Anionic Interactions with Cationic Gemini Surfactants

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ABSTRACT: The objective of this paper is to expand the study of interactions between anionic and cationic surfactants to specific gemini surfactants and to investigate whether their interactions depend upon the linkage group between them.

Relatively few new classes of materials have come into existence since the first surfactant was formulated into a product. Recently, gemini surfactants have drawn increasing attention and commercial success. Originally, the term gemini surfactant was coined to describe a dual hydrophobic tail surfactant. It subsequently has been expanded and applied to a number of multiple-head surfactants. This article looks at some of the properties of gemini surfactants with differing flexibility of the linkage groups. These surfactants have been shown to exhibit superior properties in terms of wetting and emulsification at very low concentrations when compared to traditional surfactants.

The rigid gemini surfactant was the hardest of the series, showing a marked incompatibility with SLS.

Background

One of the many methods of dividing surfactants into groups is based on the charge on the organic portion of the molecule. According to this scheme, surfactants fit into one of the following classifications: anionic (negatively charged), cationic (positively charged), nonionic (without a charge), or amphoteric (positively and negatively charge)—see Surfactant Classifications. 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 make up a formulation. The functionality of the shampoo depends not only on the nature of each ingredient in the formulation, but also on the interactions between the ingredients. It is these interactions that provide, among other things, optimum detergency, foam, wetting and viscosity. The consumer's perception of the attributes given to a product makes for its success or failure on the market. Consequently, it is important for formulators to understand the interactions occurring between ingredients.

The interaction between anionic and cationic materials generally is understood. When stearidonium chloride and sodium lauryl sulfate are mixed together, a white, gunky paste results. The nature of this interaction, and the interaction of cationic and anionic surfactants, has been investigated in a previous article. In that work, hard and soft quats were defined. Hard quats were incompatible with anionic surfactants. Soft quats, on the other hand, were quats that formed thick, clear, high-foaming complexes with anionic surfactants. Differences also were found in the hardness of the anionic surfactants: sodium laureth-2-sulfate (SLES-2) was found to be more...
compatible with quats than sodium lauryl sulfate (SLS).

The objective of this paper is to expand the study of interactions to specific gemini surfactants and to investigate whether their interactions depend upon the linkage group between them.

**Gemini Surfactants**

Generally, conventional surfactants have one hydrophilic group and one hydrophobic group. However, a recent class of compounds having at least two hydrophobic groups and at least two hydrophilic groups has been introduced. This class has become known as the gemini surfactants, with much of the pioneering work carried out by M. Rosen, Ph.D. While there are earlier references to compounds having at least two hydrophilic groups and at least two hydrophobic groups, they were not referred to as gemini surfactants until 1993.3

Recently, B. S. Selkoe4 described gemini surfactants: "A gemini surfactant (GS) consists of two conventional surfactant molecules chemically bonded together by a spacer. The two terminal hydrocarbon tails can be short or long; the two polar head groups can be cationic, anionic or nonionic; the spacer can be short or long, flexible or rigid. The GS need not be symmetrically disposed about the center of the spacer. GSs can self-assemble at much lower concentrations and are superior in surface activity as compared to conventional surfactants. GSs are attractive for catalysis and adsorption applications, new synthetic vectors for gene transfection, analytical separations, solubilization processes, nanoscale technologies, biotechnologies, enhanced oil recovery and as paint additives."

The micellization behavior of gemini surfactants is qualitatively different from that of conventional surfactants. The lower critical micelle concentration (CMC) can be attributed directly to the increase in the number of hydrocarbon groups in the molecule. The CMC of gemini surfactants is a nonmonotous function of the number of spacer hydrocarbon groups, with a maximum value of approximately 4-6 polymethylene groups. Furthermore, in the case of ionic gemini surfactants, the spacer reduces the intermolecular repulsion between the head groups. This leads to micelle formation at low CMC values in gemini surfactants.

Gemini surfactants generally are superior to conventional surfactants in terms of surface activity. This is due to the distortion of the hydrophobic groups by water. Gemini surfactants are twin surfactants having symmetrical charges and hydrophobic groups linked by a so-called linkage group. The two hydrophobic groups in a single molecule are more disruptive than the individual chains in conventional surfactants. This property promotes the migration of micelles to the air/water interface.

Gemini surfactants also can be used in smaller quantities than conventional surfactants. Gemini surfactants have been found to be effective emulsifiers when used at very low concentrations. This superior detergency at lower concentrations has drawn increased interest in recent years.

