A doctoral associate measures the diffusion coefficient of particles in solution, which in turn, can give information about the particle size.

The Interdisciplinary Approach to Surface Science

By Claudia M. Caruana, Associate Editor

A New York ophthalmologist inserts an intraocular lens made of *polymehyl methacrylate polymer* (Plexiglas) into the lens cavity of a patient whose cataract she has just removed. She is particularly concerned that the plastic lens *will not stick* to the surrounding tissue or corneal surface. Otherwise, the tissue could be damaged while the eye is healing.

In recent years, medical researchers have created a *viscoelastic gel* (e.g. sodium hyalyronate) extracted from rooster combs, which ophthalmologists can insert in the cataract-removed eye for 24 hours to coat the lens. But a viscoelastic gel made from rooster combs is expensive, costing more than $800,000 a kilogram. Can other viscoelastic gels be made that would be equally as effective, safe, and less costly?

Oil prices are expected to rise in the next several years, and petroleum engineers need to increase the oil recovered from existing wells. To do this, they have experimented with a variety of flooding processes, using several methods to extract the oil remaining in the well. Emulsions are created in these processes, which make it difficult to remove the remaining oil. Will using different porous media change the economics of the process?

Although the disciplines that researchers confront in these two cases appear unrelated, the solutions to both problems require an understanding of surface phenomena. "And it is this unlikely relationship," Dr. Dinesh O. Shah, director of the Center for Surface Science and Engineering at the Univ. of Florida at Gainesville, points out, "that makes the interdisciplinary study of physics, biology, and chemistry of surfaces so crucial."

Thus, it came as no surprise that Shah, an AIChE member and professor of chemical engineering, anesthesiology, and biophysics proved instrumental in the formation of a research facility that would make the interdisciplinary study of surfaces a top priority.

That facility, the Center for Surface Science and Engineering, was established in

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Graduate student works on flow dynamic visualization by use of TiO_2 smoke.

January, 1985 by Florida's Board of Regents. At present, there are 23 faculty members drawn from the Colleges of Agriculture, Arts & Sciences, Engineering, Medicine, Pharmacy, and Veterinary Medicine with terminal degrees in areas as diverse as chemical engineering, medicine, physics, cell science, food engineering, materials science, soil science, and comparative and experimental pathology.

A total of 75 doctoral students and post doctoral associates are at the Center, which now has approximately $5 million in grants from private industry, foundations, and the federal government. Future fund-raising efforts will be directed toward industry membership in the Center.

Students here have undergraduate degrees in engineering and the basic sciences. Shah explains, however, that although students focus their course work on interdisciplinary study and research projects, graduate degrees are granted in specific disciplines such as chemical engineering, mechanical engineering, materials science, biology, chemistry, and physics.

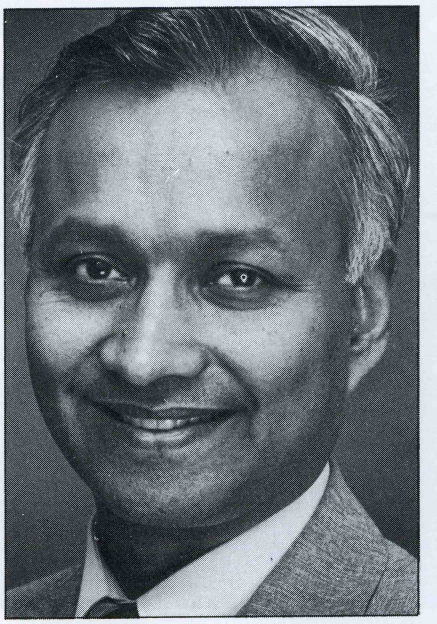
Currently, research work is carried out in laboratories in other university buildings of the various schools. Typically, faculty members work with students on several research projects concurrently.

"The domain of surface science is perhaps one of the most interdisciplinary areas of modern science and technology," Shah emphasizes. He believes that the synergistic approach to engineering and a unified knowledge of biology, physics, and the chemistry of surfaces "lead to a cross fertilization of ideas and provide new solutions to complex research problems. For example, when testing which wetting solutions might be best for contact lens wearers, it can be helpful if one exchanges ideas with other researchers at the Center who may be studying permeability, polymer adsorption, biolubrication, or microemulsions."

Shah is quick to point out the engineering applications of surface science ranging from agricultural sprays to oil recovery and such areas as catalysis, coatings, dispersions, electronics, flotation of minerals, and lubrication.

