polyquaternium-10 was fluorescently labelled and deposited onto hair tresses to simulate cationic buildup. Fluorescence spectroscopy was then used to quantify the amount of labelled cationic polymer on the hair tresses before and after treatment. Results indicate the inclusion of this 1% (active) sodium polystyrene sulfonate^d in a mild cleansing shampoo will

^a Mirasil DME silicones (dimethicone and succinoglycan gum) are a product of Rhodia, Cranbury, New Jersey USA.

^b Sodium lauryl ether sulfate (INCI: Sodium laureth sulfate)

^c Jaguar C14S (INCI: Guar hydroxypropyltrimonium chloride). Jaguar is a registered trademark of Rhodia, Cranbury, New Jersey USA.

increase polymer removal by 25%. Similar results are shown using reflectance measurements of lumicrease dye to track the removal of cationic polymer.

Sodium polystyrene sulfonate^d provides an alternative to strong surfactancy for the removal of polymeric buildup. In addition, its anionic charge makes this material novel amongst the predominantly cationic, static fly-away suppressants.

Structured Surfactant Technologies

The infrequency of significant change in shampoo systems logically leads to speculation as to the nature of the next major technological advance and when it will occur. In this regard, it may be worthwhile to note that the functionality of the two technologies already described is based upon the ability to retain the activity of a highly functional material in a medium where, hitherto, it was lost. The potential to provide this same type of protection leaves structured surfactants a favored candidate.

The term “structured surfactant” is used to refer to:

...pourable, fluid, non-Newtonian compositions which have the capacity to physically suspend solid particles by virtue of the presence of a surfactant mesophase or solid phase, which may be interspersed with a solvent phase. The latter is commonly an aqueous electrolyte phase. The surfactant phase is usually present as packed spherulites dispersed in the aqueous phase. Alternatively a thin mobile lamellar phase or a bicontinuous reticular interspersion of aqueous and lamellar phases may be present. Hexagonal phases are usually insufficiently mobile to form the basis of a structured surfactant, but may, exceptionally be present.⁶

While these and similar systems have already gained usage in liquid cleanser formulations, they have yet to leave their mark in shampoos.

^d Flexan II (INCI: Sodium polystyrene sulfonate). Flexan is a registered trademark of National Starch, Bridgewater, New Jersey USA.

Advancing the potential application of this technology to shampoos, Huntsman has recently developed optically clear structured systems that can be made using surfactant, carbohydrate and water. X-ray diffraction studies indicate these systems have repeat spacing of 20–50 nm, which is approximately twice the typical repeat spacing measured for electrolyte-structured expanded G-phase systems, and approximately four times that of a conventional spherulite system.

This technology is capable of suspending solid, liquid, and gaseous particles, which suggests its use in delivery of functional or active ingredients. This is of interest to hair care formulators because such particles could incorporate anti-dandruff agents, silicones and encapsulated actives.

This technology provides polymer-free, transparent formulations having excellent suspending power, pseudoplastic rheology, low freezing point and a wide thermal stability range (-5°C to $+50^{\circ}\text{C}$). Further, Huntsman reports these systems are easy to formulate and manufacture, using readily available raw materials, and are surprisingly self-preserved.

On a lighter but nonetheless important note, these systems are capable of providing a variety of interesting visual effects due to low-miscibility color regions. These include horizontal and vertical stripes, vertical segments and marbling. When viewed through crossed polarizers, these systems provide a visually impressive birefringence phenomena.

Delivering Multifunctional Benefits

It is worthwhile to note that for the above cited examples of changes in shampoo technology, the notable improvements were not related to the primary purpose of cleansing, but instead, towards the multifunctional benefit of conditioning. Importantly, the delivery of multifunctional benefits continues to be of vital importance to shampoo and conditioner technology (and marketing).

Adding color: The incredible growth of hair coloring during the past 10 years has further stimulated and encouraged the delivery of multifunctional benefits. Here, all manners of hair products have been enticed to include color protection as a secondary benefit, or to

directly add hair coloring functionality. The latter has frequently and conveniently been achieved through the inclusion of basic/cationic dyes^{a,b} that provide temporary to semi-permanent deposition of dye. (Conversely, most hair color products claim conditioning as a secondary benefit.)

Such multifunctional hair coloring products must be carefully formulated to provide meaningful color effects while maintaining their primary functionality. This is particularly true of color shampoo systems where the use of cationic dyes generally precludes the use of anionic surfactants.

Further, in shampoo systems the competition is keen between attraction of the dye for the anionic sites of hair and resolubilization and removal by the surfactant system. Tilting the competition in favor of the hair, Huntsman Surface Sciences recently developed a high purity cocamidopropyl betaine (CAPB) that is reported to improve the deposition of these basic dyes from shampoo formulations. The material is substantially lower than conventional CAPB in sodium chloride and sodium dichloroacetate, electrolytes known to interfere with cationic dye functionality.

Huntsman investigated the dye uptake of basic dyes on tresses of bleached blonde human hair from coloring shampoos based on either conventional CAPB, disodium cocoamphodipropionate or high purity CAPB. Color results revealed the high purity CAPB-based formula significantly outperformed the other materials without compromise of either foam or mildness characteristics.

Protecting color and adding fragrance: Several recent materials have been demonstrated to protect existing color while also providing conditioning functionalities. Among these is an ultra high molecular weight silicone emulsion^c from Dow Corning. It has an internal viscosity of more than 120 million centistokes.

Employing visual range spectrophotometry to determine color changes, Dow Corning determined this silicone emulsion to provide

^a Jaracol dyes. Jaracol is a trademark of James Robinson Ltd., Huddersfield, England.

^b Arianor dyes. Arianor is a registered trademark of Warner-Jenkinson, South Plainfield, New Jersey USA.

^c Dow Corning HMW 2220 Non-ionic Emulsion (INCI: Divinyldimethicone/dimethicone copolymer (and) C12-C13 parath-3 (and) C12-C13 parath-23) is a product of Dow Corning, Midland, Michigan, USA.

strong color protection from repeated shampoo and (accelerated) UV exposure. Further, results of detangling studies by their expert panelists, revealed this material to reduce wet de-tangling time in shampoos and conditioners up to 50% (at 3% dosage) on Caucasian hair.

Finally, this silicone emulsion enhances delivery of fragrance in shampoos. An analysis by expert panelists revealed a perception of up to 30% more fragrance intensity on hair after lathering, rinsing, blow drying, and even 6 hours after use. This was further validated through consumer tests.

Protecting color and giving silicone functionality: Crompton Osi Specialties recently introduced a material^d that provides both silicone functionality and color protection to dyed hair. This new hair care ingredient reportedly provides a “unique” feel to hair, along with the performance properties expected of a functional silicone, while lessening the loss of dyed hair color when washed with a conditioning shampoo containing this ingredient.

Demonstrating this functionality, Crompton researchers evaluated the color fastness of dyed bleached blonde hair after ten shampoos with a conditioning shampoo containing 1% of the silicone functionality ingredient versus that with a cleansing shampoo. They report that visual comparison and reflectance measurements showed a significant difference between the two treatments.

Protecting color with a quaternary compound: Croda recently introduced a hair conditioning and softening agent that also improves the shampoo resistance of dyed hair. The agent^a is a quaternary compound combining the imidazoline functional group and two behenyl alkyl chains.

In testing, a rinse-out conditioning formulation containing 1% (active) of this quaternary compound was applied to blonde hair that was dyed to a deep red with a commercial demi-permanent oxidation dye product. The dye fastness of these tresses was then

^dSilsoft A 454 (INCI: Dimethicone bisaminohydroxyethylidihydroxypropyl propolyol/TEA stearate (and) water). Silsoft is a registered trademark of Crompton OSi Specialties, Endicott, NY USA.

^aCrodazofsoft DBQ (INCI: Quaternium-91 (and) cetrimonium methosulfate (and) cetearyl alcohol) is a product of Croda Inc., Parsippany, New Jersey, USA.

compared, before and after 15 shampoos, with that of identical dyed tresses, either treated with a commercial rinse-out conditioning color sealant, or given no after coloring treatment (untreated control). The rinse-out conditioners were reapplied after each fifth shampoo. At the completion of testing it was determined that both instrumental data^b and visual observations indicated tresses treated with the quaternary compound exhibited very little color fade and shade change.

Strengthening: In addition to those functional agents related to color enhancement and protection, a number of interesting new strengthening and conditioning ingredients have recently been introduced. Among these is a Croda copolymer complex^c of hydrolyzed vegetable protein and silicone. Croda claims this copolymer dramatically improves the strength of damaged hair.

Croda demonstrated the hair-strengthening performance of this complex by using a technique termed “flexabrasion.” This technique draws weighted fibers across a tungsten wire in cycles, with the fiber’s “fatigue lifetime” represented by the number of cycles that it is able to endure prior to breaking.

Contrasting flexabrasion with more static measurements, investigators reported that the movement and forces it creates are more representative of those experienced during grooming. Using flexabrasion measurements, they determined that treatment with the hair strengthening complex significantly increased hair’s resistance to breakage. In one study, treatment with a conditioner containing 1% of the complex increased the strength of bleached hair by 180%, as contrasted to an increase of 60% for the same conditioner without the product.

Conditioning: Another new material is a water-soluble organo-silicone composition^d that is approximately 70% silicone by weight. It delivers exceptionally high silicone levels to hair care formulations, according to the developer, Uniqema. Patented pyrrolidone

^b HunterLab LabScan [®]XE reflectance spectrophotometer for color measurement is a registered product of HunterLab, Reston, VA USA.

^c Keravis (INCI: Hydrolyzed vegetable protein PG-propyl silanetriol) is a product of Croda Inc, Parsippany, New Jersey, USA.

^d Arlasilk Phospholipid PLN is a product of Uniqema, New Castle, Delaware, USA.

and phospholipid chemistry reportedly increases the polarity of this organosilicone, yielding a product that is extremely mild, substantive and water-soluble. A major benefit of the material is its ability to deliver excellent wet combing and conditioning performance in clear formulations.

Improving Test Methodology

Earlier I noted that, amongst other things, we are in a period during which emphasis is being given to the meaningful improvement of test methodology. Prominent among these improvements is a new strategy for materials discovery that combines miniaturization and automation to produce and test very large numbers of new materials in a parallel manner. Here, ingredient synthesis is typically carried out in parallel on arrays of 10 to 1000 elements, each containing 100 to 1000 mg of material.

These arrays, or “libraries,” are then formulated into model products and screened for chemical and physical properties of interest. This quickly identifies the most promising formulations, which are then scaled up to larger quantities and evaluated by conventional techniques. Unsuccessful formulations, in contrast, are identified and rejected before considerable time and money have been spent on their development.

This approach, known as “high throughput screening” or “combinatorial chemistry,” is capable of evaluating hundreds or even thousands of new formulations per week. Originally developed in the pharmaceutical industry for the rapid identification of new drug candidates, these methods have since been extended to cover all of materials science. Their successful application to the very different materials and methods found in the personal care industry has required new and innovative ways of rapidly synthesizing polymers and small molecules in small quantities; blending these materials into small-scale model formulations, which could be solutions, dispersions, or emulsions; applying these formulations to appropriate surfaces (such as hair); and measuring their physical characteristics.

For example, using high throughput approaches, one can create arrays of new water-soluble segmented polymers, incorporate

promising candidates into model formulations, determine relevant properties of these formulations, treat hair with the most promising candidates, and then measure the resultant physical changes. Clearly, such testing could play an important role in increasing the frequency with which we experience major changes in shampoo and conditioner technology.

Conclusion

There have been few major innovations in shampoo and conditioner technology during the past 30 years. Only two significant innovations in shampoo chemistry have greatly impacted the industry—the incorporation of a cationic polymer into an anionic surfactant system in the early 1970s and the functional incorporation of silicone in the late 1980s. While significant time has elapsed since these discoveries, their impact persists though the continual improvement of these technologies and the ever-growing emphasis on the achievement of multifunctionality through the intact delivery of functional ingredients. For example, efforts continue to improve cationic guar based shampoo systems, new silicone derivatives continue to be introduced, and a number of new shampoo and conditioner ingredients focus on multifunctional benefits. Here, given the incredible growth of this product category during the past decade, multifunctional benefits related to hair dyes are the prime focus of a number of new chemical ingredients.

In response to the logical speculation as to the basis for the next major advance in shampoo technology, the use of structured surfactant technology is offered as a prime candidate. With unique properties resulting in the ability to suspend and deliver ingredients from surfactant systems, these materials have the potential to deliver advanced multifunctional benefits—the primary basis for the last two revolutionary changes in hair care. Further, the application of high throughput methods (or combinatorial chemistry) offer the possibility of dramatically reducing the time lapse between major advances. Employing these methods, steps from ingredient synthesis to incorporation in model formulations and evaluation on hair are executed in miniaturization, resulting in 100- to 1000-fold reductions in R&D time.

Given such methods and innovations in chemical ingredients, it appears that we have a number of tools in place for the development of the next significant change. Regardless of its composition and timing, one can be certain that it will be exciting to experience and interesting to track its conformance to history, as well as its impact on the future.

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Deposition from Conditioning Shampoo: Optimizing Coacervate Formation

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KEY WORDS: *deposition, coacervate, polymers, hair conditioning, shampoos*

ABSTRACT: *New techniques are being offered to produce formulations faster and more cost effectively than ever before. Researchers at the Institute for Formulation Science have addressed this challenge by developing robotic combinatorial techniques for the preparation and investigation of complex mixtures.*

Most conditioning shampoos depend on deposition of a polymer-surfactant coacervate to confer good wet-combing and manageability. Complex coacervate formation is crucially dependent on the molecular characteristics of the polymer and surfactant species, and it is significantly affected by the presence of other ingredients such as cosurfactants and dissolved salts. The optimization of these systems presents a challenge to the formulator because of the astronomical number of possible compositions with different performance outcomes.

Conventional formulation practice requires literally years of laboratory experimentation to characterize and optimize products that depend on complex coacervate formation. Robotic combinatorial

techniques that accelerate the characterization and optimization of complex coacervate formulations have been explored at the Institute for Formulation Science. There has been success in constructing compositional phase diagrams that “fingerprint” the compositional range of complex coacervate formation as a function of polymer and surfactant molecular characteristics and the presence of other ingredients. These diagrams quickly guide the formulator to compositions of interest, and dramatically reduce the time and effort required for the screening of new ingredients, the formulation of new products and optimization of existing products. This chapter briefly describes the application of combinatorial techniques to the detailed study of complex coacervation from the system: guar hydroxypropyltrimonium chloride (and) sodium lauryl ether sulfate (and) water (*aqua*) (GHCSL)^a.

Goddard’s original research into the nature of the interaction of cationic polymers with anionic surfactants formed the technological platform for modern conditioning shampoos.¹ For systems comprised of a cationic hydroxyethylcellulose and anionic surfactants, Goddard showed that below the surfactant critical micelle concentration (CMC), an insoluble coacervate phase was formed and this phase was resolubilized at a surfactant concentration that was above the CMC. This mechanism formed the basis of the now familiar dilution-deposition concept for conditioning shampoos that relied on formulation of the solubilized coacervate in the shampoo and deposition of phase-separated coacervate as the system was diluted below the CMC upon rinsing.

However, behind this apparently simple mechanism there lies a complexity that continues to engage formulators to this day. Thus, patents continue to be issued in this area although more than 30 years have passed since the original discovery. The nature of the coacervate in these systems critically depends on factors such as polymer molecular weight, charge density, charge density distribution, and details of surfactant structure, cosurfactant ratio and the presence of electrolyte.

^a INCI: name Guar hydroxypropyltrimonium chloride (and) sodium laureth sulfate and water (*aqua*)

The coacervate properties must depend upon the conformation of the cationic polyelectrolyte and the hydration of that polyelectrolyte. The conformation of the polyelectrolyte depends, in turn, upon the ionic strength of the system as well as the exact nature of the ion-exchange process that causes surfactant to bind to the cationic sites.

The overall hydration will be affected by the availability of water binding groups such as hydroxyl groups on the polymer. Interaction of the cationic polymer with anionic surfactant micelles would be expected to change the micellar structure. It is well known that an increase in ionic strength will cause structural transitions from spherical to rod-like micelles, worm-like micelles or even lamellar phase. All of these micellar structures have distinct rheological properties and kinetics. Prediction and optimization of these systems is complicated by the complexities of the interactions. Alternatively, empirical formulation for ultimate understanding and optimization of the systems would require the study of a large number of possible polymers, charge densities, structures, molecular weights, surfactant types and ratios, ionic strength and electrolyte type. Such a study would require an army of formulators or a very long time to complete.

This challenge has been addressed by the Institute for Formulation Science with its development of robotic combinatorial methods for the study of these types of formulation problems requiring the generation of large data sets. At the present time researchers at the institute are engaged in developing their understanding of complex coacervates systems by the rapid generation and investigation of thousands of formulations in short time periods. The properties of these formulations are plotted as composition diagrams to guide the formulator.

The Combinatorial Investigation of Complex Coacervation

At the current time, the preferred method for the preparation of complex mixtures at the institute is to utilize a robotic liquid handler^a and to prepare mixtures in 96-well plates in which each well

^a A product of Beckman-Coulter, Inc., Fullerton, Calif., USA

contains a sealable glass vial of appropriate size for the system being studied. The robotic equipment is limited to handling low-viscosity liquids. Therefore, researchers at the institute have developed multiple manual pipetting techniques to handle high-viscosity liquids.

New pipette tips were used for each solution in order to avoid cross-contamination of the samples. When high throughput screening is conducted, it is necessary to include standard compositions to ensure the accuracy of the results; because instruments do drift with time, components such as pumps can fail. It is important to correct these deviations to avoid flawed data. With this in mind, at least two standard compositions in each 96-well plate were included and the measured values of these compositions were plotted. Any significant deviation was investigated immediately and, if necessary, corrective measures were taken.

The compositions were mixed by vortexing the 96-well plate. In order to ensure that the samples adequately were mixed, two dyed samples were included in each 96-well plate. Measurement of λ_{\max} of the dye solution was a monitor for adequate mixing (see **Figure 29.1**).

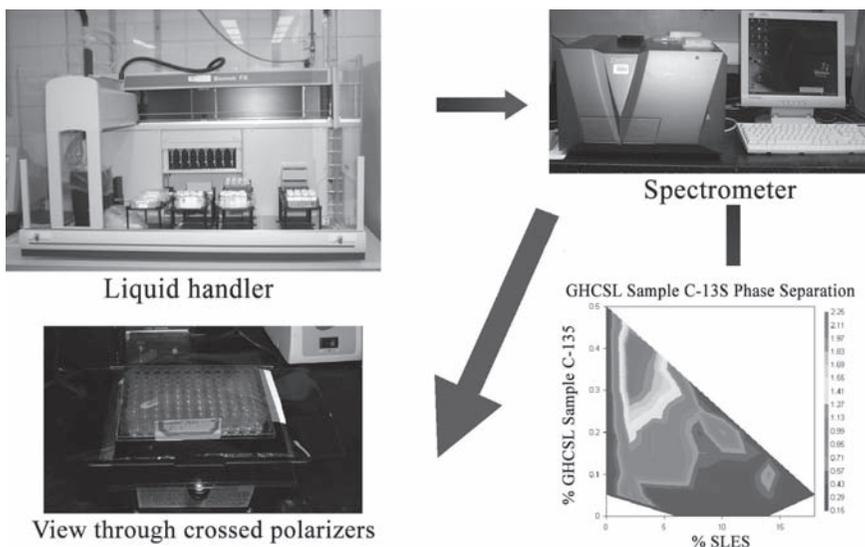


Figure 29.1. A combinatorial approach to the formulation of liquid products

High Throughput Analytical Techniques

Measurement using light or other common electromagnetic radiation is quick and nondestructive. Therefore, whenever possible, a spectrometers capable of reading 96 samples as a single batch was utilized. This instrument provided the capability to measure entire spectra, to measure wavelength shifts and to measure concentrations of desired species in a few minutes using Beers' Law.

The samples were viewed through crossed polarizers to detect birefringent phases such as liquid crystals. Microviscosities were measured by observing depolarization of biphenyls. The amount of coacervate in a sample was assessed by measurement of the absorbance in the visible region.

The data was collected in an interactive database and then visualized as color-coded composition maps. These composition maps showed the volume of complex coacervate formed as a function of polymer structure and composition, surfactant composition and electrolyte concentration. In original work to date, these maps have been shown to be distinctive for each polymer investigated. The precise mechanisms of coacervate formation and the driving forces involved were deduced from the characteristic patterns in the maps.

An important and usually time-consuming aspect of each of the studies is the validation of the high throughput experimentation methods with standard laboratory procedures and confidence that the methods will scale-up reliably.

Results

Cationic polymers, such as guar hydroxypropyltrimonium chloride, provide hair conditioning from shampoos. Guar hydroxypropyltrimonium chloride compounds, with varying molecular weights and charge densities, were combined with the anionic surfactant sodium lauryl ether (3EO) sulfate to form complex coacervates. Generating more than 350 compositions for each polymer/surfactant combination, researchers used high-throughput screening formulation methods to identify the structure and amount of coacervate formed. These results were represented using contour phase diagrams in order to map specific areas to study in

detail. The detailed structures of the lyotropic association colloids that were selected from **Figures 29.2, 29.3** and **29.4**, were identified using polarized light microscopy.

One might expect that coacervate amount and composition range would increase with increase in polymer charge density. This indeed was observed as displayed in **Figure 29.2**, which shows increased amounts of coacervate as the polymer cationic charge density is increased from 0.14 to 0.17 moles per equivalent anhydroglucose unit.

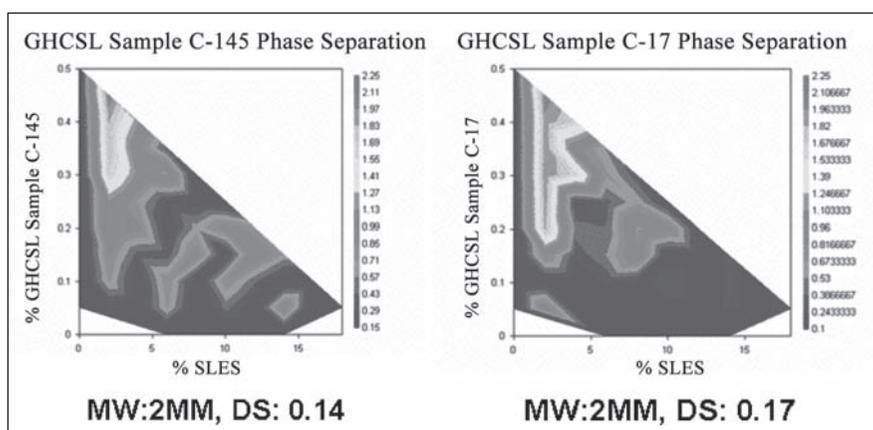


Figure 29.2. Composition diagrams for GHCSL. The diagrams are color-coded in accordance with the visual spectrum with blue representing the absence of coacervate and red indicating the maximum concentration of phase-separated coacervate. Each diagram was constructed from observations on at least 368 separate compositions and each composition was duplicated to check accuracy. The molecular weight was identical for both cationic guar samples but the degree of cationic substitution is 0.14 in diagram (a) and 0.17 in diagram (b).

The influence of polymer molecular weight on coacervate formation can be seen from **Figure 29.3**. Each of the three cationic guar samples possessed the same degree of cationic substitution (0.14), but they ranged in molecular weight from 1 million daltons (d) to 2 million d. It clearly is observed that the amount of coacervate formed increased in amount and concentration range as the polymer molecular weight was increased, despite the constancy of polymer charge density. There is a minimum polymer concentration that must be exceeded for coacervate formation to be observed. The lowest molecular weight polymer displays two islands of coacervate formation. It is suspected that this indicates two distinct

mechanisms; one relying primarily on ion-exchange between the polymer and the anionic surfactant, and the other being driven by a change in surfactant micelle size and shape.

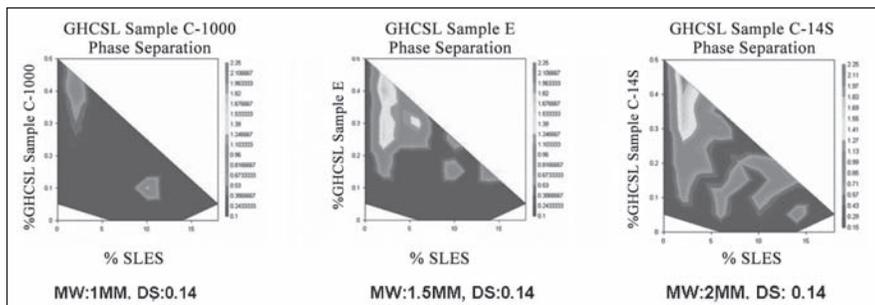


Figure 29.3. Composition diagrams showing regions of coacervate formation for GHCSL for cationic guar having the same change density but different molecular weights.

It is reasonable to assume that the interaction between oppositely charged polymer and surfactant should result in a collapse of the electrical double layers of both species. If this is the case, the response of the surfactant micelle should be to increase in size and to adopt a shape having lower surface curvature. Ultimately, the micelles might be expected to grow into lyotropic liquid crystals. Anisotropic lyotropic liquid crystals are optically birefringent; that is they rotate the plane of plane-polarized light. If lyotropic liquid crystals are present, they should be detectable by observing the compositions through crossed polarizers. This experiment was conducted for the systems shown in **Figure 29.3**. The result of the birefringence measurements are shown in **Figure 29.4**.

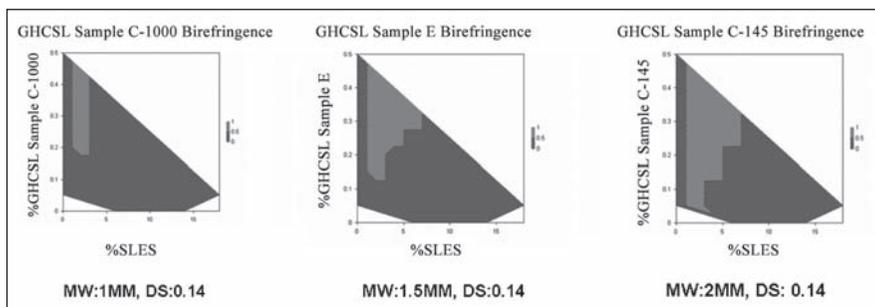


Figure 29.4. Composition diagrams showing regions of birefringent compositions for GHCSL for cationic guar having the same change density but different molecular weights. Birefringent compositions are shown in red.

It is notable that the compositional regions of birefringence correspond closely to the coacervate compositions reported in **Figure 29.3**. It was concluded, therefore, that the micellar structure of these coacervates is lyotropic liquid crystalline in nature.

Summary

Today's competitive environment demands that formulators produce tangible results at a greatly accelerated pace. Composition maps can be constructed rapidly to clearly show the effect of polymer molecular weight and charge density on the composition range of coacervation. Studies of birefringence indicate that the coacervates contain lyotropic liquid crystals. The composition maps provide valuable direction to formulators and can accelerate the development of new products and novel intellectual property.

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Hair and Amino Acids

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KEY WORDS: *amino acid, hair, interaction, damage care, luster*

ABSTRACT: *Amino acids are taken up by hair and assist in improving hair surface hydrophobicity, tensile strength and luster. This chapter discusses interactions between amino acids and hair.*

According to a rigid definition, an amino acid is an organic acid that possesses at least one amino group.¹ Almost a limitless number of molecules with various functional groups fall under this definition, but in more general terms, the definition limits the number of choices to the small group of natural L- α -amino acids that make up proteins and some other naturally occurring compounds.

Most proteins are composed of approximately 20 types of amino acids in varying proportions. Some additional amino acids are only found in special proteins; for example, hydroxyproline occurs in collagen and gelatin. All amino acid constituents of proteins are α -amino acids, referring to their molecular structure wherein the amino group is attached to the same carbon atom as the carboxyl group. Amino acids with a β -, γ - and δ - structure, or even with a sulfonate acid group instead of a carboxyl group, are found in living organisms in forms of small peptides or as free amino acids. The term *free* here is used to describe the amino acids that are not embedded in proteins.²

For most consumers, the term *amino acid* is still not as familiar as protein or vitamin, yet amino acids have been used in cosmetics for a long time. Among the various applications, the most significant is the use of natural moisturizing factor (NMF) amino acids and hydrolyzed proteins, and the latter has been used in hair care

applications for nearly 50 years.³ Several moisturizers for cosmetic applications containing amino acids were reported as early as 1983.⁴

NMF is a complex mixture of free amino acids and other low molecular weight, water-soluble compounds found in corneocytes.⁵ It is known to contribute to the maintenance of water balance in the stratum corneum. The main components of NMF are pyrrolidone carboxylic acid (PCA), lactic acid and amino acids, and it is used mainly in skin care as a powerful moisturizer.

Hydrolyzed proteins often contain free amino acids, to some extent. They are used in skin care and also are known to contribute to conditioning and protection of hair. Hydrolyzed collagen and hydrolyzed keratin are well-known, although various hydrolyzed proteins of vegetable origin have been introduced in recent years.

The properties of hydrolyzed proteins are determined by their average molecular weight and amino acid composition. Thus, it should be quite useful to understand the properties of amino acids before applying them in hair care. In this paper, the interaction and benefits of amino acids for hair are discussed.

Amino Acids and Hair Interaction

Fundamentals: Two fundamental factors can be involved in the interaction of hair and amino acids in simple aqueous solutions: diffusion and electrical charge of the molecules.

Given the small molecular size of amino acids and their hydrophilicity, diffusion is considered to play a major role in the uptake of amino acids but the hydrophobic nature of human hair is apparently a barrier for the diffusion process. Thus it is supposed that damaged hair shows higher affinity for amino acids than the natural hair due to its lower hydrophobicity. In addition, the increased number of ionic groups on the damaged hair protein will also contribute to the higher affinity. **Figure 31.1** shows the comparison of arginine uptake by natural and damaged hair. The damaged hair takes up more arginine than the natural hair.

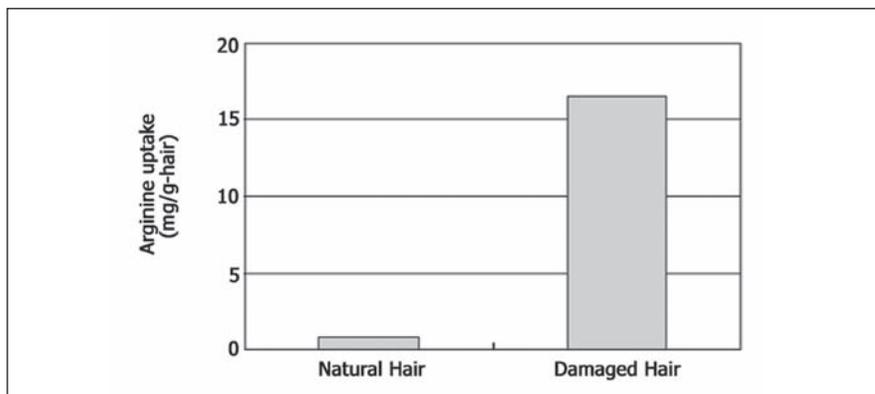


Figure 30.1. Arginine uptake by natural and damaged hair; arginine: $5.74\mu\text{M}$, pH 6, 1 min immersion @ 40°C ; damaged hair was treated with a thioglycolic acid waving lotion and a sodium bromate neutralizer

Amino acids that possess additional carboxylic groups on their carbon backbone are called acidic amino acids, and those with additional basic groups are called basic amino acids. This classification is useful to understand the nature of the interaction. Arginine is a basic amino acid that possesses a guanidinium group. The acid dissociation constant of the guanidinium group is 9.04, so it bears a cationic charge at a pH below 9. Therefore, arginine has strong affinity for hair in a pH range of 4–9. Acidic or neutral amino acids have a negative or neutral net charge in a pH range of 3–7, thus they are hardly taken up by hair (see **Figure 30.2**).

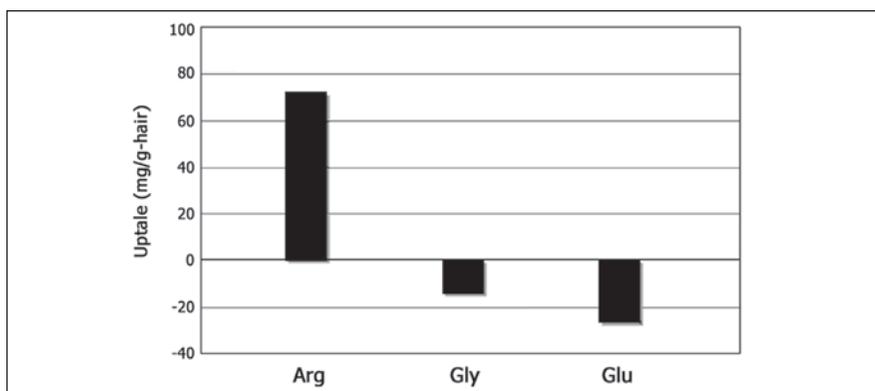


Figure 30.2. Uptake of amino acids from the aqueous solutions by waved hair; amino acid: $11.5\mu\text{M}$, 30 min immersion @ 25°C .

Above all, the guanidinium group of arginine is known to have quite a high affinity for hair protein.⁶ **Figure 30.3** shows the amount of arginine recovered from hair either by water or by acidic buffer solution (pH 3.5).

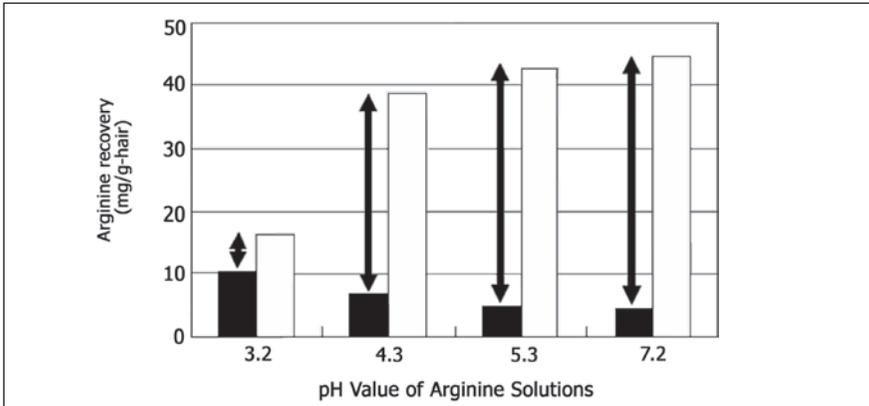


Figure 30.3. The amount of arginine recovered from intensively bleached hair by water (■) or by buffer solution (□); note how the difference of the two columns (arrows) changes depending on the pH of arginine treatment. Arginine treatment: 30 min immersion, 20 sec rinse @25°C; recovery: 30 min immersion @25°C

The arginine recovery differed between the two conditions, shown by the errors, and the difference increased as the pH of the arginine solution was increased. This difference represents the existence of a strong interaction between acidic groups on hair and arginine.

Applications: Understanding the interaction of hair and amino acids in cosmetics is much more complicated than the above described cases because cosmetic formulations are complex mixtures of chemicals. Consequently, the chemical interaction between amino acids and other ingredients has to be taken into consideration. For example, neutral glycine and acidic glutamic acid present in conditioner are also taken up by hair.

Figure 30.4 shows the amount of each amino acid taken up by hair from solutions containing different concentrations of a mixture of amino acids^a.

^a ProdeW 500 (INCI: Sodium PCA (and) sodium lactate (and) arginine (and) aspartic acid (and) PCA (and) glycine (and) alanine (and) serine (and) valine (and) proline (and) threonine (and) isoleucine (and) histidine (and) phenylalanine) is a product of Ajinomoto Co., Inc., Tokyo, Japan.

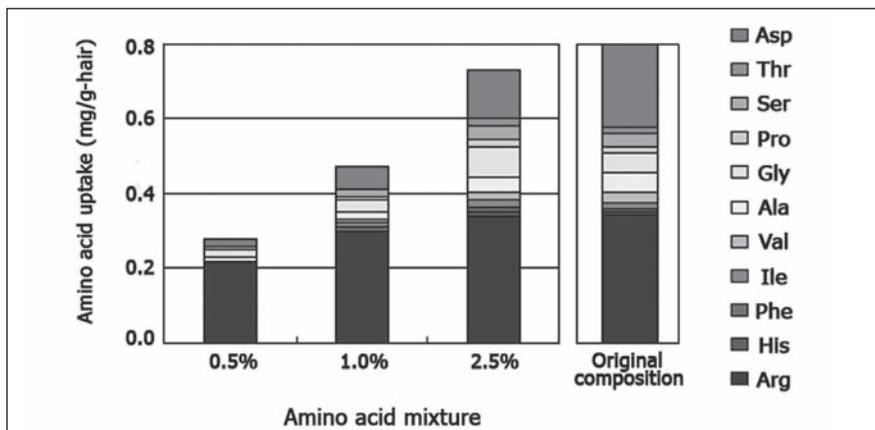


Figure 30.4. Uptake of amino acids from solutions containing a mixture of the amino acids; original mixture including amino acid composition is shown on the right; amino acid treatment: 10 min immersion, 1 min rinse, pH 5 @35°C; recovery: 30 min immersion in a buffer solution (pH 3.5) @25°C

At lower concentrations, arginine uptake predominates, and at higher concentrations, the uptake of the other amino acids increases. This hints at the possibility of arginine being used as an anchor for the deposition of other ingredients having weaker affinity to hair. One example is illustrated in **Figure 30.5**.

When PCA is applied to hair as an arginine salt, the uptake is larger than that of sodium, lysine and histidine salts.

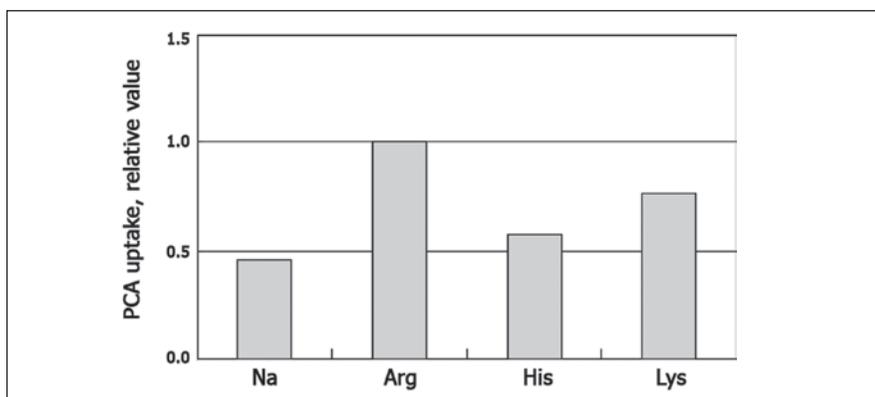


Figure 30.5. Uptake of PCA—the influence of the counter ion; PCA treatment: 0.2% w/w as the PCA salt, 30 min immersion, pH 5.4 @25°C; recovery: 30 min immersion in a buffer solution (pH 3.5) @25°C; the amounts of PCA uptake are described as the relative value against that of arginine salt

Benefits of Amino Acids

Arginine is employed as an alkalizer in oxidative coloring agents and bleaching agents to reduce the irritative odor of ammonia and to develop milder products for the hair and scalp.⁶ Arginine prevents the decrease of tensile strength and hair surface hydrophobicity that are caused by oxidative coloring. It is also reported to prevent undesirable effects of hydrogen peroxide on hair proteins and hair surface lipids.⁷ During the coloring process, a considerable amount of the arginine contained in coloring agents is taken up by hair. This residual arginine confers a moist feel to hair and prevents color loss during the shampooing process.

Damage Care

A layer of fatty acids covalently linked to the surface of hair cuticle is responsible for the hydrophobic nature of natural hair. It also provides some benefits such as the low friction, smoothness and combability to the hair.⁸ Oxidative processes cause a decrease in hair surface hydrophobicity, resulting in the lack of smoothness. Cationic surfactants and silicones are often employed to improve the hydrophobicity.

Figure 30.6 shows surface hydrophobicity of bleached hair treated with hair conditioners. The average contact angle for natural hair was 100 degrees and a four-time bleaching treatment brought it down to 65 degrees. After treatment with a stearyltrimonium chloride conditioner (STAC), the contact angle increased slightly. The addition of 1.5% w/w of L-alanine resulted in a significant increase of the contact angle to a value, similar to that obtained with a distearyldimonium chloride conditioner (DSDAC).

Several amino acids have been reported to increase the tensile strength of hair in a dry state.⁹ This reinforcement is mainly achieved by ionic and hydrogen bonds, so the effect should diminish in a wet state; however, some amino acids have proven to be effective even in a wet state. **Figure 30.7** shows the tensile strength of bleached hair measured in water. A significant increase was observed when phenylalanine and histidine were applied.

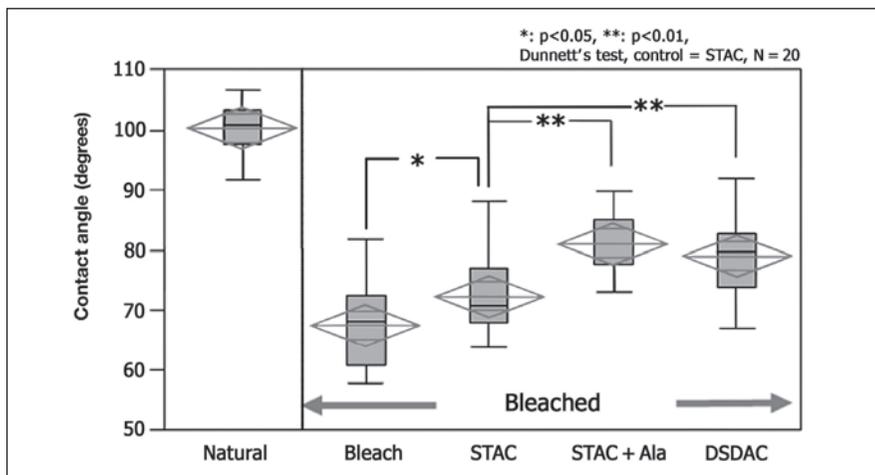


Figure 30.6. Improvement of surface hydrophobicity by alanine; conditioner formulations: cationic surfactant 0.6% w/w active, cetyl alcohol 3.0% w/w. A hair fiber was fixed in a horizontal position and 1 μL of deionized water was mounted on the point 10 cm from the hair tip end. A contact angle on which a water droplet on the fiber surface was formed was measured microscopically 20 sec later.

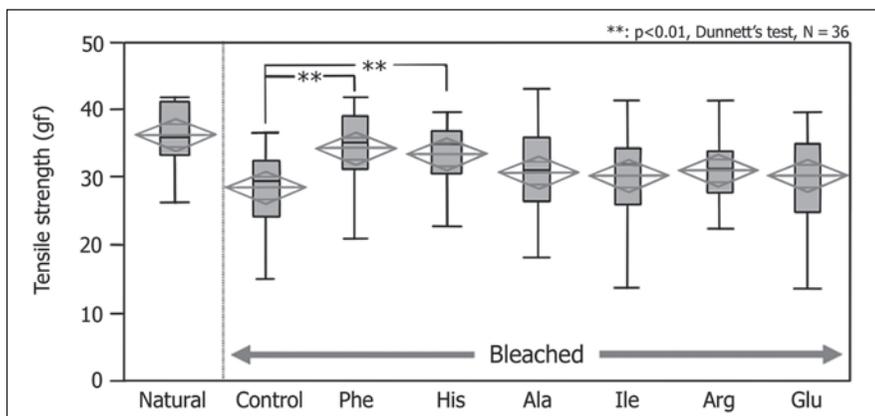


Figure 30.7. Effects of amino acids on the tensile strength measured in water; amino acid treatment: 2.0% w/w, 10 min immersion, pH 5.3 @35°C; rinse: 1 min immersion in deionized water @35°C

Improvement of Luster

Formation of *medulla*, or air-filled structures sometimes found at the center of hair shafts, and *voids*, hollow structures formed among cuticular or cortical cells, by chemical treatment and grooming is known to result in a lusterless appearance in Asian hair.¹⁰

This finding is interesting because it indicates that not only the hair surface but also its internal structure is responsible for luster. Hair luster improved by treating bleached Asian hair with an amino acid mixture (see **Figure 30.8**).

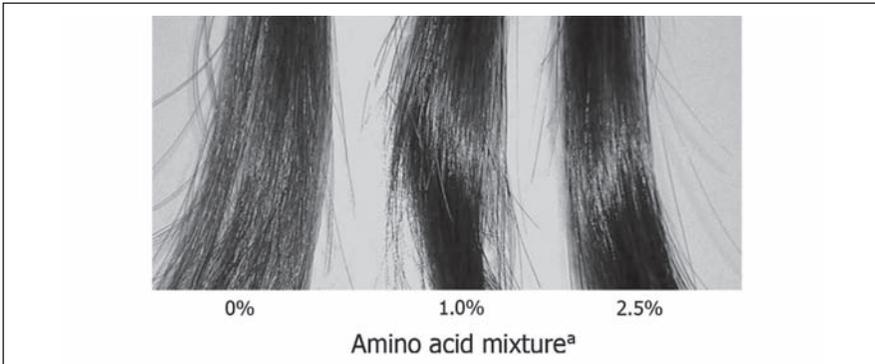


Figure 30.8. Appearance of hair tresses treated with solutions of a mixture of amino acids; treatment: 10 min immersion, 1 min rinse, pH 5 @35°C

A decrease of the light scattering lacunal structure is observed under a microscope, suggesting the amino acids penetrate and fill the void spaces to make hair shine from the inside. The moisturizing effect of amino acids is hypothesized to complement this function.

Conclusion

As mentioned, understanding the chemistry and interaction between amino acids and hair can provide a base for the development of hair care formulations containing hydrolyzed protein. However, it also should be noted that using specifically chosen, purified amino acids instead of hydrolyzed protein apparently has some advantages, such as: the possibility of avoiding odor and color problems; formation of stable products of high quality; minimizing the risk of allergic reactions; and the possibility of designing custom blends. Amino acids have been known and used as moisturizers for a long time, but because of their diverse chemical structure, they have the potential to exert a variety of functions in hair care preparations. This chapter provides only a quick introduction for the novice formulator.

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SECTION V

Raw Materials

Cosmetic formulations are clearly complicated compositions made up of many different types of ingredients that interact with each other. The nature of these interactions in many cases is the cause of the cosmetic attributes the consumer prizes. The availability of new raw materials and the understanding of how they are used in formulation can be every bit as important in formulation of highly effective personal care products. This section presents nine new raw materials and formulation techniques for their use.

- 31** Pseudo-Nonionic Surfactant Complexes in Soap Bars
- 32** Diglycerol: A Humectant with Unique Sensory Qualities
- 33** Esters from Vegetable Sources with Care Effects for Skin
- 34** A Novel Presentation of Nonionic PEG Surfactants

Pseudo-Nonionic Surfactant Complexes in Soap Bars

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KEY WORDS: *pseudo-nonionic surfactant complexes, anionic and cationic surfactants, soap physical properties, soap sensory attributes, soap irritation potential*

ABSTRACT: *Pseudo-nonionic surfactant complexes formed between anionic and cationic surfactants improved physical and sensorial attributes of soap formulations. Two complexes are described; one more stable and the other having the lowest irritation potential.*

The most commonly used substance for cleaning the skin is soap. It is understood that cleaning the skin with soap removes the skin's natural moisturizers (such as amino acids, lactic acid, urea and salts), drying the skin. This has a very negative impact on the "skin feel" perceived after washing, and attempts have been made to alleviate these harsh effects of soap by adding mildness additives to soap bars.

Anionic-cationic surfactant complexes are usually too insoluble to be used as surfactants in aqueous solutions. However, these complexes become soluble in excessive detergents. Anionic and cationic surfactants are soluble in aqueous media due to their negative and positive charges respectively. When these surfactants are mixed, the charges are neutralized and consequently the solubility is diminished. This results in the precipitation of the complex.

There have been very few studies on the physical properties of anionic-cationic complexes due to their insolubility in aqueous media. Recently, soluble pseudo-nonionic surfactant complexes were prepared by introducing large additional hydrophilic groups in anionic or cationic surfactants.¹ These charge-neutralized surfactants behave like nonionic surfactants. They exhibit cloud point phenomena unlike their ionic surfactant components and have a low critical micelle concentration.² Pseudo-nonionic surfactant complexes are more surface active than their ionic surfactant components as shown by their equilibrium and dynamic surface tension experiments. They pack at the interface more than their ionic component.²

The objective of this work was to develop mildness additives by using combinations of cationic and anionic surfactants to form complexes to improve the mildness and skin feel of a soap bar. Equally important, these surfactant complexes were also explored as agents to enhance the physical properties (hardness, slough, use-up and lather) of soap bars.

Materials and Methods

Several pseudo-nonionic surfactant complexes were prepared from the two cationic surfactants, the anionic surfactant and the anionic hydrotrope^a listed in **Table 31.1**, which also gives the abbreviations we will use for these compounds in this chapter. **Figure 31.1** shows the chemical structures of these compounds as well as the structure of sodium cocoylisethionate (SCI) used in one of our experiments.

Infrared and differential scanning calorimetry were used to establish the formation of the complexes. The complexes were then added to different soap bases for both regular soap bars and synthetic detergent (syndet) bars. The physical and sensory properties were measured to evaluate the beneficial effects of the pseudo-nonionic surfactant complex in soap bars. The bars were also tested for irritation potential using a collagen swelling assay.

^a Hydrotropes are organic compounds used to increase the solubility in water of other organic substances. They have a structure similar to those of surfactants in that they have a hydrophilic and a hydrophobic group in the molecule, but they differ from surfactants in that the hydrophobic group is short.

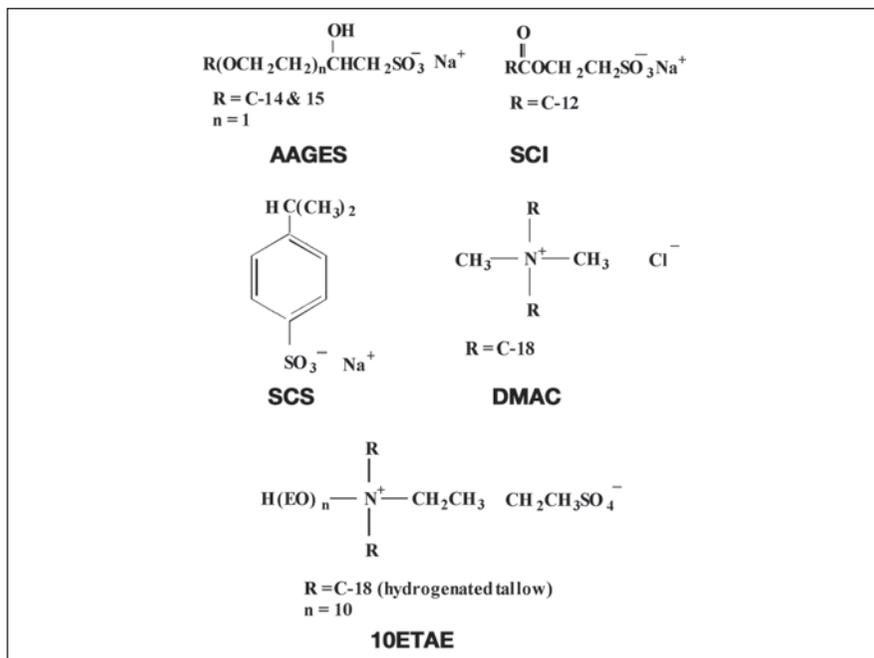


Figure 31.1. Chemical structure of the compounds cited in this chapter

Table 31.1. Surfactants and complexes cited in this chapter

Ingredients	Complexes	Abbreviation	Type
Distearyldimethylammonium chloride		DMAC	cationic surfactant
Ethoxylated ditallowethylammonium ethylsulfate		10ETAE	cationic surfactant
Alkoxylated alkyl glyceryl ether sulfonate		AAGES	anionic surfactant
Sodium cumenesulfonate		SCS	anionic hydrotrope
	AAGES + DMAC		pseudo-nonionic surfactant complex
	AAGES + 10ETAE		pseudo-nonionic surfactant complex
	SCS + DMAC		pseudo-nonionic surfactant complex
	SCS + 10ETAE		pseudo-nonionic surfactant complex

The formation of a complex between a cationic surfactant and anionic surfactant/hydrotrope brings about increased structural attributes in a soap bar. The addition of this complex was found to increase the bar hardness, believed to result from tighter packing of the molecules, as well as weaker electrostatic repulsive interactions between the hydrophilic heads. The complex also decreased the amount of slough, due to the decreased hydrophilicity of the surfactant heads resulting from the formation of a pseudo-nonionic surfactant complex. Additionally, the complex enhances lather and provides conditioning and moisturizing effects.

Analysis of Complexes

Samples of the four pseudo-nonionic surfactant complexes shown in **Table 31.1** were prepared and analyzed by infrared spectroscopy. The samples were run as KBr plates on a spectrometer.^a

The IR analysis showed the presence of a new, complexed molecule as opposed to a mixture of two components. The sulfonate stretching frequency^b was monitored for the formation of the complex, and it was determined that the sulfonate-stretching band for AAGES and SCS complexes had moved to a lower frequency as compared to AAGES and SCS separately. This indicates the removal of electrons from the AAGES and SCS by the cationic surfactants DMAC and 10ETAE, which weakens of the sulfonate bond in the complex. The sulfonate frequency of the anionic surfactant/hydrotrope and the different complexes is shown in **Table 31.2**.

Preferential Formation of SCS Complexes

Seven different pseudo-nonionic surfactant complexes were prepared by mixing equimolar amounts of the anionic surfactants/hydrotrope and the cationic surfactants listed in **Table 31.3**. The cationic surfactants were DMAC and 10ETAE. The anionic surfactants were soap (tallow/coco soap), SCI, AAGES and SCS.

^a Model 1800 IR spectrometer, Perkin Elmer, Wellesley, Massachusetts USA

^b Editor's note: Stretching frequency is an indicator of one of the types of energies involved in bond vibrations. The energy in this vibration depends on factors such as the length of the bond and the mass of the atoms at either end. Stretching frequency is one of the measurements obtained when infra-red spectroscopy is used to characterize the structure of different compounds.

Table 31.2. Infrared sulfonate frequency of the anionic surfactant, anionic hydrotrope and complexes cited in this chapter

Surfactants/Complexes	Infrared sulfonate frequency, cm-1
AAGES	1269, 1230 cm-1
SCS	1210, 1195
AAGES + DMAC	1154, 1127
AAGES + 10ETAE	1151
SCS + DMAC	1135
SCS + 10ETAE	1163, 1140

Table 31.3. Melting endotherms of the tested surfactants and complexes

Surfactants/Complexes	Peak Temperature
DMAC	68°C
SCS + DMAC	33
Soap + DMAC	78
SCS + Soap / DMAC	33
AAGES + DMAC	49
SCI + DMAC	78
SCS + 10ETAE	50
AAGES + 10ETAE	38

The formation of complexes was monitored and confirmed by the differential scanning calorimetry spectroscopy^a. The complexes had a characteristic melting endotherm that differed from that of the individual surfactants (**Table 31.3**).

Our testing of different pseudo-nonionic surfactant complexes in soap formulations showed that the SCS/DMAC complex provides the best benefit in terms of physical, sensory and foaming characteristics. SCS was added to the preformed soap/DMAC complex, and the differential scanning calorimetry spectrum was taken. The

^a DSC 7 system spectroscope, PerkinElmer, Wellesley, Massachusetts USA

anionic surfactant (soap) in the complex (soap/DMAC) was displaced by SCS (**Figure 31.2**) and the spectrum obtained was similar to the SCS/DMAC complex.

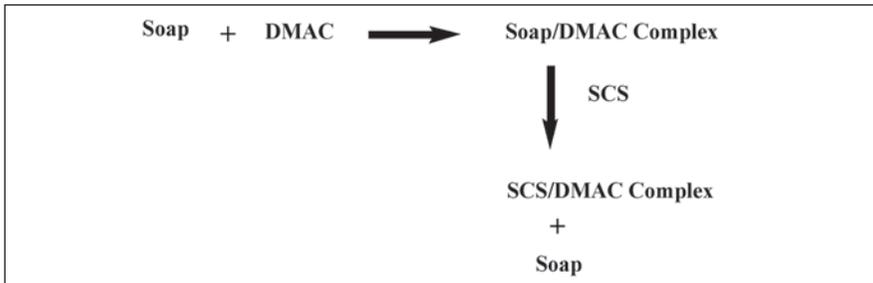


Figure 31.2. SCS displaces soap in the soap / DMAC complex

The observation that SCS/DMAC is preferentially formed was not surprising since SCS is a stronger nucleophile than soap. However, the displacement of the anionic surfactant once the complex is formed was very surprising. This information is very important. The order of addition is now not important with these surfactants in soap formulations, and the SCS can be added at any stage. This provides improved flexibility in the manufacture of different formulations.

Adding Complex to Regular Soap Bars

A 1:1 molar complex of SCS with either DMAC or tricetylmethylammonium chloride (TCAC) was prepared by premelting DMAC and TCAC and then adding SCS. The preformed complex was then added at 3.0% level to 60/40 tallow/coco soap with 7.0% free fatty acid and 10.0% water.

The pseudo-nonionic surfactant complex was added to the soap chips (60/40 tallow/coco soap with 7.0% free fatty acid) in the amalgamator. The mixture was mixed for a period of 15 minutes. The soap chips were then milled, plodded and pressed into soap bars. The results of the physical tests are shown in **Table 31.4**. The addition of the complex (SCS / DMAC or SCS / TCAC) to the soap chips improved the hardness (the lower the number, the higher the bar hardness) and slough (the lower the number, the less the amount of unwanted slough) of the bars.

The conditioning effects of the soap bar were also evaluated by different individuals who washed their hands with the bars. The conditioning effects were evaluated on a scale of 1–10 with 1 being the lowest conditioning and 10 the highest. As shown in **Table 31.4**, the addition of the complex clearly improved the skin conditioning effects of the soap bars.

The irritation potential of soap chips containing the complexes was measured by collagen swelling assay. The pseudo-nonionic surfactant complexes were made from cationic surfactants DMAC and anionic hydrotrope SCS. The soap chips consisted of 60/40 tallow/coco soap base with 7% superfatting. The pseudo-nonionic surfactant complex was added in varying amounts from 4% to 20%. Also included in this study was the 10ETAE / SCS complex. The results of this test are given in **Table 31.5**.

Table 31.4. Physical testing of regular soap bars with and without pseudo-nonionic surfactant complex

Bar	Hardness	HH Slough	Conditioning
Control bar (60/40/7)	4.13 mm	15.0 g	3
Bar with SCS / DMAC	3.40	12.2	8
Bar with SCS / TCAC	3.50	11.6	8

Table 31.5. Collagen swelling values for pseudo-nonionic surfactant complexes

Product	Avg value
Soap	8.63 $\mu\text{l}/\text{mg}$
Soap + 4% DMAC / SCS	8.88
Soap + 8% DMAC / SCS	8.85
Soap + 12% DMAC / SCS	7.35
Soap + 16% DMAC / SCS	7.68
Soap + 20% DMAC / SCS	6.90
Soap + 8% 10ETAE / SCS	7.48
Soap + 20% 10ETAE / SCS	5.54

The results of this test indicated that as the amount of complex in the soap base increased, the irritation potential of the soap decreased. However, there was no improvement observed up to the 8% complex level. The collagen swelling data showed that the 10ETAE / SCS complex is more effective at reducing irritation than the DMAC / SCS complex at the same levels (8% and 20%) of addition.

Adding Complex to Syndet Bars

The different pseudo-nonionic surfactant complexes were evaluated for use in different synthetic detergent bar formulations to improve the physical (hardness, slough, use-up and lather) and sensory properties.

DMAC was complexed with the anionic surfactants (soap, SCI) in an equimolar amount. This premixed complex was added to the remaining ingredients in **Formula 31.1**. The final mixture was mixed, flaked on a chill roll and processed into bars. The bars were tested for hardness, slough and use-up.

It is clear from **Table 31.6** that the addition of the pseudo-nonionic surfactant complex (DMAC with either soap or SCI) improved the hardness, slough and use-up (the lower the better) as compared to the control syndet bar (**Formula 31.1a**). The sensory effects (lather and skin feel) were better for the SCI complex (**Formula 31.1b**) than the soap complex (**Formula 31.1c**) in testing by a trained panel (data not shown). Therefore, the SCI complex is preferred as compared to the soap complex in the syndet formulations.

Table 31.6. Physical testing of syndet bars with and without pseudo-nonionic surfactant complex

Test	a (Control)	b (with SCI / DMAC)	c (with Soap / DMAC)
Hardness (mm)	4.04	3.65	2.84
Slough (g; high humidity)	24.1	20.4	22.6
Slough (g; low humidity)	10.5	9.2	9.5
Use-up (g)	33.9	26.7	29.5

Formula 31.1. Syndet bar

Ingredient	a (Control)	b (with SCI / DMAC)	c (with Soap / DMAC)
SCI	49.0%	49.0%	49.0%
Soap	15.0	15.0	15.0
Water (aqua)	6.5	6.5	6.5
Stearic acid	27.0	25.0	25.0
DMAC	0.0	3.0	3.0
Miscellaneous*	qs	qs	qs

* Fragrance, preservatives, etc.

The effect of adding a pseudo-nonionic surfactant complex formed by mixing SCS and DMAC was also examined in syndet formulations.³ The soap in control formulation (**Formula 31.2a**) was replaced by the pseudo-nonionic surfactant (DMAC/SCS) (**Formula 31.2b**). The physical properties of these formulas were measured.

Table 31.7 shows that the use-up and hardness measurements were significantly better with the complexed bar (**Formula 31.2b**) than with the control bar (**Formula 31.2a**). The mildness was also evaluated by collagen swelling assay, which showed the irritation potential for the complexed bar was less than for the control bar (data not shown).

The addition of this pseudo-nonionic surfactant complex (DMAC / SCS) not only makes the bar harder but also reduces the use-up rate. In addition, the bar was found to elicit more lather, less wet skin slip and less wet skin residue than the control bar in testing by a trained panel.

Table 31.7. Physical testing of syndet bars with and without pseudo-nonionic surfactant complex

Test	Formula 2a (Control)	Formula 2b (with DMAC / SCS)
Hardness (mm)	3.21	2.61
Use-up (%)	27.2	20.4

Formula 31.2. Syndet bar

Ingredient	a (Control)	b (with DMAC / SCS)
SCI	30.0%	30.0%
Soap	27.0	24.0
Stearic acid	30.0	30.0
DMAC / SCS	0.0	3.0
Paraffin wax	4.0	4.0
Miscellaneous*	qs	qs

* Water, fragrance, preservatives, etc.

Conclusions

Several pseudo-nonionic surfactant complexes formed between anionic and cationic surfactants were developed to improve the physical (hardness, slough and use-up) and sensory attributes (lather, skin feel and skin residue) of different soap formulations. Infrared and differential scanning calorimetry spectroscopy was used to establish the formation of the complex between a cationic and an anionic surfactant.

The complex formed between sodium cumenesulfonate and the cationic surfactant is the most stable and is formed preferentially over other anionic surfactants examined, providing more flexibility in the manufacture of different formulations.

The irritation potential as measured by the collagen swelling assay of these soap formulations with the addition of these complexes was also considerably reduced. The ethoxyditallow/ethylammonium ethylsulfate complexed with the anionic detergents had the lowest irritation potential among all the complexes examined.

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Diglycerol: A Humectant with Unique Sensory Qualities

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KEY WORDS: *diglycerol, humectant, flavor/fragrance impact, longevity, oral care, deodorant*

ABSTRACT: *Diglycerol is a humectant that also provides unique sensory qualities in toothpaste (improves impacted flavor and longevity of cooling and fresh breath sensation) and deodorant sticks (reduces irritation and tackiness; improves clarity, fragrance impact and fragrance longevity).*

It is always the desire of a formulator of personal care products to identify materials that will provide cost-advantageous sensory qualities to those products. Often, materials are identified for certain uses in products but can be used in other applications to create unique qualities.

Humectants are hygroscopic materials that act as moisturizers by binding water. They are important ingredients in cosmetic formulations, as moisturizers and also to prevent formulations such as creams from drying out. The ability of humectants to moisturize the skin is a function of their propensity for water absorption as well as water retention.¹

Humectants play an important role in toothpaste and deodorant sticks. It is in these two areas that we shall discuss the incorporation of a unique material: diglycerol (INCI: diglycerin).

Diglycerol

Diglycerol is a humectant consisting of two molecules of glycerol bonded by an ether linkage (**Figure 32.1**).

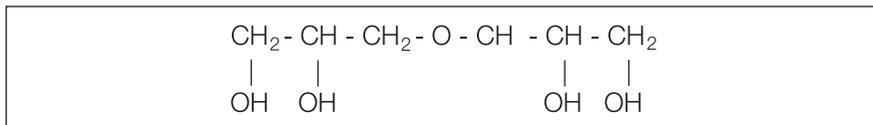


Figure 32.1. Structure of diglycerol

Diglycerol has a lower hydroxyl number than glycerol, which imparts a lower water-binding ability upon the product. Being a bigger molecule, it also has a lower rate of moisture absorption and should be retained on the skin surface for a longer period of time. Compared to glycerol, diglycerol absorbs less water, more slowly and has been claimed to have longer-lasting effects on the skin.²

If diglycerol will provide effects that last longer on the skin, could it do the same in the oral cavity? It has long been a desire of oral hygiene development chemists to design products that will provide for “long lasting” effects of cooling and fresh breath. Generally, the only means of achieving this is through costly encapsulation methods. But, what if a humectant could do the same thing? This is the question we sought to answer and prove.

High Purity Diglycerol

Polyglycerols have been known since the beginning of the 20th century. Polyglycerol fatty acid esters have been used in Europe and America since the 1940s. These esters were approved for food use in the United States in the 1960s.

Typically these polyglycerols contain several oligomers with a wide distribution. For example, polyglycerol-2 can contain as little as 30–40% diglycerol and up to 40% glycerin, the remainder of the formulation consisting of higher oligomers.

In the early 1990s, one company^a introduced a high purity diglycerol for food and cosmetic applications in European and Japanese

^a Solvay S. A., Brussels, Belgium, and in North America at Solvay Interlox, Inc., Houston Texas

markets. In early 2000, this same product was introduced to the North American market.

This high purity diglycerol, which we will call HPD, is a colorless, clear, viscous liquid much like glycerol, having almost no odor. It contains a minimum of 90% diglycerol, (principally the α,α' -diglycerol isomer), with the remainder being a combination of glycerol and triglycerol. The manufacturing process is designed to produce a high purity material, and reduce batch-to-batch variability.

This composition apparently gives the unique sensory qualities we observed when we used HPD in oral care and deodorant stick formulations.

Oral Care

Toothpaste: HPD has a higher refractive index than glycerin (1.49 vs. 1.43), which means in the clear gel toothpaste more water (refractive index = 1.33) can be used to reduce the cost of the formulation. Hydrated silica is used as both a thickener and cleaning agent, having a refractive index of 1.44 in gel toothpaste. The water:humectant ratio must match the refractive index of the silica to create a clear product. With a higher index for HPD, more water can be added to bring the combined refractive index down to the index of the silica.

We prepared two similar formulations (**Formula 32.1**). The only difference was that one contained glycerin and the other contained HPD. Both formulations produced clear gels. The gel with the HPD had a more “stringy” quality and a slightly higher viscosity (28,000 cps for the HPD gel versus 20,000 cps for the glycerin gel).

When we researchers brushed our teeth with these formulations, we discovered something very unique. The formulation with the HPD deposited the flavor onto the teeth and gums and held it there for a long period of time providing for a sustained release of flavor and cooling.

We theorized that because the diglycerol molecule is larger than the glycerin, it would have a lower dissolution rate, and will remain on the teeth and gums for a longer period of time, being more slowly dissolved by the saliva. With the flavor ingredients being entrapped

Formula 32.1. Gel toothpaste

Ingredients	A	B
Polyethylene glycol 400	3.00%	3.00%
Sodium carboxymethylcellulose	1.20	1.20
Carrageenan	0.30	0.30
Diglycerin (Diglycerol from Solvay)	35.90	–
Glycerin	–	35.90
Sodium benzoate	0.20	0.20
Sodium saccharin	0.30	0.30
F.D.&C. Blue #1, 1% soln	0.10	0.10
Hydrated silica	15.00	15.00
Sorbitol 70%	25.10	25.10
Fumed silica	0.25	0.25
Flavor	1.20	1.20
Sodium lauryl sulfate	1.15	1.15
Water (aqua), deionized	<u>16.30</u>	<u>16.30</u>
	100.00	100.00

in the diglycerol film, they will be released over a longer period of time, as is the diglycerol.

We have discovered that the HPD, in a clear gel toothpaste, first deposits the flavors directly onto the teeth and gums. Secondly, through slower dissolution of the larger diglycerol molecule, it provides a sustained release of flavor over a longer period of time (enhanced breath freshening and cooling that is longer lasting).

To further test what we found, the formulations were evaluated by our internal expert panel. This is a panel of 10 people who have been trained in the sensory evaluation of products for sweet, sour, salty, bitter and umami. The panelists brushed with both formulations on each of two consecutive days and rated each formulation for flavor impact (initial) and after each 30-second interval for a total time period of 20 minutes. As can be seen in **Figure 32.2**, the product with HPD showed a cooling effect that was approximately 50% longer than the product without HPD.

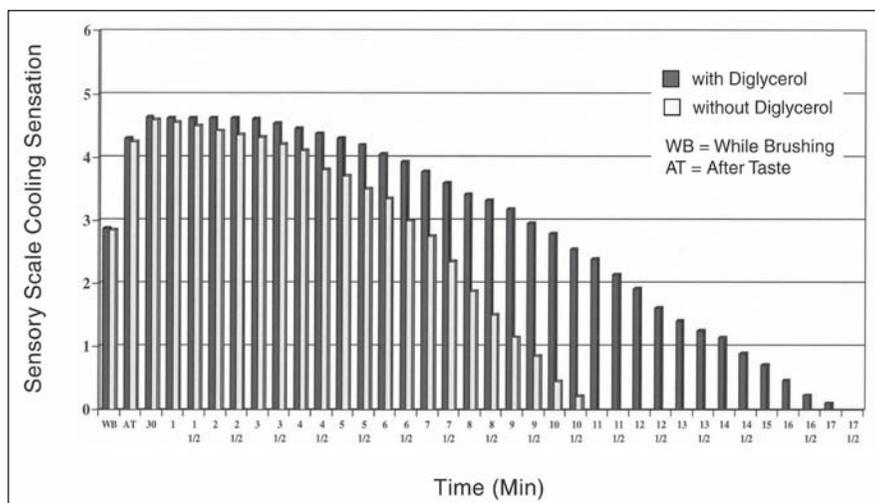


Figure 32.2. Cooling sensation evaluation of toothpastes with and without high purity diglycerol

Formula 32.2. Mouthwash

Ingredients	A	B	C
Glycerin	10.00%	10.00%	10.00%
Xanthan gum	0.12	0.12	0.12
Diglycerin (Diglycerol from Solvay)	20.00	10.00	–
Sorbitol 70%	–	10.00	20.00
Sodium saccharin	0.10	0.10	0.10
Titanium dioxide	0.10	0.10	0.10
PEG-40 hydrogenated castor oil PCA isostearate (Cremophor RH 40, BASF AG)	0.45	0.45	0.45
Flavor	0.15	0.15	0.15
Water (aqua), deionized	<u>69.08</u>	<u>69.08</u>	<u>69.08</u>
	100.00	100.00	100.00

Mouthwash: The toothpaste findings led us to evaluate HPD in a mouthwash formulation (**Formula 32.2**). We found the same results.

Conclusion: These findings are at odds with a report³ of a synergistic effect when glycerin and diglycerol were used in a skin product at a ratio of 1:1. We did not experience that in our formulations for

oral hygiene use. We did discover that diglycerol is not only an excellent humectant; it also possesses very unique sensory qualities that enhance oral hygiene formulations. We have applied for a patent on the use of diglycerol in oral hygiene products for its specific sensory qualities.⁴

Deodorant Sticks

The very surprising results generated with HPD in oral hygiene products suggested the possibility of incorporating HPD into other personal care applications, such as deodorant sticks.

Desirable properties: The consumer desires deodorant compositions that have enhanced and stronger fragrance impact and fragrance longevity. The fragrance masks the malodor that can occur at the axilla as a result of wetness and microbiological activity. Also, particularly in applications where the deodorant composition is in the form of a stick, clarity is desired.

Therefore, we tested HPD in a deodorant stick to see if—compared to traditional sticks—it provided improvements in clarity, fragrance characteristics (impact and longevity), ease of application and skin feel (e.g., reduced tackiness and stickiness), as well as reduction in irritation potential.

Findings: HPD is a clear and aesthetically pleasing product that is practically colorless and odorless and very mild to the skin. On the other hand, propylene glycol, which is traditionally used in deodorant stick-type compositions, has the drawback of generally being associated with irritation potential.

We found that deodorant compositions containing HPD have exemplary clarity, which is particularly important when the deodorant composition is in the form of a clear stick. While not wishing to be bound by any theory, we believe that this may result from the optical density of HPD which is 1.49 compared to clear gels that generally have a refractive index between 1.44 and 1.45.

We found that deodorant stick compositions containing HPD exhibit an increase in fragrance longevity and stronger fragrance impact from the stick. While again not wishing to be bound by any theory, we believe that this may result from the size of the diglycerol

molecule and its interaction with the fragrance. Because of the relatively slow dissolution rate of diglycerol, the fragrance will be maintained in the deodorant film that is formed upon application of the deodorant. Because of the size of the diglycerol molecule, it will bind the fragrance after application, and its diffusion from the film will be slower.

Finally, we observed that deodorants containing HPD have improved skin feel; there is less tack and stickiness during and after application. Again, without committing to any particular theory, we may suggest that the smooth feel of these compositions may occur because the diglycerol remains on the surface of the skin and acts as a barrier against transepidermal water loss by evaporation. Also, the deodorants containing HPD will have reduced irritation potential because the compositions either do not contain propylene glycol, or have a reduced amount of propylene glycol, compared to conventional deodorant formulations.

Examples: Deodorant compositions were prepared according to **Formula 32.3**—one with HPD and a comparison version with dipropylene glycol.

The deodorant sticks were observed for optical clarity. The stick prepared with HPD (**Formula 32.3a**) had excellent clarity; however, the comparative formulation (**Formula 32.3b**) was opaque and white in color.

The two sticks were evaluated for fragrance strength from the package and impact on skin (at initial application). The evaluation was performed by sensory perception of each stick immediately upon opening the package and upon initial application to the skin (impact on skin). The stick with HPD had better fragrance strength and impact on skin than the stick with dipropylene glycol.

The sticks were subjected to a six-hour blind fragrance study using eight expert panelists. An expert panelist is trained in sensory perception. The two deodorants were applied to different forearms of the panelists, and the panelists did not know which sample was applied to which forearm. Each panelist was asked to record which forearm had the greater fragrance intensity, or an equal amount, at application and at 1, 3 and 6 hours after application. The results are set forth in **Table 32.1**.

Formula 32.3. Clear deodorant stick

Ingredients	A	B
Tripropylene glycol	31.05%	31.05%
Dipropylene glycol	–	30.00
Diglycerin (Diglycerol from Solvay)	30.00	–
Propylene glycol	10.00	10.00
Water (aqua), deionized	19.50	19.50
Sodium stearate	6.00	6.00
Stearyl alcohol	0.20	0.20
Sodium chloride	0.50	0.50
Dimethicone copolyol	0.50	0.50
Triclosan	0.25	0.25
Fragrance (parfum)	<u>2.00</u>	<u>2.00</u>
	100.00	100.00

Table 32.1. Count of panelists (n=8) rating fragrance intensity of clear stick deodorants with high purity diglycerol (Formula 3G) as greater than, less than or equal to the fragrance intensity of a similar stick with dipropylene glycol (Formula 3H)

Time after application (hours)	Fragrance intensity ratings count (panelists)		
	3G > 3H	3G < 3H	3G = 3H
0	5	1	2
1	5	2	1
3	5	2	0
6	8	0	0

At application and at 1 hour and 3 hours, five panelists reported that the HPD stick had the greatest fragrance intensity and at 6 hours, all eight panelists reported that the HPD had the greatest fragrance intensity.

Conclusion: By incorporating HPD into a deodorant stick formulation, we improved clarity, created a stronger fragrance impact

initially and increased fragrance longevity. We also reduced tackiness, stickiness and irritation. Based upon these positive results, we have applied for a patent to cover this application in clear deodorant sticks.⁵

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Esters from Vegetable Sources with Care Effects for Skin

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KEY WORDS: *esters, glyceryl oleate, cetyl palmitate, personal cleansing products, lipid layer enhancement, moisturization, smoothness, skin elasticity, mildness, sensorial effects*

ABSTRACT: *Lipid layer enhancement, moisturization, smoothness and elasticity, mildness and sensorial effects can be achieved in skin cleansing compositions using vegetable-sourced esters, such as glyceryl oleate, cetyl palmitate and glycol distearate.*

Ingredients providing care benefits in personal cleansing products for skin and hair are becoming increasingly important. When optimum use is made of care ingredients, the positive effects on skin and hair can actively support the marketing claims of finished products. Maintaining the right balance of care ingredients and surfactant base is important in order to avoid an overload of effects that can negatively influence properties such as cleansing and lathering. In this chapter, we will focus on cleansing applications for the skin and will feature the positive effects of esters produced from vegetable raw materials as active ingredients.

Function

Esters are present as components in many products that accompany us unnoticed in our daily lives. Esters are involved in forming fragrances and flavors in wines, brandies and whiskeys. Esters are found in many food products to provide flavor and nutrition. In addition, esters are essential ingredients in leave-on cosmetic products for face and body care. By virtue of their versatility and their natural presence in human skin, ingredients with functional ester-groups provide a wide range of possible applications in personal cleansing products.

This chapter focuses on selected esters from vegetable sources, and describes their use for personal cleansing preparations with varied effects on skin and hair. These esters (**Figure 33.1**) are glyceryl oleate (GMO), cetyl palmitate (CP) and glycol distearate (EGDS).

In terms of applied technology, these selected ingredients can be classified according to their use in either of two types of cleansing formulations: clear or opaque. In general, we found that effective levels of GMO can be incorporated into surfactant-based formulations at concentrations up to 1.5% for clear product concepts. CP and EGDS, which are waxy materials, provide appreciable effects when incorporated into personal cleansing formulations as finely dispersed particles. As such, CP and EGDS are suitable for opacified or pearlized products.

A growing requirement in the cosmetic industry is the production of personal care products with ingredients that are cold-processable. GMO, CP and EGDS esters are solid materials at room temperature and therefore require significant heating and process time to utilize in

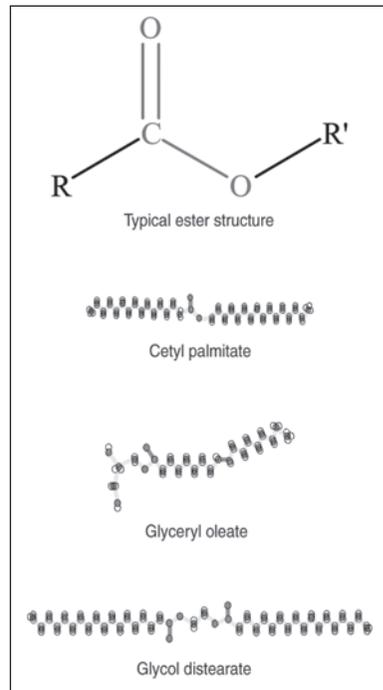


Figure 33.1. Ester structures

production. Having the option of using cold-processable ester ingredients will save time and energy costs. To meet this growing need, Cognis has developed several cold-processable liquid compounds based on these esters. For example, a cold-processable blend based on GMO (and) coco glucoside is available, as is a cold-processable wax dispersion based on EGDS (and) coco glucoside (and) glyceryl oleate (and) glyceryl stearate.

Another advantage of producing these ester compounds in easy-to-handle liquid form is the ability to consistently supply EGDS and CP wax dispersions with closely defined particles of uniform size. This aspect is very important to the final formulation's performance. In general, ester-based wax dispersions in pearlized products with a mean particle size significantly larger than 10 microns show a low effectivity on skin and hair. As the particle size decreases, the positive effects of these wax particles become more appreciable. In general we found that wax dispersions are optimal for skin and hair effects when the average particle size is less than 4 microns.

Characteristics and Application Properties of Esters

Analysis of skin surface lipids shows that a wide variety of different substances are present with the largest proportion being wax esters (approximately 25%) and ester-functional fats (mono-, di- and triglycerides, representing 43%); the remainder (32%) is cholesterol esters, squalene and free fatty acids.¹

Our investigations have revealed that small amounts of GMO can be found naturally in untreated skin. Four hours after completely removing skin lipids from the foreheads of various test subjects, these lipids were again extracted and tested for GMO-content. The results showed that there was a natural GMO-regeneration taking place with all the test subjects. Similar results were also found regarding the natural presence of CP in human skin.

In order to identify ester substances such as GMO or CP with skin care effects, we needed to ensure that during washing (**Figure 33.2**) these substances are adsorbed onto the skin from the surfactant-based cleansing formulation. This adsorption, known as lipid layer enhancement, was proven for GMO and for CP at various

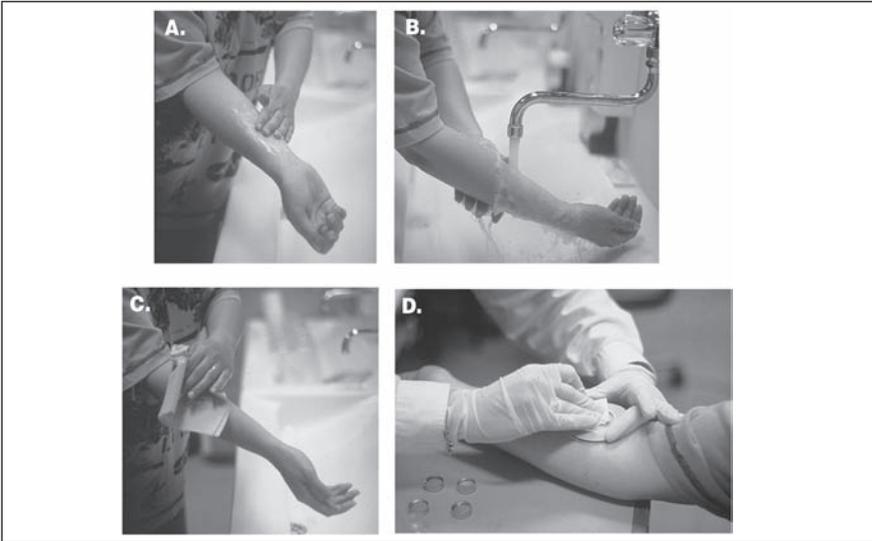


Figure 33.2. Washing of forearms for skin adsorption tests

- a) Apply 1 mL of product for 15 sec
- b) Rinse off
- c) Dry
- d) Extract with ethanol pads

ester concentrations in a 10% active sodium laureth sulfate (SLES) solution as the test formulation base. The test formulations were applied in a single wash application on the forearms of 20 persons. As mentioned before, GMO and CP are naturally present in human skin and will regenerate even after cleansing with the SLES test formula without esters. **Figure 33.3** shows that as the concentrations of these esters increase in the SLES formula, so does the level found on the skin after treatment. In addition, washing treatments over a long period of time showed a positive correlation to the frequency of use and increasing levels of GMO and CP on the skin.

Various methods have been used to extract lipids and active ingredients from the skin surface and from deeper in the skin, respectively. Superficial extraction of skin lipids can be achieved by wiping the skin surface with a cotton swab or pad saturated with ethanol. For deeper extraction, an ethanolic elution (liquid) of the skin can be used. The results of skin extractions using these methods show that GMO at 0.8%, applied to the skin in a shower gel product via a single wash treatment of several forearms, penetrates into the

stratum corneum (**Figure 33.4**). By contrast, we found using ultrasound imaging (**Figure 33.5a**) that CP appears to adsorb on the skin surface and not penetrate into the stratum corneum. Absorption effects comparable to CP can also be found when using petrolatum.²

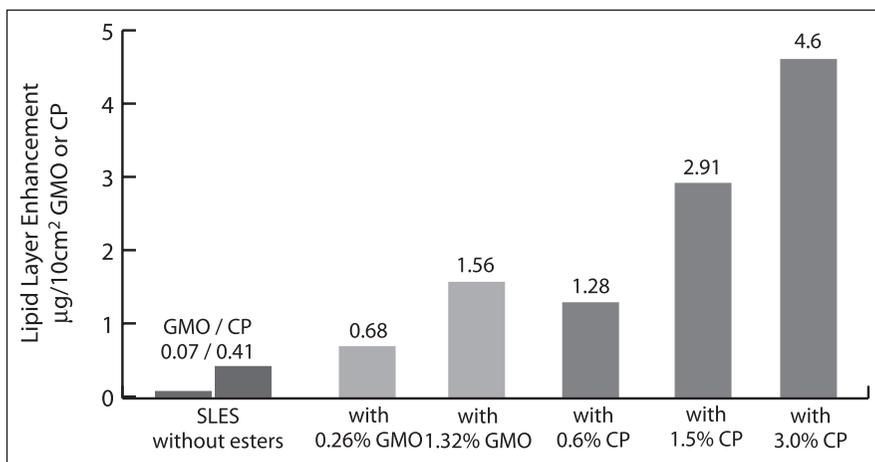


Figure 33.3. Skin adsorption of GMO or CP from 1 mL of an SLES-based personal cleanser applied for 15 sec, rinsed off, dried and extracted with ethanol pads

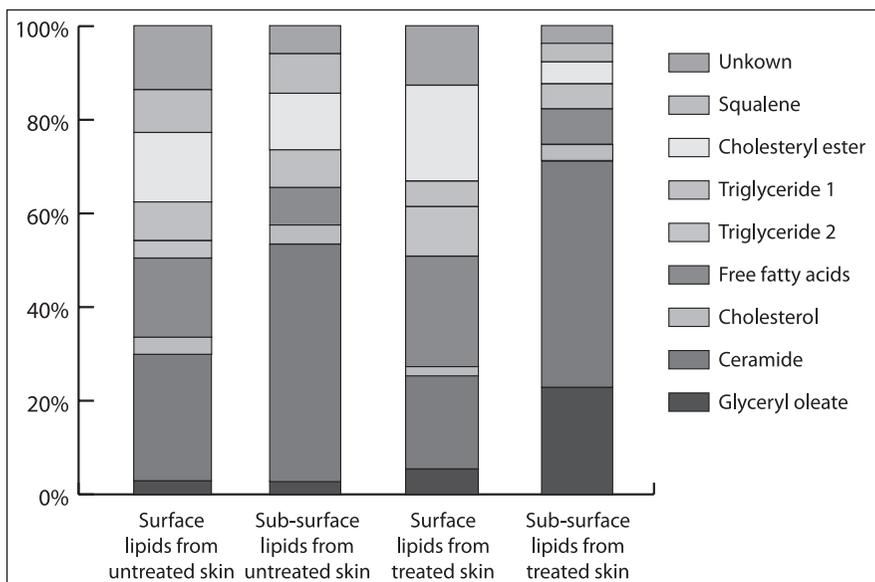


Figure 33.4. Skin penetration of GMO in treated skin washed by a surfactant-based shower gel containing 0.8% GMO

Ester Care Effects on the Skin

So far we have focused on the characteristics and application properties of these ester ingredients. Now we will focus attention on the desired effects these ingredients can have on the skin when used in personal cleansing formulations.

Skin elasticity: Dermal torque meters are used to measure the angle of skin deformation at a given torque or twisting force. By using skin torsion measurements, we can see the positive effects of GMO and CP at relatively low levels in a 10% active SLES test formula. Any change in torsion allows us to draw conclusions regarding skin elasticity, suppleness and, indirectly, the moisture content of the skin. In our in vitro torsion study using test skin (i.e., pig epidermis) we found that the negative effect of SLES on skin elasticity is significantly reduced by incorporating GMO or CP in the SLES test formula. When four different test skin samples were washed one time with SLES alone, there was a significant reduction in elasticity as indicated by a large negative change in skin torsion (i.e., 32% less torsion) when compared to the unwashed skin condition. Similarly, test skin samples washed with GMO (1.3%) and with CP (0.6%) in the SLES test formula exhibited significantly less negative change in skin torsion, (i.e., 9% less and 17% less torsion, respectively). In fact when CP was tested 1.5% in the SLES test formula, a positive change in skin torsion resulted (i.e., 7% more torsion). This result indicates that CP can even improve the elastic condition of the skin compared to its untreated condition.³

Skin smoothness: Other changes in skin structure can be monitored by the FOITS method (Fast Optical In-vivo Topometry of Human Skin) (**Figure 33.5b**). The skin smoothness of 30 test subjects was significantly improved by using a GMO-containing shower gel formula (**Formula 33.1**) applied to the forearms during washing over a period of 3 weeks.⁴ Three times each day the forearms were washed for 30 sec with 0.5 mL of the product with and without GMO, followed by water rinse off and gentle wiping. FOITS measurements were taken on day 1 before the start of treatment, again four hours after the final treatment on day 21, and again on day 22 at 24 hours after the final treatment.

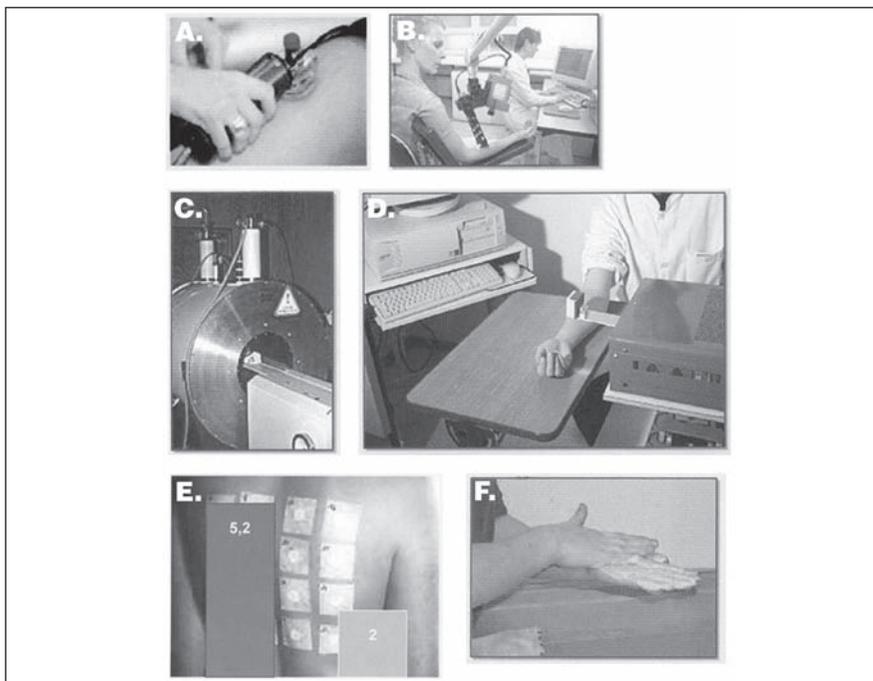


Figure 33.5. Measurement techniques

a = Ultrasound (50 MHz)

b = FOITS

c = MRI (2.35 Teslas)

d = Corneo-spinometer

e = Patch test

f = Sensory assessment

Formula 33.1. Shower gel test formulations for FOITS study

	(no GMO) % wt active	(with GMO) % wt active
Sodium laureth sulfate	11.2	11.2
Cocamidopropyl betaine	1.6	1.6
Cocoglucoside	1.9	1.9
Glyceryl oleate	-	0.8
Preservative	0.1	0.1
Fragrance (parfum)	0.3	0.3
Water (aqua)	qs 100.0	qs 100.0
pH value	5.5	5.5
viscosity (mPa.s)	5000	5000

When using the GMO-containing shower gel, an improvement in skin smoothness was measured by a reduction in surface depth and micro-roughness as indicated by FOITS analysis. **Figure 33.6** shows that after three weeks of treatment, the skin surface was nearly 2% rougher (compared to pretreatment conditions) when forearm skin was washed with the shower gel formula without GMO. At the same time it was more than 1% smoother (again compared to pretreatment conditions) when washed with the same shower gel formula containing GMO. In fact, the skin was slightly smoother after three weeks of treatment with the GMO-containing shower gel than skin that was not treated at all. This result indicates that GMO can actually mitigate the skin roughing and related drying effect of SLES-based personal cleansing products. It is interesting to note that the FOITS results obtained 24 hours after the last application (i.e., day 22) indicate this improvement is not just a short-term effect.⁵

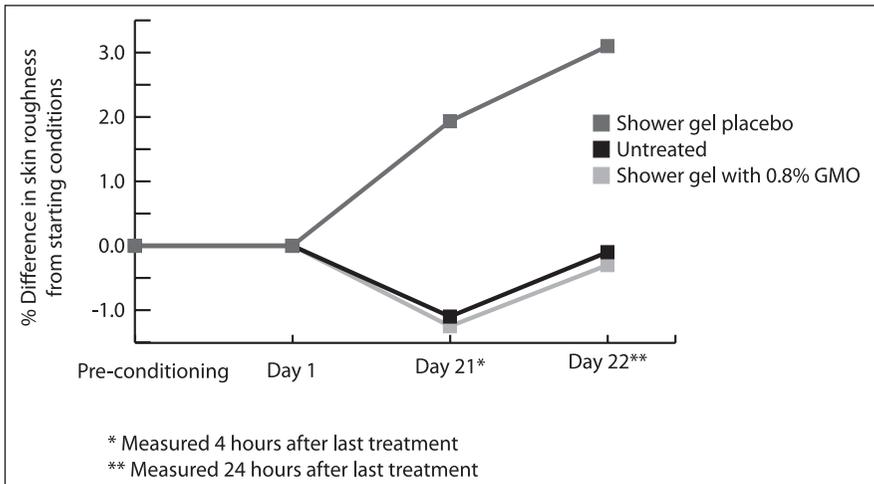


Figure 33.6. Percentage difference in FOITS measurement of skin surface roughness, compared to pre-treatment conditions, for forearm skin treated with a shower gel (Formula 1) with and without 0.8% GMO

Moisturization and skin suppleness: One of the most important effects these ester ingredients can have in personal cleansing products is improved skin moisturization. Because such an effect is relatively small in rinse-off applications, a very sensitive method must be utilized. MRI (Magnetic Resonance Imaging) (**Figure 33.5c**)

enables precise measurements of skin moisture and provides reliable results that are independent of climatic influences. An increase in epidermis transversal relaxation time T2 which measures bound water of hydration corresponds to an increase in the skin moisturizing effect.^{6,7,8}

The skin test areas in this MRI study were additionally tested with a corneo-spinometer (**Figure 33.5d**). This device tests skin elasticity in a manner similar to the earlier skin torsion measurements. The result is expressed by a Dynamic Spring Rate (DSR), which is the ratio between constant mechanical torque (force) and angular skin deformation (variable). A decrease of DSR corresponds to an improvement of stratum corneum suppleness due to better hydration.

For these tests, the shower gel formula (**Formula 33.2**) with and without GMO (1.3%) was applied to a 25-cm² area on the forearms of 10 test subjects once each day during washing over a period of two weeks. The forearms were washed for 10 sec with 1.0 mL of **Formula 33.2** (with and without GMO), after which they were rinsed for 20 sec and then gently dried. As with other testing procedures, it is necessary to pre-condition the skin of test subjects at the beginning of the study.

Formula 33.2. Shower gel test formulations for MRI and corneo-spinometer studies

	(no GMO) % wt active	(with GMO) % wt active
Sodium laureth sulfate	11.2	11.2
Cocamidopropyl betaine	1.6	1.6
Cocoglucoside	1.9	1.9
Glyceryl oleate	-	1.3
Preservative	0.1	0.1
Fragrance (parfum)	0.3	0.3
Water (aqua)	qs 100.0	qs 100.0
pH value	5.5	5.5
viscosity (mPa.s)	5000	5000

T2 measurements were taken on day 1 before the start of treatment, again at 24 hours after the final day 14 treatment, and again at 48 hours after the final day 14 treatment. Waiting 24 hours and 48 hours after final treatment allows for a more accurate moisture reading by avoiding the short-term hydration influence on the skin due to the washing treatment and water rinse.