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Understanding Gemini Surfactants

Common properties of both gemini and traditional surfactants were examined and compared. The specific gemini surfactants chosen for study included rigid-bridge gemini surfactants (Figure 1), flexible bridge gemini surfactants (Figure 2), and non-gemini surfactants (Figure 3).

One of the top interests in gemini surfactants is the alpha-omega (α-ω) arrangement of their hydrophobic groups and what this arrangement means at the surface of water.

A traditional surfactant will orientate itself at the surface of the water with the polar head in the water and the oil-soluble tail out of the water. The reason for this arrangement is to obtain a state of minimum free energy. With the surfactant so orientated, the minimum number of hydrogen bonds is distributed between water molecules and the lowest free energy is obtained.

Considering the gemini surfactant, the hydrophobic tails cannot simply rotate out of the water to obtain minimum free energy. In order for both hydrophobic tails to rotate out of the water to obtain minimum free energy, the molecule must at least bend into a hairpin configuration. This results in a significantly different aqueous solution than traditional surfactants. It also should be clear that as the bridge group becomes more and more flexible, the ease of obtaining a low-energy hairpin is increased.

Interest has grown in the interaction of cationic and amphoteric surfactants with anionic surfactants in aqueous solutions. The terms hard and soft quats have been proposed based on compatibility of the quat with anionic surfactants. Soft quats are soluble and form a gel with anionic surfactants at near stoichiometric concentrations. Gemini surfactants offer a new class of compounds to potentially improve solubility of the cationic/anionic complex. An additional aspect of such complex solubilization is the bridging group. The alteration of the bridging group used in gemini surfactants should have a dramatic impact upon the hardness of a gemini quat, as this paper will investigate.

Anionic Surfactants

The anionic surfactants studied were SLS (designated as S-1) and SLES-2 (designated as S-2). Their structures are shown in Figures 4 and 5, on page 59.

Foam Conclusions

The foam of the gemini surfactant by itself in water shows an interesting dependence upon structure. Table 1 and Figure 6, both on page 60, show the results of foam evaluation using the standard Ross Miles Foam test.

In the case of the cocompounds studied, the flexible bridge gemini surfactant had the highest foam of the series in both the 3- and 5-min time frame, despite lower initial foam. The non-gemini surfactant had the best initial foam in the cocom series. In the
case of the castor compounds studied, the glyceryl compound performed better than either gemini surfactant at all times studied.

**Anionic Compatibility**

A study of the compatibility of cationic materials and SLS and SLES-2 was conducted. The anionic compounds were diluted to 10% active with water. The cationic compounds were likewise cut to 10% active with water. In addition, 10% active quat was titrated to 100 g of 10% active anionic surfactant.

The viscosity was measured using a viscometer and spindle. During the addition of the quat to the SLS and SLES-2 the solution gels and thickens; after the mixture settles, the gel becomes softer.

**SLS Results**

Compatibility with SLS was independent of the alkyl group studied (see Table 2, on page 61, and Figure 7, on page 62). The rigid quat had the most incompatibility with SLS. The glyceryl (non-gemini) quat had the next best compatibility, and the flexible gemini was infinitely compatible. In other words, the rigid gemini surfactant was the hardest of the series, showing a marked incompatibility with SLS. The

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1 Brookfield Synco latex viscometer is a product of Brookfield Engineering Inc.
2 Brookfield Synco latex sphere 11 and 11’ are products of Brookfield Engineering Inc.
glyceryl compound was more polar and softer, thus more compatible with the SLES. The flexible gemini compounds were soft quats, compatible with SLES over a wide range.

**SLES-2 Results**

Compatibility with SLES-2 was independent of the alkyl group studied and similar to that observed with SLES (see Table 3 and Figure 8, both on page 63). The rigid quat had the most incompatibility with SLES-2. The glyceryl (non-gemini) quat had the next best compatibility, and the flexible gemini was infinitely compatible. In other words, the rigid gemini surfactant

![Table 1. Ross Miles foam data (in mm) @ 25.0 ± 0.2°C; 1% active quat](image)
was the hardest of the series, showing a marked incompatibility with SLES-2. The glyceryl compound was more polar and softer, i.e., more compatible with the SLES-2. The flexible gemini compounds were soft quats, compatible with SLES-2 over a wide range.

