Surfactants are molecules that possess surface-active properties. In other words, they are capable of changing the surface tension of the aqueous solution in which they are dissolved.

Their surface activity is a direct consequence of the amphiphilic properties of the surfactant molecule’s chemical structure. In this structure, one end of the molecule is hydrophobic (or water-fearing) and the other end is hydrophilic (or water-loving). As a result, when surfactant is added to an aqueous solution, the surfactant molecules partition themselves on the surface of the solution with the hydrophilic part of the surfactant solvated in the aqueous phase and the hydrophobic part exposed to air. By so doing, the surface tension of the aqueous solution is lowered.

As more surfactant molecules are added to the solution, a so-called critical micelle concentration (CMC) is reached at which point the surfactant molecules aggregate to form micelles. In the simplest form, the hydrophobic ends of surfactant molecules pack the center core of the micelles, with the hydrophilic part of the surfactants forming the “shell” of the aggregates. The ability to form micelles is important to the surfactants’ detergency and solubilization properties desired in many applications. These properties allow the surfactant to remove dirt and grease from the soiled articles.

Many microorganisms synthesize compounds with structures that fit the description of an amphiphilic molecule. The majority of these biomolecules indeed possess surface active properties and are therefore referred to as biosurfactants. These microbial biosurfactants generally fall into one of three chemical classes: glycolipids, lipopolysaccharides, and cyclic lipopeptides. Examples of a few most widely studied microbial biosurfactants are shown in Table 1.

In comparison to the petrochemical and biobased surfactants and detergents (i.e., synthetic chemical surfactants), the microbial biosurfactants often possess additional functionalities, such as antimicrobial activity and metal chelating capability. Furthermore, these biosurfactants are produced from microbial fermentation of renewable feedstocks, and are biodegradable and generally non-ecotoxic. These properties have made microbial biosurfactants more desirable from an environmental standpoint and more appropriate for certain specialty uses.

**Microbial biosurfactants have many uses**

Microbial biosurfactants have been investigated for a myriad of food and non-food applications covering fields as wide ranging as enhanced bioremediation (use of biological organisms such as plants and microbes to aid in the removal of hazardous substances from contaminated soil), improved oil recovery, food thickeners, herbicide and pesticide preparation, consumer and household products manufacturing, and lubricant production. Articles and patents abound describing these varied uses of microbial biosurfactants.

Large-volume commercial markets for these materials, however, have not yet fully developed. Apparently the markets still await further improvement in the cost and performance factors of these biosurfactants. Nevertheless, projections for the market penetration of biosurfactants are guardedly optimistic. One projection places the numbers at 8-25% (depending on the application) of detergent market being captured by biosurfactants by year 2010.

Among the many microbially produced biosurfactants known to date, the four microbial products shown in Table 1 have been most studied for their applications. Thus, emulsan, a polyanionic hetropolysaccharide having acyl chains esterified to the sugar moieties, has exceptionally good emulsifying property and has been targeted by the U.S. Army Natick Soldier Center at Natick, Massachusetts for use as aqueous-based, biodegradable degreasing agent and detergent, to be used in their formulation of environmentally friendly cleaning solution and degreasers to remove oil and grease deposited on military equipment stored at various Army depots. In the medical field, emulsan has also been shown to have adjuvant activity. Adjuvants are used to increase the potency of vaccines.

The high emulsifying capacity of emulsan has also made it a favorable bio-based ingredient to use in the formulation of various cosmetic and personal care products. One of the marketers of emulsan is Gelsenkirchen-based Spinrad GmbH, a German retailer specializing in selling natural products including cosmetics and detergents. The material is sold under the trade name of Emulsan II for use as water/oil emulsifying agent in cosmetic creams and lotions; it purportedly possesses skin-maintaining function by providing moisture and protection to the skin.

**Surfactin**

Surfactin is another microbial biosurfactant attracting a high interest for various applications. It is a cyclic oligopeptide with an acyl chain esterified to one of the amino acid residue. This class of cyclic lipopeptide compounds not only possesses surface active properties, but often also has a high level of antimicrobial activity. As with many microbial metabolites, one of the limitations of surfactin commercialization is its low production yield. Showa Denko K.K. at Chiba, Japan claims to have developed an improved production process that allows for commercial-scale production of surfactin, and has marketed the product under the trade name of Aminofect. The company markets the product as a non-irritating surfactant for cosmetic applications, such as creams, milky lotions and cleaning agents.

**Table 1. The four most widely studied microbial biosurfactants**

<table>
<thead>
<tr>
<th>Chemical Class</th>
<th>Surfactant Producing Organism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lipopolysaccharide Emulsan</td>
<td>Acinetobacter calcoaceticus RAG-1</td>
</tr>
<tr>
<td>Cyclic lipopeptide Surfactin</td>
<td>Bacillus species</td>
</tr>
<tr>
<td>Glycolipid Rhamnolipid</td>
<td>Pseudomonas species</td>
</tr>
<tr>
<td>Sophorolipid Candida species</td>
<td>Rhodotorula bogoriensis</td>
</tr>
</tbody>
</table>
also reports that surfactin’s high surface activity allows minimal use of the material in a formulation to achieve high emulsification stability and dispersion.

Aside from cosmetics, another area of application of surfactin is in the improved oil recovery (IOR) field. It is attractive for such application because of its broad-range tolerance to pH and salt concentration, and of its low toxicity. Surfactin enables enhanced oil recovery by reducing the interfacial tension between oil and water interfaces and by changing the wettability index of the rock matrix in which the oil is lodged. With this application in mind, the Idaho National Laboratory at Idaho Falls, Idaho developed a bioprocess to produce surfactin from potato process effluent using Bacillus subtilis to contain costs of production.