Results of the two tests (**Figures 33.7 and 33.8**) confirmed the positive influence of GMO in the shower gel (**Formula 33.2**) to improve the skin condition of our test subjects. In the MRI study, the ΔT_2 results comparing the shower gel with GMO treatment ($\Delta T_2 = +4.41$) to the placebo ($\Delta T_2 = +2.49$) show a significant skin moisture increase after 24 hours (day 15). Similar results were found after 48 hours (day 16). In addition, the corneo-spinometer results show the skin elasticity of test subjects improves significantly with the GMO formula treatment compared to the placebo. It should be noted that the long-term positive effect of GMO is confirmed by the 48-hour values of both the MRI and corneo-spinometer studies.

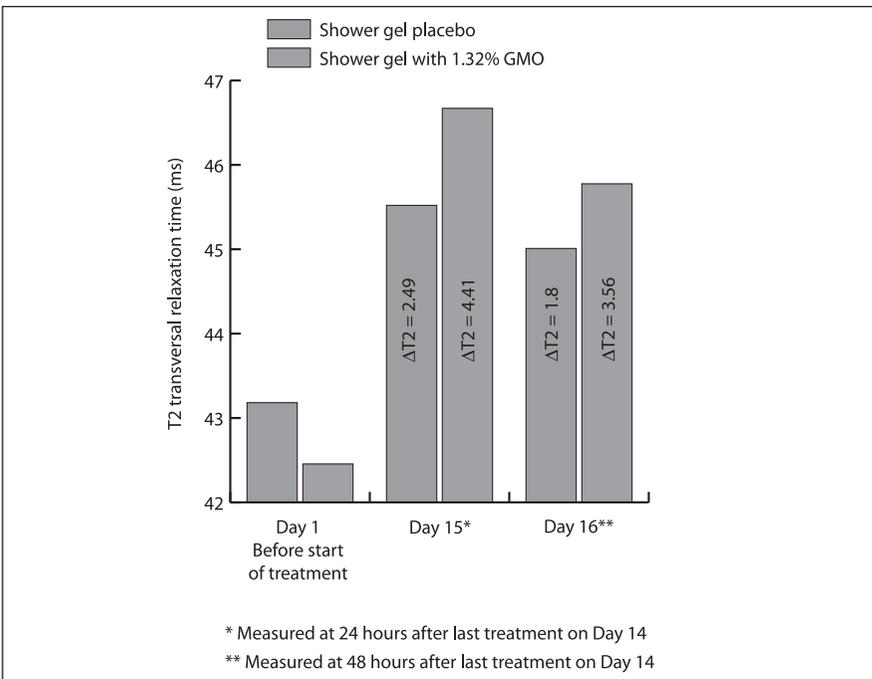


Figure 33.7. Differences in MRI T2 relaxation time for forearm skin treated with a shower gel (Formula 2) with and without 1.32% GMO

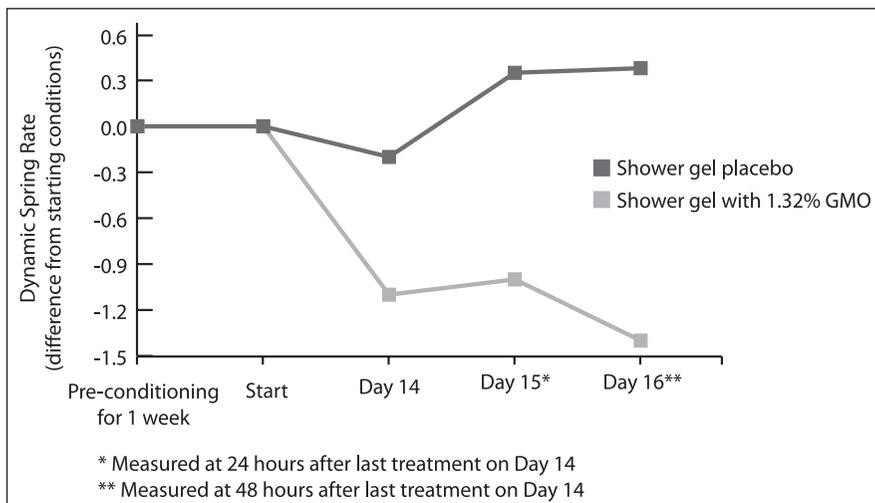


Figure 33.8. DSR measurements of forearm skin treated with a shower gel (Formula 3) with and without 1.32% GMO

Skin mildness: Another important effect ester ingredients can provide when formulated into personal cleansing products is improved skin mildness. For example, incorporating GMO in a shower gel SLES surfactant-based composition (**Formula 33.3**) significantly reduces skin irritation as measured by in vivo patch testing (**Figure 33.5e**). Using the Finn Chamber test method, the shower gel **Formula 33.3** with and without GMO was applied to the back of 20 test subjects under occlusive conditions for 24 hours. The shower gel was tested at 5% actives, which is a common test concentration for personal cleansing products.

Skin reactions were evaluated at various time intervals (6, 24, 48, 72 hrs) after the patches were removed and the observed reactions were rated in terms of reddening (erythema), swelling, scaling, and fissures. The sum of the ratings for each irritation classification were reported. The higher the score, the greater the irritation. For our purposes, the erythema-based irritation scores are most relevant. These scores were 5.2 for the shower gel without GMO and 2.0 for the shower gel with GMO. We know from experience that the shower gel formula without GMO is considered relatively mild to skin. Addition of GMO significantly lowered the erythema score of this formula by 3.2 units (60% reduction), making this shower gel composition even milder to skin.

Formula 33.3. Shower gel test formulations for skin mildness study

	(no GMO) % wt active	(with GMO) % wt active
Sodium laureth sulfate	11.2	11.2
Cocamidopropyl betaine	1.6	1.6
Cocoglucoside	1.9	1.9
Glyceryl oleate	-	0.9
Preservative	0.1	0.1
Water (aqua)	qs 100.0	qs 100.0
pH value	5.5	5.5
viscosity (mPa.s)	5000	5000

Sensory assessment: In our final evaluation, sensory assessment was used to prove the skin care benefits of an EGDS wax dispersion with particle sizes in the 2-4 micron range. Here (**Figure 33.5f**) we evaluated the foam properties and skin feel of a shower gel (**Formula 33.4**) containing EGDS at 1.1% and at 2.2% versus a standard

Formula 33.4. Shower gel test formulations for sensory assessment

	With 1.1% EGDS % wt active	With 2.2% EGDS % wt active	Standard % wt active
Sodium laureth sulfate	8.7	8.7	8.7
Cocamidopropyl betaine	2.9	2.9	2.9
Cocoglucoside	1.3	1.3	1.3
EGDS wax dispersion	1.1	2.2	-
Cationic polymer	0.2	0.2	0.2
Styrene/acrylates copolymer	-	-	1.2
Preservative	0.1	0.1	0.1
Fragrance (parfum)	0.3	0.3	0.3
Water (aqua)	qs 100.0	qs 100.0	qs 100.0
pH value	5.5	5.5	5.5
viscosity (mPa.s)	5000	5000	5000

(shower gel without EGDS). To assess the sensory performance of the shower gel samples, 10 trained panelists were used. These panelists evaluated each test product versus the standard using hand washing to evaluate foam properties and forearm washing to evaluate the skin feel after drying.

Figure 33.9 clearly illustrates the sensory performance of the shower gel is dependent on the EGDS concentrations used. Addition of 1.1% EGDS to the shower gel formula provides a positive effect on the flash foam and foam volume, and directional improvements in creaminess, foam stability, and skin feel. Increasing the EGDS to 2.2% decreases the foam properties while significantly improving the perceivable skin care effects after drying. Positive sensory results can also be gained using GMO and CP in personal cleansing products.

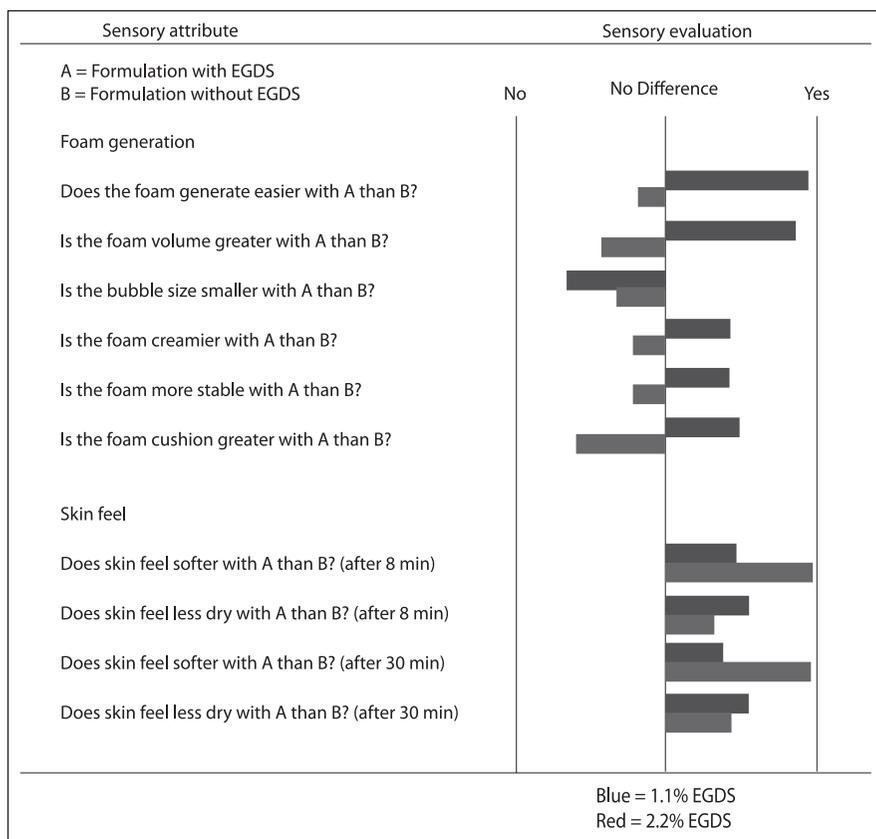


Figure 33.9. Sensory assessment of foam characteristics and skin feel of skin washed with a shower gel (Formula 4) with 1.1% or 2.2% EGDS wax dispersion

Summary

The positive effects of these vegetable-based esters on skin have been confirmed by these evaluations. When used in personal cleansing formulations, GMO, CP and EGDS can provide valuable skin care benefits including lipid layer enhancement of the skin, improved skin elasticity and smoothness, increased skin moisture and reduced irritation. In addition, our sensory assessment shows these esters can provide perceivable effects.

When optimum use is made of these ester ingredients in cleansing formulations, the positive effects on skin can actively support the marketing claims of finished products.

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Compiling, understanding, and interpreting the results of this work required significant effort from many contributors. The authors would like to thank the Cognis colleagues from the departments of Applied Technology and Performance Testing, whose contributions made this comprehensive study possible.

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A Novel Presentation of Nonionic PEG Surfactants

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KEY WORDS: *PEGs, nonionic surfactants, formulating, direct comparisons, pH, viscosity, Hydrophilic/Lipophilic Balance (HLB)*

ABSTRACT: *The authors develop data on 10 attributes of 16 naturally derived PEGs and suggest a presentation technique by which the formulator may view two measured attributes simultaneously.*

Polyethylene glycol ingredients (PEGs) are often used in cosmetics to impart various properties to a formula. Choosing the best PEG for the desired formula is currently done by educated trial-and-error, which adds much time to the development cycle. To reduce the time involved in selecting the best PEG, we measured 10 important attributes of 16 commonly used, naturally-derived PEGs. We present these quantitative results in such a way that a formulator can simultaneously view two attributes of the PEGs at once. This presentation significantly facilitates the choice of the best PEG for the product being developed.

The PEGs we examined in this study are the products of ethoxylated natural oils.¹ They are nonionic and have properties unlike other classes of surface-active agents; this makes them valuable to cosmetic formulators. As the name “nonionic” implies, these PEGs do not dissociate into ions, nor do they carry a positive or negative charge.² These 16 nonionic PEGs are primarily employed in cosmetics and personal care product formulation as emulsifiers,

conditioning agents, and solubilizers.¹ A variety of natural PEGs were chosen, from tropical (macadamia) to desert (jojoba) plants, including both trendy (soy) and classic (castor, lanolin) cosmetic ingredients. **Table 34.1** lists the 16 analyzed PEGs.

For each PEG, we examined 10 attributes (**Table 34.1**), each of potential importance to a cosmetic formulator. Basic tests included measurements of pH, viscosity and solubility. Characteristics that are more descriptive of the PEGs functionality in cosmetic products were also evaluated, such as HLB, clarity in water and moisturizing properties. These 10 attributes are:

- HLB (reported by manufacturer);
- pH of the PEG in 5% aqueous solution;
- Viscosity of the PEG in a 5% basic surfactant solution;
- Skin moisture at 1 hour of 5% aqueous solution;
- Skin moisture at 6 hours of 5% aqueous solution;
- Amount of foam from PEG at 0.35% with 0.25% SLS aqueous solution;
- Clarity of the PEG at 5% in water;
- Clarity of the PEG at 5% in a stearate stick;
- Slip of the PEG on glass plate;
- Spread of the PEG on filter paper.

The importance of each attribute will depend upon the system being formulated, and its desired properties. For example, the foam and clarity attributes of the raw material are obviously not serious considerations when formulating a lotion, but the HLB and moisturizing attributes of the PEG are probably important. When formulating a shampoo however, the foam and the clarity of the application are often essential. That is why we included a variety of PEG attributes in the study, so that we could cover a wide use of PEGs in the cosmetic industry.

The Basics

pH: The pH of each PEG in a 5% aqueous solution was measured. As expected, the range of pH values was quite narrow; all the results have a pH in the expected cosmetic range. The average pH is 5.5.

Viscosity: The viscosity of the test PEGs was measured in a solution of 5% test PEG, 28% sodium lauryl sulfate and 0.2% sodium chloride in water. The viscosity of each PEG at 5% in a basic surfactant solution provides information on how the selected PEG will affect the formulation. When formulating, a desirable consistency can be achieved in a number of ways. Selecting raw materials that aid in thickening a cream or thinning a shampoo can facilitate the process. The viscosity measurements are reported in units of natural log of centipoise.

HLB: The Hydrophilic/Lipophilic Balance (HLB) was included in the comparison graphs. The values used are those reported by the manufacturers of the included PEGs. Selecting the best emulsifier can be difficult and knowing the HLB value of the PEGs being considered for a formulation helps reduce trial and error. HLB values help formulators by simplifying the choice of possible surfactants to meet the constraints of the emulsion.

Moisture Measurements

When formulating a moisturizing personal care product, the moisturizing impact of a PEG alone will help in selection of a PEG that will best enhance the formulation. The moisture properties of an aqueous solution containing 5% of the test PEG was measured on several participants after one hour and again six hours after the application of the solution to evaluate the ability of the PEGs to enhance moisture retention on the skin. The measurements were taken using a dermatological laboratory instrument^a on the participant's forearm and then compared to a control reading. Both the one-hour and six-hour moisture results reported are the average of six trials of each solution.

The skin moisture measurements of the PEGs alone (**Table 34.1**) will enable formulators to better predict the immediate and longer-term skin feel that the inclusion of one of the PEGs will have on their products. The results were reported as percentage over the baseline. A substantial range of results was obtained. Sample F, whose one-hour moisture measurement was more than 10% higher than

^a Nova DPM 9003, NOVA Technology Corporation, Portsmouth, NH

Table 34.1. PEGs and tests in this study

PEGs TESTED INCI Name	HLB	THE BASICS				MOISTURE MEASUREMENTS			
		pH	Viscosity		One hour		Six hours		
			n = 3	sd	n = 6	sd*	n = 6	sd*	
A PEG-7 Glyceryl Cocotate ^a	12.0	6.1	6.65	0.00	150	36.9	131	23.5	
B PEG-10 Olive Glycerides ^b	13.0	6.0	6.16	0.00	149	24.8	136	27.1	
C PEG-10 Soy Sterol ^c	12.0	4.2	4.93	0.03	156	35.3	134	14.1	
D PEG-10 Sunflower Glycerides ^d	8.0	6.9	4.87	0.01	144	34.5	138	34.3	
E PEG-16 Hydrogenated Castor Oil ^e	8.5	4.7	4.30	0.07	143	40.9	115	23.1	
F PEG-16 Macadamia ^f Glycerides	13.0	6.2	4.62	0.01	185	43.6	151	33.8	
G PEG-18 Glyceryl Oleate/Cocotate ^g	12.0	4.0	6.34	0.01	156	34.4	125	13.0	
H PEG-24 Hydrogenated Lanolin ^h	14.5	4.9	4.17	0.00	145	28.5	130	8.6	
I PEG-25 Hydrogenated Castor Oil ⁱ	10.8	6.8	4.08	0.00	159	34.1	130	31.9	
J PEG-40 Castor Oil ^j	13.3	6.2	5.21	0.00	136	20.9	117	29.5	
K PEG-40 Hydrogenated Castor Oil ^k	15.0	6.0	3.95	0.00	160	21.8	137	16.3	
L PEG-60 Almond Glycerides ^l	15.0	6.4	5.12	0.00	141	27.6	122	24.6	
M PEG-75 Lanolin ^m	15.0	5.2	3.50	0.00	118	21.1	106	9.6	
N Jojoba Wax PEG-80 Esters ⁿ	17.0	5.2	3.87	0.01	112	20.3	110	18.3	
O Jojoba Wax PEG-120 Esters ^o	18.0	5.7	3.74	0.00	154	58.3	128	40.9	
P PEG-200 Hydrogenated Castor Oil ^p	15.5	4.0	4.33	0.04	118	23.3	117	17.7	

Supplier: ^aCognis, ^bInolex, ^cCognis, ^dFloritech, ^eJeen, ^fFloritech, ^gGoldschmidt, ^hFanning, ⁱUniqema,

FOAMING IMPACT		Water Friendly?				More Methods			
Foam		in Water		in Stearate		Slip		Spread	
n = 2	sd	n = 4	sd	n = 4	sd	n = 4	sd	n = 4	sd
275	0.0	29.3	9.3	43.8	1.9	80.1	0.75	15.5	1.0
250	0.0	90.8	1.0	31.8	1.7	78.5	1.08	16.3	2.7
250	0.0	6.0	2.2	10.3	2.1	77.0	0.91	15.4	3.3
200	0.0	14.7	0.6	49.0	5.3	76.8	0.65	10.2	2.0
250	0.0	2.0	0.8	12.3	3.9	77.6	1.60	20.8	1.6
300	0.0	95.3	1.3	45.6	2.9	75.5	0.58	22.0	3.1
225	0.0	10.8	1.5	31.0	1.7	71.9	3.12	19.9	2.5
263	12.5	84.8	7.9	49.0	5.0	78.8	0.96	16.6	3.9
350	0.0	96.0	3.2	34.6	2.9	79.0	0.41	18.1	3.3
288	12.5	94.8	2.1	38.0	6.9	80.0	0.71	21.7	2.2
400	0.0	72.5	7.9	38.3	1.0	75.1	0.25	19.7	4.4
300	0.0	93.8	3.5	43.3	2.6	77.9	1.31	18.9	4.8
513	14.0	88.0	2.9	52.0	2.2	77.1	1.11	24.3	4.8
488	12.5	96.5	3.1	41.9	1.4	79.6	1.03	26.2	4.8
463	12.5	98.8	1.5	45.3	1.0	78.9	1.11	23.5	5.0
300	0.0	83.5	5.7	28.3	2.6	76.8	1.19	28.0	1.2

any other PEG, was the highest moisturizing sample at one and six hours. The lowest moisturizing samples were Samples M and O.

Foaming Impact

When cleansers are being formulated, the foaming that results is important. PEGs are not regularly employed as foaming agents, however the formulator may find it useful to consider the impact the inclusion of a PEG will have on foaming. The Foam Test, a Floratech method based on two ASTM methods^b, was conducted. The solution tested was 0.35% test PEG and 0.25% sodium lauryl sulfate (SLS) in water. The solution was blended for five minutes and the total volume of the solution and foam was recorded. This test measures the degree to which the PEG in question may alter the foam characteristic of a cosmetic formula.

The values obtained for each PEG can be compared to the foaming of the standard solution, containing no PEGs, to give formulators an idea of the impact the different PEGs will have on the foaming property of the material being produced. When developing a shampoo or body wash, the formulator can enhance the amount of foam produced by proper selection of the PEG. The lowest-foaming sample was Sample D; at 200 milliliters, Sample D was 50 milliliters below the foam output of the next lowest-foaming sample. Samples M, N and O each produced more than 450 milliliters of foam after blending.

Water Friendly?

The water solubility and clarity in water of nonionic surfactants can range considerably, depending on the length of the polyoxyethylene chain that contains the hydrophilic groups. The clarity at 5% in water and the clarity in a stearate stick were measured by spectrophotometer and are reported as percent transmittance (**Table 34.1**).

There was a substantial range of clarity resulting when 5% of each PEG was incorporated into an aqueous base. The results varied from

^b ASTM D3601-88 Foam In Aqueous Media (Bottle Test) and ASTM D1173-53 Foaming Properties of Surface-Active Agents

the clear 98.8% transmittance of Sample O to the cloudy 2.0% transmittance of Sample E.

The transmittance of the PEGs was also measured at 5% in a stearate stick. A stick formulation was made of 5% test PEG, 50% propylene glycol and 8% sodium stearate in water. The clarity measurements of the PEGs in stearate had a narrower scope, ranging from 10.3% to 52.0% transmittance.

The effect of clear shampoos, liquid soaps and gels is substantially reduced when the product contains any cloudiness. The inclusion of one ingredient that has low transmittance will affect the visual impact of a product even if it is added at a low percent. Therefore, when formulating clear applications, the clarity of the PEG added is important to consider.

Slip and Spread

The slip and spread values for a cosmetic ingredient reveal important information about the benefits of its inclusion in a formulation. The skin feel prediction of these tests are valuable when formulating. To measure slip and spread, we conducted two additional tests on the PEGs.

Slip: The slip test is conducted on a Chatillon Break Strength instrument that we modified (**Figure 34.1**) to determine the angle at which a material will facilitate slip. The basic test involves placing a disk coated with the test material on a glass plate, which is subjected to a gradual increase in incline. The angle at which disk slips on the plate is measured and the complement angle is reported as the resulting slip value.

A higher slip value (complement of slip angle) indicates a more slippery material. This property can be useful in formulating because the slip value can be translated into an ease-of-application



Figure 34.1. Modified Chatillon break strength instrument

measurement. For example, a lip balm or massage oil formulation benefits from a higher slip value, because the measurement implies that the application of the material will be smoother. The slip values for raw materials can aid formulators who want to produce a final product with a slippery skin feel or a dry, non-slip feel. Higher slip values also indicate good “payout” of a product. “Payout” refers to how well a product provides coverage; for example a lipstick with good “payout” has an even application of color.

The slip test was conducted on a solution containing 5% of the test PEG in propylene glycol. The reported slip results (**Table 34.1**) are the average of four tests conducted on each PEG solution. By comparing the slip values of different PEGs a formulator has a factor to consider when choosing an appropriate PEG ingredient.

Spread: The spread test assesses the spreading properties of cosmetic ingredients. It enables a formulator to characterize materials based on how easily the raw materials spread. If a formulator is developing a lotion that needs to spread evenly and uniformly, the spread data for raw materials can save time and development efforts. This can be useful when making a sunscreen formulation for example. It is important that the raw materials in a sunscreen have an even and thorough spread for the active ingredients to be effective. In other cases a lack of spread may be beneficial, such as in color cosmetics when it is desired that the material remain where it is applied.

In this study, we have defined the spread value of a raw material as the ability to migrate uniformly on a porous surface in a defined length of time. The medium used to measure the spread of the samples is filter paper. The filter paper is uniform in grain, texture and thickness and has a consistent weight, in milligrams per sheet. The filter paper was selected as a lab test substitute for porous human skin. The filter paper is placed on a base used to eliminate any variability in lab bench surfaces. The surface must be flat and smooth to avoid influences of gravity on the rate of spread. Hard marble surfaces differ from wooden and Formica surfaces; each has a different degree of porosity, which may affect the spread of the liquid through the paper. A known volume of the sample is applied

to the center of the paper in uniform drops. The liquid is allowed to spread on the paper for a period of 10 minutes, following which the spread value is determined by measuring the percent spread by weight. The reported spread result for each PEG is the average of four separate tests.

The samples were tested in an aqueous solution containing 5% of the test PEG. The PEGs' spread values (**Table 34.1**) ranged from approximately 10% to 28%. The PEG with the lowest value was Sample D at 10.2%; the next lowest value was for Sample C at 15.4%. The highest spreading PEG sample was Sample P.

Direct Comparisons

Once the results for all 10 attributes of the 16 PEGs were obtained, the purpose of the project was accomplished by making direct comparisons of the PEGs. The tables of results were converted into several charts in a graphic format often referred to as a “strategic map.” Each chart displays two of the attributes tested for all 16 PEGs simultaneously. For example, HLB versus pH is charted in **Figure 34.2**; the letters on the chart represent the corresponding PEG labels in **Table 34.1**. The position of a PEG's letter signifies where the numerical value for that attribute falls in relation to the value of that attribute in other PEG samples.

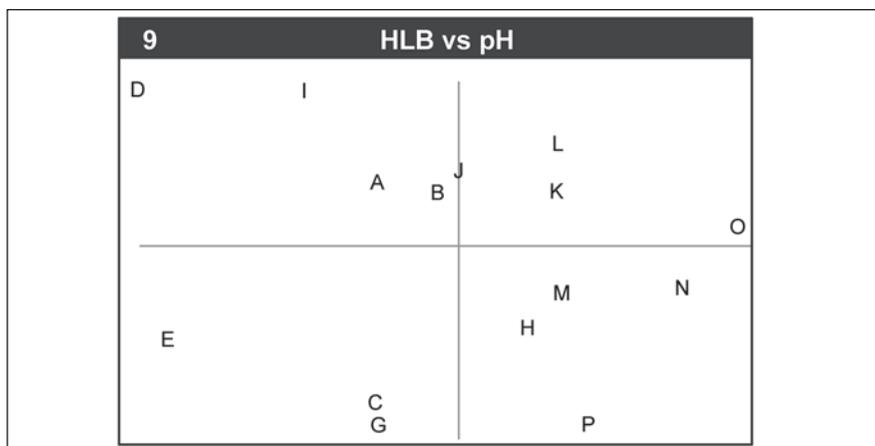


Figure 34.2. Direct comparison chart of HLB versus pH

The first attribute in the title is displayed on the x-axis and the second is read on the y-axis. The intersection of the axes represents the average point for both properties represented on the chart. The actual values are not displayed on the chart; they are found in **Table 34.1**. The purpose of the charts is to provide a spatial representation of the relative attributes. From **Figure 34.2** you can learn, for example, that point O, which represents Sample O, has the highest HLB value of all the PEGs as well as a higher-than-average pH value.

Each possible combination of two attributes was charted, which resulted in 45 charts. These 45 charts and other detailed information about methods, test solutions and results are available from the authors.

Here is an example. A formulator develops an eye area moisturizing cream using PEG-16 hydrogenated castor oil, with an HLB of approximately 8. The emulsion is stable, but spreads too readily for use in the eye area. The formulator must reduce the spread but hold HLB constant in order to keep the emulsion stable. The formulator may substitute the PEG, referring to both HLB and spread simultaneously. The chart in **Figure 34.3** clearly shows that PEG-10 sunflower glycerides (Sample D) possesses a lower spread, but roughly equal HLB to the PEG-16 hydrogenated castor oil (Sample E) and may therefore be examined as a promising alternative.

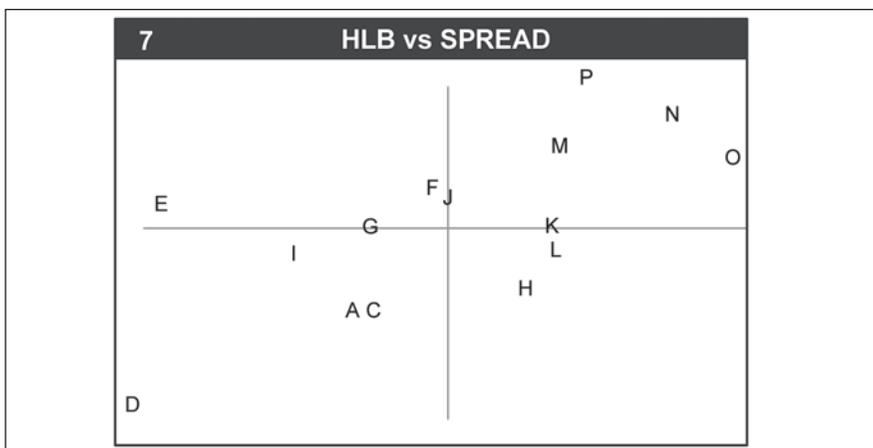


Figure 34.3. Direct comparison chart of HLB versus Spread

Formulation Results

In a formulation example, three of the PEGs were used, each at 5%, in three versions of a shampoo formula. The PEG ingredients used were samples D, M and N. Both the viscosity and slip of these shampoo formulas were tested. The values obtained are presented in **Table 34.2**. The values of the shampoo formula were compared to the values of the PEG ingredients in order to determine whether the comparison data can be used to choose a PEG ingredient. The shampoo formula results correlate to the original PEG ingredient charts. A spatial representation of the correspondence is shown in **Figures 34.4** and **34.5**.

Table 34.2. Slip and viscosity test results (with standard deviation) from shampoo formulations based on sample PEGs. (n=4 for slip; n=3 for viscosity)

PEG	Slip	SD	Viscosity	SD
D	75.3	0.96	8.5	0.07
M	75.3	0.50	7.4	0.31
N	78.3	0.50	8.0	0.02

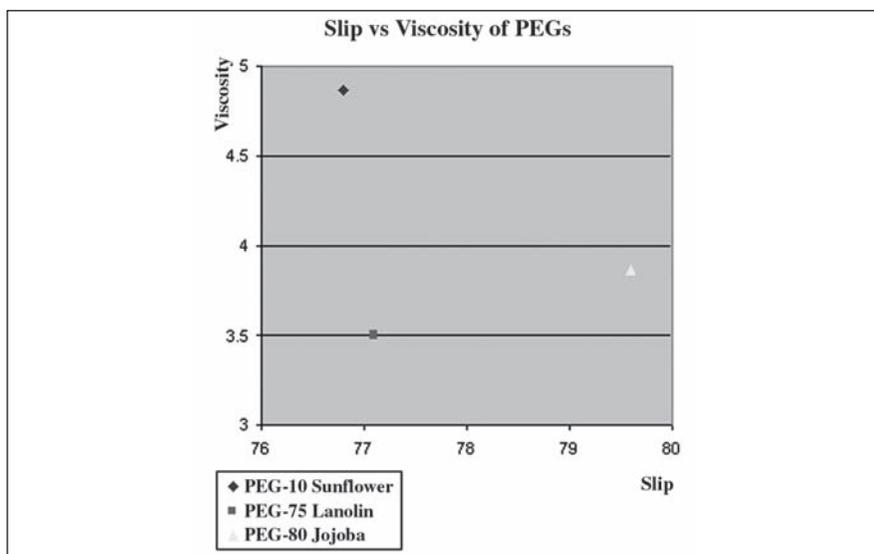


Figure 34.4. Comparison chart showing slip versus viscosity of three PEGs

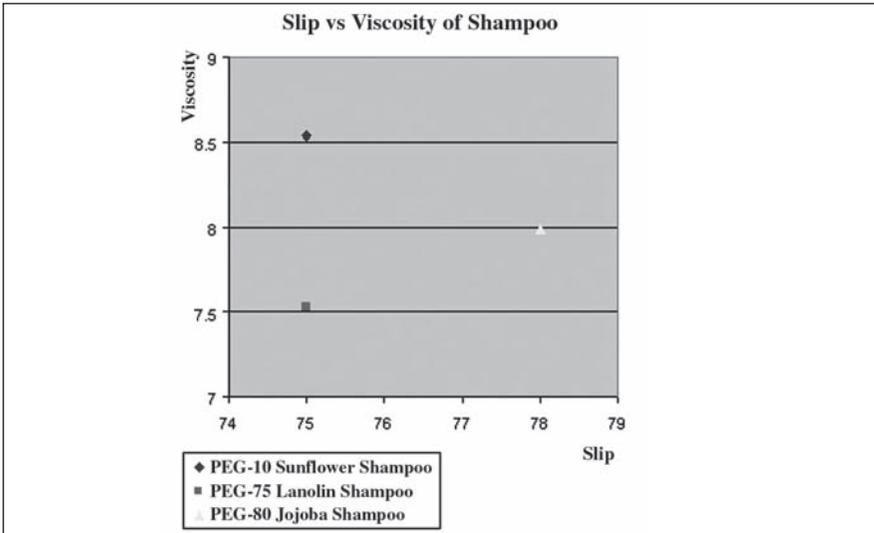


Figure 34.5. Comparison chart showing slip versus viscosity of three shampoos

Conclusion

The true value of the results obtained in this study lies in the simultaneous comparison presentation format. In general, a cosmetic formulator may seek either a high or low value of any attribute, depending on the specific project and desired result. The results of this study provide the ability to select two attributes essential to a formulation, and then choose a PEG based on those two attributes. When formulating a clear shampoo, having the knowledge of which PEGs are simultaneously clear and high foaming can facilitate selection by eliminating the PEGs that are high foaming but cloudy and those that are clear but suppress foam.

The basic properties of a raw material often contribute directly to the properties of a finished product. The selection of a raw material to best complement the function of a formulation will surely aid a formulator in optimizing the finished formula. The study results are of great value to any cosmetic formulator. They reduce trial and error, thus shortening product development time.

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SECTION VI

Underarm

This section includes the following chapters:

- 35** Underarm Technical Review: Consumer Drivers
- 36** Linear Polyethylenes and Long-Chain Alcohols in Underarm Sticks and Soft Solids

Underarm Technical Review: Consumer Drivers

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KEY WORDS: *antiperspirants, deodorants, Final Antiperspirant Monograph, regulation of antiperspirants, claims substantiation, market share*

ABSTRACT: *The Final Antiperspirant Monograph and patent activities (new actives, improved deodorant protection and formulation enhancements) are among the forces reviewed here for their effect on future antiperspirants and deodorants.*

Underarm products. What drives this category's growth? Already there is high per capita use of antiperspirants in the industrialized world. Therefore, global category growth will come from population growth and from steady growth in per capita income in emerging markets that had been primarily deodorant-only markets.

Most changes that have occurred over the past 30 years have been through external forces. The biggest change was the ban on ozone-depleting fluorocarbons in aerosols, leading to overriding growth of the solid stick market. For change to occur, either a new breakthrough technology needs to be developed, or some external force will dictate change. Will the publication of the OTC Final Monograph on Antiperspirant Products¹—almost 30 years in the making—be a catalyst for change? Are regulations in other countries not far behind?

The Final Antiperspirant Monograph details the rules and requirements to market and sell an antiperspirant product in the United States and standardizes what can be said and how it has to look to the consumer. Will an established and rigid monograph solidify the primary brands with good consumer awareness? Will this make it harder to differentiate brands, forcing more aggressive positioning in the marketplace with multiple benefits in addition to wetness and odor control?

The Final Antiperspirant Monograph

As outlined in the monograph, antiperspirants are defined as “a drug product applied topically that reduces the production of perspiration (sweat) at that site.” The effective date has been set at 18 months from publication (June 9, 2003) so that full compliance will be required by December 9, 2004 for products shipped into the U.S. consumer market. The monograph addresses the following issues:

- It standardizes which antiperspirant actives are allowed and how much can be used. An acceptable antiperspirant active must be listed in the U.S. Pharmacopoeia-National Formulary (USP-NF), and include a statement relating metals to chloride (Al/Cl, Al/Zr, Al+Zr/Cl atomic ratio).² Maximum use levels are shown in **Table 35.1**.
- It standardizes back label “Drug Fact” information³ (**Figure 35.1**) in such a way that will create uniformity in wetness and odor protection claims. Complex label requirements may also increase costs per unit.
- It standardizes and provides guidelines⁴ for how to test for efficacy and allowable claim language (see **Efficacy Testing of Antiperspirants sidebar**).
- It standardizes strength and duration claims and how one goes about substantiating them (see **Strength and Duration Claims for Antiperspirants sidebar**).

Table 35.1. Maximum use levels for antiperspirant actives in aqueous solution non-aerosol dosage form, according to the Final Antiperspirant Monograph

Antiperspirant active	Maximum anhydrous percentage
Aluminum chloride*	15%
Aluminum chlorohydrate	25
Aluminum dichlorohydrate	25
Aluminum sesquichlorohydrate	25
Aluminum chlorohydrate polyethylene glycol	25
Aluminum dichlorohydrate polyethylene glycol	25
Aluminum sesquichlorohydrate polyethylene glycol	25
Aluminum chlorohydrate propylene glycol	25
Aluminum zirconium octachlorohydrate	20
Aluminum zirconium tetrachlorohydrate	20
Aluminum zirconium pentachlorohydrate	20
Aluminum zirconium trichlorohydrate	20
Aluminum zirconium octachlorohydrate Gly	20
Aluminum zirconium tetrachlorohydrate Gly	20
Aluminum zirconium pentachlorohydrate Gly	20
Aluminum zirconium trichlorohydrate Gly	20

*calculated as hexahydrate

Drug Facts

Active Ingredients

Aluminum Zirconium
Tetrachlorohydrate - Gly (19% w/w)

Purpose

Antiperspirant

Use

reduces underarm wetness

reduces underarm perspiration due to stress

Warnings

For external use only and do not use on broken skin

Stop use and ask a doctor if rash or irritation occurs

Ask a doctor before use if you have a kidney disease

Keep out of reach of children. If swallowed get medical help or contact a Poison Control Center right away

Drug Facts (continued)

Directions

•Apply to underarm only

•Remove cap and seal

•Turn dial so that there a small amount of product is dispersed

•Apply a thin layer to underarm

Inactive Ingredients

Water, Cyclopentasiloxane, PEG-10
Dimethicone, Isocetyl Alcohol, Fragrance

Questions or Comments

1-800-111-1000

Distributed by
The XYZ Company
Someplace, USA 10000



Figure 35.1. The Drug Facts information for the label, as standardized by the Final Antiperspirant Monograph

Market Activity

Commercial success is tied to consumer driver purchase intent. Triggers for purchase intent have not significantly changed over the past 20 years. These fundamental triggers are:

- Wetness protection—dry all day;
- Odor protection—fresh all day;
- Aesthetics experience—invisible and non-tacky during application and during the day;
- Skin care benefits to deliver value-added benefits.

The past five years have shown minor shifts in leadership positioning, with four to five companies controlling more than 70% of the marketplace (**Figure 35.2**). Surprisingly, only a few new brands (such as Dove “moisturizing” and Axe “deodorant ... seductive fragrance Body Spray”) have been added to the category, demonstrating the consumer’s continued search for new and improved performance beyond odor and wetness control.

Efficacy Testing of Antiperspirants

The Final Antiperspirant Monograph standardizes how to test for efficacy and allowable claim language.

- “Efficacy” requires substantiating a minimum 20% sweat reduction for 50% of the test population using proper statistical models.
- “Extra effectiveness” terminology is allowed,⁵ provided there is at least 30% sweat reduction in 50% of the test population.
- Effectiveness for control of emotionally induced sweating can be sufficiently demonstrated by gravimetric sweat tests combined with mental stress tests. No additional testing is needed as long as the product contains monograph antiperspirants that meet the following language guidelines:

also { decreases
lessens
reduces } underarm { dampness
perspiration
sweat
sweating
wetness } due to stress

Worldwide patent activity continues at a break-neck pace and may highlight future trends. How is this changing the marketplace and delivering better drivers for increased consumer purchase?

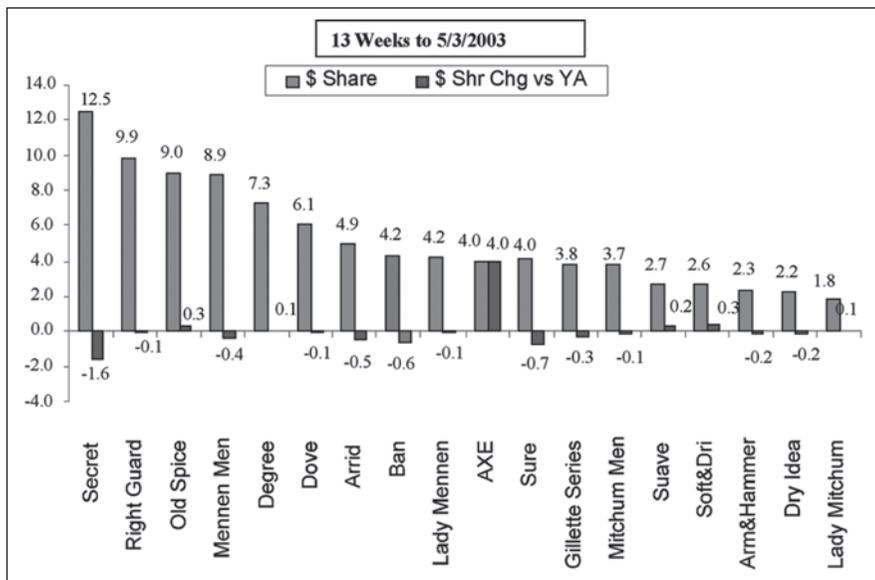


Figure 35.2. Product share for branded antiperspirants during the 13-week period ending May 3, 2003

Patents on New Antiperspirant Actives

Only a few discoveries have been patented based on new antiperspirant actives. The citations mainly discuss modification of the physical form or solubility changes.

This scant patent activity on new antiperspirant actives could be due to the costly and time-consuming process of a New Drug Application. Developers of new actives have to ask themselves if the cost and time really achieve increased purchase intent in the marketplace.

Patents on Improved Deodorant Protection

There is a lot of work going on to improve deodorant protection. Is this because it provides marketers with a unique point of differentiation with stronger long-lasting odor control claims or visual cues that something is there and working? There are a few examples from

1999 and later that could point to what may be the future in novel ways to deliver better odor protection.

A Gillette patent⁸ application describes microsphere particles coated with zinc oxide, a zinc salt, or any mixture thereof.

A Unilever patent⁹ describes a cosmetic method of reducing the acidity of sweat excreted from human eccrine glands. According to the patent, the topical application of a V-ATPase inhibitor to the skin in the vicinity of the eccrine glands may result in a range of benefits, including enhanced appreciation of topically applied perfume and enhanced efficacy of topically applied antiperspirant salt.

Senomyx discloses low molecular weight acetal, alcohol, O-acylated alcohol and ester compounds that block the odor of specific carboxylic acids, especially propionic acid, butyric acid, isovaleric acid, 3-methyl-2-hexenoic acid and hexanoic acid.¹⁰

Henkel describes a non-therapeutic use of selected beta-glucuronidase-inhibiting substances in a cosmetic deodorant or antiperspirant in order to reduce body odor caused by the decomposition of steroid esters.¹¹

Novozymes describes a method for killing or inhibiting microbial cells by treating them with a composition consisting of a laccase or

Strength and Duration Claims for Antiperspirants

The Final Antiperspirant Monograph standardizes how to substantiate claims of strength and duration.¹

- “Extra strength” claim (may also include “maximum strength” claim) is not acceptable verbiage because adding additional amounts of antiperspirant ingredient does not necessarily result in improved product effectiveness.⁶
- “Enhanced duration” claims⁷ (“all day protection,” “lasts all day,” “lasts 24 hours,” “24-hour protection”) are permitted provided there is a greater than 20% sweat reduction over a 24-hour period after application.
- Greater than 24-hour duration claims are not permitted. However, the Cosmetic, Toiletry and Fragrance Association has filed a citizen petition requesting permission for longer duration claims when available data supports those claims.

a laccase-related enzyme together with oxygen and an enhancing agent.¹²

A recent Kao patent describes a deodorant composition consisting of a water-soluble metal salt (chloride, a hydroxide or a carbonic acid compound of sodium, potassium, magnesium, calcium, iron, copper or zinc), a nonionic surface-active agent, silicone oil, and the balance of water.¹³

Unilever discloses an antimicrobial deodorant composition consisting of a C₁ to C₄ monohydric alcohol carrier fluid, an iron (III) chelator and a solubility promoter.¹⁴

Patents on Formulation Enhancements

Most published citations deal with formulation enhancements. As already mentioned, there continues to be a need to add and provide additional skin care benefits. A lot of focus is on using water as a carrier or adding skin benefit additives. There are some recent inventions that may hold promise for new products in the future.

Unilever describes structured antiperspirant micro-emulsions, possibly in the form of liquid crystals, containing cosmetic oils, a solution of antiperspirant salt in a hydrophilic solvent, a surfactant and an oil structurant.¹⁵ The structured micro-emulsions are preferably clear and can be used in soft solids or firm stick applicators.

The Andrew Jergens Company discusses semi-solid antiperspirant compositions that do not leave a significant white residue on the skin and exhibit good skin feel when applied by incorporating free water into the formulation without deactivating the antiperspirant active.¹⁶ This is particularly useful in the incorporation of solutions of natural botanical components into the composition.

Colgate-Palmolive describes emulsions with naphthalate esters in the external (oil) phase.¹⁷ Compositions of this type contain 15–33% of an external phase and 85–67% of an internal phase, which is made with an active ingredient in a glycol solvent. The external phase is made with at least one selected naphthalate organic ester, a volatile silicone-based emulsifier and a volatile silicone.

Dow Corning describes an optically clear one-phase microemulsion that is transparent at temperatures from 0 to 70°C.¹⁸ Example

compositions contain at least one nonaqueous polar solvent, at least one nonpolar solvent immiscible with the polar solvent and at least one oxy-alkylene-containing polydi-organosiloxane. The microemulsions of this invention are useful as delivery vehicles for personal care active ingredients such as antiperspirant salts, sunscreens, alpha-hydroxy fatty acids and vitamin E.

Milliken describes a series of patents disclosing improvements on the basic dibenzylidene sorbitol acetals (DBS) technology. This technology is useful as gelling agents for water and organic solvents, particularly those used in the preparation of antiperspirant gel sticks. One patent in the series describes certain asymmetric benzylidene sorbitol acetals compounds containing specific pendant groups, such as C1-C6 alkyl, C1-C6 alkoxy, phenyl, naphthyl, or substituted phenyl, or pendant groups combined to cyclic moieties, such as cyclopentyl, cyclohexyl (tetralin), and methylenedioxy.¹⁹ This is a part of a series of citations disclosing improvements on the basic DBS technology useful as gelling agents for water and organic solvents, particularly those used in the preparation of antiperspirant gel sticks. Some related patents discuss the following: novel fluorinated and alkylated alditol derivatives and compositions and polyolefin articles containing same; reaction product mixtures including both symmetric compounds and asymmetric dipolar multi-substituted alditol derivatives; compositions and articles containing asymmetric dipolar multi-substituted alditol derivatives.

A Cognis patent describes a highly-viscous microemulsion containing a sugar surfactant, an oil component and an aluminum-zirconium salt.²⁰ The resulting transparent composition has a Brookfield viscosity on the order of 100,000 mPas or greater.

Patents Affecting Consumer Habits

Here are two interesting technical options to changing consumer habits and practices using an underarm product.

Henkel discloses a foam method for reducing odor or sweat formation.²¹ The deodorant or antiperspirant foam is operated either with air or with a volatile propellant and a liquid, foaming composition.

Colgate-Palmolive has devised a gelled stick or soft gel composition for reducing underarm wetness.²² The compositions are comprised of starch-grafted homo-polymers and copolymers of poly (2-propenamide-co-2-propenoic acid) sodium salt. Included in the composition are volatile silicones, a gelling agent (selected from silyconized polyamide or silicone elastomer), water or a water-soluble organic solvent or surfactant, and an emollient.

Conclusion

What is next? The market continues to evolve because of safety and regulatory issues, and because of revolutionary products and packaging. Odor protection claims (such as 24-7, full body refreshment, feel refreshed fast, power packed for stronger and longer odor protection) continue to merge the deodorant and antiperspirant/deodorant market into one. Axe and body wipes broaden the application away from an underarm product to full body odor care.

In the 1970s the ban on fluorocarbon use radically influenced delivery systems for antiperspirants. Will the potential emotive and scientific issues revolving around cyclomethicone cause the next key change?

Just when you thought you had heard it all, along comes Botox. Does this not sound like anti-cholinergic drugs all over again? Botox injections are used for focal hyperhidrosis, in which the excessive sweating is limited to the armpits or palms and occasionally the soles of the feet (about 1–3% of the population). Botox keeps nerves from releasing acetylcholine, a chemical that activates sweat glands, and controls occasional bouts of excessive nervous sweating.

Stay tuned; the market continues to clearly solidify new horizons.

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Linear Polyethylenes and Long-Chain Alcohols in Underarm Sticks and Soft Solids

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KEY WORDS: *antiperspirant, C20-40 alcohols, cyclomethicone, gellant, polyethylene, stearyl alcohol*

ABSTRACT: *Linear polyethylenes and long-chain alcohols are alternatives to stearyl alcohol for gelling systems based on cyclomethicone. These materials have particular utility in formulations for antiperspirant or deodorant sticks and soft sticks.*

In today's increasingly competitive personal care market, formulators of underarm products need technologies that can help them deliver novel and aesthetically pleasing product forms to consumers—while at the same time satisfying manufacturing needs for easy formulating and cost efficiency.

Stearyl alcohol is a common gelling agent for antiperspirant sticks and gels. However, new technological developments allow formulators to use lower quantities of totally linear polyethylenes and linear, long-chain alcohols (in the range of C20 to C50, compared to C18 for stearyl alcohol) as gellants.

Although other long-chained materials exist, the completely linear form of the polyethylenes and alcohols is distinctive and makes

these polymers more crystalline than branched polymers or shorter-chain polymers. Using these materials allows more flexibility in formulation because less gellant is required, and the ultimate structure is characterized by a latticework of smaller crystals than those associated with other gellants. This structure can improve formulation aesthetics as well as enhance the distinctive sensory properties of cyclomethicone to give soft, dry and smooth application without drag. In addition, the smaller crystal size improves stability of the final formulation.

This chapter describes these linear polyethylenes and their corresponding long-chain alcohols, compares their gelling efficiency and stability with that of stearyl alcohol and uses microscope photographs to illustrate their crystalline characteristics. In addition, a prototype formulation demonstrates use of the materials in a soft solid product form.

New Options with Polyethylenes and Alcohols

These materials are linear ethylene homopolymers having the structure:



where

X = CH₃ for polyethylenes or OH for alcohols,

n = 9-106 and

MW = 400-3000.

For the polyethylenes, typical materials have melting points in the range of 84–128°C. Those with the lower melting points (i.e., approximately 84–88°C) have viscosities in the range of 4–7 cP at 99°C, while materials with higher melting points (approximately 100–128°C) have viscosities in the range of 5–130 cP or more at 149°C. The polyethylenes are hydrophobic film formers and can be used as viscosity modifiers or emulsion stabilizers. They are compatible in a variety of common organic materials and silicones.

In the case of the C20-40 alcohols, typical materials have melting points in the range of 79–105°C. These ingredients can be used

as replacements for natural waxes to modify rheology. They can act as secondary emulsifiers and dispersants, or serve as conditioning agents or film formers. Like their polyethylene counterparts, they are compatible in a number of common organic materials and silicones.

When formulating systems with cyclomethicone, it is advisable to use the polyethylenes and C20-40 alcohols with lower melting points, due to the volatility of the silicone.

Gelling Efficiency

Studies were conducted to determine the gelling efficiencies of the polyethylenes and long-chain alcohols in cyclomethicone. Blends of these ingredients at 10% and 20% concentration were prepared in the silicone. Several polymers were evaluated: C20-40 alcohols (MW 375)^a, C20-40 alcohols (MW 460)^b, C30-50 alcohols (MW 550)^c, polyethylene (MW 450, C20-40)^d and polyethylene (MW 500, C30-50)^e. For simplicity, in this work we will refer to those five polymers as LCA1, LCA2 and LCA3 (for the long-chain alcohols) and PE1 and PE2 (for the polyethylenes), respectively. We also evaluated a blend of PE1 and LCA2 at a ratio of 1:4. These materials were compared with stearyl alcohol. **Table 36.1** shows the INCI names, the carbon counts and the molecular weights of the linear polyethylenes and long-chain alcohols used in this study.

The test materials were cooled overnight in covered metal tin cans, after which penetration values were recorded using a 35 g cone needle and a penetrometer.^a Five measurements of gel firmness were recorded by measuring the needle penetration at five different points within the sample. ASTM D-1321 was used as a guide. Measurements in decimillimeters were averaged and standard deviations were calculated.

^a PERFORMACOL 350 Alcohol, New Phase Technologies, Sugar Land, Texas, USA.

PERFORMACOL is a registered trade name of New Phase Technologies.

^b PERFORMACOL 425 Alcohol

^c PERFORMACOL 550 Alcohol

^d PERFORMALENE 400 Polyethylene. PERFORMALENE is a registered trade name of New Phase Technologies.

^e PERFORMALENE PL Polyethylene

^a Model K19500 Penetrometer, Koehler Instrument Company, Bohemia, New York USA

Table 36.1. Gelling agents used in this study

Code	INCI name	Trade name*	Carbon Count	Molecular Weight
LCA1	C20-40 alcohols	PERFORMACOL 350 Alcohol	20-40	375
LCA2	C20-40 alcohols	PERFORMACOL 425 Alcohol	20-40	460
LCA3	C30-50 alcohols	PERFORMACOL 550 Alcohol	30-50	550
PE1	Polyethylene	PERFORMALENE 400 Polyethylene	20-40	450
PE2	Polyethylene	PERFORMALENE PL Polyethylene	30-50	500

*New Phase Technologies, Sugar Land, Texas

Figure 36.1 compares the gelling ability of various linear polyethylenes and long-chain alcohols. For each of the materials, a linear relationship was assumed between 10% and 20% polymer in cyclomethicone. However, the equations should not be used to extrapolate points outside this range.

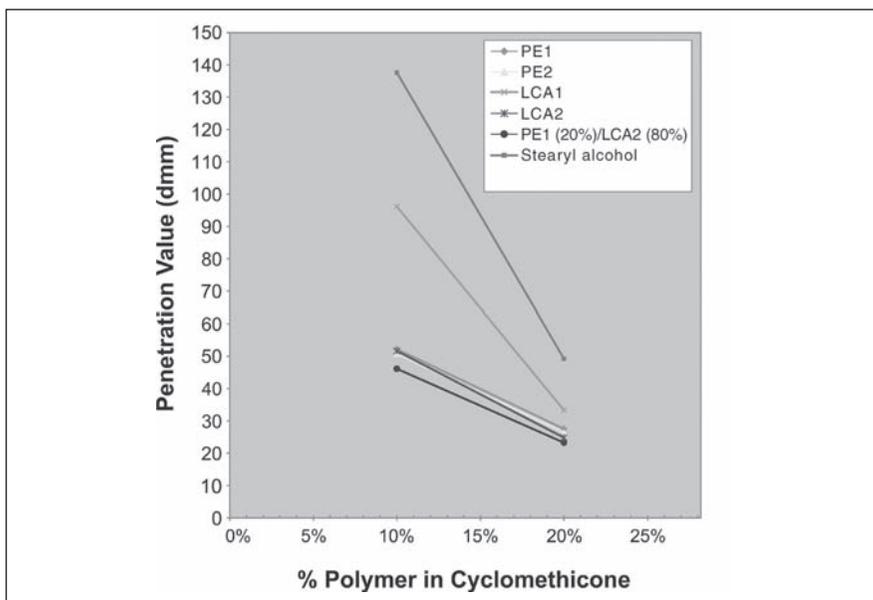


Figure 36.1. Comparison of gelling among linear polyethylenes and long-chain alcohols

Penetration data show that these polymers are more efficient than stearyl alcohol at gelling cyclomethicone. Efficiency depends on the level of polymer used and the desired penetration value. In this study, the higher the molecular weight of the polymer, the harder the resulting gel, with the 500 MW polyethylene having the highest gelling efficiency of a single polymer. However, with the combination of PE1 and LCA2, there is a slight synergistic effect, and the resulting gel is firmer than with either material when used alone.

Better Stability for Sticks and Soft Solids

Linear polyethylenes and their long-chain alcohols have the distinct ability to form a tight network of small, regular crystals. **Figures 36.2a** through **36.2c** compare the crystal structures of stearyl alcohol, PE2 and LCA2. It is this crystal structure that gives enhanced stability and aesthetics to the polyethylene and its alcohol.

Soft solid antiperspirants based on cyclomethicone illustrate how these polymers improve formulation stability. Formulations of this type present a challenge to formulators because the pressure required to extrude the soft solid through the holes of the package can cause syneresis, or bleeding, of the silicone. Although specialized packaging has been developed to alleviate the pressure problem, it adds cost to the finished product.

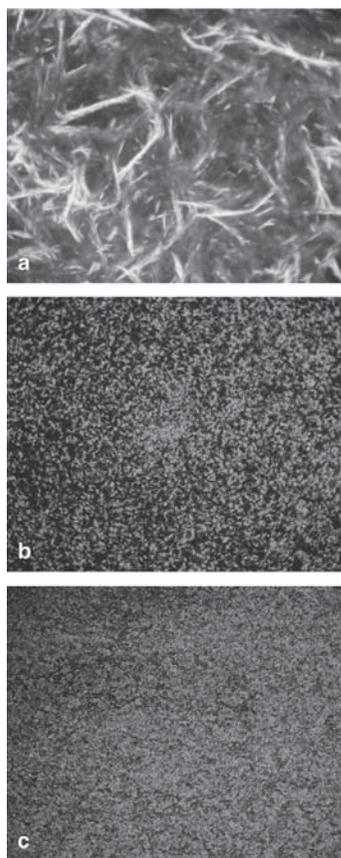


Figure 36.2. Comparison of crystal size in cyclomethicone systems gelled with selected gelling agents (Magnification = 100X)
a = Stearyl alcohol
b = C30-50 Polyethylene (MW 500) (PE2)
c = C20-40 Alcohols (MW 460) (LCA2)

In contrast, formulations based on the long-chain alcohols form more stable systems because the compact, uniform crystal structure effectively entraps the silicone. In addition to being efficacious, this solution is also economical because specialized packaging is not required.

Figure 36.3 illustrates the stability of a soft solid antiperspirant system based on cyclomethicone that is gelled with various long-chain alcohols and polyethylene. Notice that at levels of 4–5%, the long-chain alcohols form stable soft solid formulations for at least 12 weeks. Also, the addition of 1% PE1 to a formulation containing 4% LCA2 increased stability from approximately one week to at least 12 weeks.

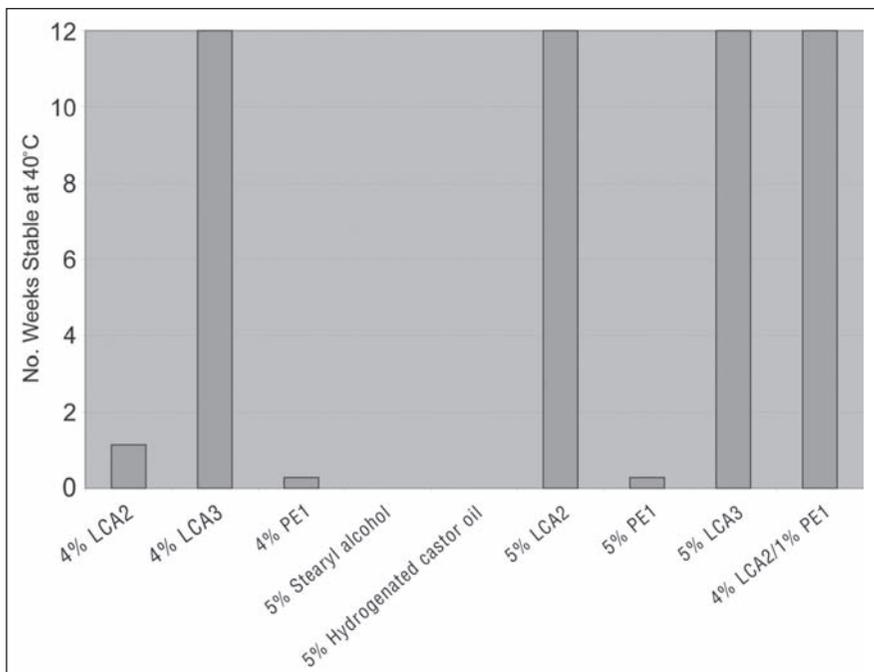


Figure 36.3. Stability of soft solid antiperspirant (cyclomethicone/dimethicone system) incorporating linear polyethylene or long-chain alcohol gellants

Formula 36.1 illustrates the use of LCA2 and PE1 in a soft solid antiperspirant formulation. The two polymers thicken and stabilize the volatile cyclomethicone and low molecular weight dimethicone. The formulation has excellent stability, a soft and creamy texture, and it feels light and comfortable on the skin.

Formula 36.1. Soft solid antiperspirant

A. C20-40 alcohols (MW 460) (Performacol 425 Alcohol, New Phase Technologies)	4.0% wt
Polyethylene (MW 450) (Permalene 400 Polyethylene, New Phase Technologies)	1.0
Cyclopentasiloxane (SF 1202, General Electric)	60.0
Dimethicone (SF 96-100, General Electric)	10.0
B. Aluminum zirconium tetrachlorohydrate GLY (Reach AZP-908, Reheis)	<u>25.0</u>
	100.0

Procedure: Heat A to 92–95°C with mixing until dispersed and uniform, covering to retain cyclopentasiloxane. Maintain temperature while adding B with high shear mixing. After fully dispersed, remove from heat and fill containers.

Conclusions

Linear polyethylenes and their corresponding long-chain alcohols (C20-C40) are more efficient at gelling cyclomethicone than traditional gellants such as stearyl alcohol, and they present new formulating options for stick and soft solid antiperspirant applications. In the case of soft solid formulations, those gelled with 5% long-chain alcohol (or a combination of 4% 460 MW alcohol and 1% 450 MW polyethylene) show better long-term stability with no syneresis.

These materials allow formulators to use less gellant, with greater formulation flexibility and better aesthetics—ultimately providing opportunity for innovative new product forms in the underarm market.

SECTION VII

Skin Care

Skin care is one of the most important market segments for the personal care business. The market demands are ever changing and new benefits are always being proposed to the consumer. Consumers demand many properties from products applied to skin. Skin care products vary quite considerably based upon where and why they are applied. Generally skin needs to be cleansed, moisturized, and have a growing number of actives delivered to it. Specific skin areas need to have pigment applied, while other areas need to be protected from odor associated with perspiration. Skin needs to be protected from the sun. This is a growing area of concern as the incidence of skin cancer grows. The number of articles published in *Cosmetic and Toiletries* the segment addressed by those articles is quite extensive.

- 37** Makeup Powders Preservation and Water Activity
- 38** The Color Game, No Easy Feat
- 39** Correlating Water Contact Angles and Moisturization/Sensory Claims
- 40** Cream in Powder Form: A New Concept in Makeup
- 41** Blush Just Got Smarter
- 42** Hyperbranched Polyalphaolefins Enhance Anhydrous Stick Formulations
- 43** Formulating Scrubs

Makeup Powders Preservation and Water Activity

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KEY WORDS: *preservation, water activity, equilibrium relative humidity, makeup powders, eyeshadow, mold, bacillus*

ABSTRACT: *Spores of Bacillus subtilis and selected molds were used to demonstrate the impact of different thermodynamic water activities on the behavior of microorganisms inoculated in makeup powders with or without preservatives.*

One of the problems still facing the cosmetics industry is microbiological pollution and its various consequences. For the manufacturer, contamination alters a product's organoleptic and physicochemical characteristics and degrades its active ingredients, which leads to a refusal of the product. For the consumer, the application of a product contaminated by a pathogenic microorganism could result in infections, or at least could alter the balance of the skin/mucous membrane, our first barrier against infections.

Contamination may derive from a variety of sources: the raw materials, the manufacturing process, storage, packaging or use. To ensure that the microbiological quality remains good from manufacture to utilization, most products are preserved by the addition of antimicrobial agents.

Regulations and changes in safety requirements in cosmetology promote optimization of preservatives added to formulas, but for very specific formulations such as makeup powders the principal difficulties are encountered when evaluating the efficacy of these preservatives. In order to optimize the preservation system, the aims of this study were to evaluate the microbiological risk of makeup powders in terms of specific forms of microorganisms adapted to makeup powders. Thus for test microorganisms we chose *Bacillus* spores and mold spores, and not *Staphylococci* and Gram negative bacteria that rarely or practically never are found in powders.

The Concept of Water Activity

In the analysis of microbiological risk, we considered water to be a fundamental parameter. Moisture content quantitatively characterizes the hydration in a product, but alone is not enough to account for the availability of the water. Therefore we use the concept of thermodynamic water activity to express the availability of water for microbial growth in a product.

This concept was introduced by Lewis,¹ who seems to have been the first to speak of the “activity of water,” universally abbreviated as A_w (or a_w). To illustrate the concept, consider a heterogeneous product containing several parts. In the presence of an atmosphere, water migrates, possibly with endo- or exothermic effects: some parts hydrate, others dry; water vapor diffuses to the atmosphere or inversely gives up water to the product. After a certain time (sometimes several hours) a thermodynamic equilibrium is established in the system, characterized by three conditions:

- The temperature is identical at all points.
- The “chemical potential” of any constituent, and notably of water, is identical in each part. In the case of water, this chemical potential in fact represents the change in enthalpy needed to transform one mole of water from the free-vapor state to the bound state in the substance.

- There is a certain partial pressure (p) of water vapor in the atmosphere in equilibrium with the product. By definition, above pure water (the reference state) this pressure is equal to the saturation vapor pressure (p') where the relative humidity is equal to 100% and the A_w of the atmosphere above pure water is 1.0.

Thermodynamics allows us to establish ratios between absolute values (which we can't measure) and reference values (which we can measure). Thus, we can obtain the "relative activity" as a ratio of the actual chemical potential of any ingredient to the reference chemical potential of that ingredient. Similarly, the "relative pressure" is a ratio of the actual pressure of any ingredient to the reference pressure of that ingredient. In the case of water, the first ratio is called the "water activity" (A_w) and the second ratio is called the "relative humidity" (RH).

Although vapor is not a perfect gas, we can with only a small error (on the order of 0.2%) state the following equivalence:

$$A_w = \text{RH}\% \div 100 = p \div p'$$

Confusion has therefore often arisen because although there is numerical equivalence, the two concepts are physically different. A_w is in fact the chemical potential of the water in the substance (i.e., the free energy). RH is a ratio of two pressures in a gas.

It is vital to understand that the A_w equivalence only holds if there is thermodynamic equilibrium between the product and the atmosphere. Without this equilibrium (the product is drying, for instance), this equality is meaningless. Also, the term A_w is meaningful only if the product is aqueous or has a water-continuous phase (i.e., an o/w emulsion). For powders, this condition is not initially fulfilled but if products pick up moisture from air during storage and use, a water-continuous system may appear at the surface.

Microbiological risks are directly related to A_w . Microbial behavior differs greatly depending on the water's availability (**Table 37.1**).^{2,3} In this kind of product, risks may be different over time, because A_w measurements could change during storage or use (as a result of drying or picking up of moisture).

Table 37.1. Limiting A_w for growth of microorganisms at optimal temperature

Species	Minimum at growth
Most bacteria	>0.95
<i>Bacillus cereus</i>	0.93
<i>Bacillus subtilis</i>	0.99
<i>Clostridium botulinum</i>	0.94
<i>Pseudomonas spp.</i>	0.95
<i>Lactobacillus spp.</i>	0.88
Most yeasts	>0.85
<i>Debaryomyces hansenii</i>	0.83
<i>Saccharomyces bailii</i>	0.80
<i>Saccharomyces rouxii</i>	0.62
Most molds	>0.85
<i>Aspergillus flavus</i>	0.78
<i>Aspergillus niger</i>	0.75
<i>Penicillium aurentiogriseum</i>	0.81
<i>Penicillium veridicatum</i>	0.81
<i>Monascus bisporus</i>	0.61

Water Activity and Water Content

The molecular interactions between water and the product constituents (principally hydrogen bonds between water molecules and polar radicals of proteins, carbohydrates and lipids) are expressed macroscopically by a relation of thermodynamic equilibrium that graphically reflects the sorption-desorption isotherm (**Figure 37.1**).

The generally sigmoid sorption isotherms depict relations obtained at thermodynamic equilibrium between moisture content and the equilibrium relative humidity (ERH) of the surrounding air, or the A_w of this product.

The nonlinearity of the sorption isotherm reflects the successive phases through which the product gradually passes as it is hydrated. For low A_w values (**Figure 37.1a**), the first water fractions

are strongly bound to the macromolecules of the substrate and are unavailable for reactions that use water as the reagent or diffusion medium. In the median part of the curve (**Figures 37.1a** through **37.1c**), the A_w and the moisture content change in parallel. Some scientists consider that in this area, successive layers of water molecules (hydrogen bonds) pile up on the monolayer formed at the start of hydration.

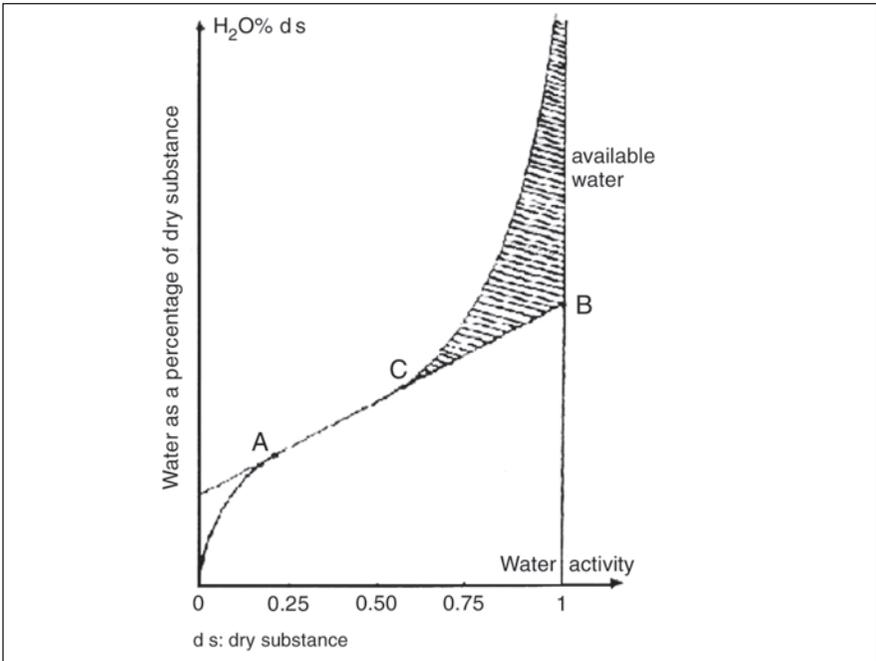


Figure 37.1. Sorption-desorption isotherm for a generic material. With increasing water activity and water as a percentage of dry substance, water becomes weakly bound and available as a diffusion medium.

A = strongly bound water amount

B = Non-solvent water maximum amount

C = Critical point of solvent water appearance

However, moisture content increases faster than A_w in the area (**Figures 37.1c** to **37.1b**) where the sorption isotherm straightens. In this part of the curve the water is progressively bound more weakly to the substrate (osmotic phenomena, capillarity and other factors) and is therefore more available for certain biochemical or microbiological reactions. Such “solvent” water is absolutely necessary for the growth of microorganisms.

Considering the shape of the sorption isotherm, it is therefore relatively easy to predict at which water content values a given product will be host to microbial growth. Following work by Scott,⁴ the thermodynamic concept of water activity has been used by microbiologists to describe microbial behavior as a function of hydration.

Materials

Substrate: The production of the makeup powders used in this study was subcontracted, and the powder composition cannot be detailed for reasons of confidentiality. The powder referenced as “FA” is a formulation without preservative manufactured at our request and is not available commercially. The powder referenced as “F2” contains preservative and is commercially available.

Nonetheless, we consider it important to give the general formula of these powders (**Formula 37.1**). This formula shows the specific main ingredients of the makeup powders tested in the study.⁵ We chose conventional formulas that represent most of our references. Powders with a high oil (binders) or wax content were excluded from the study.

Culture media: Tryptic soy agar^a was used to preserve, grow and enumerate bacterial strains. Sabouraud dextrose agar^b was used to preserve, grow and enumerate surface molds. Yeast glucose chloramphenicol agar^c was used to enumerate mold strains by inclusion.

Malt extract agar was used to harvest mold spores. One liter of this agar medium contains 40 g of malt agar^d and 3 g of soytone^e. One liter of the broth used to obtain *Bacillus* spores contained 5 g of tryptone^f and 2 g of glucose^g.

We used neutralizing polyvalent diluent for microbial enumeration of products after inoculation. One liter of the neutralizing polyvalent diluent contains 30 g of polysorbate 80^h added to 28 g of lethin polysorbate thiosulfate (LPT) foundation broth^k.

^a T.C.S. Biomérieux reference 41466, Biomérieux, Craponne, France

^b S.D.A. Difco reference 210950, Difco, Becton Dickinson France, Le Pont de Claix, France

^c Y.G.C. Biomérieux reference 42600

^d Difco reference 0024-17-3

^e Difco reference 0436-175

^f Difco reference 0123-17

^g Merck reference 24 370.294, Merck, Briare le canal, France

^h Merck reference 8.22187.2500

^k AES reference AEB 140562, AES, Combours, France

Formula 37.1. A general formula and specific raw materials for the powders used in this study

General formula	Raw material used in this study	Amount % (w/w)
Talc and/or mineral	Hydrous magnesium silicate ($3\text{MgO}\cdot 4\text{SiO}_2\cdot \text{H}_2\text{O}$)	50-80
Pigment	Yellow iron oxide (CI 77492): hydrated ferric oxide $\text{FeO}(\text{OH})\cdot n\text{H}_2\text{O}$	5-30
	Red iron oxide (CI 77491): ferric oxide Fe_2O_3	
	Black iron oxide (CI 77499): mixture of ferrous and ferric oxides	
Fat binder	Titanium oxide (CI 77891): titanium dioxide (TiO_2)	2-10
Preservatives		0-0.8

Microorganisms

The microorganisms detectable in this type of product are molds or sporulating bacteria. We decided to work with mold spores and *Bacillus* spores. We chose xerophilic molds known to be sporulating:

Penicillium aurentiogriseum IP 1231.80

Aspergillus niger IP 1431.83

Aspergillus ochraceus no. 933677

The first two were from the national collection of cultured microorganisms of the Institut Pasteur de Paris and were kept frozen at -80°C , according to the laboratory's procedures (established following AFNOR standards). The third (*A. ochraceus*) came from the mold collection of the Museum d'Histoire Naturelle de Paris and was kept cold ($+5^\circ\text{C}\pm 2^\circ\text{C}$) by successive subcultures on agar medium.

For the bacteria, we chose to work with spores of *Bacillus subtilis* CIP52.62, a strain also coming from the collection of the Institut Pasteur de Paris.

Equipment: Water activity was measured using an instrument^a that was designed for the determination of the ERH above the product, at a constant adjustable temperature. The instrument consists

^a Thermoconstanter TH200; model RTD200, Novacina, Pfäffikon, Switzerland

of a controlled temperature chamber and a measurement device fitted with a probe using a mixture of electrolytes of several salts. The probe is used to measure product samples such as powders, granulates, pastes and liquids. The instrument is calibrated using six saturated salt solutions of ERH between 11% and 98%.

For some tests at 85% ERH, we used a climatic chamber^b designed to study the influence of temperature and humidity. The control panel displays the recommended and actual values of the temperature and the percentage relative humidity.

Surface inoculations were done with a spiral plater^c to be used with pre-poured Petri plates. A microprocessor drives a syringe, which logarithmically distributes a volume of 50 μl . A distribution tip applies the sample in decreasing amounts as it moves from the center to the periphery of the plate. This application system enables enumerations of suspensions of microorganisms containing between 4×10^2 and 4×10^5 CFU/ml.

Methods

Equilibrium Relative Humidity: The different ERH chosen were maintained using the saturated salt solutions in **Table 37.2**.⁶ The solutions were prepared by adding sterile distilled water. The mixture was stabilized at 30°C. Surplus water was discarded to leave just the “slurry.”

Table 37.2. Theoretical ERH values at 25°C for the saturated salt solutions used in this study

Salt	ERH (%)
$(\text{NH}_4)_2\text{SO}_4$	80
KCl	85
BaCl_2	90
K_2SO_4	98

^b VC0020 climatic chamber, Votsch, Balingen, Germany

^c WASP spiral plater, AES, Combourg, France

Preparation of inocula of *Bacillus* spores: We deemed it very important to preserve the integrity of the product during the evaluation of the efficacy of the preservatives. For this reason, we used anhydrous inocula in the form of spores to contaminate products during the study.

After 7 to 10 days of incubation at $30^{\circ}\text{C}\pm 2^{\circ}\text{C}$, the broths containing the *Bacillus* spores were centrifuged twice at 3500 rpm for 3 minutes, with a distilled water washing between each centrifugation.

The centrifuge tubes were immersed in a 100°C water bath for 8 minutes and then in melting ice for 2 minutes. Two centrifugations at 3500 rpm for 3 minutes were then performed, with a wash in distilled water in between. The pellets were collected in sterile talc and dried overnight at $40^{\circ}\text{C}\pm 2^{\circ}\text{C}$, then mixed with decontaminated talc. After enumeration and adjustment with sterile talc to obtain an inoculum of 10^4 to 10^5 spores, this contaminated talc was used as inoculum for the tests.

Preparation of inocula of mold spores: Again, to preserve the integrity of the product during evaluation of the preservative efficacy, we used anhydrous inocula in the form of spores.

The molds were inoculated on the surface of a Petri plate containing malt agar and were incubated for six days at $25^{\circ}\text{C}\pm 2^{\circ}\text{C}$. Sterile glass beads 3 mm in diameter were placed on the surface of the subcultures. Depending on the mold tested, a bead represented an inoculum of 10^4 to 10^5 spores. These spore-coated beads were used as inoculum for the tests.

Protocol: After seeding, the powders were added to the sterile Petri plates, which were then stored either in sealed chambers containing the saturating salt solutions or left in the ambient atmosphere whose ERH was measured as about 50%. All tests were performed at room temperature (approximately 20 – 25°C).

Sampling was scheduled at times t_0 , $t+7$ days, $t+14$ d, $t+28$ d and $t+60$ d (for certain tests, samples were also collected after 6 months and 1 year of contact). At each sampling, 1 g of product was diluted tenfold in a validated neutralizing diluent. After 30 minutes of contact, the microorganisms were enumerated by inclusion in trypticase soy agar or yeast glucose chloramphenicol agar and by surface seeding of prepoured Petri plates. The incubation was done at $30^{\circ}\text{C} \pm 2^{\circ}\text{C}$

for the bacteria for 72 hours for the enumeration by inclusion and for 24 to 48 hours for the surface enumerations. For the mold spores, the incubation at $25^{\circ}\text{C} \pm 2^{\circ}\text{C}$ was conducted for 5 days for the enumerations by inclusion and for 48 hours for the surface enumerations. The results were expressed as X (\log_{10} CFU/g).

Results and Discussion

Aw of powders: We first examined some commercial products (free or compact powders) whose A_w ranged from 0.25 to 0.35. These values are well below the values shown in **Table 37.1** as the threshold of growth for various microorganisms.

Evolution of A_w values during storage of powders and different constituents at 98% ERH: After 1 month—and for some products after 4 or 6 months—we determined the A_w values of free powders, compact powders and their principal components (shown in **Table 37.3**) when stored at high ERH (98%). The aim of the test was not to precisely define the minimal time to reach fixed values (may be shorter) but only to establish the maximal values reached after an overtime storage, and also check stability of data by new measurements after 4 or 6 months.

After 60 days of contact, the A_w values of the powders were essentially identical irrespective of their texture. The increased surface contact in the free powders versus compact powders did not

Table 37.3. Evolution of A_w values during storage of powders and different constituents at 98% ERH

	A_w at T0	A_w at T + 30 days	A_w at T + 51 days	A_w at extended time
Titanium dioxide	0.36	0.82		0.89 (after 6 months)
Yellow iron oxide	0.38	0.90		0.91 (after 6 months)
Red iron oxide	0.30	0.88		-
Black iron oxide	0.38	0.75		-
Free powder	0.24	0.72	0.71	0.68 (after 4 months)
Compacted powder	0.25	0.64	0.72	0.63 (after 4 months)

affect the fact that maximal value of A_w is reached in approximately 1 month.

Failure to reach an A_w value greater than 0.90 after one month or more of contact denoted a low affinity of the tested products for water. Lower values obtained for the compacted powder (0.64) and free powder (0.72) do not favor the growth of most microorganisms.

Another test confirmed the low affinity of this type of product for water. Several pots of compact eyeshadow were placed in a chamber at 98% ERH. After one month of contact, A_w was measured as 0.85. Then we took a second pot and crumbled its powder before measuring A_w , which was 0.51. This showed that crumbling of the powder allowed a rapid and significant drop in A_w .

Number of *Bacillus* spores: impact of preservative as a function of two relative humidities: We compared the numbers of *Bacillus subtilis* spores in two eyeshadows at two different relative humidities. The first eyeshadow (FA) contained no preservative; the second (F2) was a commercial product containing 0.4% (w/w) of a mixture of three preservatives. We monitored spore numbers for two months at 85% ERH and at approximately 50% ERH. The results are presented in **Figure 37.2**.

No decrease in *Bacillus subtilis* spore numbers was observed at either ERH and regardless of the time of contact. Other tests not presented here showed a significant regression in the case of an inoculum with the vegetative form of *Bacillus subtilis*. Anagnastopoulos and Didhu⁷ observed that the percentage germination of *Bacillus stearothermophilus* dropped when A_w decreased.

The tests presented in **Figure 37.3** were done in sealed chambers containing a saturated salt solution. To validate our results, we did the same tests in parallel in an oven in an atmosphere of 85% ERH. All the results were in full agreement.

Mold spore population: impact of different relative humidities on a product without preservative: We measured the mold spore population in specifically prepared eyeshadow without preservative at five equilibrium relative humidities. The results are presented in **Figure 37.3**.

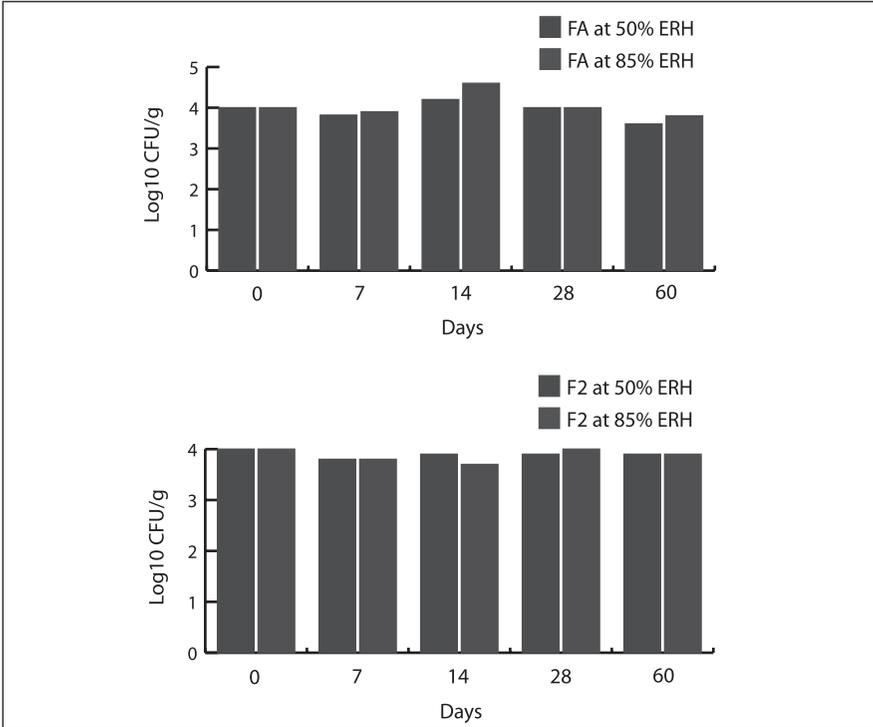


Figure 37.2. Evolution of *Bacillus* spore populations in eyeshadows without (above) and with (below) preservative at different ERH values and at constant room temperature

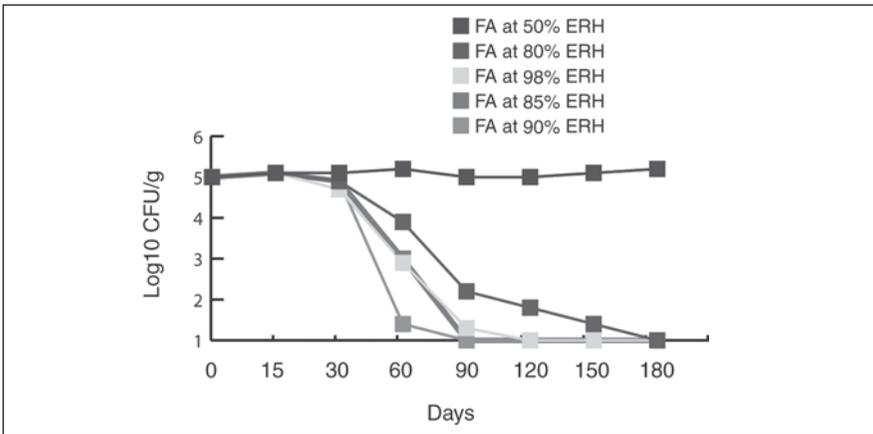


Figure 37.3. Evolution of *Penicillium aurentiogriseum* spore population in eyeshadow without preservative at different ERH values and at constant room temperature

At an ERH of about 50%, no decrease in spore population was measured after 6 months of contact. At higher ERH values, after 2 months of contact there was a significant decrease in viable spores, even without preservative, which were no longer numerable after six months of contact.

In the next test we determined the number of mold spores in an eyeshadow with preservative at two different relative humidities. Three molds were tested: *Penicillium aurentiogriseum*, *Aspergillus niger* and *Aspergillus ochraceus*. The results are presented in Figure 37.4.

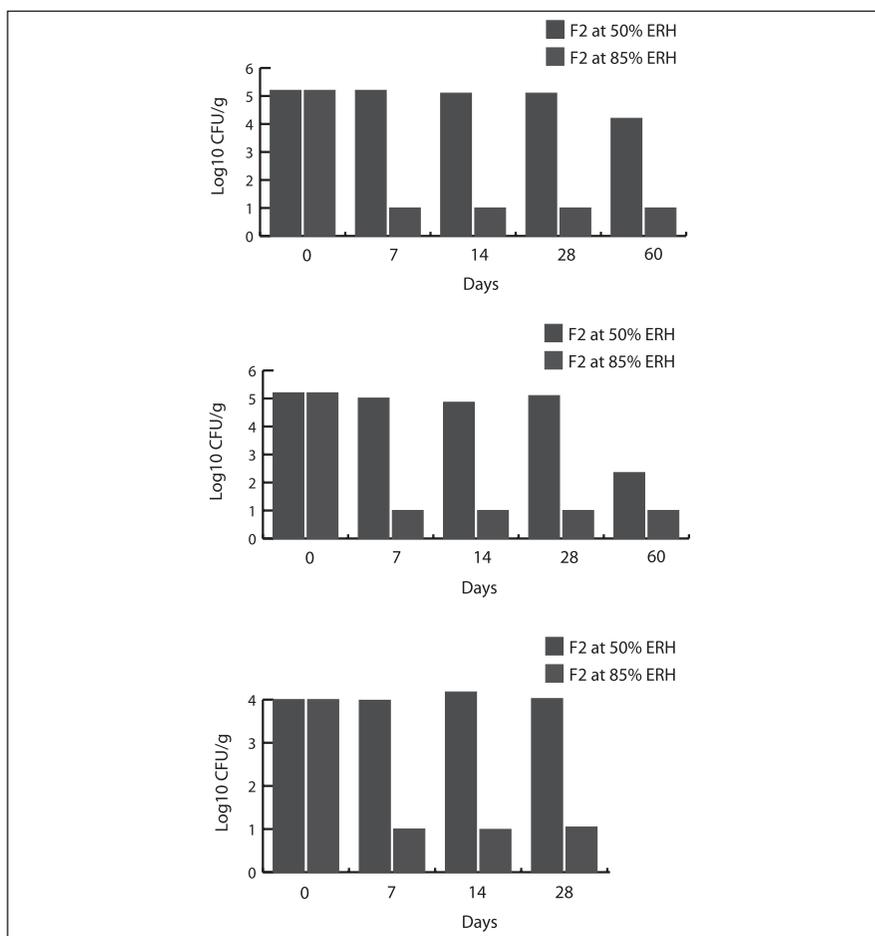


Figure 37.4. Evolution of different mold spore populations in eyeshadow with preservative at different ERH values and at constant room temperature
 above = *Penicillium aurentiogriseum*
 middle = *Aspergillus ochraceus*
 below = *Aspergillus niger*

At an ERH of about 50%, the three test strains behaved similarly during the first thirty days, with a measurable decrease after two months for *Aspergillus ochraceus*.

At an ERH of 85%, viable mold spores were undetectable after 7 days, regardless of the strain studied. At 0.85 Aw, it can be assumed that the xerophilic spores exhibit incipient metabolic activity. During this phase, they may be more vulnerable. At this ERH, the increasing mobility can then favor the action of the preservative. The tests done on eyeshadow F2 are presented in **Figure 37.4**. Two other formulations were tested under the same conditions (ERH and strains), and the results (not presented here) were similar to those presented in this study.

Conclusions

The following conclusions can be drawn from this study:

1. The tested commercial products and their main constituents have very low intrinsic Aw values.
2. As can be seen in **Table 37.3**, these same products have little affinity for water, indicated by initial Aw values between 0.24 and 0.38. The Aw values reached a maximum of 0.91 for an equilibrium value of 98% EHR.
3. For *Bacillus subtilis*, we observed no increase in the number of viable spores in any test. The powders studied have little affinity for water and the risk of bacterial growth is remote, even nonexistent.
4. Regarding the results obtained from different strains in different conditions and for different products, the behavior of the molds differed markedly from that of the *Bacillus* spores.
 - In a powder without preservative, for the higher ERH (85%), at a period of 30 days there is no modification of the mold-viable spores number. Beyond this period, the number of mold-viable spores decreases. In contrast, the same spores were stable throughout the study at 50% ERH.
 - In a powder with preservative, at 85% ERH, spores are undetectable after 7 days. For the lower ERH, the preservatives efficiency is not demonstrated.

- This shows that even without preservative and with a water supply, these products that interact poorly with water do not favor the survival, germination and growth of mold spores. More over, preservative efficacy is higher against mold spores when ERH increases. Maybe we can argue that water is useful for the transfer of the preservatives to the cells and that, at the same time, the activation of mold spores by an increase of humidity has a weakening effect.
5. This study shows that these eyeshadows have little affinity for water and are a very poor substrate for the growth of microorganisms, irrespective of the test conditions. Furthermore, under extreme conditions (high ERH), the preservative was effective against the molds tested.

At low relative humidity, one of the identified risks is that microorganism counts do not decrease even in products with preservative. This risk implies actions upstream in the manufacturing process and hence excellent microbiological quality of the ingredients and during their handling. The action of the preservatives in this type of product is enhanced at high equilibrium relative humidity.

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The Color Game, No Easy Feat

Jane Hollenberg

KEY WORDS: *color cosmetics, color dispersion, wetting, intensity, creativity, U.S. Food and Drug Administration (FDA), pigment, emulsion*

ABSTRACT: *The following is a summarized interview with Jane Hollenberg. Jane Hollenberg has over 30 years of experience in color cosmetics, including R&D, with Coty, Revlon and Rona. In 1996, she founded JCH Consulting, focusing on formulation, troubleshooting and the scale-up of color cosmetics. Hollenberg teaches courses on color cosmetics for the Society of Cosmetic Chemists, Center for Professional Advancement and Fairleigh Dickenson University USA.*

Creative with Color

Innovation in color cosmetics has definite boundaries in terms of novel raw materials. Color additives are limited to those approved by the U.S. Food and Drug Administration (FDA). The trends tend to become then, not what new pigment you can work with, but rather what can you do with existing colors in combination with new raw materials, or novel formulation concepts to improve performance, said Jane Hollenberg, of JHC Consulting.

She added that in today's game, formulators attempt to discover better methods for color dispersion and try to improve wetting, skin feel, and stability with surface treatments. "If someone wants a pigment like ultramarine blue below pH7, a surface coating can be added to make it stable in acid, wetting can be improved to allow

incorporation of more pigment into a system and achieve more intense color again by the surface treatment, or the particle size of the color additives can be mechanically reduced to obtain more intensity.”

Other Topics, Other Times with Jane Hollenberg

What we can learn from pigment wetting capability

Comparison of pigment wetting capability via suspension viscosity is a simple method used in the paint industry that anyone can perform. One can compare wetting ability of oils of similar viscosity, effect of adding wetting agents, or effect of pigment surface treatments. Better wetting translates to creamier feel in lipstick with no loss of elevated temperature stability, better mass tone/write off agreement, less brittle structure, particularly in shades containing high levels of pearl.

http://www.zenitech.com/documents/Zenigloss_Zwetting.pdf

Surface treatments of cosmetic pigments

Virtually all surface treatments improve pigment dispersibility, reducing the need for high energy agitation during processing of the finished cosmetic, due to the deagglomeration achieved during the coating process.

As new approaches to the formulation of color cosmetics are developing, so are new types of surface treatments to meet the needs of the cosmetic chemist. Efforts continue to impart true skin-treatment properties to pigments, by using them as carriers for the sustained release of active ingredients. Improvement of adhesion to the skin, particularly of colored pigments, is also an ongoing area of research.

(Cosmetics & Toiletries magazine, January 2002)

On the relisting of carbon black in August 2004

In spite of the obstacles to overcome, cosmetic chemists and marketers are excited by the positive properties offered by the approval of D&C Black #2. For those in Regulatory Affairs, FDA approval of one delisted colorant raises the hope that the cosmetic chemist's color palette—which has been shrinking since 1960—can again be expanded.

(Cosmetics & Toiletries magazine, April 2005)

Paying Dues in Color

The complexity of color should not be underestimated. It may be one of the most challenging aspects of formulating.

As hard as it is to make oil and water mix to form a stable emulsion, the color cosmetic formulator has to throw in a dry powder, the pigment, and keep the whole mixture homogenous. Whereas in emulsified foundations, the pigment is a 3rd phase, some mascara formulations have 4 phases to maintain an equilibrium: the water phase, the wax phase, the pigment, and that of a polymer emulsion.

“The color cosmetic formulator has a tough job,” she said.

In the Horizon

Recent innovations in color cosmetics have focused on improving wear, providing skin-treatment functionality, and using special-effect pigments to improve the skin's appearance. Light-diffusing pigments provide the illusion of a “second skin” obscuring imperfections, yet avoiding a made-up look.

Hollenberg finds the new pearl pigments based on totally smooth, transparent substrates “incredible looking” and also praised the color-travel pigments (colors that go through the entire spectrum). “They're exciting, but expensive.”

For mascaras, resins are better, and experimentation is being done on new fibers. In the lab people are attempting to imitate hair lash, a concept she defined as, “a very interesting approach.”

Correlating Water Contact Angles and Moisturization/Sensory Claims

Olga V. Dueva-Koganov, B. Scott Jaynes, Colleen Rocafort, Shaun Barker and Jianwen Mao

KEY WORDS: *substrate, contact angle, TEWL, foam block, hydration chamber*

ABSTRACT: *This chapter focuses on the link between the contact angles of water and the moisturization properties of a moisturizer. A new test has been developed to test these properties, and is examined in this chapter.*

A link has been found between the contact angle of water on a particular substrate treated with selected commercial moisturizers and the moisturization claims associated with those moisturizers. A test methodology was developed using measurements of the contact angle of water to quantify the effects on the surface properties of a skin-substitute substrate when skin care products were applied to the substrate. This methodology can be used as an effective tool for optimizing product development, differentiating among skin care products, competitive benchmarking and selecting prospective candidates for human studies.

