Basu. "We can also easily adapt this process to coating long tubes."

Simulations Reveal Morphological Transition in Simple Foams

By deriving an equation of state for compressible foam and then simulating it numerically, researchers at the University of Illinois predict a dramatic morphological change that will occur as the surface tension is increased or, equivalently, the volume of the foam is greatly expanded. Foams are ubiquitous in nature and widely used in industry, from foamy foods such as bread and ice cream to foamy materials such as plant stems, bones, magma, and foam rubber. All foams have one characteristic in common: The bubble-delimiting films minimize surface energy by encapsulating the largest volume while using the least amount of material.

Hassan Aref, professor and head of the Theoretical and Applied Mechanics Department, said, "In a common liquid foam, like a soap froth, the elastic energy in the films is negligible compared with the work required to compress the air in the bubbles. The individual bubbles, which are often of roughly comparable size, retain constant volumes, except for the slow redistribution of gas by diffusion or the rupturing of films between bubbles. If you imagine greatly enhancing the surface tension, however, the elastic energy in the films will compress most of the bubbles, leading to a very different structure."

To investigate this phenomenon, Aref and graduate student Dmitri Vainchtein first derived the equation of state for compressible foam. "This equation shows that foam with a free boundary will expand to a maximum volume if the external pressure is lowered at constant temperature," Aref said. "The equation also suggests that the same foam—when enclosed in a container—can be expanded further but will become unstable at a certain volume that we can predict."

Though difficult to explore experimentally, as reported in the December 1999 issue of *Physics of Fluids*, the nature of the instability was revealed in a series of numerical simulations. Aref said, "We observed what may be described as two 'phases' of foam. In one phase, we have a large number of small bubbles clustered together. In the other phase, we must then have a small number of much larger bubbles that occupy most of the space in the container."

The increased surface tension appears to compress most of the bubbles, forcing the remaining bubbles to expand to fill the space, Aref said. This phenomenon might provide a model for the undesirable formation of large voids in solidifying foams, including those that form when baking bread. "As bread is baked, the bubble membranes begin to harden, which may roughly correspond to an increase in surface tension," Aref said. "The resulting segregation instability results in a loaf that contains clusters of tiny bubbles embedded in a background of a few much larger bubbles."

Carbon Nanotubes Exhibit Tensile Strength of 63 GPa

Researchers at Washington University in St. Louis have found that 63 GPa is the highest tensile-strength value of the outermost shell of a single nanotube. In an experiment performed by Rodney S. Ruoff, associate professor of physics, and his research group, individual multiwalled carbon nanotubes (MWCNT)—rolled sheets of graphite—were picked up, positioned, and firmly attached on a nanometer length scale, and tested with tension until broken.

As reported in the January 28 issue of *Science*, MWCNTs break with what Ruoff refers to as a "sword-in-sheath" mecha-

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