But it does not end there. In the biomedical area, Shah adds, "Surface science can contribute to the study of artificial implants, biomembranes, lipoproteins, lung surfactants, and ophthalmology."

Shah acknowledges that several surface science centers have been established at American universities in recent years. But it is the interdisciplinary approach to surfaces at Florida, and its diversified faculty from the various disciplines and professional schools, which distinguishes it from the others, he maintains. The Univ. of Florida at Gainesville is one of the three universities in the United States (Ohio State Univ. and the Univ. of Minnesota are the other two) that has the greatest number of academic and professional disciplines located on one campus.



Dr. Dinesh O. Shah

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Interdisciplinary approach

A top priority at the Center, according to Shah, is to become a major interdisciplinary organization that joins academic research with emerging technology.

"The knowledge of chemistry and physics of surfaces has taken great strides in the past three decades," he says, noting that the Center has five major goals:

- Development of a framework of theoretical and experimental knowledge related to surface science and its engineering and biomedical applications;
- Promotion of interdisciplinary research involving surface chemistry, surface physics, and biomedical surface science;
- Development and availability of both undergraduate and graduate courses, seminars, and symposia in the areas of surface science and engineering;
- Education of future scientists and engineers with an in-depth understanding of surface phenomena; and
- Continuation of advanced research in surface science and engineering with support from federal agencies, private industries, and foundations.

Recent research

Shah emphasizes that basic research can be costly for individual companies, and the use of a university facility and graduate students has many benefits in addition to the obvious financial one. "True, with graduate students we can usually do a project for one-fifth the cost of an industrial in-house operation. But using an interdisciplinary center like ours has a special benefit: It allows for a multidisciplinary approach that might not be possible in-house. For the graduate students and postdoctoral associates, there is the benefit of their working on projects they will see in the industry setting. And for the company, they are able to see qualified talent that they may want to hire."

To highlight current research at the Center, this spring Shah initiated an annual two-day review of surface science and engineering and a tour of the state-of-the-art laboratories for industry researchers.

"Through such a program, we let our faculty and students discuss their accomplishments. Industry researchers see the variety of problems academic researchers have on their agenda. They also will see the quality of our graduate students, which might lead to their being hired at some later date," Shah explains.

"The academic/industry relationship also benefits graduate students because they will be better prepared to meet the demands of industry research. It is our hope that the cooperation between academic researchers and industry will contribute to emerging technologies and to the education and training of the next generation of researchers in surface science and related areas."

Like other academic/industry collaborations, research contracted at the Center belongs to the Univ. of Florida. Exclusive

or nonexclusive licensing agreements, however, permit the applications of the research to be used by the sponsoring companies or organizations.

Beginning this fall, the Center will sponsor a four-day short course on surface science for industrial researchers who want to learn more about its interdisciplinary aspects.

At the May research review, which was attended by more than 40 industrial leaders from U.S. and international companies, there was an interchange of ideas focusing on industry's needs and goals on specific problems. Also discussed were the professional qualities industry research leaders sought in new recruits.

A sample of the variety of research discussed at this conference included:

- Dr. David E. Clark, a professor in the Dept. of Materials Science and Engineering, is studying the chemical durability of glass with respect to nuclear waste disposal and coatings on various substrates prepared using the sol-gel method. With financial support from General Motors, 3M Co., and Du Pont's Savannah River Laboratory, he is investigating the large inventory of nuclear wastes stored worldwide, particularly, those related to the defense industry. These, he points out, accounted for approximately 40 million gallons of nuclear waste stored at Du Pont's Savannah River Plant near Aiken, S.C. These wastes will be encapsulated in a borosilicate glass matrix starting in 1990 and eventually buried in a stable geologic repository. Clark's research has shown that the leaching mechanism is a surface-related phenomenon and the rate of leaching is *highly dependent* on the surface films that form during exposure.

According to Clark, ceramic coatings have a wide range of potential applications, ranging from thermal barriers on superalloys to oxidation barriers on composites.

"My research group is focusing on the sol-gel (chemical) method where the solution is a hydrolyzed alkoxide. Ceramic coatings can be deposited onto both metal and ceramic substrates using this method. To date, we have deposited ZrO_2, Al_2O_3, SiO_2, and various combinations of these with SiC whiskers, such as composite coatings."

- Shah and research associates M.J. Hou, R. Leung, H.K. Lee, and K. Kumar are studying the phase behavior and solubilization characteristics of microemulsions. Using quasi-elastic light scattering measurements, the group has established that "interaction between droplets is an important factor in determining the solubilization capabilities of microemulsions." The results from quasi-elastic light scattering measurements, "provide an apparent diffusion coefficient. Using the Stokes-Einstein equation, the hydrodynamic radius of the particle can be calculated from this apparent diffusion coefficient."