**Foam and Wetting Properties**

Table 4, on page 63, and Figure 9, on page 64, show Ross Miles foam data and Draves wetting data on quat titrations with SLS @ 1% active @ 25.0°C. The coco glyceryl quat was insoluble in SLS combination and provided no foam. It was a hard quat with SLS. The castor glyceryl material was softer and provided foam. Regardless of the alkyl group, the foam height followed the following order:

<table>
<thead>
<tr>
<th>Quat Combination Foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glyceryl &lt; Flexible &lt; Rigid</td>
</tr>
</tbody>
</table>

**Table 2. Quat interactions with SLS**

<table>
<thead>
<tr>
<th>SLS</th>
<th>Quat sample</th>
<th>Grams added to haze point</th>
<th>Viscosity @ 21.5°C</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coco HP (rigid)</td>
<td>43.5</td>
<td>155</td>
<td>Gel formed during addition</td>
</tr>
<tr>
<td>2</td>
<td>Coco PEG DHP (flex)</td>
<td>Soluble to a 1:1 ratio</td>
<td>44</td>
<td>No gel formed, no haze point</td>
</tr>
<tr>
<td>3</td>
<td>Coco Glyceryl (non-gemini)</td>
<td>83.0</td>
<td>50</td>
<td>Gel formed during addition</td>
</tr>
<tr>
<td>4</td>
<td>Castor HP (rigid)</td>
<td>30.9</td>
<td>775</td>
<td>Gel formed during addition</td>
</tr>
<tr>
<td>5</td>
<td>Castor PEG DHP (flex)</td>
<td>Soluble to a 1:1 ratio</td>
<td>35</td>
<td>No gel formed, no haze point</td>
</tr>
<tr>
<td>6</td>
<td>Castor Glyceryl (non-gemini)</td>
<td>91.3</td>
<td>75</td>
<td>Gel formed during addition</td>
</tr>
<tr>
<td>7</td>
<td>Coco/Castor PEG DHP (flex)</td>
<td>Soluble to a 1:1 ratio</td>
<td>64</td>
<td>No gel formed, no haze point</td>
</tr>
</tbody>
</table>

SLES-2 @ 1% active @ 25.0°C is shown in Table 5, on page 64, and Figure 10, on page 65. The coco glyceryl quat was insoluble enough in SLES-2 combination as to provide marginal foam, as opposed to no foam for the SLS. It was a hard quat, but the SLES-2 was a softer anionic than SLS. The combination was therefore somewhat more soluble and provided marginal foam. The castor glyceryl material was softer and...
provided foams. Regardless of the alkyl group, the foam height followed the following order:
  - Glyceryl < Flexible < Rigid

Wetting Results

The Draex wetting times were quite different for SLS and SLES-2 (see Figure 11, on page 66). The coco-glycerylquat had the longest wetting time by far in SLS, and the coco flexible quat had the longest wetting time in SLES-2.

General Conclusions

The surfactant properties of anionic and cationic materials are determined by interactions between the two. The complex that forms determines not only solubility in water, but also how the complex packs at the surface and ultimately the surfactant properties. Optimization of properties vis-à-vis foam, detergency, wetting and irritation likely will be an area of much activity in personal care as work is conducted to provide optimum performance in complex formulations.

Surfactant Literature

References

A literature review provides insight into the recent interest in Gemini surfactants. While the basic concept has been known for quite some time, it was in the 1990s that the interest grew in these surfactants. Recent pioneer work has been performed by a group of researchers, including Milton Rosen, David Tracy, Ruixin Li, Manish Dahamayake and Jiang Yang. This area of surfactant research will almost certainly enjoy

![Graph showing Quat interaction with SLS](image-url)

2. U.S. Patent Number 2,534,197, issued in 1950—Describes surfactants that are amionic and cationic in nature and are claimed to give good detergency and wetting properties.


4. U.S. Patent Number 3,855,196, issued in 1975—Describes surfactants that are amionic and cationic in nature and are claimed to give good detergency and wetting properties.

5. U.S. Patent Number 5,409,206 (Briggs) and EP 0,688,781, A1 (Adams)—Discloses a number of amionic gemini surfactant species in which the hydrophobic portion is comprised of a long-chain lower alkyl or alkenyl while the hydrophilic portion is comprised of an ethoxylate group. These materials are said to be outstanding detergents that give soil resistance to fabrics.

6. U.S. Patent Number 5,160,450, issued in 1992—While not using the term emulsion, this patent describes surfactants that have the necessary spacer units and the fatty tails. The invention describes surface-active agents, having two hydrophobic chains and two hydrophilic groups exhibiting properties suitable as emulsifiers, dispersants and solubilizing agents for use in the fields of industrial, cosmetic, domestic and medical goods.