Introduction

Studies of contact angles of liquids on surfaces have great technological importance. This is especially true with water because every action of water on earth is controlled by its wetting behavior on the solid with which it comes into contact.¹ The hydrophobic or hydrophilic tendency of the surface can be characterized by the angle formed by water on the liquid-surface interface. Water forms droplets with contact angles 90 degrees and higher on a hydrophobic (low-energy) surface and less than 90 degrees on a hydrophilic (high-energy) surface.

Human skin is a hydrophobic surface and the contact angle of water on the skin is approximately 90 degrees.¹ Skin care products are complex systems containing numerous ingredients with different physicochemical properties. Among these ingredients are water, polymers, polar and nonpolar emollients, sunscreen actives, surface active ingredients, humectants, solvents, particulates and pigments. After application of creams and lotions, the skin surface becomes enriched with a mixture of polar and nonpolar molecules with various functional groups. This enrichment leads to the modification of the skin surface and a change in the skin surface energy.

It is reasonable to assume that the change of water contact angle on skin after application of finished goods products represents a superposition of the effects of all its components. The determination of the possible relationship among contact angles of water formed on skin after application of creams and lotions, and the specific benefits that are delivered by these products, will give an important instrumental tool providing insights and optimization criteria for the formulators.

Materials and Methods

Materials: A commonly used commercial skin substitute^a was selected as a substrate because it effectively mimics the surface properties of human skin. It contains both optimized protein and lipid components and is designed to have topography, pH, critical surface

^a VITRO-SKIN (N-19) is a product and registered trademark of IMS Inc., Orange, Conn., USA.

tension and ionic strength similar to human skin. It is used in a broad range of in vitro methods including the measurement of SPF/UVA protection factors, evaluation of the water resistance and photostability of sunscreen formulations, assessment of the performance of sunless tanning formulations, evaluation of the performance of adhesive bandages and assessment of emollient spreading.²

Tests confirmed that the substrate is hydrophobic and the contact angle (θ) of water on the substrate is in the range of 104.9 ± 3.25 degrees (**Figure 39.1a**).

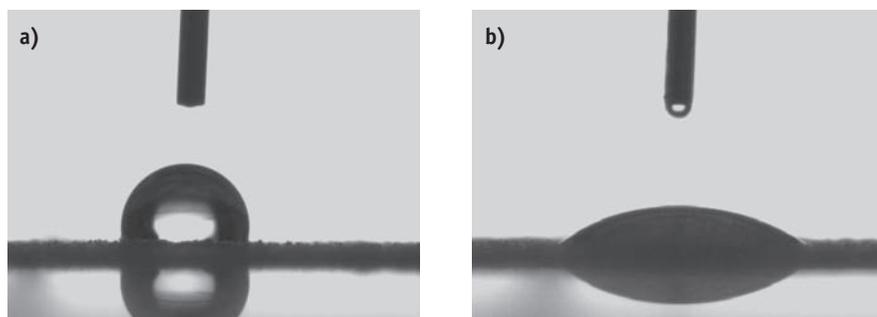


Figure 39.1. Contact angle (θ) of water on a substrate that mimics the surface properties of skin.

a) Untreated substrate

b) Product-treated substrate

The substrate, foam block, hydration chamber and glassless slide mounts 2.4 x 3.6 cm were purchased^b, as were the powder-free rubber finger cots^c.

Substrate preparation: The substrate was pre-cut into 4 x 4-cm pieces and placed in a closed, humidity-controlled chamber for 16–22 hrs prior to the tests. The humidity in the chamber was regulated by the 14.7% aqueous solution of glycerin placed in the bottom of the chamber. The substrate was placed above the liquid on a shelf. This step insures reproducible hydration of the substrate before product application.

^b VITRO-SKIN (N-19), Lot No. 5188, IMS Inc., Orange, Conn., USA

^c Powder Free Rubber Finger Cots (# 11-392-9B) are available from the Fisher Scientific Catalog.

Product application and contact angle measurements: Contact angles were measured instrumentally^d according to the static or sessile drop method and using deionized water as a probe solution.³ The substrate was prepared according to the procedure already described. A piece of hydrated substrate was mounted in a glassless slide and air-dried in a flat position with application side up for 15 min. It was used as a reference for untreated substrate during the contact angle measurements. Controlled humidity conditions were utilized.

Test products were applied on the skin topography side of the substrate placed on a plastic-covered foam block. Exactly 0.032 g of test product was applied evenly across a 4 x 4-cm section of the substrate, resulting in a standardized product application dose of 2 mg/cm². Immediately after product application, the product was rubbed into the film with a finger covered with a finger cot. Then the film was placed in a slide, mounted and air-dried for 15 min. Before measurements, the substrate was removed from the slide mount and the air-dried part of the substrate was cut into several small pieces to be used for the measurements. Pieces needed to be small to assure a flat position of the film on the sample table during the measurements. Extra care was taken to assure that the rough side was up and the film was flat. Contact angle measurements were conducted expeditiously, within approximately 1 min.

Results and Discussion

Twenty-three commercially available creams and lotions were randomly selected for this study. All tested products were o/w emulsions with ingredients that are used commonly in the cosmetic industry. The names and major ingredients of these products are shown in **Table 39.1**.

It should be pointed out that the tested formulations were produced by reputable companies and randomly selected for this study. Claims of 8-, 12- or 24-hrs moisturization usually are substantiated by these companies via instrumental measurements such as TEWL or impedance; claims related to skin feel are substantiated by sensory evaluations.

^d DSA-10 Contact Angle Measuring System, Krüss GmbH

Table 39.1. Name and major ingredients of the tested products

Product Code	Product Name / Major Ingredients
A	<p>Aveeno Active Naturals Ultra-Calming Daily Moisturizer SPF 15 (Lot# 0205C)</p> <p>Sunscreen actives, arachidyl alcohol, arachidyl glycoside, behenyl alcohol, benzyl alcohol, C12-15 alkyl benzoate, C12-16 alkyl hydroxyethyl ethylcellulose, C13-14 isoparaffin, cetearyl alcohol, cetearyl glycoside, cyclohexasiloxane, cyclopentasiloxane, dimethicone, ethylene/acrylic acid copolymer, glycerin</p>
B	<p>SK II Advanced Signs Treatment (Lot# 6062211801)</p> <p>Saccharomycopsis ferment filtrate, glycerin, niacinamide, isohexadecane, dimethicone/dimethiconol, polyacrylamide/C13-14 isoparaffin/laureth-7, isopropyl isostearate, panthenol, sucrose polycottonseedate, stearyl alcohol, cetyl alcohol, titanium dioxide/ammonium polyacrylate, behenyl alcohol, cetearyl alcohol/cetearyl glucoside, PEG-100 stearate, stearic acid</p>
C	<p>Oil of Olay Quench Normal to Dry Skin Body Lotion (Lot# 4258PR)</p> <p>Glycerin, niacinamide, isohexadecane, petrolatum, isopropyl isostearate, dimethicone, stearyl alcohol, cetyl alcohol, aluminum starch octenylsuccinate, polyethylene, caprylic/capric triglycerides, sodium acrylates copolymer, behenyl alcohol, benzyl alcohol, cetearyl glucoside, dimethiconol, stearic acid, PEG-100 stearate, propylene glycol, C12-13 pareth-3, laureth-7</p>
D	<p>Cetaphil Daily Facial Moisturizer SPF 15 (Lot# 38295)</p> <p>Sunscreen actives, diisopropyl adipate, cyclomethicone, glyceryl stearate, PEG-100 stearate, glycerin, polymethyl metacrylate, acrylates/C10-30 alkyl acrylate crosspolymer, carbomer 940</p>
E	<p>Neutrogena Oil-Free Moisture SPF 15 (Bar Code 7050105650)</p> <p>Sunscreen actives, octyldodecyl neopentanoate, glycerin, dimethicone, emulsifying wax NF, glyceryl stearate, PEG-100 stearate, carbomer</p>
F	<p>Oil of Olay Complete Defense daily UV Moisturizer SPF 30 (Lot# 5136PR)</p> <p>Sunscreen actives, glycerin, isopropyl lauroylsarcosinate, dimethicone, polyacrylamide, isopropyl isostearate, polymethylsilsequioxane, polyethylene, C13-14 isoparaffin</p>

continues

Table 39.1. Name and major ingredients of the tested products (continued)

Product Code	Product Name / Major Ingredients
G	Neutrogena After-Sun Treatment Natural Soy (Lot# 2 E3) Glycerin, C12-15 alkyl benzoate, dimethicone, cetearyl alcohol, glyceryl stearate, PEG-100 stearate, hydroxyethyl acrylate/sodium acryloyldimethyltaurate copolymer, polymethyl metacrylate, xanthan gum, cetearyl glycoside, polysorbate 60
H	Pond's S (Lot# 04285M06) Water, mineral oil, isopropyl palmitate, petrolatum, glycerin, stearic acid, ceresin, glyceryl stearate, cetyl alcohol, sorbitan oleate, candelilla wax, triethanolamine, laureth-23
I	Aveeno Moisturizing Lotion with Natural Colloidal Oatmeal (Lot# 0095LK) Oat kernel flour, glycerin, isopropyl palmitate, petrolatum, cetyl alcohol, distearyldimonium chloride, dimethicone
J	Jergens Ultra Healing Extra Dry Skin Moisturizer (Lot# T075204ZZ) Glycerin, cetearyl alcohol, petrolatum, mineral oil, cetearth-20, cetyl-PG hydroxyethyl palmitamide, allantoin, dimethicone, cyclomethicone, glyceryl dilaurate, stearic acid, aluminum starch octenylsuccinate, carbomer
K	Neutrogena Healthy Skin Eye Cream (Lot# 1815L) Cetyl alcohol, glycerin, C12-15 alkyl benzoate, stearic acid, glyceryl stearate, PEG-100 stearate, melibiose, retinyl palmitate, glycolic acid, ascorbic acid polypeptide, tocopheryl acetate, panthenol, bisabolol, dimethicone, octyl palmitate, mica, silica, xanthan gum
L	Johnson and Johnson's Bedtime Cream —Baby Formula (Lot# 0105VB) Glycerin, petrolatum, mineral oil, dimethicone, cetyl alcohol, glyceryl oleate, stearyl alcohol, carbomer, cetearth-6
M	Aveeno Baby Soothing Relief Moisture Cream (Lot# 0125D) Glycerin, petrolatum, mineral oil, cetyl alcohol, dimethicone, oat kernel flour, carbomer, butylene glycol, stearyl alcohol
N	Gold Bond Ultimate Healing 7 Intense Moisturizers (Lot# 05N149) Glycerin, dimethicone, petrolatum, jojoba esters, cetyl alcohol, cetearyl alcohol, distearyldimonium chloride, steareth 21, steareth-2, stearamidopropyl PG-dimonium chloride phosphate, methyl gluceth-20, polysorbate 60

Product Code	Product Name / Major Ingredients
O	Curel Continuous Comfort (Lot# T164206BZZ) Glycerin, distearyldimonium chloride, petrolatum, isopropyl pamate, cetyl alcohol, shea butter, acacia senegal gum, dimethicone, gelatin
P	Neutrogena Intensified Day Moisture SPF 15 (Lot# 1445L) Glycerin, C12-15 alkyl benzoate, cyclomethicone, cetyl alcohol, C10-30 cholesterol/lanosterol esters, isopropyl isostearate, panthenol, glyceryl stearate, PEG-100 stearate, carbomer
Q	Lubriderm Skin Nourishing Moisturizing Lotion (Lot# 07824B) Caprylic/capric triglycerides, glycerin, cetyl alcohol, petrolatum, cocoa butter, castor oil, cetyl alcohol, wax, glyceryl stearate, PEG-100 stearate, xanthan gum,
R	Dove Intensive Firming Cream (Lot# 02255PP17) Glycerin, stearic acid, caprylic/capric triglyceride, dimethicone, glycol stearate, PEG-100 stearate, cyclomethicone, petrolatum, acrylates/C10-30 alkyl acrylate crosspolymer, cetyl alcohol, glyceryl stearate, carbomer, ceramides, acacia senegal gum
S	Johnson's Softlotion 24 hrs Moisture-Baby (Lot# 2604G) Glycerin, mineral oil, carbomer, cetareth-6, stearyl alcohol, glyceryl oleate, squalane
T	Johnson's Soothing Naturals Nourishing Lotion (Lot# 0045LK) Glycerin, cetyl alcohol, glycine soja (soybean) oil, cornstarch, potassium cetyl phosphate, dimethicone, propylene glycol, carbomer
U	Neutrogena Combination Skin Oil Free Moisture (Lot# 1645L) Cyclomethicone, cetyl caprylate, glycerin, cetyl ricinoleate, stearyl alcohol, glyceryl stearate, PEG-100 stearate, acrylates copolymer, lysine carboxymethyl cysteinate, lysine thiazolidine carboxylate, tocopherol, silica, xanthan gum—Microsponge technology was utilized
V	Johnson and Johnson's Softcream Extra Care Healing Hand Cream (Lot# 025VB) Glycerin, mineral oil, cetyl alcohol, dimethicone, stearyl alcohol
W	Lubriderm Skin Nourishing w/Premium Oat Extract (Lot# 06084B) Glycerin, petrolatum, caprylic/capric triglyceride, polysorbate 60, xanthan gum

The measured contact angles and moisturization and sensory claims are presented in **Table 39.2**.

At this stage of the research, the authors sought primarily to establish a correlation with manufacturer-supported claims. The research could be extended with additional studies such as the following: determining the concentration of moisturizing ingredients or emulsifiers in each tested product; adding materials such as glycerin, mineral oil or petrolatum to a simple formula and then conducting contact angle studies; blind panel testing to relate sensory properties to contact angle. These studies could be performed to provide valid and specific information. For comments related to moisturization, see **Other Voices on TEWL and Contact Angle sidebar**.

The obtained data indicates that both products yielding a contact angle in the range of 40–50 degrees have a light sensory attribute and one product provides all day (for at least 8 hrs) moisturization. As **Figure 39.1b** shows, the contact angle of water on the substrate was reduced to about 40 degrees after application of the product.

In the range of 50–60 degrees, all products have light, lightweight or nongreasy claims and one product, representing about 15% of test products in this group, provides 24-hr moisturization. Interestingly, this particular product is the only one that contains petrolatum. In addition, there are two products (40%) with all-day or 12-hr moisturization.

In the range of 60–70 degrees, 60% of products moisturize for 24 hrs and 30% make claims of all night or at least 8 hrs of moisturization; 60% are nongreasy or lightweight or both. In this group, all products with 24-hr or all night moisturization claims contain petrolatum or petrolatum and mineral oil, and the majority of lotions with nongreasy or lightweight claims have a particulate: aluminum starch octenylsuccinate, silica, oat kernel flour or silicon derivatives, or their combination.

In the range of 70–80 degrees, 70% of test products provide 24-hr moisturization, and 15% claim 12-hr moisturization. Among them, 70% are nongreasy or lightweight or both. The majority of the 24-hr moisturizers contain petrolatum or mineral oil.

Table 39.2. Contact angles (θ) in degrees (\pm StDev) of water on a selected skin-mimicking substrate after application of commercially available creams and lotions

Product Code*	Contact Angle	Sensory/Moisturizing Claims
A	41.5 \pm 3.7	Light, fast-absorbing, moisturizes all day
B	43.2 \pm 4.1	Renews moisture and balance, light
C	56.5 \pm 4.5	Nongreasy, provides an immediate burst of moisture that continues for 24 hrs
D	50.0 \pm 6.5	Lightweight, facial moisturizer, nongreasy
E	51.0 \pm 2.6	Lightweight, 12-hr moisturization, nongreasy
F	57.8 \pm 8.2	Light, absorbs quickly, daily moisturizer, nongreasy
G	53.9 \pm 8.1	Non-sticky, absorbs quickly, 12-hr moisturization
H	60.1 \pm 3.2	Moisturizing cream, deep overnight hydration
I	62.6 \pm 5.0	nongreasy, fast-absorbing, 24-hr moisturization
J	62.9 \pm 5.9	Fast-absorbing, 24-hr moisturization
K	65.1 \pm 3.3	Lightweight, provides effective moisturization
L	63.7 \pm 4.1	Moisturizes all night
M	69.2 \pm 4.6	Nongreasy, 24-hr moisturization
N	64.8 \pm 2.5	Nongreasy, 24-hr moisturization, penetrates fast
O	73.5 \pm 3.7	Nongreasy, 24-hr moisturization, absorbs quickly
P	74.9 \pm 6.1	Lightweight cream, moisturizes for 12 hrs, nongreasy, absorbs quickly
Q	77.7 \pm 1.7	Nongreasy, draws in and retains moisture, 24-hr moisturization
R	78.9 \pm 2.9	24-hr moisturization
S	71.7 \pm 3.2	24-hr moisturization, Nongreasy, Fast-absorbing
T	73.1 \pm 3.6	Nongreasy, fast-absorbing, 24-hr moisturization
U	73.4 \pm 4.6	Lightweight, nongreasy, moisturizer
V	81.2 \pm 9.1	24-hr moisturization
W	85.2 \pm 2.8	24-hr moisturization, nongreasy, fast-absorbing

* See Table 1 for explanation of Product Code

Other Voices on TEWL and Contact Angle

- One industry expert and a peer reviewer of the accompanying article noted the need for studies to relate transepidermal water loss (TEWL) to contact angle measurements. “These studies are critical. They would prove if contact angle measurements really relate to moisturization,” the expert said.
- John Sottery is president of IMS Inc., the supplier of the substrate described in the accompanying article. Sottery said, “I believe that ingredients that would give you a higher contact angle probably are also going to give you some occlusive effect. The products that talk about having a 24-hour moisturization usually can make that claim because they have set up this occlusive film on the skin and the water that over time would normally be leaving the skin builds up in the higher layers of the stratum corneum. As the contact angle increases, so does the likelihood that the manufacturer will make 24-hour moisturization claims. You could almost say that all the products that are giving this 24-hour moisturization would appear to be working through some kind of an occlusivity mechanism. But that’s speculation. We don’t have enough data to say that, but that certainly is a possibility.”
- Elkhyat et al. reported on an in vivo study that establishes “a correlation between cutaneous hydration and contact angle,” in the opinion of Dueva-Koganov. This study was conducted to quantify the influence of spray application of an isotonic mineral water on the hydrophobic tendency of dry skin and to compare spreading of two types of water (bidistilled and mineral) on the skin through contact angle measurement of each water drop on the skin before and after mineral spray application. Contact angles were measured by a system allowing both in vitro and in vivo measurements. Cutaneous hydration and other parameters also were measured before and after mineral water application. The hydrophobic tendency of the dry skin tested in this study was strongly decreased after mineral water application. This parameter was illustrated by an increase in cutaneous hydration and a decrease in contact angle value.
- An article^b in *Scientific American* describes how Turkish scientists created a highly porous gel coating of polypropylene on the surface of a glass slide. The slide then had a super hydrophobic surface with a contact angle of 160 degrees and water-repelling capabilities comparable to those of the lotus leaf, one of nature’s most water-repellent surfaces.

^a A Elkhyat et al, Assessment of spray application of Saint Gervais water effects on skin wettability by contact angle measurement comparison with biodistilled water, *Skin Res Technol* 10 4 283 (2004)

^b L Wright, Lotus leaf inspires waterproofing scheme, www.sciam.com/article.cfm?articleID=00088C40-BE58-1E5F-A98A809EC5880105&ref=sciam, *Scientific American* (Mar 3, 2003)

Both products in the 80–90 degree range provide 24-hr moisturization, and only one is nongreasy. Both of these products contain petrolatum or mineral oil.

A fast-absorbing claim is found in 40–60% of the products from each group. It should be noted that all products tested contain glycerin in various concentrations.

Figure 39.2 shows the correlation between contact angle of water on the product-treated substrate and the sensory or moisturization claims made for the products.

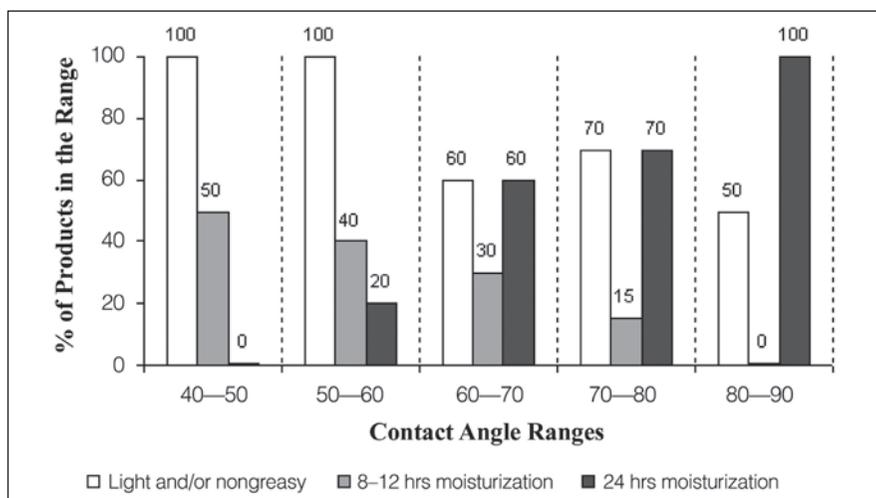


Figure 39.2. Correlation between contact angle ranges and product claims

The data shows that contact angle measurements can be used to quantify and compare the effects of skin care products on the surface properties of this proprietary skinlike substrate. Products that generate relatively low contact angles tend to make more sensory claims related to light and nongreasy feel, while products that produce relatively high contact angles tend to make more claims related to long-term moisturization.

Conclusions

A correlation exists between moisturization and sensory properties of skin care products on the one hand and water contact angles measured on a substrate that effectively mimics skin surface properties on the other hand.

The contact angle technique uses a methodology that is simple, but innovative. It can be effectively utilized for the optimization of product development as a preliminary step before claim substantiation and consumer studies, and to differentiate among skin care products and competitive benchmarks.

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Cream in Powder Form: A New Concept in Makeup

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KEY WORDS: *cosmetic formulation, cream, powder, treated pigments, thickeners*

ABSTRACT: *The present work describes a cosmetic technology based on a newer formulating concept—cream in powder form. The final formulation can be created by two different technical processes to produce either water- or oil-based cosmetics. In each case, the proper selection of ingredients determines the stability of the finished products.*

Sample-sized packaging, single doses and wipes are current cosmetic market trends, especially since the new Transport European Directive came about that limits the presence of liquids or pasty substances on an aircraft. This legislation has reinforced the current evolution toward seeking new textures.

Beauty products must be discreet yet effective, practical and even fun. The described cream in powder form, developed by LCW Laboratories, is a loose powder that traps a high content of liquid. The resulting product offers interesting properties and an outstanding sensory texture upon application.

Principle

Powders, creams and cream-to-powders are well-known product forms. Since the cosmetic industry continues to seek new tactile

sensations, this cream in powder concept has been formulated to create interesting texture. The principle of the innovation is based on the development of a powder that is turned into a cream (see **Figure 40.1**).

Indeed, it is a loose powder containing a high proportion of a liquid phase. Upon application, the fine powder disappears under soft massage on the skin and is transformed into a cream or oily gel. The specific ingredients chosen can provide innovative results—treated pigments are combined with cosmetic powders and a liquid phase to create this concept.



Figure 40.1. Powder changing to cream

Key Ingredients

Cream in powder form is based on the specific combination of two families of ingredients: treated pigments and thickeners.

Treated pigments: Coatings on pigments and cosmetic fillers modify surface characteristics by imparting new performance properties such as good dispersibility, better adhesion on skin, water resistance and tactile effects.¹ The surface treatments applied to traditional pigments or more sophisticated powders have become essential to modify the textures and stability of formulas while improving their feel, application and wetting capabilities.

In particular, silicone or silane surface treatments provide hydrophobic properties to powders, limiting their absorption capacity of liquid while giving an improved soft feeling. For this reason, silane- or silicone-treated pigments are chosen for use in the aqueous version of the cream in powder form. These treated pigments have low affinity for the liquid phase and consequently, they contribute to maintaining the physical form of loose powder—avoiding the disastrous formation of a thick paste.¹

In addition, other treated pigments combine hydrophobic and lipophobic properties. They are coated with perfluoro substances, giving them good resistance to perspiration and sebum and better adhesion on the skin with long-lasting finish. They are not affected by the presence of oil in the oil-based version of the cream in powder form. As a result, these pigments maintain the stability of the loose powder formulation. **Table 40.1** and **Figure 40.2** show characteristics of treated pigments.¹

Table 40.1. Characteristics of treated pigments

Nature	INCI	Hydrophobic	Lipophobic
Silane	Triethoxycaprylylsilane	X	
Silicone	Dimethicone	X	
Perfluoro	Perfluoroalkylphosphate	X	X
Perfluoro	Triethoxycaprylylsilane (and) perfluoropolymethylisopropyl ether	X	X

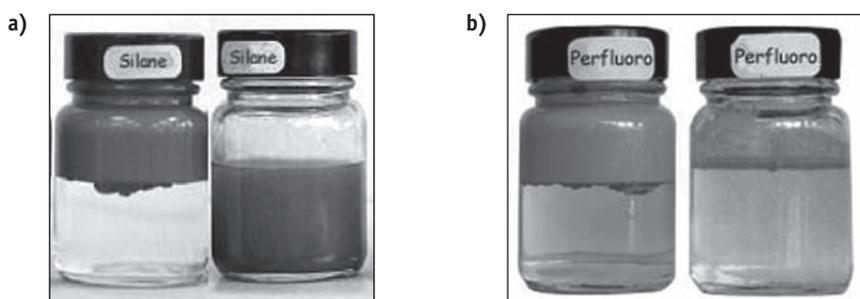


Figure 40.2. a) Hydrophobic and lipophilic pigments; b) hydrophobic and lipophobic pigments

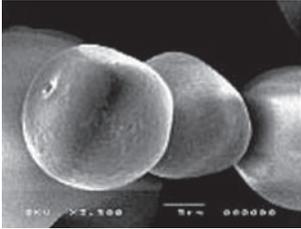
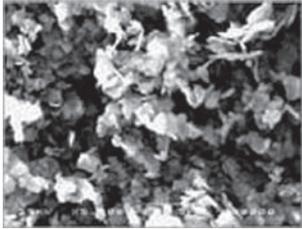
Conventional pigments have been used in the past primarily to give color to a formulation; however, with modifications to their surface, they also can contribute to the creation of new sensory textures.

Thickeners: Thickeners have an essential function in the described cream in powder concept in that they dictate the final formula texture by stabilizing the gel structure. Their selection depends on the nature of the liquid phase in which they are used—aqueous or oily. For example, sodium carboxymethyl starch is the best thickener

for success in an aqueous phase. It is a unique natural thickener and presents a fine, soft texture and instant gelling capacity. Characteristics of thickeners are shown in **Table 40.2**.

If used in the oily phase, a thickener based on mica with great affinity for oils is preferred. In particular, lamellar sheets trap the oily phase in their structure² while conferring a soft feeling upon application.

Table 40.2. Characteristics of thickeners

	Aqueous phase	Oily phase
Thickener nature	Sodium carboxymethyl starch	Mica
Microscopic structure		
Appearance	White powder	White powder
Viscosity	7500 cps in pure water	14000 cps in oil

Formulations

Aqueous phase: An aqueous cream in powder formulation is based on the mixture of: cosmetic powders selected for their texture, thickeners with unique performance, actives, surface-treated pigments and an aqueous phase. This composition could contain up to 80% water (see **Formula 40.1**).

The finished product is created by mixing all the powders with water in a blender; its stability is expressed by the formation of a loose powder and not a thick paste. Formula stability is dependent on the presence of cosmetic powders having low affinity for the aqueous phase, surface-treated nanofine titanium dioxide and hydrophobic pigments. Moreover, the use of treated pigments in the formulation imparts excellent wear, comparable to conventional cream.

Formula 40.1. Cream in powder form (PEG-free)

Sodium carboxymethyl starch (Covagel, LCW)	3.80% w/w
Mica (and) triethoxycaprylylsilane (Mica 8 AS R0433, LCW)	2.40
Talc (and) triethoxycaprylylsilane (Talc AS R0435, LCW)	3.80
Sodium stearyl fumarate (Covafluid FS, LCW)	1.00
Methyl methacrylate crosspolymer (Covabead LH 85, LCW)	2.40
Titanium dioxide (and) trimethoxycaprylylsilane (PW Covasil S1, LCW)	3.30
Water (<i>aqua</i>)	81.00
Algae (and) sorbitol (Fucosorb, LCW)	2.00
Preservative	0.30
Triethanolamine	<u>qs to pH 8</u>
	100.00

Cream in powder form can be composed of a combination of actives in powder or liquid form, while also offering the opportunity to add fragrance without affecting the effectiveness or stability. The concept can be adapted to skin care or makeup, as well as incorporate raw materials for application in hair coloring formulas. For hair coloring, colors can be pearls, pigments or hair dyes (see **Formulas 40.2** and **40.3**). Pearls provide temporary color effects (see **Figure 40.3**) and pigments and hair dyes achieve color results that are more resistant to shampoo. The cream in powder technique maintains the hair dyeing properties of the coloring raw materials used.

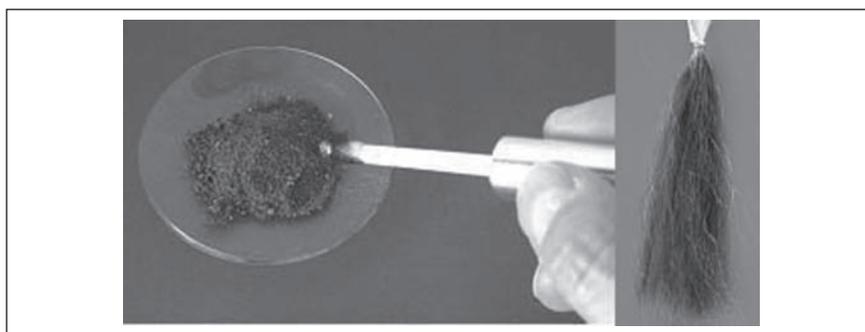


Figure 40.3. A temporary color effect can be provided by pearls, such as for root touch-ups. (Left) the black powder to cream from Formula 3; and (right) the final result after 15 min of application and rinse with water

Formula 40.2. Hair color cream in powder (brown)

CI 12250 (306002 Arianor Mahogany, LCW)	0.12%w/w
CI 12245 (306003 Arianor Madder Red, LCW)	0.06
CI 56059 (306004 Arianor Steel Blue, LCW)	0.30
CI 12719 (306005 Arianor Straw Yellow, LCW)	0.30
Tetrasodium EDTA (Covastyle ED, LCW)	0.20
PEG-8	4.00
Cetrimonium chloride	2.00
TEA	1.50
Preservative	0.30
Citric acid	qs to pH 8
Water (<i>aqua</i>)	67.02
Sodium carboxymethyl starch (Covagel, LCW)	3.30
Talc (and) triethoxycaprylylsilane (Talc AS, LCW)	1.10
Mica (Mica 8, LCW)	3.30
Methyl methacrylate crosspolymer (Covabead LH 170, LCW)	8.80
Titanium dioxide (and) trimethoxycaprylylsilane (PW Covasil S1, LCW)	<u>7.70</u>
	100.00

Formula 40.3. Hair color cream in powder (black)

Hydrogenated polyisobutene (Squatol S, LCW)	2.00%w/w
PEG-12 dimethicone	2.00
CI 77266 (and) glycerin (Noir Covarine W9793, LCW)	10.00
Water (<i>aqua</i>)	57.30
Sodium polyacrylate (Covacryl MV 60, LCW)	0.20
Mica (Submica M, LCW)	5.00
Talc (and) triethoxycaprylylsilane (Talc AS, LCW)	2.00
Mica (Mica 8, LCW)	0.50
Methyl methacrylate crosspolymer (Covabead LH 170, LCW)	11.00
Titanium dioxide (and) trimethoxycaprylylsilane (PW Covasil S1, LCW)	<u>10.00</u>
	100.00

Oily phase: In an oily phase cream in powder form, the association of cosmetic powders, thickeners and treated pigments is combined with natural or synthetic oils. In this case, the use of powders with low affinity for the oily phase and lipophobic treated pigments and nanofine titanium dioxide are recommended. The lipophobic pigments are selected in the family of the perfluoro treatments. The same manufacturing procedure is applied in the oil-based version; the product's stability also is exemplified by the formation of a loose powder and not a thick paste.

The oily formulation (see **Formula 40.4**) has a drier feeling but it is characterized by better waterproof performance and an increased resistance to perspiration and sebum.¹ In skin care, makeup or hair care, the formulation is more emollient and provides a long-lasting effect. The appropriate choice of oils can lead to shiny products.

Formula 40.4. Anhydrous cream in powder

Titanium dioxide (and) perfluoroalkylphosphate (PW Covafleur, LCW)	25.10%w/w
Talc (and) perfluoroalkylphosphate (PF5 Talc JA 46-R, Daito)	8.50
Mica (Submica M, LCW)	8.50
Methyl methacrylate crosspolymer (Covabead LH 170, LCW)	3.50
Red iron oxide (and) perfluoroalkylphosphate (PF-5 Red R-516 L, Daito)	0.70
Yellow iron oxide (and) perfluoroalkylphosphate (PF-5 Yellow 601, Daito)	2.50
Black iron oxide (and) perfluoroalkylphosphate (PF-5 Black BL-100, Daito)	0.20
Hydrogenated polyisobutene (Squatol S, LCW)	<u>51.00</u>
	100.00

Packaging

Specific packaging is advised for cream in powder products. For example, the chosen applicator will need to adapt to the loose powder form. Water-tight and rigid plastic packs, slightly opaque, are recommended to preserve the stability of the product. As noted, this product form also is designed to fit the current trend toward smaller

packaging and single dose products—only a small quantity of the finished product is required by the consumer, and packaging the product in smaller amounts helps to maintain its stability.

Conclusion

The described cream in powder innovation³ is based on the specific selection of ingredients and a learnedly adjusted manufacturing process, which ensures the stability of the product. This concept allows formulators to create new surprising texture changes upon application to the skin, combined slow release of actives, and other sensory experiences in today's modern cosmetic products that are appreciated by consumers.

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Blush Just Got Smarter

James Joo

KEY WORDS: *pigment, blush, antioxidants, microcirculation, energy*

ABSTRACT: *The following is a summarized interview with James Joo. James Joo, vice president of R&D for The Color Factory Inc., has nearly 12 years of experience in global skin care formulation that spans from OTC products to hair care, body care and color cosmetics. He has published technical papers with a number of scientific societies and journals, and has three registered patents in the areas of multiple emulsions and water. He is a member of the Society of Cosmetic Chemists.*

The Evolution of Blush

Some say the use of blush and rouge began in ancient Roman society, where women rubbed rouge onto their cheeks. This practice progressed with the Persians who used henna; through the Middle Ages when women bled themselves and smudged it on their cheeks; to the Victorian age when crushed beets and strawberries were used, or women pinched their cheeks—all to achieve a healthy glow.

The category, of course, has evolved to a more sophisticated use of color that involves pigment, chemistry and now biology. New to the market are blushes that use the skin's chemistry to help the products achieve a natural flush—essentially, blush has become smarter.

Smashbox Cosmetics recently unveiled O-Glow, a blush incorporating a technology developed by The Color Factory Inc. The product claims to be a “microcirculating cheek color with goji berry-C complex.” It is said to react with an individual's skin chemistry to turn the color that person blushes naturally.

The Makeup of the Makeup

James Joo, vice president of R&D for The Color Factory Inc., developed the product and explains its premise.

“I tried to combine chemistry, biochemistry, biophysics and physical chemistry into one product,” said Joo.

According to Joo, the product is made up of four components: an energy source, antioxidants, a microcirculation enhancer and a pigment (see **Figure 41.1**).

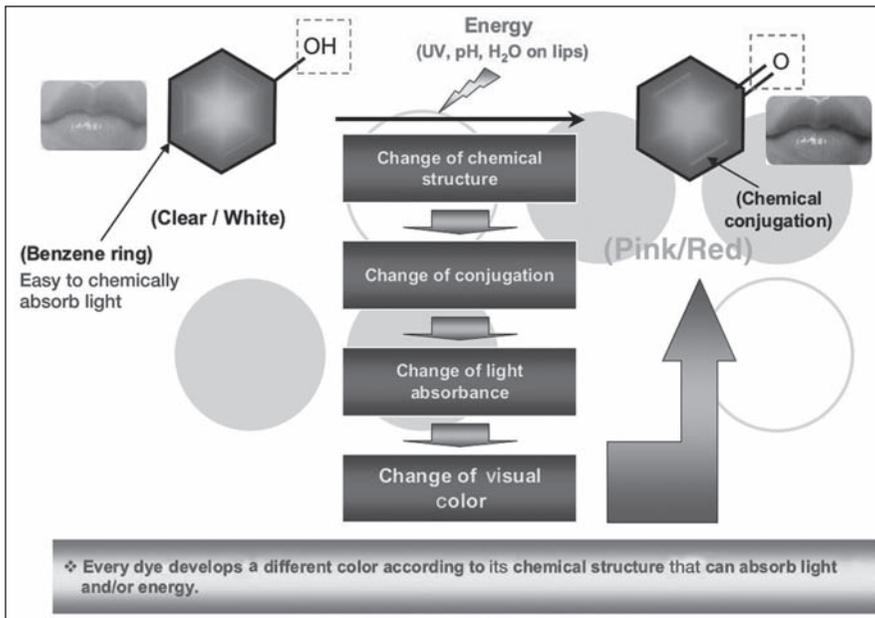


Figure 41.1. Mechanism of pigment, an illustration provided by the Color Factory Inc.

The material considered the energy source was incorporated for its ability to produce adenosine triphosphate (ATP) to enhance microcirculation. In this case, the material is derived from plankton extract, which provides both energy and a nutritional source.

Antioxidants were needed to prevent biological oxidation due to metabolism or the consumption of energy.

“Goji berry extract is also a famous antioxidant and immune system enhancer,” said Joo, who chose the extract for its antioxidant benefits only to discover later that it also aided microcirculation. In

addition to goji berry, pomegranate seed extract and vitamin C are included as antioxidants.

The microcirculation enhancer is a combination of goji berry extract and ginkgo leaf extract.

“Ginkgo leaf extract has been used in microcirculatory medicine for a long time. There are also reports that goji berry extract has a microcirculation effect, in addition to its antioxidation effect,” said Joo.

The final element is the pigment, specifically Red 27 (CI 45410), which Joo chose since it is triggered by skin pH and moisture to create a visual effect.

“The pigment reacts with protons in the skin and the pigment’s chemical structure (resonance) is changed so that the visual color changes from white to pink,” explained Joo.

The Magic Behind the Makeup

Curious consumers wonder how the product varies when applied to different skin tones, as the product claims. The pigment begins as a benzene ring that is clear or white. Energy through UV light, pH and water then change the chemical structure of the pigment. That change in structure further changes conjugation to alter light absorbance and finally the visual color to pink/red.

According to a presentation by Joo, every dye develops a different color based on the individual’s chemical structure, which can absorb light and/or energy.

“Normally, higher water content within the skin will produce a stronger color intensity,” added Joo.

One of Joo’s main goals, when designing the gel blush, was to create a product that offered other benefits in addition to being a color cosmetic.

“I wanted to design a product that has total care benefits even though it is a color cosmetic. I love something unique.”

Hyperbranched Polyalphaolefins Enhance Anhydrous Stick Formulations

Florence Nicholas and Jeff Brooks

New Phase Technologies, a Division of Baker Petrolite Corp., Sugar Land, Texas USA

KEY WORDS: *pouring temperature, stick, synthetic wax, hyperbranched polyalphaolefins (HBPs), pour point*

ABSTRACT: *Hyperbranched polyalphaolefins offer distinctive functional and aesthetic properties due to their branch-on-branch configuration. In anhydrous stick formulations containing polyethylene or other crystalline waxes, the addition of hyperbranched polyalphaolefins is shown in this article to lower pour points by as much as 10C, increase gloss, modify structure and improve formula stability.*

In today's global personal care marketplace, consumers have specialized needs based on function as well as fashion. In response, formulators strive to develop unique, high-performance products to meet rapidly evolving trends. Ingredients that combine multiple benefits offer potential for differentiated solutions while making formulation simple and more cost-effective. Among the array of product forms, cosmetic sticks are practical and easy to use. However, they can also present formulation challenges in terms of structure, stability and aesthetics.

A Multifunctional Solution

Hyperbranched polyalphaolefins (HBPs) commonly are used to form flexible films and impart gloss. Known by their INCI designation as *synthetic wax*, HBPs also have film-forming properties that allow them to act as conditioners and moisturizers. Their distinctive branch-on-branch structure enables them to lower pour points, modifies structure and improves formula stability, making HBPs useful for a number of personal care applications ranging from lipsticks to lotions. **Figure 42.1** illustrates the structure of these materials, which can be designed in numerous branch lengths.

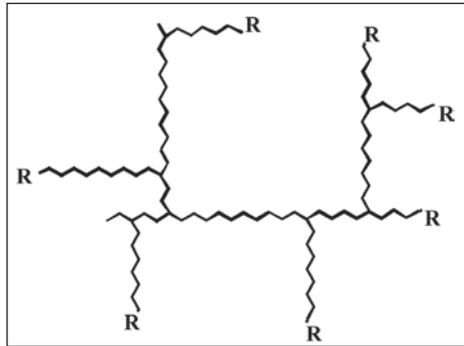


Figure 42.1. Structure of hyperbranched polyalphaolefins

Depending on branch length and associated molecular weight, HBPs exist as low-melting solids or as liquids, which have the added advantage of making them cold-processable.

Polyethylene and other highly crystalline waxes typically are used in stick formulations to provide efficient structuring and to prevent syneresis that can be associated with natural materials such as beeswax, carnauba wax and candelilla wax. However, the use of polyethylene results in high pour points and a matte finish—issues that can be resolved by adding HBPs.

Four HBP products^a, designated in this article as HBP-1 through HBP-4 according to their branch lengths from longest to shortest, were evaluated in anhydrous stick formulations where polyethylene was the main structurant for commonly used oils. The oils were mineral oil, isododecane, isopropyl palmitate, C12-C15 alkyl benzoate and safflower oil. In addition to their wide use in personal care formulations, these five materials were chosen to illustrate polar and

^a Performa V 103 polymer (designated here as HBP-1), Performa V 260 polymer (HBP-2), Performa V 343 polymer (HBP-3) and Performa V 825 polymer (HBP-4) (all INCI: Synthetic wax) are products of New Phase Technologies, a division of Baker Petrolite Corp., Sugar Land, TX USA.

Table 42.1. Physical properties of tested HBPs

HBP	Length Branch	Molecular Weight (Mn)	Melting Point (°C)	Viscosity (cP, 99°C)	Refractive Index*
HBP-1	Longest	2900	74	350	1.510
HBP-2	Long	1900	54	300	1.506
HBP-3	Short	1800	41	130	1.486
HBP-4	Shortest	1200	Liquid	1200 (RT)	1.473

* Refractive indices for the solid synthetic waxes HBP-1, HBP-2 and HBP-3 were measured via the Becke line method (589.3 nm at 25°C) by Cargille Laboratories Inc., Cedar Grove, NJ USA. For the liquid HBP-4, the refractive index was measured according to the ASTM D542-00 (2006) Standard Test Method for Index of Refraction of Transparent Organic Plastics, by Plastics Technology Laboratories Inc., Pittsfield, MA USA.

nonpolar examples, and to include one natural ingredient. **Table 42.1** summarizes the properties of these HBPs.

In the tests described here, the control in each case was a polyethylene/oil base (**Formulas 42.1** and **42.2**). If the oil was isopropyl palmitate, C12-C15 alkyl benzoate, mineral oil or safflower oil, polyethylene was added at 12%. In the case of isododecane, 30% polyethylene was added to achieve an appropriate stick structure. The various HBPs were added at 5%, which is an average level used in the industry. In actual personal care formulations, use levels for the solid HBPs -1, -2 and -3 are typically less than 10%. In the case of HBP-4, use levels may be 5% or higher because of the liquid nature of the material.

Lowering Pour Point

Research has shown that polyalphaolefins can act as pour point depressants by modifying crystal shape and size, as well as flow characteristics.^{1,2} This attribute can also provide advantages in personal care applications, including safer handling, easier mixing and lower energy costs.

Pouring temperature is the lowest temperature at which a molten wax mixture can be easily dispensed. Blends of polyethylene in various oils were tested as controls and the impact of adding 5% of

Formula 42.1. Anhydrous stick base

	Control	Test
Mineral oil or safflower oil or isopropyl palmitate or C12-C15 alkyl benzoate	87%w/w	83%w/w
Polyethylene	12	12
HBP	—	<u>5</u>
	100	100

Formula 42.2. Anhydrous stick base

	Control	Test
Isododecane	70%w/w	65%w/w
Polyethylene	30	30
HBP	—	<u>5</u>
	100	100

the HBPs was evaluated. The test was conducted by solubilizing the waxes in the oil and slowly cooling the specimen under observation. The pouring temperature was recorded at the point where the mixture was still homogeneous and fluid, but the authors observed a sharp increase in viscosity. Thereafter, viscosity continues to increase until the specimen reaches the congealing point, or “no flow” condition. In this study, HBPs were found to depress the pour points for high-melting crystalline waxes (**Figure 42.2**).

In combination with mineral oil, HBP-1 depressed the pouring temperature by a full 10°C, to 62°C. Although, as described later, this combination is not stable on a long-term basis, the addition of HBP-3 and HBP-4 at 5% lowered the pouring temperature nearly as much, to 63°C and 64°C respectively, in mineral oil; both combinations were found to be stable. In the case of isopropyl palmitate, HBP-3 lowered the pouring temperature by 9°C.

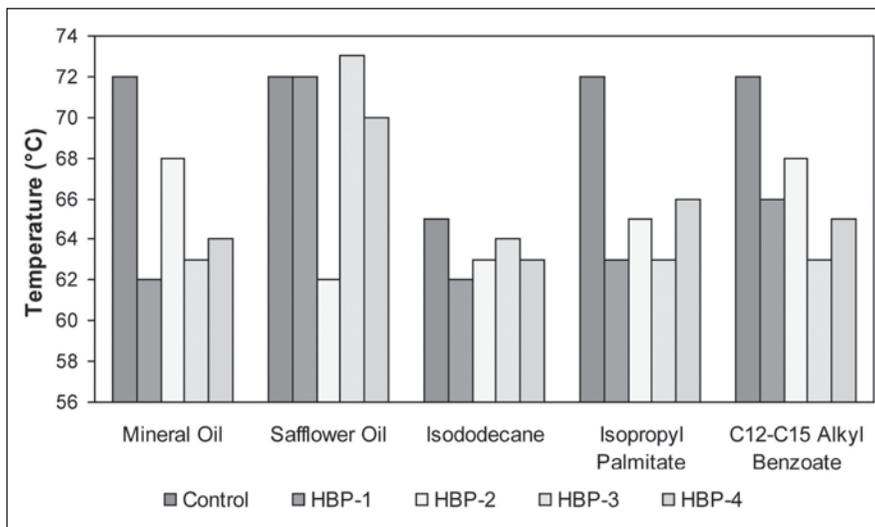


Figure 42.2. Pouring temperature of polyethylene/oil bases with 5% addition of several HBPs

The present studies on HBPs as well as research noted in the literature^{1,2} suggest the pour point depressant mechanism of HBPs is influenced by the average side chain length, the distribution of side chains and the characteristics of the oil in the mixture. The HBPs modify the shape and size of the waxy hydrocarbon crystal to slow agglomeration and lower the effective pouring temperature. SEM photos (**Figure 42.3**) illustrate the changes in the wax crystals formed.

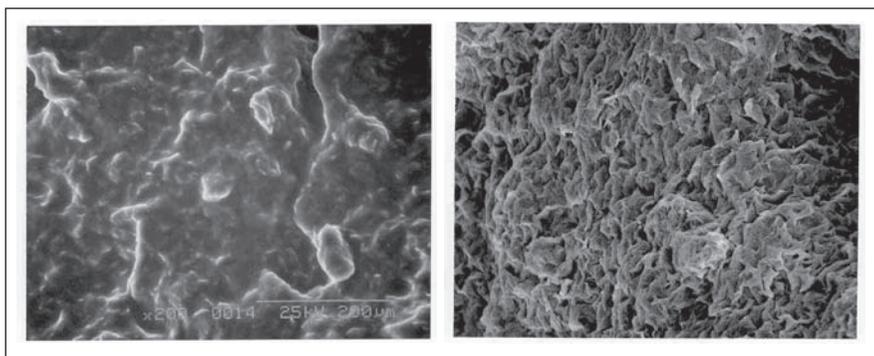


Figure 42.3. SEM of stick base structures of polyethylene/isododecane (left) and polyethylene/isododecane/HBP-3 (right)

Lowering pouring temperature adds another dimension of formulating flexibility by offering greater protection for volatile ingredients such as fragrance, isododecane, volatile active ingredients or combinations of ingredients that may be sensitive to heat.

Gloss Improvement

HBP can enhance gloss in anhydrous systems. To evaluate this effect, gloss measurements of the samples were conducted using a glossmeter^a and following a standard method³ for specular gloss.

A specimen of each test formula (**Formulas 42.1** and **42.2**) weighing 0.5 g was applied to a 4.5 x 5.5-inch test surface^b with a circular motion for 1 to 2 min, and a minimum of three gloss readings were taken at an angle of 60 degrees.

Polyethylene typically imparts a matte appearance. However, in anhydrous systems, HBPs provide gloss even in matte bases. Enhanced gloss primarily is the result of the highly branched characteristics of the HBP. This structure results in high refractive indexes (RIs). For example, the tested HBPs all showed RIs in the range of 1.473 to 1.510 (**Table 42.1**), comparing favorably with the 1.46 value achieved by the widely used cosmetic industry glossing agents^a phenyltrimethicone and hydrogenated polyisobutene.

In most cases, gloss measurements based on the addition of various HBPs to the polyethylene/oil blends showed noticeable improvement versus the blends alone (**Figure 42.4**).

In additional studies⁴ with prototype formulations, the HBP allowed greater pigment loading and aided wetting and dispersion, resulting in highly stable systems. Micronized pigments and organic lakes dispersed in HBPs also imparted higher gloss and color strength without change of hue compared to nondispersed pigments and lakes.

^a The D48-7 Glossmeter is a product of Hunter Associates Laboratory, Reston, VA USA.

^b Leneta card, a product of the Leneta Company Inc., Mahwah, NJ USA

^a Examples are DC556 (INCI: Phenyltrimethicone) from Dow Corning, Midland, Michigan USA, and Indopol H (INCI: Polyisobutene) from Ineos Olefins & Polymers USA, League City, Texas USA.

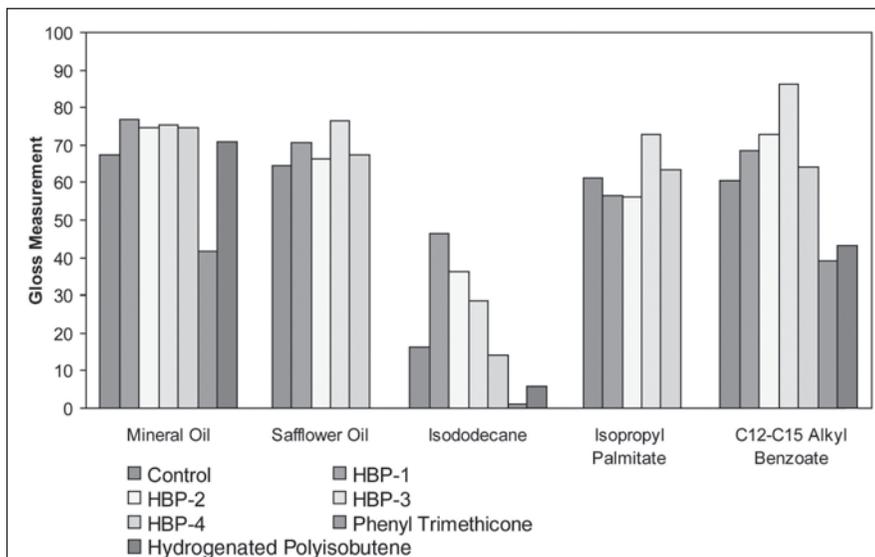


Figure 42.4. Gloss of polyethylene/oil bases with 5% addition of several HBPs

Structuring and Stability

Evaluations of the structuring capability and stability of the HBPs were conducted, again using **Formulas 42.1** and **42.2**. In these evaluations, stability is defined as the lack of syneresis—i.e., no oil bleed—in the mixture.

The HBPs were evaluated for structuring capability and stability. The anhydrous systems of **Formulas 42.1** and **42.2** were cooled overnight in covered containers. On the following day, a minimum of three penetration values were recorded using a 35-g cone needle and a penetrometer^b. This approach measures the distance a cone penetrates into the test material in five seconds; thus, the lower the measurement, the harder the material. Measurements of hardness were recorded in decimillimeters (dmm) at various sections within the sample using a standard protocol.⁵ **Figure 42.5** illustrates the results of this test.

Overall, HBP-2 and HBP-3 performed best in the systems that were identified as stable, i.e., without syneresis for more than six weeks (**Table 42.2**). Each sample was evaluated for six weeks at room temperature, at 49°C and through three freeze-thaw cycles.

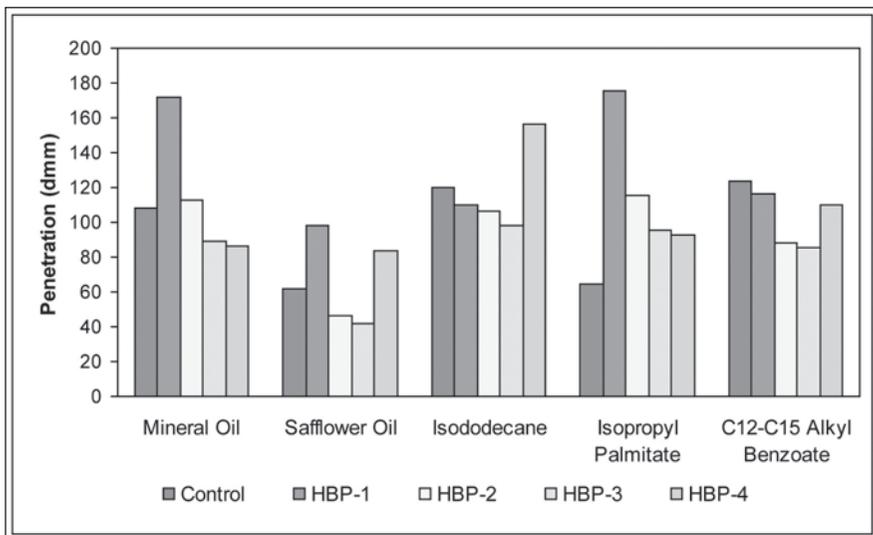


Figure 42.5. Hardness of polyethylene/oil bases with 5% addition of several HBPs

Table 42.2. Effect of 5% HBP on oil bleed stability of prototype stick bases

S = Stable after six weeks; no syneresis

NS = Not stable

Oil	Control	HBP-1	HBP-2	HBP-3	HBP-4
Mineral oil	S	NS	NS	S	S
Safflower oil	S	NS	NS	S	S
Isododecane	S	S	S	S	S
Isopropyl palmitate	S	NS	NS	S	S
C12-C15 alkyl benzoate	NS	NS	S	NS	S

In some cases, the addition of HBP softened the sample. For example, the two HBPs with the long branch length (HBP-1 and HBP-2) softened the systems with mineral oil, safflower oil and isopropyl palmitate and made them unstable, an effect not seen in these same systems when the two HBPs with short branch lengths were added. It is important to select the correct branch length of HBP for specific formulation types or requirements. In general, HBPs with

shorter branch lengths result in greater stability, while longer branch lengths tend to reduce structuring effects.

The SEM photographs in **Figure 42.3** show that the addition of an HBP creates a structure that is more uniform with smaller wax domains. This effect suggests the HBP acts as a compatibilizer between the oil and polyethylene to help disperse the polyethylene in the oil, with the result being a smaller crystal size and the entrapment of oil within the crystalline matrix.

With its longest branch length, HBP-1 is effective at low levels for modifying the crystalline characteristics of the polyethylene/oil system; however, it has an optimum use level. In contrast, the SEM photographs in **Figure 42.6** illustrate how an excess of the HBP can affect the crystalline matrix of polyethylene. Here, the compatibilizing effect is too great, resulting in a crystal size that is too small and not stable. In this example, decreasing the level of HBP-1 from 5% to a level less than 5% might improve its oil-binding capabilities, resulting in a more stable system.

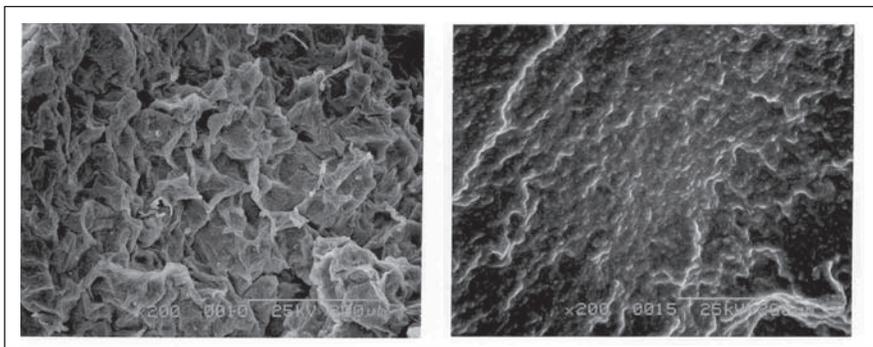


Figure 42.6. SEM of stick base structures of polyethylene/C12-C15 alkyl benzoate (left) and polyethylene/C12-C15 alkyl benzoate/HBP-1 (right)

In general, the degree of compatibilization is related to both branch length and type of oil. The longer the chain length of an HBP, the more it typically decreases structuring capabilities. However, oil binding may also be affected depending on branch length. For this reason, it is important to assess these parameters with the specific ingredients used in individual applications.

Summary

Given the specific concentrations of polyethylene and HBPs in the present studies, it is possible to make some general statements related to pouring temperature, gloss and stick structure. These results may help to serve as a screening tool during ingredient selection. However, formulators should carefully evaluate ingredients based on their specific formulations and applications.

Mineral oil: Among the stable systems shown, HBP-3 and HBP-4 were best for depressing pouring temperature and increasing gloss in mineral oil. They were also best for increasing hardness, with improvements of 19 and 22 dmm, respectively.

Safflower oil: HBP-2 was found to be the most effective for reducing pouring temperature—from 72°C to 62°C—although this system did not show long-term stability. Among the stable systems, the HBP-4 wax performed best. The best material for enhancing gloss and hardness was HBP-3, with an increase of 12 points for gloss and a 20 dmm improvement in hardness.

Isododecane: All four HBPs reduced pouring temperature slightly, with HBP-1 performing best for a drop in temperature of 3°C. In terms of gloss, HBP-1 again was best, raising gloss by nearly 30 points. The addition of HBP-4 resulted in a slight decrease of gloss; HBP-3 was best for enhancing hardness, with a decrease of 22 dmm.

Isopropyl palmitate: Among the stable systems, HBP-3 performed the best for reducing pouring temperature, with an improvement of 9°C. This wax also showed the best enhancement for gloss. All HBPs softened the stick base containing isopropyl palmitate.

C12-C15 alkyl benzoate: Among the systems showing long-term stability, HBP-4 was shown as the best for lowering pouring temperature. HBP-2 was best for enhancing gloss and hardness in the stable systems.

Conclusions

The results of several evaluations indicated that HBPs can lower pour points, with chain length and oil type as factors that resulted

Formula 42.3. Lip moisturizer stick

A. Polyethylene (Permalene 400 Polyethylene, New Phase Technologies)	9.00%w/w
C20-40 alcohols (Performacol 425 Alcohol, New Phase Technologies)	10.00
Cetyl lactate	4.00
<i>Theobroma cacao</i> (cocoa) seed butter	5.00
Di-C12-15 alkyl fumarate	3.00
Hexyl decanol	48.90
Synthetic wax (Performa V 343 Polymer, New Phase Technologies)	8.00
B. Mica (and) titanium dioxide (and) tin oxide	5.00
C. <i>Carthamus tinctorius</i> (safflower) oil	3.00
<i>Simmondsia chinensis</i> (jojoba) seed oil	3.00
Mineral oil (and) <i>Cocos nucifera</i> (coconut oil) (and) <i>Aloe barbadensis</i> leaf extract	1.00
Tocopheryl acetate	0.10
D. Fragrance (<i>parfum</i>)	qs

Procedure: Heat A to 94–99°C with propeller mixing until dispersed and uniform. Reduce temperature to 85–90°C. Add B and continue propeller mixing until dispersed and uniform. Reduce temperature to 80–85°C and add C. Add D at 75–80°C; continue mixing until uniform. Pour into lipstick molds.

in different performance. The results also indicate that stick stability is more likely to be compromised by the incorporation of longer branch length HBPs—in these tests, HBP-1 and HBP-2. HBPs can also increase gloss and improve formula stability. Two of the polymers tested also improved hardness in most of the oils tested. While demonstrating new benefits, the results of this study have potential as a screening tool to help formulators focus on useful combinations of materials for specific applications. This approach may help reduce development time and cost.

The anhydrous sticks discussed in this article and illustrated in **Formula 42.3** have obvious applications in the color arena in product forms such as lipsticks, lip balms, foundation sticks, concealers and eye shadow sticks. It should be noted that the applications extend to other areas of personal care, such as sunscreen sticks, AP sticks and facial sticks, and beyond to laundry sticks for the

household and acne control stick products in the pharmaceutical area. Overall, HBPs can be valuable ingredients to help formulators create novel, high-performance personal care, household and pharmaceutical products that meet changing global needs.

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Formulating Scrubs

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KEY WORDS: *cleansing, body treatments, aqueous-based scrubs, nonaqueous-based scrubs, natural oils*

ABSTRACT: *Nonaqueous-based scrubs provide more functions and benefits for complete treatment of the body's skin and are a new category of cleansing tools focusing on cleansing, conditioning and treating. Oils, glycols and silicone oil are three continuous phases in non-aqueous scrubs discussed in this chapter.*

Scrub products have gained popularity in recent years and continue to enjoy an upswing in the growing spa market, which emphasizes the holistic philosophy of de-stressing and relaxation. In addition to traditional aqueous-based scrubs,¹ several new nonaqueous types are flooding into the market. These focus on skin treatment and rejuvenation in addition to the traditional function of cleansing. Scrub products have gradually adapted from prestige origin into mass markets.^{2,3,4}

In general, scrubs function both by removing old cells to produce a smooth and rejuvenated skin surface and by providing physical stimulation to skin through a massaging effect. Scrub performance depends on the water-soluble or water-insoluble abrasives used in a scrub product. Water-soluble abrasives, such as salt and sugar, are used in nonaqueous-based formulas. Water-insoluble abrasives, such as polyethylene beads, natural shells or seeds and pumice, are used in water-based formulas. An additional benefit is the treatment of skin with conditioners such as minerals, natural oils, emollients, vitamins and other nutrients.^{1,5}

There are not many references available for describing fundamental formulations and methodologies despite the numerous nonaqueous scrubs appearing in the market. This work is intended to fill the gap and provide some practical information for formulating chemists.

Aqueous Formulary

Aqueous-based scrub products have been in market for years.^{6,7,8,9} There are three basic types of aqueous formulas: paste-like, gel-like and cream or lotion-like (**Table 43.1**). Paste-like formulas are mainly based on sodium stearate/stearic acid mixtures, which are able to suspend the abrasive particles.⁶ The gel-like formulas are anionic surfactant systems with additional gelling agents for suspending the abrasives.^{7,8} The emulsion type is a thickened cleansing emulsion, which is capable of suspending abrasive particles.^{6,7,8}

Table 43.1. Aqueous Formulary

	Polyethylene	Natural shells
Gel-like	X	X
Emulsion	X	X
Paste-like	X	X

Abrasives used in aqueous-based scrub formulas include natural shells or seeds, polyethylene beads and pumice. Natural shell or seed scrubs include, for example, apricot seed, almond shell, birch powder, coix seed, grape seed, jojoba beads, peach seed, sunflower seed, walnut shell, watermelon seed and cottonseed shell. Waxes and other items include orange peel and almond meal. Synthetic abrasives include polyethylene powder, nylon powder, polypropylene, cellulose beads and polystyrene.

Pumice is a very light porous volcanic scoria, usually gray in color. It consists of pores the size of capillaries that are organized in parallel configuration, giving it a fibrous structure. It is produced by the escape of water vapor from liquid or plastic lava.

Abrasives are evaluated on the basis of three factors—hardness, particle size and shape—and should be chosen according to desired performance. Nakahira et al. have developed an apparatus and method for evaluating these factors.¹ Scrubs made with large, hard and irregularly shaped abrasives will give a rough feel on skin and may cause irritation and sometimes damage. In contrast, softer or powder-like abrasives do not give enough massaging effect for de-stressing claims. The most appropriate range of hardness is from 0.5 to 7 (hardness scale from 0 to 10, 0 is hardest and 10 is softest).¹⁰ The most appropriate shape is spherical, and the best range of size is from 40–80 Mesh (180 to 420 microns). Special attention should be paid when using natural shells or seed abrasives because they are susceptible to bacterial contamination. The safest way to prevent contamination is to radiate these raw materials before use in manufacture.

Nonaqueous Formulary

Salt and sugar scrubs have recently become very popular for body, hand and foot applications. These products were developed to meet the consumer trend of cleansing, treating and rejuvenating skin all at the same time. Because salt and sugar are water-soluble, their abrasive properties can only be utilized in nonaqueous formulations. Listed in **Table 43.2** are oils (including natural ester oils, mineral oil, and/or synthetic oils), glycols and silicone fluids. These are the most common liquids used in the continuous phase of nonaqueous formulations. The salt or sugar abrasives can either be immersed or suspended in the continuous phase.

Table 43.2. Non-aqueous Formulary

	Salts Separated	Sugar Suspended	Separated	Suspended
Oils	X	X	X	X
Glycols	X	X		
Silicones	X	X	X	X

Dead Sea salts, sea salts, magnesium sulfate and sodium chloride are salts commonly used in this type of formula. Sea salts, especially Dead Sea salts, contain a substantial amount of essential minerals. The composition of Dead Sea salts is 31% to 35% magnesium chloride, 24% to 26% potassium chloride, 0.1% to 0.5% calcium chloride, 4.0% to 6.0% sodium chloride and 26% to 30% of crystallizing water.¹¹ It has been experimentally and clinically confirmed that Dead Sea salts are effective in the treatment of osteoarthritis,¹² rheumatic discomfort¹³ and psoriasis.¹⁴

The size and shape of salts are critical for product performance. The most preferred sizes range from 20–80 Mesh (180–840 microns). Facial scrubs normally employ finer particles, while body scrubs have medium range particles and foot scrubs still larger. Cubic (or more regular) shapes are preferable for less skin irritation and improved feel.

When the abrasive properties of sugar and salt are compared, sugar is found to have certain advantages: sugar is softer and can be made with a variety colors. On the other hand, sugar is slightly more expensive than salt and contains no minerals for treatment functions. Therefore, the sugar scrubs are not as popular as salt scrubs.

Oil-based scrubs: Oils include natural ester oils, mineral oil and synthetic oils. Some of the natural oils included are shown in **Table 43.3**. Most of these oils are triglycerides, which deliver good skin feel, moisturization and skin protection.

One problem with natural oils is their tendency to become rancid. Antioxidizing agents such as tocopherol (vitamin E), BHT (butylated hydroxytoluene) or benzotriazolyl dodecyl p-cresol^a are necessary to prevent rancidity. In addition, winterized natural oils are preferred to prevent temperature-related sedimentation.

In oil scrub formulas that carry salt/sugar abrasives, the total amount of oil is 25% to 40%, with corresponding salt/sugar levels of 60% to 75%. The specific gravity of these particles is higher than oil; thus, they will sink to the bottom of the container when immersed in oil. When this occurs, the overall product will present with two distinct phases.

^a Tinogard TL, from Ciba Specialty Chemicals Corp., Basel, Switzerland

Table 43.3. Natural oils found in oil-based scrubs

Common	Latin	Common	Latin
Almond	<i>Prunus dulcis</i>	Orange	<i>Citrus sinensis</i>
Aloe vera	<i>Aloe barbertiniae</i>	Peppermint	<i>Mentha piperita</i> x
Avocado	<i>Persea americana</i>	Palm	<i>Setaria palmifolia</i>
Borage	<i>Borago officinalis</i>	Passion fruit	<i>Passiflora edulis</i>
Camellia	<i>Camellia japonica</i>	Peanut	<i>Arachis hypogaea</i>
Canola	<i>Brassica napus</i>	Pecan	<i>Carya illinoensis</i>
Castor	<i>Ricinus communis</i>	Pistachio	<i>Pistacia vera</i>
Coconut	<i>Cocos nucifera</i>	Rosemary	<i>Rosmarinus officinalis</i>
Cottonseed	<i>Baccharis halimifolia</i>	Safflower	<i>Carthamus tinctorius</i>
Evening primrose	<i>Oenothera deltoides</i>	Sesame	<i>Sesamum indicum</i>
Hazelnut	<i>Corylus heterophylla</i>	Spearmint	<i>Mentha spicata</i>
Jajoba	<i>Simmondsia chinensis</i>	Soybean	<i>Glycine max</i>
Kukui nut	<i>Aleurites moluccana</i>	Sunflower	<i>Helianthus annuus</i>
Lemon	<i>Citrus limon</i>	Tea tree	<i>Leptospermum scoparium</i>
Macadamia nut	<i>Macadamia integrifolia</i>	Walnut	<i>Juglans spp</i>
Meadowfoam seed	<i>Limnanthes douglasii</i>	Wheat germ	<i>Triticum aestivum</i>
Olive	<i>Olea europea</i>		

There are some limitations when employing natural oils in salt and sugar scrubs. Changing the color of the oil phase is difficult because most natural oils have a yellow or green-yellow hue. In addition, natural oils do not spread easily across surfaces. Therefore the spreadability of natural oils comes into play and is normally represented in terms of viscosity. Light natural oils (low viscosity) are preferred to heavy natural oils (high viscosity) because they are easier to spread across the skin surface and do not leave a heavy feel. The preferred viscosity range of oil or oil blends is 50–200 cps. It is the unfortunate case, however, that natural oils (except sunflower oil and safflower oil) show moderate comedogenicity.¹⁵

Mineral oil, isoparaffin or synthetic esters (oils) can also be used in scrub formulations. They are usually colorless and odorless and, as such, are readily colored and fragranced to meet marketing requirements. They are also easy to spread and are perceived to be

less “heavy” on skin. Viscosities below 300 cps are preferred in better performing products. Formula ratios of oil phase to salt/sugar phase for this base type are the same as with natural oil formulations.

It is worth mentioning that mineral oils are colorless, clear and odorless liquids. They are excellent cosmetic emollients because they are inert and do not penetrate into the skin. Mineral oils have superb skin compatibility and show little or no comedogenic effects.¹⁵

There are many synthetic esters (oils) that can be used in scrubs. Included are: isopropyl esters, ethylhexyl esters, oleic acid esters, caprylic/capric acid esters, n-butyl stearate, isocetyl stearates, octyl-dodecanol, diisopropyl adipate and pentaerythritol tetraistearate. The price of synthetic oils ranges widely, depending on the chemistry involved in making these oils. Generally however, they cost more than natural or mineral oils.

Suspended oil scrubs: It is somewhat inconvenient to use dual-phase salt/sugar and oil mixtures, since salt/sugar particles settle to the bottom of the container. It then takes time and effort to mix two phases into a degree of homogeneity. To simplify the application process, these abrasives are suspended in the mixture permanently. In suspended formulas, salt/sugar is blended in the oil phase and will not sink to the bottom of the container.

Several methods are used to achieve suspension of salt/sugar abrasives in the oil phase. In the following example, oils are gelled with thickening agents that impart yield value to the solution. It is the yield value that allows particles to remain in suspension. Fumed silica^a is one of the agents for gelling the oil phase.¹⁶ It should be noted that fumed silica is very light and dusty, and special protective measures should be taken by compounders. The use of ethylene copolymers is another method of creating gelled oils.¹⁷ Both methods form gels that break easily under shear stress, yet recover viscosity and yield quickly over time, which is to say they have thixotropic properties. As such they are considered a desirable medium for supporting and suspending particles in scrub formulations. The amount of fumed silica or ethylene copolymers varies according to oil type and the desired consistency of the final product.^{16, 17}

^a Cab-O-Sil, Cabot Corporation, Tuscola, Illinois USA

Other oil thickening agents are quaternium-18 bentonites^b or stearalkonium bentonites,^b trihydroxystearin,^{c,18,19} and Rhus verniciflua peel wax.^{d,20} These gelling agents also impart yield to the continuous phase and thus will suspend salts or sugar.

Certain pre-made gels are also suitable for this application. One company offers several pre-made gels^e composed of mineral oil, ethylene/propylene/styrene copolymer and butylene/ethylene/styrene copolymer.²¹ Another company's line^f has more than ten different pre-made gels that are oils thickened by bentonite derivatives.¹⁸

Consistency will vary with the amount of salt or sugar added to the formulation. The consistency can further be modified by incorporating surfactants into the system, which can improve both the viscosity, foaming or nonfoaming, and skin after-feel.

The ratio of oil to salt/sugar is more flexible in suspended oil scrubs than in the previously mentioned nonaqueous systems. The percentage of oil can range from 30% to 60% and salts/sugar can range from 40% to 70%. In summary, colorless oils can be easily colored to obtain different appearances, and the performance can be adjusted using surfactants.

Special attention should be paid to the temperature dependency of viscosity and yield. For suspending salts or sugar, the viscosity and yield of oil phases should be stable in the temperature range of -20°C to 50°C . Different oil thickeners have different temperature dependency of viscosity and yield. Careful evaluation is needed to safeguard the stable products.

Glycol-based scrubs: Glycols and other humectants can be used as carriers in salt scrubs. Included in this category are glycerin, propylene glycol, butylene glycol, pentylene glycol, hexylene glycol and polyethylene glycols of various chain lengths. Sugar is somewhat soluble in glycols and is not appropriate for this type of formula.

Glycol-based scrubs have a self-heating function when they are rinsed with water, which provides an interesting consumer

^b From Süd-Chemie Rheologicals, Louisville, Kentucky USA

^c From Süd-Chemie Rheologicals and from Southern Clay Products, Inc., Gonzales, Texas USA

^d From Botanigenics, Inc., Northridge, California USA

^e Versagel M 200, Versagel M 500 and Versagel 750 from Penreco, Houston, Texas USA

^f Mastergel, from Süd-Chemie Rheologicals

perception for treating and rejuvenating skin as these products are used.

Glycol scrubs have two important benefits: they are colorless and are not susceptible to chemical change. Thus, chemists can easily make a variety of colorful products and need not worry about problems such as rancidity.

Both separated and suspended scrub types are achievable with glycols. The ratio employed in the salt/sugar and oil formulary also holds for glycol formulas: 25% to 35% glycols and 65% to 75% salt phase. The disadvantage for this type of scrub is lack of good skin after-feel. Suspended formulas are more popular in the market. In suspended formulations, a thickened glycol phase is achieved by adding rheology-modifying polymers, emulsifiers with emollients, or a combination of both. The polymers must be glycol-soluble in order to thicken the continuous phase. Examples of applicable polymers include polyquaternium-10 or xanthan gum.

When formulating glycol-based scrubs using emulsifiers and emollients, one could use the same approach used for a normal water-based cream or lotion. In this case however, water is replaced by glycols. Possible emulsifiers are glyceryl stearate, certain polysorbates^a and other nonionic surfactants. Possible emollients are fatty alcohols, natural and synthetic oils, and plant extracts.

Glycol scrubs impart skin benefits via humectants (as moisturizers), minerals (for treating skin), and emollients (for improved skin feel and protection). The performance is adjustable by changing the ratio of these ingredients. The salt concentration varies from 50% to 70% and the glycol concentration varies from 50% to 30%.

Dramatic temperature dependency of viscosity is the nature of glycol scrubs. The formula should be well balanced with emulsifiers and emollients to ensure the product's integrity in normal temperature variation in different seasons.

Scrubs based on silicone oils: To achieve the best skin after-feel, silicone oils can be used in scrub formulations. Both separated type and suspended type can be formulated with silicone oils.

^a Tween-20 (INCI: polysorbate 20) and Tween-80 (INCI: polysorbate 80) are products of ICI Surfactants, Inc., Wilton, Middlesbrough, Cleveland, England.

The consistency of silicone oils is critical in separated formulas. Dimethicone and/or cyclomethicone (pentamer) fluids must have viscosities lower than 300 cps to be useful for this purpose. The performance can be adjusted by adding water-soluble dimethicone copolyols into silicone oils. The amount of salt is about 65% to 75% and the amount of silicone oils is about 35% to 25%.

Suspended formulas are made by using silicone elastomer to thicken low molecular weight silicone oils. The performance also can be adjusted with water-soluble dimethicone copolyols. The ratio of salt/sugar to silicone oils is about the same as the separated type. Another way to thicken silicone oils is by incorporating quaternium-18 bentonites or tridihydroxyesterin.¹⁸

Scrubs based on silicone oils give the best skin after-feel, but provide less skin protection and cost more than other types. Still, they are applicable in high-end products.

Future of Scrubs Formulary

Scrub products have only recently gained momentum.^{2,4} It seems that this section of the market will continue to increase in popularity with increasing consumer knowledge of skin “de-stress” and “detoxification” within the mass market. From a formulation viewpoint, the nonaqueous-based products will probably show increased preference since they are easy to use and possess more functions and benefits. Thus skin after-feel and skin protection will encourage more consumers to buy these products.

Summary

There are two categories of cleansing scrubs, aqueous and nonaqueous. Water-insoluble abrasives are used in aqueous-based scrubs. Hardness, shape and particle size are three critical factors for evaluation of abrasives. The most appropriate hardness range is from 0.5 to 7. The most appropriate shape is spherical and the best size ranges from 40–80 Mesh (180 to 420 microns). Gel-like, paste-like and cream (emulsion)-like solutions are three different types of aqueous formulas wherein abrasives are varied from 0.5% to 10%.

In contrast to traditional aqueous scrubs, nonaqueous-based scrubs are focused on cleansing, conditioning and treating skin at the same time. Oils, glycols and silicone oils are three possible continuous phases in nonaqueous scrubs. Lower viscosity liquids are preferred in the continuous phase, giving better performance in application. The abrasives normally used in these scrubs are salt and sugar. They can be suspended or allowed to settle to the bottom of the container depending upon the formulation desired. The hardness, size and shape of abrasives are paramount factors in determining scrub performance. The most preferred sizes range from 20–80 Mesh. The cubic (more regular) shapes are preferred for less abrasive skin-feel. Skin benefits stem from both the continuous phases and abrasives.

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SECTION VIII

Physical Chemistry

Like it or not, the formulation of personal care products places the chemist in a position of having to deal with some sophisticated and challenging physical chemistry. Formation of a bubble (foaming), wetting of hair or skin (wetting), removal of soil (detergency), spreading of a film (spreading) and many other of the processes that make our cosmetic products work all are governed by complex physical chemistry. Fortunately, we can master the concepts and make elegant products without the complex math we all tried to avoid in school.

All cosmetic formulations are compositions; not single compounds, but mixtures. The reason we formulate is to take advantage of the interactions between the individual compounds in a formulation to provide a cosmetically elegant product. The nature of the interaction and being able to maximize it is key to the formulation of efficient products. This section provides insights into the various interactions and processes that are vital to our formulations.

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- 45** A New Dimension in Hairstyling—VP/Methacrylamide/
Vinyl Imidazole Copolymer
- 46** Enhancing the Feel of Vegetable Oils with Silicone
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A Brief Review of Polymer/Surfactant Interaction

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KEY WORDS: *polymer, surfactant, polymer-surfactant interaction, conditioning shampoos*

ABSTRACT: *In this chapter, the significance of parameters such as correlation length (blob size), micelle structure, comicellization, polymer adsorption conformation and coacervate structure are introduced with relevance to the conceptual appreciation of polymer-surfactant interactions and its bearing on recent advances in conditioning shampoos.*

This brief review of polymer-surfactant interaction opens by describing how polymers behave in solution. Then we survey the literature on the interaction of nonionic polymers with surfactants, and the interaction of polyelectrolytes with ionic surfactants of opposite charge. After a brief discussion of polymer adsorption at interfaces, we consider the implications of these interactions on the design of shampoo products.

Polymers in Dilute and Semi-dilute Solution

Polymer-surfactant interaction in personal care compositions usually occurs in aqueous media. In order to understand the concepts of this type of polymer-surfactant interaction, it is first necessary to

grasp how typical polymers behave in solution. The condition for a polymer molecule to dissolve is that the polymer-solvent interaction is greater than both polymer-polymer and solvent-solvent interactions. If this condition is achieved the polymer will dissolve and, depending upon the concentration, a dilute solution or semi-dilute solution will be formed.

A dissolved polymer can occupy many times the volume of the polymer molecule itself—that is, a polymer swells when it is dissolved and the volume inside the swollen polymer contains solvent. It is not unusual for a dissolved polymer to be swollen to a thousand times its original size. In a dilute solution each dissolved polymer molecule will be isolated. If the polymer concentration is increased, eventually there comes a point when the entire space is filled with swollen polymer molecules and above this concentration the polymer can only occupy the solution if the molecules entangle and thread through each other's domains.

The concentration of the onset of entanglement is called the “critical overlap concentration” (C^*). Above the critical overlap concentration the system is in the semi-dilute regime. When polymers phase-separate from solution, they usually do so in the semi-dilute or concentrated condition and therefore they are in an entangled state. Polymer scientists gain conceptual understanding of the process of separation by introducing the concept of correlation length. The correlation length is known more colloquially as the “blob size.” In dilute solution, the blob size is the size of the entire polymer molecule and in semi-dilute solution the blob size becomes the distance between entanglement points (**Figure 44.1**). The blob size decreases as polymer concentration increases even in dilute solution. This is depicted in **Figure 44.2** in which $g(r)$ represents the blob size and the horizontal axis represents polymer concentration.

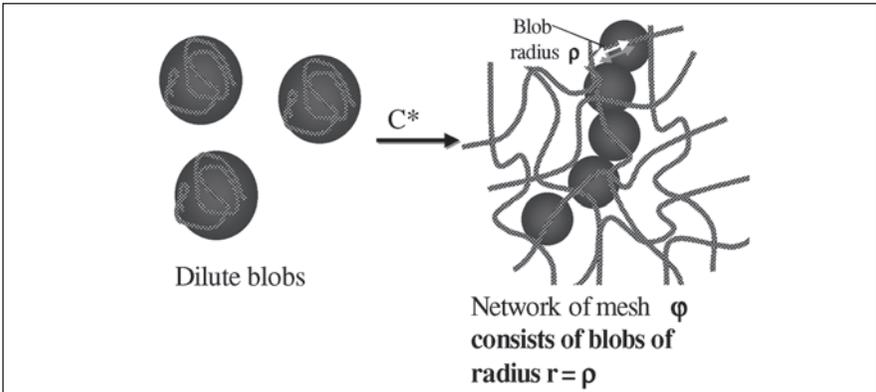


Figure 44.1. Blobs in dilute to semi-dilute solutions

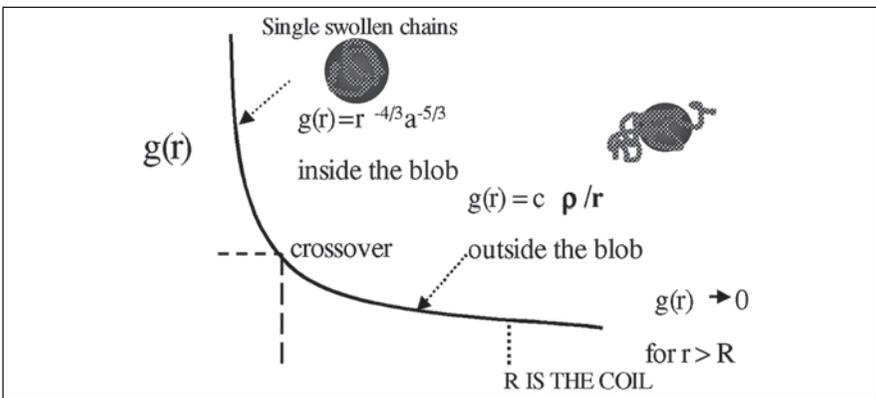


Figure 44.2. The decrease in blob size as the polymer concentration increases

Interaction of Nonionic Polymers with Surfactants

The field of polymer surfactant interaction owes a great deal to Suji Saito, whose early work formed the basis of much of the formal research that has been conducted subsequently. In 1952 he observed that the water-insoluble hydrophobic polymer polyvinyl acetate completely dissolved in micellar sodium dodecyl sulfate solution.¹ This was intriguing because the polymer molecules were substantially too large to fit into the micelle and therefore the existing theories of solubilization could not explain this phenomenon.

Based upon simple viscosity measurements, Saito and Sata proposed a model of micellar aggregates along the polymer chain. This

“pearls on a string model” is now well accepted and has been validated by more sophisticated methods such as neutron scattering.¹

In a 1957 publication, Saito extended this model to explain the sodium dodecyl sulfate-induced increase in the viscosities of aqueous solutions of the hydrophilic polymers methyl cellulose and poly(N-vinylpyrrolidone).^{2,3} For these hydrophilic polymers, he explained that ionic repulsion between the “micellar pearls” caused expansion of the polymer chain, which in turn caused an increase of this viscosity. Today, we would refer to this as an increase in the ionic persistence length of the molecule—or an increase in “blob size.”

The model was further advanced by Jones in a study of polyethylene oxide interaction with sodium dodecyl sulfate in aqueous solution.⁴ Jones noted that in the presence of the polyethylene oxide the normal surface tension curve of the surfactant showed a premicellar breakpoint, T_1 , followed by a slow descent to meet the normal micelle curve at higher concentrations, T_2 , than the measured critical micelle concentration (CMC) of the surfactant. Jones described the T_1 point as the lowest surfactant concentration at which interaction occurred between the surfactant and polymer and T_2 as the surfactant concentration at which both the polymer and the air-water interface became “saturated” with surfactant and normal micelles first appeared (**Figure 44.3**). Jones’ concepts and methods are still used today to probe polymer-surfactant interactions.

A careful NMR study by Professor Nagarajan of Penn State University showed that polyethylene oxide decorated the outside of surfactant spherical micelles, penetrating deeper than the micelle’s palisade layer and the polymer extended between many micelles to form the “pearls on a string.”⁵

Hydrophobically modified hydroxyethylcellulose is usually supplied as the hydrophilic polysaccharide backbone with less than one mole percent hydrophobic modification. The slight modification provides sufficient hydrophobic interaction between the chains to form a temporary network and to confer enhanced aqueous thickening properties on the molecule. It is interesting to note that the hydrophobically modified species phase separates from the unmodified species in aqueous solution. This is attributed to the fact that the hydrophobic associations form a network having a mesh size smaller

than the unmodified polymer in solution;⁶ that is, upon hydrophobic modification the blob size of the polymer becomes smaller. This example demonstrates the fact that similar polymers with different blob sizes will not thermodynamically mix in solution.

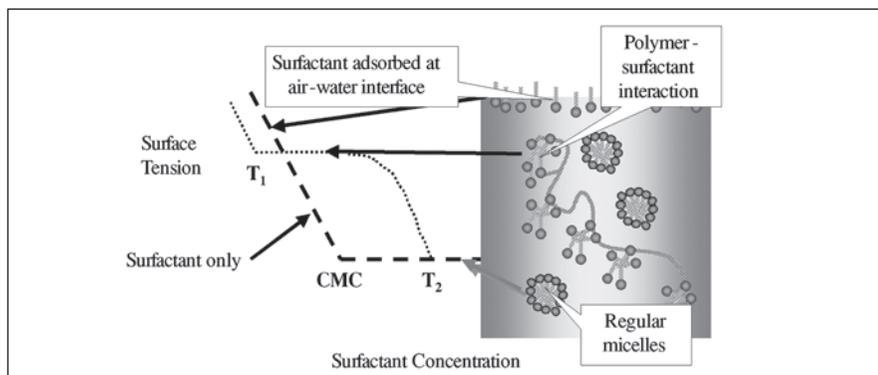


Figure 44.3. Polymer-Surfactant interaction

The network is not complete, however, because this polymer has a relatively stiff polysaccharide backbone and a number of the hydrophobes on the backbone will be sterically restricted from intermolecular hydrophobic association in aqueous solution. The addition of surfactant to solutions of this polymer, in the region of the CMC, causes a dramatic increase in viscosity followed by an equally spectacular decrease in viscosity to levels below that measured for the polymer solution in the absence of surfactant (**Figure 44.4**).

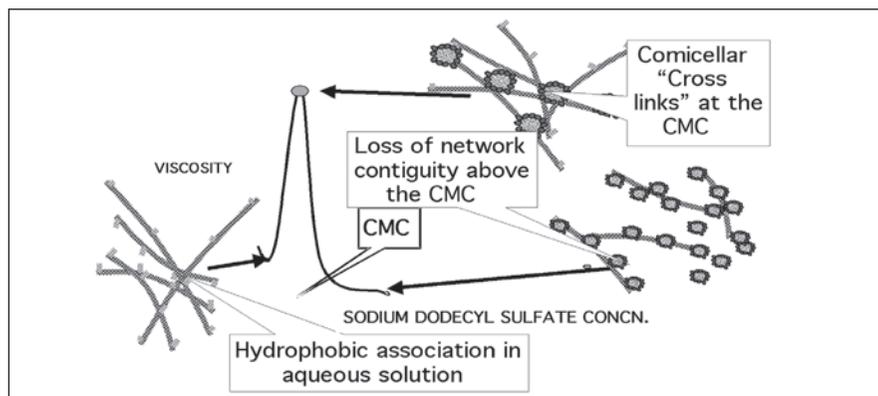


Figure 44.4. Comicellization of polymer hydrophobes with surfactant hydrophobes (hydrophobically-modified hydroxyethyl cellulose)

This behavior has been attributed to comicellization of the polymer hydrophobes with surfactant hydrophobes.⁷ The comicellization is stoichiometric and when micelles first form, they link hydrophobes that were previously isolated, and as a consequence a better network of smaller blob size is formed and this results in an increase and the viscosity. As more surfactant micelles are introduced, a micelle concentration will be reached at which comicellization will not result in junction zones but rather in repulsion between polymer chains as they become effectively polyions. The loss of network structure results in the observed dramatic loss in the viscosity at concentrations immediately above the critical micelle concentration.

Similar behavior is observed for hydrophobically modified alkali swellable acrylate thickeners, as exemplified by acrylates/stearath-20 methacrylates copolymer, but in this case the viscosity increase is less dramatic. On the contrary, completely different behavior has been observed for hydrophobically modified ethoxylated urethane thickeners. These are block copolymers having a poly(ethylene oxide) chain end-capped with hydrophobes, or they consist of hydrophobes grafted to a poly(ethylene oxide) chain.

The flexibility of the polyethoxy chain allows these molecules to form micelles by themselves at very low concentrations. A network structure is formed by some of the polymers stretching from micelle to micelle. In this case, even small quantities of a low molecular weight surfactant comicellize with the polymer micelles and this results in immediate breakdown of the network structure and loss of the viscosity even at surfactant concentrations well below the CMC (**Figure 44.5**).

Increase in the surfactant concentration, introduction of cosurfactants such as cocamidopropyl betaine, or increase in the ionic strength of the solution causes an increase in the micelle size. Spherical micelles become rod-like or they may even grow to become worm-like or branched micelles. These large micelles form exceptionally large junction zones and stoichiometric comicellization with hydrophobically-modified hydrophilic polymers results in a large increase in viscosity that can be maintained over a broad surfactant concentration range (**Figure 44.6**).⁸

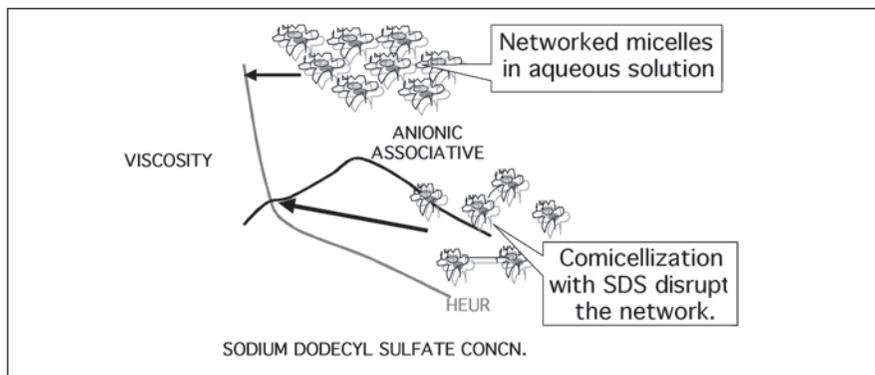


Figure 44.5. Effect of surfactant on low shear rheology

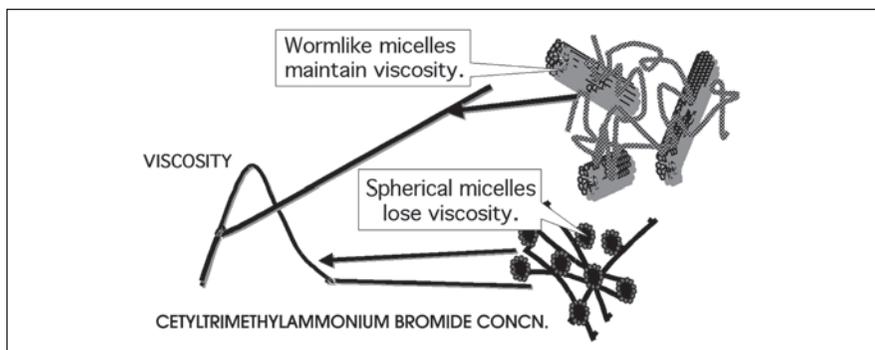


Figure 44.6. Interaction of hydrophobically-modified hydrophilic polymer (hydrophobically-modified hydroxyethyl cellulose) with micelles

In general, hydrophilic polymers will phase-separate from concentrated liquid crystal phases by a mechanism of depletion that results from osmotic competition between the components in such “crowded” situations. However, hydrophobically-modified hydrophilic polymers can be induced to interact with hexagonal liquid crystal phase and to penetrate the interlamellar layers of lamellar liquid crystal phase. The conditions for this occurring are that the reduction in free energy due to mixing of the hydrophobes more than compensates for the loss of conformational free energy of the chain when it changes shape from solution state to the stretched conformation within the galleries of lamellar phase^{9,10,11} and the blob size within the gallery must be less than the width of the lamellar interlayer.¹²

Interaction of Polyelectrolytes with Ionic Surfactants of Opposite Charge

Since the inception of conditioning shampoos in the 1970s, the concept of forming and depositing complex coacervates has held the attention of conditioning shampoo formulators. The interaction between a polyion and its counterions is described by a theory that was developed by Professor Gerald Manning at Rutgers University.^{13,14,15,16} This theory is based upon the concept that counterions in the presence of polyions can exist in one of two states; that is, either free in solution or condensed to the counterion. Manning asserted that if the polyion possessed an ionic charge above a certain critical charge density, then sufficient counterions would condense on the polyion chain to maintain the charge density at its critical level.

The significance of this is that the ultimate charge density of any polyion is limited to this critical value. Thus, Manning predicts that for sodium polyacrylate as the complete salt in pure water, about 65% of the sodium ions would condense on the chain and the maximum charge density that could be achieved for the polyacrylate ion would correspond to about 35% of the carboxylate groups. If the ionic charge of the counter ions is increased, then a higher proportion of the counterions would condense. Thus, Manning predicts that 82% of divalent counterions would condense on a polyacrylate chain and the highest charge density that the polyion could reach would correspond to only 18% of the acrylate groups.

An increase in the ionic strength of the solution would also inevitably lead to a higher proportion of condensed ions. Decreased counterion solubility is also expected to lead to a greater proportion of condensed ions. Due to hydrophobic interaction, amphipathic surfactant ions are necessarily less soluble in water than simple salt ions, such as chloride or bromide. It would be expected, therefore, and it is observed in practice that surfactant ions condense readily upon polyions and that these amphipathic ions readily ion exchange for the more soluble chloride, bromide and sulfate counterions associated with cationic polyions.