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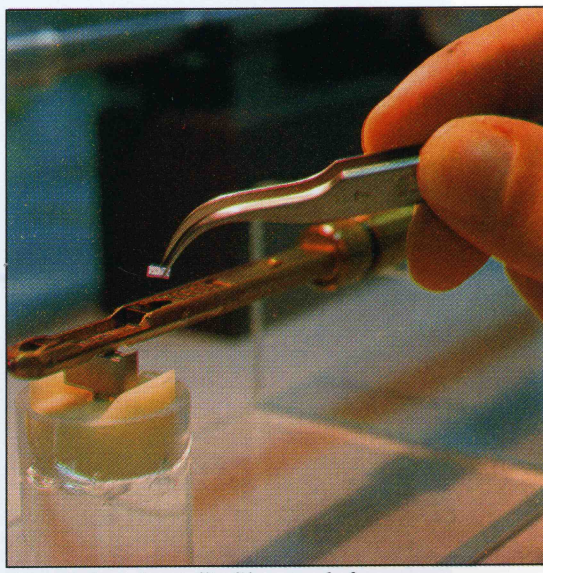
The group also has shown that as one exceeds the solubilization limit in a microemulsion, the nature of the excess phase can provide an insight into the factors controlling the phase separation process. In a water-in-oil microemulsion, for example, if excess water separates out, it suggest *rigidity* of the interface as a *controlling factor.* If, on the other hand, the separated phase is *excess oil* in equilibrium with water-in-oil emulsions, the phase separation is dominated by the inter-droplet attraction in the microemulsion phase. In the latter case, increasing the rigidity of the interface decreases the inter-droplet attraction, and, hence, increases the solubilization of the microemulsion.

- These researchers also have studies enhanced oil recovery, using modified polymer flooding with a submicellar concentration of surfactant. According to Shah, research shows that a low surfactant concentration solution ($< 0.1\%$ concentration) exhibits "a fairly low interfacial tension in the presence of added polymers in the aqueous phase."

The research group proposed that the molecular mechanism responsible for the ultralow interfacial tension involves the "excluded-volume effect." Since both surfactants and polymers are negatively charged, "we do not expect a Coulombic attraction between them." A patent application has been filed by the Univ. of Florida for a modified polymer flooding process.



Preparation of metallic film sample for examination by an electron scanning microscope. © 1987, Ron Franklin, Univ. of Florida at Gainesville.

- In the area of biolubrication, Shah and his associates have shown that surface phenomena, such as spreading of Meibomian oil (secreted by the eyelid) at the air/tear interface, the kinetics of thinning of the tear film, the rate of evaporation of water from the tear film and lubrication of corneal surface and the eyelid are pertinent to the normal blinking process.

Shah's research has proposed that the degree of comfort during blinking one's eyes is related to the frictional forces encountered during the sliding process. The instillation of eyedrops containing polymer molecules is believed to reduce the coefficient of friction and enhance the degree of comfort during blinking.

According to the research team, the polymers present in the eyedrops can improve the lubrication by several mechanisms, including the polymer adsorption at the cornea/tear and eyelid/tear interface, or by increasing the thickness of the boundary layer of the aqueous solution in contact with the cornea. They also have been able to measure the coefficient of friction of various polymer solutions and rank the various polymers according to their coefficient of friction.

At present, Shah and his associates have a technique to delineate at a molecular level the adsorption and desorption of polymer molecules on contact lens surfaces. Further research is designed to correlate the structure of the polymer with its adsorption, desorption, and lubrication characteristics.

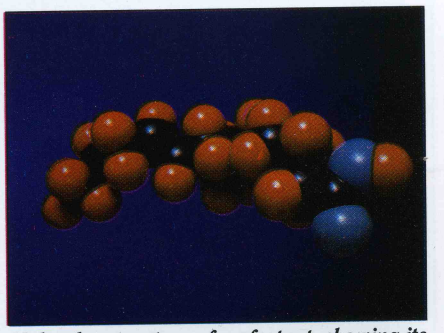
In addition to continued research on "dry eye" in older adults and better wetting solutions for contact lens wearers, Shah and his colleagues are studying several viscoelastic gels for intraocular lens implants for individuals who have cataracts removed.