7. U.S. Patent Number 5,534,197, issued in 1996—Describes gemini polyhydroxy fatty acid amides; describes gemini polyhydroxy fatty acid amide compounds and laundry, cleaning, fabric and personal care compositions.

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**Figure 8. Quat Interactions with SLES-2**

**Table 3. Quat interactions with SLES-2**

<table>
<thead>
<tr>
<th>SLES -2</th>
<th>Quat sample</th>
<th>Grams added to haze point</th>
<th>Viscosity @ 21.5°C</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coco HP (rigid)</td>
<td>85.7</td>
<td>230</td>
<td>Gel formed during addition</td>
</tr>
<tr>
<td>2</td>
<td>Coco PEG DHP (flex)</td>
<td>Soluble to a 1:1 ratio</td>
<td>320.5</td>
<td>Gel formed during addition, no haze point</td>
</tr>
<tr>
<td>3</td>
<td>Castor HP (rigid)</td>
<td>45.4</td>
<td>210</td>
<td>Gel formed during addition</td>
</tr>
<tr>
<td>4</td>
<td>Castor PEG DHP (flex)</td>
<td>Soluble to a 1:1 ratio</td>
<td>57</td>
<td>No gel formed, no haze point</td>
</tr>
<tr>
<td>5</td>
<td>Castor Glyceryl (non-gemini)</td>
<td>87.5</td>
<td>95</td>
<td>No gel formed during addition</td>
</tr>
<tr>
<td>6</td>
<td>Castor Glyceryl (non-gemini)</td>
<td>87.5</td>
<td>95</td>
<td>No gel formed during addition</td>
</tr>
<tr>
<td>7</td>
<td>Coco/Castor PEG DHP (flex)</td>
<td>Soluble to a 1:1 ratio</td>
<td>180</td>
<td>No gel formed, no haze point</td>
</tr>
</tbody>
</table>

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**Table 4. SLS Quat combination foam**

<table>
<thead>
<tr>
<th>Product</th>
<th>Immediate (mm)</th>
<th>1 min (mm)</th>
<th>5 min (mm)</th>
<th>Draves (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coco HP (rigid)</td>
<td>170</td>
<td>150</td>
<td>140</td>
<td>8.0</td>
</tr>
<tr>
<td>Coco PEG DHP (flex)</td>
<td>165</td>
<td>145</td>
<td>135</td>
<td>9.0</td>
</tr>
<tr>
<td>Coco Glyceryl (non-gemini)</td>
<td>155</td>
<td>130</td>
<td>125</td>
<td>6.6</td>
</tr>
<tr>
<td>Castor HP (rigid)</td>
<td>150</td>
<td>140</td>
<td>130</td>
<td>5.8</td>
</tr>
<tr>
<td>Castor PEG DHP (flex)</td>
<td>150</td>
<td>140</td>
<td>130</td>
<td>5.8</td>
</tr>
<tr>
<td>Castor Glyceryl (non-gemini)</td>
<td>155</td>
<td>130</td>
<td>125</td>
<td>4.4</td>
</tr>
<tr>
<td>Coco/Castor PEG DHP (flex)</td>
<td>165</td>
<td>145</td>
<td>140</td>
<td>3.97</td>
</tr>
</tbody>
</table>
comprising these compounds, and teaches a method for the preparation of a nonionic gemini surfactant wherein the hydrophilic head is a sugar or carbohydrate while the hydrophobic head is a long-chain alkyl, the two joined by a short alkyl chain.

8. U.S. Patent Number 5,585,516, issued in 1996—Describes two tail-two head and two tail-one head surfactants; discloses two tail-two head and two tail-one head surfactants including biphenolic hydrocarbon moieties.

9. A series of patents covering gemini surfactants assigned to Rhodia is important to this class of materials. These include:

U.S. Patent Number 5,811,384, issued in 1998—Disclosed nonionic gemini surfactants; discloses compounds that are very effective o/w emulsifiers. The inventors disclose:

"Because of their unusually high surface activity, coupled with their hydrophobicity and solubilization properties, compounds of this invention will provide exceptionally high performance properties at very low concentrations in practical applications such as detergency emulsification, solubilization, dispersancy, hydrotropism, foaming and wetting.

In addition, due to their extremely low monomer concentration at standard use levels and because of their extremely low CMC values, the use of lower concentrations of the compounds of the invention than conventional surfactants can provide extremely low or no irritation in personal care applications, as well as being nonionic, biodegradable and environmentally friendly."