Rhamnolipids

Rhamnolipids (RL) have also found applications in the IOR field. A patent (U.S. Patent 5,866,376) describes a process using RL to achieve enhanced oil recovery from storage tank and oil field. The process employs either the crude culture broth of RL-producing Pseudomonas aeruginosa or the acid-precipitated, resolubilized RL to reduce viscosity of crude oil for the purpose of enhanced oil recovery. The patent claimed that the process effectively reduces the viscosity of viscous crude oil from 10,000–500,000 centipoise (cp) to only 100–500 cp at 25°C. This should aid improved recovery of oil from, for example, oil tankers which typically lose 5% (as much as 12 tons) of oil from the original load. The inventors claimed that RL is desired in this kind of application because it is less foamy, low in toxicity, easier to dissolve and biodegradable, and does not require the use of toxic organic solvents for its formulation.

Another exciting market for RL is in the manufacture of the high value, large volume printing inks for inkjet applications. Patents abound describing the use of RL as one of the ingredients for the formulation of inks for the high speed inkjet printing. In inkjet printing, speed is critical. The ultimate goal is to achieve the speed of a laserjet without compromising the quality of the print. The surface tension of the ink mixture is important in controlling the permeability of the ink onto printing paper and thus the print quality. When the surface tension is less than 20 mN/m, the ink tends to penetrate into the recording paper, causing a reduction in image density and blur of characters. If the surface tension exceeds 35 mN/m, on the other hand, the ink fails to penetrate the recording paper enough to give proper drying and thus it is not preferred for high-speed printing. Patents by Tokyo, Japan-based companies Fuji Xerox Co., Ltd. and Ricoh Co., Ltd. as well as others have described the use of RL as a biosurfactant for use in the formulation of their ink mixtures, to fine tune their surface tension.

Rhamnolipid has also received U.S. Environmental Protection Agency’s (EPA) approval for use as liquid contact biofungicide in agricultural, horticultural and turf settings against zoosporic plant pathogens such as downy mildews, Pythium and Phytophthora. Jeneil Biosurfactant, Inc. at Saukville, Wisconsin is the beneficiary of the
EPA approval, and has marketed the biofungicide under the trade name of ZONIX Biofungicide.

The company also developed its RECO product line used to clean and recover oils from storage tanks. Various grades of RL are also marketed by the company for use in applications as wide ranging as cosmetics and shampoo (as emulsifier), asphalt and concrete (as surface bonding agent), leather tanning and dyeing (as wetting agent), and bioremediation processes to treat oil and heavy metal (e.g., cadmium) contamination.

As a surface active agent capable of disrupting biomembranes, RL has also been patented for use to enhance permeabilization of lactic acid bacteria for the purpose of removing lactose in foods. Lactose is a component of dairy products that causes digestive-tract problems in lactose-intolerant populace. The membrane permeabilization process essentially transforms the bacterial cells into microcarriers where beta-galactosidase enzyme (responsible for breaking down the lactose molecules) inside the cells is now freely accessible to the infused substrate molecules.

Sophorolipids

Sophorolipids (SL) are another class of emerging microbial biosurfactant with a great potential for large-scale commercialization. The most attractive feature of this product is its high volumetric yields achievable through fermentation of renewable feedstocks by Candida bombicola. Like RL, sophorolipids have been studied for a wide range of applications. The most important use of SL is in the cosmetics industry. Aside from biosurfactant properties, SL possesses interesting biological activities for formulating high value products. For example, the use of SL to stimulate the metabolism of skin fibroblast cells (resulting in the neogenesis of collagen) has been described in an issued patent (U.S. Patent 6,596,265). This property is apparently valuable for the formulation of skincare products. In another application, SL in combination with a fruit acid, such as citric acid, lactic acid and tartaric acid, is formulated into a germicidal solution suitable for cleaning fruits, vegetables, skin and hair by rapidly lysing microbes (E. coli, Salmonella and Shigella) attached to the objects. It is the combination of SL’s skin-cell stimulating property and antimicrobial activity (e.g., Corynebacterium xerosis and Propionibacterium acne Propionibacterium acne) that has made it especially attractive for use in therapeutic cosmetics applications. It is for this specialty chemicals market that SL is produced and sold under the trade name of Sopholiance by Groupie Soliance of Colombes and Pommacle, France. In the consumer product category, SL in combination with another nonionic surfactant has been incorporated into a laundry detergent composition.

Future applications

Although this article has showcased a variety of applications of microbial biosurfactants exemplified by emulsan, surfactin, rhamnolipids and sophorolipids, the list is by no means exhaustive. Furthermore, as the price of these surfactants becomes more competitive, their properties further improved, and their additional novel activities discovered, many more applications will undoubtedly be developed.

Continued R&D efforts to use renewable feedstocks and low cost byproduct streams from agricultural and industrial sources and processes for the production of these biosurfactants are heading in the right direction to help reduce the production costs. However, production yields (including the turn-around time) and downstream processes to purify the products need improvement to further help lower the production costs. With regard to improvement of properties, further in vitro modification of the microbial products to generate the next generation compounds should be explored, much like the way the pharmaceutical industry improves on its products. When these goals are achieved, the immense potentials of these microbial biosurfactants can then be fully realized.

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Recommended background reading on microbial surfactants: