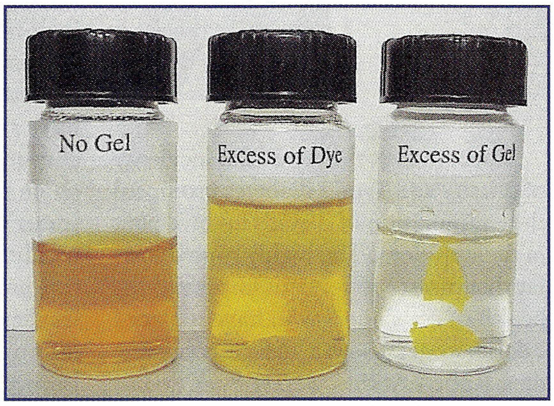
Special uses of surfactants

By Lynn Crandall

Workers at the more than 35,000 dry cleaning companies across the United States know the hazards of traditional dry-cleaning solutions. They deal with the pungent odor and try to ignore the U.S. Environmental Protection Agency (EPA) statistics that indicate the chemical they work with, perchloroethylene (perc), is a toxic waste and a probable human carcinogen. But from his research laboratory at the University of North Carolina, Chapel Hill, Joseph M. De Simone has taken the "toxic" out of the industry, cleaning up the dry-cleaning business through the development of surfactants for use with carbon dioxide. He is one of many researchers exploring ways to utilize surfactants in innovative ways.

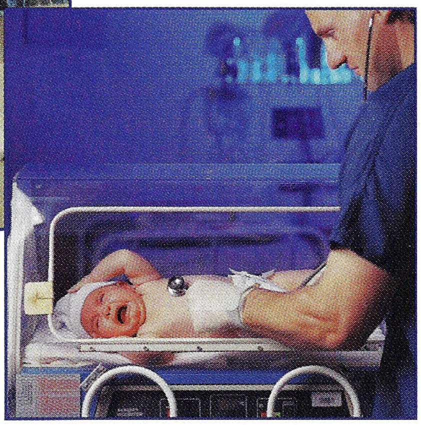


Steve Kline has developed a macroscopic micellar gel that will absorb oils and contaminants like a micelle but then turn them into a gel that can be easily removed, which is an aid in wastewater cleanup.

Comprised of molecules containing both hydrophobic (water-hating) and hydrophilic (water-loving) ends, surface active agents, commonly known as surfactants, are substances that affect the surface forces between two interfaces, said Paul Sosis of Sosis Consulting Services of Oakland, New Jersey, who has worked with surfactants in the laundry industry for more than 25 years.

"Surfactants' functional chemistry is what makes them useful for reducing the interfacial forces. Their functional chemistry is related to the ionic charges and the hydrophilic and hydrophobic aspects of the molecule," Sosis said. "Cell walls retain integrity because of surface tension. Many times the reason a soap or detergent kills bacteria is because it reduces those forces around the cell wall and the bacteria implode. Laundry detergents and household cleaners are the largest applications for the workhorse surfactants, but the world is replete with applications where surface-active forces are at work and where a wide variety of surfactants prove useful. From cleaning and dissolving to providing lubrication and uniformity, surfactants are in literally thousands of applications in products globally."

It is surfactants' versatility that has researchers like De Simone turning to them for solutions to various environmental concerns.



Surfactants clean up nasty business

"The solvent perc has a lot of health issues associated with it. It is a groundwater contaminant, and it is linked with cancer in workers and customers," De Simone said.

Through a research program funded by the National Science Foundation and the U.S. EPA, De Simone's team of researchers developed the first surfactants capable of working in conjunction with CO_2, and in 1996, commercialized pollution-free dry-cleaning technology with Micell Technologies in Raleigh, North Carolina. Today Micell's technology is used in 60 dry cleaners in the U.S., called Hangers Cleaners, that process clothes with a system of liquid CO_2 as the solvent and specialty surfactants. The Hangers Cleaners process requires less heat (because CO_2 is a gas and therefore easier to remove than the liquid solvent), is gentler on clothing, and leaves clothes with a pleasant fragrance. Although the process requires dry cleaners to purchase new equipment, De Simone said the advantages outweigh the up-front costs.