U.S. Patent Number 5,846,926, issued in 1998—Discloses nonionic gemini surfactants with three hydrophilic heads and two lipophilic tails. The compounds have a critical micelle concentration that is very low, and is at 0.001 wt.%. The trimeric gemini surfactant is highly surface-active, even at very low concentrations. Tracy et al.

U.S. Patent Number 5,863,886, issued in 1999—Discloses nonionic gemini surfactants having multiple hydrophobic and hydrophilic sugar groups; discloses: "The molecular structure provides energetically favorable decreases in the free energy of adsorption and micellization through the favorable distortion

**Figure 9. SLS quat combination foam**

**Table 5. SLES-2 quat combination foam**

<table>
<thead>
<tr>
<th>Product</th>
<th>Immediate (mm)</th>
<th>1 min (mm)</th>
<th>5 min (mm)</th>
<th>Draves (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coco HP (rigid)</td>
<td>165</td>
<td>145</td>
<td>140</td>
<td>11.7</td>
</tr>
<tr>
<td>Coco PEG DHP (flex)</td>
<td>155</td>
<td>140</td>
<td>130</td>
<td>16.3</td>
</tr>
<tr>
<td>Coco Glyceryl (non-gemini)</td>
<td>No initial foam</td>
<td>10</td>
<td>7</td>
<td>8.6</td>
</tr>
<tr>
<td>Castor HP (rigid)</td>
<td>175</td>
<td>155</td>
<td>150</td>
<td>6.0</td>
</tr>
<tr>
<td>Castor PEG DHP (flex)</td>
<td>150</td>
<td>140</td>
<td>135</td>
<td>9.0</td>
</tr>
<tr>
<td>Castor Glyceryl (non-gemini)</td>
<td>150</td>
<td>130</td>
<td>130</td>
<td>3.4</td>
</tr>
<tr>
<td>Coco/Castor PEG DHP (flex)</td>
<td>160</td>
<td>140</td>
<td>135</td>
<td>5.3</td>
</tr>
</tbody>
</table>
of water structure, and at the same
time providing a close-packed
arrangement at the interface. This is
reflected by the relatively low surface
area per molecule that is unexpected
from the molecular dimensions for
the molecule. The area per molecule
for the compounds of the invention
is comparable to corresponding
conventional surfactants. The ability
of the compounds of the invention
to distort water structure through
inhibition of crystalline or liquid
crystalline phase formation in bulk
phase and at the same time to
pack closely on adsorption at the
interface is contrary to conventional
wisdom.”

This again demonstrates the
uniqueness of the molecular design
for these compounds, which is
critical to providing the unexpected
exceptional surface and performance
properties. The exceptional sur-
face activity and unique structural
features of the surfactants of the
present invention provide two other
important performance properties
that can have immense practical
application in industry. One is their
hydrophilicity, which is the ability
of organic substances to increase the
solubility of other insoluble organic
substances in water. Secondly is
their solubilization, or the ability
to dissolve water-insoluble organic
compounds into aqueous surfactant
solutions above their CMC levels.
The compounds of the invention,
because of their very low CMC
values, are efficient solubilizers. This
latter property will not only allow
the formulation of homogeneous
water-insoluble materials, but also
will enhance the surface activity of
other surfactants whose low water
solubility restricts their use. These
novel surfactants of the invention are
far better than comparable conven-
tional surfactants in hydrostroping
and solubilizing properties.

Regardless of the alkyl

group, the foam height
followed the following
order:

Glyceryl < Flexible < Rigid

Because of their unusually high
surface activity, coupled with their
hydrophilicity and solubilization
properties, compounds of this inven-
tion will provide exceptionally high
performance properties at very
low concentrations in practical
applications such as detergency emuls-
fication, solubilization, dispersancy,
hydrophilicity, foaming and wetting.
In addition, due to their extremely
low monomer concentration at stan-
dard use levels, and because of their
very low CMC values, the use of lower
concentrations of the compounds
can provide extremely low or no irritancy
in personal care applications, as well
as being nonionic, biodegradable and
environmentally friendly.

U.S. Patent Number 5,900,397, issued
in 1999—Discloses nonylphenol non-
ionic gemini surfactants; discloses:
“Novel nonylphenol nonionic gemini
surfactants are extremely effective
emulsifiers for oil emulsions that
provide improved detergency at even
low concentration levels.”