Academic achievements

The 49-year-old Shah received his undergraduate training in biophysics at the Univ. of Bombay and completed doctoral work in biophysics in 1965 at Columbia Univ., working in the Surface Chemistry Laboratory of the late professor J.H. Schulman, a pioneer in surface and colloid science.

After earning his doctorate degree, he was awarded a NRC-NASA Resident Research Associateship to conduct research on chemical evolution and origin of life at the NASA Ames Research Laboratory. Later, he moved to the Biological Oceanography Division of Columbia Univ. and investigated dispersion of oil spills, retardation of evaporation, and wave damping by thin films of surface active agents.

In 1970, Shah joined the Univ. of Florida as an assistant professor and continued his research in the areas of monomolecular films, foams, wettability and contact angle, microemulsions, liquid crystals, improved oil recovery, combustion of coal dispersions in oil and aqueous media, surfactant-polymer interactions, boundary lubrication and surface phenomena in magnetic media, membranes, lungs, vision, and anesthesia. From 1975 until 1980, he organized, managed, and directed a multidisciplinary research program on enhanced oil recovery, with a budget of more than $1.6 million. He also organized the Univ. of Florida's Microemulsion Research Program supported by the National Science Foundation and a consortium of industrial companies.



Molecular structure of surfactant, showing its polar and non-polar parts. © 1987, David Blankenship, Univ. of Florida at Gainesville.

Internationally recognized as a leading researcher in surface chemistry and colloid science, Shah has written more than 125 research papers, technical articles, and several books on the surface chemical aspects of chemical, biomedical, and petroleum engineering systems. But despite his heavy commitment to research on surface chemistry and colloid science, Shah has never lost sight of his responsibilities to students in the classroom.

In 1972, he received Standard Oil of Indiana Foundation's Excellence in Teaching Award at the Univ. of Florida. He also was the recipient of the President's Scholar Award in 1975, and received the outstanding service award of the College of Engineering in 1976. Two years ago, he received the Univ. of Florida's highest honor, the Teacher/Scholar of the Year Award and the President's Medallion for Excellence in Teaching and Scholarship.

Shah was responsible for the introduction of an undergraduate and two graduate courses on interfacial phenomena in the chemical engineering curriculum which "continues to attract not only students from chemical engineering but also from other engineering and basic science departments." In previous years, he has taught graduate courses on membrane biophysics, biochemical engineering, and enhanced oil recovery processes.

Currently, he supervises various biomedical and chemical engineering research projects with 10 post-doctoral associates and graduate students and teaches two graduate courses on interfacial phenomena.

Although Shah acknowledges he could do other things with his career, "I want to be an academic all my life. The interaction I have with the students and my colleagues is important to me. I learn from my students as they learn from me. It is both gratifying and satisfying." ■

Research in Progress

Below is a list of the research projects underway at the Center for Surface Science and Engineering:

Chemicals and Minerals—Flotation of minerals, boundary lubrication, foam and detergency, macro and micro emulsions; liquid crystals and phase transitions; kinetic properties of micelles; formation of ultrafine particles and crystal growth; monomolecular films and organized molecular assemblies (L-B films); surface chemistry of composite materials.

Energy—Enhanced oil recovery processes by polymer, microemulsions and foam flooding; catalysis; photochemical reactions and solar energy; combustion and rheology of coal-water, coal-oil slurries; alternate fuels (e.g., methanol and gasoline mixtures); heat transfer by microstructured fluids.

Environment—Adsorption of virus and bacteria to clays and minerals; coagulation; flocculation and precipitation processes in waste water treatment; adsorption, desorption, and transport of chemicals in air, water and soil; retardation of evaporation of water from lakes and reservoirs by monolayers.

Agriculture and Food Technology—Agricultural sprays; herbicides and fungicides; adsorption, desorption and transport of chemicals in soil; food emulsions and gels; wetting and dispersion of food powders; surface phenomena in food processing and preservation.

Information Display and Storage—Surface phenomena in magnetic media; rheology of pigment dispersion; surface phenomena in coating processes; thin films and microelectronics; surface phenomena in reprography; paper-toner interactions.

Pharmaceuticals and Biotechnology—Microemulsions and multiple emulsions for drug delivery; controlled release of drugs and microencapsulation; tear substitutes for contact lens solutions; rheology and surface properties of gels for intraocular lenses; biological and model membranes; virus-filter and virus-cell interactions; lung surfactant and alveolar stability; lipoproteins; proteins; metabolism and lipid protein interactions; bioactive materials for implants; skin interactions with cosmetics and perfumes; fermentation and separation processes.