Interaction of cationic polysaccharides with anionic surfactants forms the basis of the modern conditioning shampoo and the

mechanism is well known. In the 1970s, Goddard, who continues to be the leader in field,^{17,18} showed that polyquaternium-10 and common anionic surfactants formed coacervates that are one-phase systems at shampoo concentrations but they phase separate upon dilution during the shampooing process to deposit conditioning agents on the hair. Goddard's explanation for the mechanism is presented in **Figure 44.7**, which is a depiction of a binary polymer-surfactant phase diagram.

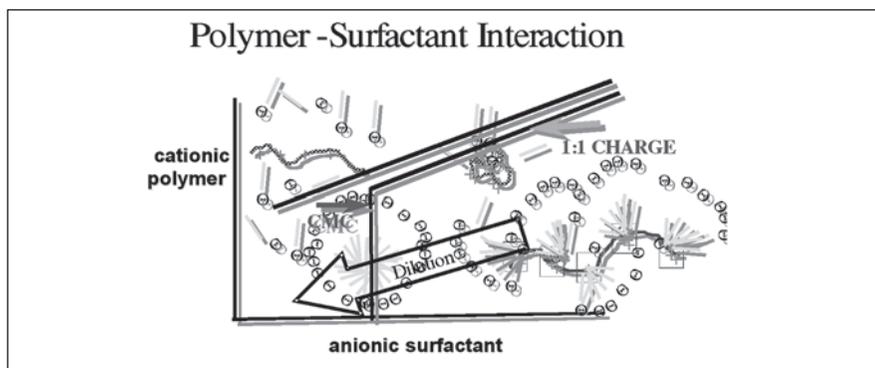


Figure 44.7. The schematic illustration of the principle of conditioning shampoos, according to Goddard^{17,18}

At low surfactant concentration, below the CMC, the anionic surfactants condense on the polycation and the resulting ion-pair converts the cationic site into a hydrophobe-substituted site. Hydrophobic interaction within and between the modified polycation chains causes phase separation and this phase separation persists if the polycation:surfactant anion equivalent ratio is maintained at stoichiometric equivalence.

It is notable that the surfactant-treated polycation displays a rapid increase in viscosity around the surfactant CMC in similar fashion to hydrophobically-modified hydroxyethylcellulose and indeed for this system an elastic gel is formed.^{19,20} Above the CMC comicellization with surfactant micelles results in a one-phase system. Fluorescence spectroscopy and ¹³C NMR techniques have shown the presence of hemi-micelles along the polycation chain in the region of the phase separation and have delineated crucial differences in

that hemi-micelle structure depending upon the detailed structure of the surfactant.²¹ It was also shown in this work that the addition of sodium chloride moved the onset of the phase separation to higher surfactant concentrations, in accordance with Manning theory, and resulted in “resolubilization” at lower surfactant concentrations. This result is consistent with the salt-enhancing water structure, which in turn enhances the hydrophobic effect, and causes a lowering of the CMC.’

Polymer Adsorption at Interfaces

When a dissolved polymer adsorbs at an interface, if the interaction free energy between the polymer and the interface is low, the polymer will adsorb close to its solution conformation. This type of interaction has been named “mushroom adsorption” because polymers with one anchor point appear to have a mushroom stem and a “button” made up of the cloud of polymer in its swollen conformation (**Figure 44.8**).

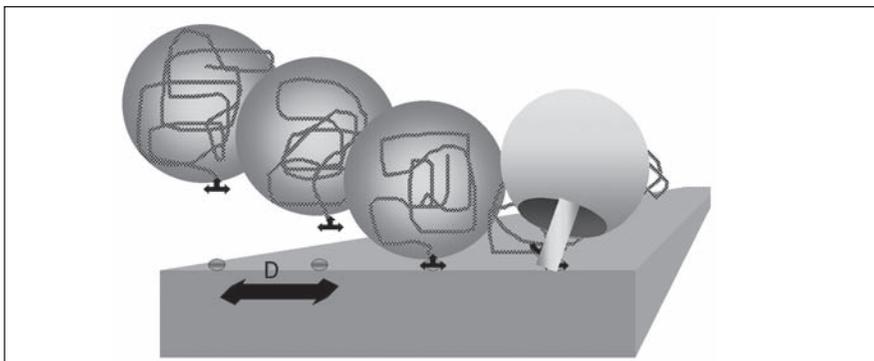


Figure 44.8. Adsorption as mushrooms

It is generally accepted that most real polymers possess several anchor groups along the chain and these are adsorbed as trains where the interaction between polymer and surface is high, and as loops and tails where the interaction between the polymer and solvent is high (**Figure 44.9**). For example, this should be the case for adsorption of slightly charged polyquaternium-11 to hair at pH values above the isoelectric point of the hair.

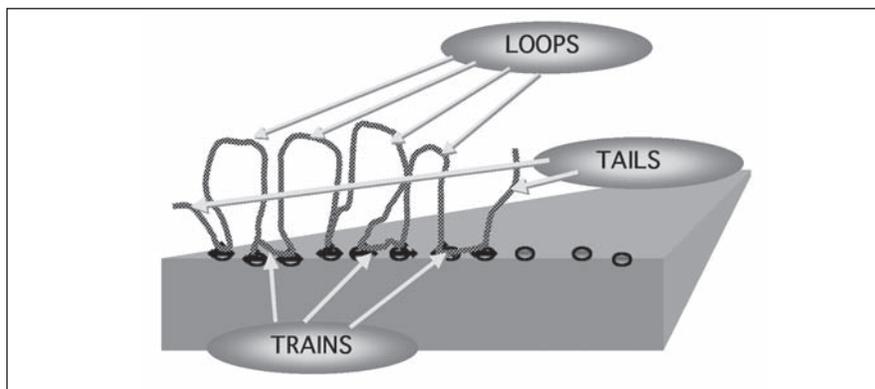


Figure 44.9. Loops, trains and tails

If the interaction between the surface and the polymer is strong, the polymer adsorbs in a conformation that is flat and aligned with the surface. For example, this would be the case with polyquaternium-6 and hair at high pH, where the polymer and the hair surface would carry opposite ionic charges.

Recent Advances in Conditioning Shampoos

The interaction of polymer and surfactant bearing opposite ionic charges is utilized in conditioning shampoos and it results in the formation of a complex coacervate that separates upon dilution of the shampoo composition and during the rinsing stage of shampooing. Complex coacervate formation depends upon a number of parameters such as molecular weight, concentration, ionic strength of the solution, change density of the interacting components, pH and temperature.^{22,23,24}

Confocal fluorescence scanning microscopy and scanning electron microscopy have been used to show that deposition of the coacervate occurs preferentially at the cuticle edges²⁵ but measurement of the wetting force of single hair fibers reveals that the coating on the hair has relatively uniform surface free energy along the hair fiber.²⁶

Polyquaternium-10 is a water-soluble polymer that forms clear films and the improvement conferred upon hair appearance has been ascribed to such films.²⁷ It has been reported that polyquaternium-10 of high charge density forms solid-like gels over a limited

concentration range, whereas the low charge-density species form a liquid-like gel over a much broader concentration range.²⁶ In this context, it is interesting that the inclusion of high molecular-weight poly(ethylene oxide) reduces the particle size of the coacervate, produces higher foam volume and density, reduced combing forces, enhanced deposition and gives more uniform deposition on hair.²⁸ An investigation of the mechanism of poly(ethylene oxide) synergism is warranted.

Clear depositing systems have been claimed for lower molecular weight guarhydroxypropyltrimonium chloride and it would be interesting to investigate if this finding correlates with a smaller polymer blob size.²⁹ The coacervate deposits on the hair and it can co-deposit other beneficial agents such as silicone fluids, gums and resins. Such conditioning shampoos should confer the wet hair attributes of softness and ease of wet-combing, and the dry-hair attributes of good cleansing efficacy, long-lasting smooth, moistened feel, manageability control, and no greasy feel. Particle sizes below 5 microns are reported to deposit efficiently on hair because they are trapped within the coacervate upon dilution.³⁰ It has been asserted that the polymer-surfactant coacervate alone delivers good wet conditioning but does not give good dry feel.³⁰

Recent patent applications have been directed towards insoluble particles other than silicones. For example, PPG-15 stearyl ether,³¹ condensates of adipic acid and pentaerythritol, polybutene and mineral oil³² have recently been revealed in the patent literature as attempts to provide manageability control for dry hair, reducing interfiber friction, providing a moisturized feel, while alleviating the "greasy feel" of conventional complex coacervate-based conditioning shampoos.

The opposite effect is targeted in coacervate-driven deposition of particles (titanium dioxide, clay, pearlescent mica, or silica) to confer interfiber friction in order to enhance styleability of the hair.³³ It is also seen in spherical particles (hollow silica, hollow polymer spheres) for slip and conditioning attributes.³³ In this case high molecular weight (100,000 to 3 million Daltons) cationic guar polymers are specified with a charge density of less than 4–5 meq/g.

Specific mixtures of cationic polymers have been claimed to deliver more uniform coverage and thinner deposited films than conventional coacervate-based conditioning shampoos.³⁴ This same source cites the use of mixtures of poly(acrylamide-co-acrylamidopropyl trimonium chloride), hydroxypropyl guar trimonium chloride, and silicone quaternium-13.

The influence of cationic polymer on surfactant self-associated structures is shown in a recent patent application that reveals that synthetic polymers such as poly(methacrylamidopropyltrimethylammonium chloride) (MAPTAC) cause phase-separated lyotropic liquid crystals to form in shampoo compositions and that these liquid-crystalline coacervates confer conditioning benefits on hair.³⁵ Another recent patent application³⁶ reveals that styling and gloss benefits can be conferred from rinse-off compositions containing an anionic surfactant, a cationic polymer and an amphiphilic, branched block copolymer. An investigation of the fundamental physical mechanisms that underpin this technology could lead cosmetic formulators to new and useful delivery systems.

Measuring and Characterizing Deposition from Shampoos

The multiple attribute consumer assessment study is an important hurdle to qualify products for market. Common attributes that are tested by consumer study are cleansing, ease of wet and dry combing, hair softness, and lather amount and creaminess.³⁴

Secondary ion mass spectrometry can be used to detect the distribution of silicone on the hair. This technique is especially useful to assess whether the distribution is even or localized on, for example, cuticle edges or regions of weathering or damage.³⁴

The thickness of silicon layers on hair can be measured by X-ray photoelectron spectroscopy. This technique measures silicon:carbon:oxygen and because these ratios are different for the silicone and for the hair surface, the depth at which the ratio changes from silicon to hair can be measured. This technique can measure even one or two monomolecular layers of silicone.³⁴

The Instron ring compression test is a useful technique to measure interfiber friction in a hair swatch. This has been claimed to correlate with ease of dry combing. In this test, the force required to thread a hair swatch through a ring of predetermined size is measured using the extension mode of an Instron tester.

Future Directions

Shampoo depositing systems have largely concentrated on poly-quaternium-10 and guar hydroxypropyltrimonium chloride as the "active" ingredients. As competition in this arena intensifies, as patents expire, and as our mechanistic understanding is enhanced by modern scientific methods, it is likely that new and improved cationic polymers will be identified to enhance conditioning attributes.

Also, we are now beginning to make headway in the experimentally and conceptually difficult area of polymer interaction in concentrated surfactant systems. Breakthroughs in understanding such concentrated systems should translate into better 2-in-one and 3-in-one cleansing products, emulsions, and conditioners.

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A New Dimension in Hairstyling—VP/ Methacrylamide/Vinyl Imidazole Copolymer

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KEY WORDS: *styling polymer, hair gels, hair mousses, nanoindentation, mechanical measurements*

ABSTRACT: *Data on friction, hardness, tack and other mechanical properties obtained from a nanoindenter on an atomic force microscope combined with conventional stress strain measurements demonstrate the potential of VP/methacrylamide/vinylimadazole copolymer, a new hairstyling polymer.*

Hair gels and mousses have a high rank among styling products. Approximately half of the styling polymers are employed in these application forms, and approximately 25% are used in gel formulations.¹

Gels are favored for short hairstyles and are particularly used by men. Due to VOC regulations, the trend in the United States is toward water-based styling gels and mousses—away from aerosol hairsprays with propellant and solvent. In Asia, water-based and alcohol-free styling formulations are correlated with purity and traditionally preferred. On strong, dark Asian hair, styling gels and mousses accomplish good setting without flaking.

Most of the hair gels on the market have cross-linked polyacrylic acid as the thickener because it gives them an important

advantage: they are thixotropic and have a yield point. This means that they are effortlessly taken from a container, do not flow from the hand, and are easily dispersed on hair. But, only a limited number of setting polymers in these gels are compatible with the thickener. Almost every cationic or anionic setting polymer is incompatible with cross-linked polyacrylic acid, which leads to turbid formulations or precipitation, poor gel rheology, or instability.

Therefore, we set out to create a specialty polymer for clear hair gels. The required properties were excellent clarity in hair gel formulations with cross-linked polyacrylic acid, very low tack, high setting effect and high resistance to humidity. Many of these properties were determined conventionally on human hair as well as with a nanomechanical testing device.

New material development and understanding existing market products requires testing of surfaces or thin films at smaller scales for elastic and friction properties. Nanomechanical testing with a nanoindenter on the atomic force microscope (AFM) provides data with small forces and high lateral resolution, especially thin surface layers down to 100 nm.

Viscoelastic materials such as hair care polymers for styling applications were investigated with this method. These data were compared with data on the sensory assessment of personal care formulations applied to human hair. Subjective manual test results and nanomechanical AFM data of various hair care products evidently correlate to each other. Accordingly, the combability of hair after polymer application is associated to the reduced microscopic friction coefficient determined by a nanoscratching device on polymer films. Polymer raw materials as well as complete cosmetic formulations such as styling gels were tested regarding their performance.

These insights into the mechanical properties of materials were used to create new polymers with defined structures. Nanomechanical testing was recognized as a useful method for the investigation of cosmetic polymers and polymer-containing cosmetic formulations.

The specialty polymer^a we developed has the INCI name VP/methacrylamide/vinyl imidazole copolymer. In this chapter, we will refer to it as VPMVI copolymer. It is a 20% aqueous solution of a

^a Luviset Clear, BASF, Ludwigshafen, Germany

copolymer of N-vinylpyrrolidone, methacrylamide and N-vinylimidazole (**Figure 45.1**).

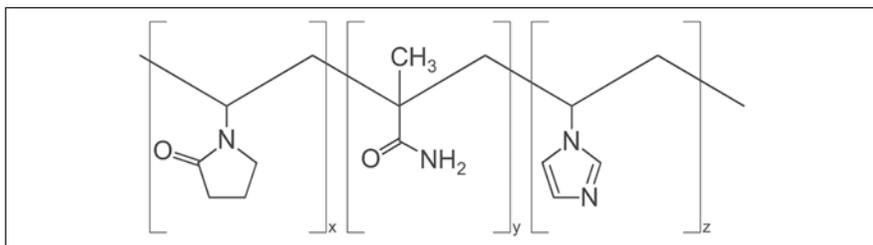


Figure 45.1. Structure of VPMVI copolymer

Mechanical Properties of Films

The mechanical properties of VPMVI copolymer were optimized during its development. An important requirement for high setting effect is a high tensile strength of the polymer film (**Figure 45.2**). The mechanical properties of several polymer films (34.5 mm long by 6.0 mm wide by 0.13–0.15 mm thick) were determined with a solids analyzer^a in a measuring chamber with defined relative humidity of 55%. The VPMVI copolymer was compared to PVP K90 and PVP K30^b which are the conventional setting polymers used in hair styling gels. The comparison shows the much higher tensile strength of the VPMVI copolymer.

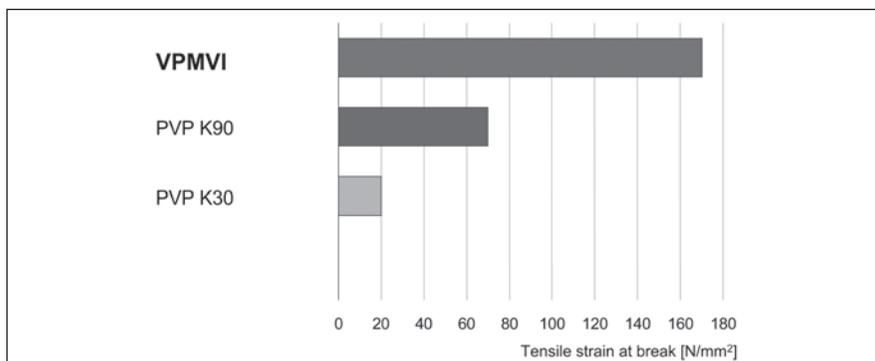


Figure 45.2. Stress-Strain measurement of polymer films VPMVI, PVP K90 and PVP K30 (250–500 μm ; 55% RH)

^a Rheometric Scientific Solids Analyzer RSA II, New Castle, Delaware, USA

^b Luviskol K30 and Luviskol K90, BASF Corp., Mt. Olive, New Jersey, USA

Tack at various humidities: The nanoindentation method is appropriate to study material properties fast and reliably at various relative humidities in a climate chamber. A nanoindenter^c was used for the nanomechanical measurements (**Figure 45.3**). During operation, the probe tip is first lowered into contact with the sample, then indented into the surface, and finally lifted off the sample surface. The indentation depth and the actual force applied to the tip are recorded simultaneously by an electromechanical capacitive 2D-transducer. A plot of the vertical force as a function of indentation depth for one complete indentation and retraction cycle is called a load displacement curve. Such curves were obtained from about 20 different areas on duplicate surfaces. Hardness and reduced E modulus were calculated from the load displacement curves using an algorithm for an elastic/plastic indentation.^{2,3,4,5}

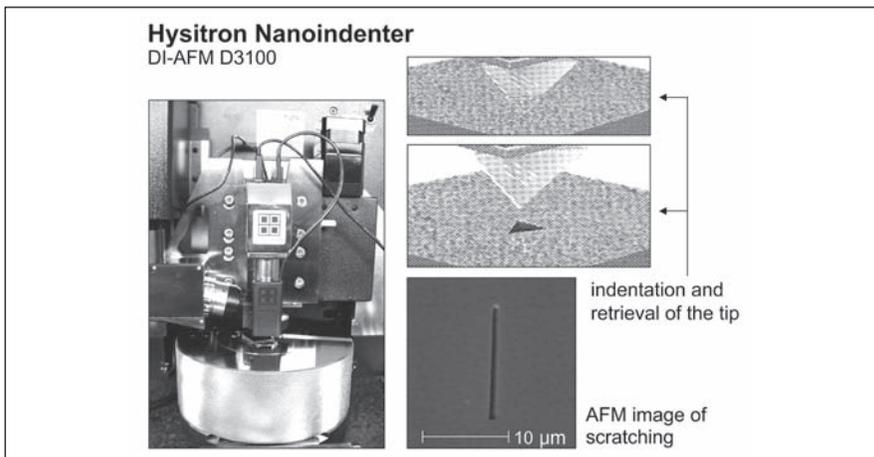


Figure 45.3. Hysitron nanoindenter (DI-AFM D3100)

The low tackiness of VPMVI copolymer (panel test, subjective and objective tests on glass plates) is supported by the nanoindentation measurements. Contrary to PVP, there is almost no dependence on relative humidity with the new setting polymer (**Figure 45.4**).

Friction coefficient: The nanoscratch experiment was performed by applying a constant vertical force of 10 μN and a constant lateral velocity of 500 nm/s. The so-called friction coefficient R from

^c Hysitron Nanoindenter, Hysitron, Minneapolis, Minnesota, USA

nanoscratching was determined from the ratio of lateral force to normal monitored during scratching. VPMVI copolymer has a strikingly low friction coefficient at high relative humidity (**Figure 45.5**). The experience with different polymers substantiates a correlation between friction and combability of hair.⁶ A low friction coefficient (as in the new setting polymer) goes along with ease of combing.

Tack while drying: A tack tester^a revealed substantially lower tackiness than PVP during the drying period of the polymer film (**Figure 45.6**).

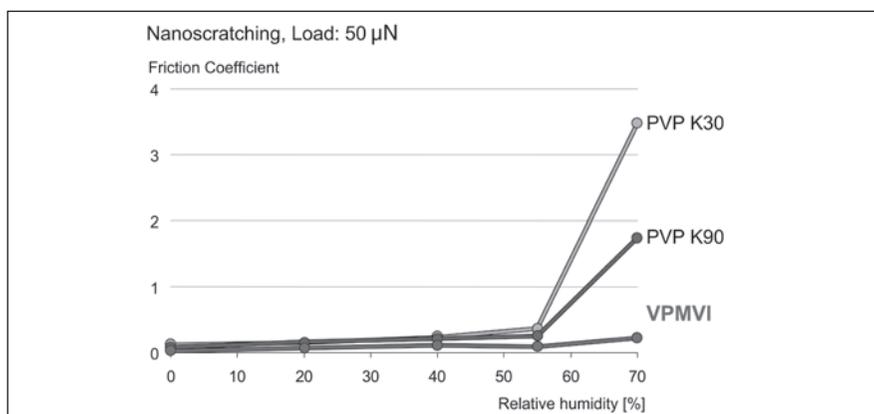


Figure 45.4. Tackiness of polymer films measured with Hysitron nanoindenter

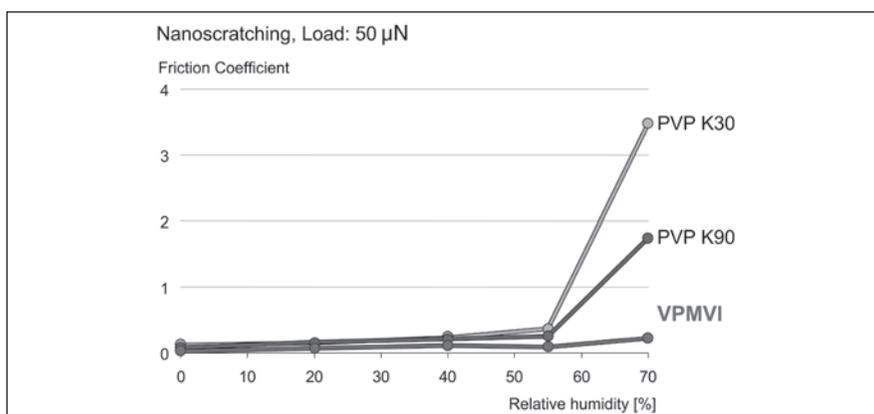


Figure 45.5. Friction coefficient of polymer films measured by Hysitron nanoindenter (Nanoscratching, load = 50 μ N)

^a Tack Tester, A. Coesfeld Ltd., Dortmund, Germany

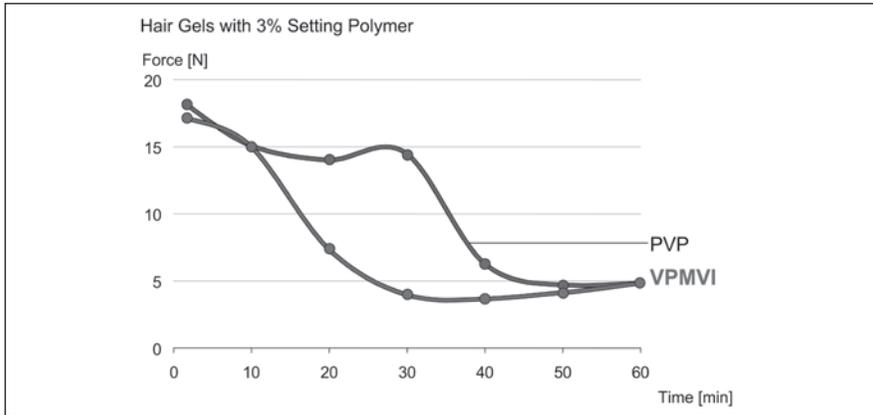


Figure 45.6. Tackiness of polymer films during drying. Measured by Diastron method. Hair gels with setting polymer at 3%.

Testing the Properties of Gels or Mousses

Tackiness of gels after drying: The tackiness is evaluated with mechanical testing as well as with sensory assessment.

During the mechanical testing, the tested gel is spread with a 120 μm spiral coater on a glass plate. The dry film on the glass plate is put into a climate chamber at 25°C and 90% relative humidity overnight. A rubber stamp presses a carbon band for 10 seconds onto the polymer film. The stickier the polymer surface is, the more printing ink from the carbon band adheres to the polymer film. The print is evaluated to a ranking from 0 (not tacky) to 5 (very strongly tacky).

For the sensory assessment, the tested gel is applied to a hair swatch. After drying, the tackiness is evaluated by at least two persons. They press their hands on a damp cloth and subsequently compress the hair swatch for 10 seconds in their hands. At release, the stickiness is evaluated with a ranking from 0 (not tacky) to 3 (strongly tacky). For comparison, always a standard should be used in parallel.

Tackiness of gels during drying: With a tensile tester^b, the force until separation (given in Newtons) of a metal stamp pressed on a drying polymer film is measured as a function of drying time. The measurement is performed in a climate chamber at 20°C and 65% relative humidity.

^b Tensile Tester, A. Coesfeld Ltd., Dortmund, Germany

Stiffness test: The stiffness test is the determination of the bending stiffness of a gel. The tested gel is diluted until a low viscous mass is formed. Hair tresses are dipped repeatedly into the diluted gel. Excess gel is wiped off and formed by hand to a round cross-section. At 20°C and 65% relative humidity, the tresses are dried overnight. The measurement of the bending stiffness is performed with a tensile tester. During testing, the gel film breaks, and the needed force in Newtons is monitored. Each sample of diluted gel is tested with at least five different hair tresses for its bending stiffness.

With mousses, the wet hair tresses are dipped into the solution of the mousse formulation containing setting polymer and prepared as described above. The measurement of the bending stiffness is performed as described above.

Curl retention of a gel or a mousse: A sufficient amount of the tested gel is spread on a glass plate, and the gel is applied with a scoop evenly on a hair tress. Excess gel is squeezed off and the hair tress is coiled around a Teflon curler. After that, the prepared tresses are dried overnight at 70°C. After 30 minutes of cooling to room temperature, the curl is carefully removed from the curler. The curls are hung up at one end, and their starting length is recorded. The determination of the curl retention is performed at 25°C and 90% relative humidity. After 5 hours, the final length of the curls is recorded. The stability of the curls in the particular climate is calculated and given in percent.

With mousses, the wet hair tresses are dipped into the solution of the mousse formulation containing setting polymer and prepared as already described. The determination of the curl retention is performed at 25°C and 75% relative humidity and determined as already described.

Combing force measurement for mousse application: The mousse is dispersed into the wet hair swatch. Prior to measurement, the hair swatch is detangled until no loops or coils remain. Next, the swatch is positioned into a clamp and combed into the testing comb that is part of the tensile tester. The combing force reduction is given in percent and calculated from the force ratio between treated swatch value and blank value (untreated swatch).

Light transmittance of gels (clarity measurements): The measurement of the transmittance is carried out with a UV/VIS spectrometer. Macro cuvettes with layer thickness of 1 cm were used. The transmittance value is determined at a wavelength of 600 nm. For comparison, the transmittance of distilled water is measured.

Results: Excellently transparent hair gels were made with VPMVI copolymer as the setting polymer. The precondition is a transparent thickener base, such as acrylates / C10-C30 alkyl acrylate crosspolymer^a. **Figure 45.7** shows the clarity of a formulation consisting of this thickener at 0.4% and VPMVI copolymer at 3.0% in distilled water. The light transmission of the gel base with 0.4% thickener is 97.4% (middle image). The addition of VPMVI copolymer enhances transparency to more than 99% (right image).

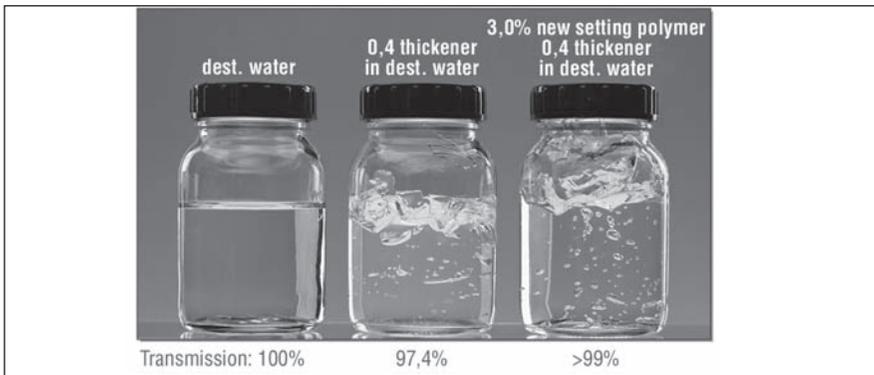


Figure 45.7. Clarity of a hair gel with VPMVI copolymer

With 3% content of the setting polymer, one can achieve a very strong setting that outperforms most of the commercially available gels on the market. As shown in **Table 45.1**, VPMVI copolymer is recommended at levels between 1% and 5% with the commonly used thickeners for the manufacture of clear gels. The details of formulation procedure vary from one formulation to the next, but in general the recommended procedure requires these steps:

1. Making of a diluted solution of the thickener;
2. 100% neutralization of the thickener solution and formation of the gel;
3. Addition of the 20% VPMVI copolymer solution

^a Ultrez 21, Noveon, Cleveland, USA

Table 45.1. Recommended percentages of some common thickeners used with VPMVI copolymer

INCI name	Trade name	Supplier	Solid content (%)
Acrylates / C10-C30 alkyl acrylate crosspolymer	Ultrez 21	Noveon	0.4-0.5
Acrylates beheneth – 25 methacrylate copolymer	Aculyn 28	Rohm & Haas	ca. 1.0
Carbomer	Carbopol 940	Noveon	0.4-0.5

In **Table 45.2**, the properties of VPMVI copolymer in hair gels are pointed out. The clarity of certain formulations is even better than that of polyvinylpyrrolidone formulations. The setting effect is high. The curl retention is above 90%.

As **Table 45.3** shows, VPMVI copolymer is appropriate in hair mousses also. It can be used as a single setting polymer or in combination with various polyquaterniums. For example, the combination with polyquaternium-46^a is recommended for extra strong hold and high humidity resistance. Combined with polyquaternium-16^b, it achieves high conditioning performance and better curl retention than with conventional VP/VA copolymers.

Sample formulations are shown in **Formulas 45.1, 45.2 and 45.3**.

Table 45.2. Properties of 3.0% VPMVI copolymer in hair gels thickened with 0.5% acrylates / C10-C30 alkyl acrylate crosspolymer

	VPMVI	PVP K90	PVP K30
Clarity*	crystal clear	clear	clear
Transmission* (%)	99.2	96.8	98.8
Tackiness at 90% RH (rating)	0-1	3	3
Stiffness test (cN)	190-200	125-145	70-80
Curl retention at 90% RH (%)	> 90	61	47

*Visually in 250 ml glass tubes; Transmission T at 600 nm

^a Luviquat Hold, BASF Corp., Mt. Olive, New Jersey, USA

^b Luviquat Style, BASF Corp., Mt. Olive, New Jersey, USA

Table 45.3. Properties of 3.0% VPMVI copolymer in hair mousses

	Setting (cN)*	Curl retention (%)**	Combability (%)***
VPMVI (3%)	217	81	70
VPMVI (2%) and PQ-46 (1%)	299	66	72
VPMVI (2%) and PQ-16 (1%)	295	24	78
PVP/VA 64 (3%)	67	2	62

* Stiffness Test in Newtons
 ** measured at 75% RH
 *** Combing Force Reduction in %

Formula 45.1. Spiky hair gel for very strong hold

A. Water (aqua), distilled	48.95% w/w
Preservative	qs
B. Acrylates/C10-30 alkyl acrylate crosspolymer (Ultrez 21, Noveon)	0.5
Triethanolamine	0.75
C. Water (aqua), distilled	22.00
PEG-40 hydrogenated castor oil (Cremophor CO 40, BASF)	0.10
Fragrance (parfum)	qs
D. PEG-8 (Pluracare E 400, BASF)	2.00
Panthenol	0.50
PEG-25 PABA (Uvinul P25, BASF)	0.10
Dimethicone copolyol (DC190, Dow Corning)	0.10
VP/methacryamide/vinyl imidazole copolymer (Luviset Clear, BASF)	25.00

Procedure: Put A into a beaker, stir and disperse B into it until the particles sink to the bottom. Then add C and stir until a homogeneous gel has been formed. Prepare D and stir until dissolved. Then add D to the gel.

pH value: 7.2

viscosity (Brookfield): 30500 mPas

transmission: 97% (600 nm)

Formula 45.2. Shiny hair gel

A. Water (aqua), distilled	74.10% w/w
PEG-40 hydrogenated castor oil (Cremophor CO 40, BASF)	0.10
Fragrance (parfum)	qs
B. VP/methacryamide/vinyl imidazole copolymer (Luviset Clear, BASF)	15.00
Acrylates beheneth-25 methacrylate copolymer (Aculyn 28, Rohm & Haas)	5.00
Glycerol 87%	5.00
Dimethicone copolyol (SF 1288, GE Silicones)	0.10
PEG-25 PABA (Uvinul P25, BASF)	0.10
Preservative	qs
C. Triethanolamine	0.60

Procedure: Solubilize A. Weigh the components of B into A and stir until homogeneous.

Neutralize AB with C and stir until homogeneous.

pH value: 7.0

viscosity: 90200 mPas

transmission: 97.0% (600 nm)

Formula 45.3. Volumizing aerosol mousse 6% VOC

A. Water-(aqua), distilled	47.10% w/w
VP/methacryamide/vinyl imidazole copolymer (Luviset Clear, BASF)	10.00
Polyquaternium-46 (Luviquat Hold, BASF)	5.00
Preservative	qs
B. Water (aqua), distilled	30.00
Cetareth-25 (Cremophor A-25, BASF)	0.20
Cocotrimonium methosulfate (Luviquat Mono LS, BASF)	0.40
Laureth-3 (Rhodasurf L-3, Rhodia)	0.70
Fragrance (parfum)	qs
C. Propellant A70 (propane/isobutane)	6.00

Procedure: Add ingredients of A in order listed with adequate agitation, making sure all components are completely dissolved before adding the next. Premix ingredients of B until homogeneous. Add B to A with adequate agitation. Fill into appropriate containers and charge with C.

Summary

VPMVI copolymer is an innovative ingredient for clear hair gels, hair mousses and other styling products. New is the combination of the ability to formulate clear hair gels based on cross-linked polyacrylic acid with improved properties during application and after drying on hair. The new setting polymer can be employed as single polymer or in combination together with other styling polymers. VPMVI copolymer provides low polymer film tackiness. The values of curl retention at 90% relative humidity (values above 90%) and the setting effect are high. The advantages of the new setting polymer over conventional setting polymers are demonstrated by application assessments and conventional mechanical studies.

In particular, nanomechanical measurements are well suited to differentiate between polymer film properties on substrates. This method of nanoindentation and nanoscratching was introduced into the material science for cosmetics for the first time. It can be applied to polymer films as well as films of complete cosmetic formulations. Tack, hardness and friction of the VPMVI copolymer films correlate with important application properties on hair, such as tackiness, setting effect and combability. These insights into the mechanical properties of materials were used to tailor the new polymer, which takes formulations to a higher level of product performance.

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Enhancing the Feel of Vegetable Oils with Silicone

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KEY WORDS: *Borago officinalis* seed oil, sensory, silicone, surface tension, triglycerides, vegetable oil

ABSTRACT: *Adding silicone to natural oils can reduce surface tension thus improving spreading characteristics. This results in finished formulations with improved sensory profiles and in addition, expands on the opportunities for using these natural ingredients.*

As consumer interest in natural ingredients continues to grow, along with the demand for novel textures and product forms, the use of vegetable oils in personal care formulations is increasing. In fact, the consumption of natural oils in Europe is forecasted to grow approximately 5% during the next five years.¹ Although these natural ingredients offer distinct benefits including emolliency, gloss and lubricity,² they also challenge formulators to provide easy application and pleasant aesthetics without a greasy or oily feel.

Lipids and silicones can act as complementary ingredients in finished formulations.³ This chapter illustrates how silicones such as caprylyl methicone, phenyl trimethicone, cetyl dimethicone and cyclopentasiloxane can enhance the feel of natural lipids, allowing formulators greater flexibility to expand the use of natural ingredients in their products. Even at low use levels, silicones can decrease the surface tension of vegetable oils, improve their spreading characteristics and offer a wider range of sensory profiles.

The Source for Vegetable Oils

Vegetable oils, also referred to as natural lipids, are oily substances derived from plant sources. They have a variety of chemical compositions but most used in personal care are rich in triglycerides that are mechanically extracted from the seeds of plants. The non-triglyceride components are referred to as the unsaponifiable fraction and this typically consists of tocopherols, sterols, free fatty alcohols and triterpenes.

Triglycerides are esters composed of one glycerin molecule bonded to three fatty acids—long-chain carboxylic acids in which the alkyl chain normally contains ten or more carbons. This structure is depicted in **Figure 46.1**, where R₁, R₂ and R₃ are fatty acids.

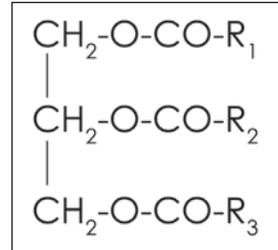


Figure 46.1. Triglycerides are esters composed of one glycerin molecule bonded to three fatty acids.

The three fatty acids can have equal or different chain lengths and their carbon chains can be saturated or unsaturated. The fatty acid composition of triglycerides varies according to their source. For example, triglycerides derived from coconut are rich in lauric acid (saturated C₁₂ fatty acid), and in many cases, materials such as sodium lauryl sulfate still retain a slight odor of coconut oil from which this surfactant is derived.

Based on the International Nomenclature Cosmetic Ingredient (INCI) system, natural lipids are named according to the genus and species of the plant. For example, the INCI name for borage oil is *Borago officinalis* seed oil.

Complementary Silicones

Silicones are synthetic polymers made from quartz, a natural form of crystalline silicon dioxide, and methanol. These materials have been used in personal care products for more than 50 years. Most silicones for personal care applications are based on polydimethylsiloxane or dimethicone. This linear polymer is available in a range of molecular weights, with the molecular weight for a particular dimethicone determining its viscosity. Volatile silicones such as

cyclopentasiloxane are short-chain cyclic polydimethylsiloxanes. Another commonly used silicone is phenyl trimethicone, a highly branched phenyl-functional silicone.

Silicones are good emollients that improve the feel of formulations, while lipids act as moisturizers and can also restore the barrier function of skin.

Two vegetable oils were evaluated in this study: borage oil^a and a vegetable oil blend^b composed of *Brassica campestris* (rapeseed) seed oil and *Elaeis guineensis* (palm) oil.

These oils were blended with four compatible silicones:

- caprylyl methicone, a caprylyl-branched liquid trisiloxane;
- phenyl trimethicone, a highly-branched, liquid phenyl-functional silicone;
- cetyl dimethicone, a linear liquid polysiloxane with alkyl chains randomly distributed, which is highly compatible with organic ingredients; and
- cyclopentasiloxane, a cyclic molecule that provides transient emolliency because of its volatility.

Lowering Surface Tension

Surface tension is a measure of the work needed to create a new surface area. High surface tension, together with high viscosity, can contribute to tackiness.⁴ A bubble pressure tensiometer^a was used in the present study to measure dynamic and static surface tension.

Gas bubbles were produced in the sample liquids at an exactly defined bubble generation rate. As the dynamic surface tension is recorded as a function of bubble life time, the rate decreases while the bubble life time increases. The bubbles enter the liquid through a tube of known radius, calibrated before taking measurements, and the pressure reaches a maximum that is recorded by the instrument.

Silicones have an inherent low surface tension (see **Table 46.1**) due to the methyl groups attached to the backbone.

^a Cosmosil B (INCI: Borago officinalis seed oil) is a product of International Cosmetic Science Centre, Lystrup, Denmark.

^b Dow Corning HY4008 Vegetable Oil Blend (INCI: Brassica campestris (rapeseed) seed oil (and) Elaeis guineensis (palm) oil) is a product of Dow Corning Corp., Midland, MI USA.

^c The Science Line T60 tensiometer is a product of SITA Messtechnik GmbH, Dresden, Germany.

Silicone	Static Surface Tension (mN/m)
Caprylyl methicone	20.34
Phenyl trimethicone	21.76
Cetyl dimethicone	26.62
Cyclopentasiloxane	19.00

Figure 46.2 shows the decrease of dynamic surface tension of borage oil with the addition of phenyl trimethicone. **Figure 46.3** shows the decrease of static surface tension of borage oil with the addition of cyclopentasiloxane, phenyl trimethicone, caprylyl methicone or cetyl dimethicone. Similar results were obtained with the vegetable oil blend.

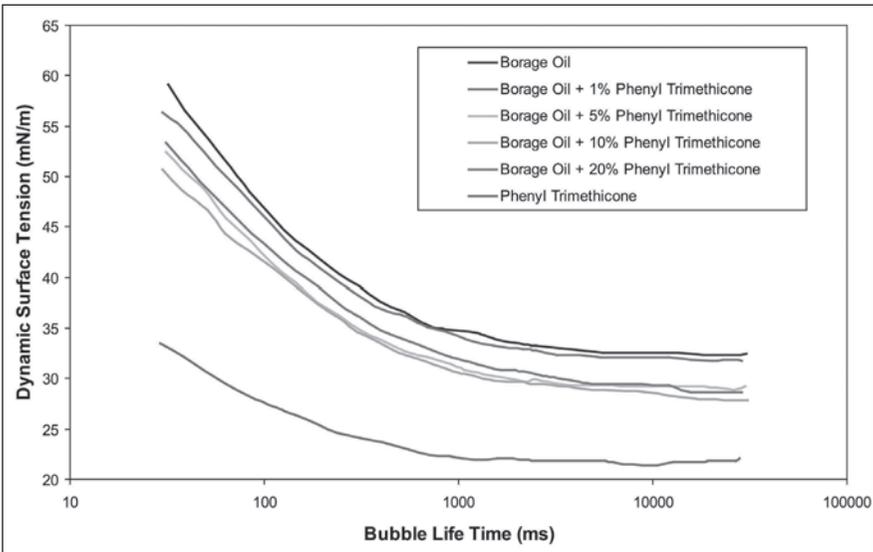


Figure 46.2. Effect of the addition of phenyl trimethicone on the dynamic surface tension of borage oil

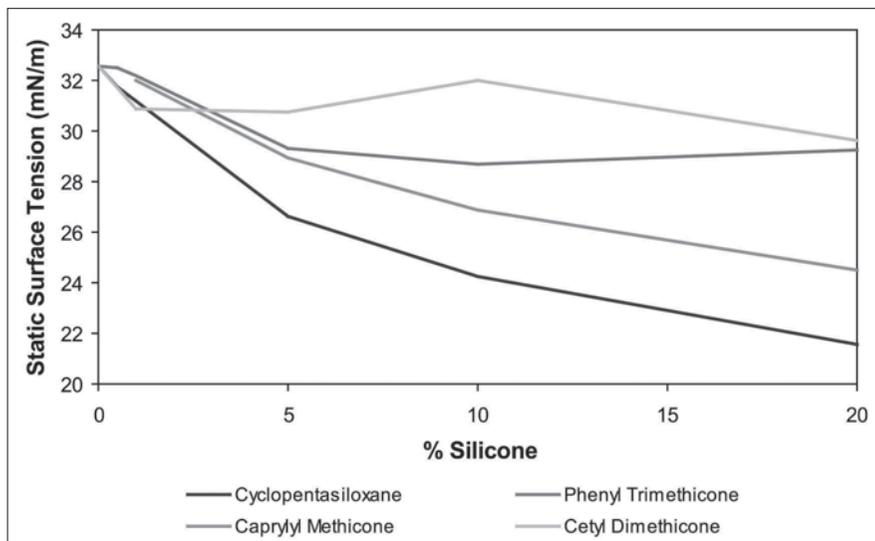


Figure 46.3. Effect of the addition of cyclopentasiloxane, phenyl trimethicone, caprylyl methicone or cetyl dimethicone on the static surface tension of borage oil

Enhanced Spreading

The spreading characteristics of cosmetic oils determine how easily they can be applied and how well they will be distributed onto the skin. In general, the more readily the oil spreads, the more pleasant it will feel on the skin. A gelatin test is a common *in vitro* method for measuring the spreadability of cosmetic oils because gelatin is a fairly representative model of the human skin surface. To conduct this test, a gelatin film is applied to polystyrene plates (Petri dishes) and a 5- μ L sample of the cosmetic oil is applied onto the film. A stereomicroscope is used to measure the diameter of the oil droplet at time zero and after 10 min. **Equation 46.1** shows how spreadability is calculated.

$$\text{Oil Spreadability} = \frac{\left(\text{Droplet size at 10 min} \right) - \left(\text{Droplet size at time zero} \right)}{\text{Droplet size at time zero}} \quad \text{Equation 46.1}$$

Values can be compared only when they have been determined under identical humidity and temperature conditions, and the average of at least three measurements should be used. Results are expressed as an enhanced spreadability factor (see **Equation 46.2**).

$$\text{Enhanced Spreadability Factor} = \frac{\text{Spreadability of oil with additive}}{\text{Spreadability of pure oil}} \quad \text{Equation 46.2}$$

This method was used to determine the effect of silicone on the spreadability of vegetable oils. If the enhanced spreadability factor is found to be greater than 1, the additive improves spreadability; if it is less than 1, the additive decreases spreadability.

Figure 46.4 shows how the spreadability and surface tension of borage oil can be influenced by the addition of silicone. The improvement of spreadability depends upon the type and level of silicone used.

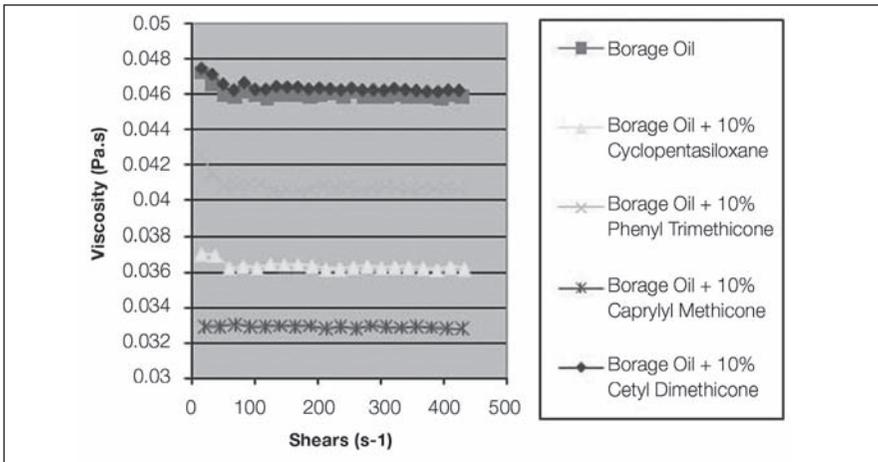


Figure 46.4. Effect of the addition of cyclopentasiloxane, phenyl trimethicone, caprylyl methicone or cetyl dimethicone on the viscosity of borage oil

The effect of silicone on viscosity also was studied using a rheometer and a stress ramp procedure (see **Table 46.2** and **Figure 46.5**).

Results demonstrated that borage oil and its blends with silicone are Newtonian liquids. The addition of cyclopentasiloxane, phenyl trimethicone or caprylyl methicone decreases the viscosity of borage oil, while the addition of cetyl dimethicone increases its viscosity slightly. The greatest reduction in viscosity was obtained with caprylyl dimethicone.

Additional trials were carried out with the vegetable oil blend (**Figure 46.6**).

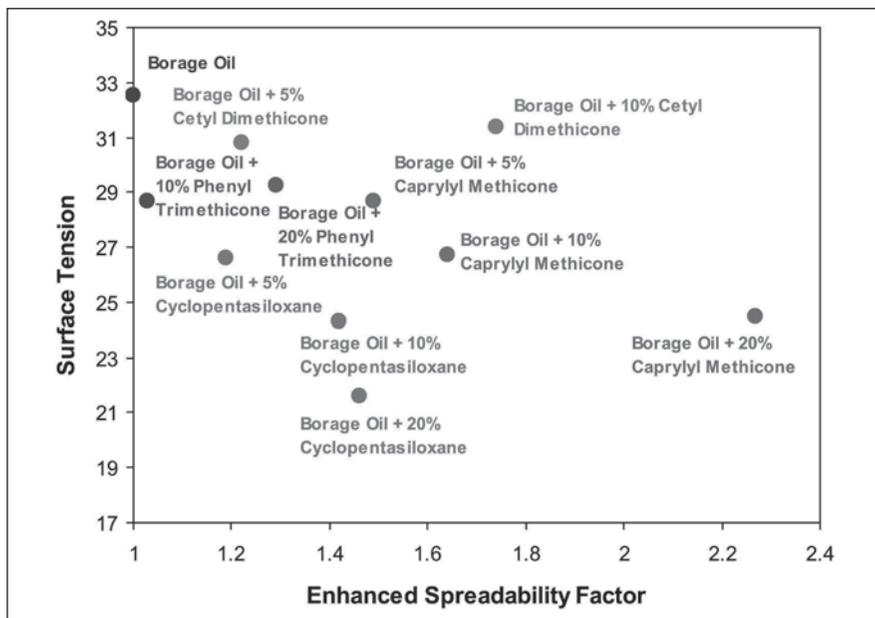


Figure 46.5. Relationship between surface tension and spreadability results for borage oil

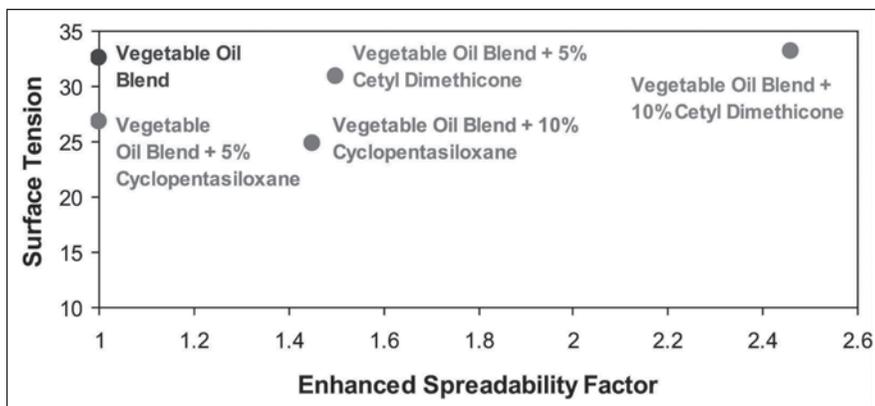


Figure 46.6. Relationship between surface tension and spreadability results for a vegetable oil blend

These results show that spreadability improvement can be achieved for more than one type of vegetable oil with the addition of silicone.

Table 46.2. The Effect of Silicone on Viscosity of Test Samples

Borage oil	Borage oil + 10% Cyclopentasiloxane		Borage Oil + 10% Phenyl trimethicone		Borage oil + 10% Cetyl dimethicone		Borage oil + 10% Caprylyl methicone		
	Shear rate 1/s	Vis. Pa.s	Shear rate 1/s	Vis. Pa.s	Shear rate 1/s	Vis. Pa.s	Shear rate 1/s	Vis. Pa.s	
15.86	0.04715	17.54	0.03694	14.76	0.04260	15.81	0.04740	22.52	0.03292
33.04	0.04653	39.09	0.03685	34.20	0.04153	32.62	0.04708	46.36	0.03293
50.78	0.04587	61.56	0.03619	54.24	0.04078	49.87	0.04654	70.05	0.03303
68.27	0.04581	83.41	0.03628	73.73	0.04082	67.25	0.04621	94.23	0.03290
85.01	0.04611	105.30	0.03620	92.88	0.04086	83.66	0.04662	118.00	0.03293
102.70	0.04590	126.70	0.03638	112.40	0.04085	101.20	0.04624	141.80	0.03295
120.30	0.04569	148.60	0.03635	132.50	0.04059	118.20	0.04625	165.70	0.03293
137.10	0.04590	170.30	0.03636	151.90	0.04059	134.80	0.04641	189.60	0.03294
154.40	0.04591	192.50	0.03629	171.60	0.04055	152.00	0.04637	213.90	0.03281
171.60	0.04592	214.70	0.03614	190.60	0.04068	168.90	0.04637	237.30	0.03291
189.40	0.04576	236.60	0.03616	209.90	0.04077	186.30	0.04627	261.90	0.03282
206.30	0.04586	258.20	0.03624	229.50	0.04068	203.10	0.04633	285.10	0.03295
223.20	0.04598	279.90	0.03628	248.70	0.04075	220.20	0.04628	309.30	0.03288
241.40	0.04574	302.10	0.03620	269.00	0.04057	237.50	0.04622	333.60	0.03284
257.60	0.04605	323.60	0.03625	287.80	0.04074	254.10	0.04632	357.10	0.03291
275.50	0.04582	345.60	0.03624	307.20	0.04075	271.50	0.04621	381.20	0.03285

Borage oil		Borage oil + 10% Cyclopentasiloxane		Borage Oil + 10% Phenyl trimethicone		Borage oil + 10% Cetyl dimethicone		Borage oil + 10% Caprylyl methicone	
Shear rate 1/s	Vis. Pa.s	Shear rate 1/s	Vis. Pa.s	Shear rate 1/s	Vis. Pa.s	Shear rate 1/s	Vis. Pa.s	Shear rate 1/s	Vis. Pa.s
293.30	0.04575	368.10	0.03618	326.90	0.04071	288.70	0.04623	405.50	0.03282
310.80	0.04574	390.30	0.03609	346.90	0.04064	305.90	0.04620	429.90	0.03278
327.40	0.04584	411.40	0.03625	365.60	0.04069	322.30	0.04630		
345.00	0.04576	433.40	0.03616	385.00	0.04072	339.60	0.04623		
362.20	0.04580			405.10	0.04065	357.10	0.04618		
379.80	0.04581			424.60	0.04067	374.30	0.04614		
397.70	0.04567					391.60	0.04613		
413.90	0.04586					407.80	0.04621		
431.20	0.04581					425.20	0.04619		

Sensory Attributes

Generally formulators are most interested in sensory enhancements that can be perceived on the skin; thus, a series of sensory panel tests was also conducted. Comparisons of pure oils and the same oils blended with silicone were tested by an experienced sensory panel of 18 Caucasian participants. The sensory evaluations were performed in a controlled climate, with humidity at $50\% \pm 5\%$, and the temperature at $20^\circ\text{C} \pm 2^\circ\text{C}$. Each panelist applied 0.02g of both product samples and assigned scores for several sensory attributes during rub-in as well as after they perceived the product had been absorbed on the skin—i.e., the ratings were based on panelists perceptions, not biological skin absorption. For example, panelists found that 5% cetyl dimethicone improved a number of sensory attributes of a vegetable oil blend (see **Figures 46.7** and **46.8**). They noted less greasiness and a lighter skin feel during rub-in and after absorption, and less gloss after absorption.

Other sensory evaluations revealed that:

- 20% caprylyl dimethicone gave a lighter skin feel for borage oil during rub-in;
- 10% phenyl trimethicone reduced the tackiness of borage oil during rub-in;
- 10% cyclopentasiloxane improved the skin feel of borage oil, resulting in less greasiness during rub-in and a lighter skin feel during rub-in and after absorption; and
- 10% cyclopentasiloxane improved the feel of the vegetable oil blend, making it easier to spread and less tacky during rub-in.

Prototype **Formulas 46.1**, **46.2** and **46.3** illustrate the use of silicones with the vegetable oil blend.

Discussion

The addition of caprylyl dimethicone resulted in a significant decrease in the surface tension and viscosity of vegetable oils and that can be translated as enhancement of spreadability on gelatin. Panelists confirmed the improved sensory properties obtained

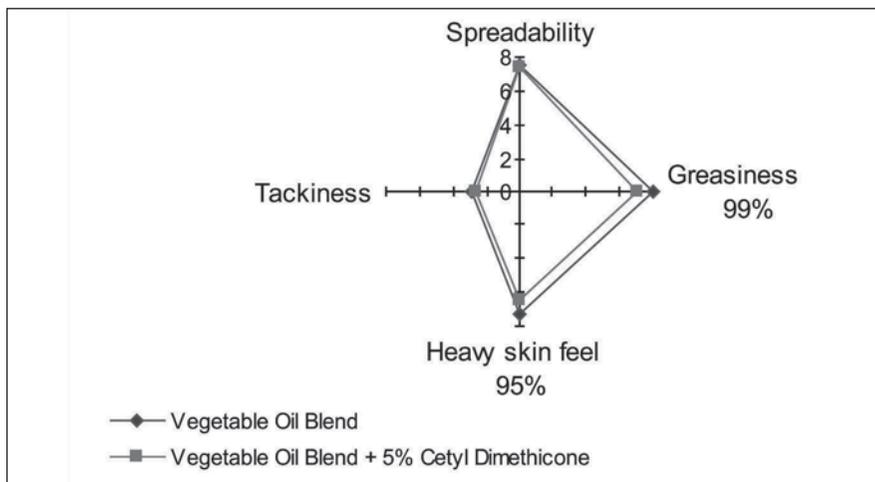


Figure 46.7. Sensory evaluation of a vegetable oil blend before absorption; percentages indicate level of confidence.

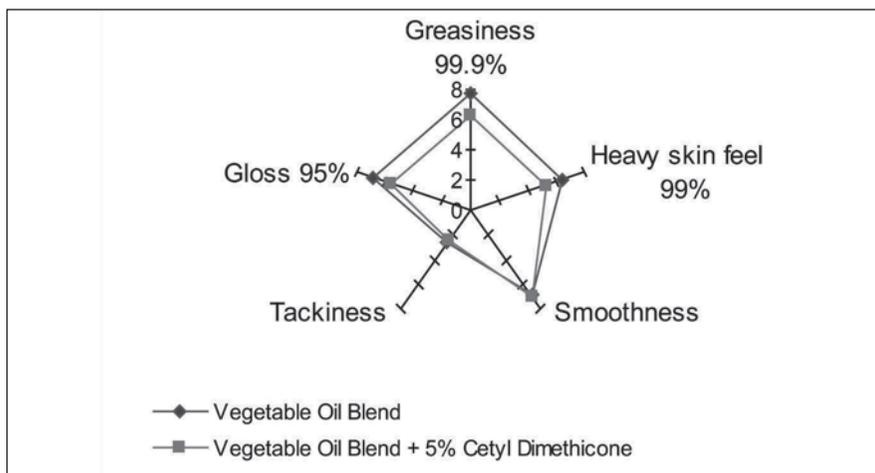


Figure 46.8. Sensory evaluation of a vegetable oil blend after absorption; percentages indicate level of confidence.

for borage oil with 20% caprylyl dimethicone. Lower addition levels were not tested by the sensory panel. Phenyl trimethicone also decreased the surface tension and viscosity of vegetable oils. The addition of 20% phenyl trimethicone resulted in a significant improvement of the spreadability of borage oil. The panel test showed improvement of the skin feel of borage oil with the addition of 10% phenyl trimethicone.

Formula 46.1. Body cream

A. <i>Brassica campestris</i> (rapeseed) seed oil (and) <i>Elaeis guineensis</i> (palm) oil (DC HY-4008 Vegetable Oil Blend, Dow Corning)	20.0% w/w
Phenyl trimethicone (DC 556 Cosmetic Grade Fluid, Dow Corning)	4.0
Sodium polyacrylate (and) dimethicone (and) cyclopentasiloxane (and) trideceth-6 (and) PEG/PPG-18/18 dimethicone (DC RM 2051 Thickening Agent, Dow Corning)	3.0
B. Water (<i>aqua</i>)	71.0
C. Fragrance (<i>parfum</i>) (Perfume Sensual 1, Givaudan)	1.0
Phenoxyethanol (and) ethylhexylglycerin (Euxyl PE 9010, schülke inc.)	<u>1.0</u>
	100.00

Procedure: Combine A and mix. Add B with mixing. Add C and mix until homogeneous.

Formula 46.2. Massage oil

<i>Brassica campestris</i> (rapeseed) seed oil (and) <i>Elaeis guineensis</i> (palm) oil (DC HY-4008 Vegetable Oil Blend, Dow Corning)	94.0% w/w
Cetyl dimethicone (DC 2502 Cosmetic Fluid, Dow Corning)	5.0
Essential oil	0.5
Fragrance (<i>parfum</i>)	<u>0.5</u>
	100.00

Procedure: Combine all and mix thoroughly.

Cetyl dimethicone slightly decreased the surface tension of vegetable oils and slightly increased their viscosity; however, results showed an improvement in spreadability and sensory properties. Panelists were able to detect a sensory difference at 5% cetyl dimethicone in the vegetable oil blend.

The greatest reduction in surface tension was found with cyclopentasiloxane. Panelists confirmed that the addition of 10% cyclopentasiloxane in borage oil or in a vegetable oil blend improved sensory attributes.

Formula 46.3. Topical spray

A. <i>Brassica campestris</i> (rapeseed) seed oil (and) <i>Elaeis guineensis</i> (palm) oil (DC HY-4008 Vegetable Oil Blend, Dow Corning)	15.0% w/w
<i>Mangifera indica</i> (mango) seed butter (DC HY 3001 Mango Butter, Dow Corning)	4.0
B. Isopropyl myristate	18.0
Caprylyl methicone (DC Toray FZ-3196, Dow Corning)	62.5
Fragrance (<i>parfum</i>)	<u>0.5</u>
	100.00

Procedure: Combine A and mix with heating at 30°C until completely melted. Remove from heat and continue to mix. Add B in order and mix until homogeneous.

Summary

The present study shows that it is possible to lower the surface tension of vegetable oil and improve its spreadability with the addition of silicones such as caprylyl dimethicone, phenyl trimethicone, cetyl dimethicone or cyclopentasiloxane. In some cases, the improvements were confirmed by sensory panel testing.

Combining vegetable oils and silicone is one way for formulators to obtain improved sensory characteristics and broaden the opportunity to create innovative skin care products that expand the use of natural materials.

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Reducing Odiferous Volatiles with Zeolites

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KEY WORDS: *zeolite, odor adsorption, odor removal, headspace, GC-MS*

ABSTRACT: *Undesirable odors transmitted by volatile molecules in some personal care ingredients can be substantially reduced by adding 5% of an appropriate odor-adsorbing zeolite powder. Here, the authors show this reduction by observing the headspace (HS) over the ingredients via gas chromatography-mass spectrometry (GC-MS).*

Users of personal care products occasionally are offended, understandably, by undesirable odors that may arise from certain ingredients in products or other sources. Fragrances added to formulations may hide smells, but this technique is not always successful. For example, self-tanning lotions produce undesirable odors from the Maillard reaction that produces the tan. Since different odors are produced at different times during tanning, it is difficult to mask a continually changing profile of odors. An alternative solution is to add a zeolite that adsorbs the odors that are produced (see **Formula 47.1**).

The successful elimination of odor from self-tanning lotions spurs the question: Are there other unwanted odors of common personal care ingredients that can be removed with odor-adsorbing zeolites? This work demonstrates that the characteristic odors of many personal care ingredients can be substantially reduced by odor-adsorbing zeolites.

Formula 47.1. Self-tanning lotion with sodium silicoaluminate

A. Water (<i>aqua</i>)	56.20% w/w
Disodium EDTA	0.10
Methylpropanediol	2.00
B. Xanthan gum (Keltrol CG T,CP Kelco)	0.15
C. Preservative	qs
D. Glyceryl stearate (and) PEG-100 stearate	2.00
Steareth-21	1.00
Cetearyl alcohol	1.50
Isododecane	5.00
Steareth-2	0.50
BHT	0.05
Trimethylpentanediol/adipic acid copolymer (Lexorez TL 8, Inolex Chemical Co.)	2.00
Caprylic/capric triglyceride	2.00
Dimethicone, 100 cSt.	1.00
Hydrogenated polydecene	4.00
E. Polyacrylamide (and) C13-14 isoparaffin (and) laureth-7 (Sepigel 305, Seppic)	3.50
F. Erythrose	1.00
Water (<i>aqua</i>)	10.00
Dihydroxyacetone (and) tyrosine (Instabronze, Alban Muller)	0.50
Dihydroxyacetone	5.50
Sodium silicoaluminate (Asensa DS 912, Honeywell)	2.00
G. Sodium hydroxide, 20%	qs

Procedure: Combine A and heat to 75°C. Slowly sprinkle B into A with stirring and mix until fully hydrated. Add C to AB. Separately mix D and bring to 75°C, then add it to ABC. Add E to batch and begin cooling to 40°C. At 40°C, add F in order. Adjust batch to pH = 4.0–5.0 with G.

Zeolite History

In the mid-18th century, A.F. Cronstedt observed rocks that “danced” when they were rapidly heated.¹ Recognizing that water evaporating from the rocks caused this motion, he combined the

Greek words meaning *to boil* and *stone* to create the descriptive name *zeolite*.

Most zeolites are porous aluminosilicate that have severe restrictions on their porosity.^{2,3} The pores cannot be the result of fractures in their crystalline system; they must be nano-sized pores that are actually part of the crystalline structure. As a result, the porosity is not a surface feature of the mineral but a bulk property.

A variety of complex pore systems can be formed as aluminum ions are judiciously substituted for the silicon atoms in silicate structures. About 50 different types of naturally occurring zeolites have been discovered, but more than 200 other types have been made synthetically. Because there are negatively charged aluminum ions incorporated in the structure, there must also be positively charged ions such as sodium to neutralize the system.

The size of the pores in the zeolite determines what molecules can enter, so zeolites are sometimes called molecular sieves. One zeolite application is to select appropriate pore sizes to permit only small impurities to enter; for example, methanol or ethanol can be purified as appropriate zeolites trap the smaller water molecule impurities. However, even when the molecule targeted for removal is not differentiated by its small size, the surface of the pore wall may be chosen to give selective adsorption. This process is temperature dependant, and at a sufficiently high temperature, all molecules will desorb.

Zeolites that successfully adsorb odor generally have relatively large pores and a high silicon to aluminum ratio.

The large size pore sizes are useful since odiferous molecules have a large range of sizes. A low aluminum content makes the pore walls less polar, which promotes adsorption of many but not all odors. Naturally occurring zeolites are generally not effective for this purpose but certain synthetic zeolites have been found to be very effective at removing odor.

Materials and Methods

Table 47.1 lists typical oleophilic and hydrophilic ingredients with disagreeable odors that typically are incorporated into personal care products. These ingredients were the subjects of the present

Table 47.1. Common personal care ingredients used in this study

Common name	INCI name	Trade name, Supplier
Castor oil	<i>Ricinus communis</i> (castor) seed oil	Crystal Crown, CasChem
Avocado oil	<i>Persea gratissima</i> (avocado) oil	Avocado Oil, Columbus Oils
Sulfur powder in olive oil	Sulfur (and) refined olive oil	Newsulfur O, TRI-K
Essential fatty acids	Linoleic acid (and) linolenic acid (and) tocopherol	TRI-K EFA Special, TRI-K
Exthoylated soybean oil	PEG-35 soy glycerides	Acconon S-35, Abitec Corp.
Sulfur powder in surfactants	Sulfur (and) polysorbate 80 (and) oleth-10	Newsulfur W, Tri-K
Sepia melan ink	Melanin	SepiaMelanInk, MeL-Co
1% Tea tree oil in mineral oil	<i>Melaleuca alternifolia</i> (tea tree) leaf oil (and) <i>Paraffinium liquidum</i> (mineral) oil	Tea Tree Oil in Mineral Oil, white, heavy; TRI-K and Aldrich Chem. Co.

investigation. The mechanisms of their physiological receptors are quite different from those of zeolites, and this selection of molecules was chosen to represent a variety of classes of compounds with distinctly different smells.

All samples were obtained from ingredient suppliers and each material was analyzed with and without a 5% loading of an odor-adsorbing zeolite^a. The ingredients were not incorporated into cosmetic formulations.

Evaluation of both organic and inorganic volatiles was conducted by sampling the headspace (HS) and analyzing it by gas chromatography-mass spectrometry (GC-MS). HS-GC-MS experiments were performed using 0.5 g aliquots of each ingredient sample as received, and then with 0.5 g of ingredient sample with 25 mg of zeolite added to provide a 5% loading of the adsorbent. The aliquots were sealed in 20 mL HS vials by means of aluminum crimped septa for analysis using an automated headspace analyzer.

Each sample vial was heated for 30 min at 50°C. Then the vial septum was punctured and the headspace gases were sampled

through a valving system and injected into a gas chromatograph. Organic volatile species were chromatographically separated on a gas chromatography column^a that was interfaced with a mass spectrometer operating in electron impact (EI) mode.

Characteristic GC peak retention times and EI MS fragmentation patterns allow characterization of the distributions of thermally volatile species from each personal care ingredient (see **HS-GC-MS Analysis sidebar**).

The peak areas analyzed from the individual ingredients, with and without zeolite, allow researchers to quantitatively compare the relative reduction of individual volatile components. The sum of all observed peak areas provides an overall assessment of total volatile reduction for that ingredient due to the zeolite adsorbent.

Results and Discussion

Quantitative comparison of HS-GC-MS patterns from the eight different personal care ingredients in **Table 47.1**, analyzed with and without the addition of 5% of the odor-adsorbing zeolite, showed various degrees of reduction for total volatiles. The total volatiles observed from each ingredient are compared as normalized percentages in **Table 47.2** and **Figure 47.1**.

Table 47.2. Percent of volatiles remaining after addition of 5% odor-adsorbing zeolite

Ingredient	% Volatiles Remaining
Castor oil	39
Avocado oil	24
Sulfur powder in olive oil	15
Essential fatty acids	25
Exthoylated soybean oil	32
Sulfur powder in surfactants	16
Sepia melan ink	4
1% Tea tree oil in mineral oil	93

^a The DB-624 capillary GC column is a product of Agilent Technologies.

HS-GC-MS Analysis

HS-GC-MS identifies a sampling, separation and characterization method that identifies and quantifies the components of complex mixtures. Since odors are volatile molecules detected by the olfactory system, HS-GC-MS is a preferred technique for odor analysis. Component analysis using computer-controlled instrumentation provides valuable chemical information on odors and other volatile species using relatively small sample sizes in minutes.

Headspace (HS) analysis is a particularly useful method for sampling low levels of volatile components from a bulk sample. HS conditions can be varied in an effort to optimize volatilization of compounds of interest into the atmosphere of a closed sample container.

Gas chromatography (GC) is a separations technique. The gaseous sample material is swept through a valving system via an inert carrier gas such as helium, and into a GC column where it interacts with a partitioning liquid coating in the column. As a mixture of molecular species passes through the column, the species are separated based on vapor pressure and relative affinity for the column liquid phase.

Generally, lower boiling species pass through the column in a shorter time; however this elution time, or retention time, is also affected by various interactions between the analyte and the liquid phase. Heating the column in a temperature-programmed oven facilitates elution of higher boiling species. At the end of the GC column is a detector that provides a chromatogram of intensity, e.g. total current, versus time. Under the experimental conditions, retention time is characteristic of a chemical component and signal intensity is a function of the amount of that particular compound.

Mass spectrometry (MS) is applied for qualitative and quantitative analysis of gas, liquid and solid materials, either for major composition or trace determination. For GC-MS, the gas from the GC enters the MS where it is first ionized and then analyzed. The most common ionization mode for GC-MS is electron impact (EI) that generally provides both molecular ions and fragment ions from breakdown of the energetic molecular ion. These ions are then separated according to their mass to charge ratio (m/z), for example by a quadrupole analyzer.

The plot of ion intensity versus m/z provides a mass spectrum that is characteristic of a particular molecule. The EI mass spectrum of a compound typically includes a molecular ion whose m/z equals the monoisotopic molecular weight (MW) of the particular molecule. The ionization method also induces fragmentation of the molecular ion to lower mass ions (and corresponding neutral losses) that provides chemical information about the molecular structure. For example, a fragment ion with m/z observed 15 units

below the molecular ion indicates the presence of a labile methyl group in the structure of the molecule. MS patterns are characteristic of compound structure and both were used to confirm the presence of known compounds and interpreted to help identify compounds of unknown structures.

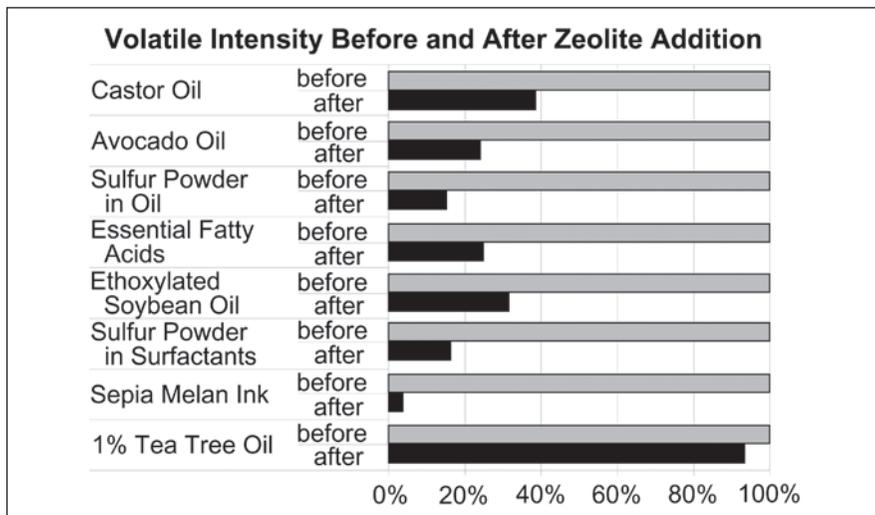


Figure 47.1. Intensity of volatiles in headspace before and after the addition of 5% odor-adsorbing zeolite

The data revealed substantial reductions in overall volatiles; e.g. 85% volatile reduction from sulfur powder in olive oil; 84% volatile reduction from sulfur powder in surfactants; and 96% volatile reduction from sepia melan ink. The pore size and the pore wall of the tested zeolite appear to be effective in trapping odor-causing chemicals.

HS-GC-MS can also provide information about absolute levels of volatiles from various ingredients, as well as specific chemical identification about individual volatile compounds or classes of compounds. More detailed results such as these can focus on more specific odor problems.

Sulfur powder in olive oil showed an 84% reduction of total volatiles with the addition of odor-adsorbing zeolite. HS-GC-MS (see **Figure 47.2**) also identified the observed volatile species as consisting of primarily sulfur-containing species and a series of aliphatic hydrocarbons.

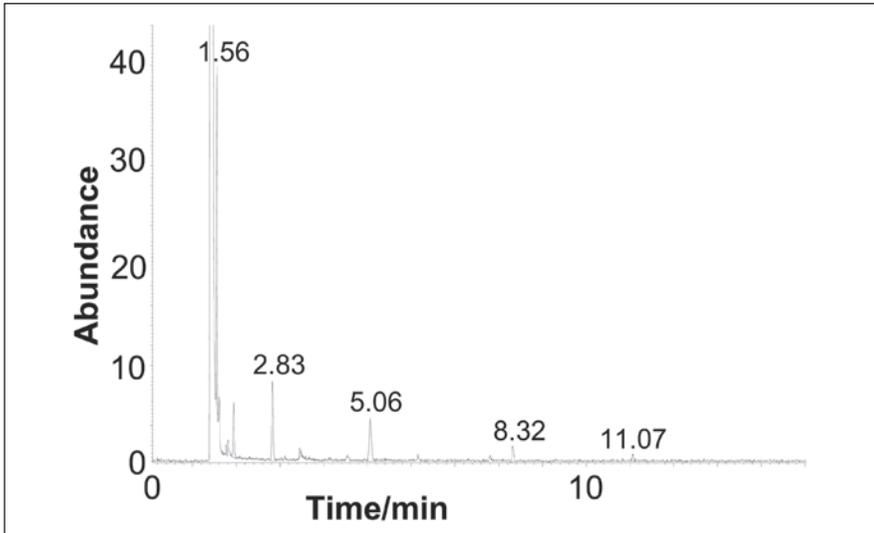


Figure 47.2. HS-GC-MS of sulfur powder in olive oil before odor-adsorbing zeolite is added

The major volatile peak is hydrogen sulfide (seen eluting at 1.56 min in **Figure 47.2**), which has the characteristic odor of rotten eggs. Hydrogen sulfide (H_2S) is identified in GC-MS by the mass to charge ratio (m/z) of its characteristic molecular weight (MW 34) with sulfur isotope (two mass units higher) and fragmentation pattern—hydrogen losses, one and two mass units lower—as seen in **Figure 47.3**.

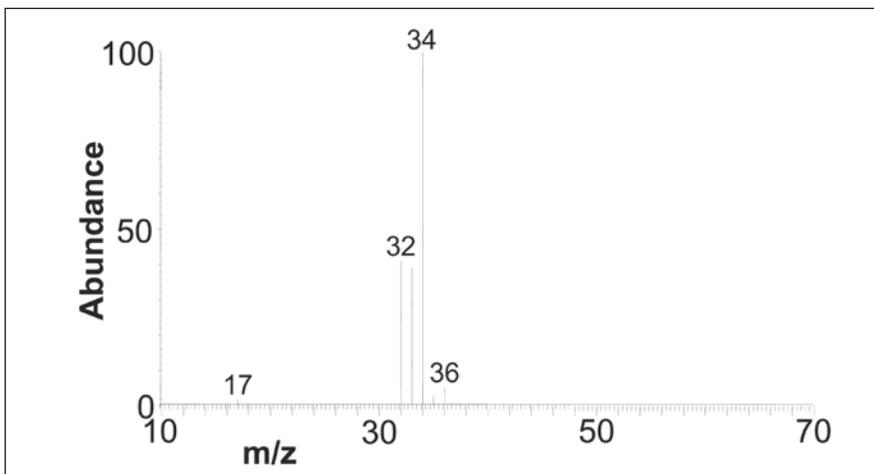


Figure 47.3. EI mass spectrum of hydrogen sulfide

The specific H_2S peak from sulfur powder in olive oil is significantly reduced by adding 5% odor adsorbing zeolite (see **Figure 47.4**).

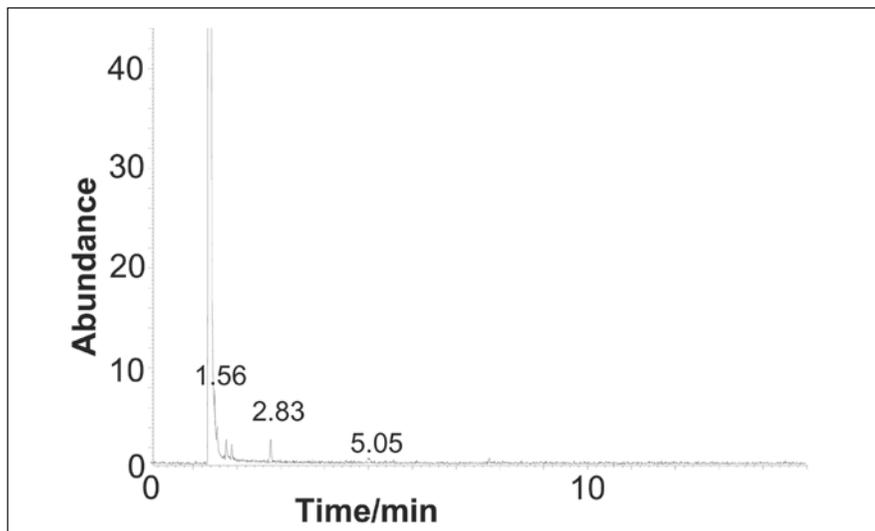


Figure 47.4. HS-GC-MS of sulfur powder in olive oil after 5% odor-adsorbing zeolite is added

The other sulfur-containing compounds and the aliphatic hydrocarbon species are also reduced, though the aliphatics, possibly associated with oil, do not produce the offensive odor of H_2S .

Ethoxylated soybean oil shows only a 68% reduction of total volatiles with the odor-adsorbing zeolite; however, again, HS-GC-MS (**Figure 47.5**) can specifically characterize the chemistry of the volatiles distribution.

The main volatiles from ethoxylated soybean oil consist of a series of aliphatic hydrocarbons and aldehydes, as well as some aromatic species. An intense peak eluting at 2.06 min is identified as acetaldehyde, which has a pungent odor. Acetaldehyde, probably from degradation of the ethoxylate, is characterized in its EI mass spectrum (see **Figure 47.6**) by MW 44 and fragmentation pattern, particularly including m/z 43 (M-H)⁺ and m/z 29 (M-CH_3)⁺.

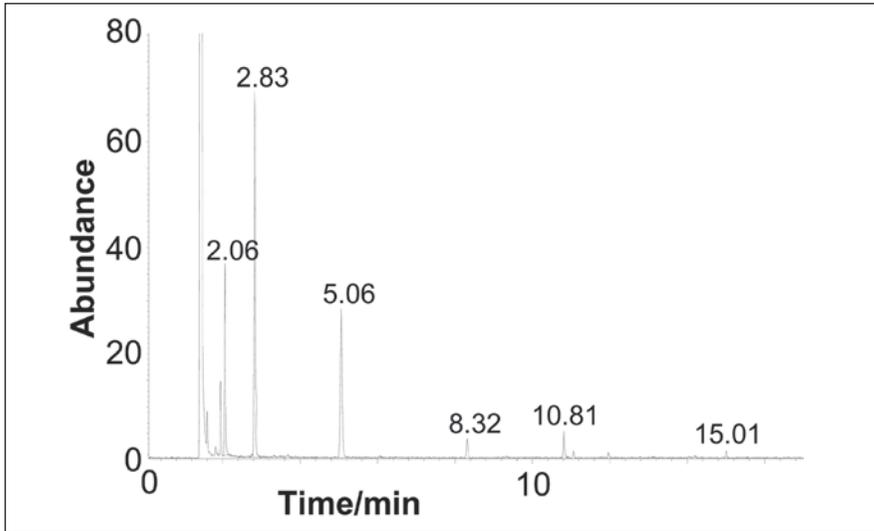


Figure 47.5. HS-GC-MS of ethoxylated soybean oil before odor-adsorbing zeolite is added

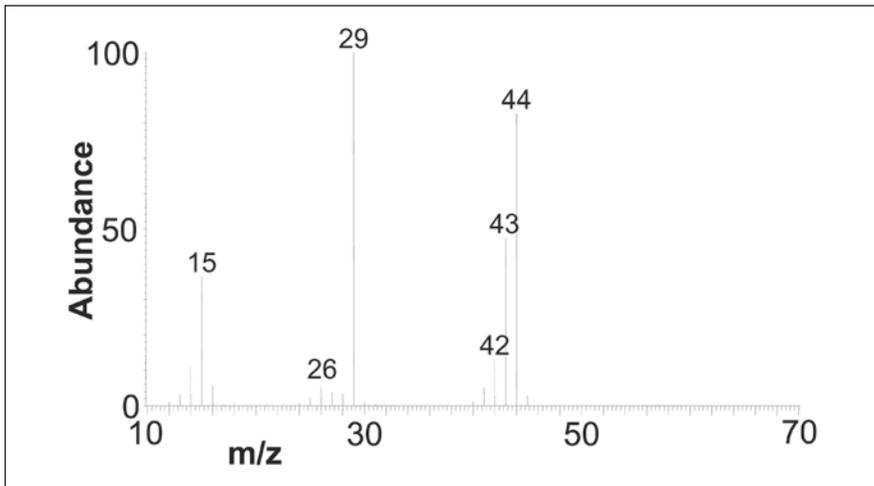


Figure 47.6. EI mass spectrum of acetaldehyde

The specific acetaldehyde evolution from ethoxylated soybean oil is substantially reduced by 5% the odor adsorbing zeolite (see **Figure 47.7**).

Other minor aldehydes and the hydrocarbons also appear reduced, essentially across the chromatogram.

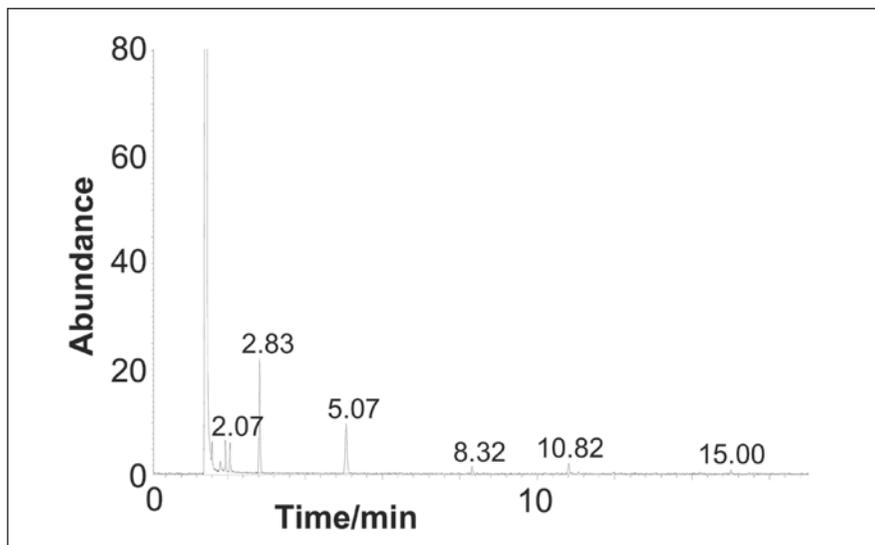


Figure 47.7. HS-GC-MS of ethoxylated soybean oil after 5% odor-adsorbing zeolite is added

Tea tree oil at 1% in mineral oil showed little overall reduction in total volatiles with the odor-adsorbing zeolite. Even at this dilution in mineral oil, the HS-GC-MS (**Figure 47.8**) of this ingredient shows very high absolute levels of volatiles.

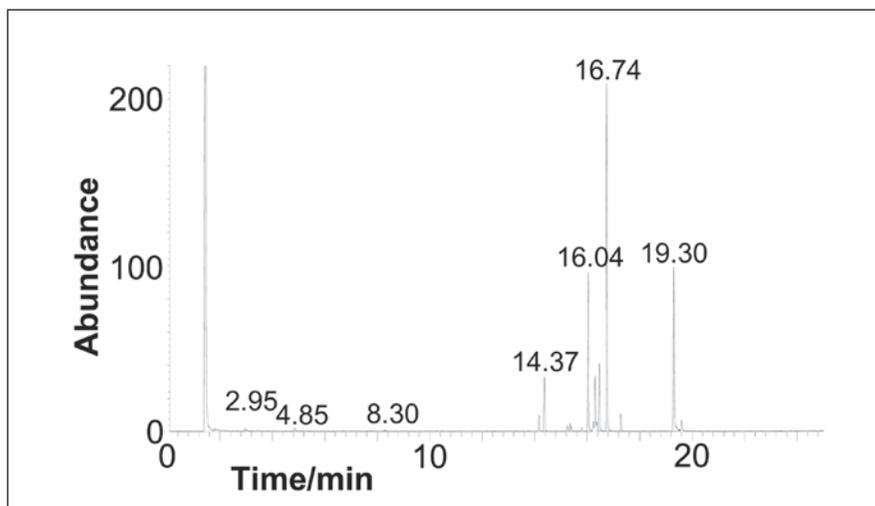


Figure 47.8. HS-GC-MS of 1% tea tree oil in mineral oil before odor-adsorbing zeolite is added

The dominant volatiles observed from tea tree oil are terpenes, particularly monoterpenes (MW 136). These major terpenes are not significantly affected by 5% odor adsorbing zeolite (see **Figure 47.9**).

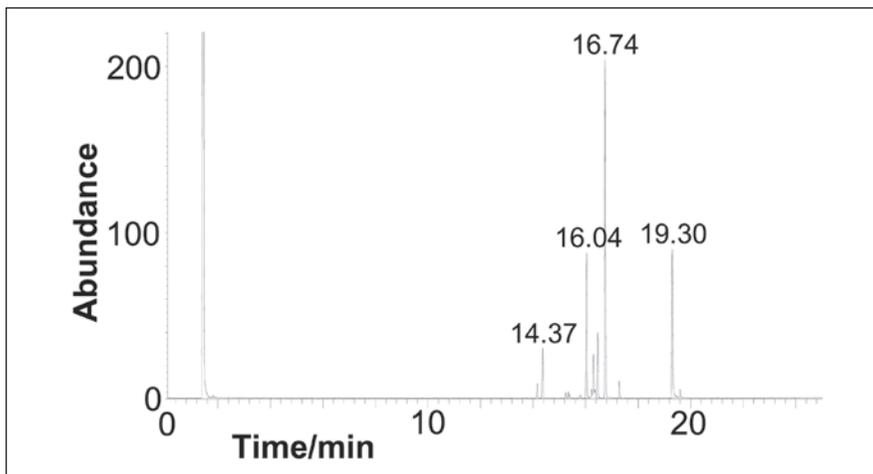


Figure 47.9. HS-GC-MS of 1% tea tree oil in mineral oil after 5% odor adsorbing zeolite is added

Chemicals in the terpene class are generally odorous. Some odors in this class of chemistry are generally considered pleasant, smelling like lemon; while others may or may not be so agreeable—i.e., characteristic of turpentine. However, an early eluting, lower boiling minor series that includes malodorous aldehydes is substantially removed from the tea tree oil volatiles with the addition of the odor-adsorbing zeolite (see **Figure 47.9**). This minor series may represent possible oxidative degradation by-product from the terpenes, for example, isobutyraldehyde (MW 72) eluting at 4.85 min, which has a pungent odor.

Conclusion

Addition of odor-adsorbing zeolites at a 5% level to personal care ingredients with recognized malodors can substantially reduce the total volatiles as measured by HS-GC-MS. Moreover, this technique can identify and quantify specific chemical species among total volatiles. In several examples, HS-GC-MS showed that odor-adsorbing zeolite substantially reduced particular chemical species known for malodors. However, in the case of tea tree oil, little or no reduction

was observed for the major distribution of terpenes. Nevertheless, in that case, the odor-adsorbing zeolite provided a relative reduction in a chemically separate, minor distribution of malodorous aldehydes.

These results suggest new opportunities for the formulator. A wider array of components can now be considered for use in formulations and less fragrance will be needed to mask undesirable odors. Finally, more formulations can now be made in fragrance-free versions.

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Selecting Silicone Surfactants for Personal Care Formulations

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KEY WORDS: *silicone surfactants, surface tension, wetting, foam, fatty surfactants*

ABSTRACT: *Interactions between a silicone surfactant and a fatty surfactant can alter the properties of a formulation. Here, the authors provide a case study of dimethicone copolyols in a shampoo.*

Silicone surfactants such as a dimethicone copolyol contain hydrophobic and hydrophilic portions enabling them to lower the surface tension of water.¹ The reduction of surface tension is a necessary first step in providing foam, emulsification, wetting and other surfactant properties. Each of these surfactant properties requires a molecule that lowers surface tension. Put another way, all molecules capable of foaming, emulsifying or wetting must be able to lower the surface tension, but not all molecules that lower surface tension provide these properties. The lowering of surface tension depends on the presence of hydrophilic and hydrophobic portions in the molecule. Additional surfactant properties depend on the structure of the molecule and its activity at the surface.

The function of dimethicone copolyol or any other silicone compound alone in aqueous solution may be of academic interest.

However, it is of limited interest to a formulator because formulations are never simply water and dimethicone copolyol. The key to formulation is the interaction between the surfactants and other ingredients that alter the performance of the surfactants at the surface. There are interactions between different formulation components and understanding them and optimizing them for a given effect is key to formulation success.

This work is intended to educate cosmetic chemists in the chemistry of dimethicone copolyols and their potential effects in surfactant systems, such as shampoos or body washes. It will investigate some of the interactions between selected dimethicone copolyol compounds and a fatty surfactant and how they alter the properties of a solution or formulation. The structures of materials chosen for evaluation are shown in **Figure 48.1**. Sodium lauryl sulfate (SLS) and sodium laureth-2 sulfate (SLES-2) were chosen because they are commonly used in personal care products. **Table 48.1** outlines the molecular weight information, the INCI name and the shorthand used to designate the compounds in this chapter.

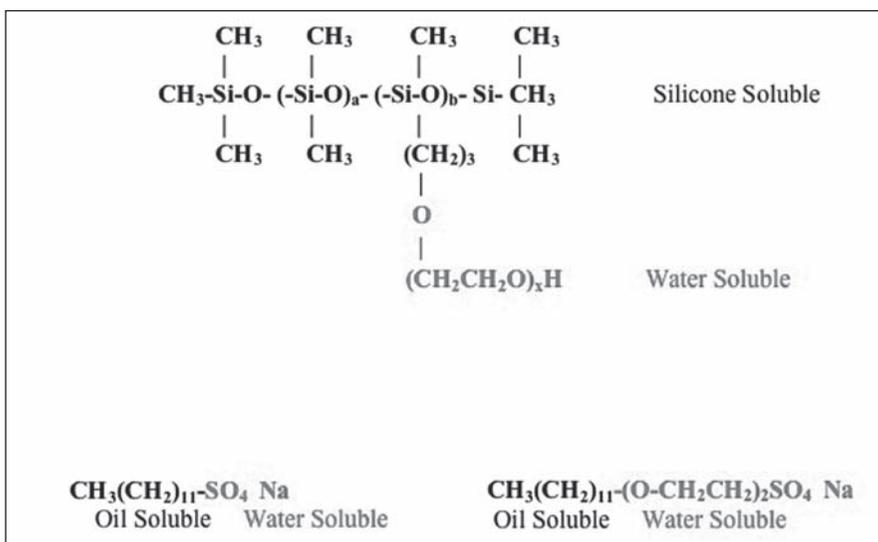


Figure 48.1. Compounds evaluated: a) dimethicone copolyol, b) SLS and c) SLES-2 sulfate

Table 48.1. Compounds evaluated

Material	Approx MW	INCI
SLS	320	Sodium lauryl sulfate
SLES-2	410	Sodium laureth-2 sulfate
DMC-1	700	PEG-8 dimethicone
DMC-2	5800	PEG-8 dimethicone
DMC-3	2500	PEG-8 dimethicone
DMC-4	1620	Bis-PEG-8 dimethicone

Surface Tension in Aqueous Solutions

Aqueous solutions were prepared with the various materials at 1% by weight. The surface tension of each material was determined using a tensiometer^a.

Table 48.2 lists the results and clearly shows that the sulfated fatty alcohol surfactants have a surface tension in the range of 30–32 dynes/cm². The silicone surfactants have lower surface tension, in the range of 21–28 dynes/cm². The variation of surface tension within the class of silicone compounds is noteworthy. There has been a tendency to make generalizations that all silicone surfactants have essentially identical surface tension values. Clearly, this is not

Table 48.2. Surface tension of selected materials at 1% in aqueous solution

Material	Dynes/cm ²
SLS	31.2
SLES-2	31.0
DMC-1	21.3
DMC-2	27.3
DMC-3	21.3
DMC-4	24.6

^a K100SF Tensiometer, Kruss GmbH

the case. As the silicone molecule contains less and less silicone, the surface tension becomes more like that of a fatty surfactant.

The surface tension is determined by the orientation of the surfactant molecule at the air/water interface. More specifically, surface tension is determined by the orientation of the organic functional groups on the surfactant molecule. These groups include silicon-containing portions, methyl groups, methylene groups and polyoxyalkylene groups. Action at the interface depends on the group that predominates at the surface when the molecule is in the lowest free energy conformation. The silicone portion of the molecule has an abundance of methyl groups, which makes the surface tension lower. The fatty surfactant groups have an abundance of methylene groups ($-\text{CH}_2-$), which makes the surface tension higher.

It is important to note that all silicone surfactants do not have the same low surface tension. Molecules that have long chains of ethylene oxide or propylene oxide have surface tensions like fatty surfactants, not silicone surfactants. As will be shown, the performance in formulations is complex; it depends upon the other components present.

Surface Tension in Binary Mixed Systems

Water is a unique material in that it orientates itself by hydrogen bonding. A hydrogen bond is a special type of dipole-dipole force that exists between an electronegative atom and a hydrogen atom bonded to another electronegative atom. Hydrogen bonding results in an orientation of molecules that have the lowest energy in the solution. This lowest energy state is favored. It results in the high surface tension of water. The reason oil and water separate from each other is that the two separate phases are at lower energy than when they are together. Simply stated, the number of hydrogen bonds between water molecules that need to be disrupted to keep oil in a water phase results in the separation of the phases being the lowest energy.