Surfactants clean up foul water

Surfactants are also helping researchers find better ways to clean groundwater contaminated by industrial solvents.

Disposed of in trenches and pits during the 1940s through the 1970s, the chlorinated solvents were expected to evaporate. But because they have a low viscosity, low vapor pressure, and a specific gravity greater than one, these solvents sink into the ground, penetrating the subsurface all the way down to the impermeable layer at the base of the aquifer, where they pool. As the groundwater flows through the aquifer and over the pool of solvent, it becomes contaminated through dissolution. Contaminated plumes can travel miles out from the aquifer, creating an enormous volume of contaminated water from even relatively small pools of solvent.

The conventional method used to remediate contaminated groundwater relies on pumping out the contaminated water, treating it, and injecting uncontaminated water back into the aquifer. The high rate of pumping with this pump-and-treat method overcomes the tendency of the groundwater flow to carry the contaminant off-site, thereby stopping the migration of the contaminated plume. However, the process doesn't remove the pollutant pool, just the solvent that has been dissolved, so it's expected to take hundreds or thousands of years to completely remediate the aquifer.

Jeff Harwell, professor of chemical engineering at the University of Oklahoma, and his colleagues have developed a surfactant system technology that improves on the conventional aquifer remediation method.

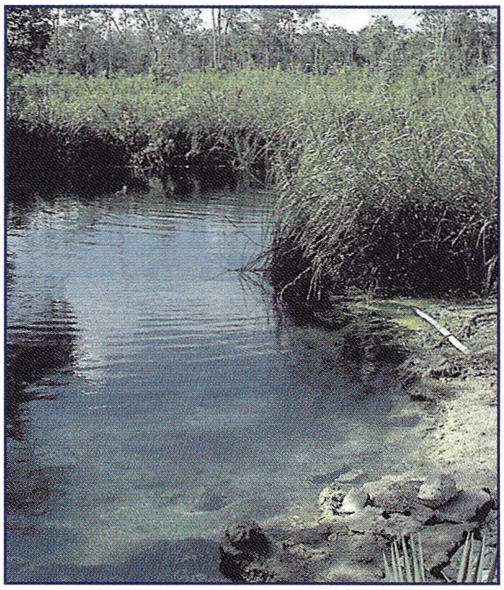
"We saw the opportunity to apply surfactants to a particularly intractable environmental remediation problem. It is very difficult, very expensive to deal with those drinking water aquifers contaminated by industrial solvents," Harwell said. "Because of the ability of surfactants to create ultralow interfacial tensions that could release solvent from the pore structure of the aquifer, we saw a unique, economical solution to a very serious problem."

His group's technology involves injecting a surfactant solution into the aquifer to dissolve the contaminant and then pumping it out. Because the surfactants lower the interfacial tension between the solvent and water, Harwell can design a surfactant system so that the interfacial tension becomes low enough to eliminate the forces that trap the solvent in the aquifer. Delivering the surfactant to the contaminated zone and capturing it offers the advantage of fully remediating the aquifer to drinking water status—rather than just containing the solvent—in a matter of months.

Now commercialized through Surbec-ART Environmental of Norman, Oklahoma, the technology is still proving itself but has been used successfully to remediate several pilot and field demonstration sites, including the site of a former gasoline station and a contaminated site at the U.S. Naval Air Station in Alameda, California.

"We're being able to do this with off-the-shelf, commercial surfactants. . . . If you have to have custom-made surfactants, it gets really difficult to be able to afford the process," Harwell said. "In 10 years, the surfactant-based remediation system will be widespread and probably a $100 million-a-year industry."

Surfactants developed by Steve Kline, an instrument scientist at the National Institute of Standards and Technology in Gaithersburg, Maryland, are also being put to work in new ways for cleaning water. By polymerizing and cross-linking micelles (colloidal aggregates of surfactant molecules) to create a macroscopic micellar gel, Kline said he is developing a new class of materials that could go in any direction but may be particularly adaptable to wastewater cleanup.