U.S. Patent Number 5,922,663, issued
in 1999—Discloses an enhance-
ment of soil release with gemini
surfactants; discloses a composition
comprising a conventional sur-
factant, a gemini surfactant and a
polymeric soil release agent. The
compositions are useful as surfactant
additive packages, detergents and
fabric softeners.

U.S. Patent Number 5,945,393,
issued in 1999—Discloses nonionic
geminisurfactants; discloses: "Novel nonionic geminisurfactants are extremely effective emulsifiers for o/w emulsions that provide improved detergency at even low concentration levels."

U.S. Patent Number 5,952,290, issued in 1999—Discloses anionic geminisurfactants and methods for their preparation; discloses: "a new, and improved class of anionic geminisurfactants consisting of two hydrophilic groups and two hydrophobic moieties joined by a bridge that possess improved surfactant functionalities yet may be characterized as mild for use in personal care products and environmentally benign."

U.S. Patent Number 6,204,297, issued in 2001—Discloses nonionic geminisurfactants; discloses: "Novel nonionic geminisurfactants are extremely effective emulsifiers for o/w emulsions that provide improved detergency at even low concentration levels."

10. U.S. Patent Number 6,334,271, issued in 2002—Discloses geminisurfactants in cleaning compositions; discloses: "Geminisurfactants, optionally in combination with ingredients customary in rinse aids, optionally with further nonionic surfactants and anionic surfactants, and to the use of the geminisurfactants for improving the wetting behavior in rinse aids."

U.S. Patent Number 6,777,384, issued in 2004—Discloses: "Gemini surfactants, optionally in combination with ingredients customary in laundry detergents, dishwashing detergents and cleaners, optionally with further nonionic surfactants and anionic surfactants, and to the use of such geminisurfactants for improving the wetting behavior and the compatibility with plastics, for the simplified preparation of solid cleaners and as foam-suppressing surfactant in rinse aid formulations."

U.S. Patent Number 6,794,345, issued in 2004—Discloses: "Gemini surfactants, optionally in combination with ingredients customary in dishwashing detergents and cleaners, optionally with further nonionic surfactants and anionic surfactants, and to the use of such geminisurfactants for improving the wetting behavior and the compatibility with plastics, for the simplified preparation of solid cleaners and as foam-suppressing surfactant in rinse aid formulations."

U.S. Patent Number 6,797,687, issued in 2004—Discloses: Gemini surfactants are "useful as components in laundry detergents, dishwashing detergents and cleaners, and for improving the wetting behavior on various surfaces."

U.S. Patent Number 6,805,141, issued in 2004—Discloses mixtures of geminisurfactants and
fatty alcohol alkoxylates in rinse agents.

U.S. Patent Number 6,982,078, issued in 2006—Discloses a novel class of polymeric gemini compounds having specific quaternized amine based upon a dimer acid amido amine quaternary compound. The materials are substantive to human skin and are well-tolerated by human tissue, making them suitable for use preparation of barrier products for personal care applications.

**Gemini Surfactant Literature**

**References**

A number of gemini surfactants are reported in the literature:

1. Zhu et al, J of the Amer Oil Chem Soc (JAOCS) 68 7,539—Teaches the preparation and properties of bis(sulfonate) amphipathic compounds with three long-chain alkyl groups. The compounds were prepared by reacting n-acetyldiethanolamine diglycidylethers with long-chain fatty alcohols. These triple-chain surfactants are asserted to be soluble in water and exhibit superior micelle formation and surface active properties than conventional single-chain surfactants. (1991)

2. Zhu et al, JAOCS 69 7,626—Discloses the preparation and properties of glycerol-derived double or triple-chain surfactants with two hydrophilic ionic groups. The ionic groups are comprised of sulfate, sulfonate and carboxylate groups, and the surfactants allegedly exhibit superior surface active properties such as micelle formation and the ability to lower surface tension as opposed to conventional single- and even double-chain surfactants. (1992)

3. Gao et al, JAOCS 71 7,771—Investigates the dynamic surface tensions of a number of surfactants, some being gemini surfactants with three hydrophobic chains. It is asserted that the apparent diffusion coefficient decreases with an increase in the number of alkyl chains and the resulting bulkiness of the surfactant molecule. (1994)

**Acknowledgement:**

The evaluation of properties was conducted by Laura Anderson, a chemistry major at Rollins College, Orlando, Fla., USA.

**References**

Send e-mail to author Tony O’Lenick at tolenick@mindspring.com.

4. BS Spikman, Gemini (dimeric) surfactants: the two-faced molecules, Resonance 40-49 (Mar 2004)

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