Surfactants (fatty or silicone) experience hydrogen bonding in water. If there are several different surfactant types in water the interaction becomes more complicated albeit still driven by achieving the lowest energy.

The combination of SLS or SLES-2 with the various dimethicone copolyols suggests numerous possible interactions:

- Interactions from incompatibilities of the silicone, fatty and water-soluble domains in the surfactant. As with the oil and water interaction just described, these domains are incompatible with each other.
- Interactions from hydrogen bonding occurring between polyoxyalkylene domains of one molecule interacting with polyoxyalkylene domains or polar domains on another molecule.

The nature of all of these interactions collectively determines the surface tensions of the various blends.

DMC SLES-2 systems: Blends of SLES-2 at 95%, 90% and 50% with each DMC were prepared in solution with 1% of the blend and evaluated for surface tension. **Table 48.3** shows the results. Only DMC-1 had an impact on the surface tension of the solution. Of the four DMCs tested, DMC-1 had the lowest molecular weight. The interaction between the various functional groups in a formulation and the stability of the resulting complexes is critical to functionality of the formulation. If lowering surface tension is the goal of the addition, DMC-1 is the only DMC that will effectively accomplish the goal.

DMC SLS systems: Blends of SLS at 95%, 90% and 50% with each DMC were prepared in solution with 1% of the blend and evaluated for surface tension. **Table 48.3** shows the results. As in the case of SLES-2, only DMC-1 had an impact, albeit slight, on the surface tension of the solution.

Foam and Wetting in Aqueous Systems

Table 48.4 shows the Draves wetting times for the neat surfactants at 1% in water. SLS and SLES-2 are both good wetting materials and good foaming compounds. DMC-1 is a good wetter and a fair foaming agent. DMC-2 and DMC-3 are neither good wetting agents nor good foaming compounds.

Table 48.3. Effect on surface tension, wetting and foam in 1% surfactant solutions when the surfactant is a blend of a dimethicone copolyol surfactant and a fatty surfactant, and the sulfate is 95%, 90% or 50% of the blend

Property	DMC	Fatty surfactant					
		SLES-2 95%	SLES-2 90%	SLES-2 50%	SLS 95%	SLS 90%	SLS 50%
	DMC-1						
Surface tension (dynes/cm ²)		30.3	29.9	26.7	30.3	30.0	28.1
Draves (sec)		4.0	4.4	5.3	3.5	3.0	7.7
Ross Miles (mm)							
Immediate		175	170	150	175	165	155
1 min		165	160	135	160	150	140
5 min		160	150	130	155	145	135
	DMC-2						
Surface tension (dynes/cm ²)		30.9	30.9	30.9	30.9	31.0	31.0
Draves (sec)		3.7	4.9	7.7	3.5	3.8	9.8
Ross Miles (mm)							
Immediate		185	180	150	170	170	160
1 min		170	170	140	150	150	140
5 min		160	160	135	145	150	135
	DMC-3						
Surface tension (dynes/cm ²)		30.6	30.6	30.6	31.0	30.9	31.0
Draves (sec)		4.5	4.6	12.9	3.7	4.8	14.3
Ross Miles (mm)							
Immediate		180	170	155	185	180	165
1 min		165	160	145	160	160	145
5 min		160	150	140	150	155	135
	DMC-4						
Surface tension (dynes/cm ²)		30.3	30.3	30.3	30.4	30.5	30.5
Draves (sec)		3.6	3.7	7.0	2.4	3.0	6.6
Ross Miles (mm)							
Immediate		170	170	145	180	180	150
1 min		150	155	120	155	160	135
5 min		140	150	40	145	155	130

Table 48.4. Draves wetting and Ross Miles foam for neat surfactants at 1% in water

Property	SLES-2	SLS	DMC-1	DMC-2	DMC-3	DMC-4
Draves (sec)	4.8	3.8	8.4	82.7	28.3	13.4
Ross Miles (mm)						
Immediate	170	180	115	105	100	120
1 min	155	165	110	95	80	115
5 min	150	150	110	85	65	105

Foam and Wetting in Binary Mixed Systems

DMC and SLES-2 systems: Because SLES-2 is a high foaming surfactant, it was expected that the addition of DMC to SLES-2 would not improve foam. In fact, that is what happened. At concentrations of up to 10% added DMC, there was no negative effect upon foam or wetting with all blends of SLES-2. The foam was adversely effected with 50% added DMC. **Table 48.3** shows the results.

DMC and SLS systems: At all concentrations of added DMC, there was no negative effect upon foam or wetting with all blends of SLS. However, DMC-4 improved wetting in SLS systems.

Table 48.3 shows the result.

Simple Shampoo System

Materials and methods: The effect of DMC compounds on simple shampoos was studied using **Formula 48.1**. The results are shown in **Table 48.5**. Conditioning on hair swatches was evaluated on a scale from 1 (worst) to 5 (best).

Results and discussion: The selection of a silicone to add to a shampoo formulation—even a very simple one—depends upon the effect desired. The appropriate silicone can be determined only in the formulation and can have no relationship to the properties of the silicone in solution alone.

Formula 48.1. Simple shampoo

Water (<i>aqua</i>)	47.0% w/w
Sodium laureth-2 sulfate	40.0
Cocamidobetaine	10.0
Cocamid DEA	2.0
Dimethicone	<u>1.0</u>
	100.0

Table 48.5. Draves wetting, Ross Miles foam and conditioning for dimethicone copolyol in a sodium laureth-2 sulfate shampoo (Formula 1)

Property	DMC-1	DMC-2	DMC-3	DMC-4
Draves (sec)	8.4	82.7	28.3	13.3
Ross Miles (mm)				
Immediate	115	105	100	120
1 min	110	95	80	115
5 min	110	85	65	105
Conditioning	1	4	3	2

Table 48.5 makes the following points for this simple formulation:

- For wetting effects, DMC-1 provides the best results;
- For foaming effects, DMC-4 provides the best results; and
- For conditioning effects DMC-2 provides the best results.

These results would not have been predicted from the data generated by evaluating either surfactant in water. The finished formula's raw materials, taken as a whole, are critical to determining the effectiveness of adding the silicone. There are significant interactions between surfactants in a formulation that alter the properties obtained when formulated together. The cosmetic formulation is more than merely the sum of its ingredients.

Conclusion

The selection of dimethicone copolyol for inclusion in hair care products is a complex process. The use of INCI names alone will be fruitless for picking the proper dimethicone copolyol for use in formulations. Likewise, the use of dimethicone copolyol's properties themselves in water to predict the functionality in formulation can be misleading. This is because there are various interactions between the dimethicone copolyol and the other surface active agents in the formulation. The formulation itself needs to be tested to determine if the formulation performs as desired.

The best test will be in the salon because in the final analysis consumer perception is the key to formulation performance. Dimethicone copolyols can be engineered to be formulator-friendly and provide the desired effect(s) in formulations.

It also needs to be noted that the compounds studied in this project are nonionic silicone compounds, an important but limited class of materials. Improved conditioning can be obtained by working complexes of anionic and cationic silicones, designed specifically for that application.

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Anionic/Cationic Complexes

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KEY WORDS: *foam, anionic/cationic interaction, quats, SLS, SLES-3, compatibility*

ABSTRACT: *Understanding the interactions of surfactants is important to optimizing their properties in formulations. The author describes how the anionic/cationic interaction is critical to properties such as foam, viscosity, conditioning properties and minimal irritation.*

There have been a multitude of approaches to the formulation of hair care products that provide multifunctional benefits. This partially is because the various functions expected from products do not coexist well in one formulation. Consumers demand cleansing, viscosity, foam, wet conditioning (antistat and wet comb) and longer-term conditioning (dry-property conditioning). It would be ideal if a universal surfactant existed that had just the right amount of each property so formulation would be easy, but there is none. Any step toward increasing the level of understanding related to the interaction of surfactants and providing optimized properties in formulation is desirable.

One major area in which interactions are critical is the anionic/cationic interaction. Most formulators of 2-in-1 shampoos understand that indiscriminate mixing of anionic and cationic materials can result in undesired insoluble “gunky” solids. Anionic and cationic materials that are incompatible when mixed together have been classified as *hard complexes*. As the expression implies, the

cationic and anionic compounds possess properties that when added together form insoluble complexes such as salts. In contrast, anionic and cationic compounds that can be mixed over a wide range of ratios and provide a clear, viscous, high-foaming complex are defined as *soft complexes*. Optimized soft complexes have many desirable properties including high levels of foam, viscosity build without alkanolamides, conditioning properties, and low levels of eye and skin irritation.

The terms used for quats and anionic materials are an adaptation of the work of R. G. Pearson used to describe acids and bases. Pearson proposed that “hard acids bind strongly to hard bases and soft acids bind softly to soft bases;”¹ the anionic and cationic interactions of surfactants are exactly analogous.

Structural changes can “soften” cationic surfactant molecules, making them more compatible with anionic systems. The compatibility of specific quats with sodium lauryl sulfate (SLS) and sodium laureth-3-sulfate (SLES-3), the foam properties of the combinations with SLS and SLES-3, and the substantivity of these combinations with SLS and SLES-3 are key factors in understanding the function of conditioners.

In order to understand the interaction, several quats were studied (see **Figure 49.1**) in combination with SLS and SLES-3 (see **Table 49.1**). The entire work is published.²

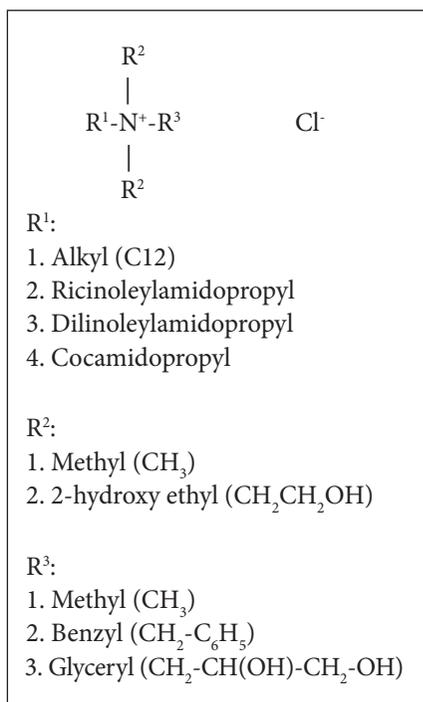


Figure 49.1. Several quats were studied.

Table 49.1. Compounds studied

Name	R1	R2	R3	Description
AMB	Alkyl (C12)	CH ₃	Benzyl	Coco dimethyl benzyl ammonium chloride
AME	Alkyl (C12)	CH ₂ CH ₂ OH	CH ₃	Coco di-2 hydroxyethyl methyl ammonium chloride
AMG	Alkyl (C12)	CH ₃	Glyceryl	Coco dimethyl glyceryl ammonium chloride
AMM	Alkyl (C12)	CH ₃	CH ₃	Coco tri-methyl ammonium chloride
AEB	Alkyl (C12)	CH ₂ CH ₂ OH	Benzyl	Coco di-2 hydroxyethyl benzyl ammonium chloride
AEG	Alkyl (C12)	CH ₂ CH ₂ OH	Glyceryl	Coco di-2 hydroxyethyl glyceryl ammonium chloride
CaMB	Castor Amido	CH ₃	Benzyl	Ricinoleylamidopropyl dimethyl benzyl ammonium chloride
CaMG	Castor Amido	CH ₃	Glyceryl	Ricinoleylamidopropyl dimethyl glyceryl ammonium chloride
DMB	Dimer Amido	CH ₃	Benzyl	Dilinoleylamidopropyl dimethyl benzyl ammonium chloride
DMG	Dimer Amido	CH ₃	Glyceryl	Dilinoleylamidopropyl dimethyl glyceryl ammonium chloride
DMM	Dimer Amido	CH ₃	CH ₃	Dilinoleylamidopropyl trimethyl ammonium chloride
MMB	Cocamido	CH ₃	Benzyl	Cocamidopropyl dimethyl benzyl ammonium chloride
MMG	Cocamido	CH ₃	Glyceryl	Cocamidopropyl dimethyl glyceryl ammonium chloride
MMM	Cocamido	CH ₃	CH ₃	Cocamidopropyl trimethyl ammonium chloride

Test Methodology

A determination of compatibility of a variety of quats with the anionic surfactants, SLS and SLES-3 was made. A 100g sample of 10% active solution of SLS and SLES-3 was prepared, as was one for each of the quats evaluated. The 100g solution of sulfate was added to a 250-ml beaker and under good agitation the solution was titrated with the 10% quat solution. The endpoint was the first sign of (a) an insoluble complex, (b) haziness, or (c) viscosity build.

Results

The quats that were compatible with SLS or SLES-3 are shown in **Table 49.2**. All others in the study group were incompatible. The use of the proper quat with a given anionic will allow the formulator to maximize the performance of formulations.

Table 49.2. Soft quats—gel formers

Quat Sample	Soft quats in SLS (viscosity of gel)	Quat Sample	Soft quats in SLS-3 (viscosity of gel)
MMB	14,000	AME	7,000
MMM	13,400	DMM	6,200
DMM	6,000	MMM	50,000
CaMB	1,000	CaMB	1,000
MMG	19,200	AMG	1,000
DMG	12,000	MMB	9,800
		MMG	40,000
		DMG	6,800
		AEG	1,000
		CaMG	1,000

Foam Testing

The solutions shown above were cut with water to 1% active and evaluated in cylinder shake foam tests. The foam data is shown in **Table 49.3**.

Conclusions

Quaternium compounds can be classified as hard or soft by their ability to form gelled systems with anionic systems. Cationic systems that form a gel at near stoichiometric amounts are classified as *soft* quats; those that form precipitates of haze without appreciable viscosity build-up are classified as *hard* quats. Soft quats can produce foam in the systems they gel, albeit at levels below the volume of foam generated by the anionic, per se.

Table 49.3. Foam heights (cylinder shake foam test)

Quat sample	Foam height (ml) (SLS)	Foam height (ml) (SLES-3)
AMB	Does not foam	Does not foam
AME	190	90
AMG	500	400
AMM	600	500
AEB	300	200
AEG	200	100
CaMB	250	150
CaMG	200	100
DMB	400	300
DMG	300	200
DMM	250	150
MMB	400	300
MMG	400	300
MMM	400	300
Control (no quat)	600	450

Quaternium compounds titrated with SLES-3 produced greater viscosities with amido quats. The exception was amido quats containing a benzyl group that exhibited a low viscosity in SLES-3.

Good foaming results also were seen with a number of complexes. Additional work needs to be performed to expand the testing to a variety of compounds including silicone-based compounds.

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Amphoteric Anionic Interactions

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KEY WORDS: *surfactant interactions, anionic surfactants, amphoteric surfactants, foam, viscosity, salt curve, betaine*

ABSTRACT: *A study of interactions between anionic surfactants and amphoteric surfactants in solution demonstrates that betaines and anionic surfactants interact to have positive effects on viscosity, foam and the salt curve.*

The interaction that occurs when combining the raw materials used in the formulation of personal care products is more than the sum of the properties of each of the raw materials. There are a number of interactions that include formation of self-assembling complexes. These complexes can either strengthen or weaken the functional attributes of the formulation. Because most of today's high performance formulations are very complex and contain a plethora of ingredients, it is difficult to predict the effect of changes in those formulations. In an attempt to understand these interactions, a simple system is used. The results of these interactions then can be used to help formulate more effective products.

Surfactants

Surface active agents, commonly called surfactants, can be divided into groups depending upon the charge on the organic portion of the molecule.¹ According to such a scheme, surfactants are classified

as anionic, cationic, nonionic or amphoteric, with the charges as shown in **Figure 50.1**.

These materials are used in a variety of formulations and rarely are used alone. A look at a typical shampoo bottle will show numerous materials that all interact, in many instances producing viscosity-altering nanostructures. It is the nature of these

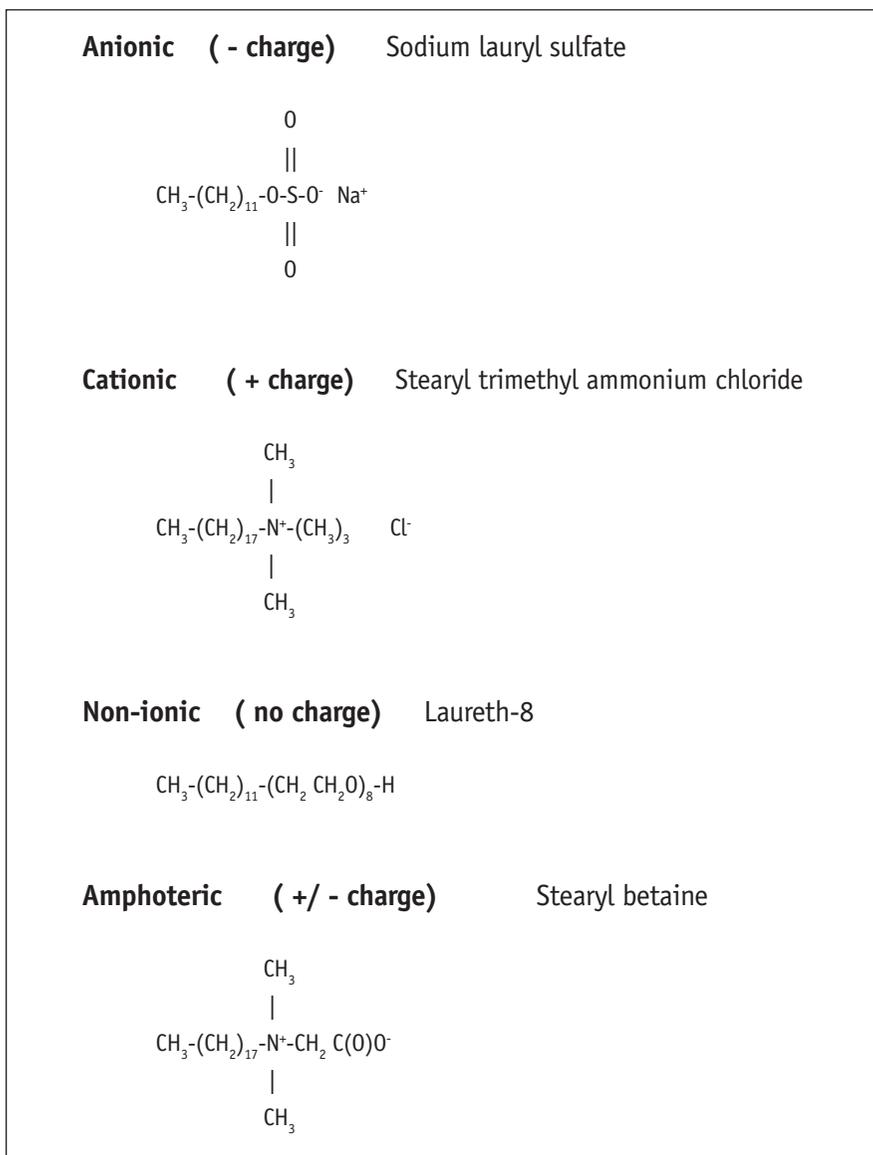


Figure 50.1. Surfactant classes, according to charge

interactions that make formulations work or fail. Consequently, it is helpful to understand the interactions between the groups. More than two decades ago, Ken Klein suggested the possibility of maximizing the effect of the interaction. The present work results from an attempt to understand these interactions.

Materials with anionic-cationic interactions: A common misunderstanding is the interaction between anionic and cationic materials. Formulators mixed stearalkonium chloride and sodium lauryl sulfate and observed the white, pasty gunk that results. The nature of such interactions and maximizing the effect in formulation is an important aspect of formulation science.

The interaction of cationic and anionic surfactants were investigated in a previous study.² In that work, two types of quats, one hard and the other soft, were defined. Hard quats were those products that were incompatible with anionic surfactants. On the other hand, soft quats were defined as those quats that formed thick, clear, high-foaming complexes with anionic surfactants. There were differences in the hardness of the anionic surfactants, with sodium laureth-2-sulfate (SLES-2) being more compatible with quats than sodium lauryl sulfate (SLS).

The nature of water and the hydrogen bonding that occurs between molecules of water makes water a unique material that is essential to life as it is known. The interaction of ionic surfactants in dilute aqueous solution is important in formulation and utilization of personal care products.

Surfactants that possess charges can be selected and combined to form self-assembling units. These units are important to the functionality of these materials, forming useful nanostructures. The first step is to engineer the polymer using well-known techniques. The driving force for assembly is obtaining the lowest free energy in the system. Many times the lowest free energy state is not the least-ordered, but rather the most-ordered system. This particularly is true in aqueous systems where oil floats on water.

Because anionic and cationic materials have an opposite charge, they will attract each other and form a salt complex. It is the nature of this complex, rather than the properties of the surfactants themselves, that determines how the formulations function. As ionic

materials are added to water, opposite charges attract and the same charges repel. As the concentration of point charges increases, the solution becomes so ordered that: (a) the solubility product of the salt is exceeded and a precipitate occurs, or (b) the viscosity of the solution increases, or (c) the complex becomes insoluble. The nature of this interaction is the focus of the present study.

The current authors distinguish between two types of complexes that are made of anionic and cationic surfactants in aqueous solution. Those that thicken and remain clear are identified by the term *soft complexes*, while insoluble complexes are referred to as *hard complexes*. The chemical structure of each determines the hardness or softness of the complex. As a 10% active cationic surfactant is titrated into a 10% active solution of an anionic, such as SLS, more and more of the cationic surfactant complexes with the anionic. As the number of anionic and cationic species becomes equal, the number of interaction complexes will be greatest and at the same point, the concentration of uncomplexed surfactant becomes lowest. For this reason, the highest viscosity of the blends of anionic and cationic surfactant occurs at roughly equal amounts.

Materials with anionic-amphoteric interactions: The objective of this chapter is to expand the study of interactions to include several amphoteric surfactants, including betaines, amido betaines, and aminopropionate surfactants. Because amphoteric surfactants have both a positive and negative charge on the structure, the interactions were thought to be somewhat different than the interactions between quats, which have only a positive charge on the structure.

The Surfactants

To study the interactions between anionic and amphoteric interactions, the surfactants chosen were the most traditional surfactants in the cosmetic industry. They are listed with their abbreviations and CAS numbers in **Table 50.1**. All surfactants were obtained from a commercial supplier^a.

The anionic surfactants chosen were SLS and SLES-2 (**Figure 50.2**). Many amphoteric surface active agents could be evaluated in

^a Colonial Chemical, South Pittsburg, Tenn.

Table 50.1. Surfactants used in this study of interactions

Charge	Description	Abbreviation	CAS #
Anionic	Sodium lauryl sulfate	SLS	151-21-3
Anionic	Sodium laureth-2 sulfate	SLES-2	3088-31-1
Amphoteric	Cocamidopropyl betaine	CAB	61789-40-4
Amphoteric	Dimer amido propyl betaine	DAB	(pending)
Amphoteric	Cetyl betaine	PB	693-33-4
Amphoteric	Lauric myristic amido betaine	LMAB	4292-10-8
Amphoteric	Lauramphopropionate	LP	14960-06-6
Amphoteric	Coco betaine	CB	68424-94-2

the study. For simplicity, the ones chosen were betaines and propionates (**Figure 50.3**), two classes of compounds that are important to the personal care market. Candidates were chosen in each class.

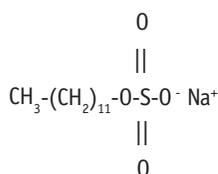
The protocol used was one in which surfactants were diluted to 10% actives in order to evaluate the interactions.

A Viscosity Study

Methodology: In the protocol used, the surfactants first were diluted to 10% before evaluating the interactions. The protocol calls for these steps:

1. Prepare a 10% solution of anionic.
2. Prepare a 10% solution of amphoteric.
3. Prepare blends at 25:75, 50:50 and 75:25 by weight.
4. Run viscosity at 60 rpm, 30 rpm and 6 rpm using a Brookfield viscometer LV Spindle 4.

Sodium Lauryl Sulfate (SLS)



Sodium Laureth-2-Sulfate (SLES-2)

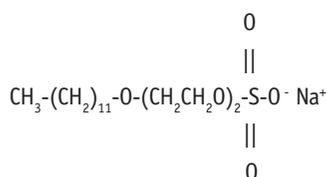


Figure 50.2. Structures of tested anionic surfactants

Results: The results are shown in **Tables 50.2** and **50.3**. No viscosity build was noted at any ratio using LP and either SLS or SLES-2.

Conclusions: There are significant differences in the degree of interactions occurring between anionic surfactants and amphoteric surfactants depending upon the nature of the amphoteric surfactant studied. Amino propionates exhibit no interaction. Alkyl betaines exhibit some interaction, but can become insoluble as the concentration approaches stoichiometric. Amido-betaines have strong interactions and better solubility, enabling production of gels.

Likewise, there are differences in the degree and direction of the interactions that occur between amphoteric surfactants and SLS or SLES-2. The effect of going from SLS to SLES-2 is variable and determined by the exact solubility of the amphoteric evaluated.

Table 50.2. Viscosity of SLS blends at selected blend ratios and RPM

Blend	RPM	Viscosity at selected blend ratios		
		25:75	50:50	75:25
CAB:SLS	60	5	5,850	3,950
	30	4	12,000	7,900
	6	4	31,500	39,500
DAB:SLS	60	5	4,800	2,000
	30	4	8,100	2,800
	6	4	14,000	6,000
PB:SLS	60	7		9,650
	30	7	SPLIT	11,400
	6	7		23,000
LP:SLS	60	4	4	4
	30	4	4	4
	6	4	4	4
LMAB:SLS	60	6	4,100	57
	30	6	6,900	57
	6	6	14,500	55
CB:SLS	60	13	218	367
	30	13	361	365
	6	20	1,250	375

Table 50.3. Viscosity of SLES-2 blends at selected blend ratios and RPM

Blend	RPM	Viscosity at selected blend ratios		
		25:75	50:50	75:25
CAB:SLES-2	60	11	2,550	10
	30	10	3,200	9
	6	10	3,500	9
DAB:SLES-2	60	6	1,700	3,000
	30	4	3,800	5,100
	6	4	14,500	18,500
PB:SLES-2	60	6.5	1,200	5,430
	30	5	1,620	7,160
	6	5	3,400	12,000
LP:SLES-2	60	10	10	10
	30	10	10	10
	6	10	10	10
LMAB:SLES-2	60	9	4,100	120
	30	7	6,700	120
	6	5	13,500	100
CB:SLES-2	60	367	3,700	7
	30	7,200	7,200	7
	6	28,800	28,800	2

Table 50.4. Complex interactions

Property	Insoluble complex	Marginally soluble	Soft complex	Soluble complex
Viscosity	Low	Some viscosity	High	Low
Appearance	Solid chunks	Milky	Clear	Clear
Example	PB:SLS (50:50)	PB:SLS (25:75)	DAB:SLES-2 (50:50)	LP:SLS-2 (50:50)

The nature of the interaction causes the observed differences in clarity and viscosity. The interactions can be classified as shown in **Table 50.4**.

A Foam Study

Because in all instances the 50:50 blends had the highest viscosity, a 1% active solution of the 50:50 blends was subjected to the Ross-Miles Foam Height test^a. For example, the 50:50 blend of CB:SLS produced a foam height of 250 mm, 225 mm and 185 mm at the immediate, 1 min and 5 min times, respectively, and a Draves wetting score of 8.8 sec. Results for the other nine blends tested and for SLS and SLES-2 alone are available at www.cosmeticsandtoiletries.com. **Table 50.5** summarizes the results on the initial foam heights.

It was a surprise that SLS and SLES-2 appear near the bottom of the list, meaning that including betaine had a synergistic effect upon the foam. Even the combination with lowest foam was comparable to SLS. This result means there is a wide possibility to formulate products that have outstanding foam using blends of anionic and amphoteric surfactants. It also implies that the complex so formed has different foam properties than the SLS or SLES-2 alone. This explains why betaines are so commonly used in personal care formulation. They improve foam, an attribute that is very important to the consumer.

The Draves wetting test measures the amount of time it takes for a 1% solution of surfactant to cause a cotton skein to sink. Consequently, the lower the time required to sink, the better the wetting.

The wetting times of the blends (**Table 50.6**) vary quite a bit depending upon the betaine used. The addition of all but the DAB material improved the wetting time of both SLS and SLES-2. The DAB products are much slower in terms of wetting time. This is not unexpected, because they are the most substantive products evaluated and provide outstanding conditioning not seen in combinations of anionic and other betaines.

^a The Ross-Miles Test is a standardized method (ASTM 1173) issued by an international testing company, ASTM International, West Conshohocken, Penn. USA.

**Table 50.5. Initial foam
(from highest to lowest)**

Material	Foam (mm)
CB:SLS	250
CB:SLES-2	200
CAB:SLS	200
CAB:SLES-2	200
LMAB:SLS	195
PB:SLES-2	190
LMAB:SLES-2	180
SLS	180
SLES-2	175
DAB:SLS	175
DAB:SLES-2	160

**Table 50.6. Wetting
(from fastest to slowest)**

Material	Wetting (sec)
LMAB:SLS	2.9
CAB:SLS	3.0
PB:SLES-2	3.1
CAB:SLES-2	3.3
CB:SLS	4.0
SLS	4.8
CB:SLES-2	8.8
LMAB:SLES-2	12.4
SLES-2	12.4
DAB:SLS	39.5
DAB:SLES-2	42.1

A Salt Addition Study

A standard method employed in formulation of cosmetic products is a so-called salt curve. Salt is added in increments and the viscosity is tracked with each add. There will be an increase, but at a certain point the maximum viscosity will be reached, then the viscosity will drop. This is why the addition of water to a shampoo formulation might actually increase viscosity. Two salient attributes of the salt curve are important: the maximum viscosity and the amount of salt needed to reach it.

Procedure: Salt additions were made to the 10% solid blends consisting of 75% anionic and 25% betaine to determine peak viscosity. This ratio was chosen for two reasons: a) the viscosity of the 50:50 blend already was high in most instances, and b) the 25% amphoteric : 75% anionic blend was more interesting commercially in terms of formulation cost.

Increments of 0.5% salt were added at a time to a 10% active solution of the specified blend. The viscosity was measured with a viscometer^a after every addition at 22.0±0.3°C.

Rheology of Complex

While the peak viscosity is a measure of the interaction of the anionic and amphoteric surfactants, the resistance to shear is a measure of the stability of the complex.

The term *Newtonian* describes a material in which a linear relationship exists between shear stress and shear rate. In Newtonian fluids (typically water and solutions containing only low-molecular-weight material) the viscosity is independent of shear strain rate.

The term *pseudoplastic* is used to describe a material that experiences a decrease in viscosity with increasing shear rate (a process called *shear-thinning*). Pseudoplastic materials instantaneously decrease in viscosity with increase in shear strain rate (also called *flow*) and are therefore easier to pump and mix. They are shear-thinning. This often is a consequence of high-molecular-weight molecules being untangled and oriented by the flow. Generally this behavior increases with concentration.

A specific type of pseudoplastic material is a thixotropic liquid. It exhibits a time-dependent response to shear strain rate over a longer period than that associated with changes in the shear strain rate. These materials may liquefy on being shaken and may or may not solidify when the shaking has stopped.

The term *dilatant* is used in common practice to refer to a material that increases in viscosity as shear rate increases (a process called *shear-thickening*).

Results: Table 50.7 and Figure 50.4 give an example of the type of data obtained for SLS and used as a control. Similar data for SLES-2 and the ten blends tested are available at www.Cosmeticsand-Toiletries.com.

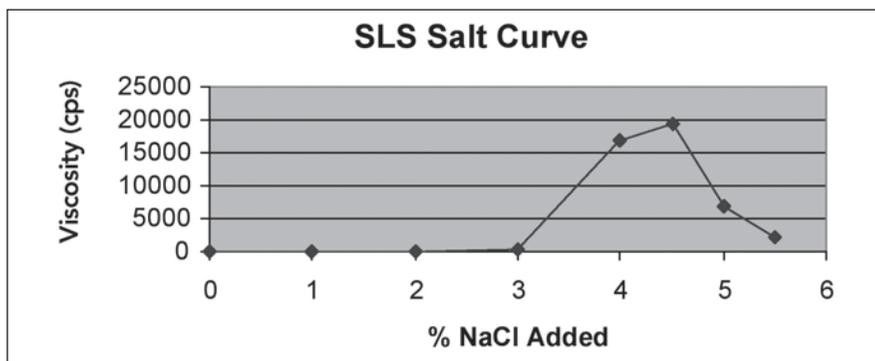


Figure 50.4. SLS salt curve

Table 50.7. Control salt curve data for SLS (100%)

% Salt	Spindle #	RPMs	Viscosity (cps)
0	LV 1	60	4
0.5	LV 1	60	4
1.0	LV 1	60	4
1.5	LV 1	60	5
2.0	LV 1	60	12
2.4	LV 1	60	50
3.0	LV 2	60	362
3.5	LV 3	30	2,120
4.0	LV 4	12	17,000
4.5	LV 4	12	19,500
5.0	LV 4	12	7,000
5.5	LV 3	30	2,060

Conclusion: As **Table 50.8** indicates in summarizing the peak viscosity data for SLS, the addition of betaine and salt to the SLS resulted in improved peak viscosity in all cases except the CB betaine. In all instances, addition of betaine shifted the salt curve to the left. In other words, the amount of salt needed to reach peak viscosity dropped when betaine is present. In many instances the curve also was broadened. The presence of the conditioning betaine DAB actually increased peak viscosity and lowered the amount of salt needed to reach it in SLS systems and did so without adverse effect upon foam.

Table 50.9 indicates that the addition of betaine and salt to the SLES-2 resulted in lowering of the peak viscosity in all cases. LMAB decreased peak viscosity least. In all instances the addition of betaine shifted the salt curve to the left, demonstrating again that the amount of salt needed to reach peak viscosity dropped when betaine is present. The inclusion of the conditioning betaine DAB provided good viscosity and conditioning.

Table 50.8. Peak viscosity from salt curve data for blends of SLS at 75% and selected amphoteric surfactants at 25%

Blend	Peak Viscosity (cps)	% NaCl Added
DAB:SLS	37,500	3.0
CAB:SLS	37,000	3.5
LMAB:SLS	23,000	3.5
PB:SLS	22,500	2.5
SLS	19,500	4.5
CB:SLS	18,600	2.0

Table 50.9. Peak viscosity from salt curve data for blends of SLES-2 at 75% and selected amphoteric surfactants at 25%

Blend	Peak Viscosity (cps)	% NaCl Added
SLES-2	25,000	5.5
LMAB:SLES-2	24,000	3.0
DAB:SLES-2	19,250	2.5
CB:SLES-2	18,500	2.5
CAB:SLES-2	15,750	2.0
PB:SLES-2	15,200	2.5

Conclusion

The combination of betaines and anionic surfactants is a powerful tool to the formulator to provide value-added formulations. This study looked at only a few of those value-added attributes. Others include conditioning, foam thickness and bubble structure, and feel on the skin. All these properties will benefit by proper selection of a betaine. The formulator should investigate such interactions and maximize them for the specific formulation goals desired.

Acknowledgements

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2. *Ibid*, p 112

Going to a Wetting

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Technical Editor, Cosmetics & Toiletries magazine

KEY WORDS: *pigment, cosmetic formulation, wetting, dispersion, surfact tension, critical surface tension*

ABSTRACT: *Wetting is part of the process involved in incorporating pigments into liquids. This chapter examines certain materials used for wetting pigments.*

In order to marry a pigment to a cosmetic formulation, the pigment has to go to a wetting. As supplied, pigments are insoluble colorants that are usually agglomerated and granular in consistency. They may be organic compounds like the D&C lakes or inorganic compounds like the iron oxides, mica, titanium dioxide and zinc oxide.

Wetting and dispersion are terms used to describe the steps involved in the incorporation of pigments into liquid vehicles. Wetting is the ability of a liquid to spread over the surface of a solid, displacing air as the medium, and replacing it with the liquid. Dispersion refers to the suspension and subsequent size reduction of the pigment agglomerates by mechanical means (stirring or milling). Finally, the dispersion must be stabilized before it is added to the cosmetic formulation.

In this chapter we'll look at some vehicles used for wetting pigments. With one exception, they are all oils or polymerized natural oils. We'll also look at two wetting agents that functions like a matchmaker to facilitate the wetting. After all, what would a wetting be without at least one matchmaker?

Silicone Carbinol Fluid

At In-Cosmetics in Milan earlier this year, Dow Corning launched a silicone carbinol fluid^a for use in color cosmetics and other personal care applications (see **Figure 51.1**).

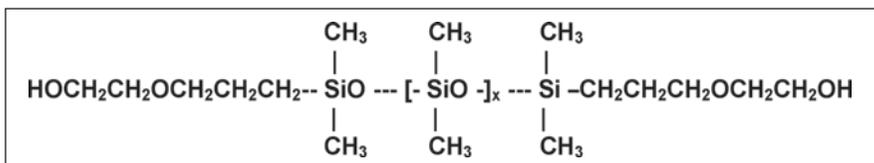


Figure 51.1. Silicone carbinol fluid

“This silicone carbinol fluid is very good at wetting and spreading, and with it one can easily create stable pigment dispersions,” said Heidi Van Dort, Ph.D., Dow Corning’s group leader, personal care. “This is due to the combination of silicone and small polar organic substituents on the molecule, which impart the important physical characteristics for wetting. Contact angle, viscosity and surface tension are all important variables in wetting,” Van Dort said, citing the following equation:¹

$$\text{Wetting Rate} \sim (\gamma \cos \theta) / 2\eta$$

γ = surface tension

θ = contact angle

η = viscosity

“For a liquid to effectively wet another material, it must have a surface tension that is lower than the other ingredient. The lower surface tension liquid will spontaneously spread over the surface. The silicone carbinol fluid has a low surface tension, which indicates that it is a good wetting vehicle and has good spreading properties.” **Table 51.1** shows the surface tension (liquids) and critical surface tension (solids) data for a variety of ingredients used in skin care color cosmetic products.

“In addition to the low surface tension, the silicone carbinol fluid also gives low contact angles on surfaces, partly because of its extremely flexible backbone,” Van Dort continued.

^a DC 5562 Carbinol Fluid, a product of Dow Corning, Midland, Michigan USA

Table 51.1. Surface tension of various substances (mJ/m²) (courtesy of Dow Corning Corporation)

Dow Corning 5562 Carbinol Fluid	24
Glycerin	66
Olive oil	33
Castor oil	36
Capryl caprylic triglyceride	30
Skin	27
Yellow iron oxide	>73
Carbon black	40
Talc	48
Red iron oxide	28
Water	73

“This ingredient also creates low-viscosity pigment dispersions,” she added. “We measured the final viscosity of pigment dispersions of TiO₂, Yellow #5 Aluminum Lake, and Red Iron Oxide in castor oil, the standard dispersion vehicle for lipsticks. And then we dispersed those same pigments in silicone carbinol fluid. In every case, the final viscosities were lower for the silicone fluid (4477, 710, 4180 cps) than for the castor oil (19500, 7913, 12413 cps), which indicates that the silicone carbinol fluid is a better pigment wetting vehicle than castor oil.”

Pigments are colored organic or inorganic crystalline materials that are typically not soluble in liquid wetting vehicles. As supplied, most exhibit considerable agglomeration and/or aggregation. Typically, suppliers and end users employ high-energy processes—three-roll mills or a bead mill—to deagglomerate and separate the pigment particles one from another in dispersed systems

Complete wetting involves the homogeneous distribution of pigment particles that are separated from one another by a barrier envelope. That’s the first step in making color cosmetics. “You start with a powdered pigment and create a pigment dispersion that contains individual pigment particles that are stably surrounded by a liquid vehicle. If you don’t perform this step well, you will not be

able to create a good cosmetic product. You'll impact the physical properties of your formulation. For example, you won't get good color development and the resulting films can have defects, like 'fish eyes' or an 'orange peel' appearance," Van Dort said.

"When I think of making a color cosmetic, I first want to get my pigment wet and well dispersed," she concluded. "Then I look at compatibility with the other ingredients in the formulation. And finally, I look at the other attributes that I want to bring to that formulation, such as forming a film (substantive or not), forming gloss, moisturizing the skin, or any other function I want the final product to have."

Castor Oil Polymer

Castor oil has been used for centuries to wet pigments, especially in lipsticks. Now Zenitech Products (Old Greenwich, Connecticut) has created a family of polymers naturally derived from castor oil. Zenitech claims these products have good wetting properties and are compatible with a wide range of cosmetic waxes and oils, making them particularly suitable for use in color cosmetics.

One example is Zenigloss, a viscous polyester derived from castor oil and succinic acid. It provides adhesion and shine in lip glosses and lipsticks. Lip products containing Zenigloss are aromatic-free and reportedly have higher luster with reduced tendency to run or smear. The high molecular weight and branching of these patented products provide the gloss and substantivity.

"Being a highly branched polymer, Zenigloss actually produces grinds and dispersions of lower viscosity, indicating better pigment wetting properties and improved gloss," said Carter La Vay, President of Zenitech.

In comparing the wetting ability of oils, La Vay notes that the effect of pigment surface treatments should be taken into account because most pigments are treated in today's products. "Other parameters being equal, the lower the viscosity of a suspension, the better the vehicle has spread over the pigment surface, replacing adsorbed air and water," La Vay said.

Zenitech ran tests on a Zenigloss dispersion of mica at 20%. The mica and Zenigloss were blended for 30 minutes using a paddle

mixer, then the suspension was allowed to stand for five minutes, after which readings were taken using a viscometer. The same procedure was followed for mica dispersed in castor oil. Results showed that although Zenigloss had a higher neat viscosity (1630 cps for Zenigloss vs 780 cps for castor oil), it had a lower mica suspension viscosity (3600 cps for Zenigloss vs 3760 cps for castor oil), indicating that Zenigloss does a better job of wetting inorganic pigments such as mica.

“We are developing many new uses for castor oil because of the presence of three hydroxyl groups and because of our ability to turn it into a polymer. We can react additional functionalities into the polymer to improve functionality, such as a gloss, emulsification, or conditioning. These polymers can also be used a substitute for lanolin. As a wetting vehicle, Zenigloss prevents the pigments from re-agglomerating, probably because of its higher viscosity and high molecular weight,” La Vay said. “So we’re just beginning to examine this product’s versatility. We have now combined castor polyesters with silicone and expect these materials will be of great interest in pigmented products, providing a bridge between the two types of products having very different solubility.”

Esters

Esters are molecules with a COOC bond formed by reacting a fatty acid and a fatty alcohol. These molecules owe their properties to the various chain lengths, chain configurations and substituent groups of the particular fatty acids and fatty alcohols involved. There are innumerable possible combinations. Natural oils, such as castor oil, tend to be triglycerides. Triglycerides are esters of fatty acids and glycerol.

The mechanism by which different esters achieve wetting is varied, and not clearly understood, according to John Imperante, president of Phoenix Chemical Inc. in Somerville, New Jersey. Phoenix sells a number of wetting vehicles under its Pelemol and Phoenate brand names. Here he describes two esters for pigment wetting and grinding.

“Our nonionic Pelemol TGC (INCI: trioctyl dodecyl citrate) has a free hydroxy group. It is compatible with hydrocarbons, and

finds use in anhydrous pigment systems containing mineral oil, petrolatum, and/or microcrystalline wax. Pelemol PHS-8 (INCI: polyhydroxystearic acid) is a nonionic all-vegetable-derived polyester with many nucleophilic sites. Its substantivity and solubility profile strongly suggest its use in color cosmetics. But another possibility with both of these nonionic esters is that the hydrophobic surface of the pigment and the hydrophobic ester will interact to bring the entire system to the lowest free energy state, thereby encouraging wetting.”

A wetting ester from Croda is its Crodamol STS (INCI: PPG-3 benzyl ether myristate), which is described as a multifunctional silicone alternative emollient ester. It has a viscosity of 100 cps, which is low compared to castor oil (780 cps) or Zenigloss (1630 cps), but high compared to isostearyl neopentanoate (14.2 cps) and cetearyl ethylhexanoate (10.1 cps), two emollient esters commonly used as vehicles for color cosmetics.

What is important is not the absolute viscosity of the vehicle or the dispersion, according to Barbara Woldin, marketing administrator-communications at Croda. What matters is the relative viscosity of the pigment dispersion in comparison to the neat viscosity of the wetting vehicle, a concept mentioned earlier by Carter La Vay.

“The fact that Crodamol STS has a rather high neat viscosity of 100 cps does not detract from its pigment wetting ability,” Woldin said. “For instance, Crodamol PTIS is a heavy cushion ester with a neat viscosity of 305. Its mica suspension viscosity is 19,500; that is a 64-fold increase. Our lowest viscosity ester Crodamol OPG has a neat viscosity of 4.5 and a mica suspension viscosity of 18,800; that’s a 4178-fold increase! For a mica suspension in Crodamol STS, you get a 119-fold increase. The lower the pigment suspension viscosity is in proportion to the neat viscosity, the higher the pigment wetting will be,” Woldin said.

Another Croda wetting vehicle is Cromollient DP3A (INCI: Di-PPG-3 myristyl ether adipate), a patented di-ester that acts as solvent, pigment dispersant and emollient for a variety of makeup products. It easily disperses TiO₂ and ZnO. It also has synergistic effects, enhancing the pigment wetting properties of other esters, according to the company.

Estolide

Meadowestolide (INCI: meadowfoam estolide) is a new ingredient derived from meadowfoam seed oil by The Fanning Corporation in Chicago. An estolide is an oligomer, basically a short polymer with only a few molecules strung together. According to Alan Wohlman, Ph.D., Fanning Corporation's senior vice president of science and technology, Meadowestolide results from the acid-catalyzed condensation of meadowfoam fatty acids to produce a dimeric ester having the structural formula shown in **Figure 51.2**.

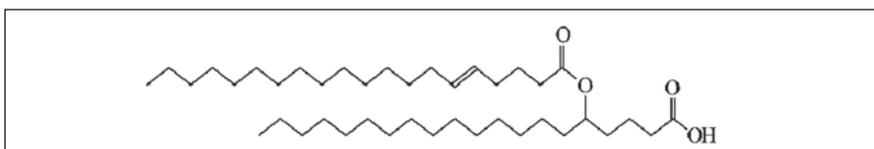


Figure 51.2. Meadowfoam estolide

“Meadowestolide has marked hydrophilic and lipophilic binding sites owing to the clearly defined linear spatial geometry of polar and nonpolar centers,” Wohlman said. “This attribute confers upon this molecule excellent wetting and pigment dispersion properties.”

The Wetting Agent

Now suppose you change the surface of the pigment so what is presented to the wetting vehicle is more compatible with the vehicle. That's what wetting agents do. You add 0.5–1.0% of a wetting agent to the vehicle and the viscosity drops dramatically. The agent is attracted to the pigment surface, where it adsorbs, encouraging the vehicle to spread all over the pigment surface. Water-based systems have one set of wetting agents; oil-based systems have another.

One example for oil-based systems is Phoenate COPA (INCI: castor oil phosphate) from Phoenix Chemicals. This monophosphate ester of castor oil functions as a pigment dispersing and coating agent. Phoenate COPA is anionic in character and will hydrogen bond with hydroxy groups on a pigment surface. The resultant castor oil coating enhances the pigment's dispersibility in castor oil and other oily phases.

Comment

Table 51.2 brings together scattered data on the oils discussed in this work. But the table should be approached with caution, according to Heidi Van Dort. “I think it would be good to understand more information about the pigments that were used (which vendor, were they treated or untreated) and how the experiments were set up (for example, how much fluid versus the pigment). For the experiment to give the most meaning, the researcher should use the critical pigment volume concentration. For the carbinol fluid and castor oil experiments by Dow Corning, we used untreated red iron oxide (C33-2199 from Sun Chemical), untreated FD&C Yellow #5 Aluminum Lake (C69-4424 from Sun Chemical) and untreated Cosmetic White Titanium Dioxide (C47-056 from Sun Chemical). We also completed all of our experiments at the critical pigment volume concentration.”

Jane Hollenberg agreed that the table should be approached with caution. Hollenberg is director of JCH Consulting, specializing in pigmented cosmetic formulation.

“The different pigments would show different pigment suspension viscosities just on the basis of their different porosities, regardless of their oil’s wetting properties. Their oil absorption is all different,” Hollenberg said. “You can’t compare apples and oranges.”

However if we isolate the apples in the table, we can draw some conclusions. For example, isostearyl neopentanoate and cetearyl ethylhexanoate have similar neat viscosities at 14.2 cps and 10.1 cps, respectively. Isostearyl neopentanoate is heavier. But the mica suspension at 35% in each of these oils gives a suspension viscosity of 600 cps for isostearyl neopentanoate and 3300 cps for cetearyl ethyl hexanoate in data from Zenitech. “So in this case the heavier oil is the better wetting vehicle. That’s remarkable. And it seems to be backed up by the TiO₂ data from Croda,” Hollenberg said.

Looking beyond **Table 51.2**, Hollenberg suggested ways in which pigment suspension data can be most useful, and that is by holding all variables constant, except one. “If all oils are of the same viscosity and you use only one pigment, you can get a series and see which oil does the best wetting. If you’re using the same oil and the same

Table 51.2. Neat viscosity of wetting vehicles and suspension viscosities of pigments from various sources mentioned in this chapter

Wetting vehicle	Viscosity Neat (cps)	Suspension Viscosities (cps)			
		Mica	TiO ₂	Yellow #5	Red Iron Oxide
Silicone carbinol fluid	50		4477 ^d	710 ^d	4180 ^d
Castor oil	780	3760 ^a	19500 ^d	7913 ^d	12413 ^d
Zenigloss	1630	3600 ^a			
Isostearyl neopentanoate	14.2	600 ^b	4400 ^c		
Cetearyl ethylhexanoate	10.1	3300 ^b	8400 ^c		
PPG-3 Benzyl ether myristate	100	11860	33640		
Isopropyl myristate	5.7	21500 ^b			
Ethylhexyl palmitate	9.0	2500 ^b			
Di-PPG-3 myristyl ether adipate	81.0	1200	24500		
Meadowfoam estolide	250				

a 20% mica suspension (source: Zenitech)
b 35% mica suspension (source: Zenitech)
c 30% TiO₂ suspension (source: Croda)
d (source: Dow Corning)

pigment, and you try different wetting agents at 1%, you can decide which is the best wetting agent for your system. If you take the same oil and the same pigment but you vary the surface treatment, then you can see which surface treatment modified the surface to give the best wetting. That's when the test makes sense," Hollenberg said. "But comparing a light oil and a heavy oil is like comparing apples and oranges. You can't learn anything."

We've learned that pigments need to be prepared before they enter a formulation. They need to go to a wetting, where sometimes a wetting agent assists. Then they need to be mechanically de-agglomerated to uniform size and finally stabilized.

Is there an analogy in life, where two people need to be prepared before they enter a life-long relation? They go to a wedding, where

sometimes a matchmaker assists. They are carried away in a vehicle. They go through an emotional adjustment process, ideally yielding two partners of equal stature. Then they stabilize. Can we learn anything from this, or does this analogy compare apples and oranges?

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Properties of Surfactants: Wetting

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KEY WORDS: *surfactants, wetting, surface tension, hydrophilic-lipophilic balance (HLB), Draves Wetting test, dimethicone copolyol, sulfosuccinate diesters, phosphate esters*

ABSTRACT: *In formulation, the key attributes of surfactants are conditioning, wetting, emulsification, and detergency. This chapter describes the features of surfactants that provide wetting properties in aqueous systems. Specifically, the properties of interest include surface tension reduction, HLB, molecular weight, branching, and level of ethoxylation. The choice of the best wetting agent depends upon chemical structure and the formulation.*

Surfactants are a major class of materials that provide the functional basis of most personal care products. The term “surfactant” is a word that was coined by contracting two words: surface-active agent. Surfactants, as surface active agents, are compounds that are active at interfacial surfaces. Surfactants function in a variety of ways, depending upon their chemical structure, but all the surfactant functionalities are driven by the systems in which the surfactant is placed and the need to get to the lowest free energy in the system.

This chapter deals with surfactants from a functional point of view. The function a surfactant brings to a formulation is in fact the reason one chooses the particular surfactant. It will address the properties surfactants provide namely conditioning,¹ wetting, detergency, and emulsification.

Wetting

The topic of this work is wetting, and specifically wetting from aqueous systems. This means the type of wetting that occurs on hair and skin when washing, as opposed to the type of wetting that occurs when an oil is applied to a pigment, which is referred to as oil wetting.

When considering surfactants for water-based formulations, cosmetic chemists can easily neglect wetting as an important attribute and concentrate on detergency for cleansing systems and conditioning for systems designed to condition the hair. However, both systems need to possess the requisite wetting to achieve a product with the proper aesthetics.

If a shampoo does not wet the hair satisfactorily, it will not apply easily and will not spread onto the hair. Most consumers want thick shampoos poured into their hands from a bottle, but for the shampoo to spread rapidly onto the hair, wetting is an important attribute.

Because most conditioners are inherently hydrophobic and because consumers want their conditioners to have a high viscosity, wetting is critical to customer acceptance. Wetting agents help spread out the formulation on the hair. With these systems, a conditioner properly formulated for wetting provides enough spreadability to minimize gunky deposits left on the hair. Because many skin care products are emulsions or lotions, the ability to spread out both the oil phase and the water phase is critical to performance, and may well require two different chemicals to optimize performance.

Wetting phenomena are complex and depend upon several processes and factors such as diffusion, surface tension, concentration, and the nature of the surface being wet.² This chapter will describe some of the features of surfactants that alter wetting properties. Many types of surfactants can have wetting properties. Among these surfactants are specific compounds from the anionic, cationic, non-ionic, and amphoteric classes. The choice of the best wetting agent in each class depends upon chemical structure.

A Definition of Wetting

For our purposes, a good working definition of wetting is obtained from the BASF Web site, which says “Wetting is the displacement of one fluid on a surface by another.”³ Thus, wetting always involves three immiscible phases. Theoretically, only two fluid phases are required for wetting to occur.

A wetting agent is any substance that increases the ability of water to displace air from a liquid or solid surface. Wetting agents can cause three different kinds of wetting: spreading, adhesion, and immersion.

This work describes two different measurements of wetting.

- *Draves Wetting* is a measure of how long it takes to sink a skein of fiber (weighted, waxed cotton yarn) in a solution of surfactant at the critical micelle concentration.⁴ The units of Draves Wetting are seconds.
- *Wetting Power* is the number of grams of wetting agent per liter needed to sink a skein of fiber in 25 seconds. The units of Wetting Power are concentration expressed in grams/liter.

Required Attributes of Wetting Agents

Some of the required attributes of wetting agents are independent of the chemistry of the surfactant. Every wetting agent has to reduce surface tension and provide a certain HLB value.

On the other hand, some required attributes vary from one wetting agent to the next, depending on the structure of the agent. In this case, wetting depends on factors such as molecular weight, branching, and ethylene oxide content.

A discussion of these two types of attributes (general and structure-specific) and examples from three families of surfactants constitute the remainder of this chapter.

General Attributes of Wetting Agents

The following are required attributes of wetting agents independent of the type of compound.

Surface tension reduction: Wetting agents must provide a surface tension of below 30 dynes/cm². This is one key requirement for a wetting agent.

Hydrophilic-Lipophilic Balance range: No discussion of surfactants is complete without a discussion of Hydrophilic-Lipophilic Balance (HLB), which has a connection to wetting. The concept of HLB was developed some 50 years ago by Griffin,⁶ and remains a very useful concept to this day.

HLB, which is a measure of the percent of ethylene oxide in a nonionic molecule, is defined as $HLB = \% EO/5$ where % EO is the percentage of ethylene oxide in a molecule. Generally, nonionic surfactant water solubility is achieved at a HLB of around 10, at which point the molecule will be 50% ethylene oxide. Wetting agents contain even higher percentages of ethylene oxide.

Therefore, according to **Table 52.1**, we can expect a wetting agent to have between 45% (9X5) and 70% (14X5) water-soluble portion on it to be a wetter. It is interesting that there is overlap between the properties and the composition. With a HLB between 12 and 14, a surfactant will have both wetting and detergency properties. It is quite common to see both wetting and detergency properties in a single molecule, but it is far more common to see formulations containing multiple surfactants to cleanse and wet.

Table 52.1. HLB values corresponding to solubilities of surfactants in water⁵

Solubility in Water	HLB Value	Description
Insoluble	4-5	Water in oil emulsifier
Dispersible	9-14	Wetting agent
Translucent to clear	12-15	Detergent
Very soluble	14-18	Oil in water emulsifier

Structure-Specific Attributes of Wetting Agents

All surfactants have one common structural similarity: the presence of a hydrophilic portion and a hydrophobic portion (**Figure 52.1**). The hydrophilic end is water-soluble and is a polar or ionic group.

The hydrophobic end is water-insoluble and it is a hydrocarbon chain, an aromatic group, or silicone.



Figure 52.1. Basic structure of a surfactant

This dual functionality (hydrophobic and hydrophilic) is the source of the surface activity. The activity is attributable in large part to the unique structure of water. The water molecule has a great deal of intermolecular hydrogen bonding. This accounts for the surface tension of water. Anything that disrupts the hydrogen bonding in water does so at a high energetic cost.

Put another way, oil floating on water, which appears to be an ordered system, is at the lowest free energy because the oil molecules disrupt the fewest number hydrogen bonds in the water. This concept of lowest free energy of the system drives all of the surfactant properties.

An understanding of how surfactants behave in aqueous systems is key to understanding the functionality of these materials. When a surfactant is added to water, the surface tension of the water drops. If the surfactant is titrated in small increments and the surface tension measured, the drop in surface tension as a function of surfactant concentration can be plotted. Fatty surfactants will lower the surface tension from 70 to the mid 30s (dynes/cm²), depending upon the exact product chosen. At some concentration, adding more surfactant will not lower the surface tension any more; instead, micelles form. This is referred to as the Critical Micelle Concentration, or CMC.

Effects of molecular weight: The effect of molecular weight upon wetting is easily demonstrated by considering a homologous series of dimethicone copolyol (DMC) compounds. These materials, now called PEG/PPG dimethicone compounds, are a class of silicone/polyoxyalkylene derivatives. DMC surfactants are a class of compounds that conform to the general structure shown in **Figure 52.2**.

The compounds are surface-active agents because they have a water-soluble polyoxyalkylene group and a water-insoluble silicone portion.

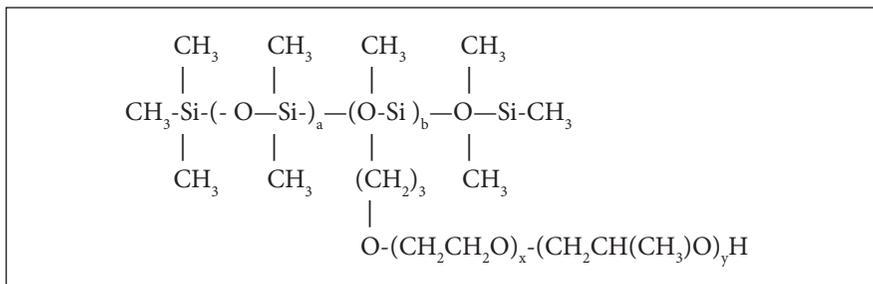


Figure 52.2. General structure of dimethicone copolyol surfactants

A shorthand nomenclature has been developed to describe these DMC molecules. The shorthand is based upon the type of groups present in the molecule. Each group is called an M unit, a D unit, a T unit, or a Q unit, depending on whether 1, 2, 3, or 4 oxygen atoms are sharing one silicon atom (**Table 52.2**). If organofunctional groups other than carbon are introduced, then corresponding groups are called an M* unit, a D* unit, or a T* unit. There is no Q* unit because there is no possibility of functional groups. Thus, for example, the structure for MD₂D₃*M is as shown in **Figure 52.3**.

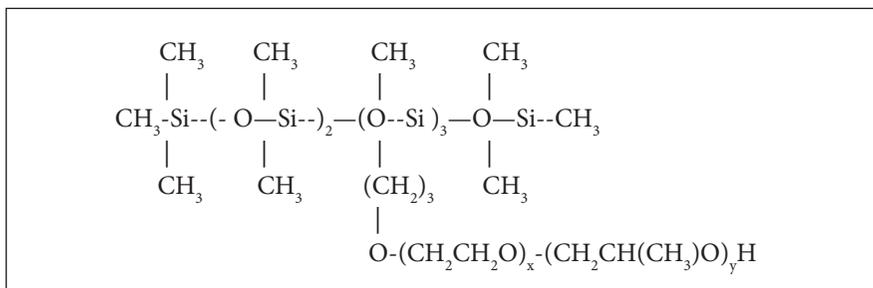


Figure 52.3. Structure for MD₂D₃*M

Table 52.3 is helpful in understanding several key aspects of surfactants. First, it is not too surprising that a series of homologous silicone surfactants has almost identical surface tensions at the CMC. Second, it is also not too surprising to see that the CMC is somewhat higher as one increases the molecular weight. This can

Table 52.2. Nomenclature for dimethicone copolyol compounds

Nomenclature	Description	Compound Structure
<u>Methyl Substituted Compounds</u>		
"M unit"	monosubstituted (1 oxygen atom shared by the silicon)	$\begin{array}{c} \text{CH}_3 \\ \\ -\text{O}-\text{Si}-\text{CH}_3 \\ \\ \text{CH}_3 \end{array}$
"D unit"	disubstituted (2 oxygen atoms shared by the silicon)	$\begin{array}{c} \text{CH}_3 \\ \\ -\text{O}-\text{Si}-\text{O}- \\ \\ \text{CH}_3 \end{array}$
"T unit"	trisubstituted (3 oxygen atoms shared by the silicon)	$\begin{array}{c} \text{O} \\ \\ -\text{O}-\text{Si}-\text{O}- \\ \\ \text{CH}_3 \end{array}$
"Q unit"	tetrasubstituted (4 oxygen atoms shared by the silicon)	$\begin{array}{c} \text{O} \\ \\ -\text{O}-\text{Si}-\text{O}- \\ \\ \text{O} \end{array}$
<u>Organofunctional Compounds</u>		
"M*" unit"	monosubstituted (1 oxygen atom shared by the silicon) with organofunctionality	$\begin{array}{c} \text{CH}_3 \\ \\ -\text{O}-\text{Si}-\text{CH}_3 \\ \\ \text{R} \end{array}$
"D*" unit"	disubstituted (2 oxygen atoms shared by the silicon) with organofunctionality	$\begin{array}{c} \text{CH}_3 \\ \\ -\text{O}-\text{Si}-\text{O}- \\ \\ \text{R} \end{array}$
"T*" unit"	trisubstituted (3 oxygen atoms shared by the silicon) with organofunctionality	$\begin{array}{c} \text{O} \\ \\ -\text{O}-\text{Si}-\text{O}- \\ \\ \text{R} \end{array}$
"Q*" unit"	tetrasubstituted (does not exist) (no possibility of organofunctionality)	

Table 52.3. CMC and surface tension of a homologous series of DMC compounds

Designation	CMC (mg/L)	δ at CMC (dynes/cm ²)
MD*DM	3	20
MD ₂ *D ₂ M	4	19
MD ₃ *D ₅ M	6	23
MD ₃ *D ₇ M	5	21
MD ₄ *D ₈ M	14	21

be attributed by observing that smaller molecules can better pack the surface of the water and be more effective at lowering surface tension.

The most interesting property that varies with increasing molecular weight is wetting. The data in **Figure 52.4** shows that for DMC there is a strong relationship between molecular weight (and structure) and wetting. The materials with lower molecular weight have faster wetting times. Again, the smaller molecule allows for more efficient packing and dynamics. The materials with lower molecular weight were extremely effective at the higher concentration of 1.0% by weight. Their wetting speeds were almost instantaneous. For DMC compounds there is a strong relationship between molecular weight (and structure) and wetting.

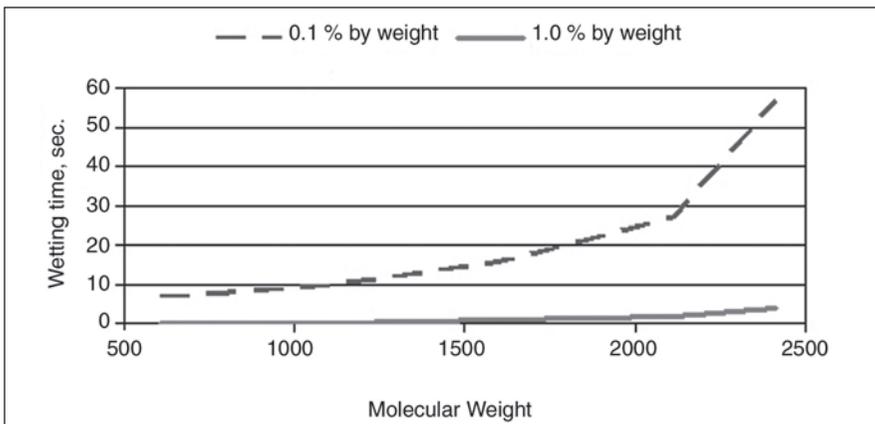


Figure 52.4. Wetting time vs. molecular weight of dimethicone copolyol wetting agents

The Draves Wetting data in **Figure 52.4** shows the slope of the curve does not change much until the molecular weight of the DMC reaches approximately 1200. The nonlinearity of the graph of wetting time vs. molecular weight of the DMC predicts that molecules having a molecular weight between 600 and about 1200 should be effective wetting agents.

Effects of branching: The effects of branching on wetting are seen with sulfosuccinate diesters. These materials are an anionic class of surface-active agents. They are sulfonated diester derivatives of maleate esters. Because they are sulfonates, they have a stable C-S bond. However, they also have ester linkages in the molecule, so unlike a olefin sulfonates, sulfosuccinates are not stable in acid or base. Sulfosuccinate diesters conform to the following formula shown in **Figure 52.5**.

The following general structure/function relationships for sulfosuccinates have been established:⁵

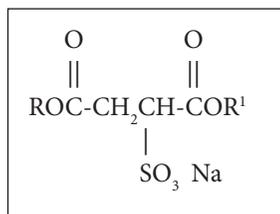


Figure 52.5. General structure of sulfosuccinate diesters

- Sulfosuccinate diesters having a total of 8 carbon atoms or less in the 2 hydrophobic groups are too water-soluble to be of interest as surfactants. For example, dibutyl sulfosuccinate has 8 carbon atoms in the 2 hydrophobic groups, 4 in each.
- Sulfosuccinate diesters having a total of 20 or more carbon atoms in the 2 hydrophobic groups, such as didecyl sulfosuccinate, are generally too water-insoluble to be of interest as surfactants.
- As the number of carbon atoms in the surfactant increases, the solubility in water decreases and the wetting power increases until about 18 carbon atoms are present in the nonpolar hydrophobe.
- The best wetting agents in the diester class are those products that have a total of between 14 and 18 carbon atoms in the 2 hydrophobic groups.

- When branched alcohols are used in synthesis of diester sulfosuccinates, the resultant products are more water-soluble than the homologous diester sulfosuccinates based upon linear alcohols.
- Symmetrical sulfosuccinate diesters (i.e., those made from the same alcohol, R = R') generally have the best wetting properties.
- The wetting properties of sulfosuccinates are maximized at or near their critical micelle concentration (**Table 52.4**).

Table 52.4. Sulfosuccinate wetting power⁷

R Group	Molecular Weight	Solubility in water at 30°C (g/L)	Wetting Power (g/L)
2-methyl butyl sulfosuccinate	360	530	10.0
n-pentyl sulfosuccinate	360	460	4.4
2,2-dimethyl butyl sulfosuccinate	388	310	1.1
n-hexyl sulfosuccinate	388	270	1.1
1-methyl hexyl sulfosuccinate	416	142	0.53
n-heptyl sulfosuccinate	416	65	0.25
2-ethyl hexyl sulfosuccinate	443	15	0.20
n-octyl sulfosuccinate	444	14	0.32
n-butyl pentyl sulfosuccinate	472	4.7	1.1
n-decyl sulfosuccinate	500	1.5	--

Effect of ethylene oxide content: A somewhat more complicated structure function relationship for wetting properties is observed with phosphate esters. Phosphate esters are a well known class of surfactants that have been used historically as emulsifiers. More recently, however, there has been a trend to use mono-alkyl phosphate esters in a variety of personal care formulations. The proper selection of a phosphate ester for use in personal care applications is likely to result in wider usage of this class of compounds as emulsifiers and detergents.

Phosphate esters are part of a class of anionic surface active agents. The commercial products are complex mixtures of the components shown in **Figure 52.6**.

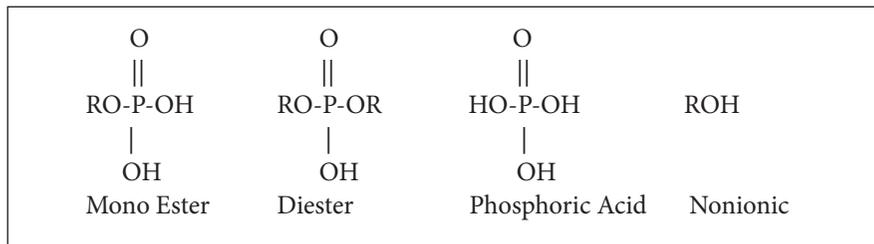


Figure 52.6. Components of commercial mixtures of phosphate esters

Table 52.5. Wetting speeds of phosphate esters as a function of degree of ethoxylation

Phosphate Type	Ethylene oxide Added (moles)	Hydrophobe C Atoms	Wetting Time (sec)
Hexyl	0	6	15
Octyl	0	8	17
Decyl	0	10	28
Decyl	2.5	10	8
Decyl	6.0	10	23
Decyl	8.0	10	33
Tridecyl	0	13	34
Tridecyl	6.5	13	29
Myristyl	0	14	34
Myristyl	3.0	14	30
Myristyl	7.0	14	39
Myristyl	9.0	14	49
Myristyl	12.0	14	42

The monoester component of a phosphated product is most commonly the fastest wetter in the series. When using higher-molecular-weight nonionic surfactants or when process modification increases the surfactant's concentration, the best

wetting agent is obtained. It is highly desirable to keep the free phosphoric acid content as low as possible in most applications. Most phosphate esters used in personal care are so called mono-alkyl phosphate esters (MAP) products.

As the molecular weight of the hydrophobe increases, the wetting time likewise increases. The lowest molecular weight hydrophobe (hexyl phosphate) with no ethylene oxide was the best wetter in the series of non-ethoxylated species. In fact, as the molecular weight of the hydrophobe containing no ethylene oxide increases the phosphate produced will have a longer wetting time. This is true for hydrophobes having 6 to 14 carbon atoms.

Within each set of hydrophobes, the ethoxylated materials all reached the fastest wetting times with between two and three moles of ethylene oxide added.

Summary and Conclusions

Wetting is an important function of surfactants. It is related to (1) molecular weight, (2) branching, (3) ethylene oxide content, and many other attributes. Wetting is also important in formulation of cosmetic products. Products that effectively wet hair and skin are more aesthetically appealing. When formulating cosmetic products, one should, of course, consider both foam and detergency, but one also needs to consider the effect surfactants have upon wetting, as well as the ultimate effect wetting has on the product performance.

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* This chapter is an excerpt from the book, "Surfactants: Strategic Personal Care Ingredients," by Anthony J. O'Lenick, Jr. Complete details of the studies and literature are available in the new book published by Allured Publishing Corp. 2005.

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SECTION IX

Formulating Tips

This section includes the following chapter:

53 Formulating for Efficacy

Formulating for Efficacy

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KEY WORDS: *active ingredients, emollient selection, formulation design, octanol/ water partition coefficient, Relative Polarity Index, skin distribution profiles*

ABSTRACT: *Via the introduction of the Relative Polarity Index, the authors show that the choice of emollients in cosmetic formulations determines the total amount of skin penetration of active ingredients whereas the choice of the emulsifier determines the distribution within the skin.*

Active ingredients have been popular for more than a decade, and new actives are continuously being identified, studied and promoted. Many of these are supported by good in vitro efficacy data, and there is an increasing number of ingredients for which also good in vivo efficacy evidence is available.

Based on this, one would expect to find many active cosmetic products in the marketplace, but unfortunately this is not the case. Assuming that the efficacy data provided is robust (i.e., the active ingredient has indeed its claimed cosmetic activity), questions arise about the formulation development process that should assure that the efficacy of an active ingredient is transformed to an efficacious cosmetic product. Cosmetic formulators should therefore select their ingredients and manufacturing procedures in such a way that

cosmetic efficacy is obtained. In other words, they should formulate for efficacy. In many cases, however, this does not happen.

Many companies have a number of standard formulations to which the latest new active ingredient is simply added. Following stability testing and elimination of those failing the stability tests, small clinical trials are performed with the remaining formulations to assess whether the claimed efficacy of the active ingredient is maintained in the standard formulation. In most cases, no efficacy is seen and after some additional work, the active ingredient is discarded. Whereas the reasons for using standard formulations are very understandable, this strategy does not lead to the best possible product because it completely ignores the principles that underpin the skin delivery of the active ingredient.

This article describes the selection criteria for ingredients in cosmetic formulations that help to optimize the delivery of the active ingredient into the skin. As formulations can be very complicated, many factors need to be taken into account. To date only a few have been systematically studied. The guidelines described in this article are, therefore, only guidelines but the guideline recipe will be a lot closer to an efficacious cosmetic formulation than a random choice from a selection of standard formulations. As further results from new work become available, the system will be further refined.

Theoretical Considerations for the Skin Delivery of Cosmetics

As illustrated in **Figure 53.1**, Barry described the skin penetration process as a series of consecutive steps, each of which can potentially be rate limiting.¹ First, the chemical needs to diffuse within the formulation to the skin surface. There it partitions into the skin, diffuses through the stratum corneum, partitions into the viable epidermis and diffuses through the viable epidermis. It then partitions into and diffuses through the dermis before partitioning into the fat deposits or it partitions into the blood capillaries just beneath the viable epidermis/dermis interface.

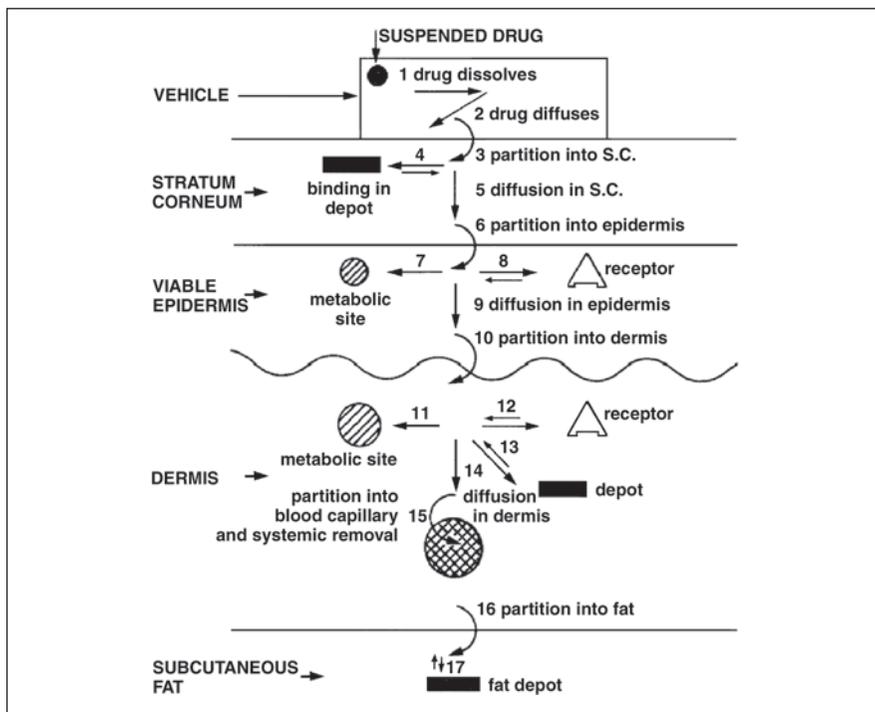


Figure 53.1. The various subsequent steps that an active ingredient will have to undertake during its journey from the formulation in which it is incorporated to its site of action. Reproduced with the permission of the author and Marcel Dekker Inc., New York, NY, USA.

From this, it can be concluded that both partition and diffusion are very important in determining skin penetration. They are normally combined in the permeability coefficient according to the formula:

$$k_p = \frac{K_{oct/water} \cdot D}{L} \quad (\text{Equation 53.1})$$

in which k_p is the permeability coefficient, $K_{oct/water}$ the octanol/water partition coefficient, D the diffusion coefficient and L the length of the pathway of diffusion of the penetrating molecule. The unit of the permeability coefficient, cm/s, indicates that this parameter basically reflects the speed with which a chemical diffuses through the stratum corneum. However, in order to obtain efficacy a sufficiently high

concentration of the active ingredient needs to be reached at the site of action and maintained for a sufficiently long period of time. Absolute amounts are therefore also important but here some conflicting evidence is obtained from skin penetration theory.

The most logical way to increase the degree of skin penetration is to increase the concentration of the active ingredient in the formulation, according to the well-known formula:

$$J = k_p \cdot \Delta C = \frac{K \cdot D}{L} \cdot \Delta C \quad (\text{Equation 53.2})$$

in which ΔC is the concentration difference of the penetrating molecule over the stratum corneum, i.e., the difference in concentrations between the formulation and the deepest layers of the stratum corneum. The larger this concentration difference, the greater the flux through the stratum corneum. At the same time, the more soluble an active ingredient is in the formulation, the more active ingredient can be contained in the formulation and the more can therefore penetrate into the stratum corneum.

But difficulties arise when increasing the solubility of the active ingredient in the formulation. According to the definition of the partition coefficient, the $K_{sc/form}$ of the penetrating molecule, the solubility of the active ingredient in the stratum corneum is related to its solubility in the formulation as expressed in **Equation 53.3**:

$$K_{sc/formulation} = \frac{C^{penetrant} \text{ in stratum corneum}}{C^{penetrant} \text{ in formulation}} \quad (\text{Equation 53.3})$$

in which $K_{sc/formulation}$ represents the solubility of the penetrating molecule in either the stratum corneum or the formulation. Because this K is the same as those in Equations 1 and 2, the quantity of penetrating molecules into the stratum corneum can be increased by increasing the solubility of the penetrating molecule in the stratum corneum or by reducing its solubility in the formulation. One therefore needs to increase the solubility of the active ingredient in the formulation in **Equation 53.2** to achieve sufficiently high quantities

to obtain efficacy in the skin, but one needs to reduce the same solubility in order to force the material to leave the formulation and partition into the stratum corneum.

The remainder of this article will describe how can one increase and reduce the solubility of the active ingredient in the formulation at the same time via formulation design using the Relative Polarity Index (RPI).

The Influence of Formulation Characteristics on Skin Delivery

The theoretical discussion above clearly indicates that the formulation determines the following parameters:

- The total amount dissolved in the formulation that is available for skin penetration; the higher this amount, the more will penetrate until a saturation concentration is reached in the skin, therefore a high solubility in the formulation is required.
- The polarity of the formulation relative to that of the stratum corneum; if a penetrant dissolves better in the stratum corneum than in the formulation, then the partition of the active ingredient will favor the stratum corneum, therefore a low solubility in the formulation is required.

Both requirements cannot be fully met at the same time but the problem can still be solved using the novel concept of a Relative Polarity Index (RPI). In this systematic approach, it is essential to consider the stratum corneum as yet another solvent with its own polarity.

It appears that the stratum corneum behaves very similar to butanol, but in a somewhat more polar fashion than butanol with respect to its solubilizing ability for penetrants.² The experimentally determined $\log K_{\text{octanol/water}}$ of 1-butanol is 0.88.³ For the purpose of this work, the polarity of the stratum corneum as expressed by its octanol/water partition coefficient is set at $10^{0.8}$, which is 6.3.

Partition Coefficient Determination or Calculation

For the following, it is essential to know what an octanol/water partition coefficient is. The octanol/water partition coefficient is calculated according to the formula:

$$K_{\text{octanol/water}} = \frac{C_{\text{max}}^{\text{penetrant}} \text{ in octanol}}{C_{\text{max}}^{\text{penetrant}} \text{ in water}} = \frac{C^{\text{penetrant}} \text{ in octanol}}{C^{\text{penetrant}} \text{ in water}} \quad (\text{Equation 53.4})$$

n-Octanol and water do not mix and the octanol/water partition coefficient is a measure of the polarity of a chemical. If the chemical is lipophilic, larger amounts will dissolve in the lipophilic *n*-octanol than the polar water. For a hydrophilic chemical, this will be reversed.

This coefficient can be experimentally determined by assessing the maximum solubility of a chemical in *n*-octanol and in water, respectively, or by assessing the ratio of the concentrations of the chemical when dissolved in both phases at levels below the maximum solubility. Alternatively, the partition coefficient can be estimated from the chemical structure, although care should be taken which method of calculation is being used.⁴ One should realize that the partition coefficient is often expressed by its logarithmic value; in this article the RPI value of a chemical, stratum corneum or formulation is the ¹⁰log of the corresponding octanol/water partition coefficient.

The Relative Polarity Index

The Relative Polarity Index (RPI) is a way to compare the polarity of an active ingredient with that of the skin and emollient components of cosmetic formulations. It is visualized as a vertical line with a high polarity at the top and a high lipophilicity at the bottom. The polarity is expressed by the octanol/water coefficient. In order to use the concept of the Relative Polarity Index, three numbers (on log₁₀ scale) are required, namely:

- The polarity of the stratum corneum, here set at 0.8 (but in reality this value will change with the hydration state of the stratum corneum that is determined by factors such as the external relative humidity);⁵

- The polarity of the penetrating molecule;
- The polarity of the formulation. For multiphase (i.e., multipolarity) systems like emulsions, this is the phase in which the active ingredient is dissolved.

The polarities of these three entities can be placed on the RPI by simply marking their position on the vertical line.

Case I: Penetrants with a polarity equal to the stratum corneum:

Imagine the example of an active ingredient with a $\log K_{\text{oct/water}}$ equal to that of the stratum corneum (0.8). If the formulation now also has the same polarity, the solubility of the penetrant in the stratum corneum and the formulation would be the same. After equilibrium is reached, the concentration of active ingredient over the two phases (formulation and stratum corneum) would be the same although the absolute amount in both layers will depend on their respective volumes.

Based on the physicochemical characteristics of the system, there is no drive for the active ingredient to leave the formulation and enter the skin, apart from the fact that the stratum corneum does initially not contain any penetrant (i.e., a dilution effect). Such a situation is very unlikely because in reality almost all active ingredients have polarities that differ from that of the stratum corneum. The second and third case are therefore much more common and deserve separate discussion.

Case II: Penetrants more polar than the stratum corneum:

In order to illustrate the use of the RPI with a penetrant that is more polar than the stratum corneum, it is assumed that the active ingredient is the skin whitener arbutin with a calculated $\log K_{\text{octanol/water}}$ of 0.01. First, the polarity difference between the stratum corneum and the penetrant is calculated by subtracting the polarity of the penetrant from that of the stratum corneum; in this case $0.8 - 0.01 = 0.79$. See **Figure 53.2**.

In the second step, the polarity of the formulation is calculated. The polarity of the phase of the formulation in which the active ingredient is dissolved should be 0.79 more or less than that of the active ingredient itself; that means either greater than 0.8 ($0.01 + 0.79$) or smaller than -0.78 ($0.01 - 0.79$).

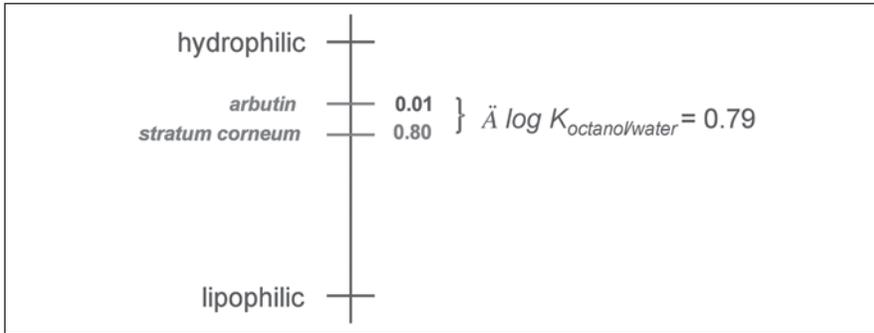


Figure 53.2. Visualization of the penetrant polarity gap between an active ingredient more polar than the stratum corneum (in this case arbutin) and the stratum corneum using the Relative Polarity Index

For formulations that are more lipophilic than the stratum corneum, the arbutin will be more soluble in the stratum corneum than in the formulation and would therefore prefer to be located in the stratum corneum, creating a driving force for partitioning into the stratum corneum. The more extreme the difference in polarity between the formulation and the active ingredient, the greater this driving force for partition into the stratum corneum. This is illustrated on the left in **Figure 53.3** by the width of the red blocks (arrows).

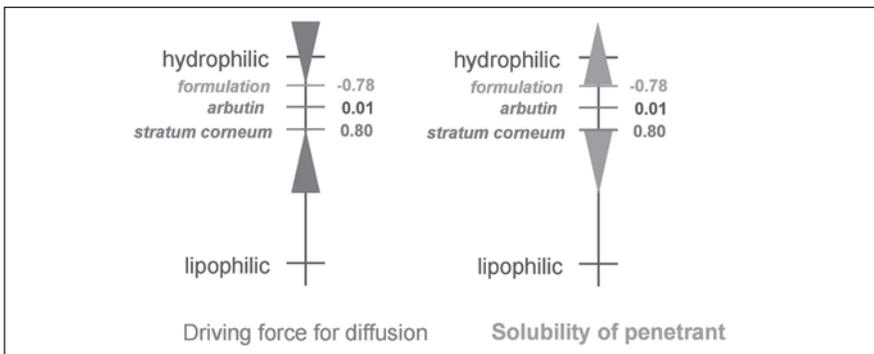


Figure 53.3. Example of the calculation of the polarity of a formulation for penetrants more polar than the stratum corneum. Arbutin is used as an example. On the left, the influence of the polarity of the formulation on the driving force on diffusion is illustrated and on the right, the influence of the polarity of the formulation on the solubility of the penetrant is illustrated.

However, at the same time, the solubility of the penetrant in the formulation will reduce if the polarity difference between formulation and active ingredient is enlarged. This is illustrated by the green blocks on the right in **Figure 53.3**.

In the case of arbutin, a formulation with a polarity of 4 has a greater driving force for partitioning arbutin into the stratum corneum than a formulation with a polarity of 1 because $3.99 (4 - 0.01)$ is greater than $0.99 (1 - 0.01)$. Likewise, a formulation with a polarity of -3 has a greater driving force for partitioning arbutin into the stratum corneum than a formulation with a polarity of -1 because $3.01 (-3 - 0.01)$ is greater than $1.01 (-1 - 0.01)$. Only the absolute difference counts. Practically, of course, it is much more difficult to dissolve arbutin in an aqueous solvent with a polarity of -3 than -1 or a lipophilic solvent with a polarity of 4 than 1.

Case III: Penetrants more lipophilic than the stratum corneum:

A much more common situation is that in which the penetrants are more lipophilic than the stratum corneum. This time, it is assumed that the active ingredient is octadecenedioic acid (referred to hereafter as dioic acid), a much more lipophilic skin whitener⁶ with a theoretical $\log K_{\text{octanol/water}}$ of 5.84 and an experimentally determined $\log K_{\text{octanol/water}}$ of 5.74 ± 0.29 . For simplicity, the value of 5.8 has been used in the calculations. Again, the polarity difference between the stratum corneum and the active ingredient needs to be calculated first, which is 5 ($5.8 - 0.8$). See **Figure 53.4**.

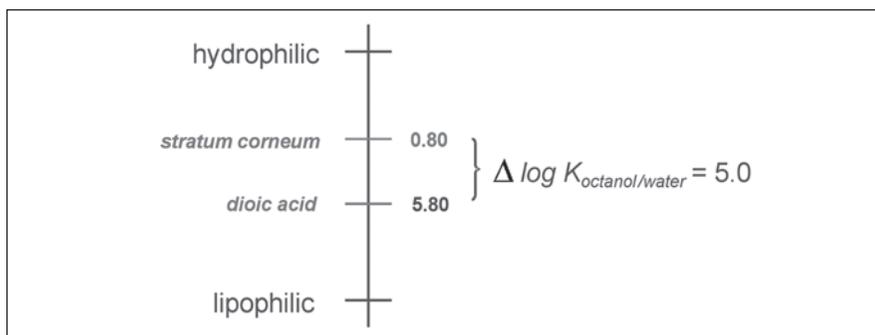


Figure 53.4. Visualization of the polarity gap between an active ingredient more lipophilic than the stratum corneum (in this case octadecenedioic acid) and the stratum corneum using the Relative Polarity Index

In the next step, the polarity of the formulation should be calculated. The polarity of the phase of the formulation in which the active ingredient is dissolved should be more than 5 away from that of the active ingredient itself; that is, either above 10.8 ($5.8 + 5$) or below 0.8 ($5.8 - 5$).

For formulations that are less lipophilic than the stratum corneum, the dioic acid is more soluble in the stratum corneum than in the formulation and would therefore 'prefer' to be located in the stratum corneum rather than in the formulation, creating a driving force for partition into the stratum corneum. As before, the more extreme the difference in polarity between the formulation and the active ingredient, the greater the driving force for partition into the stratum corneum. This is illustrated on the left in **Figure 53.5**.

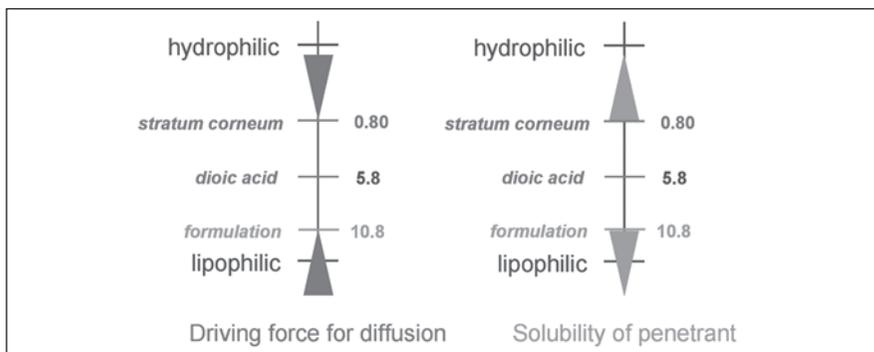


Figure 53.5. Example of the calculation of the polarity of a formulation for penetrants more lipophilic than the stratum corneum. Octadecenedioic acid is used as an example. On the left, the influence of polarity of the formulation on the driving force on the diffusion is illustrated and on the right, the influence of the polarity of the formulation on the solubility of the penetrant is illustrated.

At the same time, the solubility of the penetrant in the formulation will reduce if the polarity difference between formulation and active ingredient is enlarged. This is illustrated on the right in **Figure 53.5**.

In the case of dioic acid, a formulation with a polarity of 10 has a greater driving force for partitioning dioic acid into the stratum corneum than a formulation with a polarity of 7 because 4.2 ($10 - 5.8$) is greater than 1.2 ($7 - 5.8$). Likewise, a formulation with a polarity of -3 has a greater driving force for partitioning dioic acid into the stratum corneum than a formulation with a polarity of -1 because

8.8 ($-3 - 5.8$) is greater than 6.8 ($-1 - 5.8$). Again, only the absolute difference counts. Practically, of course, it is much more difficult to dissolve dioic acid in an aqueous solvent with a polarity of -3 than -1 or a lipophilic solvent with a polarity of 10 than 7.

Using the Relative Polarity Index in Practice

From the theory discussed above, it can be concluded that the polarity of the formulation needs to be as far away as possible from the polarity of the active ingredient in order to increase the driving force of the active ingredient into the skin, but at the same time as close as possible to that of the active ingredient to ensure that high concentrations can be reached to ensure that enough material penetrates. Because these two opposing requirements cannot be met at the same time, it is necessary to describe how to find the optimum polarity of the formulation from the point of view of skin delivery.

Step 1: Optimizing the solubility by selecting the primary emollient or solvent: After having calculated the polarity difference between penetrant and stratum corneum and hence the acceptable polarity ranges of the formulation, the formulator should have an idea whether the phase containing the active ingredient will be hydrophilic or lipophilic in nature. In other words, will the formulation be at the top or at the bottom of the RPI as indicated by the arrows in **Figures 53.3** and **53.5**? It is important to note that if a lipophilic penetrant is dosed in an o/w emulsion and dissolved in the internal oil phase, the phase containing the penetrant is lipophilic in nature whereas the formulation may be hydrophilic in nature.

As a first step, an emollient (for lipophilic active ingredients) or a water-miscible solvent (for hydrophilic active ingredients) in which the active ingredient dissolves well should be identified. This primary emollient or solvent is chosen in the direction of the required RPI. In other words, choose an emollient with a RPI value not too far away from that of the active ingredient, for instance 7 or 8 in case of dioic acid if the polarity of the final formulation will be lipophilic or 3 or 4, if the final formulation will be hydrophilic. **Table 53.1** provides RPI values of some typical emollients and hydrophilic solvents that span a wide range. These RPI values can be used to select a suitable solvent or emollient.

Table 53.1. Relative Polarity Index values for some hydrophilic solvents and lipophilic emollients typically used in cosmetic formulations

INCI name	Trade name, supplier	Calculated log P value
Glycerin	Pricerine 9091, Uniqema	-1.76
Dipropylene glycol	DPG LO+, Dow Chemical USA	-1.20
Propylene glycol	1,2-Propylene Glycol Care, BASF	-0.92
Ethanol	Pharconix BPS PF, Ichimaru Pharcos.	-0.32
Triethylhexanoin	Estol 3609, Uniqema	2.70
Glyceryl isostearate	Prisorine 2040, Uniqema	4.76
Isopropyl myristate	Estol 1512, Uniqema	5.41
Propylene glycol isostearate	Prisorine 2034, Uniqema	6.08
Isopropyl isostearate	Prisorine 2021, Uniqema	7.40
Ethylhexyl palmitate	Estol 1543, Uniqema	9.12
Ethylhexyl isostearate	Prisorine 2036, Uniqema	10.05
Vegetable squalane	Pripure 3759, Uniqema	14.93
Triisostearin	Prisorine 2041, Uniqema	18.60
Trimethylolpropane triisostearate	Prisorine 3630, Uniqema	20.27
Pentaerythrityl tetraisostearate	Prisorine 3631, Uniqema	25.34
Isostearyl isostearate	Prisorine 2039, Uniqema	26.98

Step 2: Optimizing the driving force by selecting the secondary emollient or solvent: Once a suitable primary emollient or solvent has been selected, the driving force for penetration into skin needs to be increased by reducing the solubility in that solvent. This is typically done by incorporating another solvent, the secondary emollient or solvent, in which the active ingredient is far less soluble but still miscible with the originally chosen solvent or emollient.

When adding increasing amounts of the secondary emollient or solvent, the solubility of the active ingredient is gradually reduced and, as a consequence, the total amount of active ingredient dissolved relative to what could be dissolved increases. Sufficient secondary emollient or solvent has been added when this fraction of maximum solubility has reached a value of about 90% in that solvent mixture.

Skin Delivery Experiments Demonstrating Use of RPI

An example of the use of RPI is the formulation of dioic acid for which RPI values of more than 10.8 and less than 0.8 would be acceptable.

Propylene glycol isostearate with an RPI of 6.08 was chosen as the solvent for this particular penetrant and the solubility assessed to be 17% w/w. This solubility was too high to guarantee a good driving force for diffusion; therefore, increasing amounts of triethylhexanoin were added to reduce the solubility to just above 2% in the total formulation (10% in the oil phase). In this way, the composition shown in **Formula 53.1** was created. **Formula 53.2** was made simply based on physical stability of the emulsion system. **Formulas 53.1** and **53.2** were used to demonstrate the influence of the emollients on skin delivery. **Formula 53.3**, which differed from **Formula 53.1** principally in the choice of surfactants, was used to investigate the influence of the emulsifier on skin delivery.

The influence of the emollients: **Formulas 53.1** and **53.2** were tested separately for skin delivery.