"Micelles solubilize oily things. Once you have the oil solubilized in the micelle, you can't easily separate the micelle from the water. They're too small, so you can't filter them out. You can't centrifuge them out. But I've made a gigantic cross-linked micelle that you can make as big as you want; not the tens of angstroms that a normal micelle is, but centimeters in size. So it will absorb oils and contaminants like a micelle but you can actually reach in and pick up these pieces of gel," Kline said.

Kline's micelle gel material could be functionalized to recognize different chemicals in solution and may turn out to be a basic recipe for numerous applications.

Surfactants contribute to micromachine technology

A futuristic vision materializing into today's technology, nanoengineering is being used to explore ways of assembling the basic ingredients of life—atoms and molecules—into nanostructures that promise to change the world for the better with new materials. Scientists see surfactants playing a pivotal role in that technology.

"We're very interested in using the phase behavior of surfactants for generating self-assembling nanosystems," said Harwell of his work at the University of Oklahoma.

De Simone and his research team have moved on with the CO_2-based cleaning processes to focus on commercializing a process for cleaning 200- and 300-

millimeter size silicon wafers used to make integrated circuits in the microelectronics industry. The CO_2-based technology utilizes specially formulated surfactants that reduce the numerous steps needed in wet cleaning. The new technology will reduce water and solvent effluent and the accompanying costs, health concerns, and regulations. By converting to dry processing, De Simone said microelectronics manufacturers could improve product quality.

"The structures of an integrated circuit are in the nanometer scale. Water has a very high surface tension and actually can be damaging to tiny structures. The CO_2-based system can eliminate that problem," he said.

Although nanotechnology is an emerging field, scientists around the world expect it to change how many things are made, from recording media and vaccines to computers and airplanes.

Surfactants save lives, eliminate pain, and hold promise of cures

Special uses of surfactants are offering researchers solutions for medical challenges.

Infant mortality rates have substantially dropped since the introduction of products that mimic the surface-active properties of human lung surfactant. Current products for use with respiratory distress syndrome (RDS) in premature infants include Infasurf (calfactant), developed by ONY Inc., Amherst, New York; and Surfaxin (lucinactant), invented at the Scripps Research Institute, LaJolla, California, and developed by Discovery Laboratories, Doylestown, Pennsylvania.

Human lung surfactant is a lipid and protein film lining the air sacs, called alveoli, inside the lungs. During expiration the film lowers surface tension to near zero, preventing lung collapse so oxygen and carbon dioxide exchange between blood and air is continuous, not tidal. Human surfactant synthesis does not turn on until approximately 36 weeks *in utero*, so babies born prematurely lack the surfactant necessary to breathe and suffer from RDS.

"RDS used to be the leading cause of death in premature babies," said Dr. Edmund Egan, professor of pediatrics and physiology at State University of New York, Buffalo, and president of ONY Inc., which recovers lung surfactant from inside the lungs of slaughtered calves to make Infasurf. "But with surfactant replacement therapy and effective respiratory therapy, deaths from RDS are now quite rare."

While animal-based surfactant replacements contain varying amounts of the most important surfactant protein, protein B, Surfaxin is the first synthetic peptide-based complete surfactant that mimics protein B. It is in Phase III clinical trial for RDS in premature infants. Surfaxin offers a potential for wider accessibility than animal-derived surfactant because it would not be limited by production or pose the potential to transmit disease, said Deni M. Zodda, senior vice president, business and commercial development, of Discovery Laboratories. The company is looking to develop therapies for additional respiratory applications, including meconium aspiration syndrome (MAS) in full-term babies and acute lung injury/acute respiratory distress syndrome (ALI/ARDS) in adults.

MAS is a respiratory problem resulting when a baby inhales amniotic fluid contaminated with meconium, a baby's first bowel movement, and suffers degradation of natural lung surfactant, resulting in respiratory distress and potentially chronic respiratory and neurological problems.

ALI/ARDS occurs as a result of inflammation of the lungs associated with direct or indirect causes, such as pneumonia or sepsis, and is a leading cause of death in the developed world.