For the delivery-optimized formulation (**Formula 53.1**), full-thickness pigskin dermatomed to 400 μm was used in vitro in a

Formula 53.1. Dioic acid-containing o/w formulation designed according to the Relative Polarity Index principles, i.e. skin delivery optimized

Propylene glycol isostearate (Prisorine 2034, Uniqema)	15.0% w/w
Triethylhexanoin (Estol 3609, Uniqema)	3.0
Octadecenedioic acid (Arlatone Dioic DCA, Uniqema)	2.0
Steareth-21 (Brij 721, Uniqema)	5.0
Steareth-2 (Brij 72, Uniqema)	1.0
Glycerin (Pricerine 9091, Uniqema)	4.0
Xanthan gum (Keltrol, Kelco)	0.2
Phenoxyethanol (and) methylparaben (and) propylparaben (and) 2-bromo-2-nitropropane-1,3-diol (Nipaguard BPX, Nipa)	0.7
Aqua (water)	qs 100.0

Formula 53.2. Dioic acid-containing o/w formulation designed solely on physicochemical stability and not optimized for skin delivery

Caprylic/Capric triglyceride (Estol 3603, Uniqema)	10.0%w/w
Glyceryl stearate SE (Estol 1461, Uniqema)	3.0
Steareth-21 (Brij 721, Uniqema)	5.0
Steareth-2 (Brij 72, Uniqema)	1.0
Cetyl alcohol (Lanol C, Seppic)	2.0
Octadecenedioic acid (Arlatone Dioic DCA, Uniqema)	2.0
Glycerin (Pricerine 9091, Uniqema)	3.0
Benzoic acid (Unisept BZA, Universal Preserv-A-Chem Inc.)	0.2
2-Amino-2-methyl-1-propanol (AMP, Angus Chemie GmbH), to pH 5.5	qs
Aqua, distilled	qs 100.0

Formula 53.3. Dioic acid-containing o/w formulation designed according to the Relative Polarity Index principles using a different emulsifier system than Formula 1

Propylene glycol isostearate (Prisorine 2034, Uniqema)	15.0%w/w
Triethylhexanoïn (Estol 3609, Uniqema)	3.0
Octadecenedioic acid (Arlatone Dioic DCA, Uniqema)	2.0
Sorbitan stearate (and) sucrose cocoate (Arlatone 2121, Uniqema)	5.5
Glycerin (Pricerine 9091, Uniqema)	4.0
Xanthan gum (Keltrol, Kelco)	0.2
Phenoxyethanol (and) methylparaben (and) propylparaben (and) 2-bromo-2-nitropropane-1,3-diol (Nipaguard BPX, Nipa)	0.7
Aqua (water)	qs 100.0

Franz-diffusion cell dosed at a rate of 10 $\mu\text{L}/\text{cm}^2$. Cells were left in place for 24 hours after which the formulation was removed; the skin was tape-stripped 21 times; strips, remainder of skin and receptor fluid were analyzed to assess skin penetration.

For the formulation that was not optimized for skin delivery (**Formula 53.2**), full-thickness pigskin (500 μm) was used in vitro in a Bronaugh flow-through diffusion cell dosed at a rate of 66 $\mu\text{L}/\text{cm}^2$. Cells were left in place for 20 hours after which the formulation was removed; the skin was tape-stripped 5 times; strips, remainder of skin and receptor fluid were analyzed to assess skin penetration. Results of these experiments are given in **Figure 53.6**.

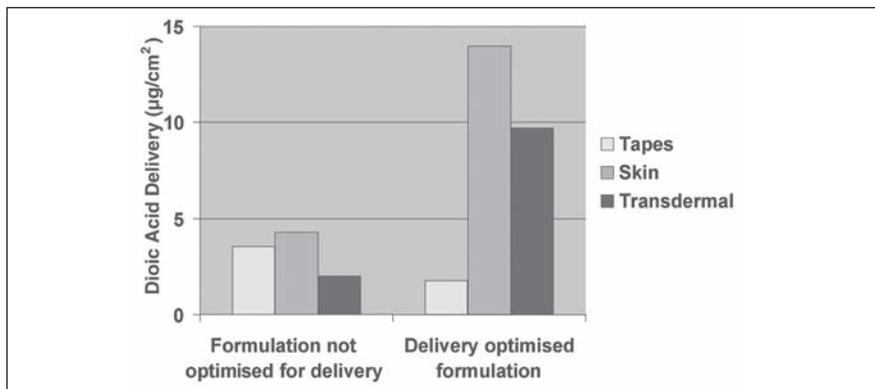


Figure 53.6. Skin delivery of octadecenedioic acid of a formulation not optimized for skin delivery and a delivery optimized formulation according to the Relative Polarity Index concept (for composition, see Formula 2 and 1, respectively). Note that the latter delivers significantly more dioic acid to the skin.

As can be seen from **Figure 53.6**, the total delivery (i.e., the sum of the amounts recovered in the tapes, the skin and transdermal delivery) is far greater from the formulation that was optimized for skin delivery, therefore illustrating the validity of the use of RPI values for selecting emollients to enhance skin delivery.

The differences in skin penetration methodologies between the two experiments were only minor; although the delivery-optimized formulation had a 6-fold lower dosing rate than the formulation not optimized for skin delivery (favoring the skin penetration from the latter), both were performed under infinite dosing conditions. Dermal delivery after 22 hours may be considered to be constant after steady-state transdermal fluxes have been achieved (data not shown). In other words, we believe the observed difference in skin penetration to be due to differences in formulation design rather than to differences in skin penetration methodology.

Because dioic acid needs to be delivered to the melanocytes where it reduces the quantity and/or half-life of the tyrosinase enzyme (the enzyme involved in skin color formation),⁷ the delivery to the skin layer should be as high as possible. Due to the use of the RPI concept, the skin delivery has increased 3.5-fold, from 4.3 to 14.0 $\mu\text{g}/\text{cm}^2$, without an increase in the concentration of the active ingredient in the formulation.

Concentrations of above 2% dioic acid in the formulation that was not optimized for skin delivery were previously tested for skin delivery⁸ and demonstrated that a 4-fold increase in dioic acid concentration in the formulation (from 2 to 8%) resulted in only a 2-fold increase of skin delivery (from 4.3 to 8.0 $\mu\text{g}/\text{cm}^2$). It may therefore be advisable to change a standard formulation by selecting emollients according to the RPI concept rather than change the active ingredient or its concentration.

The influence of the emulsifier: So far, the tested formulations only differed in terms of their emollients, which showed that the choice of the emollients greatly influences the total quantity of active ingredient absorbed into the skin. But the effect of the emulsifier on skin delivery of active ingredients is also of interest. Emulsifiers often act as skin penetration enhancers, in particular the cationic, followed by the anionic and finally the nonionic. Whereas the nonionic surfactants penetrate better into skin, their interaction with skin lipids and therefore skin penetration enhancement is less extensive.⁹

In order to investigate the effect of the emulsifier on the skin penetration of dioic acid, **Formula 53.3** was prepared using the same concentrations of dioic acid, propylene glycol isostearate and triethylhexanoin as in the skin delivery-optimized formulation, but a different surfactant was selected. Because this emollient combination was selected on the RPI concept, this is also a skin delivery optimized formulation. The only difference from the **Formula 53.1** is the emulsifier system.

Skin delivery results are depicted in **Figure 53.7** and show that while the total amount delivered is high in both cases (due to the choice of primary and secondary emollient via the RPI concept) a

completely different skin distribution pattern is obtained. Because this has been observed a few times for different emulsifiers, both o/w and w/o, it is suggested that the emulsifier influences the distribution of the active ingredient within the skin. No explanation can be given for this phenomenon at the present time.

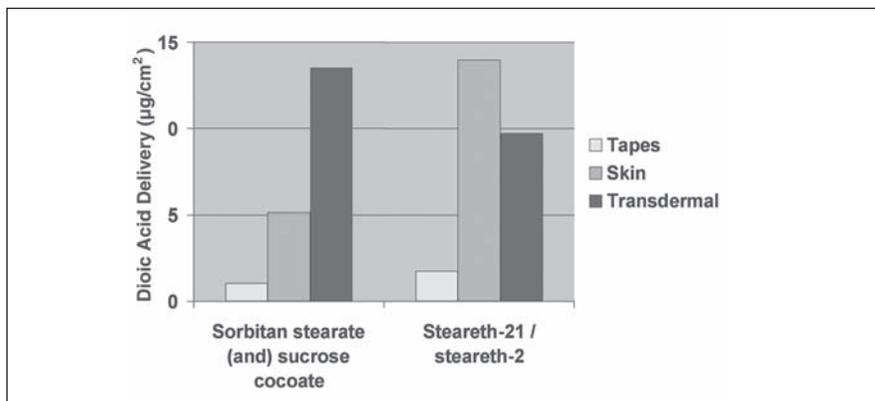


Figure 53.7. Skin penetration results of two almost identical formulations, only differing in their emulsifier system. Full composition details of the steareth-2/steareth-21 formulation are given in Formula 1 and that of the sorbitan stearate (and) sucrose cocoate formulation in Formula 3. Note that whereas the total amount delivered is high in both cases (as determined by the choice of the emollient(s)), the distribution profile of octadecenedioic acid is highly influenced by the choice of the emulsifier.

Conclusions

Most cosmetic companies will formulate their active ingredients into a few standard formulations prior to efficacy testing, almost exclusively based on physical and chemical stability and sometimes on sensory properties. Subsequent efficacy tests often reveal the cosmetic product to be without cosmetic activity.

Based on theoretical considerations, it was predicted that the polarity of the phase in which the active ingredient of a cosmetic formulation is located would have a profound influence on the flux of the active ingredient into the skin. Examples for a hydrophilic and a lipophilic penetrant clearly demonstrate that the efficacy of formulations can be improved by selecting the right emollient (system) using the Relative Polarity Index. This involves dissolving an active ingredient at the highest possible concentration in a primary

emollient and then reducing its solubility to an acceptable level using a secondary emollient.

Initial skin penetration experiments showed that formulations designed according to this concept deliver significantly more active ingredient into the skin than formulations that have “only” been optimized for physical stability.

Further research into the other components of cosmetic formulations revealed that the choice of emulsifier is also important, because it seems to determine the distribution profile of the active ingredient within the skin. Whereas the reasons for the choice of the emollient are clearly understood from a theoretical point of view, the rationale for selecting the right emulsifier remains unclear and further research will be necessary to elucidate the exact influence of the emulsifier on skin delivery.

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SECTION X

Specials

This section includes the following chapters:

- 54** Effects of Occlusion (II): Wound Healing
- 55** Personal Care Wipes: Manufacturing Practices & Microbiological Control

Effects of Occlusion (II): Wound Healing

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KEY WORDS: *skin, semipermeable membranes, wound healing, water loss, skin occlusion, Langerhans cells*

ABSTRACT: *The present chapter focuses on the effects of occlusive and semipermeable membranes on wound healing and summarizes related data.*

Skin occlusion is a complex issue that includes altering epidermal lipids, DNA synthesis, epidermal turnover, pH, epidermal morphology, sweat glands, Langerhans cells stresses, etc.^{1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17} Occlusion usually means the skin is covered directly or indirectly by impermeable films or substances such as diapers, tape, chambers, gloves, textiles garments, wound dressings, transdermal devices, etc.;¹ but certain topical vehicles that contain fats and/or polymer oils (petrolatum, paraffin, etc.) may also generate occlusive effects.²

A broad selection of occlusive or semi-occlusive dressings has been long employed to speed the healing processes in acute and chronic wounds.¹⁸ They keep healing tissues moist and increase superficial wound epithelialization.^{2,18,19,20,21,22} However, occlusive or semiocclusive dressings can increase microorganisms and hence induce wound infections.^{2,23,24,25} Significant increases in the density of *Staphylococcus aureus* and lipophilic diphtheroids were observed after 24 h occlusion in eczematous and psoriatic skin.¹⁴

Effects of Occlusive and Semipermeable Membranes on Wound Healing

Superficial wounds in domestic pigs: Alvarez et al.²¹ compared the effects of several types of occlusion on superficial wounds in domestic pigs. The occlusion types were: two different occlusive dressings; non-occlusive wet to dry gauze dressings; and air exposure. Collagen synthesis and re-epithelialization were increased in the wounds treated with occlusive dressings. Re-epithelialization was increased beneath both the oxygen-impermeable and the oxygen-permeable dressing. When removed, the wet to dry gauze dressing and one of the occlusive dressings often damaged the new epidermis.

Biopsy punch in rabbits: Surinchak et al.²⁶ monitored healing process by measuring water evaporation. In the first study two wounds were created with a 2-mm biopsy punch on the backs of each of 15 rabbits and covered with occlusive and semioclusive dressings. Water loss increased from a preoperative value of 6 g/m²/hr to 55 g/m²/hr after biopsy. Water loss from the occluded site returned to baseline values in 9 days as opposed to 17 days for the semiocluded sites ($p < 0.05$).

Full-thickness 4 x 4 cm wounds in rabbits: A second study by Surinchak et al.²⁶ followed the healing of full-thickness 4 x 4-cm wounds in five rabbits treated with fine-mesh gauze and five treated with a human amnion dressing.²⁶ Wound area and water loss were observed during the repair process. In visual evaluations of the wound area, the injuries appeared 100% healed on day 30. However, the evaporimeter detected significantly increased water loss up until day 45 when original baseline values were reached. No differences were observed between the gauze and amnion groups.

The evaporimeter presents a simple yet accurate, noninvasive tool for measuring the wound healing endpoint based on regeneration of the epidermal water barrier.

Human dermabrasion wound: Pinski²⁷ compared a series wound dressing utilizing a human dermabrasion wound healing model. Occlusive dressings hastened healing time as much as 50% over air-exposed sites.

Acetone-induced wounds in hairless mice: Grubauer et al.²⁸ treated hairless mice with acetone that removed stainable neutral lipids from the stratum corneum (SC) and compared the rate of repletion of stainable lipids, barrier recovery, and epidermal lipogenesis in animals covered with occlusive membranes or vapor-permeable membranes versus uncovered animals. Acetone treatment perturbed epidermal barrier function, which returned to normal in uncovered animals in parallel with the reappearance of SC lipid; when animals were covered with an occlusive membrane, barrier function did not recover normally. In contrast, occlusion with vapor-permeable membranes allowed barrier function to recover normally.

They concluded that occlusive membranes prevented the increase in epidermal lipid synthesis while a vapor-permeable membrane increased epidermal lipid synthesis in animals.

Wounds produced in human subjects: Silverman et al.²⁹ examined the effects of occlusive dressings on the reestablishment of the cutaneous barrier to transepidermal water loss (TEWL) after standardized skin wounds produced in human subjects. Wound repair occurred more quickly under occlusive or semioclusive dressings than when it was allowed to proceed exposed to the environment. However, no significant improvement in the rate of reestablishment of the barrier to TEWL was measured between the covered test or uncovered control sites in each subject.

Suction blister wound model in humans: Levy et al.³⁰ utilized a suction blister wound model to assess drug effects on epidermal regeneration with 20 healthy volunteers. Four suction blisters were produced on the volar aspect of the forearm. Then the epidermis was removed to create a standardized subepidermal wound. Thereafter, the wounds were treated topically for 6 h daily during 14 days. The following treatments were compared: a topical clobetasol 17-propionate preparation under occlusion; a corticoid-free cream under occlusion; no treatment and occlusion (aluminium chamber); no treatment and no occlusion.

Daily measurement of TEWL above the wounds was performed. The 0.05% clobetasol 17-propionate preparation caused a dramatic delay in TEWL decrease, whereas the untreated unoccluded

field showed a continuous decrease over 14 days. Occlusion and corticoid-free treatment led to a weak but significant delay of TEWL decrease when compared to the untreated unoccluded test field.

Tape stripping wound in humans: Visscher et al.³¹ evaluated the effects of semipermeable films on human skin following a standardized tape stripping wound by measuring of TEWL, skin hydration, rate of moisture accumulation, and erythema. Wounds treated with semipermeable films underwent more rapid barrier recovery than either unoccluded wounds or wounds under complete occlusion. Barrier films that produced intermediate levels of skin hydration during recovery produced the highest barrier repair rates.

Conclusions

Occlusion dressing may hasten the healing time^{2,18,19,20,21,22,27,29} but complete occlusion dressings have some disadvantages,^{21,26,28,30} particularly when compared to semioclusion dressings. Therefore, an ideal wound dressing would require a compromise between occlusion and nonocclusion. It should absorb exudate, thus decreasing bacteria; permit fluid evaporation; and either avoid incorporation into the eschar or be sufficiently fragile to allow its removal without compromising the healing wound.

Advanced dressings attempt to specifically maintain a moist wound environment. Natural, pure, and non-woven dressings from calcium alginate fibers can rapidly absorb and retain wound fluid to form an integral gellified structure, thereby maintaining an ideal moist wound healing environment.³² It can also trap and immobilize pathogenic bacteria in the network of gellified fibers. And it can stimulate macrophage activity and activate platelets, resulting in homeostasis and accelerated wound healing.

The biologic effects of dressings remain a complex science: at a minimum, clinical relevance for man requires a multifaceted interpretation based on our current knowledge of “validation for man.” When can we extrapolate from rodents to man, what is the overlying “Rosette Stone” that might relate the more “superficial” (stripping and/or solvent extraction) knowledge to split and full thickness wounds? What can be learned from other factors (O₂, CO₂, and

electrolytic transport)? These represent but a few of the challenges for wound dressing developers.

Today, with the rapid development of new technologies in bio-science, we can expect greater efficacy and optimal dressings or materials that can absorb excess water in accelerating the healing of wounds without the unfavorable effects of occlusion.

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Personal Care Wipes: Manufacturing Practices & Microbiological Control

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KEY WORDS: *wipes, microbiological control, manufacturing processes, contamination, substrate control*

ABSTRACT: *In order to control microbial contamination in personal care wet wipes, one must understand the substrate raw materials, the requirements of the manufacturing environment, the complexity of the product system and the specialized equipment employed in the processing and packaging operations.*

The need for microbiological control in the manufacture of personal care wet wipes and related products is, for the most part, a well established concept in the wet wipe industry. The means of accomplishing this goal, however, may not be as clearly defined or as effectively implemented as would be desired.

In terms of existing guidelines, the CTFA has provided a wealth of valuable general guidance in the CTFA Technical Guidelines. It is strongly suggested that these guidelines be consulted since they do provide an excellent overview of the basic requirements for good manufacturing practices as related to microbiological control.

However, the recent expansion of the wet wipe market (see **An Expanding Market sidebar**) and consideration of the unique characteristics and qualities of personal care wipe production suggest that existing procedures and/or practices currently in place in many operations may require some adjustment. In order to control

microbial contamination in this product form, it is necessary to have a complete understanding of the nature of the substrate raw materials, the requirements of the manufacturing environment, the complexity of the product system and the specialized equipment employed in the processing and packaging operations.

Up until this time, very little meaningful and comprehensive information has appeared in the literature relating to the identification of microbiological vulnerabilities in the wet wipe manufacturing process. In addition to the numerous questions associated with formulation and substrate interaction, the next most commonly sought after information appears to be focused on the effective microbiological control of the manufacturing environment as well as the various materials, equipment and personnel involved in the production operation.

This work will attempt to clarify some of the major issues and concerns related to sanitary wet wipe production.

The Wet Wipe Product System

The typical wet wipe product is composed of a combination of non-woven substrate or wipe material coupled with a functional liquid or lotion formulation which is contained in any one of a number of different packaging configurations. It is the blending of these various

An Expanding Market

The personal care wet wipe market has expanded exponentially over the last number of years. New and novel approaches to utilizing the unique delivery properties of the wipe concept have allowed manufacturers to adapt this relatively old technology to a myriad of new product applications essentially unheard of in the past.

Wipe products designed for baby and adult cleansing, makeup removal, skin moisturization, sunscreen and insect repellent delivery, skin disinfection as well as skin nutrition and treatment have become commonplace in the market.

With so many new wipe product forms appearing, the need for additional specific guidance in controlling microbial contamination becomes a major challenge.

technologies that creates the uniqueness of this product form while at the same time creating some of the more difficult, and sometimes frustrating, challenges to microbiological control.

The nonwoven substrate or wipe material used in these products can be composed of any one of a variety of fiber types including cellulose or wood pulp, rayon or viscose, polyester and polypropylene polymer extrusions or bicomponent materials. The susceptibility of the substrate to contamination during its manufacture as well as its influence on the effectiveness of the preservative system in finished products will vary considerably depending upon the type of substrate being used.

Further complicating the situation is the fact that there are many different processes used for the production of substrates. The major nonwoven technologies include airlaid, spunlace, carded web, hydrospun, hydroknit, spunbonded, meltblown, needle punched and wet laid. With the possible exception of the spunbonded and meltblown processes, each of the others brings its own degree of potential microbiological risk to the product system if not properly controlled.

Substrate Control

In addition to the actual nonwoven process, the handling, storage, packaging and shipping conditions of the substrate rolls can pose a potential microbiological concern. Damaged or poorly protected rolls can be exposed to significant environmental contamination during the handling, storage and shipping of the material. Because environmental bacteria and, more importantly, fungal contamination are significant problems in wet wipe products, it is critical that this material be controlled both before and after receipt by the wipe manufacturer. Although most reputable substrate manufacturers or converters have implemented fairly extensive in-house programs to minimize microbiological contamination during and after production, it is the wet wipe manufacturer's responsibility to verify that these controls are adequate to properly ensure the microbiological integrity of this critical wipe system component.

As with other providers of critical product components, substrate suppliers should be regularly monitored/audited to verify proper compliance to in house standards of acceptability. Minimally, all substrate receipts should undergo appropriate incoming inspections according to pre-established inspection guidelines and specifications. Samples should be taken using a predetermined sampling plan and evaluated appropriately for both bioburden and conformance to the in-house criteria of acceptability.

Particular attention should be paid to the cleanliness of the incoming roll stock. Dust and dirt are major sources of environmental bacterial and fungal contaminants and, if not properly removed from incoming materials, can easily spread throughout the facility. Many companies have adopted a mandatory policy that no raw material, component, container, corrugate, pallet or other incoming receivable be moved to any location in the facility until it has been properly cleaned. This would also apply to previously received and stored materials. A policy of this type can significantly reduce the spread of dust, dirt and environmental contaminants. Considering that one of the primary microbiological threats to wet wipe production comes from sources of environmental dust and dirt, it would appear to be wise to consider adopting this form of preventative microbiological control.

The Manufacturing Environment

One of the more popular misconceptions regarding the type of manufacturing facility required for wet wipe production is related to the need for a certified clean room manufacturing environment. As with most cosmetic and personal care production, the manufacturing environment for wet wipes need not be in a clean room category. The production areas must be acceptably clean and meet the established criteria and requirements as set forth by the CTFA guidelines and/or other in-house or industry standards for a properly controlled manufacturing environment. There is nothing wrong with using a clean room if it is available and cost effective, however, a clean room is not a mandatory or, for that matter, necessary requirement for quality production.

The first step in a good environmental microbiological control program consists of the development and implementation of appropriate methods, procedures and protocols that can effectively and consistently prevent or significantly reduce the probability of microbial contamination. An established SOP program, which includes specific direction for achieving an acceptable degree of control over the potential critical environmental sources of contamination, is mandatory. Key steps in this program are listed in **Table 55.1**.

Table 55.1. Key steps in an SOP program for a microbiological environmental quality system

- Control microbiological air and water quality;
- Control compressed air quality;
- Control humidity and temperature;
- Control air particulate quality;
- Housekeeping;
- Maintain facility and equipment;
- Control surface contamination (i.e. floors, walls, fixtures, piping);
- Validate the process and the system;
- Establish meaningful microbial action limits for air, water and surfaces;
- Develop appropriate air and surface testing methodology, sampling site plans and a responsive reporting system;
- Develop and implement environmental audit guidelines;
- Establish a useful SOP environmental documentation system;
- Determine and assign departmental functional responsibilities;
- Implement effective facility/equipment preventative maintenance and ongoing employee awareness training programs.

The final and most critical step in the establishment of a truly effective manufacturing environment microbiological control system is based upon the attitude of management and their dedication and effort to adopt and implement a comprehensive program of contamination prevention. Without this support, the probability of achieving success would be severely limited.

Sources of Contamination

The risks and potential sources of microbial contamination for the liquid component of wet wipes are essentially similar to those associated with the production and filling of batches of conventional cosmetic and personal care products. All susceptible raw materials, including water, must be of acceptable microbiological quality. In order to confirm raw material acceptability, a program of routine sampling and testing coupled with appropriate microbial specifications and expiration dating should be instituted. The system for the treatment and delivery of water for batch production requires appropriate validation utilizing a pre-established criteria of acceptability.

Cleaning and sanitizing: Process, converting and packaging equipment must be of good sanitary design and be capable of being effectively cleaned and sanitized. Written procedure for the cleaning and sanitization of mixing and storage tanks, transfer equipment, liquid fee hoppers, spray and fill mechanisms, recirculation systems as well as auxiliary equipment such as pumps, hoses, valves, fittings, couplings, and filters should be available.

The emphasis in the procedures should be on the cleaning process, which is the most critical aspect for ensuring that the sanitization for the equipment will be effective and that microbial contamination be controlled. Residual liquid product and substrate debris not removed from product contact surfaces can drastically impede the efficiency and effectiveness of the sanitization process. In all cases, validation of the effectiveness of the cleaning and sanitization protocols is strongly suggested. For OTC product forms, validation is a mandatory part of the cGMP requirements.

Converting master rolls to stacks: In addition to the issues cited previously regarding substrate receipt, storage and handling, additional potential microbiological concerns may be involved in the conversion of the master rolls to stacks or canister rolls. The microbiological concerns here are primarily those of excessive exposure of the equipment and in-process materials to personnel and the general environment during the operation.

Dust and dirt on equipment and overhead fixtures, extended conveyor system exposure time and the possibility of fans and/or air

diffusers blowing unfiltered air directly onto exposed material are some of the more commonly encountered high risk situations.

For tubs, travel packs, refills and similar stacked product configurations, automated equipment is most commonly used whereby the slitting, cutting and stacking of the wipes is normally accomplished simultaneously with the liquid addition or wipe saturation process. The general operational conversion or production process for these product types usually includes a single or multiple roll feeder system followed by spray bar liquid saturators. On some older equipment, a liquid recirculation system may also be present, however, recirculation units are notorious for being hot beds of microbial growth and proliferation and should be strictly avoided.

The next steps in the process are the slitting, folding and stacking operations. For horizontal multiple roll feed systems, a secondary saw house or stack cutting station is also included. On some of the vertical single roll units, total saturation of the wipes may not be possible; in this case the use of a secondary liquid filling station is required.

Depending upon the type of equipment, automatic stack insertion into tubs may or may not be available. If not available, manual stack insertion, which is a high risk and high exposure operation, is necessary. Personnel involved in this function require specialized training in aseptic handling technique. Hand covers and protective garments are generally advised.

The final phases of the operation include the automatic or manual closing of the tub lids followed by shrink wrapping or, for refills, overwrap packaging.

Converting master rolls to canisters: Using significantly different processes and equipment, the converting operation for canisters presents its own unique contamination control challenges. Essentially, a typical canister process involves two distinct and somewhat separate stages.

The first stage encompasses the manufacture of the individual canister rolls. This is often accomplished by using a single master roll feeding system that conveys substrate to a log roller/perforation unit. The log roller produces smaller perforated substrate logs containing a predetermined number of sheets. These logs are then fed into a

slitter unit that cuts the logs to the predetermined canister roll size. Some of the newer equipment is capable of combining both of these operations in the same function.

Once the canister rolls are formed, they are often stored until needed for final product production. As with other manufacturing processes, all the equipment substrate contact surfaces must be appropriately cleaned and sanitized prior to use. Additionally, since there can be a significant amount of manual handling of both the logs and the individual canister rolls, operating personnel should receive suitable training regarding microbiologically safe operational techniques.

The second stage of canister production involves the insertion of the rolls into the canisters and the liquid filling operation. There are several variations of the process. Generally, the rolls can be inserted into the canisters manually or using automated equipment. Major manufacturers obviously prefer the automated process, however, the manual process may be the most common.

Once the rolls are inserted into the canister, the canisters are conveyed to the primary filling unit where the appropriate volume of liquid is sprayed into the roll/canister unit. There are a number of variations in the types of fill nozzles used for this purpose. One of the more efficient approaches utilizes a shower spray configuration that is capable of delivering a homogeneous spray pattern that completely saturates the top of the roll.

An alternative approach to filling involves a partial prefill of the canister prior to inserting the roll. A secondary spray fill is then used to deliver the volume.

Following the filling operation, the lid is put in place and the unit proceeds to labeling and coding. Some manufacturers prefer to invert the canisters in the shipping cartons in order to ensure a complete saturation of the roll.

The liquid fill operation should be controlled in the same manner as required for typical liquid and lotion cosmetics and personal care products. Some of the more basic guidelines to prevent the growth of microbial contaminants include the following requirements:

- All equipment must be appropriately cleaned and sanitized prior to use.

- Spills should be cleaned from floors, equipment and conveyer surfaces as quickly as possible.
- Special precautions for protecting the lines from environmental contamination should be taken during periods of interrupted operation.
- All operating personnel must be properly attired and trained in the fundamentals of microbiological control and good manufacturing practices.

Conclusion

As becomes obvious when one considers the complexity of the equipment, materials and processes employed in the manufacturing of wipe products, the need for the development and implementation of an effective microbiological control program specifically designed for wipe operations becomes readily apparent. This combination of specialized technologies and unique processes requires the manufacturer to become more aware of the inherent potential microbiological risks involved. Preventing contamination is the cornerstone of microbiological control and can only be achieved by making a concerted effort to emphasize all aspects of operational good manufacturing practices.

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Sensory

Consumer acceptance is the key to success in our industry. How the customer perceives the product is what drives sales of a product and sales of a product drives our industry. There are many subtle factors that effect how a consumer responds to a product. Most sensory evaluations of personal care products are carried out using well-trained panels. The desire to have a correlation between consumer perception and a measurable laboratory metric for that perception is the goal of many scientists. This section will look at these studies.

With personal care products, the relationships that link the sensory properties of products to both consumer acceptance and consumer perceived benefits are thought to be more difficult to “get at”. This is because personal care products are marketed with glamour language that promises “beauty” and “youth” and consumers do not have very concrete language to describe the products or the effects of the products.

There are many sensory properties that one can evaluate. One article suggests sensory properties of cosmetic products are key characteristics and many of these properties are often related with rheological properties. The appearance is the customer’s first visual contact with the product and therefore very important. Then the product is applied on the skin and rubbed out. In this phase the skin feel properties of the product are important.

- 56** How Sensory Evaluation Can Provide Development Direction: An Approach
- 57** Linking Sensory and Rheology Characteristics
- 58** Significant Statistical Differences in Sensory Research
- 59** Market Segmentation

How Sensory Evaluation Can Provide Development Direction: An Approach

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KEY WORDS: *product development, descriptive analysis, principal component analysis, sensory, rub-out characteristics, afterfeel*

ABSTRACT: *The authors explain how linking product sensory attribute documentation, through descriptive analysis panels, with consumer exploration through one-on-one interviews, provides clear direction to product development. In addition it permits the product development team to track progress of the prototypes.*

Product development often relies on sensory evaluation and consumer research guidance to direct the product development process—by identifying products that consumers want and need. With cosmetics and toiletries, the relationships that link the sensory properties of products to both consumer acceptance and consumer perceived benefits are thought to be more difficult to “get at” than in the product development of foods and home care products. This is because personal care products are marketed with glamour language that promises “beauty” and “youth” and consumers do not have very concrete language to describe the products or the effects of the products. Many of the attributes are integrated, combining both consumer language with descriptive language, for example “youthful” or “glow.” Sensory evaluation techniques can help tease apart the terminology and provide a deeper understanding of the sensory experience.

Early Stage Research

Often the developer doesn't know where to begin; the process of understanding seems to be mysterious. Yet it doesn't have to be a mystery—in fact it is just a matter of putting information together, as the following problem illustrates.

One of our global clients wants to understand the key drivers for a hand lotion product including key benefits for the consumer (moisturizing, protection, non-greasy, therapeutic, etc.) This early stage research is intended to extract information and insights for R&D to move forward to develop some viable prototypes.

The traditional approach is for sensory scientists and marketing research professionals to depend on some large-scale quantitative research, conducted in a central location or in home environment. The quantitative data are thought to be critical for making business decisions since many companies require hard numbers to move the development process forward. This approach at this stage of development is expensive and limiting. The prototypes are often a shot in the dark (best guess) and sometimes not different enough from existing products to provide any real information. The luxury of working at the early stages of product development permits the sensory scientist and product developer to “explore” both the consumer and product landscapes in search of buried treasure.

An approach that provides a map to the treasure combines descriptive analysis via a trained panel (to document the sensory properties of the product without indication of preference or acceptance, much like an analytical instrument) with qualitative interviews.

Large-scale consumer research is generally linked statistically to the documentation of the descriptive data to benchmark the product category. However, at early stages in the development process before the prototypes are developed at the bench, the sensory and development scientists can collect some preliminary information and direction.

Collecting Preliminary Information

The first step is to document a large array (15–30) of hand lotion products in the marketplace from which a diverse subset of (4–8)

are selected for discussion with consumers. In this case, a trained panel used our descriptive analysis method^a to evaluate and rate the perceived sensory attributes (see **Table 56.1**) on an intensity scale of 100 points thus defining precisely what the products feel like as they are dispensed in the hand and on the skin. The 10–15 panelists were trained for more than 100 hours to describe in great detail the appearance, fragrance and/or feel of products in terms of the words to describe the attributes and the numerical scale to describe the intensity or strength of each attribute. **Table 56.2** gives a descriptive profile of two lotions and **Figure 56.1** shows the attribute range graph of the rub-out characteristics.

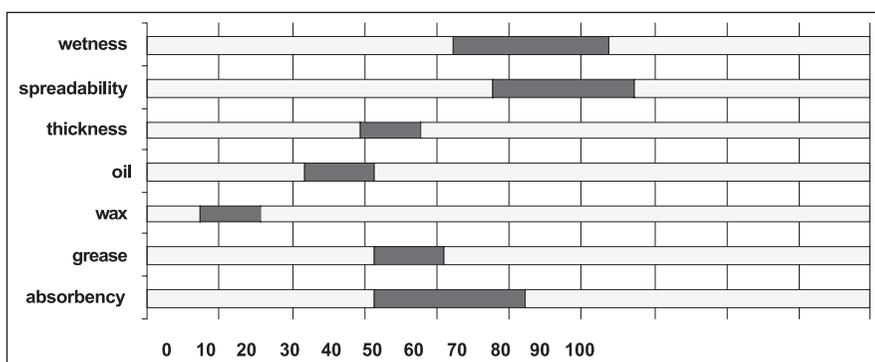


Figure 56.1. Data range graph for descriptive analysis rub-out characteristics

Note that the descriptive intensity range covers a large space—not all samples are similar. The descriptive panel results are analyzed using multivariate statistical techniques, such as Principal Component Analysis (PCA). Principal Component Analysis is a technique which analyzes multivariate (multi-variable) data in order to express their variation in a minimum number of primary components or linear combination of the original variables (see **Principal Component Analysis sidebar**). It allows the researcher to determine the relationship within combinations of variables (in this case attributes) and between samples and variables. Maps of the data permit the researchers to look into/onto the range of attributes that encompass the sample hand lotions. **Figure 56.2** shows a PCA map of descriptive analysis rub-out characteristics.

^a Spectrum Descriptive Analysis Method is a trademark of Sensory Spectrum, Inc.

Table 56.1. Sensory characteristics measured by descriptive analysis

Phase	Attribute	Scale	
Rubout (about the product)	Wetness	Dry → Wet	
		Spreadability	Easy to Spread → Difficult to Spread
		Thickness	Thin → Thick
		Oily	None → Much
		Waxy	None → Much
		Greasy	None → Much
		Absorbency	# rubs to absorb
Pick Up (about the product)	Firmness	Soft → Firm	
		Stickiness	Not Sticky → Very Sticky/Tacky
		Cohesiveness	Ruptures/Peaks → Cohesive/Strings
		Peaking	No Peaks → Sharp Peaks
Afterfeel (about the skin)	Gloss	Dull → Glossy/Shine	
		Tautness	None → Much
		Stickiness	Not Sticky → Very Sticky/Tacky
		Moistness	Dry → Moist
		Slipperiness	Drag → Slippery
		Occlusion	None → Much
		Suppleness	None → Much
		Dry/Roughness	None → Much
		Amount of Residue	None → Much
		Type of Residue	Total = 100%
- Oily	0 – 100%		
- Waxy	0 – 100%		
- Greasy	0 – 100%		
- Silicone	0 – 100%		
Skin Texture Visibility	None → Much		

Table 56.2. Spectrum descriptive profile for competitor vs. current lotion

Attribute	A	B
Rubout		
cool	45.7	48.1
wetness	52.2	42.2
spreadability	58.8	47.6
thickness	33.3	35.6
oil	26.7	22.8
wax	8.3	9.4
grease	38.7	40.8
absorbency	37.1	39.1
Afterfeel		
Immediate		
gloss	16.1	14.7
tautness	27.8	30.3
stickiness	10.3	13.4
moistness	11.9	12.8
slipperiness	72.1	67.6
occlusion	9.8	12.2
suppleness	51.7	45.2
dryness/roughness	42.2	41.7
amount of residue	13.7	17.1
oil %	7.2	6.7
wax %	49.4	45.6
grease %	25.6	41.7
silicone %	16.7	6.1
skin texture visibility	41.7	45.0
Pick-Up		
firmness	34.7	37.1
stickiness	23.9	27.4
cohesiveness	9.3	11.2
peaking	37.3	41.2

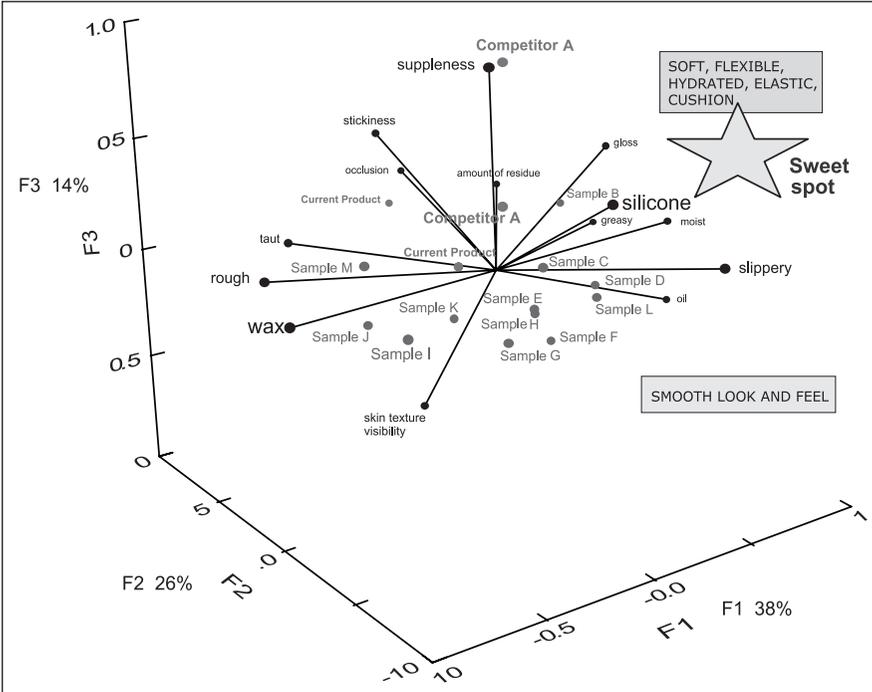


Figure 56.2. PCA map of descriptive immediate afterfeel characteristics

To explore the “landscape” of key consumer attributes, four sets of interviews are conducted; each set of six to eight consumers are interviewed one at a time to explore one of the key attributes of interest identified in marketing research studies; moisturizing, non-greasy, protecting and therapeutic. Each consumer spends an hour with a trained facilitator/moderator who presents different hand lotion products to provoke language from the consumer to describe his or her sensory experience, the perceived benefits and the emotional responses.

The verbatim responses are recorded on paper and video during the sessions. Later the consumer responses are explored to identify the language, properties and benefits that are linked to specific products. The consumer language fell into five groupings of words: moist, glow, disappears quickly, no greasy residue and natural. **Table 56.3** shows a partial list of attributes collected during consumer interviews.

Principal Component Analysis

Principal Component Analysis (PCA) is widely used in signal processing, statistics and neural computing. In some application areas, this is also called the (discrete) Karhunen-Loève transform, or the Hotelling transform. PCA is used to find the components s_1, s_2, \dots, s_n so that they explain the maximum amount of variance possible by linearly transformed components. The basic goal in PCA is to reduce the dimension of the data. Such a reduction in dimension has important benefits. First, the computational overhead of the subsequent processing stages is reduced. Second, noise may be reduced, as the data not contained in the first components may be mostly due to noise. Third, a projection into a sub-space of a very low dimension is useful for visualizing the data.

Source: Helsinki University of Technology Web site. Available at: <http://www.cis.hut.fi/~aapo/papers/NCS99web/node5.html>. Accessed Feb. 21, 2005.

Table 56.3. Partial list of consumer attributes (collected during consumer interviews)

Consumer Terms

Moisturized/Hydrated	Polished Look
Glow/radiant/luminescence	Absorption
Smoothness	Even skin tone
Skin elasticity—look/feel firmer	No greasy afterfeel
Feels light	No oily residue after rub in

Studying the Descriptive Data

At this point we had some confidence in the structure of the consumer understanding of the hand lotion product category. The sensory scientists then began to study the products' "space" (the descriptive data) in the light of the consumer language for their needs and wants.

The nature of the descriptive analysis results permits the sensory scientist and the product developer to see how each of the samples sits in the space of hand lotions. It also permits the team to

understand the relationship of this class of products to the larger set of lotions (therapeutic, youthful, etc.) if those data are available.

In this example, the map (Figure 56.2) of the immediate afterfeel attributes reveal that one of the products produced by competitor A was considered to have a “supple” afterfeel. In the interviews, consumers describe this sample as having a “soft, flexible, cushion and hydrated” feeling. Notice that neither of our client’s current products fit within the space of hydrated or smooth look and feel. By considering the known range of sensory intensities from the original array, the product developers can now develop a guideline for intensity—in other words provide a development direction. This is illustrated in Figure 56.3.

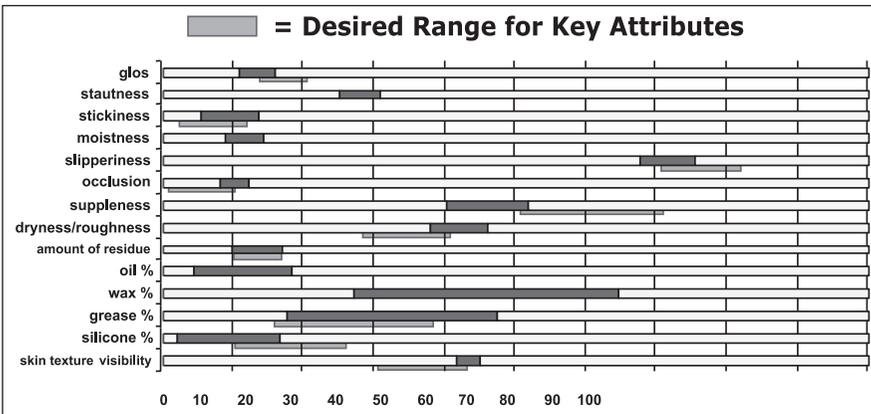


Figure 56.3. Suggested direction for afterfeel characteristics

The ultimate test of this research approach is in relating these analytical descriptive panel results to the consumer language and insights. Sensory properties are important to define the tactile, appearance and fragrance characteristics of a product but it is only in linking the attributes to consumer acceptance, preference or perception of efficacy or benefits that the research team has direction for development of a successful product.

Consumers understand what characteristics they want in hand lotions but are unable to articulate them in terms that product developers can use to create products that deliver consumer needs. Linking product sensory attribute documentation, through

Blind Product Analysis

Analysis of blind product testing allows us to evaluate product performance without the possible effect of branding and its associated imagery. This is obviously important if interest centers on improving product performance through product design features that matter to consumers. However, since consumers are influenced by variables other than sensory performance, such as perceived health, imagery, what their friends are choosing and what will help them to fit in, there must be an associated sensory penalty paid for the consumption of those products that the consumer would not choose on a blind basis.

Source: The Institute for Perception Web site. Available at: <http://www.ifpress.com/pdfs/Spring%202005.pdf>. Accessed: Mar. 10.

descriptive analysis panels, with consumer exploration through one-on-one interviews, provides clear direction to product development. In addition it permits the product development team to track progress of the prototypes by using the descriptive panel to test prototypes along the way and place them in the product maps to see if they are approaching the “sweet spot” in the map that satisfies consumer needs.

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Linking Sensory and Rheology Characteristics

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KEY WORDS: *sensory properties, rheology, emulsion structure, Principal Component Analysis, Partial Least Squares regression, cohesiveness*

ABSTRACT: *The authors introduce a method to use rheological properties (such as dynamic viscosity and yield stress) to describe and predict skin sensory attributes (such as cohesiveness) of cosmetic products. This is a first step in learning to use emulsion structure to predict sensory attributes.*

At present, most sensory evaluations of personal care products are carried out using well-trained panels. Sometimes this is supplemented by various instrumental methods such as viscosity, corneometry, polarity, etc. The objective of this study is to investigate the relationship between rheological properties and sensory attributes. We view this as a first step to understanding the influence of emulsion structure on sensory characteristics.

In this paper we demonstrate a methodology to use rheological properties to describe and predict skin sensory attributes. Rheological data is analyzed by Principal Component Analysis (PCA) and clear correlations were found between several rheological properties. Partial Least Squares regression showed cohesiveness can be

predicted by two rheological properties: dynamic viscosity and yield stress.

Some sensory and rheological properties clearly depend on the emulsion structure. In colloid chemistry, scientists are using models to correlate emulsion structure with rheological characteristics. In contrast, there is far less knowledge about sensory-emulsion structure relationships, but the development of rheology-sensory relationships can be the first step in building understanding about how sensory attributes are influenced by changing the emulsion structure.

Theory

Sensory properties of cosmetic products are key characteristics and many of these properties are often related with rheological properties. The appearance is the customer's first visual contact with the product and therefore very important. Then the product is applied on the skin and rubbed out. In this phase the skin feel properties of the product are important. For instance, the thickness of a product may play an important role in the sensory impression. The customer expects a thicker product for a facial cream, whereas a body lotion is expected to be less thick. The latter should be easily applied on larger parts of the body. Thickness also plays an important role during production.

Proper evaluation of sensory characteristics is time-consuming and consequently expensive. In order to save time and cost, instrumental methods could be useful to replace sensory tests. It is generally accepted that instrumental methods (such as rheology) could be very useful to increase knowledge about why different products have different sensory characteristics and others don't. Surprisingly, the amount of information found in literature about rheology-sensory correlations for cosmetic products is very limited.

Meloni¹ used rheological properties to explain unexpected moisturization properties of hydrophilic polymers, showing how ingredients can be used to change the emulsion structure. A few papers assert that sensory-rheology correlations are not noticeable in one-to-one relations. Barry² studied the correlation of sensory

tests of cosmetic emulsions with rheology, but concluded that sensory tests do not correlate with stationary viscosity alone. Brummer³ concluded that shear stress at the onset of flow alone is not an unambiguous criterion to distinguish between product types. Both Barry and Brummer are indicating that rheological properties cannot be sufficiently described by sensory property. In other words univariate methods are not capable of identifying a proper correlation. Multivariate methods are much more powerful. These methods are described elsewhere.⁴

The power of multivariate methods has been shown in several application areas. The food industry is a good example because there is clear overlap with cosmetic applications.⁵ Both applications areas often work with emulsions and in both areas sensory characteristics are very important. Nevertheless, multivariate methods are not often described in literature in combination with cosmetic applications. Wortmann⁶ used PCA to study the influence of co-surfactants and conditioning agents in shampoo. Wiechers⁷ and Wortel⁸ described several multivariate techniques to evaluate sensory attributes of both emollient and formulated products.

The scope of the chapter before you is to demonstrate a method to describe sensory attributes with rheology properties. It is not possible to give a complete theoretical introduction to either multivariate analysis or rheology. However, some basics of these techniques are required to understand this work (see sidebar). In this chapter we will focus on the advantage of multivariate analysis and use the output of its calculations without explaining the mathematics behind it.

Materials

In this study we measured 85 different formulations from both commercial products and in-house formulations. These samples were tested by a trained sensory panel. The samples were also measured with a rheometer^a to obtain information on how the emulsion behaves when a certain force is applied.

^a Physica UDS 200, Anton Paar Gmbh, Graz, Austria

The data evaluation and the regression is done by several software packages, such as SAS version 8.2^b and Unscrambler^c.

Sensory Methods

All 85 samples are evaluated using the Spectrum Descriptive Analysis method.⁹ This sensory technique relies on obtaining accurate numbers by a well-trained sensory test panel. This panel consists of approximately 10 members and each panelist evaluates each product three times using well-defined attributes with a fixed meaning. The 21 attributes can be subdivided in several groups: appearance, pick-up, rubout, immediate after-feel and after-feel after 20 minutes. This study mainly focuses on the pick-up and rubout phase because these are obviously most related with rheology.

Cohesiveness is used as a typical example to explain the applied methodology. This sensory attribute is evaluated during the pick-up phase and is evaluated by compressing the product slowly between index finger and thumb, after which the fingers are separated. The degree to which the sample strings rather than breaks when fingers are separated is defined as cohesiveness. A stringy product has a high cohesiveness number.

Rheology Methods

Various rheological techniques are applied, namely steady state (constant shear rate), constant stress (creep) and dynamic measurement (oscillatory). This allowed us to obtain 20 rheological properties, such as high shear rate viscosity, yield value (obtained from fit of the flow curve), zero shear viscosity, storage and loss modulus. For all measurements the samples are placed in the gap between a 2° cone and a 5 cm plate. Depending on the measurement, a different force (shear or stress) is applied on the sample.

Steady state (constant shear rate) measurements: For these measurements the rheometer is used as a constant shear rate instrument by rotating the cone at increasing rate. All samples are measured at a temperature of 29°C. The flow profile is measured from 0-500-0

^b Statistical Analysis Software, Cary, NC, USA

^c CAMO, Norway

s^{-1} , using 180 measuring points (0.5 sec/point) and 240 measuring points (2 sec/point). The torque on the plate is measured to give the shear stress.

The shear stress-shear rate curves are analyzed using several models to obtain the yield value and the plastic viscosity. In this study the yield stress is calculated using the Bingham model (**Equation 57.1**). According to this model the yield stress (intercept) is calculated by extrapolation to zero shear rate. This extrapolation is carried out using four points after the first measurement.

$$\sigma = \sigma_{\beta} + \eta_{pl} \dot{\gamma} \quad (\text{Equation 57.1})$$

where σ = shear stress

σ_{β} = yield stress

η_{pl} = plastic viscosity

$\dot{\gamma}$ = shear rate

Constant stress (creep) measurements: A constant stress is applied on the sample (at 25°C) and the deformation or strain is measured as a function of time for $t = 120$ seconds. Then, the stress is removed and the strain (which reverses sign) is measured for 120 seconds; this gives the recovery curve. Before the yield stress is reached, near complete recovery is obtained, i.e., the strain in the recovery curve approaches zero. When the applied stress exceeds the yield stress, the strain continues to increase with time (during time of application, $t = 120$ sec) and only partial recovery is obtained, i.e., the strain reached after $t = 120$ sec in the recovery curve is no longer zero. From the slope of the strain versus time one obtains the shear rate.

When the applied stress is divided by shear rate, one obtains the viscosity η_{σ} at this applied stress. A plot of viscosity η_{σ} versus stress σ shows a curve with two Newtonian regions: one in the low shear rate regime $\eta(0)$ (the residual or zero shear rate viscosity) and one in the high shear rate regime $\eta(\infty)$. These low and high shear viscosities are separated by a shear thinning region. The value of the stress at which the viscosity begins to decrease is sometimes referred to as the critical stress σ_{cr} .

Dynamic (oscillatory) measurements: For these measurements a sinusoidal strain with frequency ω (rad/sec) and amplitude γ_0 is applied on the sample (at 29°C) and the stress is simultaneously

measured. For a visco-elastic system, the stress and amplitude oscillate with the same frequency but out of phase. The stress and strain amplitudes are shifted by a time Δt and this allows one to calculate the phase angle shift δ ($\delta = \omega \Delta t$). From the amplitudes of the stress and the strain and the phase angle shift one can obtain the complex modulus G^* :

$$G^* = (\sigma_o / \gamma_o) \quad \text{(Equation 57.2)}$$

where G^* = complex modulus

σ_o = measured stress

γ_o = amplitude

The elastic modulus or storage modulus (G') and the loss or viscous modulus (G'') can be calculated from the complex modulus:

$$G' = G^* \cos \delta \quad \text{(Equation 57.3)}$$

$$G'' = G^* \sin \delta \quad \text{(Equation 57.4)}$$

Finally, the dynamic viscosity η' can be calculated from the loss modulus:

$$\eta' = G'' / \omega \quad \text{(Equation 57.5)}$$

In oscillatory measurements one initially fixes the frequency, for instance at 1 Hz, and measures G^* , G' , G'' and η' as a function of strain amplitude. The rheological parameters are virtually constant up to a critical strain γ_{cr} . This constant region is referred to as the linear viscoelastic region (LVER). Above γ_{cr} the values of G^* and G' start to decrease whereas G'' and η' start to increase with further increase in strain amplitude. In the present study, the value of η' was calculated using the values of the rheological parameters at the end of the LVER.

Multivariate Methods

In the first part of the study we aimed to understand the uniqueness of the rheological properties by using PCA. The visual output of this method enables the identification of similarities and differences between rheological properties. This can play an important role for the pre-selection of these properties. This step is useful to increase information density of the dataset and improve the quality of the regression (see **Multivariate Analysis sidebar**). The PCA calculation is applied on the complete data set including all 20 rheological properties calculated from all three rheology measurement techniques.

Loading plots are created to show which rheological attributes contained unique information and which properties are related in order to reduce the number of rheological attributes and to get a better overview.

In the second part, PLS regression is applied to correlate sensory attributes with rheological properties. Cohesiveness is used as an example to illustrate the prediction of a sensory attribute from rheological properties. A stepwise procedure is used to select the most significant rheological properties that are related with cohesiveness. These selected properties are used for the calibration of the model. An independent test set validation is used in order to validate the PLS model. This test set contained 10 new products. The cohesiveness was predicted by the cohesiveness model and evaluated by the sensory panel. The comparison of these results will show the reliability of the PLS model.

Multivariate Analysis

Univariate techniques are most often used to calculate the correlation between one dependent variable and an independent variable. A famous example is the relation between absorbency and concentration according to the Lambert-Beer law. Unfortunately, some references^{2,3} have shown that sensory-rheology relations cannot be explained by one-to-one correlation. Therefore more advanced techniques are applied. Two examples are Principal Component Analysis (PCA) and Partial Least Squares (PLS).

Principal Component Analysis: The basic principle of PCA is to reduce the number of dimensions by identifying linear relationships between the variables. Latent variables (principal components) are calculated to explain the variance in the data set optimally. The most important visual results of the calculation can be described by the loading and score plots.

A loading plot provides information about the variables and how these are related. For instance, this plot enables one to identify the existence of positive or negative relations between the variables. A score plot shows the similarities and differences between the products.

Partial Least Squares: PLS is a regression method that has some similarity with PCA. Instead of maximizing the explained variance in the data set, PLS maximizes the explanation of the dependent value (y -value). This process is much more focused on the dependent variable and therefore more efficient to describe the variable of interest.

Results

Rheology: The rheological properties that are mentioned in the experimental part were calculated and evaluated. The data was used as an input for the PCA calculation. For some properties a logarithmic transformation was applied in order to obtain better distributions. The loading plot (**Figure 57.1**) visualizes the relations between the rheological properties.

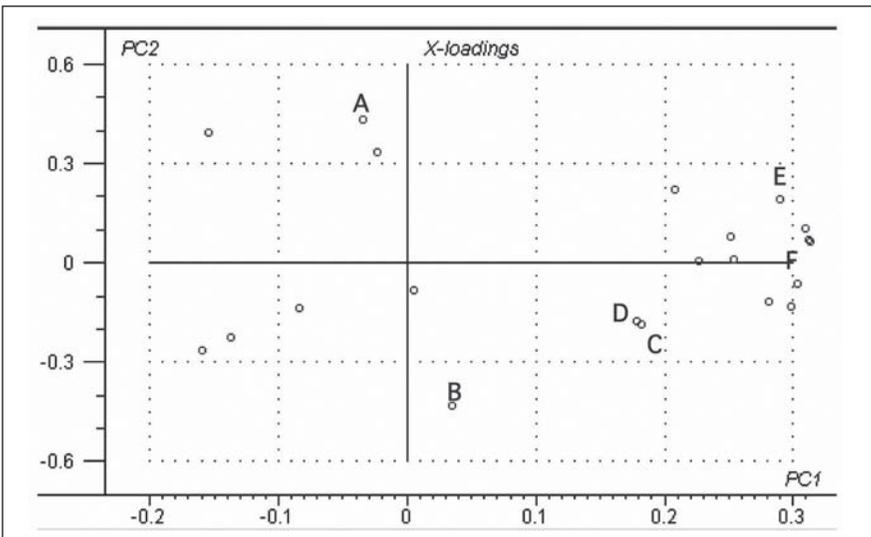


Figure 57.1. PCA loading plot

The interpretation of this plot can be explained by two clear examples. First, compare points A (elastic component) and B (viscous component); both are attributed to creep measurements. According to the loading plot these two properties are inverse correlated, i.e., if A is increasing, B must be decreasing. This can easily be explained by rheology. The creep compliance J is the deformation per stress unit and consists of a viscous component and an elastic component (**Figure 57.2**). The more elastic a formulation's behavior is, the less viscous it is, and vice versa.

The second example studies two properties that are close to each other in the loading plot; this means that these properties are directly correlated. A direct correlation means that if one property is increasing the other is also increasing. A good example is points C (cohesive energy, amplitude sweep) and D (thixotropy index,

rotation measurement) in **Figure 57.1**. These rheological properties contain similar information (for the current data set) but are results of different measurement techniques and independent calculations. Surprisingly, from a rheological point of view this correlation is unexpected, but might be a good learning point for the properties of the samples. Obviously, time can be saved by not measuring redundant rheological properties.

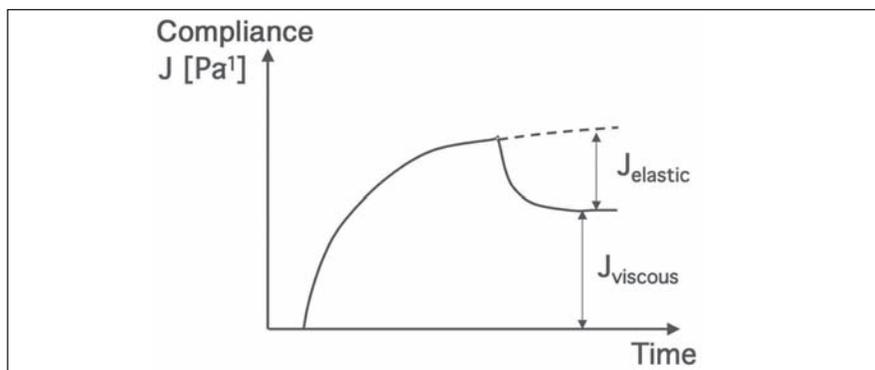


Figure 57.2. Elastic and viscous components of compliance creep

Regression: The stepwise regression shows that the dynamic viscosity and yield stress (points E and F, respectively, in **Figure 57.1**) are the most suitable to apply for the cohesiveness model. These properties are used to calculate the PLS model. The correlation coefficient of this model is 0.85, which is not very high. However, the model is based on a sensory panel evaluation, which usually contains a considerable amount of noise. The model shows that both rheological properties are directly correlated with the cohesiveness.

The selected rheological properties are from different rheological techniques. Dynamic viscosity is measured with oscillatory measurement, whereas yield stress is measured under steady state conditions. According to the PCA loading plot (**Figure 57.1**) these properties mainly differentiate on the second PC (y-axis). The yield stress contains information about how much force is required to move the product. More details about the physical interpretation are written in the discussion. The independent test set validation of the PLS model shows that most of the products were predicted with the same accuracy as the calibration (**Figure 57.3**).

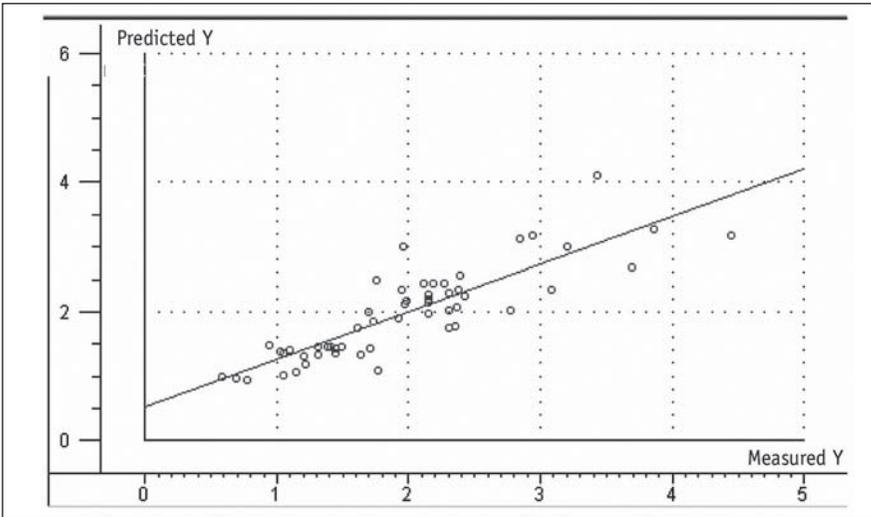


Figure 57.3. PLS-measured values vs. predicted values

Discussion

Colloid models can be used to describe the relation between rheology and emulsion structure. As a first step, we chose three samples A, B, and C that are characterized by a wide range in rheological properties. As an illustration, **Figure 57.4** shows the variation of dynamic viscosity η' with strain amplitude. **Figure 57.5** shows the shear stress-shear rate curves for these samples. From this curve, yield value σ_β was obtained by extrapolation to zero shear rate. The dynamic viscosity (**Figure 57.4**) of these samples is 69.2, 2.6 and 0.1, and the Yield stress is 178, 74 and 3.4 Pa, for A, B and C, respectively. It can be seen that the reduction in viscosity from samples A to C is much greater than the reduction in the yield stress.

Let us now consider the composition of each sample and the possible “colloidal” interactions present. Sample A is a hand cream^a. It is considered an O/W emulsion that is “structured” using liquid crystalline phases. The latter are made from a mixture of sodium cetearyl sulfate (C16/C18 sulfate anionic surfactant), cetearyl alcohol (C16/C18 alcohol) and stearic acid (C18 carboxylic acid). This

^a Neutrogena, Johnson & Johnson

combination produces lamellar liquid crystalline phases that extend into the continuous phase producing a three-dimensional “gel network” structure. The liquid crystalline structure is also enhanced by incorporation of electrolyte (Na_2SO_4) in the system. The gel network is expected to have high “cohesive” structure and hence it should give a high yield value (178 Pa) and high dynamic viscosity (69 Pa.s).

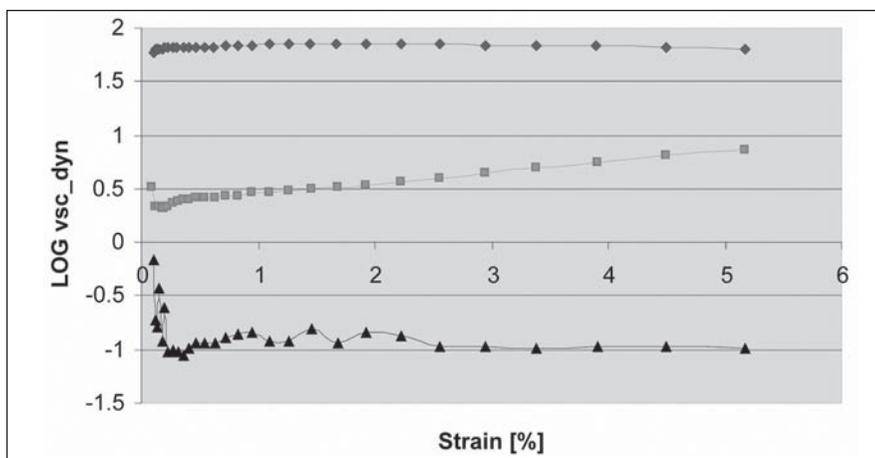


Figure 57.4. Dynamic Viscosity vs. strain amplitude (=sample A, =sample B, = sample C)

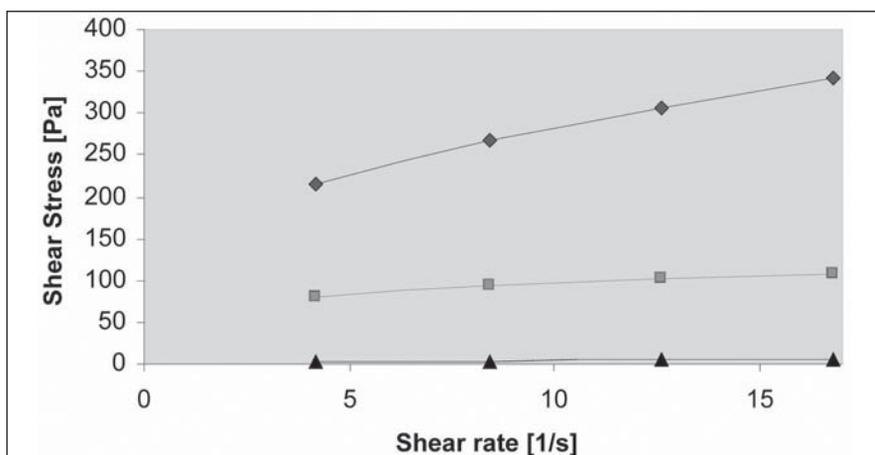


Figure 57.5. Shear stress versus shear rate (=sample A, =sample B, = sample C)

Sample B is an aloe vera gel^b, simply an aqueous natural extract. The extract is “gelled” using carbomer^c that is neutralized by triethanolamine. The carbomer is cross-linked polyacrylic acid, which on neutralization produces “microgel” particles. The latter are produced by dissociation of the COOH groups forming COO⁻ groups, and this causes swelling by expansion of the double layers. The microgel particles will have a high charge and an extended double layer. This gel structure is expected to be less “cohesive” than the three dimensional “gel network” structure produced using lamellar liquid crystalline phases. As a result, the yield value (74 Pa) and the dynamic viscosity (2.6 Pa.s) are lowered.

Sample C is an in house formulation prepared using an emulsifier/biopolymer system^a (1%) and 10% oil phase (triethylhexanoin). The emulsifier/biopolymer system consists of a surfactant mixture of steareth-100, steareth-2, glyceryl stearate citrate and sucrose, and a stabilizer (thickener) system consisting of mannan (konjac) and xanthan gums. The most likely mechanism of stabilization is based on adsorption of the emulsifier system at the oil/water interface (with the possible adsorption of some hydrocolloid system). The excess emulsifier/biopolymer system remains in bulk solution. This emulsion produces a relatively low yield value (3.4 Pa) and low dynamic viscosity (0.1 Pa.s). These low values are due to the low oil volume fraction in the system and hence droplet/droplet interaction is relatively weak. However, the biopolymer system can produce a weak “gel” structure and hence a low yield stress.

Ultimately, the fundamental knowledge obtained from the rheology-sensory relationship is actually only the first step in a process to modify specific properties of a formulation. The relationship between emulsion structure and sensory will be difficult to extract. A correlation between rheology and sensory could therefore help to obtain the desired skin sensory properties. **Figure 57.6** is a visualization of this concept.

^b Aloe vera gel from Fruit of the Earth, Irving, Texas USA

^c Carbopol 940, Noveon Inc., Cleveland, Ohio USA

^a Arlatone V-100, Uniqema

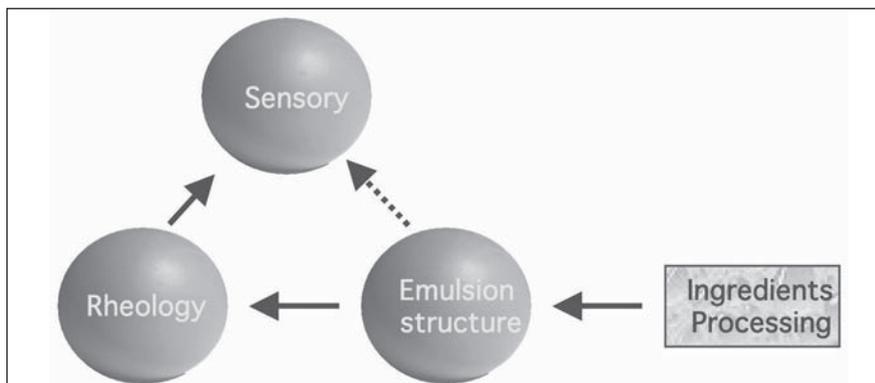


Figure 57.6. A model to link emulsion structure with sensory attributes via rheology

The discussion above shows that colloidal models can be used to explain the relationship between rheology and emulsion structure of a personal care formulation. The next challenge will be to obtain sensory attributes from the combination of the sensory-rheology relationships and the colloid models. Finally, once such a relationship has been established, it should be possible to correlate the ingredients used and the process involved to the ultimate sensory attributes of the personal care products. Then, the formulation chemist may choose the optimum ingredients and optimum process to achieve the required goal of the sensory attributes.

This knowledge should therefore facilitate the development of innovative cosmetic formulations. This study, however, has clearly shown that the relation between rheology and sensory can be found by the use of multivariate techniques.

Conclusion

The first part of the study shows that many rheological properties are highly correlated. For some properties this is very logical and for others it is unexpected. PCA might help to get a better understanding of several rheological properties on a specific set of samples.

Cohesiveness has been used as a typical example for a sensory attribute. Univariate calibration method does not show good correlations, but multivariate calibration methods proved to be successful. The regression model in this study shows that cohesiveness can be

described by yield stress and dynamic viscosity. The validation of the model shows that the error in the test set is approximately the same as the error in the calibrations model, therefore these models are reliable. Further work is in progress to build a direct link between sensory and emulsion structure and possibly to ingredients and processing condition.

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Significant Statistical Differences in Sensory Research

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Technical Editor, Cosmetics & Toiletries Magazine

KEY WORDS: *statistics, significant, consumer, Spectrum Descriptive Analysis (SDA), Quantitative Descriptive Analysis (QDA)*

ABSTRACT: *Statistics are a vital aspect of research, and understanding the way in which they shape research can help any formulator better understand the consumer and ways to market their product, as well as how to formulate their product.*

My dictionary has two definitions of the term *significant*. In common usage, *significant* means “important.” In statistics, *significant* means “of or pertaining to an observed departure from a hypothesis too large to be reasonably attributed to chance (a *significant* statistical difference).”

The difference between these two definitions is significant. As others have pointed out, a research finding may be true without being important. When statisticians say a result is “highly significant,” they mean it is very probably true. They do not necessarily mean it is highly important.¹ Importance and meaning are determined by the consumer. (See **Change the World. Be a Statistician.** sidebar.)

In sensory research, there are differences among the ways data is collected, analyzed and presented. Some of those differences were discovered during research for this work, which resulted from a process

very much like sensory research. The topic was assigned by the editor and a great deal of data was collected from various sources. I evaluated the data and used my imagination to discover a pattern, which I present here. The pattern is several instances of significant differences. I leave it to you to decide if these differences are significant in the sense of “important” or significant in the sense of “true” or significant in the sense of “what’s he talking about?”

Change the World. Be a Statistician.

If you are looking for an interesting and rewarding career that takes you to exotic places to solve problems that matter, you should choose statistics. So says one of Australia’s leading statisticians.

“Statistics is the science of turning data into insight and action,” said Murray Cameron, Ph.D., of CSIRO Mathematical and Information Sciences in Sydney, Australia.

CSIRO statisticians recently have been involved in safer treatments for disease, monitoring endangered species, understanding financial markets and improving air safety.

“It can be really exciting when you realize the numbers are telling you something no one else has seen before,” Cameron said. “For example, our scientists recently identified a particular subspecies of prawn within a larger population that was being dangerously overfished. We were able to recommend changes to make the population more sustainable, and it was all because we knew how to extract meaning from the numbers.”

From Reference 9

Differences Between Then and Now

The human being as a measuring instrument: Howard R. Moskowitz, Ph.D., is a psychophysicist at Moskowitz Jacobs Inc. in White Plains, N.Y., USA, who has written widely about sensory analysis and marketing for four decades. In his view, the single most important development in sensory analysis since the 1970s is the gradually increasing, popular acceptance of the human being as a valid measuring instrument. In other words, unpracticed individuals can assign numbers validly to reflect the perceived intensity of stimuli. Those numbers themselves have ratio-scale properties, enabling evaluation of simple sensory magnitude, hedonics (likes and

dislikes), and how various factors surrounding the stimulus affect sensory perception.²

Visualizing for decisions: Another change is in the role of statistics and statisticians.³ Product testers rely upon statistical analyses for insight and guidance. In the good old days (1960s and earlier), many researchers who used statistics did so to answer a simple question, such as: “Is Product A significantly preferred to Product B?” The level of knowledge was modest at best, and most of the use of statistics involved hypothesis testing.

Today, statistics has taken on a far more significant and vital role in research. Certainly researchers still test hypotheses with statistics, but there are substantially more applications, many of them involving exploratory data analysis and representation of data. These applications lead to insight, not just to verification of conclusions. As a result, statistics has been divided into at least two distinct branches:

- Tests of hypotheses to confirm or deny decisions
- Methods for representing data, such as showing different products in a geometrical space (mapping) to help the product manager or developer make decisions, or the clustering of different consumers into categories based on sensory preference patterns so the marketing manager can plan products.

The new role of the statistician should be to promote the widespread use and understanding of these techniques.

Discovering patterns: Concentration on difference testing no longer is enough for a researcher, according to Moskowitz. To test for differences, and to ensure that the differences measured do not arise by chance alone, is a meaningful endeavor, but if that is the only focus, then one stops considering patterns and searching for them in nature and simply looks for an answer to the question: Is the difference statistically significant? Statistical significance becomes a buzzword. There is no thought behind that question.

According to Moskowitz, one way to get out of the rut is to plot the data—either by hand or by computer—to discover patterns. “Plotting the data lays out the points in a geometrical way. Intuitively the researcher must seek patterns, or else the data only looks like a

scattergram. It is inherent in human nature to search for an organizing principle. Plotting focuses attention on an organizing principle. Gestalt psychologists recognized this a half century ago or more. Give people a set of points on a piece of paper and they will attempt to fill in the missing space, to create a meaningful pattern. By laying out the data points on paper, the researcher forces himself to apply an organizing principle to otherwise random points. That exercise alone is worth all the effort, for it brings to bear on the problem a level of concentration and insight not otherwise attainable.”³

Differences Between Methods

Two general types of statistical analysis are used in sensory research. For univariate data, which has only one scalar component, statistical analysis addresses means, variances, correlations, significant differences for attributes, preferences and related quality measures. For multivariate data, each data point has more than one scalar component; correlations between the components are a primary interest addressed by techniques such as factor analyses, multiple regression, mapping and segmentation. A *Cosmetics & Toiletries* magazine (*C&T*) article⁴ by Wiechers and Wortel discusses multivariate analysis in a personal care setting.

Three broad categories of sensory analysis can be distinguished: discriminative testing, affirmative testing and descriptive analysis. Discriminative testing focuses on specific attribute differences between various samples. Affirmative testing assesses the acceptance level of a product by focusing on preferences or liking. Descriptive analysis, on the other hand, will yield a total sensory description, taking into account all sensory perceptions during product use.

Among the various descriptive methods, two have been discussed in the pages of *C&T* magazine. They are: Spectrum^a Descriptive Analysis (SDA), developed by Sensory Spectrum Inc., in New Providence, N.J., USA; and Quantitative Descriptive Analysis^b (QDA) from Tragon Corp., Redwood City, Calif., USA. Both methods aim to accelerate product development, but there are differences in their approaches.

^a Spectrum is a trademark of Sensory Spectrum.

^b Quantitative Descriptive Analysis and QDA are registered trademarks of Tragon Corp.

As SDA developer Gail Vance Civile noted, “All descriptive methods are not the same. They differ in scale type, product focus, and the selection and training of panelists. The essential similarity is that they all measure sensory attributes and their intensities.”

Spectrum Descriptive Analysis: SDA yields a complete, detailed and accurate descriptive characterization of a selection of the product’s sensory attributes. Attribute intensities are measured in relation to absolute or universal scales based on physical properties. Attribute terms are precisely defined and test conditions are controlled carefully so the evaluated properties can be related to consumer responses and instrumental physical tests.

Panelists undergo an extensive training program exposing them to a broad array of reference samples to demonstrate the qualitative, quantitative and temporal properties of a product category. For example, a panel evaluating the tactile properties of skin care products needs to understand the tactile effects of rheology and mechanical characteristics and how these are affected by moisturizer level and particle size. The panel must demonstrate that it can use an established list of attribute terms based on understanding of the underlying technical differences among the attributes of the product.

The Spectrum method is based on extensive use of reference points—at least two and preferably three to five distributed across the range of each attribute. The use of reference points reportedly reduces panel variability. It also allows more precise correlation with stimulus changes and with instrumental data.

A *C&T* magazine article by Civile and Dus⁵ described the use of SDA to evaluate the tactile properties of a hand cream and a gel. Panel training required about 40–50 h of panel orientation and 50–75 h of practice over a three-month period. The panelists reported their attribute intensity ratings on either a 10-cm line or a 10-point scale. The terms used to describe the skin feel, the intensity scale values and the verbal descriptors of the scale endpoints were developed by Spectrum and later given to the Sensory Evaluation Committee E-18 of the American Society for Testing and Materials (ASTM) for public use. Terminology definitions and intensity scale values are shown in **Table 58.1**, along with the results of SDA, for

two of the 13 attributes. If there were 10 panelists and each panelist tested each product three times, this testing could produce a total of 780 data points (10 panelists x 2 products x 13 attributes x 3 replicates), of which only 120 are represented in the four means shown in **Table 58.1**.

After presenting all the data from the SDA, Civile and Dus observed that the products described were obviously different, as one would expect between a gel and a hand cream. “The key factor, however, is that we can describe precisely how they are different,”

Table 58.1. Selected components of SDA for tactile properties of skin care products (adapted from Reference 5)

Component	Stickiness attribute	Spreadability attribute
Definition ^a	Force required to separate fingers	Ease of moving product over the skin
Scale ^a		
0 Endpoint	No force	Difficult/Drag
↓	↓	↓
10 Endpoint	High force	Easy/Slip
Intensity Scale values ^b	0.1 oil ^c	0.2 AAA Lanolin ^g
	1.2 lotion ^d	2.9 petrolatum
	2.6 lotion ^e	6.9 lotion ^e
	4.3 lotion ^f	9.7 oil ^c
	8.4 petrolatum	
	9.9 lanolin wax ^g	
SDA results		
Gel mean	1.6	8.8
Gel SD	0.6	0.4
Hand cream mean	8.3	2.9
Hand cream SD	0.4	0.8

^a Developed by Sensory Spectrum Inc. and shared with ASTM Committee E-18

^b Developed by Sensory Spectrum Inc.

^c Baby Oil, Johnson & Johnson

^d Oil of Olay, Procter & Gamble

^e Vaseline Intensive Care, Chesebrough-Ponds

^f Jergens Aloe & Lotion, The Jergens Skin Care Laboratories

^g Amerchol

they wrote. “For instance, we can say that the gel is three times as spreadable as the hand cream and has only one-fifth as much stickiness. We can expect the same data each time the same sample is evaluated, no matter when or with what other products it is evaluated, because of the use of external references. This enables the tracking of a product through development, production runs or shelf life.”

Quantitative Descriptive Analysis: QDA is based on a panelist’s ability to verbalize perceptions of a product in a reliable manner. The process entails formal screening and training of the panelists as well as the development and use of a sensory language by the panel before products can be scored. Panelists must first demonstrate that they can discriminate between products at greater than chance occurrence, that they can describe products according to their attributes, and score their relative intensities with a high degree of accuracy and reliability. Typically, more than 90% of those who volunteer will satisfy these requirements.

The uniqueness of this method is that the panelists will use their own, consumer-based language to describe all sensory perceptions of the products used during the training phase. They also will generate their own set of definitions for each term in this language. This can take 5–6 h. Within the same panel testing, a different set of products might develop a different language. This limits the extrapolation of results between different groups of products, but not a single attribute would be missed.

Panelists do not use reference products during scoring; the ranking is more important than the absolute number scored. Consequently, each product’s attributes have to be measured at least three times and the method will rely heavily on statistical analysis. For technical reasons, it takes as many as five work days for each panelist to completely evaluate all attributes of a given product. As with SDA, a great many data points are generated.

A *C&T* magazine article⁶ by Stone and Sidel describes the use of QDA in the sensory evaluation of several hand lotions. With the guidance of the panel leader, panelists first must develop a language (terms and explanations of those terms) that reflects the products’

sensory properties in their entirety and an evaluation procedure that allows for the complete characterization of the products. This sensory language is unique in the sense that it reflects the perceptions of the panelists for that particular set of products; it is not the language of product technical experts nor is it the language of the untrained consumer. However, it can be directly linked to ingredients, formulations and consumer judgments.

During evaluation, panelists score each attribute using an appropriate scale, usually a graphic line scale anchored at each end for guidance. They mark the line at a point that best reflects the relative intensity of a given attribute. The line scale is converted to a 0–60 scale and means are calculated. No attempt is made to standardize responses because the analysis is concerned with differences between products, however each panelist rates each attribute several times so questions of reliability within and across subjects can be assessed, as can the significance of product differences obtained without reference to any standard score.

Based on analysis of variance and other statistical techniques, visual display of similarities and differences are prepared. All QDA mean results are plotted in spider plots, such as the one in **Figure 58.1**, to display the products' tactile attributes and their relative intensities; the more intense the attribute, the farther it is plotted from the center. **Figure 58.1** shows the QDA results for a marketed product (Lotion 3) and an experimental product (Lotion 1). The experimental product is very different, primarily in terms of the almond-like fragrance (not perceived in Lotion 3), and its lessened ability to maintain shape.

Note that QDA does not evaluate preferences. “Trained subjects cannot provide unbiased estimates of product preferences and such information should not be obtained from them,” Stone and Sidel wrote. Nor is any measure of importance assigned in QDA. According to these authors who developed QDA, the proper source for preference and attribute importance information is consumers.

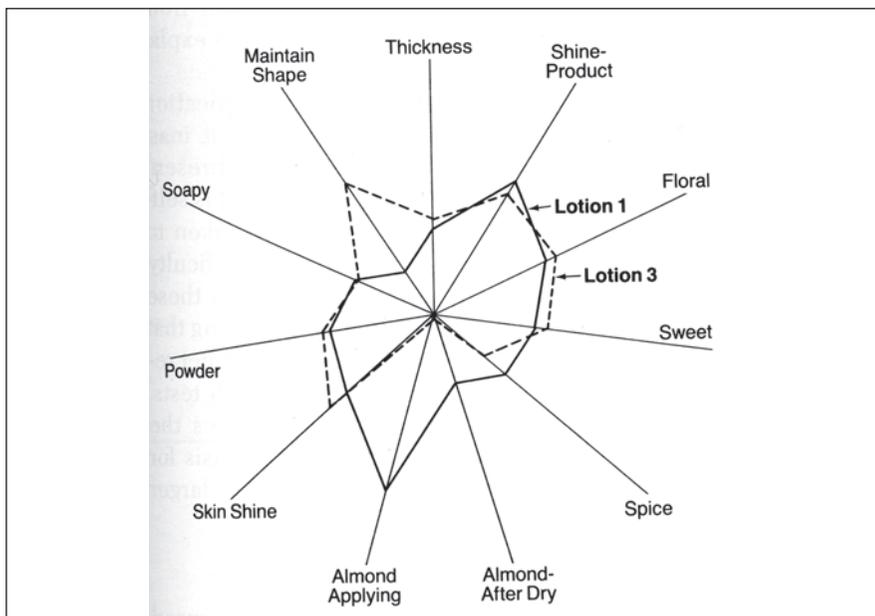


Figure 58.1. Appearance and fragrance attributes and their relative intensities from a QDA of a marketed hand lotion (Lotion 3) and an experimental hand lotion (Lotion 1) (from Reference 6)

Differences Between Experts and Consumers

Two decades ago, according to Moskowitz,⁷ sensory research and consumer research were separate and often competing activities. Sensory scientists worked in highly controlled test environments, with well-practiced panels, experts and analytical rigor. Many felt the consumer could only validly rate overall liking. However, in 1995 Moskowitz's survey of the data on interrelating experts and consumers⁸ showed that consumers can validly rate product attributes and need not be limited to ratings of liking/disliking. Furthermore, an earlier Moskowitz study showed that untrained consumers do not appear to confuse liking and sensory intensity, even when they have to assign these ratings almost simultaneously to a single attribute.

Today the sensory analyst can choose from a variety of profiles for products. These profiles come from consumers, experts, instruments and ingredients. But generally, there are few attempts to interrelate different profiles of ratings (such as expert panel vs.

An Opportunity

April is a great month to explore statistical analysis in the setting of sensory research. Tragon Corporation's Kathrine Conrad will be presenting on the topic "Early Integration of Consumer and Sensory Research" at the Seminar on Applications of Observational Research, sponsored by the ASTM Committee E-18 on April 26 at the Sheraton Centre Toronto in Ontario, Canada.

Sensory Spectrum will present a one-day course titled "Design, Analysis and Interpretation of Product Tests" on April 18 at its headquarters in New Providence, N.J., USA; the fundamental statistical techniques used to analyze, interpret and present product evaluation test results will be discussed. A four-day course on sensory evaluation techniques—including QDA and SDA and fundamentals of statistics—will be given May 29 through June 1 in Amsterdam and again on September 18–21 in New Jersey.

consumer panel). "From time to time, researchers execute studies in which they measure the stimuli by experts, consumers and instruments, and then report tables of correlations." Moskowitz said. "For the most part, these tables simply show that there exists a possible linear relation between two variables. They do not show much more."²

In 2005 at the Pangborn Sensory Science Symposium in Yorkshire, UK, Tragon showed a poster on the company's study of the early integration of consumer and sensory research. Both are quantitative approaches, as explained by Katherine Conrad, an account executive at Tragon. (See **An Opportunity sidebar**.)

"As generally accepted, sensory research measures the similarities and differences within a product set across a particular product category and yields quantitative information about intensities as perceived by the senses. Consumer research is affective testing, which means it focuses on liking/preferences and purchase interest. The results are focused on what is liked and disliked about a product," said Conrad.

"We call this 'early' integration to suggest an opportunity to begin research at the initial phase of a product's life cycle, rather than wait until a specific problem—either within the actual product

performance or within the concept and marketing imagery—needs to be addressed. Tragon funded this research to test a theory we wanted to pursue to understand how various methods of research can be used to measure different themes and then link these findings together. This research would be a way to marry the R&D, sensory, marketing and consumer insight departments within a company, rather than conduct separate research for each group,” Conrad continued.

Tragon has applied this interactive approach in a case study on four running shirts to demonstrate the benefits of early integration of consumer, sensory and interactive research methods. QDA identified 12 attributes of the shirts during running and six after running (**Figure 58.2a** and **Figure 58.2b**). Consumer testing was preferential. It provided quantitative measurements of product performance over time and across the four products. It also identified the features of an ideal shirt, as well as ways in which each shirt over-delivered or under-delivered on consumer wants and needs. Multivariate analysis aided in integrating consumer liking with sensory attributes to identify strengths and weaknesses of a target product (**Figure 58.2c**).

“The two research approaches were kept separate,” Conrad explained. “Results could be integrated, but data was not converted. Rather, correlations and relationships were identified.”

The study showed an inconsistency between consumers’ stated interest in certain features such as moisture control, ventilation and quick drying function, and consumers’ preference for products that didn’t have those features. The study also showed additional features, such as reflective tape and flexible fabric, that could be added to the target product to gain market advantage over the other shirts (**Figure 58.2c**).

“The integrated research approach identified gaps in product design with opportunities to improve in ways that are consistent with consumer needs and marketing strategy,” Conrad said. “Bridging these methods allows exploration of technical innovations to enhance the product development process.”

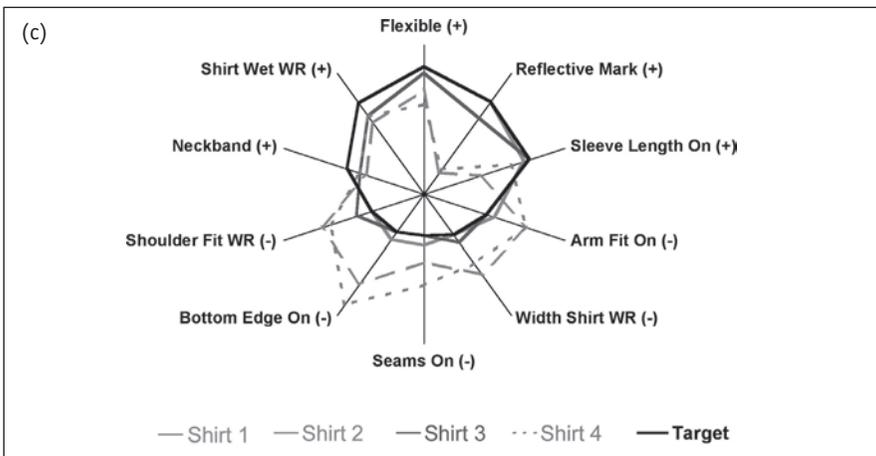
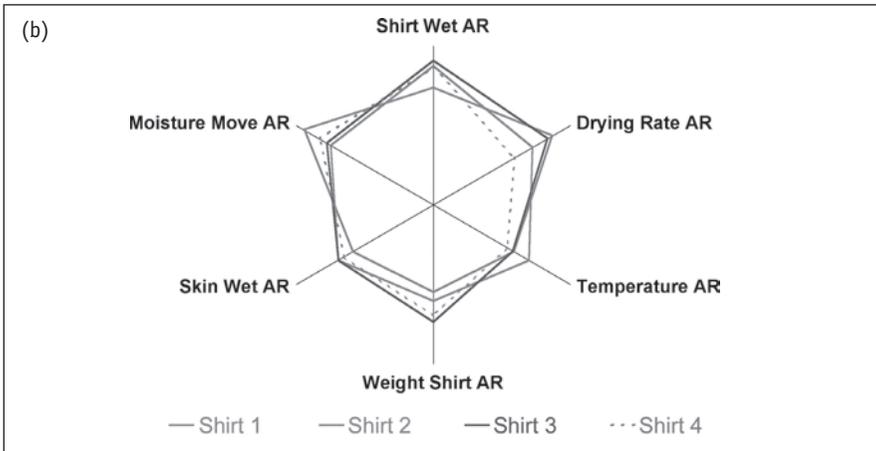
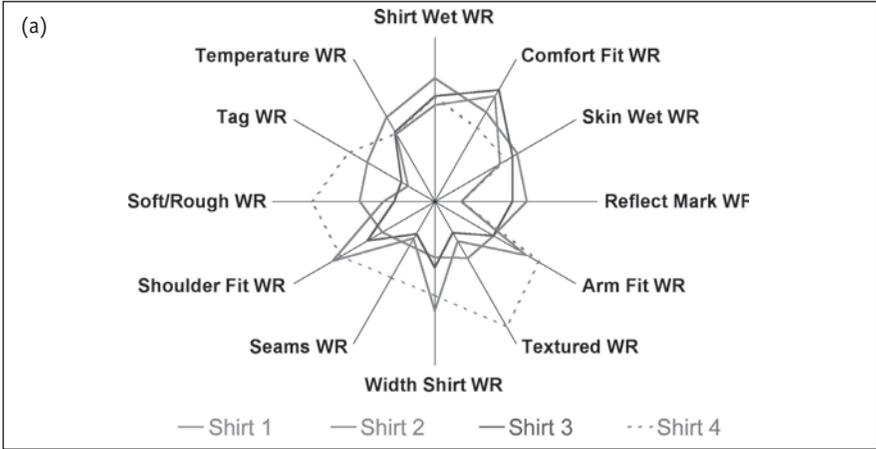


Figure 58.2. Spider plots from QDA of four models of a running shirt evaluated during running (2a), after running (2b) and as a target product resulting from combined sensory research and consumer research (2c)

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Market Segmentation

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KEY WORDS: *sensory testing, consumer-based sensory description, preference segmentation, market segmentation, cost, value*

ABSTRACT: *Used in conjunction with marketing and marketing research techniques, consumer-based sensory evaluation techniques provide an effective business strategy for product development and brand management.*

Personal care companies typically rely on numerous information sources for innovation and product development to map the sensory experience. These sources include technical experts, clinical trials, developers and perfumers to design products that the companies believe will best satisfy consumers. Experts in marketing and advertising will design compelling messaging to ensure initial trial. Focus groups and consumer testing are often used to provide insight as to what appeals to the target consumer from an advertising and marketing strategy to help drive sales.

Does the consumer actually agree with these assessments and the key benefits and marketing messages, and does the message match the product inside? Focus groups and consumer testing only provide direction that frequently is subject to alternative interpretations. Results might mean very little to the developer who is simply told by the brand manager to “make a fresh-smelling hand lotion that will leave the skin soft.”

Blind product testing by target consumers conducted at a central location (CLT) or in the home goes one stage further and provides useful quantitative information on purchase intent and consumer liking. Liking is an indirect measure of preference; it is most often

measured using a nine-point hedonic scale. A product scoring a value of 7 is preferred to a product that was scored as a 5.

Consumers might also be asked which sensory attributes they “liked” or felt were on target based on “Just-About-Right” (JAR) scales or similar consumer diagnostics. Consumers are able to express their liking, but they have difficulty explaining why, especially in terms the developer can understand and use for reformulation efforts. If responses to JAR scales are acted upon literally, the developer may be forced to alter products erroneously.

In addition, any consumer diagnostic is inherently correlated to overall liking because consumers justify scoring a product as “disliked” by stating that one or all of the attributes are off target.¹ The developer is faced with attempting to decipher vague, often conflicting consumer diagnostic responses and needs a more accurate and scientific way to understand the basis for product differences that are especially relevant in driving repeat purchase with an appropriate sensory experience.

Understanding a consumer’s complex behavior goes beyond determining the sensory attributes that are linked to liking and preference. These two behaviors are interrelated. Liking refers to a single product or an array of products, as in “I like this hand lotion very much.” Preference, either direct or implied, refers to “choice” behavior. “I prefer hand lotion A over hand lotion B.” Consumers are not homogenous in their behavior toward liking of products on a branded and unbranded basis and exhibit unique preference behavior. A consumer’s perceptual sensory behavior is not related to traditional demographic and psychographic information such as that typically found in market segmentation. Unique preference segments based on the sensory experience exist in 90% of all product categories studied by Tragon Corporation, and these segments are often global in nature.²

Segmentation by consumer preference in conjunction with segmentation by market is key to innovation, helping companies to maximize consumer appeal and develop brands that complement both the marketing and technical aspects.

Consumer-based Sensory Descriptions

One way to achieve consumer preference segmentation is through the use of consumer-based sensory descriptions. Methods to obtain these descriptions were developed to address a concern that the language used by technical or clinical experts to describe products is very different from the language used by the intended consumer. In today's consumer-focused environment, marketing must be certain that products match consumer expectations. Technical experts and clinical trials are essential, but for understanding consumer behavior it is essential that consumers are used to provide their perceptions that correlate very well with preference behavior. This provides marketing and sales with a window into the minds of the consumer on which to build brand loyalty.

Consumer-based sensory descriptions can be used in a strategic approach to product development. It is important to have a well-thought-out integrated plan to achieve a specific goal. For example, the overall objective is to develop a hand lotion for sensitive skin consumers, and that lotion should be significantly preferred to competition. This process can begin by first selecting an array of current, competitive and prototype products that capture the sensory experience for sensitive skin hand lotions. The products would be evaluated and their sensory experience would be described and quantified by a selected group of consumers that have demonstrated sensory acuity.

Tragon's method for developing those descriptions and measuring their intensity is called Quantitative Descriptive Analysis. This method fingerprints the perceived sensory experience, mapping similarities and differences among the product array. This same product array is then evaluated by the market segments to measure acceptance overall and in conjunction with key marketing messages designed for that segment. The quantified sensory fingerprints and consumer results are then mathematically related to determine which sensory attributes and marketing messages have the greatest impact on target consumer liking and, hence, repeat purchase.

By definition, product optimization is a procedure for developing the best possible product in its class.³ An objective of optimization

is to identify which product characteristics are important to sensory acceptance and the degree of importance of each. However, before this can proceed with any hopes for success, one first needs to determine how close current products are to optimal. Before a product optimization is implemented it is important to conduct a thorough category review.

Methods used to optimize products to gain market share are not new; neither is the use of trained panels or multivariate statistical techniques used to model consumer liking, analytical and sensory data. All these have been well established in the food industry.^{4,5} What is relatively new to the personal care products industry is a systematic approach that takes into account three critical factors:

- The inherent variability in products, consumers and competition. All of these factors are variable and one needs to understand how this may impact results.
- The continuous development of new ingredients, fragrances and sensory experiences that are available globally in a rapidly changing marketplace. This impacts the longevity of the results. In categories that have few new developments or new entries, results can be more stable over time. However, in rapidly changing and developing categories, results must reflect the current marketplace.
- The important process of defining the sensory space in the marketplace or one to be created. Oftentimes, the marketing department will select a competitive array of products that represent best sellers. From a sensory perspective, these products may be similar to each other and will not stretch the sensory perceptual space of appearance, fragrance, skin feel or after feel, for example. It is important to also select products or develop prototypes that create differences that consumers can observe.

Selection of the product array for optimization testing and defining the target consumer are the most critical steps in the process.

Product selection: The first stage in development of a sensory perceptual space entails selection of a large range of product styles.

Initial screening may be conducted on more than 100 products from of variety of markets and then narrowed to 14–25 test products.

The number of products that should be bench tested will depend upon test objectives. A review of the commercial hand lotions could mean that 80–100 products available worldwide could be screened in order to select a representative range of all hand lotions of interest to the company. Conversely, a review of globally available luxury hand lotions might be achieved with bench testing of as few as 40–50 products. The key is to select from the largest range of styles available to the consumer without choosing just those products that represent significant sales volume.

It is critical to select products that represent the entire range of styles to capture the sensory experience. A cross-functional team of six to eight skilled evaluators is recommended for bench-top screening of this array.

Language development: For consumer-based descriptive analysis methods, subjects must be screened for category usage and qualified based on their sensory acuity. Once selected, this group develops a rich consumer vocabulary to describe their perceived similarities and differences among the product array of interest.

The language development process is iterative and products are used in much the same manner as they are intended for the consumer before, during and after usage. **Figure 59.1** illustrates some product-specific terms that develop as consumers interact with a hand cleanser throughout usage. Once the language has been developed, consumers then evaluate products on a repeated trials basis, providing a quantitative database on which to build relationships with other consumer behavioral measures.

This information can be used for competitive assessment, innovation, new product development, strategic sourcing of ingredients, and a variety of purposes depending on the business and research objectives.

Consumer selection: Consumer recruiting criteria is critical and should be determined through a joint effort with marketing team members. The criteria will depend on the objectives of the research as it relates to a specific target or potential opportunity target consumer populations.⁶

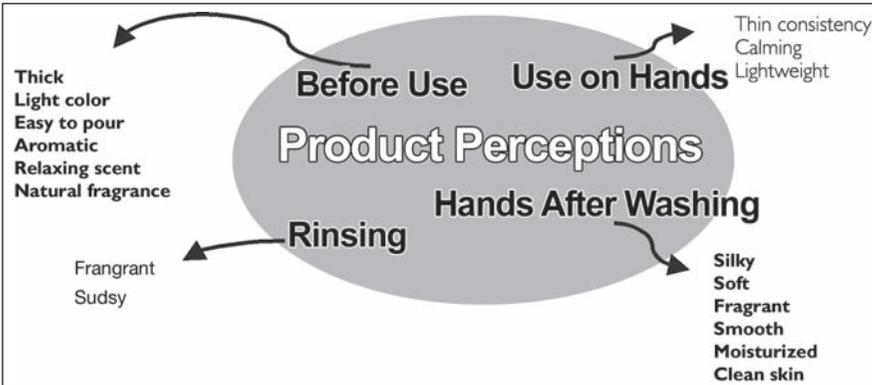


Figure 59.1. Product-specific terms that develop as consumers interact with the product throughout use

The questions to answer are how many, who and where? Multiple markets that are geographically dispersed and that have high or potentially high sales volumes are selected as the testing locations. The numbers of consumers can vary from small cells of consumers such as 100 males, to larger, more robust sizes such as 300 brand users.

Testing and usability: For optimization types of programs with larger numbers of products, testing should be conducted in more controlled environments while still mimicking a typical consumer usage situation. Testing may take place in a central location format with pre-recruited consumers over multiple, consecutive days.

Consumers complete several questionnaires during the test, some before product evaluations, some during products evaluations, and others after product evaluations. These questionnaires offer an opportunity to collect a comprehensive database of consumer information related to concepts, benefits, packaging and potential marketing messages.

Data integration and interpretation: Multivariate statistical techniques are important tools in relating sensory, analytical and consumer behavior. The analysis is used to identify the combination of sensory and/or analytical measures that best predict consumer likes and dislikes. Target values for key attributes provide marketing and development teams with specific reformulation goals to achieve optimized consumer acceptance.

Products that exhibit quantifiable sensory differences can be evaluated by the intended consumers. Then, by using a variety of multivariate analysis techniques, the key sensory characteristics that most influence consumer liking can be designed into products, and those characteristics can provide a benchmark versus key competition.

Plots in **Figure 59.2** compare consumer perceptions of two mild soaps—a prototype and a competitor. Products that fit within the target ranges would be optimal, whereas those that are outside the target ranges require additional formulation efforts. In this example, the “prototype-mild” product is farther from the target sensory attributes than is the “competition-mild” product, however both require reformulation to better achieve the target sensory characteristics.

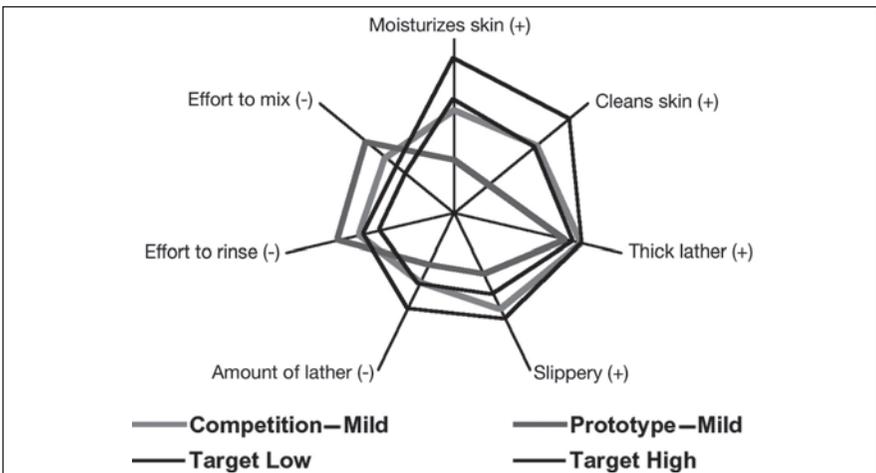


Figure 59.2. Perceptions of mild soaps: prototype vs. competition

These analysis procedures provide actionable suggestions for product improvement efforts. The suggestions are based on product sensory descriptions and their quantifiable amount and direction, rather than derived factors from a Factor Analysis or principal components from a Principal Component Analysis. This allows product development to focus on key sensory attributes that most impact consumer behavior.

Used in conjunction with marketing and marketing research techniques, consumer-based sensory evaluation techniques provide

an effective business strategy for product development and brand management.

A Comment on Cost and Value

One challenge that all companies face is whether the investment in a descriptive analysis test is justified versus a discrimination or a preference test. While larger companies understand the need for quantitative information about a product's perceived characteristics, smaller companies wonder if the investment is justified. There are several issues that need to be addressed:

1. History shows that expert descriptions of products do not match consumer perceptions and descriptions. Descriptive analysis testing provides information derived from qualified consumers for whom the product is intended.
2. Descriptive analysis methods offer some time advantages in the context of personal care products where multiple evaluations cannot be made within a single session. In terms of cost, a new panel using the Quantitative Descriptive Analysis to test four hand lotions will need as much as six weeks for completion. The same panel with more experience can complete the test in three weeks, depending on the number of replicates, and the cost is less than US \$10,000.
3. A direct comparison with other testing based on the output will show that the descriptive testing is more informative. Having quantitative product maps based on attributes that consumers recognize enables comparison with current production and competition. It provides formulation experts with a road map as to which characteristics should be changed and a means for confirming that such changes have been achieved.

Conclusion

The formulator and marketer can best take advantage of consumer-based sensory descriptions by scientifically exploring consumer behavior. Quantitative descriptive analysis is a powerful

communication tool between development teams and marketing, especially when combined with consumer-liking information. Consumers exhibit unique preference behavior and these patterns can be uncovered using sophisticated sensory science and data analysis techniques.

Sensory and consumer-based research methodologies are on the cusp of becoming the strategic tool used by marketing and sales. By targeting the market and image segments with the sensory preference segments, companies can create winning products that appeal to consumers and provide increased opportunity for brand loyalty.

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SECTION XII

Delivery

This section includes the following chapter:

60 Delivery Review: Looking at Liposomes

Delivery Review: Looking at Liposomes

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KEY WORDS: *bilayer-forming surfactants, cosmetic delivery system, elastic vesicles, liposomes, micelle-forming surfactants, skin penetration, transfersomes*

ABSTRACT: *In this short review, the author outlines cosmetic delivery systems of the past and present and gives predictions for delivery systems of the future. From transdermal drug delivery principles of the past to the latest trend in elastosomes, good scientific evidence is vital if the industry really wants to deliver benefits to its customer.*

The time when we believed that cosmetics did not penetrate skin is definitely over. They did in the past (although we preferred not to know it), and they still do today. There was a fear that cosmetics would be labelled drugs if they penetrated the skin, but it is the type of intrinsic activity of a molecule that decides whether it is a drug or a cosmetic—not its capacity to penetrate human skin. As a consequence, it is nowhere stated in cosmetic regulations that cosmetics are not allowed to penetrate the skin. Water, for instance, does penetrate our skin when we take a bath or shower, but we do not need a doctor's prescription to execute our daily hygiene routine. Delivery is the process of transporting the right chemical to the right location (the site of action) at a therapeutically relevant concentration for a sufficient period of time.

If any of these 4 requirements is not met, a product in which the active ingredient is incorporated will not be effective despite its very good efficacy profile. These 4 requirements have been called the 4 R's

of Delivery: the *Right* chemical to the *Right* site at the *Right* concentration for the *correct* period of time. All are equally important, so which one needs to be improved?

Skin delivery is a sequence of diffusion and partitioning phenomena within and between phases of different polarities. Barry¹ describes the complexity of the delivery process in a schematic way copied in **Figure 60.1**. Delivery systems need to optimise one or more of the 4 R's. To identify which one needs to be optimised, one needs to identify the rate-limiting step for skin penetration. Any of the 17 steps in **Figure 60.1** could be the rate-limiting step.

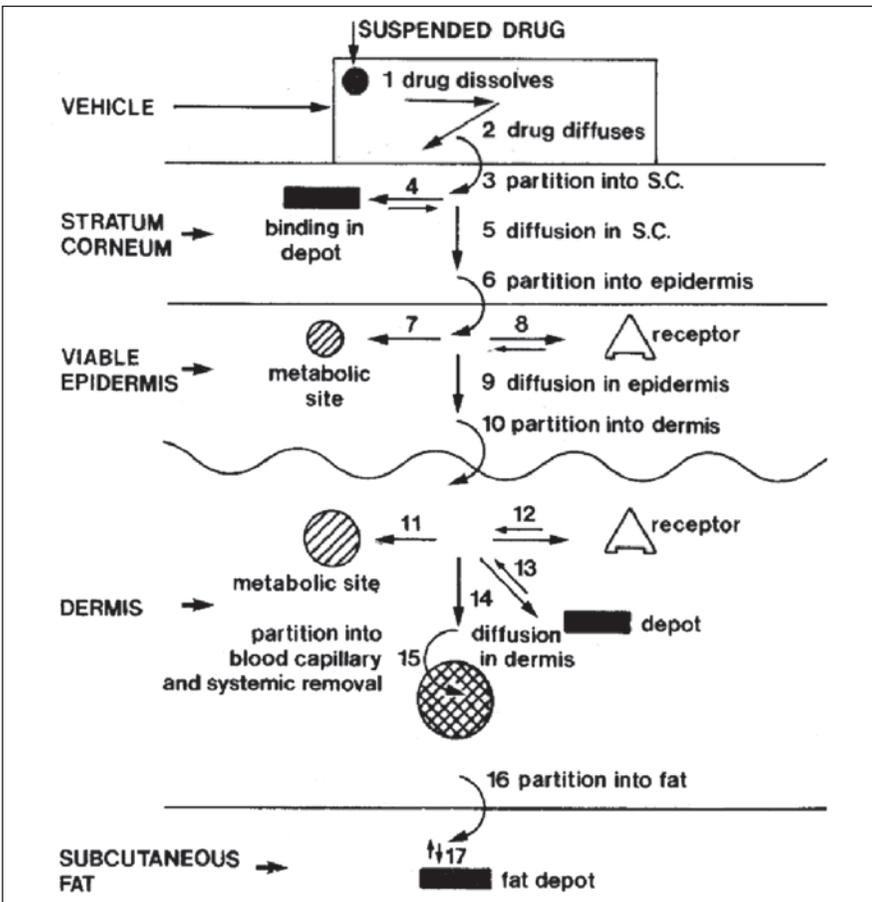


Figure 60.1. The steps an active ingredient undertakes from the formulation to its site of action

For instance, if the time span for which a chemical can remain on the skin constitutes the greatest barrier for efficacy (as is the case with most rinse-off products), any system that prolongs the contact time of the active ingredient on the skin will help to enhance the efficacy of the product. This would correspond to step 0 in **Figure 60.1**, which already assumes that a formulation is applied “infinitely” to the skin. Such systems typically deal with the time element of skin delivery, the *corRect* period of time.

When the dissolution and diffusion of the active ingredient in the formulation constitutes the rate-limiting step in skin penetration, such systems can be transferred into controlled delivery systems, as it is no longer the skin but the system that then determines the penetration rate of active ingredient into the skin. However, this only applies to systems where the transport of the active ingredient into and through the stratum corneum (SC) is sufficient to generate a clinical effect. Because this is often not the case, the popularity of “controlled delivery systems” in cosmetics is at least remarkable. Such systems typically deal with the concentration element of skin delivery, the *Right* concentration of active ingredient.

The barrier to skin penetration is typically located in the SC and in particular in the packing of the skin lipids.² Attempts to interact with steps 3 and 5 to increase the penetration into the SC and the diffusivity therein encompass issues such as prodrugs (a prodrug is a chemical modification of an active ingredient that has better skin penetration properties than the active ingredient itself); skin adjuvants (specific molecules like dimethyl isosorbide that increase the solubility of active ingredients in skin)³ and skin penetration enhancers. Such systems typically deal with the chemical and concentration element of skin delivery, the *Right* chemical and *Right* concentration.

Especially in the case of dermal delivery—in contrast to transdermal delivery—it is difficult to keep the active ingredient in the viable epidermis. After all, the main barrier for diffusion has been passed and the polarity differences between viable epidermis and dermis are small. Delivery systems to enhance the delivery to the *Right* location in the skin are few and far between. One of the few examples in our industry is the use of polyesters as topical delivery systems.

Based on the molecular design of the polyester, the active ingredient ends up in the superficial layers of the SC (as is necessary for sun care actives) or will penetrate deeper (as is necessary, for instance, for hydroxy acid formulations).⁴

Delivery Systems from the Past

The equations describing skin penetration are well known. The flux, J , of an active ingredient through the SC is proportional to the applied concentration of the active ingredient in the formulation, C , the partition coefficient, K , the diffusivity, D , and the length of pathway of diffusion, L , that can be combined in the permeability coefficient, k_p , according to the formula:

$$J = k_p \cdot C = \frac{K \cdot D}{L} \cdot C$$

Many systems in the past have, therefore, focused on increasing the flux of active ingredient into and through the SC by optimising K , D and ΔC . Whereas the first (into skin via manipulation of K and ΔC) is absolutely appropriate, the second (through skin via manipulation of D) is often completely inappropriate to maintain the active ingredient in the skin. With minor exceptions, transdermal cosmetic delivery systems are either not enhancing the efficacy of a cosmetic product or named incorrectly.⁵ But this is exactly what happened with cosmetic delivery systems in the past: they used transdermal drug delivery techniques to improve the concentration of active ingredients in the skin. In a previous presentation at the Society of Cosmetic Chemists (SCC) in New York,⁶ I described that this is not necessarily the right thing to do because rate of penetration (as expressed in the permeability coefficient, k_p) and extent of penetration (as expressed by Q , the integration J over time but in terms of dermal delivery effectively measured as the retention of active ingredient in skin) are not necessarily correlated.⁷

Dermal delivery is a lot more complex than the already complex transdermal drug delivery, simply because of having to pass the SC—the main barrier for diffusion—and then stop skin penetration as soon as this barrier has been passed. In addition, the only

techniques that do exist to quantitatively measure dermal delivery are either destructive (hence only one measurement per measuring unit and not a series of measurements as a function of time as is the case for transdermal delivery) or painful (e.g., microdialysis).⁸

Delivery Systems of Today

Many different systems are available nowadays to deliver the active ingredient into the skin. Some of these, such as the emulsion, are so common that most of us do not even recognise them as a skin delivery system. Strictly speaking, any cosmetic product is a cosmetic delivery system, but in this short review, special attention will be paid to vesicular systems such as liposomes that are specifically created or included to enhance the 4 R's of skin delivery. Emulsions using nanotechnology, cosmetic patches and the many spheres (glycospheres, microspheres, soft spheres, etc.), although of rapidly increasing interest, are not being discussed because they are simply too novel to review.

Liposomes are microscopic small vesicles (hollow spheres), consisting of one or several lipid bilayers that surround a watery nucleus.⁹ The rationale for including liposomes in cosmetic formulations is that liposomes *might* be carriers to deliver entrapped molecules into or across skin, they *might* act as penetration enhancers owing to penetration of individual lipid components, they *might* act as depots for sustained release, they *might* act as rate-limiting membranes for controlled release, they often are biodegradable, have a low toxicity and are relatively nonimmunogenic, as well as that they *might* have additional useful (cosmetic) properties. However, which of these properties of liposomes will emerge depends on a multitude of factors and as a consequence, the scientific literature in the early days of liposomes was often confusing in what a liposome would specifically do. Fortunately, this complexity has not discouraged liposome scientists from around the world and we are now reaching the phase where solid scientific evidence is available to underpin the effectiveness of liposomes as cosmetic delivery systems.

Liposome research in the 1980s: Despite that Alec D. Bangham published the first-ever paper on liposomes in 1963,¹⁰ it was not until

the early 1980s that the first papers reporting the effectiveness of liposomes in skin delivery were published. Mezei and Gulasekharam demonstrated that liposomal encapsulation of triamcinolone acetonide significantly increased the in vivo drug deposition of the drug in the epidermis and dermis, whilst its percutaneous absorption was greatly reduced.^{11,12} But others found the skin penetration of liposome-entrapped material to be reduced,^{13,14} making the drug-penetration enhancement effects of liposomes questionable at best.

This trend set in the early 1980s would continue into the next two decades. Large variations were found in the literature concerning the effectiveness of liposomes, hence enhancing their controversy as suitable (trans)dermal delivery vehicles. Several authors reported that liposomes only enhanced the drug deposition in the skin, suggesting them to be only useful for topical dermal delivery. Others, however, suggested that liposomes could deliver systematic drug concentrations, hence were suitable as transdermal delivery systems. The inconsistent results in the literature could—at least partly—be explained by the fact that liposomes with different compositions and hence physicochemical characteristics were used in different studies.

Liposome research in the 1990s: During the 1990s, new knowledge emerged that could eliminate some of these inconsistencies. In short, important factors that influence skin penetration were identified that could either enhance or reduce skin penetration of the active ingredient. The first was the thermodynamic state of the liposomes (liquid-state liposomes showed greater skin penetration than those in the gel state, suggesting that there might be a relationship between the depth of penetration and the phase transition temperature of the liposomes.^{15,16} Other factors that were found to be important—albeit to a lesser extent than the thermodynamic state of the liposome—include the following:

- the electrostatic charge (negatively charged liposomes penetrate better than positively charged liposomes);
- an intact water gradient (occlusion destroys the water gradient over the skin and therefore reduces penetration as liposomes are being drawn into skin by the hygroscopicity of the bilayer of the liposomes);¹⁷

- the size of the liposomes (an intermediate size of 0.3-0.5 μm seems to result in the highest degree of skin penetration);¹⁶ and
- the lamellarity of the liposome (unilamellar liposomes typically result in higher degrees of penetration than multilamellar liposomes).¹⁸

All these studies led to a significantly increased understanding of liposomes as skin delivery systems, but it needs to be noted that the prestige cosmetic market introduced liposomes long before it clearly understood what exactly it was doing.

Liposome research in the 2000s: After the year 2000 (helped by the increased understanding generated during the 1990s), liposome studies became more systematic, keeping constant what needed to remain constant and hence the results became more transparent. Nowadays, fundamental liposome studies often compare the delivery of a penetrant (often the water-soluble carboxyfluorescein (CF) as a model penetrant using confocal laser scanning microscopy (CLSM) as the detection method for skin penetration) with that of the model penetrant added to empty liposomes. The model penetrant incorporated into the liposome is also added to the outside of the liposome.^{19,20} These systematic studies greatly increased our knowledge but at the same time raised new questions as to what happens to the penetrant because CLSM cannot differentiate between entrapped and non-entrapped CF.

As an example, Dr. G. Blume of ROVI Cosmetics, Germany, kindly allowed me to reproduce some of her work in which she compares the skin delivery of CF with a solution, a solution containing emulsifier and a solution containing liposomes containing CF. The same was done from a cream containing the free CF, free CF in the presence of empty liposomes and liposomes containing CF. Her results for the cream formulation are depicted in **Figure 60.2**.

With the free CF, about 70% of the applied dose was found in the first three strips after a 1-hour application period (green bars). Please note that she did not wash off any non-penetrated material. Even in the presence of empty liposomes, approximately 75% of the CF was found in the top three tape-strips (blue), which confirms that these liposomes did not work as penetration boosters.

CF incorporated into liposomes (red) showed a completely different profile. About 50% could be found in the top 3 tape strips, but a characteristic peak was found from strip 9 till 15 (identical to what was seen for the lotion where she even showed the material to penetrate the deeper layers of the skin in a wave-like pattern when the distribution profiles were plotted as a function of time).¹⁹ Whereas I personally believe that the first three strips probably only contain non- or hardly-penetrated material (because the non-penetrated dose was not removed), the accumulation in the deeper layers can only be explained from the incorporation of CF into the liposomes.

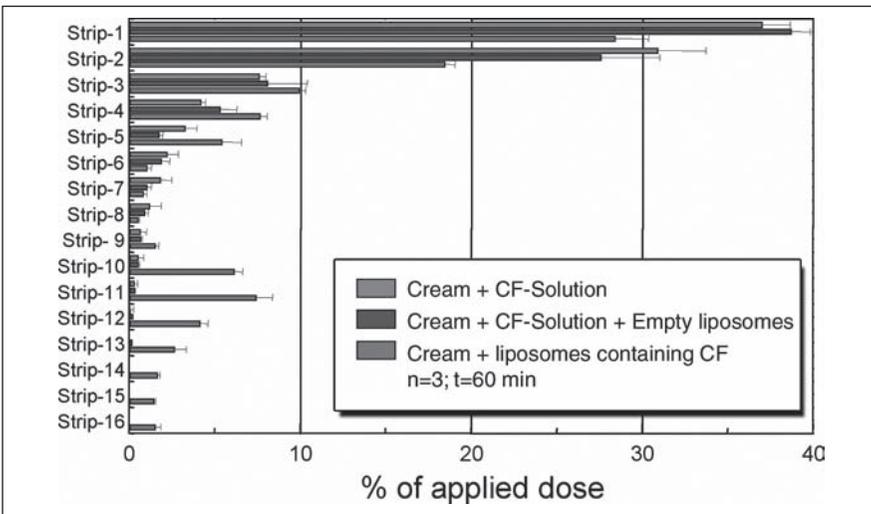


Figure 60.2. Skin deposition profiles after one hour after application measured via quantification of the amount of carboxyfluorescein (CF) in tape strips following application of a cream containing free CF (green), a cream containing free CF plus empty liposomes (blue) and a cream containing liposomes containing CF (red). Note that the skin was not washed to remove any non-penetrated material.

Latest trends in liposome research: Does this mean we now know how liposomes work and whether or not they penetrate the skin intact? And if so, do they actually release their incorporated load? Hans E.J. Hofland describes two different mechanisms by which liposomes might work. On the one hand, loaded vesicles adsorb and fuse on the skin surface leading to increased thermodynamic activity and enhanced penetration of lipophilic drugs. On the other hand, vesicles may interact with the intercellular lipid lamellar regions of

the SC, where they mix with the lipids of the SC modifying the lipid bilayers and inducing new, more permeable structures.^{21,22}

The increased understanding of the factors that influence the effectiveness of liposomes as skin delivery systems has led to the development of elastic vesicles^a that consist of phospholipids such as phosphatidylcholine and an edge activator, such as sodium cholate.¹⁷

The phospholipid acts as the bilayer forming component, adding stability to the system. Incorporation of a micelle-forming surfactant results in a destabilisation of the lipid bilayer, thereby increasing the vesicle elasticity (see **Figure 60.3**).

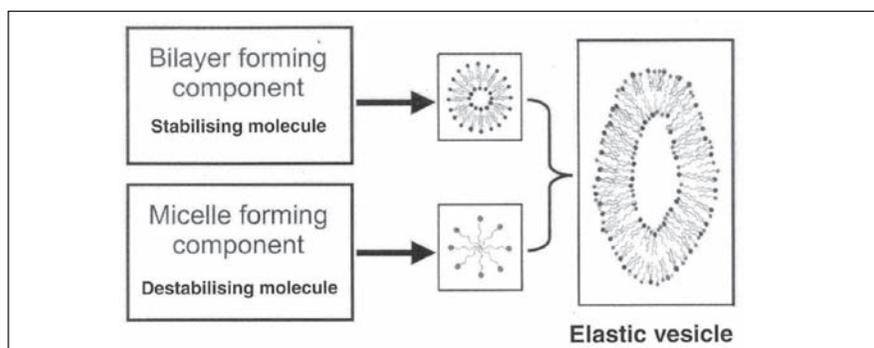


Figure 60.3. The composition of surfactant-based elastic vesicles consisting of stabilising bilayer-forming molecules and destabilising micelle-forming molecules

The vesicle elasticity is therefore strongly dependent on the ratio of the bilayer-forming and micelle-forming components. These extremely flexible systems are reported to penetrate intact into human skin.²³ In 1999, Van den Bergh et al introduced elastic vesicles consisting solely of surfactants, with the bilayer-forming surfactant sucrose laurate ester^b as the stabilising molecule and the micelle-forming surfactant PEG-8-L (octaoxyethylene laurate ester) as the destabilising molecule. These researchers were able to show that these surfactant-based elastic vesicles were more effective than rigid vesicles in enhancing the penetration of tritiated water across hairless mouse skin.²⁴

Recently, Bouwstra and Honeywell-Nguyen suggested a novel 4-step mechanism of action for these elastic vesicles^{25,26} that is depicted in **Figure 60.4**.

^a Transfersomes are product of IDEA AG, Munich, Germany.

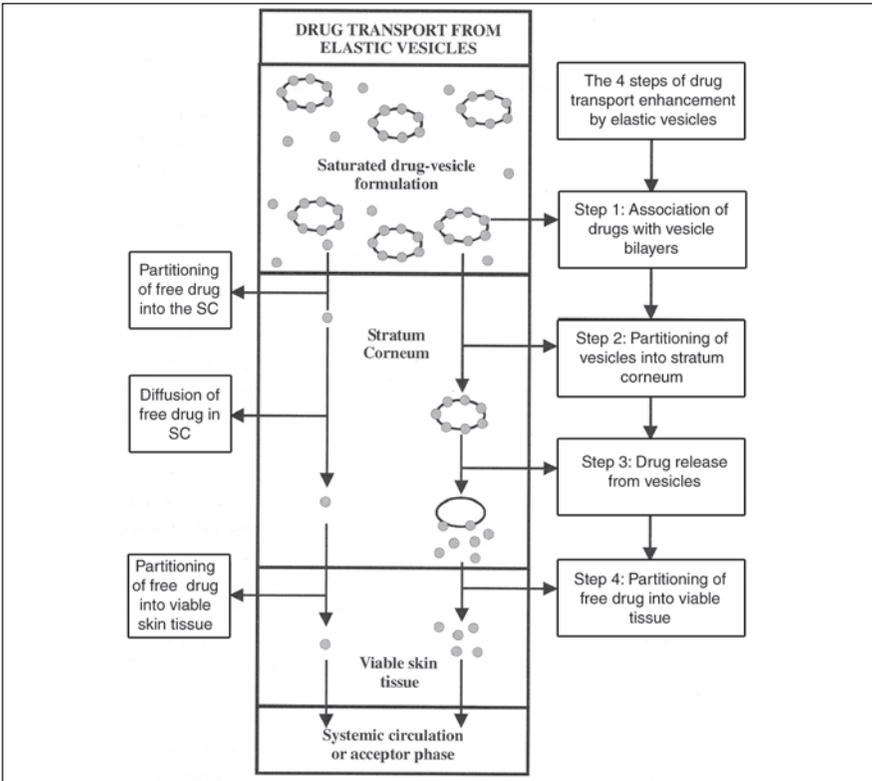


Figure 60.4. The proposed mechanism of action of surfactant-based elastic vesicles. For a description of the 4 steps involved in this mechanism, see text.

In step 1, it is essential to associate high amounts of drugs with the vesicle bilayers. Step 2 involves a fast partitioning of the vesicles into the SC. In doing so, the vesicles will enhance drug transport into the skin, as vesicles will carry vesicle-bound drug molecules into the SC. The vesicles themselves will remain in the SC and do not penetrate into the deeper skin layers in significant quantities. Vesicle-bound drug molecules are released from the vesicles (step 3) with subsequent transport of free-drug molecules into the viable skin tissue (step 4). This mechanism of action was based on *in vitro* findings but later confirmed by *in vivo* techniques using tape-stripping in combination with either freeze-fracture electron microscopy or attenuated total reflectance Fourier transformed infrared spectroscopy.²⁷

Non-vesicle-based delivery systems: Whereas it is acknowledged that liposomes are extensively discussed in this short review because they have been around since 1963, in contrast to so many of the newer techniques such as nanotechnology and microsponges, cosmetic emulsions have been around even longer. Is there something new that we may expect in the future from this direction? Recently Wiechers et al introduced the Relative Polarity Index that compares and optimises the polarities of SC, penetrating molecule and the emollient components of a cosmetic formulation. This so-called Formulating for Efficacy approach consists of identifying a primary emollient in which the active ingredient is very soluble (to ensure high absolute amounts of active ingredient in the formulation) and subsequently adding a secondary emollient in which the active ingredient is far less soluble (to increase the partition coefficient K (i.e., a low solubility in the formulation relative to that in the SC)). By using this approach, they were able to enhance dermal delivery of octadecenedioic acid, a new skin whitener, by a factor of 3.5 without changing the concentration in the formulation.²⁸ This approach is doubly effective, as it enhances the delivery without necessarily increasing the costs of the formulation.

Delivery Systems of the Future

The U.S. consumption of particulate delivery systems for cosmetics and personal care applications (excluding patches) has been estimated at between \$25 and \$30 million in 2001.²⁹ Millicapsules (1 to 4 mm; strong visual appeal as visible in clear formulations; instant gratification effect) hold a share of 40% of the market by value, followed by nanoparticles (liposomes, bilayer membrane particles; approximate size <100 to 300 nm) and microcapsules (particle size >1 micron; based on matrix or encapsulation layer; can be coated) each with a 30% market share.²⁹ Robust double-digit growth is forecasted for delivery systems over the next 5 years, with nanosomes/nanoparticles and millicapsules expected to outpace the growth of liposomes and patches. Microsponges and microemulsions are also gaining market acceptance. This clearly suggests that skin delivery systems are here to stay. Moreover, we may anticipate much of the cosmetic delivery systems currently developed for

the prestige market to be used in the mass-market within the next 5 years.

Conclusions

It is clear that there has been major scientific advancement in skin delivery and cosmetic delivery systems over the last decades. More important, however, the cosmetic industry has realised the importance of skin delivery, but again, cosmetic manufacturers will need to be careful when selecting their skin delivery systems. Do not simply use transdermal theory to enhance dermal delivery, as it will most often not work. A good first question to ask oneself is: What comprises the rate-limiting step in the overall delivery process? This is the step that should be enhanced (assuming that skin delivery should be increased). For instance, the number of new deposition systems grossly outweighs the number of applications in which the deposition time is truly the rate-limiting step.

Science is gradually catching up with the marketing promise for delivery systems. In order to differentiate the two, cosmetic manufacturers should insist on seeing good scientific and objective data that underpins the claims that are made for the delivery system. It should be realised that skin delivery research is very expensive and that it will need to be repeated with every modification of a formulation. Scientifically proven skin delivery systems therefore come, unfortunately, at a price. When one is inundated with the praises of a new cosmetic delivery system, one needs to seriously ask oneself whether this nanospeak is just meganoise to extract teradollars from the gullible taxpayer or consumer with femto return on investment! Approaches like *Formulating for Efficacy* form a nice exception but you will need to understand the scientific principles of skin delivery to use it independently. Finally, what tastes better, new wine in old sacks or old wine in new sacks?

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SECTION XIII

Infant Care Products

It has become more and more clear that the infant requires products that are different from the general-purpose products marketed to other segments of the personal care market. This section is presented to make the formulator aware of salient differences between adult and infant skin and propose approaches to making infant products more child friendly.

Knowledge of neonatal skin is essential to formulate safe and effective products for infant skin. Once the safety profile of a formulation has been established, performance testing is required to assess the effectiveness of the material relative to its intended purpose. In fact, Dr. Boisits states “Over the past half century, there have been numerous examples of infant toxicity, including illness and death, because of products used that were thought to be safe based on the history of their use in adults”.

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Formulating Infant Skin Care Products

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KEY WORDS: *stratum corneum, cleansing, hydration, humectancy, safety evaluation*

ABSTRACT: *Knowledge of neonatal skin is essential to formulate safe and effective products for infant skin. Once the safety profile of a formulation has been established, performance testing is required to assess the effectiveness of the material relative to its intended purpose.*

Over the past half century, there have been numerous examples of infant toxicity, including illness and death, because of products used that were thought to be safe based on the history of their use in adults. Because of the differences in the body mass/surface area ratio between infants and adults, infants receive larger doses on a weight-to-weight basis.¹ Today, greater caution is exercised with products used on children to avoid potentially toxic reactions. For example, warnings are displayed on some over-the-counter (OTC) drugs recommending against their use on children under 6 months of age without the consultation of a physician. Cetta et al. reported² that infants are exposed to a surprisingly large number of chemical species such as surfactants, sunscreens, emulsifiers, germicides, humectants, etc., through the application of OTC products (see **Newborn Skin Care sidebar**); the average newborn is exposed to 8 different skin care products and 48 different environmental chemicals from those products.

Much of the activity in skin development is centered on the formation of the epidermis, which ultimately generates the stratum

Newborn Skin Care

Most commonly, the following 5 types of skin care products are used for newborns: soap, bubble bath, shampoo, lotion/oil, and baby powder. Some special considerations are described for each type of product.

Soap: Although water is often sufficient, a small amount of soap may be needed. If so, a mild soap should be used such as one containing olive, coconut, or palm oil. Many pediatricians recommend avoiding antibacterial soaps.

Bubble baths: Bubble bath products for young children are often based on detergents that destroy beneficial bacteria and harm the baby's acid mantle. Furthermore, bubble baths are a leading cause of vaginitis and urinary tract infections in infants. This problem has become so prevalent that the U.S. Food and Drug Administration has ruled that bubble baths for children must carry warning labels advising parents against excess bathing of their children.

Shampoos: A mild shampoo is recommended and should not contain ingredients such as synthetic fragrances, artificial colors, or irritating preservatives including quaternium-15, imidazolidinyl urea, and parabens. It is also recommended to avoid products containing diethanolamine (DEA) or triethanolamine (TEA) as both ingredients interact with nitrites. The gentlest preservatives include retinyl palmitate, ascorbic acid, and α tocopherol.

Lotions and oils: Massage lotions and oils can relieve irritation but anything used should be free of petrochemicals (especially mineral oil), which can be irritants. Chamomile and aloe reportedly have a history as soothing and moisturizing ingredients and have a good record of safe use in cosmetics. Overall, avoid artificial colors, DEA, and TEA, and seek out products that use gentle preservatives. Additionally, many baby lotions contain lanolin—a fatty substance obtained from sheep wool and used as a base for cosmetics. Experts advise against the use of lanolin unless the company guarantees it is pesticide-free.

Baby powder: Many powders contain tiny particles that irritate the skin, as well as contain fragrance, a leading cause of allergy and irritation. Scent-free powders made with cornstarch or bentonite clay are highly recommended.

Source: Skin Care for Newborns—Less Is More by David Steinman, Natural Health, Nov.-Dec. 1994. Available at: http://www.naturodoc.com/library/children/newborn_skin.htm. Accessed: May 17.

corneum (SC) and the all important barrier contained within it. Keeping the well-being of the newborn and the environmental stresses that affect him or her in mind, formulators need to develop skin-friendly personal care products that are safe and effective, as well as considerate of the overall health of the infant. There is a myriad of carefully orchestrated activities occurring during skin development. The human neonate is abruptly taken from a warm, aqueous, intrauterine medium and—even under the best of circumstances—thrust into a terrestrial, gaseous environment with variable temperatures, invasive microorganisms, and a plethora of environmental challenges. The infant's body is suddenly adjusting to the prevention of dehydration, microbial infection, and thermal regulation. It is, therefore, paramount that the infant has a suitable skin barrier and the mechanism(s) in place to maintain the integrity of that barrier.

A healthy newborn's SC is structurally and functionally similar to that of an adult. Epidermal thickness and the number of cell layers in each epidermal compartment are comparable in adult and newborn skin, as are the cellular structure, number of cell layers and thickness of the adult and newborn SC.^{3,4} The skin adapts and changes its biophysical and physiological properties in response to specific environmental influences that include the following: light, temperature, relative humidity, hydration, bathing, surface treatments (i.e., cleansers, alcohol, etc.), diapers, creams, protective barriers, friction, soil (urine, feces), and adhesives. Of particular importance are the endogenous and exogenous water-handling properties of the SC, since the hydration status of this outermost layer is vitally important for maintaining barrier properties of the skin.⁵ It is important to note that environmental effects on the skin frequently act in combination with each other (e.g., temperature and humidity).

For the purpose of this chapter we will discuss skin care in its most basic form and restrict discussion to full-term infants only; the pre-term infant represents a unique situation because of the ever-changing state of the epidermal barrier. In this way, the concept of development and testing of personal products for infants can be presented simply.

Cleansing

Basic skin care consists of proper cleansing, hydration, and prevention of skin damage. Cleansing and hydration are important for maintenance of the SC. The prevention of damage is important to avoid compromising the barrier that can result in microbial infection. It cannot be stressed enough that the primary purpose of the epidermis is to generate the SC and the barrier contained within it. Reports in the literature have shown that infant skin will tolerate—and may actually benefit—from daily bathing.^{6,7,8} The question, however, remains whether to cleanse with water only or to use a personal cleansing product, and if so, which product should be used? A number of reports describe beneficial effects of personal cleansing bars, even soap-based bars, used as therapeutic adjuncts.^{9,10} But personal cleansing products are more frequently implicated for their potential to negatively impact skin, either directly or by acting as triggering factors in disease conditions such as atopic dermatitis or rosacea.^{11,12,13,14} Personal cleansing products are often referred to simply as “soap,” a term probably held over when true soap-based bars were the only cleansers available. The term does not adequately describe the complex nature of most cleansing products on the market today. Other surfactants have replaced soap, and products often contain mixtures of surfactants that determine a bar’s performance characteristics and skin compatibility. Furthermore, the variety of products available to consumers today provides improved performance over traditional soaps as well as enhanced skin benefits such as mildness, moisturization, exfoliation, etc. However, personal cleansing bars remain the predominant cleansing product on the market.¹⁵

Normal infants’ skin will tolerate a range of cleansing products. Soap-based cleansers, however, generally have a greater likelihood of drying and irritating than cleansing products based on synthetic surfactants, especially when used under hard-water conditions. Products based on synthetic detergents differ in their irritancy potential relative to the surfactants employed and their concentrations in the formulation. In addition to the surfactant composition of

cleansing products, formulators must be aware of other ingredients that have the potential to cause reactions with infants. Information from controlled tests can provide essential information when selecting ingredients to be used in cleansers intended for infants' skin.¹⁵

Skin Hydration

As we stated previously, hydration of the SC is vitally important for maintaining barrier properties of the skin.⁵ During the infant's first few weeks of life, the SC undergoes significant changes in water-handling capabilities. Thereafter, the skin responds to simple environmental interactions (e.g., fresh water bathing and changes in relative humidity) to maintain the necessary trans-epidermal water gradient and hydration for flexibility during movement.

Common interventions such as ointments are often used and can be effective to modulate the water-handling capability of the SC. The purpose of such interventions is to help provide the proper environment (proper ambient moisture conditions) under which the SC can grow to affect epidermal activity for the seamless maintenance of the outermost layer of skin. Application of topical treatments such as lotions and creams (see **Formula 61.1**) generally affects skin moisture content through occlusion, humectancy, or their combination. With the technology available, a dichotomy often exists, wherein the more effective materials are aesthetically displeasing (i.e., tacky or greasy) and vice versa. Petrolatum is often regarded as the ultimate treatment for moisturizing skin, as it helps to maintain water content through simple occlusion. However, in spite of its effectiveness, petrolatum's physical characteristics (i.e., occlusive capability) preclude its use under many circumstances. Alternatively, humectant materials are used that help to bind water and share it with the SC, thereby increasing the length of time water is in the skin. Because of the water-soluble nature of humectants, these materials are easily removed through cleansing and water rinsing. As such, more cosmetically appealing forms of these types of ingredients are constantly being formulated to derive a product combining both effectiveness and aesthetics.

Formula 61.1. Moisturizing Baby Cream (Desert Whale Jojoba)

A gentle conditioner that leaves baby's skin feeling soft and smooth.

A. Water (<i>aqua</i>)	68.50%
B. Glycerin (Glycerine USP, VW&R)	2.50
C. Stearyl alcohol (Lipocol S, Lipo)	3.00
Cetyl alcohol (Lipocol C, Lipo)	3.50
Stery alcohol (and) ceteareth-20 (Lipowax G, Lipo)	2.00
Glyceryl stearate (Lipo GMS-450, Lipo)	2.50
Dimethicone (DC 200 Fluid, Dow Corning)	1.00
Wheat germ (<i>Triticum vulgare</i>) oil (Wheat Germ Oil, Desert Whale)	0.50
D. Calcium starch octenylsuccinate (Skin-Flow-C, Midwest Grain)	6.50
E. Hydrolyzed jojoba protein (Jojoba PRO-HP, Desert Whale)	5.00
Jojoba (<i>Simmondsia chinensis</i>) amino acids	5.00
Preservative	qs

Procedure: Weight A into a suitable vessel. Begin mixing and add B. Continue mixing and heat to 75°C. In a separate vessel, mix C in order and heat to 75°C. When possible, begin mixing. Add C to AB with good mixing. Mix until uniform. Continue mixing and cool to 50–55°C. Continue mixing and slowly sift in D. Avoid lumping. Continue mixing and cool to 35°C. Continue mixing and add E. Continue mixing until uniform and cool to the desired filling temperature.

Safety and Efficacy Evaluation

The cosmetics industry has a long history of producing products that are both safe and effective, as judged by the methodology available. Diligent safety testing programs must be established by individual companies to ensure the continued success in the development of quality personal care products. If programs are devised using existing methods, the industry will continue to market safe products. However, the development of new methodologies will allow the industry to design even safer, more effective products.

Because of the nature of the neonate, extreme caution needs to be exercised in the selection of ingredients and vehicles used. To accomplish these goals, a program is necessary that dictates the required evaluation procedures. The most effective approach is 3-pronged: in vitro testing, in vivo testing, and assessment through

the use of typical consumers. In this way, data are collected on safety and performance, as well as consumer acceptability.

Many predictive test methods were developed to assess the irritancy potential of materials, but because there are so many available methods, they preclude being discussed in this chapter. Some tests have been mandated by government regulation. Ultimately it is up to the individual investigator to consider the purpose of particular tests and to apply principles and techniques that others have successfully employed. The area is sufficiently complex to favor the well-trained, experienced, and innovative scientist over those performing studies in “cookbook” fashion.¹⁶

More important, one should approach testing in humans cautiously; new materials and those of unknown or unfamiliar composition should be tested either on *in vitro* skin irritation assay systems or on animal skin first to determine if application to humans is warranted and testing should be conducted in stepwise fashion, with short exposure period and with open application tests being conducted first.¹⁶ It is unlikely that an *in vitro* system could ever be developed to mimic the complex cascade of reactions that occur in human skin. *In vitro* methods, however, can and should be used for initial screening to facilitate development of new materials and minimize risks involved prior to testing in humans. Typically, a safety assessment program consists of irritancy-potential evaluation, sensitization-potential evaluation, photo-allergy and phototoxicity testing, and safety-in-use evaluation.

Sensitization potential is a very important piece of the safety profile. Regulatory agencies often require that chemicals and untested materials that are intended to be newly introduced into the marketplace be evaluated for this potential hazard. Currently, the modified maximization technique of Kligman and Epstein and the modified Draize procedure (Repeated Insult Patch Test) are the methods of choice.¹⁷ In addition, results from the Repeated Insult Patch Test can also help provide information on hypoallergenicity of products.

Following collection of basic safety data, in-use evaluation is recommended. Information regarding safety or toxicity under real-world-use conditions compared with exaggerated-use conditions provides data confirming the lack of toxicity potential and/or insight

in the incidence of untoward product-induced reactions when used correctly or incorrectly.

Once the safety profile of a new ingredient or formulation has been established, performance testing is essential to assess the potential effectiveness of the material relative to its intended purpose. Performance evaluation provides the information necessary to generate and support advertising claims. Of course, where possible, performance testing using *in vitro* systems or, where applicable, small pilot studies can be conducted concurrently with safety assessment. Performance testing is carried out on the target substrate using the population fitting the demographic of the intended audience. These populations can and do include men, women, teenagers, and children, including those young enough to be wearing diapers. Subgroups include users of specific product types, as well as those with conditions such as acne, rosacea, atopic dermatitis, seborrheic dermatitis, dandruff, etc. Product is assessed objectively using trained evaluators; instrumentally, whenever possible; and subjectively, by study panelists. A performance profile is generated using this 3-pronged approach, wherein data generated instrumentally corroborates objective results and subjective findings provide further support, as well as insight into product aesthetics and performance parameters that were, perhaps, overlooked.

Conclusion

Preparation of products intended for infant's skin provides a unique challenge to the formulator, wherein effective personal care products are required that address specific needs and toxicity must be carefully considered because of potential hazards unique to the newborn. At the same time, these products need to be aesthetically pleasing.

Knowledge of neonatal skin is essential to identify and formulate safe, as well as, effective products. Comprehensive safety testing programs are required and, typically, include *in vitro* testing, *in vivo* testing, and assessment through the use of typical consumers. Irritancy and sensitization potential evaluation, phototoxicity/ photosensitization assessment, and safety-in-use evaluation are normally considered.

Once the safety profile of a new ingredient or formulation has been established, performance testing is required to assess the potential effectiveness of the material relative to its intended purpose. Performance evaluation provides the information necessary to generate and support advertising claims. Testing is carried in vitro, as well as in vivo, using target populations fitting the demographics of the intended audience. Populations can and do include men, women, teenagers, and children, including those young enough to be wearing diapers. Product is assessed objectively using trained evaluators, instrumentally whenever possible and subjectively by study panelists. A performance profile is generated using this 3-pronged approach, wherein data generated instrumentally corroborates objective results and subjective findings provide further support, as well as insight into product aesthetics and performance parameters that, perhaps, were overlooked.

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A Discussion on Emulsifiers for Baby Products

Bud Brewster

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KEY WORDS: *emulsifiers, baby lotions, baby products, organic, cationic materials*

ABSTRACT: *The following is an interview by Bud Brewster, Technical Editor of Cosmetics & Toiletries Magazine, with Ken Klein, author of "Read the Label."*

Ken: So you want to talk about emulsifiers used in baby lotions?

Bud: Baby products are one of our themes this month.

Ken: Well, in general, most lotions and creams—for baby or otherwise—are oil-in-water emulsions. The oil is dispersed as tiny droplets in the water. It is the job of the emulsifier to make the oil stay dispersed so the emulsion is stable.

Bud: How does the emulsifier maintain the dispersion?

Ken: The goal of an emulsifier is to reduce the interfacial tension between the oil phase (typically the internal phase) and the water phase (typically the external phase). It does this by having 2 distinct parts to its molecular structure. One part is polar (water loving) and is, thus, soluble in the water phase, while the other area is nonpolar and is soluble in the oil phase. Thus, the emulsifier migrates to the interface and acts as a barrier to coalescence/separation. The polar end can be charged (positive-cationic or negative-anionic) or uncharged (ethoxylated or containing several hydroxyl groups, such as polyglyceryl, sucrose, or glucose).

Another approach is to use emulsifiers that form liquid crystals. These emulsifiers thicken the “water” in proximity to the oil droplets and immobilize the oil droplets. Hence, they can’t “bang” into each other, and the emulsion is stabilized. Generally, these liquid crystal-forming emulsifiers are quite mild to the skin but are not very robust emulsifiers, and emulsion instability is a concern when using them.

Bud: Does the use of emulsifiers in products for babies pose any special challenges?

Ken: When asked to develop an emulsion designed to be applied to babies, the formulator must, of course, be very concerned with whether the emulsifier chosen will irritate the baby or compromise the barrier of the skin and, consequently, permit/promote the penetration of other emulsion components, therefore increasing the likelihood of irritation.

We must also remember that very polar (“big heads”) emulsifiers can “mobilize” the interstitial lipids between the skin cells (destroying their liquid crystalline arrangement) and increase the transepidermal water loss. So there are definite concerns when formulating for baby.

Bud: Let us see how formulators have addressed those concerns. What products do you have there?

Ken: I brought a variety of products. As a general rule, I’m not a big fan of using soap systems as emulsifiers for baby products because of their high pH and potential for upsetting TEWL. We’ll just look at the emulsifier ingredients in these products. Here’s one called **Aveeno Baby Calming Comfort Baby Lotion**.

Distearyldimonium Chloride, Cetyl Alcohol Chloride

This is a cationic emulsion system. The emulsifier (distearyldimonium chloride) is more typically found in hair conditioners. Notice the sodium chloride used as a thickener/stabilizer. While cetyl alcohol is not really an emulsifier, in this system (and many others) it acts as an emulsion stabilizer.

Bud: Many chemists are concerned that cationic materials are irritating.

Ken: But this emulsifier has 2 big fatty groups lowering its irritation potential. Use of cationic emulsifiers in baby lotions has a

long history. **Mennen** marketed its **Baby Magic** for decades using 2 cationic emulsifiers.

Bud: Hmm. Hang on a second... Yes, here is a quote from FindArticles.com about Baby Magic: “At first, the skin care market was dominated by soap-based emulsions; triethanolamine and stearic acid were common to most skin care formulas. Nonionic emulsifiers expanded the formulation opportunities by expanding the scope of compatible, functional materials. And now, cationic emulsifiers are broadening the range of aesthetics available to the formulator. The use of cationic emulsifiers is not a new concept. In fact, the application area first seen in the market was baby skin care products. Mennen marketed this line under the trade name Baby Magic using 2 cationic emulsifiers...S.C. Johnson & Son launched the second cationic emulsifier...”

Ken: Now look at this **Johnson’s Softlotion Baby Soft Skin**.

Carbomer, Cetareth-6, Sodium Hydroxide, Stearyl Alcohol

This is a nonionic emulsion (Cetareth-6) that contains a thickener (Carbomer) neutralized by sodium hydroxide.

Bud: What is that other Johnson product you have there?

Ken: It uses a different system. This is a classic. It is **J&J Baby Lotion**.

Myristyl Myristate, Glyceryl Stearate, Oleic Acid, Stearic Acid, Polysorbate 61, Sorbitan Stearate, Cetyl Alcohol, Synthetic Beeswax, Stearyl Alcohol, Carbomer, Sodium Hydroxide

This is an anionic (Sodium Stearate)/nonionic (Polysorbate-61) emulsion that uses some liquid stabilization also (Sorbitan Stearate, Cetyl/Stearyl Alcohol). Just to make sure they have good stability they also add some carbomer.

Now what else did you bring with you?

Ken: Here is **Gerber Grins & Giggles Baby Lotion, Lavender**.

Glyceryl Stearate, Stearyl Alcohol, Cetyl Alcohol, Synthetic Beeswax, Stearic Acid, Sorbitan Stearate, Polysorbate 60, Sodium Hydroxide, Carbomer, Oleic Acid

Bud: It looks as if it is basically a copy of the **J&J Baby lotion!**

Ken: I would say so. Now look at this **Banana Boat Baby Sunscreen SPF 48** and the emulsifier components from among the inactive ingredients.

Acrylates/C10-30 Alkyl Acrylate Crosspolymer, Cetyl Phosphate, Magnesium Aluminum Silicate, PEG-20 Sorbitan Isostearate, Polyhydroxystearic Acid, Sorbitan Isostearate, Triethanolamine

The Acrylates/C10-30 Alkyl Acrylate Crosspolymer and Cetyl Phosphate are being neutralized by the Triethanolamine to form a thickener/anionic emulsifier system. They also add some other materials that complex at the interface forming a good emulsifier system. The Magnesium Aluminum Silicate helps with high temperature stability.

The last example I brought is this **Mustela Hydra-Bebe Lotion, for Normal Skin.**

Hydrogenated Cocoglycerides, Hydrogenated Palm Glycerides, Glyceryl Stearate, Laureth 23, Cetearyl Alcohol, Cetareth 20, Cetareth 12, Carbomer, Xanthan Gum, Cocoglycerides, Sodium Hydroxide

This emulsion uses a very robust emulsifier system that stabilizes via nonionic ethoxylates (Laureth 23, Cetareth 20, Cetareth 12), as well as liquid crystal stabilizers (Cocoglycerides, Cetearyl Alcohol, Hydrogenated Cocoglycerides, Hydrogenated Palm Glycerides, Glyceryl Stearate). The combination of Xanthan and Carbomer also helps with high temperature stability.

Bud: That is very helpful, Ken. Right here on this table we have examples of baby lotions with a variety of emulsifiers: cationic, nonionic, anionic, and combinations. Now let me ask you to read the label on 2 other baby products I find here on the Internet. The first is **Erbaviva Light and Natural Baby Cream.**

Organic Almond Oil, Cetearyl Wheat Bran Glycosides and Cetearyl Alcohol (natural emulsifiers), Avocado Oil, Algae Extract, Allantoin, Sodium Hydroxymethylglycinate (preservative at only 0.3%), organic essential oils of lavender and roman chamomile

The company says this product is “carefully made from high quality natural ingredients. Using completely natural emulsifiers and organic moisturizing oils we have made a cream that is both superclean and light, while nourishing to the most tender baby skin.” What do you think?

Ken: They do indeed have a mild emulsifier blend that forms liquid crystals. What makes them “very high quality” is beyond my understanding. I think that is just marketing hype!

Bud: And here is another baby product ingredient list off the Internet. It is **Baby Secrets: Smooth and Silky Moisturizing Cream.**

Purified Water, Mineral Oil, Stearic Acid, Cetyl Alcohol, White Petrolatum, Polyoxyethylene Stearate, Propylene Glycol, Almond Oil, Jojoba Oil, Aloe Vera Extract, Vitamin E Acetate, Calendula Extract, Dimethicone Copolyol, Methyl Paraben, Butyl Paraben

What is the emulsifier here?

Ken: The Polyoxyethylene Stearate is the nonionic emulsifier (it is mislabeled and should be a PEG-stearate), being helped by the free Stearic Acid and Cetyl Alcohol that may form some liquid crystals. The Dimethicone Copolyol may also be acting as a nonionic emulsifier. Sometimes it is difficult to determine the function of a material because its function depends on its level of use and the amount of “polar” group (PEG).

Bud: Now let me ask you about this. I was just searching Kosmet.com on the keyword “baby” and I found an abstract from the 2004 SEPAWA Kongress. It is Degussa talking about baby wipes. It says the solutions for baby wipes “most often are based on PEG-based emulsifiers and solubilizers. However, these are increasingly in public discussion. The cosmetic industry searches more and more for environmentally friendly formulations. Therefore PEG-free formulations are of high interest.” Apparently Degussa offers PEG-free and paraffin-free systems using raw materials such as Glyceryl Stearate Citrate and Polyglyceryl-4 Caprate.

Ken: Another approach when formulating emulsions designed for baby is to make emulsions with very low levels of emulsifier or even without any emulsifier at all. These “emulsions” are stabilized through the use of hydrophobically modified polymeric thickeners. These thickeners have pendant fatty groups that stick into the oil droplets while thickening the water phase. They form a “fake” emulsion and are very mild! The formulator can add low levels of emulsifier to reduce the particle size and, thus, control the emulsion break and spreadability. This last approach has been used successfully for water-resistant sunscreen formulations designed for babies.

Emulsifying the New Line of Organic Baby Products from Earth's Best and Jason

Phone interview with Petko Detchev, a lab chemist at Jason Natural Products.

Bud: Oh, hello, Petko. I saw that press release in May announcing that Jason was using the Earth's Best brand to introduce Earth's Best Baby Body Care, a line of 6 hypoallergenic formulas using natural and organic ingredients.

Petko: Right. The formulas are 70% organic and are free from any synthetic fragrances. Some products do contain small amounts of essential oils, but they have no lanolin, no mineral oil, no petroleum, and no waxes. These formulas contain no harmful chemicals or other skin irritants.

Bud: Are they all oil-in-water (o/w) emulsions?

Petko: The Chemical-Free Sunblock and Diaper Relief Ointment are both water-in-oil (w/o) emulsions, which give it water resistance. The Extra Rich Therapy Crème and Everyday Lotion are (o/w) emulsions.

Bud: Tell me about the challenge of emulsifying baby skin care products according to the special standards for the Earth's Best line.

Petko: Since these products go onto baby's sensitive skin, we are using super-mild emulsifiers. We are not using any ethoxylated and soap-based emulsifiers.

Bud: Talk about the emulsifiers used in these products.

Petko: Our (o/w) emulsions are based on Potassium Cetyl Phosphate (analog of the natural phospholipids in the skin); Cetearyl Oliviate and Sorbitan Oliviate (derived from olive oil); and Sclerotium Gum (natural biopolymer derived from mushroom). As a co-emulsifier we are using Potassium Cetyl Phosphate because it is an analog of the natural phospholipids in the skin (Lecithins and Cephalins), it is compatible with the skin lipids, and has one of the best safety records. Cetearyl Oliviate and Sorbitan Oliviate are a functional self-emulsifying system, nonethoxylated and soap free, forming a liquid crystal network inside the emulsion. They contain the oleic fraction from olive oil, which is very beneficial for baby's sensitive skin.

Bud: Are these products in the stores already?

Petko: Yes, in the United States since May and in the UK since June.

Bud: In fact, here is another hit from Kosmet.com. It's Gattefossé talking about emulsions without emulsifiers.³ This product, called Emulfree P, is capable of gelling oil phases. Then the oily gel can be mixed with a gellified aqueous phase to form a so-called "bigel" based on 2 nonmiscible phases dispersed homogeneously. This reticulated structure reportedly makes it possible to formulate particularly stable creams and lotions without any emulsifier.

Ken: That product has been around for a couple of years. I think it uses an association of Ethylcellulose and 2 emollient esters: Propylene Glycol Isostearate and Propylene Glycol Laurate.

Emerging Technologies for Cosmetic and Personal Care Wipes

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KEY WORDS: *wipes, hot-melt, microfibers, nanofibers, chitosan*

ABSTRACT: *Although they initially were designed to cleanse, wipes increasingly are being designed for cosmetics and skin care. This article reviews emerging technologies in both wet wipes and dry wipes and their effect in the personal care market.*

Compared to the alternatives of jars, tubes, bars, re-useable sponges, washcloths and brushes, disposable wipes offer the advantages of convenient, compact, easy and personal portability and hygiene. This chapter reviews emerging technologies that have the propensity to enhance the properties of wipes, augment their deliverable attributes and increase their market penetration.

Wipes can be divided into the categories of wet wipes and dry wipes. Wet wipes consist of a fabric substrate that is impregnated with cleansing or skin care compositions. Dry wipes must be moistened before use. In recent years, major efforts have been spent to improve the softness and absorbency characteristics of wipe and pad materials, resulting in wipes of higher absorbency and better softness that alleviate skin irritation upon prolonged or repeated usage.¹

Originally, wipes had a cleansing function, but increasingly wipes are being designed for cosmetics and skin care. For example, recent patent applications have disclosed dry cosmetic wipes in addition to

moist wipes impregnated with lotions comprising mineral oil, fatty acid esters, fatty alcohol ethoxylates and fatty alcohols that function as moisturizers.²

Wipes containing lotions are well-known. Usually the lotions are compositions that are solid at room temperature and depend on being melted by body heat during the application process.³ During use, moistened cleansing cosmetic wipes or pads are expected to produce foam. The quality of foam produced is an important cue to the consumer. Good quality foam, good cleansing and pleasant skin feel have been associated with an impregnating liquid comprised of a mixed nonionic/amphoteric surfactant mixture, a wax mixture containing a wax ester, a partial glyceride and a fatty alcohol ethoxylate, and a cationic polymer such as polyquaternium-10.

Wet Wipes

Wet wipes typically contain a non-woven substrate that is impregnated with a cleansing lotion. A typical cleansing lotion for this purpose would contain an oily phase as an emollient, moisturizing barrier, or fragrance; emulsifying surfactants; and an aqueous phase that could contain a rheology modifier. Wet wipes are designed to deal with the removal of relatively heavy soils such as makeup, and for this purpose, the lotion component is expected to be nonviscous. Such nonviscous lotions, however, can lead to problems in the package due to drainage of the lotion from the top sheets to the lower-level. It has been claimed that such drainage can be stopped by merely dispersing up to 1 percent of particulate material into the lotion.⁴ The particulate material can be selected from a large range of materials; for example, polyethylene, polytetrafluoroethylene powders, poly methyl methacrylate, nylon, polymethyl-silsesquioxane, cellulose or silica microspheres, and micronized waxes.

Hot-melt Surfactants

The use of disposable wipe products is ideal for encouraging young children to practice personal hygiene. They are easy-to-handle and the method of use is easily taught. It is important that the cleansing agent not irritate the oral mucosa, but safety alone is insufficient

because even if a safe product caused eye-sting, the child would be discouraged from using it. Any disposable wipe product should not sting when it comes in contact with the eyes.

Procter & Gamble (P&G) researchers have approached this challenge by designing wipe surfactant formulations that are extremely viscous at room temperature.⁵ The dilemma was to design a manufacturing process for these same surfactants, especially for the step of applying the surfactant to the wipe substrate. In response, P&G researchers designed a surfactant system that lost a fraction of its viscosity above 60°C, allowing it to be processed as a hot-melt, hence the nickname hot-melt surfactants. An example of such a surfactant system is one that contains 63.6% sodium laureth-3 sulfate, 23.8% cocamidopropyl betaine, 10.0% PEG-200 glyceryl tallowate, 10% polyquaternium-10, 0.5% preservative system, 0.5% whitener and 0.5% perfume.

Lotions that are applied to the wipe fabric in the melted state but solidify upon cooling to room temperature are known as hot lotions. Luu et al. point out the manufacturing difficulties associated with hot lotions:⁶ “Semi-solid or solid lotions require cumbersome and costly heating systems such as melting tanks and heated equipment to deliver the lotion to the substrate. Additionally, cleaning of buildup and solidification of lotion on the production line’s conveyer roll during and after the application process is another cumbersome and costly procedure incurred in connection with so-called hot lotions. Incorporation of water-based additives in such lotions is difficult due to phase separation and lack of uniform distribution of the additive in the lotion, either before or after application onto the product substrate. Further, hot lotions have a tendency to become stiff when excess lotion is used, and the final products tend to leave smears when used.” To overcome these drawbacks, Luu et al. suggest the use of a waterless, gelled microemulsion as the lotion component.

Sunscreen Wipes

The application of sunscreen is another task that is especially suited to wipes rather than conventional bottled lotions. Sunscreen lotions often have to trade skin feel aesthetics for SPF efficacy. The lotions

usually are spread over the body by hand, and most sunscreen users prefer to wash the excess lotion from their hands after applying the sunscreen. However, since this product is applied outdoors, washing facilities often are not located conveniently enough to facilitate hand washing immediately after sunscreen application. This is one situation in which sunscreen wipes could be advantageous. Another is the use of wipes to encourage young children to apply sunscreen. A recent patent application is directed toward satisfying such needs.⁷ In this application, the sunscreen lotion is impregnated into a wet wipe. A colored lotion lets the user know that the sunscreen has been applied uniformly to the body. Prior art exists for colored sunscreen lotions that lose most of their color when the product dries on the skin. This technology, in combination with the wipes vehicle, create the sunscreen wipe.

Microfibers

Microfiber fabrics are lightweight and relatively strong in comparison to conventional fabrics of the same weight. Microfiber fabrics usually are wrinkle-resistant, exhibit good fabric hand—an assessment of the quality of cloth by a textiles expert, retain their shape and resist pulling. Due to their smaller fiber cross sections, microfiber fabrics exhibit improved wicking capabilities. All of those properties are useful attributes for wipe fabrics.

The first stage of making microfibers is to spin multicomponent, continuous filament fibers. These multimember filaments are produced by combining separate melt extruded polymers in the spinneret hole. The resulting filament has contiguous segments of each polymer component extending along its entire length. The continuous filament is then melt-drawn to orient the constituent molecules and confer tensile strength on the fiber. The filaments then can be collected into bundles of staple fiber, which is subsequently spun and woven into cloth, or the fiber can be melt-spun directly into a non-woven web. The woven fabric or non-woven web then is subjected to immersion in a solvent for the dispersed polymer phase in the fiber, and that phase is dissolved, leaving the continuous filament polymer intact. At this stage the material has become a microfiber fabric.

As disposable wipes become more widely used, biodegradation of discarded wipes becomes more of an issue. Biodegradable microfiber fabrics may be one way to prepare useful and biodegradable substrates. One recent patent application is directed to preparing biodegradable microfiber from environmentally benign solvents.⁸

Poly (lactic acid) and poly (vinyl alcohol) are melt spun to form a bicomponent fiber with poly (lactic acid) islands in a continuous sea of poly (vinyl alcohol). The islands are arranged to form a large core of poly (lactic acid) at the center of the fiber surrounded by 12 poly (lactic acid) islets, all immersed in poly (vinyl alcohol). The poly (vinyl alcohol) component is removed by dissolution in water to produce biodegradable microfibers of poly (lactic acid). At the end of its useful life, the poly (lactic acid) microfiber fabric can readily be dissolved and hydrolyzed in caustic soda solution for easy disposal.

Nanofibers

Nanofiber materials offer the opportunity to tailor wetting, spreading and adhesion to levels that are nearly impossible within conventional fibers or even microfibers. Nanofibers can be defined as fibers having a diameter that ranges from a few nanometers to just less than a micrometer. Conventional melt-spinning techniques cannot reach down to the nanometer level because they are limited by Rayleigh instability. Rayleigh instability causes the fiber to break into droplets when the diameter falls below a critical size. The onset of instability is related directly to surface tension and reciprocally related to melt viscosity.

Nanofibers have become reality as a result of the development of a number of new processes, namely melt fibrillation, melt blowing, melt fiber bursting, melt film fibrillation and electrospinning. In all of these methods except electro-spinning, fibers are extruded or co-extruded, then fragmented or fibrillated to form the nanofibers. In electrospinning, the spinneret is raised to a high voltage and the fiber is spun toward a grounded collection grid.^{9,10} The electrical forces overcome the surface tension of the polymer solution or melt, and the spinning of nanofibers is enabled.

In some cases, the fibers divide even further and form an electro-spun nanofiber web mat on the collector. Nanofibers have enormous

surface areas and a very small radius of curvature. A diverse array of nanofibers now can be produced, including branched nanofibers, tubes, ribbons and split nanofibers, nanofiber yarns, and surface-coated nanofibers.¹¹ If the nanofiber is hydrophilic and wetted by aqueous solutions, capillary action is greatly enhanced, and large amounts of aqueous solution will wick into the fiber array. The rate and amount of wicking can be controlled in fiber arrays that have a gradient of fiber diameter or intertwined fiber of different diameters.¹²

Clearly, nanofibers offer substantial advantages for disposable wipes, but commercialization has been limited by the relatively high cost of producing nanofiber matrices. A new process has the potential to bring down the cost.¹³ This method uses melt fibrillation of high glass transition temperature (T_g) thermoplastic polymers and direct preparation of a nonwoven web. High T_g polymers are preferred rather than polyethylene and polypropylene because, as fibrillated nanofibers, they freeze faster into their final form. Suitable high T_g polymers include polystyrene homopolymers and copolymers, common polyesters, polyamides, polymethyl methacrylate, polycarbonates, poly (phenylene oxide), thermoplastic starch and poly (lactic acid).

The Lotus Effect

Hydrophilic nanofibers offer the opportunity for enhanced wicking of aqueous liquids. Paradoxically, a hydrophilic surface becomes more hydrophilic as a nanofiber array, and a hydrophobic surface will become super hydrophobic in nanofiber form. The enhancement of hydrophobicity arises from the curvature of the fibers that cause the advancing contact angle to increase above that measured on a perfectly flat surface. This phenomenon has been used for a considerable time for conventional fibers, and it has been used to waterproof fabrics such as raincoats and tents. The enhancement of contact angle on a regular fibrous substrate also is the principle that allows ducks to float. A well-preened duck is coated with hydrophobic fiber in regular array, and the geometric arrangement enhances the hydrophobicity to such an extent that it has given rise to the cliché, “like water off a duck’s back.”

When the fibers become nanosize, the effect is greatly enhanced, and the water drops roll around on the surface like ball bearings on a flat surface. This superhydrophobic effect is present in nature. The leaves of the lotus plant are covered in nanoscale hydrophobic protuberances that render its surface extremely hydrophobic and self-cleaning. Thus, the lotus plant emerges from the mud as a clean plant, and the superhydrophobic effect has been dubbed “the lotus effect.”

Superhydrophobic nanofiber arrays offer the opportunity to construct thin fabric layers that are impervious to liquid water but would allow the free permeation of water vapor. This should be useful as a waterproof backing for wearable wipes.

Scrubbing Wipes

Conventional soft, nonwoven and woven wipes are designed to clean in circumstances that usually involve soil rollup or solubilization and mere wiping. Scrubbing wipes consist of a hard abrasive surface, and apertured surface abrasive wipes have been prepared by sandwiching the soft wipe between two hard plastic abrasive layers with conical protuberances.¹⁴ The apertures are formed by processing an extruded thermoplastic sheet material over a perforated drum. Tredegar offers one example^a of materials that are bonded to polyethylene (terephthalate biocomponent fiber spunlace material to make these abrasive wipes).

Antimicrobial Wipes and Applicators

Solid antimicrobial delivery systems are important in the prevention of transmission of pathogens and in the inhibition of odors. Odors are produced on the skin in areas that are rich in apocrine, apoeccrine, sebaceous and eccrine glands. The most notable regions are the axillae, the feet, nipples, anus and genital regions. Apocrine secretions have a strong color that is rendered malodorous by bacterial (*Staph.epidermis*) hydrolysis of the secreted proteins.¹⁵ Most strains of *S. epidermis* protect the host's skin by preventing colonization of dermatophytic fungi. However, in some cases, if *S. epidermis* gets into the bloodstream, it can become an opportunistic pathogen.

Pseudomonas aeruginosa are opportunistic bacteria that can infect skin and mucous membranes and, like other species of *Pseudomonas*, they readily adapt to their environment. *Candida albicans* is a yeast that normally inhabits the human gastrointestinal tract as a part of the digestive flora. However, it can transform into an invasive mycelial fungal form that binds readily to infect skin and mucous membranes. Antimicrobial wipes are directed toward the control of these pathogens on the body.

The incorporation of antimicrobial agents is also important in the sterilization of materials, such as plastics and fibers that deform at the temperatures needed for sterilization by autoclaving.

This is significant because the cost of producing plastic implements and non-woven wipes is considerably lower than their autoclavable metal or woven-fiber equivalents. The materials can be rendered suitably antimicrobial by coating with inherently antimicrobial polymers, by the incorporation of materials for controlled release of antimicrobial agents, by embedding solid antimicrobial particles therein, or by infusing antimicrobial materials into the free volume of polymer matrices.¹⁶

Antimicrobial coatings frequently contain copolymers with amine groups or quaternary ammonium groups^{17,18} such as copolymers of t-butylaminoethyl methacrylate,¹⁹ or antimicrobial carboxylates.²⁰ Silver, copper and zinc particles have been embedded into polymeric materials to render them antimicrobial²¹ and this technology has been extended to silica²² or zeolite^{23,24} particles upon which the antimicrobial metals are adsorbed or deposited.

Melt-processable, antimicrobial thermoplastics would be particularly advantageous as materials to be included in sterile wipes for cosmetic and personal care applications. In this context, it is interesting that DuPont researchers recently have disclosed acid copolymers and ionomers for the controlled release of antimicrobial materials.²⁵ The co-polymers contain ethylene, a carboxylic acid monomer, and a softening comonomer such as an alkyl (meth) acrylate in which the alkyl group has a length of up to eight carbon atoms. The softening monomer functions by disrupting the crystallinity of the polyethylene.

Ionomers are thermoplastic polymers that contain relatively small proportions of ionic monomers. The ionic comonomers cluster within the polymer matrix and this causes a closer packing of the polymer molecular chains adjacent to the cluster. The consequent loss of free volume reduces the mobility of the polymer chains, and results in an increase in the glass transitions and moduli of the materials.

One ionomer^a from DuPont, for example, is a polyethylene that is rendered tough by the inclusion of ionic comonomers. Tetrafluoroethylene ionomers are useful as membranes for water treatment and for the separation of sodium hydroxide and chlorine gas in the chlor-alkali process. It is postulated that these membranes function by allowing the percolation of only small molecules and ions through the material via the ionic clusters. In the antimicrobial application, quaternary ammonium compounds or metals (silver is preferred) are incorporated into the structure and slowly released to prevent the growth of pathogens.

Chitosan and chitosan-metal compounds are known to have antimicrobial, antifungal²⁶ and even some antiviral activity.²⁷ Chitosan also is known to impart anti-odor properties. Chitosan is poly $-[1-4]-\beta$ -D-glucosamine, and it can be derived by the hydrolysis of chitin. Chitin is widely available from the cell walls of fungi, and the exoskeletons of insects and crustaceans. DuPont researchers recently have disclosed a less-expensive and environmentally gentle method of attaching and cross-linking chitosan to a diverse variety of woven and nonwoven fabrics.²⁸ The process consists of cleaning the fabric surface by plasma treatment, polymerizing itaconic acid and triacrylate cross-linker on the surface by electron bombardment in high vacuum, and then passing the fabric through solutions of chitosan and acetic acid. The finished product is described as being suitable to use as personal wipes or articles of clothing that confer antimicrobial and anti-odor attributes.

All of these broad-spectrum anti-microbial/antifungal wipes are designed to indiscriminately kill the flora on human skin and topically treatable areas. It would be beneficial, however, to design products that would kill or detach harmful flora while allowing

beneficial flora to continue to thrive on the upper layers of the skin. A recent study directed to that goal screened a large number of botanical compounds for their efficacy in this regard.²⁹ Green tea, horse chestnut, soluble wheat protein, yucca 70, yucca extract powder 50%, sea parsley, and cat's claw were identified as botanicals that increased the adherence to skin of the beneficial microorganism *Lactobacillus acidophilus*. In the future, expect the development of treatments that destroy or detach harmful flora while maintaining healthy cultures of beneficial microflora.

Summary and Forecast

Wipes represent a convenient and hygienic way to cleanse the surface of the body and topically deliver beneficial agents. The cosmetic and personal care industry can expect to see advances in the formulation of deliverable phases that are impregnated into wipe products. Advances in the ability to make inexpensive nanofibrous materials promise to greatly enhance the capillary-driven uptake of liquids into the wipe matrix. Advances in antimicrobial fibers offer opportunities to make wipes that are either broad-spectrum or selective biocides for treating the surface of the body and maintaining its health. The day will come when the body will be kept healthy and odor-free by wearable, disposable wipes with nanofibrous hydrophilic gradients on one side, nanofibrous breathable superhydrophobic materials on the other side and an antimicrobial layer in the middle.

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Wipes: Recently Disclosed Intellectual Property

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KEY WORDS: *cleansing wipes, lather volume test, flushable wipes, reservoirs and pillows, hydrophobic and hydrophilic soils, antiviral and antibacterial wipes, antimicrobial peptides*

ABSTRACT: *Traditionally, soaps and personal cleansers are deposited on washcloths or sponges before being applied to the body. More than a decade ago, convenience products were introduced in the form of surfactant-impregnated dry woven or nonwoven cloths. Several new patents have recently been issued in the area of wipes, which are described here.*

Cleansing Wipes

Traditionally, soaps and personal cleansers are deposited on washcloths or sponges before being applied to the body. More than a decade ago, convenience products were introduced in the form of surfactant-impregnated dry woven or nonwoven cloths. These were designed to be wetted with water before use. In this context, Fowler et al.¹ gained an advantage over conventional products such as bar soaps, creams, lotions and gels by incorporating a lathering surfactant into a water-insoluble substrate, such as a sponge or polymeric mesh, reducing the level of required surfactant while still providing effective cleansing of skin or hair with adequate lathering.

The inventors suggested that the increased lathering resulted from the surface action of the substrate. Additionally, the decreased amount of required surfactant led to skin benefits, including less

drying. Moreover, desirable products containing both cleansing surfactants and conditioners² were disclosed as an added benefit of the reduction in the level of cleansing surfactant.

The lower surfactant concentration reduced the propensity of these surfactants to inhibit the deposition of conditioning agents, and this allowed optimization of the simultaneous inclusion of cleansing surfactant and conditioners into the water-insoluble substrate. The resulting wipe, comprising a lathering surfactant and a conditioning phase impregnated into a fibrous web, was intended to be discarded after a single use.

Disposability after a single use was touted as being more sanitary than multiple re-use products, such as washcloths or sponges, because such multiple-use implements could develop bacterial growth and unpleasant odors. However, there is now a trend toward using disposable wipes again and again. This is demonstrated by a recently issued patent that extends disposable single-use to multiple uses or rinsings.³

The re-usability is achieved by incorporating a lathering surfactant into a fibrous web of thermoplastic polymer to produce a disposable dry cleansing article that could be used two or more times with a foam volume of 50 mL generated and a rinse foam volume of more than 5 mL.

The foam volume is important because dry cleansing wipe articles have had a tendency to produce short-lived foams. The product can be fabricated by blending then screw-extruding the thermoplastic resin and the lathering surfactant, followed by melt-blown extrusion to form a fibrous web. The melt-blown extrusion process involves parallel extrusion of thermoplastics into a high-velocity gas-stream that extends the extruded fibers into a microfibrinous web. In this case, the invention³ is exemplified by a polypropylene web that is co-extruded with a lathering surfactant blend of sodium cocoyl isethionate and melt-blown extrusion with a hydrophilic surfactant comprising sorbitan laurate and glycerol laurate.

As noted, these products are expected to generate a reasonable quantity of lather. A useful test to measure lather volume is described in US Patent 6,280,757,⁴ which is described here for the readers' convenience.

Lather Volume Test

The wipes are desirably capable of generating greater than or equal to about 30 mL of average lather volume, preferably greater than or equal to about 50 mL, even more preferably greater than or equal to about 75 mL—the most preferably greater than or equal to about 150 mL of average lather volume. The average lather volume is a measurement determined by the Lather Volume Test. This test provides a consistent measurement of the volume of lather/foam generated by the following described articles. The Lather Volume Test protocol includes the following steps:

1. Hands are washed with a mild soap bar^a before conducting the test. This step removes any soils that may affect the accuracy of the measurement.
2. The test article is held open in the nondominant hand with the edges turned up.
3. 10 mL of water (medium hardness of about 8–10 grains per gallon) at 95°C is added onto the test article via a 10-cc syringe or a repipetter^b.
4. Lather is then generated by rubbing the test article with the dominant hand in a circular motion between the palms for 6 sec (approximately two rotations per second), using moderate pressure (e.g., 4 oz.), and allowing the article to ball-up between the palms of the hand.
5. The test article is then held open in the nondominant hand and an additional 10 mL of water (medium hardness of about 8–10 grains per gallon) at 95°C is added onto the test article via a 10-cc syringe or a repipetter^b. The wetted article is again rubbed with the dominant hand (three rotations) using moderate force (e.g., 4 oz.) so that the test article becomes balled-up between the palms.
6. The test article is then opened and rubbed five times by holding an edge of the article in one hand and rotating the hand holding the other side to further activate lather.

^a Ivory brand soap is a product of Procter & Gamble.

^b The repipetter used is a product of Brinkmann.

7. The test article is then turned over and Step #6 is repeated using the other hand.
8. The lather is gathered by holding the test article in a cupped hand and scraping the lather off the test article with the other hand, being careful to only scrape lather from the test article. The lather from the test article is then placed into a graduated cylinder or beaker large enough to hold the generated lather. This procedure is repeated five times on the same test article and the lather from each iteration is accumulated in the same graduated cylinder or beaker. The total accumulated lather from these iterations is designated as the lather volume.
9. To achieve consistent results, the average lather volume is reported as the average of three test sample replications of steps 1–8.

Disposability: Flushable Wipes

It has generally become desirable to dispose of dry and wet wipes by flushing them down the toilet. The development of flushable wipes is somewhat of a conundrum because whereas the wipe must readily disintegrate upon flushing or residing in a landfill, it must also have sufficient web strength to maintain its integrity during use. One example of stimuli-responsive disposal is the use of boric acid or tetrasodium borate as a trigger to improve the flushability of nonwovens prepared with poly(vinyl alcohol)-stabilized latex binders.⁵

Another approach has been to use binder polymers that have inverse solubility in water. These materials are insoluble in warm water during use but are soluble in cold water in the toilet.⁶ Poly (N-isopropyl acrylamide) has extensively been touted in the scientific literature as a polymer that demonstrates such reverse solubility at biologically advantageous temperatures. Other types of polymers that are suggested by Yeo⁶ are poly(methacrylic acid) [for which a concentrated gel forms between 30°C and 47.5°C]; acrylates copolymer; poly(vinyl alcohol) that is less than 80% hydrolyzed; polyethyloxazoline [cloud point between 61°C and 64°C], poly (vinyl methyl ether) [cloud point at 33°C]; PVP in the presence of 0.86M ammonium sulfate; PVP/VA copolymer, hydroxypropyl cellulose

[cloud point at 43°C], methyl cellulose [cloud point at 49°C]; and poly (ethylene oxide) and PEG/PPG copolymers.

Another approach has been to use, as nonwoven binders, copolymers of partially neutralized acrylic acid, butyl acrylate, and 2-ethylhexyl acrylate that are soluble in water but insoluble in aqueous inorganic monovalent salt solutions having concentrations greater than 0.5% by weight.⁷ While they are useful for soft water flushes, these binders can actually become stronger by binding divalent cations in hard water when the water contains more than 15 ppm Ca^{2+} .⁸ This limits the applicability of the acrylate binder approach, especially in view of the fact that water hardness across the United States varies from nearly zero to about 500 ppm CaCO_3 (corresponding to 200 ppm Ca^{2+}).

The dispersability in hard water, up to 200 ppm Ca^{2+} and/or Mg^{2+} was improved with sulfonate anion modified acrylic acid terpolymers⁹ but these had the drawbacks of reduced initial sheet wettability, increased dry sheet stiffness, increased stickiness and high product cost. These polymeric binders have been incorporated with co-binders of poly(ethylene-vinyl acetate), poly(styrene-butadiene), or polystyrene-acrylic to provide better wet strength in use and better flushability in hard water.¹⁰

A more recent approach uses triggerable cationic polymers as binders to confer both wet strength during use and flushability upon disposal.^{11,12,23} This approach also uses salt to insolubilize the polyionic binder to confer good wet-strength during use, and then solubility in water that confers triggered disintegration upon flushing. The advantage of this approach derives from the fact that polycations are not rendered insoluble by hard water. The preferred cationic binders are exemplified as copolymer of methyl acrylate and [2-(acryloxy)ethyl]trimethylammonium chloride.

Kao researchers have tackled this challenge by including propylene glycol in fibers treated with a water-soluble, carboxyl-containing binder.¹³ The sheet does not disperse in the propylene glycol-based cleansing agent but it does disperse in water. However, the use of high amounts of propylene glycol could lead to a greasy after-feel and could cause discomfort to skin.

Reservoirs and Pillows

In the home care sector, the art of cleaning has extended to the attachment of reservoirs from which volatile liquids are applied to cleaning pads.^{14, 15} For personal care applications, self-inflating bladders can be placed inside wipes to dispense a cleansing composition or a beneficial agent to the skin on demand. The bladder can be constructed from two compartments separated by a frangible seal.¹⁶

A metal carbonate is in one compartment and an acid is in the other. The seal is broken by the user, allowing the carbonate and acid to react and produce carbon dioxide to inflate the bladder and force liquid composition to the surface of the wipe for application to skin. Reservoirs that disrupt on one side due to the pressure of application are designed to dispense liquids right at the surface that is being treated.¹⁷

Attempts to improve lathering have included the concept of inserting a water-permeable pouch within a wipe to form a pillow: In one instance, the pouch contains ingredients that effervesce on contact with water to enhance the foam.¹⁸ This technology is improved by including a highly absorbent material that swells upon contact with water to inflate the pillow and thereby release the foaming surfactant on demand.¹⁹

Useful highly absorbent gelling polymers for this purpose are cross-linked polyacrylamide and cross-linked sodium polyacrylate. It also has been found that fairly high levels (greater than 2% by weight) of cationic polysaccharide, such as guar hydroxypropyl ammonium chloride can enhance the lather volume if the lathering surfactant is an anionic surfactant such as sodium C14 olefin sulfonate, sodium cocoyl isethionate, sodium lauryl sulfoacetate or sodium stearate.²⁰ One problem with these cleansing wipes is their tendency to ball-up during use. When this occurs the wipe's cleaning surface area is substantially reduced. It has been claimed that the tendency to ball-up can be ameliorated by simply incorporating aligned slits, rather than round pores, in the water-insoluble substrate.²¹

Simultaneous Removal of Hydrophobic and Hydrophilic Soils

Some soils on the skin are mainly hydrophilic whereas others are principally hydrophobic. This creates a challenge for cleansing wipes, especially for babies and infants for whom inadequate cleaning can lead to diaper rash. In this case, diaper rash is caused by microorganisms in fecal matter and this condition can be prevented by complete removal of fecal deposits from the skin. However, fecal deposits consist of both water-compatible and oil-compatible substances, and the wipe should ideally remove both at the same time.

Johnson & Johnson researchers have attempted to address this challenge by applying wax dispersions to the absorbent sheet in patterns that produce hydrophobic areas on a hydrophilic wipe.²² The waxes are specified as having a melting range equal to or higher than 25°C. The removal of dust and debris particles by a wet wipe depends upon the adhesion of the particles to the wipe by capillary forces. The capillary forces are directly proportional to the surface tension of the liquid and also the cosine of the contact angle of the liquid at the particle surface.

The simultaneous removal of both hydrophobic and hydrophilic particles is favored by the presence of appropriate amphiphathic materials on the surface of the wipe to ensure enough wetting, and hence sufficient capillary attraction, of the disparate particles to the surface of the wipe.²³ There have been attempts to introduce three-dimensionality into cleaning sheets to improve cleaning performance. However, while the repetitive protruding patterns can clean the substrate, continuous valleys in the wipe can skip over the surface leaving the soil behind. This has led to the development of irregularly patterned cleaning sheets containing crannies and ridges that can entrain impregnated additives for improved carrying capacity of cleaning solutions and also the property of traveling over a soiled surface without leaving a streak or trail of undisturbed soil.²⁴

Wicking forces are favored by optimizing the compatibility between the liquid being wicked and the surfaces of the solid pores into which the liquid is being transported. Nanofibrous materials can be constructed with extremely small wicking channels that

rapidly “suck up” liquid. Moreover, if the nanofibers are arranged in a mat as a gradient material, then simultaneous wicking of disparate liquids in two different directions may occur. Gradient nanofiber materials of this type have been made by electrospinning a PEG solution as one component and PEG/colloidal silica dispersion as a second component. This gradient material was prepared by electrospinning using side-by-side needles with each component being fed via a different needle and collected on a collection grid.

The patent applicants in this case conclude that the creation of biodegradable gradient nanofiber webs could be achieved by electrospinning mixtures of hydrophobic and hydrophilic nanofibers, for example, by solution spinning polylactides and melt spinning polyolefin fibers.²⁵ If alignment of hydrophobic nanofibers could be achieved, the self-cleaning lotus effect materials could be a possibility. However, the cost of producing nanofibers is relatively high and this limits their commercial viability.

Fortunately, it has been found that high glass transition polymers readily form fibers of low diameter because these polymers “freeze” in their final form at high temperatures and this allows high flow rates and take-up speeds, which in turn lowers the unit cost.²⁶ Thus, polymers having glass transition temperatures above 25°C can economically produce nanofibers by a melt film fibrillation process.

Maintaining Healthy Skin

Wipes should ideally enhance skin health by cleaning away unhygienic soils but they should also protect the skin from chapping or irritation, maintain the pH balance of the skin, inhibit irritants or allergens, and maintain the lubricity and moisturization of the skin.

Wet wipes for the hands are often made from single-ply nonwoven base sheets of cuprammonium rayon, or water-needled rayon or cotton nonwoven. These have insufficient thickness and poor nerve—i.e., they are easily twisted—and as a consequence they are unsuitable for whole-body wipes because they can cause discomfort to tender skin.

Kao researchers claim to have overcome these deficiencies by incorporating a powder in the wiping sheet and controlling the ratio

of relative surface pore size of the wiping sheet to the average particle diameter of the particles to optimize the transfer of particles to the skin surface during wiping.²⁷ The invention is exemplified by impregnating monodisperse polymer particles with polysiloxane cores and poly(methyl methacrylate-*co*-styrene) shells into base sheets. The products were evaluated as whole-body wipes. In this case, the impregnating liquid comprised an aqueous dispersion of polymer beads, low viscosity silicone fluid, carbomer, ethanol and ethyl paraben.

Although the epidermis is usually an effective barrier against penetration by foreign substances, its occlusive nature may be compromised by abrasion, irritants or substances that disrupt the lipid layers of the stratum corneum and/or stratum granulosum. Measurable and comparable product improvements require evaluation by standard methods. The development of standard methods for the measurement of soothing attributes of facial tissue is attempted by Kimberly-Clark researchers in a recent patent application.²⁸ The methods involve abrasively damaging the skin of a test subject to a predetermined amount, contacting a test facial tissue with the damaged skin, and rating the tissue's soothing attributes.

Wet wipe products are usually stacked in a package. It is important to avoid gravitational settling of the impregnating liquid during storage since this will result in inadequate liquid in the top sheets and too much in the bottom sheets. This is tested by measuring the liquid content of the top sheets and comparing the results as a function of time, with those measured for the bottom sheets of the stack. In this patent, there is a limiting claim that states that the difference between the top five and bottom five sheets, in a stack of 30 sheets, should be less than 30% after 24 hr.

Improvements have been made in the lotions that are impregnated into wet wipes to offer skin care benefits; however, there is room for improvement because cleansing and skin care properties are opposing benefits. Moreover, most of the lotion in the wipe is not transferred to the skin but is discarded with the used wipe.^{29, 30}

“Top biased” products have been suggested to improve the availability of beneficial components to transfer to target surfaces.^{31, 32} Top-biasing can be achieved by aligning two layers normal to the

wipe surface such that one layer is relatively hydrophobic and the other is relatively hydrophilic. The hydrophobic layer holds the hydrophobic beneficial agents and vice-versa. The term *relatively hydrophilic* refers to a layer that has a solubility parameter that is greater than 2 (calories/cc)^{1/2} than the solubility parameter of the adjacent layer. The hydrophobic components usually are added to the wipe while they are hot.

Examples of hydrophobic beneficial agents are: petrolatum, stearyl alcohol, mineral oil, lanolin, squalane, vegetable oils, polydecene, glycosides, essential fatty acids, butters, emollient esters, isoparaffins, polyisobutylenes, silicones and waxes. The hydrophilic components usually are added to the wipe while they are cold. Examples of hydrophobic beneficial agents are: water, glycerin, PEA, glycols, PPG, glymes, lower chain alcohols, sugars, ethylated alcohol surfactant and inorganic salts such as sodium or potassium chloride.

There is a perceived consumer need for a common emulsion concentrate to which different additives can be added to produce a diverse array of wet wipes with a broad range of desired properties. This need is especially appropriate to clean fecal matter from the sensitive peri-anal area. In order to meet this need, Procter & Gamble researchers have directed research activities toward a cleansing emulsion that includes an oil phase comprising an emollient, an emulsifier and a particulate skin health benefit agent; and a water phase that contains a rheology modifier.³³ Exemplary compositions comprise water, decyl glucoside, caprylic capric triglyceride and bis-PEG/PPG-16/16 PEG/PPG 16/16, dimethicone, sucrose palmitate, glyceryl stearate, glyceryl stearate citrate, sucrose, mannan, xanthan gum, paraben preservatives and zinc oxide powder.

Antiviral and Antibacterial Wipes

Tissues that are both soft and antiviral are clearly desirable. Carboxylic acids such as citric, malic, maleic, tartaric, salicylic, glycolic, adipic, glutaric, succinic and benzoic are capable of killing rhinovirus and influenza virus. Tissues containing an antiviral acid are surface treated with amodimethicone to render them soft to meet this need for personal care tissues.³⁴

Nosocomial infections—those that originate in hospitals—are responsible for up to 100,000 deaths annually in the United States.³⁵ The vectors for these infections can be bacteria, viruses, fungi or parasites. Unfortunately, conventional antimicrobials are not very effective for killing the pathogens on surfaces. There is a need for an antimicrobial that can reliably kill on contact to prevent contact transfer of pathogens. Such an antimicrobial composition is described in a recent patent application by researchers at Kimberly-Clark.²⁵

The described composition can be applied to material substrates and is an antimicrobial that includes a mixture of at least one of:

- a primary antimicrobial agent such as polyhexamethylene biguanide, which acts by disrupting the cell membranes of bacteria and fungi;
- a second, conventional, broad-spectrum antimicrobial compound; and
- an anti-static agent or fluoropolymer.

This antimicrobial device is fast-acting; it is described as exhibiting a reduction of at least a $3 \log_{10}$ (colony forming units/g) within 30 min when placed in contact with a broad-spectrum of microorganisms.³⁶ Development of such complex antimicrobial systems will undoubtedly become widespread as resistant microorganisms continue to proliferate.

Antimicrobial peptides are potentially useful for personal care applications and administration of such peptides using wipes would be a suitable method of application. Chemical synthesis of such peptides such as by the Merrifield process is possible but prohibitively expensive. Recombinant biosynthesis offered hope that such antimicrobial peptides could become items of commerce. However, this approach can be difficult because the small peptides can be proteolyzed by the host cell's protein regeneration system or even worse, the peptides could kill their host cells preventing production.