"There is no approved therapy for MAS and ALI/ARDS patients today. The basic standard of care for these patients is to put them on a ventilator and give them supportive therapies," Zodda said. "But their lung function is compromised and it is the compromising of lung function that leads to further problems in the patient."

Zodda expects Discovery to launch Surfaxin for treatment of babies with RDS in 2004; approved treatment for MAS, currently in Phase III trials, will begin later. Discovery is in Phase II clinical trials for ALI/ARDS treatment.

Pumactant/Alec, developed by Britannia Pharmaceuticals Ltd., Redhill, Surrey, United Kingdom, was originally developed as a treatment for RDS in premature babies, but that use was discontinued. It has since been reformulated as a dry powder and is showing potential for use in asthma relief and, under the brand name AdSurf, prevents the formation of surgical adhesions.

Pumactant is a mixture of two naturally occurring phospholipids—dipalmitoylphosphatidylcholine (DPPC) and phosphatidyl glycerol (PG). Britannia presented results in May of a Phase II clinical study indicating therapeutic results in protecting against allergen-induced irritation that leads to the inflammatory process of asthma.

"There are obviously a lot of asthma therapies available, but they all work 'below the line' in terms of bronchial surface. Either they relax smooth muscle directly, or they modify the inflammatory process following the trigger from the inhaled allergen. But nothing works 'above the line' in terms of protecting against the first direct insult of the allergen or whatever stimulates a bronchoconstrictor response," said Derek Woodcock, Britannia's technical services director. "So what is exciting is that protection of the airways with Pumactant could ultimately reduce the need for other therapies, such as steroids."

Clinical trials for Britannia's AdSurf promise better medicine for the many surgical patients who suffer from postsurgical adhesions, especially in the delicate abdominal area.

Surgery to cut adhesions and repair damage is the conventional treatment, but in up to 80% of cases the adhesions regrow.

AdSurf is applied as a powder that melts just below normal body temperature, coating the internal surface tissue and assisting the body's mechanism to regenerate surfactant. It also disperses beyond the immediate area of trauma into areas that aren't suspected of damage, enhancing better overall healing.

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"It has been known for some time that the body produces phospholipids which act as boundary lubricants. Where you have two surfaces in contact, these phospholipids play a role to prevent spontaneous adhesions from forming," Woodcock said. "What we're doing is trying to restore dysfunctional, damaged boundary lubricant through applying relatively large amounts of a synthetic form of surfactant. After surgery, over 90% of people are likely to get adhesions, but only around 5% will actually go on to develop problems. But the problem is you don't know who is going to be in the 5%. So if you've got something that is able to address that . . . you prevent a lot of people from getting those problems."

Britannia expects to have final results in early 2003 from its Phase III clinical trials utilizing AdSurf for adhesions.

Scientists from five research groups and three European countries belonging to the European Network on Gemini Surfactants (ENGEMS) have collaborated to create novel gemini surfactants as synthetic vectors (carrier systems) designed to produce new vehicles for delivering both drugs and DNA. The long-term aim is gene therapy, said A.J. Kirby, professor of bio-organic chemistry at the University of Cambridge, United Kingdom, to replace defective or missing genes in patients suffering from diseases such as cystic fibrosis. The compounds offer possible costs and safety advantages over commonly used gene transfer vectors based on viruses, as well as greater carrier capacity.

"There is great interest in gene therapy. There have been isolated successes, using deactivated viruses, but these present possible problems," Kirby said. "The idea that you could effect the same success with a clean, synthetic system is very interesting. Our compounds are cationic surfactants, so they're rather good at complexing with anionic DNA. Of course, this is all building on work that has been done before. What is special about ENGEMS is that we're using these twin structures: They are known to have superior surfactant properties and turn out to be particularly good at transfection, too. The combination of the polycationic structure and the lipophilic element in the same molecule is evidently a key."

Long term, the scientists expect to develop the compounds to target specific cells with recognition elements.

"I think it's an important development in medicine, but it's still in the early days of it," Kirby said.

Lynn Crandall is a freelance writer based in Ludlow, Illinois.