Fortunately, DuPont Researchers have succeeded in developing a process for expressing antimicrobial peptides in a recombinant

host cell and eliminating host cell toxicity and antimicrobial peptide degradation.³⁷ Given the advances in this field, the industry should expect to see the emergence of antimicrobial peptides to products such as wipes.

Conclusion

This chapter surveys emerging concepts in wipes as revealed by recently published patents and patent applications. These trends include:

- Co-extrusion of soaps and polymer meshes for increased lathering.
- Flushability by designing thermally responsive or ionically-responsive systems. The latter systems can be compromised by calcium ions in hard water. The effect of calcium ions may be ameliorated by the use of polyions of strong acid monomers or by polycationic binders.
- The use of frangible reservoirs and top-bias to deliver a higher proportion of actives to the skin.
- Patterned and gradient hydrophobic/hydrophilic wipes and nanofibrous mats for simultaneous removal of hydrophilic and hydrophobic soils.
- The emergence of new antiviral/antibacterial wipes to address the challenge of nosocomial infections and the emergence of antibiotic resistant pathogens.

This list reveals that convenience products are progressing as technology progresses and as consumers learn what is possible.

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Formulating for Children's Sensitive Skin

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KEY WORDS: *sensitive skin, atopic dermatitis, eczema, baby care, cleansing*

ABSTRACT: *The sensitive and delicate nature of infant skin has been well-addressed by the current products in the marketplace. More serious skin conditions require a special level of performance. This report highlights the development of surfactant bases designed not to trigger a response during use while maintaining traditional aesthetics.*

Historically, personal care cleansing products have been developed for children with normal or sensitive skin.¹ While sensitive skin is certainly an important issue,² the next evolution in products should address the lack of aesthetically pleasing products that can be used on children with more serious conditions such as atopic dermatitis.

Atopic dermatitis (AD), commonly known as eczema, is a severe condition with more consistent and measurable symptoms than sensitive skin.³ Atopic dermatitis also is a chronic inflammatory condition generally classified as a Type I hypersensitivity of the immune system and belongs to a family of atopic diseases.³ In addition, reports of altered lipid metabolism within atopic skin⁴ have been shown to reduce the overall barrier properties of the skin.⁵ This makes the child more susceptible to irritation from chemical⁶ and environmental stresses.⁷

Atopic dermatitis typically appears early in life, with 49–70% of childhood AD manifesting before 6 months of age and 80–90% of patients exhibiting the disease before 5 years of age.⁷ Although it is

difficult to identify exactly how many people are affected by AD, an estimated 20% of infants and young children experience the symptoms of the disease. Atopic dermatitis accounts for 10–20% of all children's visits to a dermatologist.⁸ The overall financial impact on the health industry is significant with US health insurance companies spending more than US\$1 billion per year on AD.⁸

While in this scenario the sufferer of the condition is the child, the parent also experiences effects of the disease. Rather than physical manifestations the parent of a child with AD experiences emotional aspects related to feelings of inadequacy such as being a bad parent. Feeling of inadequacy in a parent then can cause a psychological feedback loop that triggers skin flare-ups. This happens when children sense stress in a parent and become stressed themselves. As the stress level increases, the immune system begins to increase activity. With AD being an immune system disease of sorts, the enhancement triggers a flare-up.⁹

In order to manage the risk of a flare-up, parents are directed to avoid treating their children with soaps or products with known allergens such as chamomile and perfumed products; to use extra rinses after use; and to continuously apply moisturizers.¹⁰ This approach does not treat the condition but is only meant to lower the risk of a flare-up. Typical rinse-off products employ surfactants that can strip lipids necessary for maintaining optimal skin hydration and barrier function.^{6,10,11}

A lack of mainstream, affordable AD care forces most AD sufferers into using high-priced specialty products. The personal care market, therefore, is in need of a complete line of affordable cleansing products tailored to those with AD. Such products need to deliver the typically favored aesthetics of mainstream products, along with the dramatically reduced irritation potential found in niche products.

Ingredient Selection

The approach described herein is similar to the evolution of traditional bar soaps to synthetic detergents as summarized by Ananthapadmanabhan et al.¹² This work highlights the critical parameters needed in a cleansing system to reduce negative

interactions between surfactants and the skin, such as after wash tightness, visible dryness, roughness, cracking and erythema, while maintaining excellent foam and lather characteristics. While this paper focuses more on normal skin, the key strategic parameters of using combinations of surfactants, conditioners and a lower final product pH are just as important in the case of AD.

The first step in developing these AD cleansing products was choosing the right ingredients. In surfactants, a balance needed to be maintained between foam, i.e., aesthetic attributes, and mildness or chemistry. Certainly a simple surfactant system could be created with the lowest irritation potential, but more than likely, this product would not meet consumer expectations for performance and price. Therefore, a reasonable starting point was to build the cleansing composition on the primary surfactant cocamidopropyl betaine (CAPB), based on concentration. This material provides a reasonable amount of foam, good solubilizing power and a degree of mildness.

In order to increase the foaming and cleansing ability of the formulation, sodium laureth sulfate (SLES) was then introduced as a secondary surfactant, also based on concentration. This surfactant has a slightly higher irritation potential than CAPB but is necessary to add for its foaming capability, which studies have shown convinces consumers of the product's cleanliness.¹³ From this base, two additional ingredients were identified and added to improve the mildness for use with AD. The first ingredient added was the tertiary surfactant, disodium PEG-12 dimethicone sulfosuccinate (DPDS). It was chosen based on supplier reports that it has low levels of irritation and mollifying effects on other anionic surfactants such as SLES. Secondly, the thickening agent PEG-150 pentaerythrityl tetrastearate (PPT) was added to thicken the product without increasing the surfactant concentration and to ensure the aesthetic properties while reducing irritation.

Surfactant–protein Interactions

A modified version of a previously reported *in vitro* method to assess the interaction between surfactants and proteins was employed to help determine whether the described choice of surfactants was appropriate.¹⁴ In this method, collagen circles are weighed

and incubated in surfactant solution for 24 hr. The collagen swelling score was then calculated by dividing the weight of the collagen after incubation by the weight of the collagen before incubation. If the collagen swelling score is high, the interaction will be stronger and the potential for irritation will be high. A higher mean weight increase indicates that the surfactant interacts with and swells proteins more aggressively and is thus potentially more irritating.

After choosing a level of surfactant for ingredient screening, researchers generated dose-response curves for a few key surfactants using active surfactant concentrations from 0.1–5.0%. For SLES, a steep increase in the collagen swelling score was seen, from 0.1–1.0% active. As the SLES level was increased to 5.0%, a leveling to approximately 1.5 times that of water alone was observed. Interestingly, the DPDS showed no dose-dependent response and remained at approximately 75% of the water-alone response. This “better than water” performance is suggestive of reduced protein interaction and potential barrier-like behavior that prevents penetration, or at least interaction, with skin proteins. The results from PPT showed no impact to water uptake.

Individual surfactant solutions next were screened at a fixed value of 0.5% active surfactant. Irritation rankings were established by examining responses of collagen across the range from water to sodium lauryl sulfate (SLS) (see **Table 65.1**).

Surfactants exhibiting swelling scores less than that of water have the protein interactions of a very mild surfactant. Swelling scores within the range of water indicate protein interactions of a mild surfactant. Responses between that of water and SLS indicate that the surfactant interacts with proteins in an irritating manner. Collagen swelling scores greater than that of SLS indicate the protein interactions with the surfactant are representative of a very irritating surfactant. The collagen swelling scores for several surfactants are shown in **Table 65.1**. These results align with the historical evidence of these surfactants and their potential for irritation. This is especially true for anionic and nonionic surfactants with some underestimation of quaternary ammonium surfactants.¹⁵ Based on the data presented here, a combination of CAPB and DPDS should make for a very mild surfactant base applicable for use with AD.

Table 65.1. Collagen swelling scores for selected surfactants

Surfactant (0.5% active)	Collagen Swelling Score		
	Mean	Std. Dev.	Grouping [§]
Sodium lauryl sulfate	21.0	3.9	A
Sodium laureth sulfate	14.8	2.5	B
Benzalkonium chloride	12.7	2.3	BC
Polysorbate 40	9.0	1.7	C
Water (<i>aqua</i>)	8.9	1.6	C
Cocamidopropyl betaine	7.4	0.91	CD
Disodium PEG-12 dimethicone sulfosuccinate	7.01	1.4	CD

[§] Codes not connected by adjoining letters are significantly different as determined by Tukey-Kramer ANOVA analysis at 95% confidence, n = 8.

Surfactant-lipid Interactions

A second screening test was employed to assess the other end of the polarity spectrum, namely the interaction of surfactants with skin lipids. The lipophilic dye extraction method utilizes classic liquid to liquid extraction techniques. In a microcentrifuge tube, a 0.06% red dye^a in an isopropyl myristate solution was extracted with each surfactant of interest, at 10% active concentration.

The tubes were vortexed and centrifuged before removing the organic layer. Final surfactant rankings were then determined by taking the absorbance readings of the samples at 517 nm following the extraction procedure.

For this screening protocol, as in the collagen swelling test, a higher mean absorbance indicates that the surfactant interacts with and removes lipids more aggressively and, is thus, potentially more irritating. Rankings of irritation can also be delineated by evaluating the responses of traditional surfactants. Although the responses of mild and very mild surfactants are quite similar, CAPB can be used as the breakpoint between the two. This method highlights a greater differentiation in amphoteric surfactants and an improved ranking

^a Oil Red-O or Solvent Red 27 from Sigma-Aldrich, Milwaukee, WI, USA, was employed for this study.

Table 65.2. Lipophilic dye extraction values for selected surfactants.

Surfactant (10% active)	Lipophilic Dye Extraction		
	Mean	Std. Dev.	Grouping [§]
Benzalkonium chloride	0.561	0.047	A
Sodium lauryl sulfate	0.350	0.021	B
Sodium laureth sulfate	0.039	0.007	C
Polysorbate 40	0.042	0.017	C
Cocamidopropyl betaine	0.040	0.013	C
Disodium PEG-12 dimethicone sulfosuccinate	0.014	0.011	D

[§] Codes not connected by adjoining letters are significantly different as determined by Tukey-Kramer ANOVA analysis at 95% confidence, n = 8.

of quaternary ammonium surfactants.¹⁵ Using the data in **Table 65.2**, again, the same combination of surfactants would be chosen to build a cleansing composition for use with AD.

Reduction of Irritation Potential

In order to assess whether DPDS is able to counteract the irritation potential of SLES, an experiment was designed utilizing the two sets of solutions found in **Table 65.3**. These solutions were designed to evaluate whether there is a measurable reduction in irritation potential of SLES, or if it is just a simple dilution effect.

In the case of the lipophilic dye extraction method, the solutions containing only SLES had the highest mean absorbance, and the absorbance decreased with increasing water or DPDS concentration. Statistical group differences were measured within each test series as the concentration of SLES decreased. However, no significant difference was seen between the DPDS series and the water series. This is indicative of merely a dilution effect, and that the potential irritating effects of SLES were not reduced, with respect to lipid extraction.

The data collected in the collagen test was a different story. The mean collagen weight change reported in **Table 65.3** follows the same trend of the collagen swelling score. Namely, a greater weight

Table 65.3. Solutions and responses to assess reduction of sodium laureth sulfate irritation potential by disodium PEG-12 dimethicone sulfosuccinate. Higher values in either test method indicate a higher potential for irritation.

	% SLES	% Other	Collagen Swelling		Dye Extraction	
			Wt. Gain (g)	Group [§]	Absorbance	Group [§]
Other =	100	0	0.218	A	0.870	A
Water (<i>aqua</i>)	75	25	0.213	A	0.494	B
	50	50	0.206	A	0.143	C
	25	75	0.185	A	0.047	C
	0	100	0.118	B	0.010	C
	Other=	100	0	0.218	A	0.870
Disodium	75	25	0.179	A	0.424	B
PEG-12	50	50	0.128	B	0.093	C
Dimethicone	25	75	0.088	B	0.059	C
Sulfosuccinate	0	100	0.087	B	0.031	C

[§] Codes not connected by adjoining letters are significantly different as determined by Tukey-Kramer ANOVA analysis at 95% confidence, n = 4. Statistical analysis performed within each test method only.

change indicates the surfactant has a higher potential for irritation. In both test series, the 100% SLES solution caused the most weight change in collagen. Increased concentrations of DPDS or water caused decreased collagen weight changes accordingly.

In the DPDS test series, the rate of change, i.e., less weight gain, is more rapid for DPDS than for water. The data points at 50% and 25% SLES are indicative of a more significant effect than just dilution. Although there were few statistical groupings within each data series, the 50% and 25% SLES solutions were significantly different between the two series, strengthening the point of reduced SLES-protein interactions when DPDS is present. This confirms the mollifying effect by DPDS in comparison to dilution of SLES with water. While the exact mechanism remains unclear, it could be hypothesized that the DPDS must block interactions between surfactants and skin proteins.

Skin Equivalent Testing

In the last phase of the development of these cleanser formulations, a skin model^a was employed to assess the impact on viable skin.

Upon receipt of the tissue cultures, they were transferred into six well plates and allowed to acclimate at 37°C and 5% CO₂ for 1 hr, after which Dulbecco's modified eagle's medium is added and incubated. For the samples receiving test material, 25 µl of test material is added on top of the skin model and placed back into the 37°C at 5% CO₂ incubator for 24 hr. Following this incubation period, the underlying media is collected and assayed for IL-1α concentration.^a The skin model was then rinsed thoroughly, removed, blotted dry, and placed into a 24 well plate for the assay for cell viability.^a The skin model was tested against solutions of those formulations listed in **Table 65.4** at 2% w/w for 24 hr, along with controls of phosphate buffered saline (PBS) and 0.25% SLS.

The assessment of potential irritation was performed using ELISA^a kits to measure IL-1α concentration as well as using the MTT³ assay to assess the cell viability.¹⁶ Skin model^b cells are metabolically active because they are human skin-like tissue structures with lipid and ceramide profiles similar to living human skin. They therefore elicit the same inflammatory compounds, namely cytokines and receptors, as seen in vivo.¹⁷

Table 65.4. Formulations and skin model^a IL-1α responses after 24-hour incubation

Formulation Composition	% SLES	% CAPB	% DPDS	% PPT	IL-1α (pg/mL)
PBS Control	---	---	---	---	42.4
0.25% SLS	---	---	---	---	577.3
Code E	0.65	2.32	1.25	1.66	78.7
Code F	1.30	2.06	1.25	1.66	85.3
Code H	1.04	2.42	2.00	1.40	47.3
Code J	2.08	2.09	2.00	1.40	118.2
Code K	3.25	1.94	1.25	1.40	110.8

^a EpiDerm, ELISA kits and MTT assays were obtained from MatTek Corp., Ashland, MA, USA.

The data in **Table 65.4** indicates a large range in the IL-1 α concentrations for the two controls. The difference is statistically significant, at 95% confidence. For the experimental codes, the results are much lower than for the SLS control. The experimental codes are all significantly different than the SLS control, but not different from the PBS control, at 95% confidence. For the five experimental codes, while there were no statistical differences, it appears that the DPDS has a greater influence on reducing signs of irritation than does PPT. Codes E and F, along with H and J, agree with the collagen swelling data that, a ratio of 2:1, DPDS to SLES has the potential to reduce the signs of SLES irritation.

Conclusions

The in vitro screening methods explained here supplied data for making critical decisions such as choice and ratio of raw materials used in a product that addresses AD. The surfactant bases ultimately developed in this fashion were designed to combine the most desired consumer attributes along with very mild ingredients to deliver consumer acceptable formulations that provide the benefit of mildness to skin conditions such as AD.

Through the use of a tertiary surfactant, DPDS, and the thickener PPT, a successful set of personal care products was created that demonstrates a lack of protein binding, very low levels of lipophilic dye extraction, and minimal to no impact in cytokine expression in a living cell model.

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SECTION XIV

Green Chemistry

Perhaps nothing is on more topical in the personal care industry than Green Chemistry. Green chemistry, also called sustainable chemistry since it is based upon renewable resources. By “renewable” is meant materials that can be remade over a time appropriate with the use by consumers. The ability to formulate totally green products will remain a challenge to formulators because in many instances the demands of consumers can only be met by incorporating some concentration of materials that themselves are not green.

Green Chemistry is also a topic of much debate. As you will see in reviewing the articles presented, not all scientists agree on all the standards, definitions and processes. Some, the purists in the group want 100% natural products, others want to maximize the use of green components, but allow for the inclusion of materials that provide a consumer benefit that is not achievable with all green materials. Still others argue that “petroleum products belong in natural cosmetics offering many advantages of petrolatum that enable it to be a highly effective ingredient for natural cosmetics”.

The articles presented were chosen to cover a range of concepts and ideas and to encourage the reader to see all points of view before deciding.

- 66** Petrolatum and Vegetable-Based Alternatives
- 67** Navigating the Challenges of Formulating
- 68** Organic Cosmetic Standards: A New Formulation Challenge
- 69** Green Formulations: Not All Components Are Equal

Petrolatum and Vegetable-Based Alternatives

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KEY WORDS: *natural cosmetics, petrolatum, petrolatum alternatives, vegetable oil, moisturization*

ABSTRACT: *The authors examine the meaning of the term natural and assert that it applies to both petrolatum and petrolatum's vegetable-based alternatives. They further assert the advantages of petrolatum as a safe, well-established moisturizer.*

Do petroleum products belong in natural cosmetics? Vegetable oil-based materials have been offered as natural alternatives to petrolatum, but the definition of the term *natural* clearly includes petroleum products such as petrolatum. This article describes the many advantages of petrolatum that enable it to be a highly effective ingredient for natural cosmetics.

How Are Natural Cosmetics Defined?

For decades, consumers have been using cosmetics containing petroleum-based ingredients, either refined hydrocarbon products or materials that are derived from petrochemical feedstocks. With the recent increasing interest in natural ingredients and their use in personal care products (see **Why is Natural Important? sidebar**), questions have surfaced about how petroleum hydrocarbons fit within these products. Some suppliers have developed alternatives to

mineral oil and petrolatum in order to provide personal care product manufacturers with cosmetic ingredients that have been obtained from vegetable or other renewable sources. These ingredients are frequently touted as being natural, which carries the connotation (intentional or not) that such ingredients are better, healthier, safer for the user, and/or less polluting to the environment.

One of the main difficulties of using natural ingredients in personal care products is that no universally recognized definition exists for a natural cosmetic product. All cosmetic ingredients can be placed on a continuum, and it is not easy to determine where natural products begin and end on such a scale. In fact, one could even make a logical argument that anything made from the first 92 elements of the periodic table could be called natural.

Because there is no clear-cut definition of the term “natural” for the cosmetic industry, different views can be found regarding which personal care ingredients are suitable for natural cosmetics.¹

Why Is Natural Important?

A claim that something is natural has broad appeal. In today's world, people are looking for an escape from technology to a simpler lifestyle that offers more time to focus on family, friends, and neighbors. Because many people equate simple with natural, the demand for natural products has increased. Natural products have been seen as one component of a better life.^{2,3}

As with any current trend, an aging population also must be considered as a factor. The older population has more money to spend on extras such as personal care, and wants products that are proven to be safe and effective. Some people tend to believe that natural ingredients, which have been around for hundreds of years, are less likely to cause harmful effects than newly-developed synthetic products. Therefore, these consumers feel more comfortable using natural products.

In 2004, sales of natural personal care were expected to reach \$9.6 billion, more than double the \$4.5 billion in sales for 2002.⁴ Though the reasons behind the trend may not be completely clear, it is believed that a double-digit growth rate in natural personal care products will continue well into the future.⁴ To better understand this growing market and its products, it is important to define what is meant by the term *natural*.

One person can say that ingredient X should not be used in natural cosmetics, while another person might argue that ingredient X is acceptable. Inconsistency also occurs due to a lack of knowledge of chemistry and chemical nomenclature: one Web site claims glycerin is safe for use in natural cosmetics because it is a byproduct in the manufacture of soaps, but the same Web site says petrochemical-derived ingredients like glycerol should be avoided. The problem is *glycerin* and *glycerol* are two names for the exact same ingredient.

Natural is not always better: The term *natural* often carries the implication that something is safer, better, or healthier than that which is not natural. This is not necessarily true: daffodils and chrysanthemums can cause contact dermatitis, yet they are natural plants. Many other natural, plant-based products (such as coniine in hemlock, urushiol in poison ivy, and strychnine) can be harmful. In fact, according to the *FDA Consumer* magazine, “There is no basis in fact or scientific legitimacy to the notion that products containing natural ingredients are good for the skin.”⁵

Consumer perceptions: Consumers differ in their perceptions of essential requirements for natural cosmetics. For example, which of the following features would you require in a natural cosmetic?

- Use only plant-based ingredients
- Use mostly plant-based ingredients
- Use some plant-based ingredients
- No animal testing
- No animal-derived products
- No mineral oil or petroleum products
- No synthetic ingredients
- Minimal use of synthetic or highly processed materials
- Chemical-free
- No artificial preservatives
- Pesticide-free

These features describe the term *natural*, but they don't define it. As one begins an in-depth evaluation of these requirements, more confusion than clarity is found. For example, squalene from shark livers may be considered an undesirable and unacceptable

ingredient for a natural cosmetic because it is an animal-derived product. However, sharks are clearly natural—they weren't synthesized by humans—so ingredients obtained from them should be considered natural. To add to the confusion, what if scientists clone a shark? Would squalene from a cloned shark be considered synthetic because humans played a role in the formation of that shark?

Additional confusion arises from the term *organic*. Because of the increase in the availability of organic foods at traditional grocery stores, many consumers tend to equate the terms *organic* and *natural*. This is a tenuous connection, because even fresh foods not grown organically are still considered natural, not synthetic or artificial.

In the United States, a frequent misconception about natural ingredients for cosmetics is that they have the same legal definition as organic foods do, and as such are subject to strict manufacturing guidelines. The United States has a program in place to certify foods as organic. Organic food standards have been developed under the National Organic Program, directed by the Agricultural Marketing Service arm of the United States Department of Agriculture.⁶ However, no such program exists for cosmetics or cosmetic ingredients.

Processing of natural ingredients: Many questions arise when the details of natural ingredients are explored. For plant-based ingredients, different refining and purification processes create legitimate disagreements over how much processing of a natural ingredient is allowed. For example, how many of the following processed ingredients would you select in preparing a natural cosmetic?

- Leaves still on a living plant, or roots still in the ground, attached to the plant. It is impossible for products of this type to be used in personal care products. As soon as the plant parts are removed, they are no longer a part of the living plant.
- An ingredient physically removed from a plant but not otherwise changed. One example is leaves removed from a plant and used in a cosmetic product “as is” (such as various herbs used in ethnic hair treatments). Another example is a vegetable oil that has been mechanically extracted without using solvents and without further refining or purification.

- An ingredient extracted from plant parts using mechanical procedures, but then blended with synthetic materials to be used as a cosmetic ingredient mixture.
- An ingredient extracted from plant parts using natural solvents, such as carbon dioxide.
- An ingredient extracted from a plant using steam distillation.
- An ingredient extracted from a plant by some method and further refined to remove undesirable impurities.
- An ingredient extracted from plant parts using solvents that are naturally derived.
- An ingredient extracted from plant parts using solvents that can be naturally derived, but may not be.
- An ingredient extracted from plant parts using solvents that are clearly synthetic.
- Ingredients that are naturally derived, but chemically modified (e.g., by hydrogenation). One example is hydrogenated castor oil.
- Ingredients that are naturally derived but include synthetic processes. These materials have a lineage to natural products, but have definite chemical processing steps associated with them, because the natural structure has dramatically changed. These include materials obtained from plant oils that have been chemically transformed by esterification, hydrolysis, or transesterification into ingredients that are not found in nature.

Is Petrolatum Natural?

Many dictionaries, including online sources, tend to have similar definitions of the term *natural*. In general, this term means “existing in, produced by, or derived from nature.” Based on this definition, it is evident that every ingredient listed in the preceding section is natural, because they all exist in nature or are derived from nature. A similar definition of this term was put forth in a 2004 article on natural household products.⁷ Interestingly, crude oil and its components (including mineral oil and petrolatum) exist in nature, so they are also natural by definition. This is not

a new or unique perception of natural; views consistent with this perception have been presented by others.⁸

Differing views also have been advocated. In Germany, the BDIH (Association of German Industries and Trading Firms for pharmaceuticals, health care products, food supplements, and personal hygiene products) introduced a certification system and label in 2000 specifically for natural cosmetic products.⁹ Guidelines and regulations have been created, and details about this program were on the agenda at the 2005 In-Cosmetics in Berlin, Germany.¹⁰ It is interesting to note that the guidelines for BDIH's natural cosmetics do not allow petroleum products to be used, but fats, oils, and waxes that have been subjected to certain chemical modifications *are* allowed as emulsifiers.

The International Association of Natural Products Producers (IANPP) has created some sample criteria for labeling natural products. These criteria, currently under development, are similar to those described by the BDIH. These IANPP criteria also do not allow petrochemicals, but some industrial processing (chemical transformation) of fats, oils, and waxes is permitted.¹¹

Clearly, mineral oil and petrolatum are not synthetic chemicals. They are simply refined from their natural state and purified to make them suitable for use, just as plant-based ingredients are refined and purified. The fact that other ingredients of crude oil may be used in petrochemical processing to make synthetic products has no bearing on the reality that mineral oil and petrolatum are natural. It also should be noted that these petroleum products are derived from decomposed plant material, confirming their place as natural ingredients. Therefore, it is illogical to argue that an ingredient that does not exist in nature but was chemically synthesized from a plant-based ingredient is considered natural, while petrolatum, simply purified from its natural source, is not considered natural.

Mineral oil and petrolatum are unequivocally natural ingredients. Therefore, there are no petrolatum alternatives that are more natural than petrolatum itself. However, there are petrolatum alternatives that are vegetable-based.

Petrolatum Alternatives

To meet the needs of consumers interested in vegetable-based products, several cosmetic ingredient suppliers have developed petrolatum alternatives based on vegetable oils and vegetable oil derivatives (see **Vegetable-Based Alternatives to Petrolatum sidebar**). The ingredients these alternatives have in common are vegetable oils and hydrogenated vegetable oils. In general, blending a liquid with a solid or semi-solid waxy material (or a gelling agent) in the correct proportions yields a product of the desired consistency. Other ingredients may be added to improve or alter product properties.

How well these products moisturize the skin seems to vary. Some are claimed to have transepidermal water loss (TEWL) results equivalent to petrolatum, while others are said to be less occlusive than petrolatum. In published studies comparing emollients, petrolatum was shown to be a better moisturizer (i.e., more occlusive) than various esters, including caprylic/capric triglyceride,¹² octyl stearate,¹² and almond oil,¹³ and petrolatum decreases xerosis better than olive oil and sunflower oil.¹⁴ Idson has noted that various vegetable oils (including avocado, peanut, safflower, and sesame oils) are less occlusive than petrolatum.¹⁵ Nevertheless, the petrolatum alternatives are considered to be moisturizers, because vegetable oils do provide some TEWL improvement.

Vegetable-based Alternatives to Petrolatum

The following vegetable-based mixtures are all commercial products whose INCI names are, in some cases, protected by confidentiality agreements. The components are shown in this format for that reason.

- Soybean Oil + Hydrogenated Cottonseed Oil
- Canola Oil + Silica + Corn Starch
- Castor Isostearate Succinate + Hydrogenated Castor Oil
- Soybean Oil + Canola Oil + Vegetable, Mineral, or Synthetic Wax
- Castor Oil + Hydrogenated Castor Oil + Beeswax + Carnauba Wax
- Castor Oil + Hydrogenated Castor Oil + Beeswax + Carnauba Wax + Methyl Soyate
- Hydrogenated Vegetable Oil

Some of these alternatives are described as drop-in replacements for petrolatum, but with a less greasy feel. In a neat form, any vegetable oil-based anhydrous product will most likely be less greasy than petrolatum. If a formulator wants to replace petrolatum with a vegetable-based material, these alternatives offer a wide range of products that should perform better than the vegetable oil alone. Depending on the finished product formula, replacement of petrolatum with a liquid vegetable oil would probably require significant reformulation if the same finished product viscosity is desired. Using a thicker, petrolatum-like alternative should allow either a direct one-for-one replacement, or require much less reformulation of the final product.

Another feature of these alternatives is the fact that they are derived from what are considered to be renewable natural resources (plants), while petrolatum is derived from nonrenewable natural resources (crude oils). Vegetable oils can be replenished every growing season, while crude oil sources cannot. Furthermore, the sources of vegetable oils (farms and crop fields) can be readily expanded to increase the overall production of the oil, if necessary.

Most of the hurdles facing the petrolatum alternatives are also related to their vegetable origins. While vegetable oil-based ingredients are more oxidatively unstable (due to the presence of unsaturation in the oils),¹⁶ creative formulating with efficient antioxidants can help overcome such issues. These petrolatum alternatives are also more likely to experience supply difficulties and/or price fluctuations due to weather conditions and crop diseases (e.g., Asian soybean rust¹⁷), and possibly have product consistency variations based on the vegetable's growing temperature and location.^{18,19} Prices of the petrolatum alternatives are generally higher than that of petrolatum because of both the lower quantities of product manufactured, and the time- and labor-intensive processing of the oils.

Petrolatum alternatives (those in the **Vegetable-Based Alternatives to Petrolatum sidebar** and others) are useful ingredients for the cosmetic chemist's bench, and can help formulators develop high-performing new products for the natural cosmetic market. By using materials like these, new products that could not be created in the past are now within reach. In addition, scientists can capitalize

on established, proven ingredients such as petrolatum for these same types of products.

Petrolatum

The petrolatum provided to the cosmetic industry today is of the highest possible quality, purity, and consistency. This material has been safely used for many decades in a wide variety of pharmaceutical and cosmetic applications. A brief survey of the literature supports its safety, its effectiveness, and its use as a skin moisturizer and conditioner (see **A Snapshot of the Literature on Petrolatum sidebar**).

Along with petrolatum's outstanding moisturizing properties comes a heavy feel. However, proper formulation of petrolatum in skin care products enables cosmetic scientists to reap the benefits of petrolatum's TEWL reduction, while minimizing its greasiness. Other advantages of petrolatum are its excellent thermal stability

A Snapshot of the Literature on Petrolatum

Petrolatum has been used regularly as a skin care ingredient for more than 100 years.

- Its citation in 1880 in *United States Pharmacopoeia* (USP) is an excellent indicator of the effectiveness and safety of petrolatum.
- Its safety has been confirmed by its long-term use and by studies indicating that petrolatum is not comedogenic,²⁰ not an irritant,²¹ and not allergenic (and, in fact, is regularly used as an inert base in the testing of materials for allergic reactions, thus validating its nonallergenicity).
- Its excellence as a skin conditioning agent has been established numerous times. Studies consistently show that petrolatum moisturizes the skin by reducing TEWL,^{12,13,22,23,24} and that petrolatum is frequently considered the best moisturizer available.^{15,25} The results of a study reported by Kligman in 1978 further attest to the effectiveness of petrolatum: "When it comes to efficacy, petrolatum is the unrivalled moisturizer. No material in our experience exceeds it in relieving ordinary xerosis."¹¹
- It has also been shown to improve barrier repair of acetone-damaged skin.²⁶

and resistance to oxidation, its consistency of supply, and the fact that it is an OTC skin protectant. Even though petrolatum is less expensive than petrolatum alternatives, price fluctuations can still occur.

Conclusion

Petrolatum and the various vegetable-based alternatives are useful products which are suitable for applications in natural cosmetics because they are all derived from nature. While the alternatives may have current appeal to formulators and marketers, petrolatum is known as a safe, well-established moisturizer that is one of the most beneficial, most available, and most cost-effective natural ingredients available today.

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Navigating the Challenges of Formulating

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KEY WORDS: *botanicals, Boswellia serrata, tetrahydrocurcuminoids, dispersibility, stability, skin permeation*

ABSTRACT: *Formulating with natural botanical extracts poses unique challenges to formulators such as color issues, ingredient instability, poor absorption of actives, dispersibility problems, and quality, safety and efficacy concerns. Following are some answers to these challenges.*

A judicious blend of art and science is critical to creating natural cosmeceuticals for use in personal care products. The major challenge is finding ingredients that are compatible with existing formulations. Aesthetics is a particularly important concern. For example, while there is much interest in using natural botanical extracts in cosmetic preparations, a too-dark color, a gritty texture, ingredient instability, poor absorption of actives, or dispersibility problems could render the “healthy and natural” ingredient unattractive. Additionally, the safety and efficacy of natural ingredients need to be established in order to enable their use in finished personal care products.

Challenges in Innovating

Color issues: Natural ingredients for antiaging skin care are prepared from botanicals with a long history of traditional cosmeceutical use, such as skin lightening, skin smoothing and antimicrobial applications, although the term itself is of recent origin. Botanicals are rich in phenolic and other pigments including carotenoids, flavonoids and related compounds, and often some of the healthful properties of these natural materials reside in the pigments themselves. An example is turmeric, a culinary spice with a tradition of topical use in South Asia. The active compounds in this case are the yellow curcuminoids that also are used as a natural colorant. This brilliant yellow color, however, does not blend well with currently manufactured personal care products. The end user is concerned about the unappealing yellow color staining the skin.

Scientific developments such as extraction processes and derivatization techniques have enabled a method to extract the mixture of biologically active curcuminoids from turmeric roots and convert them into colorless biologically active tetrahydrocurcuminoids. Such a composition finds versatile applications in personal care products, particularly in the antiaging category.

Tetrahydrocurcuminoids have been found to efficiently inhibit protein cross-linking and provide skin-lightening action as well as provide antioxidant and bioprotectant properties. This discovery is the subject of a recently granted U.S. patent.¹

Tetrahydrocurcuminoids offer additional functional antioxidant benefits in protecting fat-based compositions from oxidation. In laboratory studies,² tetrahydrocurcuminoids were found to quench free radicals more efficiently than the commonly used synthetic antioxidant, butylated hydroxytoluene (BHT).

From a safety point of view, the bioprotectant role of tetrahydrocurcuminoids is further enhanced by its low toxicity, (oral LD50 is 5000 mg/kg) with a 0.00 irritation score in a skin patch test.³ Turmeric root, the source of tetrahydrocurcuminoids, is listed by the U.S. Food and Drug Administration (FDA) as an herb generally recognized as safe (GRAS) for its intended use as a spice, seasoning and flavoring agent.⁴

Boswellia serrata in Antiaging

Olibanum, the resin from the *Boswellia* species, has been used as incense for centuries. Its major use today is as a fixative in perfumes, soaps, creams, lotions and detergents. In India, the gum resin exudates of *Boswellia serrata* and has been used in the ayurvedic system of medicine in the management of several inflammatory conditions.

Inflammation is considered to be the prime cause in aging, an inflamed site forming a micro-scar that over time develops into a wrinkle or blemish. Inflammatory mediators such as leukotrienes and prostaglandins, cytokines and growth factors target skin texture, integrity and tone. Containing inflammation at its roots is therefore an effective antiaging strategy.

Dispersibility: Botanicals often are difficult to use in formulations because of their poor solubility or dispersibility in acceptable solvents. In such cases, the formulator faces a challenging task that sometimes requires modifications to the formulation process itself. The order of addition of ingredients, the type of solvents used, temperature and pH conditions, the nature of the mixing process and several other factors influence dispersibility.

Boswellia serrata, for example, has been used in the ayurvedic system of medicine to manage inflammatory conditions (see ***Boswellia Serrata* in Antiaging sidebar**).

The active boswellic acids reside in the gum resin from the tree, which is a difficult material to formulate, and the gum constituents may irritate the skin. Natural extract manufacturers have developed efficient extraction processes that produce a composition rich in boswellic acids in a powder form. Such an ingredient can be conveniently used in formulations for soaps, lotions and cosmetic creams as an anti-inflammatory ingredient (see **Formula 67.1**)—however, the powder must be dispersed well during the formulation process. Optimal proprietary methods for formulation have been developed after extensive experimentation.

Products tested containing 5% of a standardized extract from the gum resin^a did not produce any irritation or sensitization in standard patch tests.⁵

^a Boswellin (INCI: *Boswellia serrata* extract) is a registered trademark of Sabinsa Corp.

Formula 67.1. Cream formulation with *Boswellia serrata* extract

A. Water (<i>aqua</i>)	59%–60%
Carbomer	0.25%–0.27%
B. Glycerin	4.0
Methylparaben	0.2
Edetate sodium	0.01
C. Cetyl alcohol	3.5
D. Stearyl alcohol	3.5
Stearic acid	6.5
Glyceryl stearate	2.5
PEG-100 stearate	2.5
Isopropyl palmitate	6.0
Vitamin E acetate	1.0
Dimethicone	0.1
Propylparaben	0.1
Vitamin A palmitate	0.1
Ascorbyl palmitate	0.2
E. <i>Boswellia serrata</i> extract	5.0
F. Water (<i>aqua</i>)	2.0
Triethanolamine	0.4
G. Imidazolidinyl urea	0.3
Water (<i>aqua</i>)	1.0

Procedure: Mix A under propeller agitation until dissolved. Add B to A and blend. Begin heating to 72°C–77°C and continue mixing until completely dissolved. In a separate container, charge C and add D to C in order. Heat CD to 72°C–77°C until dissolved. Mix CD with AB, maintaining 72°C–77°C. Add E to batch under propeller agitation. In a separate container, combine F until dissolved and mix with batch. Keep mixing until completely dissolved while maintaining 72°C–77°C. In a separate container, combine G until dissolved and add to the main batch. Mix and cool to 35°C–40°C and package.

Stability issues: Retaining the biological activity of natural ingredients through raw material preparation, processing, extraction, packaging and storage presents a myriad of challenges.

Nutrients in natural materials such as vitamins, growth factors, amino acids, flavonoids, pigments and essential oils are susceptible to degradation on contact with oxygen or exposure to suboptimal temperature and pH conditions.

An example is young or “green” coconut water—a reservoir of nutrients and growth factors. Green coconut water is the liquid endosperm of coconut (*Cocos nucifera* L), which is a refreshing natural drink in the tropics and traditionally used as a health and beauty aid. Natural coconut water is rich in proteins, amino acids, sugars, vitamins, minerals and growth hormones that are essential to promote tissue growth. Laboratory researchers use the material as a supplement in media for the growth of plant tissue cultures.

Coconut water is useful in hair care formulations and in topical preparations to rejuvenate, nourish, condition, soothe and moisturize the tissues. However, its short shelf life and sensitive nature of the inherent actives make it difficult to use the material in cosmetic formulations. A freeze-drying process has been developed to retain the activity of coconut water components. The process produced a light tan-colored powder consisting of coconut water solids that readily blends into cosmetic preparations. In *in vitro* irritation studies, a product formulated with the ingredient^b was found to be non-irritating.

Skin permeation: The efficacy of actives depends upon their skin permeation capabilities. Selective nutrient absorption by the skin is an important physical property of the skin. This selective process begins with the stratum corneum (SC). The function of this barrier is related to the unique composition of the lipid moiety in the epidermis. The intercellular lipids mediate transdermal delivery of both lipophilic and hydrophilic molecules. Research shows that regulating the composition of intracellular lipids in the skin can increase or decrease the bioavailability of nutrients.⁶

Besides the modification of skin lipid composition, there are several strategies to improve topical nutrient bioavailability. Improvement can be accomplished by supersaturation of the delivered ingredient. The delivery formulation also may contain ingredients that decrease the diffusional (electrostatic) resistance of the lipid bilayer to the passing molecule. Topical liposome preparations are effective penetration enhancers for the delivery of biological compounds, probably due to their role in increasing cell

^b Cococin (INCI: *Cocos nucifera* (coconut) fruit juice) is a registered trademark of Sabinsa Corp.

membrane fluidity. In addition, an increase in blood supply to the skin can enhance absorption of delivered nutrients.

Historically, a number of chemical-penetration enhancers have been used to enhance the uptake of actives. These include: solvents such as dimethyl sulfoxide (DMSO), ethanol and other alcohols; glycols such as propylene glycol; fatty acids such as oleic acid; and detergents such as sodium lauryl sulfate, polyoxyethylene lauryl ethers, and chaotropic agents such as thioglycolate, urea, and mercaptoethanol.

As such, they also have the potential to cause damage to the SC and to increase the probability of irritation. Most of these agents work by perturbation of the intercellular lipid bilayers present in the SC.

Therefore, there is a need for compounds of natural origin with low irritancy and minimal side effects that can be efficiently combined with nutrients to enhance the uptake and utilization of such active molecules.

An innovation in enhancing topical delivery of natural actives is available in the form of a proprietary extract obtained from black pepper fruits^a, a common culinary spice.

When added in small amounts (0.01%–0.1%) to cosmetic formulations, tetrahydropiperine, the active principle, enhances the uptake and delivery of other actives in the formulation. Poorly absorbed botanicals, therefore, can be made more “bioavailable” with this ingredient.⁷

Quality, safety and efficacy: Herbal raw materials available commercially as powders and extracts often do not meet global standards of quality, efficacy and safety. To preserve the authenticity and credibility of such products, it is important that the ingredients therein contain adequate amounts of biologically active principles that manifest the desired biological functions.

Plant materials pose several challenges in standardization. Natural products are complex matrices with a number of active principles varying widely in content and type, based on geographical origin, cultivation and collection practices, and processing and storage

^a Cosmoperine (INCI: Tetrahydropiperine) is a registered trademark of Sabinsa Corp.

Organic vs. Natural

According to the U.S. Department of Agriculture's (USDA) National Organic Program (NOP), the term *organic* may be used on product labels when certain conditions are met.¹

100% organic:

- This designation may be used for agricultural products that are composed of a single ingredient such as raw, organically produced fruits and vegetables and products composed of two or more organically produced ingredients, provided that the individual ingredients are, themselves, wholly organic and produced without any nonorganic ingredients or additives. (Only processing aids that are, themselves, organically produced, may be used in the production of these products.)

Organic:

- Products labeled or represented as *organic* must contain, by weight (excluding water and salt), at least 95% organically produced raw or processed agricultural product.
- Up to 5% of the ingredients may be nonagricultural substances and, if not commercially available in organic form, nonorganic agricultural products and ingredients in minor amounts (i.e., spices, flavors, colorings, oils, vitamins, minerals, accessory nutrients, incidental food additives).

Made with organic ingredients:

- Multiingredient products containing by weight or fluid volume (excluding water and salt) between 70%–95% organic agricultural ingredients may be designated as “made with organic [specified ingredients or food group(s)].” Up to three organically produced ingredients or food groups may be named in the phrase.

The term *natural*, according to the National Consumer's League (NCL), is not regulated by the FDA as far as the use of the word on personal care or cosmetic products.² The FDA's Office of Cosmetics and Colors has, however, produced consumer information regarding the *natural* claim for personal care products. Products claiming to be *all natural* or *plant-derived* may include more than just natural ingredients or plant products.

1. Source: National Organic Program (NOP) Web site. Available at: www.ams.usda.gov/nop/NOP/standards/LabelPre.html. (Accessed Jan. 23, 2006.)

2. Source: Naturally misleading: Consumers' understanding of “natural” and “plant-derived” labeling claims, National Consumers League (NCL) Web site. Available at: www.nclnet.org/naturalsreport.htm#_ednref5. (Accessed Jan. 23, 2006.)

conditions. This often leads to variations in potency, label ambiguity and related problems in finished cosmetics.

Compositional consistency of botanical extracts in terms of active principles is the key factor in ensuring potency and sustaining consumer confidence. Marker compounds are chemicals proven to be characteristic of botanicals and endowed with validated health benefits. Chemical fingerprints using chromatography and spectrophotometric methods, in combination with bioassays, are the accepted methods to ensure the presence of marker compounds in botanical materials.

A botanical's active principle may concentrate in a specific location in the plant and manufacturers often use combinations of plant materials in preparing finished extracts. Contaminant levels, including heavy metals, pesticide residues, extraneous matter and genetic modification aspects also need to be considered. The complexity of these challenges is exacerbated by mislabeling in the commercial marketplace.

Authentication of plant materials used to manufacture cosmetic ingredients is critical. Selecting appropriate extraction and purification processes is important as this reflects heavily on the quality of finished extracts. To avoid skin irritation and sensitization, solvent residues and other contaminant levels in finished extracts should be minimized.

Meeting These Challenges

In the rapidly growing market for natural antiaging cosmetics, application-oriented product development goes a long way in facilitating the introduction of traditionally used botanicals into conventional formulations. The initial challenge is to innovatively transform plant materials into safe and efficacious ingredients for functional cosmetics. Once this is achieved, the next step is to comprehensively address global regulatory issues and nurture consumer confidence through consistent quality management. Furthermore, *in vitro* testing methods for safety and efficacy need to be optimized to facilitate cruelty-free product development.

Nature provides a plethora of options to support healthy aging. Blending traditional knowledge with modern science results in innovative approaches to the effective use of plant-based materials in contemporary personal care formulations.

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Organic Cosmetic Standards: A New Formulation Challenge

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KEY WORDS: *NSF standards, Ecocert, COPA, organic calculation, allowable chemical processes*

ABSTRACT: *The popularity of the Ecocert cosmetic standards and the publication of the NSF standards have increased the complexity of the organic cosmetic landscape. This article reviews organic standards in cosmetics and contrasts how to formulate products based on Ecocert vs. NSF standards*

A vast array of US cosmetic products is being labeled “organic”—from certified organic massage oils to shampoos containing synthetic surfactants and preservatives. The resulting confusion in the marketplace indicates that the organic food industry and the organic cosmetics industry do not know what to think of, or do with, each other. The major organic food markets in the United States, the European Union (EU) and Japan have all struggled with whether—and how to—embrace the emerging cosmetic “stepchild” of organic foods. Regulators in each of these three markets have referred to cosmetics in their organic food programs, but these references have not always helped to clarify the situation. The regulatory answer to the question of using the food standards to certify cosmetics could be paraphrased in each of these markets as follows:

- United States: “Yes you can. No you can’t. OK, I suppose you can.”

- European Union: “Not now, not ever.”
- Japan: “Go ahead—just do not translate it into Japanese.”

To a company entering the organic cosmetics market, the worldwide picture will be overwhelmingly confusing. To an experienced marketer, the worldwide picture also is overwhelmingly confusing.

Standards Background

A recent article¹ provides a history of the organic cosmetic standards process in the United States and a brief summary of the worldwide organic cosmetics landscape. As the present chapter is written, that process should have resulted in the publication of a US organic cosmetics standard by NSF International (www.nsf.org), a world-renowned standards organization. NSF is accredited by the American National Standards Institute (ANSI), to create ANSI standards. ANSI is the US representative in the International Standards Organization (ISO).

The public comment portion of the NSF process (see **NSF Process sidebar**) will hopefully result in broad feedback to this standard from the cosmetics and food industries. The NSF standard, when finalized, could be used on a voluntary basis for certifying cosmetic products in the US market.

NSF Process

NSF International has created a comprehensive standards development process that requires broad representation from the industry. Food certification inspectors, cosmetic manufacturers, certifiers, cosmetic chemists, consumer groups and government regulators are all taking part in the creation of the cosmetic standard. Once published to the industry, all feedback on the standards will be considered by the committee in order to produce a final document that is presented to the NSF board for more modification or final NSF approval. The standard can then be used on a voluntary basis to certify cosmetic products. NSF is also well-versed in the process of taking a standard from development through government regulation.

Ecocert, a private food certifier in the European Union, has developed a private organic cosmetic standard that has been in use in Europe for several years. The Ecocert standard was registered with the French government in 2002 as the official organic cosmetic standard in France. Products certified to this standard are beginning to appear in the United States, which has increased the awareness of the many different standards in use and in development.

Ecocert vs. NSF

Organic foods can be certified at three different levels to make three different claims—“100% organic;” “certified organic” requiring 95% organic content; and “made with organic ingredients,” which requires 70% organic content. The decision was made by the NSF standard committee to default to the United States Department of Agriculture’s (USDA’s) National Organic Program (NOP) food standard for the two higher levels of certification, “100% organic” and “certified organic.”

According to the NOP,² a food can make a front label claim of “certified organic” if the organic content is at least 95%. The NSF standard redefines the category of “made with organic ingredients” to allow for the use of cosmetic ingredients prohibited by the NOP food standard. Examples of these ingredients are fatty alcohols and surfactants such as sodium coco-sulfate. The organic content requirement of this category, 70% minimum, mirrors the NOP food standard.

The state of California also has passed its own organic food law, the California Organic Products Act (COPA).³ COPA requires that any cosmetic product sold in California contain at least 70% ingredients that are certified to the NOP food standard, for either a “certified organic” claim or a “made with organic ingredients” claim. This law is mandatory, not voluntary, for California. The provisions in COPA for cosmetics do not restrict the content of the 30% nonorganic portion of the product. This portion may contain any ingredients acceptable for use in cosmetics.

The European Ecocert standard has two levels of certification: “organic” and “ecological.” The “ecological” level is a lower level of certification, akin to the NSF/NOP standard of “made with organic

ingredients.” The organic content requirement is lower for the Eco-cert “ecological” certification than for its “organic” certification.

The content requirements for Ecocert are much more complicated than for NSF. There are three content requirements to meet the Ecocert standard. First, the natural and naturally derived content (including water) must be at least 95% of the formula.

The second and third calculations for Ecocert certification concern organic content. The second requirement is that 95% of the plant ingredients must be certified organic. The third is that at least 10% of the finished product ingredients, not counting water, must be certified organic. At the lower “ecological” level of Ecocert certification, the natural requirement is the same as the organic level—95% of the finished product. The organic content requirements are lower—50% of the plant ingredients and 5% of the finished product. These requirements are summarized in **Table 68.1**.

Standard	Organic Claim	Lesser Claim (Made with/Ecological)
NSF	95% organic food ingredients	70% organic content from allowed processes
COPA	70% NOP food ingredients	70% NOP food ingredients
Ecocert	95% natural/95% organic/	95% natural/50% organic/ 10% organic 5% organic

It is important to note that the NSF standard is built on the USDA’s NOP organic food standard, so the organic content in the NSF standard must be NOP organic. The Ecocert standard starts from the EU’s organic food program, so it is written to require organic ingredients certified to the European Union’s EC2092/91 organic program.⁴

Allowed Ingredient Processing

The NOP food standard, which defines the organic category of the NSF standard, is not concerned with the chemical reactions

that produce the ingredients or food products. Any cosmetic ingredient produced by an NOP-allowed process such as heating, mixing or steaming is allowed. Some chemical conversions can be accomplished by the use of NOP-allowed processes and the use of sodium hydroxide, which is an “allowed synthetic” in the NOP food standard. Three of these chemical conversions are hydrolysis, esterification and saponification. Any ingredients that can be made by these reactions such as soap (e.g., sodium cocoate) can be used in a cosmetic product that is labeled “certified organic” by the NOP food standard.

The Ecocert cosmetic standard does recognize the chemistry used to produce cosmetic ingredients. This standard includes a list of the chemical reactions that can be used to make ingredients for products to be certified by Ecocert. This list is much longer than the NSF/NOP organic list, as can be seen in **Table 68.2**.

The NSF standard also recognizes and allows a list of chemical processes at the “made with organic ingredients” level of certification. The main difference in allowed chemical processes between the NSF “made with organic ingredients” standard and the Ecocert organic standard is the allowance of amphoteric surfactants by

Table 68.2. Allowable Chemical Processes

Standard	Allowed Processes	Ingredients
NOP Organic	Hydrolysis	Wheat amino acids
	Esterification	Glyceryl stearate
NSF “Made With”	<u>Everything above plus:</u>	
	Protein condensation	Sodium cocoyl glutamate
	Etherification	Lauryl glucoside
	Hydrogenation	Hydrogenated castor oil
	Hydrogenolysis	Coconut alcohol
Ecocert	Sulfation	Sodium coco-sulfate
	<u>Everything above plus:</u>	
	Amphoterics	Cocamidopropyl betaine Sodium cocoamphoacetate

Ecocert. **Table 68.2** summarizes the chemical processes that can be performed under each standard and gives examples of ingredients that can be made by each process. Imaginative ingredient manufacturers will come up with many more ingredients that fit into each category.

Example Formulas

The Ecocert standards and the NSF “made with” category allow a much broader range of cosmetic ingredients than the NSF/NOP organic category, so it follows that more functional, elegant formulas can be made in the first two categories than in the NSF/NOP organic category. With the exception of amphoteric surfactants, the NSF standards will allow the same formulation chemistry to be used in products labeled “made with organic ingredients” as the Ecocert standards allow for products labeled “certified organic.” Example formulas for a lotion and a shampoo/body wash formulated to the two standards will show the differences.

Formula 68.1 shows a lotion formulated to the NOP food standard. There are a few emulsifiers that could be made to the NOP food standard. Glyceryl stearate, made from vegetable-derived glycerin and stearic acid, and sodium stearyl lactylate, made from vegetable-derived lactic acid and stearic acid, would comply. Natural lactic acid, like natural acetic acid—the acid in vinegar—is produced by fermentation of sugar.

Formula 68.1. NOP organic lotion

Organic aloe	62.00%
Organic sunflower oil	8.00
Organic shea butter	10.00
Glyceryl stearate	2.50
Sodium stearyl lactylate	2.00
Xanthan gum	0.50
Organic ethanol	<u>15.00</u>
	100.00

Organic Calculation: 95% Organic Ingredients

Organic oils and butters would comprise the oil phase. Preservation would be the major issue, with ethanol being one of the few antimicrobial ingredients allowed.

The Ecocert standard allows the use of fatty alcohols and their derivatives. This gives a great deal of formulation flexibility in the use of the fatty alcohols themselves and in the form of sugar ethers (polyglucosides) and fatty alcohol/fatty acid esters. Preservation would be much easier with the use of benzoic and sorbic acids.

Formula 68.2 shows a typical lotion made to the Ecocert standard.

If the hydrogenated vegetable oil is produced in a certified facility, it counts toward the organic content under the two standards.

Formula 68.2. Ecocert organic cream (from standards)

Sucrose cocoate	2.00%
Cetyl alcohol	3.70
Organic hydrogenated castor oil	1.50
Isostearyl behenate	5.00
Ethyl palmitate	5.00
Organic plant extract (in organic ethanol)	8.00
Plant active substance	1.00
Vegetable-derived glycerin	3.00
Water (<i>aqua</i>)	55.00
Organic floral water	15.00
Preservatives (synthetic)	0.50
Organic fragrance	<u>0.30</u>
	100.00

Note: All of the fatty alcohols and fatty acids are of natural origin.

Ecocert Organic Calculations:

- | | |
|---|--------|
| 1. Percent natural—only synthetic is 0.5% | 99.50% |
| 2. Percent organic of total plant ingredients:
$(1.5 + 8 + 15 + 0.3)/(1.5 + 8 + 15 + 0.3 + 1) =$ | 96.12% |
| 3. Percent organic of total formula:
$1.5 + 8 + 15 + 0.3 =$ | 24.80% |

Formula 68.3. NOP organic body wash

Organic aloe	69.00%
Organic coconut oil	12.00
Sodium hydroxide	3.00
Organic olive oil	0.50
Xanthan gum	0.50
Organic ethanol	<u>15.00</u>
	100.00

Organic Calculation: 96.5% Organic Ingredients

The organic content of the Ecocert organic lotion is 24.8%. In order to increase the organic content up to the 70% requirement for the NSF “made with organic ingredients” category, the batch water and the floral water would have to be replaced by an organic plant liquid such as aloe gel. If the synthetic preservatives also were replaced by NSF-allowed preservatives, such as organic acids, the Ecocert organic lotion could be labeled by the NSF standards as “made with organic ingredients.”

Soaps made from sodium hydroxide and organic oils such as coconut would be the main candidate for foaming ingredients under the NSF/NOP organic category. A very simple organic body wash, shown in **Formula 68.3**, could be made using soap.

Preservation is again the major issue, with ethanol being a practical choice. An organic shampoo similar to the example used in the Ecocert standards (**Formula 68.4**) shows the use of a sugar/fatty alcohol ether (polyglucoside) and an amphoteric surfactant (betaine) to give a very acceptable foam.

Using this formula as a starting point, it could be modified to make it acceptable in the NSF/NOP “made with organic ingredients” category by replacing the batch water and floral water with organic aloe, using an acceptable preservative system such as ethanol and organic acids, and replacing the amphoteric surfactant with an acceptable surfactant, such as sodium coco-sulfate.

Formula 68.4. Ecocert organic shampoo

Lauryl polyglucose citrate	12.00%w/w
Cocamidopropyl betaine (65% fatty acid of natural origin, 15% synthetic acetate, 20% synthetic amine)	13.00
Hydrolyzed vegetable protein containing 40% organic vegetable protein, 59.8% water and 0.2% preservatives)	6.00
Water (<i>aqua</i>)	53.70
15% Organic floral water	15.00
Preservatives (synthetic)	<u>0.30</u>
	100.00
Ecocert Organic Calculations:	
1. Percent natural:	
$12 + (13 \times 65\%) + (6 \times 99.8\%) + 53.7 + 15 =$	95.40%
2. Percent organic of total plant ingredients:	
$15 / 15 =$	100%
3. Percent organic of total formula:	
$15 =$	15%

Beyond the differences in finished product organic content calculations, there are also differences between the NSF and Ecocert standards in organic content calculations in the ingredients themselves. The organic content of a floral water such as rosewater in the NSF standard is only the amount of water that was contained in the fresh plant material. The Ecocert standard allows the entire floral water to count as organic content if the distillation used at least 20% fresh plant material or 5% dried plant material. The NSF standard allows a standard portion of processed ingredients such as fatty alcohols (98%) or sulfates such as sodium coco-sulfate (60%) to count toward the finished product organic content. Readers interested in these complex details are referred to the standards and appendices.

It is important to note that the overall organic content of the Ecocert example formulas are 24.8% and 15%. This organic content would also be EU organic, not NOP organic. Thus, neither of these formulas would comply with COPA, so neither could be sold as an organic product in California.

Conclusion

The popularity of the Ecocert cosmetic standard and the development of the NSF standard have certainly increased the complexity of the organic cosmetic landscape. Marketers of organic cosmetic products will have to choose their organic certification program based on what they feel best fits their company's marketing goals. They will need to spend time and effort to educate the consumer about what makes their product "organic."

Consumers may be increasingly overwhelmed and confused by the complexity of the organic options. Sorting through this mass of confusion, in addition to new marketing opportunities and consumer education, will mark the progress of the industry as it strives to figure out what "organic" means to personal care. Stay tuned.

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Green Formulations: Not All Components Are Equal

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KEY WORDS: *natural cosmetics, skin health, safety, efficacy, quality*

ABSTRACT: *In the consumer's mind, a natural or green cosmetic is automatically safe; however, the safety, quality and efficacy of botanical ingredients used in formulations need to be carefully assessed. Stability is also an important issue. Current research is directing analyses of final formulations to evaluate not only their cosmetic raw materials, but also their active materials.*

Nature has always been a generous source of wellness for mankind. Since ancient times, the healing properties of various plants have represented the first medicines and cosmetics. The study of tribal and native traditions has many times laid the foundation to successfully isolate new and effective cosmetic active ingredients.

Modern functional cosmetics represent valid alternatives to dermatological treatments for preventing the signs of aging, and the plant kingdom can provide many active compounds to counteract those signs, including: skin tone and elasticity loss,¹ wrinkle formation,^{2,3} capillary fragility,⁴ and increased skin sensitivity.⁵

However, natural ingredients require specific expertise not only in their research, but also in their analysis and formulation. The quality of botanical extracts, which needs to be standardized, is a crucial point for the quality of the final formulation, among others.

Standardized Extracts

To demonstrate the efficacy and reproducibility of a botanical active's variables in a cosmetic formulation, the consistency of the natural extract is a key factor. Reproducibility is also important when considering regulatory aspects aimed to assess the toxicity and tolerability of a cosmetic ingredient.

The consistency of a botanical extract is relatively achievable when dealing with a pure product such as escin or esculin from *Aesculus hippocastanum*; glycyrrhetic acid from *Glycyrrhiza glabra*; or with a dry extract highly purified up to the isolation of a unique class of molecules such as triterpenes from *Centella asiatica*, flavolignans from *Silybum marianum*, polyphenols from *Vitis vinifera* and anthocyanins from *Vaccinium myrtillus*.

In some cases it is convenient to purify a unique active principle up to 80–90%, whereas in other cases a complete extract of numerous different compounds may be more active than the single isolated molecules. Research in this field is complex and involves not only the identification of the active principle, it also aims to investigate the interactions between the active ingredients and other molecules present in the phytocomplex.⁶

Different technologies or manufacturing methods may be necessary for different types of extracts but the main parameters include: composition constancy, stability, microbe counting and the limitation of residual solvents and pesticides. These parameters should be carefully monitored as required by health authorities.

The crucial stages of the process include, as a rule of thumb, choosing the raw material first, followed by extraction and purification. While the choice of extraction solvents in the preparation of standardized extracts is an important factor for the finished product quality, the choice of the raw material is pivotal.

From a practical point of view, the botanical source must be thoroughly checked before extraction, as far as botanical and chemical aspects are concerned (see **Table 69.1**).

The next phase is the preparation of the extract in standardized conditions, which requires the steps described in **Table 69.2**.

Extracts prepared according to the criteria in **Tables 69.1** and **69.2** can be classified as standardized. Although some of these

Table 69.1. Raw material characteristics and preliminary analysis

Parameter	Action to control the parameter
Part of plant	Botanical identification, macro and microscopic analysis, control of sophisticant and contaminant presence
Harvesting	Careful selection and control of the region, area and harvesting period
Storage	Control of harvesting, drying and storage conditions
Active principle content	Chemical analysis in order to adequately mix different batches
Heavy metals and pesticides	Chemical analysis in order to discard the polluted batches

Table 69.2. Standardization and analysis

Parameter	Action to control the parameter
Extraction	Follow a defined method, with specified grinding, solvent, temperature, pressure
Concentration (if necessary)	Follow defined procedures, with analysis at the key steps of production
Chemical analysis	Control of the content in active principles, and of their reciprocal ratio; control of the presence of impurities, heavy metal, pesticides and residue solvents
Microbiologic analysis	Control of the microbial presence and of pathogen absence
Stability	Periodical analysis, in order to confirm the extract quality

parameters appear obvious, they can be difficult to achieve. For instance, all the botanical materials must be gathered within in a short, specific time period then stored after analysis to avoid the degradation of the active ingredients. In some cases, crops from homogeneous, genetically selected strains of plantules or seeds are grown in controlled agrochemical conditions. Cultivation can be a solution for plants whose harvesting in the wild could endanger the species' survival.

Safety Issues

From a safety standpoint, the quality of a botanical extract needs to be carefully evaluated both on the raw material itself and within the final formulation—whether it is intended as a topical or oral cosmetic.

Recent evaluations⁶ have in fact demonstrated that, besides labelling claims, only a small percentage of commercial products had chemical profiles that complied with their declared content. This research focused on the commercial preparation of bilberry extract purchased from different countries.

The HPLC method developed and validated in Indena research laboratories was optimized to analyze the content of anthocyanins, the polyphenols that bestow beneficial properties to bilberry extracts. (see **Figure 69.1**).



Figure 69.1. Case study: Bilberry

Bilberry: A Case Study

Chemical and pharmacological studies of bilberry extract have identified anthocyanosides, also known as anthocyanins, as the major components responsible for the biological properties of bilberry. They have been demonstrated to possess a broad range of activities, including: antioxidant activity,^{7,8} antiplatelet aggregation,⁹ phosphodiesterase inhibition,¹⁰ interaction with collagen, phospholipids and proteoglycans,¹¹ a relaxing effect on vascular smooth muscle,¹² and arteriolar vasomotion stimulation.¹³

Bilberry is exploited for its capacity of reinforcing the blood vessel wall: it strengthens capillary walls by linking with the endothelial cell membranes, thus increasing their resistance and reducing capillary permeability by stimulating the synthesis of perivascular tissue constituents. In topical applications, these properties are particularly useful in case of heavy legs or couperose, where microcirculation improvement and capillary tone are crucial to the relief of disorders.

According to Indena research,⁶ 40 different preparations containing bilberry, marketed under 24 different brands, were collected in four different countries for analysis. The samples came from the United States, Italy, Japan and Malaysia. The labels indicated three different types of preparations:

- bilberry extracts with a 36% anthocyanin content;
- bilberry extracts with a 25% anthocyanidin content; and
- bilberry extract without content indication.

The analytical work based on HPLC revealed that 25% of the tested products had a different profile from a typical bilberry profile of either an anthocyanins content at 36%, or anthocyanidin at 25%. In fact, 10% did not even contain the active anthocyanins molecules and only 15% were found to possess a sufficient quantity of anthocyanins to be effective, as proven by clinical trials.

The fact also emerged that only 65% of the tested commercial products sold in the United States contained a quantity of ingredients matching the label claim.

Regarding the issue of appropriate labelling, a recent review¹⁴ of the described analytical work highlighted some of the confusing information provided to the final consumer. For instance, the identity of the botanical species *Vaccinium myrtillus*, the only species with a sound tradition of medicinal use and well-documented by the scientific literature, is reported in 60% of labels, whereas the genus *Vaccinium* comprises over 450 species and the part of the plant is indicated on 70% of labels.

It needs to be taken into consideration that different parts of the same plant may have different biological properties. Bilberry leaves, for instance, have been traditionally used as a remedy for diabetes. This is not surprising since bilberry leaves, although they contain few anthocyanosides, are rich in tannins. The active ingredients are not defined on the labels, making it difficult for the consumer to understand the differences between the products. The quantity it contains in either milligrams or as a percentage concentration also is not listed.

Conclusions

Callaghan observed¹⁵ that when the cosmetic industry wants to demonstrate how supplements can benefit the skin, it needs to be innovative and address questions relating to safety, toxicity, bioavailability, molecule interactions that control biological function, and age-related physiology.

The commercial preparations that have been analyzed recently highlight differences in content and variations between labelling and actual concentration, revealing a scenario of the herbal preparations that require the development of reliable analytical methods to analyze finished formulations.

It is important for formulators to be aware of the different qualities of natural extracts that may, by all means, affect the quality of the final formulations.

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SECTION XV

Regulations

One of the most important changes in our industry in the last few years is REACH. REACH stands for the Registration, Evaluation and Authorization of Chemicals. REACH will create a single system for both existing and new chemicals. It applies to all synthetic and natural substances used in all products, including cosmetics. Based on the Directive of the European Parliament and Council on REACH, there will be no grandfathering of substances. The anticipated date for REACH to become law is April 2007. There will be a six-month window, from April 2008 through October 2008, for pre-registration of phase-in substances. Phase-in substances are defined by the directive on REACH as substances listed in the European Inventory of Existing Chemical Substances (EINECS) or that have EHR-Laboratory Interoperability and Connectivity Specification (ELINCS) numbers, as well as materials manufactured in the European Community at least once in the last 15 years but not placed on the EU market.

The implementation of REACH is one of the most significant developments if our industry in many years.

70 Getting Ready for REACH

71 (Re)Formulating within REACH with Formulating from First Principles

Getting Ready for REACH

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KEY WORDS: *REACH, imports to Europe, monitoring, ingredients, safety data*

ABSTRACT: *The author offers a summary and basic description of the new REACH program that will affect everyone in the personal care industry.*

REACH stands for the Registration, Evaluation and Authorization of CHemicals. It is a new legislation that has been introduced in Europe and is certain to touch everyone in the personal care industry who manufactures or sells raw materials or finished goods that are imported into Europe. European Union (EU) members agreed to institute these new regulations on December 13, 2005. According to the EU, the major objective of the REACH legislation is to cut occupational diseases and environmental issues through better monitoring of chemical products. This will require a new level of safety and ecological data on raw materials and ingredients used in finished formulations.

REACH will create a single system for both existing and new chemicals. It applies to all synthetic and natural substances used in all products, including cosmetics. Based on the Directive of the European Parliament and Council on REACH, there will be no grandfathering of substances. The anticipated date for REACH to become law is April 2007. There will be a six-month window, from April 2008 through October 2008, for pre-registration of *phase-in* substances. *Phase-in* substances are defined by the directive on REACH as substances listed in the European Inventory of Existing Chemical Substances (EINECS) or that have EHR-Laboratory

Interoperability and Connectivity Specification (ELINCS) numbers, as well as materials manufactured in the European Community at least once in the last 15 years but not placed on the EU market.

New substances that are not exempt, that do not have EINECS/ELINCS numbers, and are manufactured in amounts over one ton require full registration. Full registration will begin in April 2008. In November 2008, a list of pre-registered substances will be published and registration for phase-in substances will open. Deadline dates for the registration of phase-in substances, including safety and ecological data, will depend on the volume of the substance being manufactured or imported: April 2010 for substances over 1,000 tons; April 2013 for substances from 100 to 1,000 tons; and April 2018 for substances from 1 to 100 tons. If an ingredient is not pre-registered, it is considered a new substance and it will need to be registered as soon as possible.

If an ingredient has been pre-registered by someone else and a company plans to bring in that same substance, that company still has to register its material. The directive instructs the forming of a consortium among companies registering the same chemical to help share in the costs associated with the testing required.

The Basic Elements

The basic elements of REACH are as follows.

1. Registration requires manufacturers and importers of chemicals, in quantities of one ton or more, to submit a registration dossier to the authorities for each substance, which has to include relevant information such as human and environmental safety data on the substances, and to use that data to manage them safely. A registration dossier is to be submitted by each company registering a substance; thus, if there is more than one company manufacturing or importing a substance, there will be more than one registration dossier.

There are increased requirements on the dossiers based on the tonnage manufactured or imported into the EU for each chemical, based on the following thresholds: 1, 10, 100 and 1,000 tons.

The requirements also are modified by the expected classification, i.e., whether the substance is bioaccumulative or toxic in any way, and use pattern describing what industries it will be used in, such as food or cosmetics. The deadline for registration submissions also depends on the quantity and the classification of the substance.

Registration under the REACH legislation is for chemical substances only—not preparations such as mixtures of substances or finished formulas. However, every chemical used in a preparation or finished formulation that is imported into the EU needs to be registered. Chemical substances manufactured or imported in volumes of less than one ton do not need to be registered.

2. To reduce testing on vertebrate animals, data sharing is required for studies on such animals. A system currently is being established to help registrants find other registrants of the same substance with whom they can share data (a consortia). Pre-registrants of the same phase-in substance then are required to share animal test data and agree on the generation of new animal test data in a substance information exchange forum (SIEF).
3. Information about hazards and risks and how to manage them will be passed down and up the supply chain.
4. Downstream users such as industrial users of chemicals will be brought into the system. They will have to have full dossiers on all chemicals in their products that are being imported into the EU.
5. The aim of the *evaluation* portion of REACH is to prevent unnecessary testing by having authorities evaluate the testing proposals made by the industry to check compliance with the registration requirements; if a proposal is not in compliance, the authorities would then request additional information. This evaluation also enables authorities to investigate chemicals with potential risks by asking the industry for further information. The information could be used later to prepare proposals under restrictions, or for authorization.

6. Substances with properties of high concern will be made subject to authorization: applicants will have to demonstrate that the risks associated with the uses of these substances are adequately controlled. In this case, the commission will grant an authorization. The substances requiring authorization will include those that are: carcinogenic, mutagenic or reproductive toxins (CMRs) category 1 and 2; persistent, bioaccumulative and toxic (PBT) or very persistent and very bioaccumulative (vPvB); or identified as causing serious and irreversible effects on humans or the environment equivalent to those above on a case-by-case basis, such as endocrine disrupters.
7. Restrictions placed on substances will include a procedure to regulate the manufacture, placement on the market, or use of certain dangerous substances. Such substances either shall be subject to conditions of use or prohibited from sale. This is meant to act as a safety net to adequately control health and ecological risks.

Impact

Exporters of finished products to Europe will experience the impact of REACH in multiple ways:

- possible higher cost for chemicals used in finished formulations;
- reduction in the number of sources for supply of chemicals;
- loss of chemicals for commercial reasons, i.e., if the cost of registering the chemical outweighs the monetary return from the sale of that chemical;
- possible need to reformulate products;
- an additional cost for compliance if a company is manufacturing some of its own chemicals or if a supplier will not support a chemical that is needed,
- it could hinder innovation through the reduction of new materials being brought to market.

Preparing for REACH

Companies can take several actions in preparing for REACH:

- Learn about the legislation and establish a REACH team.
- Focus on pre-registration.
- Establish an inventory of cosmetic ingredients and break down preparations and imported finished products into their components; also, quantify the volume of each component (chemical) used in any imported mixture or finished product that will be placed on the market.
- Identify the CAS, ELINCS or EINECS number for each component.
- Classify components according to the dangerous substances directive, including environmental classification.
- Decide the ingredients that need to be registered, including any components used above one ton per year; determine who needs to register the component: an individual from the company; an EU manufacturer, importer or distributor; or an EU representative of the manufacturer.
- If a company is a downstream user, it has no registration obligations; however, companies that supply to the downstream user need to register. Downstream users must notify suppliers of ingredients that are used in cosmetics so they can indicate that information on their registration papers.
- Companies should check the REACH exclusions listed in Annexes IV and V, and keep the REACH inventory up-to-date. They also should make sure that new materials they are interested in using are REACH-compliant.
- Companies can begin talking to suppliers to establish commitments that they will support their materials for REACH. Many suppliers may decide to discontinue the manufacture of materials if the cost of conforming to the requirements of REACH outweighs the possible profits from the sale of that material. This decision could force companies to either find alternate suppliers or reformulate products to remove that chemical from the formula. It is important to remember: no registration, no market.

- Companies should prioritize ingredients; identify the ingredients most difficult to substitute and the materials that give products a unique selling point.
- Also, the available safety data for ingredients should be identified; it should be ensured that the appropriate testing has been performed based on the quantity of material used per year. The higher the use volume, the more testing required.
- Finally, it is most important for companies to talk to their suppliers. It should be made certain that suppliers understand the impact of REACH and the significance of their ingredients for products and ultimately their own business.

REACH is a big challenge for producers of cosmetic products. Becoming compliant can only be managed with well-organized in-house procedures and supplier contacts.

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For further reading, visit the following Web sites:

http://ec.europa.eu/enterprise/reach/index_en.htm (Accessed Nov 20, 2006)

http://europa.eu/index_en.htm (Accessed Nov 20, 2006)

<http://ecb.jrc.it/> (Accessed Nov 20, 2006)

(Re)Formulating within REACh with Formulating from First Principles

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KEY WORDS: *HLB, emulsifier selection, emollient selection, active, optimized stability, optimized delivery, optimized sensory*

ABSTRACT: *With new legislation in action such as REACh in Europe, most formulations will contain at least one ingredient that will need to be eliminated and hence these formulations need to be reformulated. The authors describe a fundamental approach to formulation science allowing reformulation within the shortest time frame possible, at minimal cost, while optimizing desired skin sensory attributes, skin delivery and physical stability.*

There are at least four basic requirements to every cosmetic formulation: it should be safe, physically stable, sensorially pleasing and efficacious—i.e., do what it promises to do. Before being allowed on the market, raw materials must be tested for safety and although there are differences in registration status between the various countries, one could argue that the safety of cosmetic ingredients is generally not an issue; otherwise, the ingredients should not even be on the market.

However, with the new Registration, Evaluation and Authorization of Chemicals (REACh) legislation coming into force in Europe, a substantial portion of the raw materials currently available to the

cosmetic formulator will be eliminated. This is because low profit margin raw materials will never earn the investment of safety testing back, so they will be taken off the market. The legislation only impacts products sold in Europe but since personal care is a global industry, the impact is felt globally and this issue of reformulation will therefore apply globally. This creates a need to reformulate cosmetic products quickly and efficiently at minimal cost.

Moving forward, this article assumes for the moment that the raw materials used are safe for human application.

Cosmetic emulsions should be physically stable, i.e., they should not coalesce or separate out. Stability is predominantly influenced by the surfactants of an emulsion. A simple method to aid in stabilizing emulsions is the hydrophile-lipophile balance (HLB) system of nonionic emulsifiers, invented by William C. Griffin in 1948. Every nonionic emulsifier has an oil-loving or lipophilic part, and a water-loving or hydrophilic part. The relationship or balance between the two is called the HLB. Numerically, HLB is the molecular weight percentage of the hydrophilic part of the nonionic surfactant divided by 5.

All nonionic surfactants have an HLB value. To be emulsified, insoluble materials have an HLB requirement.^{1,2} Matching the HLB value of the emulsifiers with the requirement of the insoluble materials will give good performance. For optimum packing around emulsion droplets, a pair of nonionic emulsifiers blended to meet the HLB requirement of the insoluble phase is preferred. Using this simple yet elegant system may speed up cosmetic product development considerably.

A third requirement of cosmetic formulations is to have the correct or appropriate sensory profile. This needs to be in line with the marketing concept and the expectations of the targeted consumer group. It is often easier to describe the feel of a cosmetic product in terms of what it should not be rather than what it should be. One of the reasons for this is that the cosmetic formulator and the marketer/consumer speak different sensory languages.³ Whereas sensory attributes used by the former are precise and defined, they are fluent and often intangible for the marketer and consumer. Moreover, being more a customer requirement than a strictly technical requirement,

sensory definitions and desired sensory profiles may actually change with time.

Considerable research has been performed throughout the last 30 years to create a more objective means of measuring sensory profiles⁴ but this has not produced easier ways to translate the desired sensory profile into a raw material selection for the cosmetic product developer. Some raw material suppliers have made progress in predicting skin feel; however, the solutions provided have been limited either to one particular attribute such as spreadability,⁵ or very general.⁶ A different approach is to use an R&D-based online formulation tool such as the one used by the authors^a that combines consumer research, formulation expertise and software algorithms to mathematically deliver specific sensory attributes into formulations. More details can be found in the literature.^{7,8}

Finally, products have to be efficacious and deliver the claimed functional benefits in a consumer-perceivable manner. Most of today's cosmetics contain active ingredients that deliver the claimed benefits; however, the extent to which they are efficacious depends not only on the intrinsic activity of the active ingredient, but also on the concentration of the active ingredients in reaching the desired site of action. After all, if an efficacious molecule does not reach its site of action, the efficacy is lost, which is just as useless as a nonefficacious molecule reaching the site of action.

Recently a method was developed⁹ to ensure the skin delivery of active ingredients. This "Formulating for Efficacy" concept utilizes the so-called relative polarity index (RPI) but the terminology has slightly changed since that time (see **Working with RPI sidebar**).

A primary emollient with a small RPI value is chosen—in which the active ingredient is very soluble—and mixed in the right proportions with a secondary emollient with a large RPI value—in which the solubility is low but the driving force for diffusion into the skin is high. The right ratio of these two carefully chosen emollients ensures that the skin delivery of the active ingredient is optimized and therefore maximal. This method showed that the choice of emollients determines the extent of skin penetration,⁹ whereas the choice of the emulsifier determines the rate of skin penetration.¹⁰

^a SenSelect is trademark of Croda Inc.

Working with RPI

The meaning of *RPI* has evolved since its conception in 2004,⁹ when it was nothing more than $^{10}\log P_{\text{oct/water}}$, the octanol/water partition coefficient of an active ingredient, an emollient or the stratum corneum. This concept has since been refined and a significant number of other factors that contribute to the polarity of a chemical in a medium have been added to the numerical value of something now called the PI or polarity index, of a chemical. This PI scale is no longer a logarithmical scale; it is a linear scale that allows differences to be calculated and directly compared.

The new RPI or the relative polarity index is now defined as the absolute difference in PI between an emollient and the active ingredient under study. An active ingredient will have high solubility in an emollient if its RPI for that combination is low and low solubility if its RPI is high. Absolute values of RPI are not important but relative values are.

The primary emollient with a low RPI and high solubility is the one in which the active ingredient is dissolved, ensuring that a sufficient quantity of molecules of the active ingredient is present in the final formulation. With the secondary emollient having a high RPI and low solubility, the driving force is increased for the active ingredient to leave the formulation and penetrate into the skin. The two then need to be mixed in the right proportion to obtain the optimal polarity of the formulation as described earlier.⁹

Rationale for Formulating from First Principles

Based on the above described methods, developing cosmetic products seems fairly simple since there are systems in place that, beginning with approved safe raw materials, ensure the creation of cosmetic products which are physically stable, skin sensory-optimized and clinically effective. Why, then, is formulating cosmetic products still so difficult?

As product improvements are made, INCI lists generally tend to grow longer, not shorter—after all, it is risky to remove ingredients while producing the next generation of a blockbuster since this could eliminate the reason why the product sold that well in the past. With increasing INCI lists also comes increasing unpredictability of potential interactions, increasing thickness of the product

information package (PIP), and increased production complexity, among others.

The Formulating from First Principles concept is based on understanding formulations rather than knowing tricks. Formulations are complex and involve hard sciences such as chemistry of raw materials and physical chemistry for stability and delivery, as well as softer sciences—i.e., sensory research and psychology to understand how a product should feel.

In the history of science there are sufficient examples of theories that aim to explain everything. Such theories are characterized by one common trait: they are all wrong. Formulating from First Principles is therefore not a theory that explains everything. It is, however, a concept based on the few things that have been measured and are understood, and are combined in a logical way so that formulators, irrespective of experience, can understand and use this to their own benefit.

What is “Formulating from First Principles”?

Traditionally, formulators begin with a stable emulsion system in which they have optimized the feel and subsequently drop in the active ingredient at a certain concentration to ensure that activity is obtained. This means the formulator first decides on the emulsifiers for stability, then adds the emollients to optimize the sensory attributes. Subsequently, no operational freedom is left when it comes down to the delivery aspects of the formulation.

In essence, Formulating from First Principles is nothing more than re-arranging the sequence of raw material selection. This change is based on the realization of what these ingredients do in formulations.

In earlier work¹¹ it was established that the emulsifier is influential in determining the feel of a formulation in the initial phase of the sensory experience—the appearance, pick-up and rub-in phase or APR phase. The influence of the emollient is more apparent in the after-feel phase of the sensory evaluation.¹¹

It is therefore the combination of the emollient and the emulsifier that determines the skin feel of a formulation. The stability of a

formulation is also determined by the combination of the emollient and the emulsifier, whereas the extent of delivery is determined by the emollients and the speed of delivery by the emulsifiers. This is the reason that in the Formulating from First Principles concept, the formulator first identifies which combinations of emollients and emulsifiers give the right skin feel and only works with those materials to subsequently optimize the delivery and stability. The more combinations of emollients and emulsifiers that give the right skin feel that are available, the higher the probability of success since it allows formulators more possibilities to optimize the skin delivery of active ingredients and the physical stability of the formulation.

Experienced formulators will immediately realize this generally is not the standard order of formulating. Formulating from First Principles first optimizes the sensory characteristics of a formulation, then the skin delivery characteristics and finally the physical stability. The best way to explain why this is done is to show by example:

Step one: Select emollient/emulsifier combinations: Each of the three steps that make up the Formulating from First Principles concept is characterized by an input and an output. The input here is the desired skin sensory profile of the formulation. Again, this can most easily be accomplished by using the R&D-based formulation tool mentioned previously^a.

An alternative to using such a tool would involve the arduous task of sensory analyzing hundreds of formulations and systematically changing emollients and emulsifiers. In the end, however, there still is no clear relation between choice of emollient or emulsifier,⁸ which is why using such a tool is considerably more efficient.

Using this tool, formulators can enter specific parameters for the system to retrieve ingredient suggestions. Say, for example, a formulator is creating a new anti-acne cream containing 0.5% salicylic acid that should of course not be oily (oiliness = very low), absorb well (absorbency = high), and spread well as it is applied over the face and possibly shoulder and chest area (spreadability = very high). In order to create a freshness perception, a high wetness is preferred but this should not be too much (wetness = high). To prevent an oily look, the gloss of the product should also be low.

The formulating tool plots the top 10 recommended combinations in a graph but for reasons of space constraints the suggested ingredients are listed here as text (see **Table 71.1**). The tool also ranks them according to the percent-compliance with parameters input by the formulator. Note that the formulation tool is trade-marked and suggests trade names supplied by only one company^a but it also provides the INCI names to system users; in this article only the INCI names are listed.

Table 71.1. Recommended emollient/emulsifier combinations

Emollient	Emulsifier(s)
Propylene glycol isostearate	Sorbitan stearate (and) sucrose cocoate
Pentaerythrityl tetraistearate	Sorbitan stearate (and) sorbityl laurate
Diisopropyl dimer dilinoleate	Sorbitan stearate (and) sorbityl laurate
Triethylhexanoin	Sorbitan stearate (and) sorbityl laurate
Glyceryl isostearate	Sucrose palmitate (and) glyceryl stearate (and) glyceryl stearate citrate (and) sucrose (and) xanthan gum
Mixture 7 (a mixture of emollients)	Sucrose palmitate (and) glyceryl stearate (and) glyceryl stearate citrate (and) sucrose (and) xanthan gum
Triethylhexanoin	Steareth-21 + steareth-2
Propylene glycol isostearate	Acrylates/C10-30 alkyl acrylate crosspolymer + polysorbate 80
Propylene glycol isostearate	Sorbitan stearate + polysorbate 60
Glyceryl isostearate	Sorbitan stearate + polysorbate 60

At the end of step one, the formulator does not yet make a decision but has eliminated those combinations of emollients and emulsifiers that do not have the right sensory profiles. In order to optimize the skin delivery of the active ingredient, in this case salicylic acid, the formulator needs to pay extra attention to those recommended emollient/emulsifier combinations that have the same emulsifier but different emollients. The greater the series of emollients that can be used with a single particular emulsifier or emulsifier system, the higher the probability of being able to

optimize the skin delivery of the active ingredient without losing the right skin feel. **Table 72.1** shows there are three such series of multiple emollients with a single emulsifier or emulsifier system:

1. Three emollients: Pentaerythrityl tetraistearate, diisopropyl dimer dilinoleate and triethylhexanoin; combined with the one emulsifier: Sorbitan stearate (and) sorbityl laurate;
2. Two emollients: Pentaerythrityl tetra-isostearate and glyceryl isostearate; combined with the one emulsifier combination: Sorbitan stearate + polysorbate 60; and
3. Two emollients: a mixture of emollients, referred to as Mixture 7, and glyceryl isostearate with the emulsifier sucrose palmitate (and) glyceryl stearate (and) glyceryl stearate citrate (and) sucrose (and) xanthan gum.

All these emollient/emulsifier combinations have the same sensory profile with respect to the five selected sensory attributes of absorbency, spreadability, wetness, oiliness and gloss. The reason for focusing on these same emulsifier/different emollient groupings is that the formulator can now begin making combinations of these emollients within each grouping while keeping the emulsifier the same without changing the skin sensory feel of the formulation.

In the following discussion, the authors chose to ignore the fact that this mixture of emollients called Mixture 7 can also be used since mixtures are significantly more difficult to explain and therefore not useful in an explanatory article such as this.

Step two: Selecting emollients to optimize delivery: During step one, the formulator has effectively reduced the number of emollient/emulsifier combinations to a small subsection that provides the correct skin feel and subsequently allows for the improvement of skin delivery.

The second step is focused on further limiting the number of possible emollients down to combinations of two emollients in which the active ingredient is very soluble in one and far less soluble—or even close to insoluble—in the other, as long as the two emollients do mix in any ratio. One therefore needs to assess the solubility of the active ingredient in the emollients that were identified in step

one; in this case, penta-erythrityl tetraistearate, diisopropyl dimer dilinoleate, triethylhexanoin and glyceryl isostearate.

Before moving on to this assessment, the formulator should understand why this difference in solubility is so important.

The clinical effect of a topically applied formulation depends on three different parameters. First, it depends on the intrinsic activity of the active ingredient; it is assumed here that the formulator already has an ingredient with the right efficacy profile.

The second parameter is the quantity of the active ingredient present in the formulation. Please note, this is not meant as the concentration, but as the *absolute* amount. There simply needs to be enough of the active ingredient present in the formulation to ensure that effective concentrations at the target site can be reached. This means that it is necessary to have a *high absolute* solubility of the active ingredient in the formulation.

The third requirement is to have a good driving force for diffusion of the active ingredient rapidly from the formulation into the skin. For this to happen, the solubility of the active ingredient in the stratum corneum (SC) should be higher than that in the formulation. What this means is that the active ingredient should be very soluble in the formulation but even more soluble in the SC. This also explains why chemicals with a polarity close to that of the SC generally penetrate the skin so well.

The easiest way to use this theory in a practical sense is to use a primary emollient in which the active ingredient is very soluble, and a secondary emollient in which it is not very soluble. This can be done experimentally, but also via algorithms using the previously described RPI of the Formulating for Efficacy concept.

Return now to the proposed anti-acne formulation containing salicylic acid. The emollients still available after optimizing the skin sensory aspects are pentaerythrityl tetraistearate, diisopropyl dimer dilinoleate, triethyl-hexanoin and glyceryl isostearate. The RPI values calculated for the combination of salicylic acid and these emollients are: 15.1, 14.4, 12.8 and 8.37, respectively. This immediately tells the formulator that the solubility of salicylic acid in glyceryl isostearate will be the highest of these four emollients because this combination of active ingredient and emollient has

the lowest RPI. This will therefore be the primary emollient. The secondary emollient should be one with a high RPI and therefore penta-erythrityl tetraisostearate was chosen as the secondary emollient as it is the one with the highest number (15.4).

The next step is for the formulator to measure the solubility of salicylic acid in the primary and secondary emollients. Salicylic acid was experimentally found to dissolve in glyceryl isostearate, the primary emollient, at 10%, whereas its solubility in pentaerythrityl tetra-isostearate, the secondary emollient, was lower as predicted by the RPI value and about 5%. Please note there are most likely emollients in which salicylic acid will be more soluble or less soluble than in the two selected here; however, using any other emollients would not give the desired skin sensory profile.

Finally, to optimize the skin efficacy of a formulation, the formulator must mix the primary and secondary emollients in the right proportions. This depends on the ultimate concentration of the active ingredient in the formulation and the o/w phase ratio. For this example, a 0.5% w/w salicylic acid concentration was chosen and the oil phase maintained at no more than 10% to prevent even a hint of oiliness—even though the sensory requirements have already ensured this characteristic. This means that the internal oil phase should have a concentration of salicylic acid of 5% ($0.5/10\% = 0.5/0.1 = 5$). The internal oil phase should therefore consist of solely secondary emollient since this emollient already contains the desired quantity of salicylic acid.

During step two, the formulator further reduced the number of suitable emollient choices. This also sometimes limits the number of emulsifiers, as in the salicylic acid example.

Step three: Selecting the emulsifier using efficacy requirements and HLB: As already indicated, a first step after having found the right emollient or combination of emollients to ensure effective delivery and right skin feel, is to select the right emulsifier. Ideally at this point, more than one emulsifier or emulsifier combination would be left since the ideal surfactant will fulfill two requirements. On one hand it stabilizes the emulsion, and on the other, it determines the rate of skin penetration. Admittedly, it also contributes to

skin feel but step one has already eliminated those emulsifiers that were not ideal for the desired skin feel.

Of the two requirements the surfactant should fulfill, the stability of the final formulation is, of course, the most important one. As stated, each phase to be dispersed has an HLB requirement, whereas each nonionic emulsifier or combination of nonionic emulsifiers offers an HLB value.

The first thing a formulator should do is to determine whether one of the remaining emulsifier choices is capable of matching the HLB requirement of the selected oil phase. If only one matches, that is the one to select. In reality, combinations of emulsifiers are used together so they can match almost every HLB requirement.

If there are still more emulsifiers or emulsifier combinations possible, then the required speed or extent of skin penetration may help the formulator to decide which one to select. Earlier work has shown that emulsifiers influence the speed of skin penetration. Liquid crystalline systems, for instance, are characterized by an increased penetration for hydrophilic active ingredients, and a faster penetration for lipophilic penetrants.¹¹ This is thought to be caused, in case of lipophilic active ingredients, by a transient shift of skin lipids from an orthorhombic to a hexagonal packing order. This shift reduces the barrier function of the SC, which leads to an increased skin penetration within the same period of time, therefore a faster penetration rate.

For hydrophilic active ingredients, the situation is somewhat different. Liquid crystalline emulsion structures do not lose their water as fast as normal emulsion structures do. As a consequence, water-soluble active ingredients remain solubilized longer and therefore can penetrate during a longer period of time. The speed of skin penetration is not affected, but the time span during which penetration takes place is extended, hence skin penetration is increased.¹¹

Formulators should opt for the emulsifier combination that best suits the formula requirements—whether increased or faster penetration with the use of liquid crystalline emulsifiers, or no increased or faster penetration with the use of normal emulsifiers. Much more work needs to be conducted in this field since the performance of many emulsifiers is yet undetermined.

Returning to the nearly completed anti-acne formulation, speed and extent of skin penetration decisions are not necessary because only one emulsifier combination choice is left, the sorbitan stearate/polysorbate combination. Because this is a combination of two emulsifiers, the ratio needs to be right between the two components to stabilize the oil phase.

With an HLB requirement of 12 for pentaerythrityl tetraisostearate determined by experimentation, the formulator now needs to find the optimal blend of nonionic emulsifiers to meet this HLB requirement to produce an o/w emulsion. This HLB requirement is independent of phase volume ratio. It does not matter whether the oil phase is 10% or 50% of the total emulsion, the HLB requirement remains the same.

Sorbitan stearate has an HLB value of 4.7, whereas polysorbate 60 has an HLB value of 14.9. When blended in a 30/70 ratio, the pair meets the HLB requirement of the pentaerythrityl tetraisostearate:

$$0.3 \times 4.7 + 0.7 \times 14.9 = 11.8 = \pm 12$$

Five percent total emulsifier is a good starting point. For this example, 1.5% sorbitan stearate and 3.5% polysorbate 60 will be the optimum. The ratio of low to high HLB emulsifiers will be the same regardless of total emulsifier use level. So if a study is performed to determine whether a lower level of emulsifier can be used while maintaining emulsion stability, the ratio will remain fixed. This ratio will also remain fixed regardless of whether the oil is added to the water or vice versa during preparation of the emulsion.

The Ideal Formulation

Through all this, the formulator finally has achieved an ideal formulation (see **Formula 71.1**). It is a formulation with the feel originally entered into the formulation tool^a; with an optimal delivery of the active ingredient, in this case salicylic acid; and formulation stability.

The most interesting aspect of this formula is that it was created purely on paper and computer, without going into the laboratory, although some solubility experiments may be required with novel

Formula 71.1. Anti-acne example formula

Salicylic acid	0.5%w/w
Pentaerythrityl tetraisostearate	9.5
Sorbitan stearate	1.5
Polysorbate 60	3.5
Glycerine	4.0
Xanthan gum	0.2
Magnesium aluminum silicate	0.2
Preservative	qs
Water (<i>aqua</i>)	qs to 100.00

active ingredients. Although it took quite some time to write it all down, when these authors set out to make this formulation as shown in **Formula 71.1**, they managed to get it in roughly 45 min—and right the first time. This is a rather radical novel way of making cosmetic formulations.

Summary

With REACh coming into action in 2007, there will be many cosmetic formulations that will need to be reformulated, ideally within the shortest time frame and using less active ingredient, yet more effective than the formulation being replaced and with the same feel. The described four-step method is based on the Formulating from First Principles concept.

Initially, emollient/emulsifier combinations are identified with a formulation tool^a that gives formulators ingredient choices with the desired skin feel attributes. In the second step, the number of emollients is reduced by choosing two emollients that will provide the desired skin feel in combination with the same emulsifier, yet have a high and low solubility for the active ingredient using the RPI concept. These two emollients are mixed in the right proportion using the Formulating for Efficacy formula that provides the ideal polarity of a topical formulation.

Once the oil phase is set, the formulator can choose the right emulsifier or emulsifier combinations to create a stable formulation using the HLB concept. If ingredient choices still remain, the formulator can further optimize the skin delivery of the active ingredient by selecting an emulsifier system that gives the desired speed and extent of skin penetration of active ingredient. Interestingly, this can all be done on paper so that the first attempt in the lab will be right the first time.

This will only be the base of a skin feel, skin delivery and stability-optimized formulation; however, thickeners, rheology modifiers, antimicrobial agents and perfume will then need to be added as necessary, albeit all in relatively small amounts since they may otherwise change the base formulation cleverly put together using first principles.

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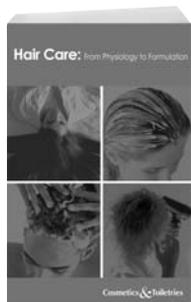
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