Questions in Fluid Mechanics:
Understanding Foams and Foaming

By D. D. Joseph

Foams are common, complex, and not well understood. Most of the common foams are a two-phase medium of gas and liquid with a particular structure consisting of gas pockets trapped in a network of thin liquid films and Plateau borders. Some of the well known foams are bubble baths, dishwater detergent foams, and the foam head on beer. Technologies impacted by foaming are widespread. Foams can be useful, from shampoos to the placement of sand in cracks in oil fields to increase secondary oil recovery. But foams can be undesirable in many chemical applications such as the high-temperature cracking of hydrocarbon oils, and unsightly downstream of paper mills. Foams are very hard to control. All foams are unstable, but some are more unstable than others, a subject in which our understanding is far from complete.

What are the conditions required to create and maintain foams?

A foam cannot form in a pure liquid; surfactants are required. Foams are thermodynamically unstable; when left to rest they collapse. To create a foam it is necessary to introduce gas at a rate faster than the collapse rate of bubbles. The rates required to create foams depend on the foaming mixture and the means by which the gas is introduced. In dishwater the gas is stirred in by a water jet, in soda water an abrupt drop in pressure causes rising gas bubbles to foam, and foaming bubble reactors, in which gas and surfactant in water are continuously injected, will foam only when the gas velocity crosses a critical threshold for a fixed liquid velocity (1). A general theory giving critical conditions for foam formation observed in practice has yet to be given.

Where is the foam?

Foaming systems segregate under gravity, foam above and bubbly liquid below. The foam in foaming bubble reactors is created at a mysterious phase change interface between the foam and bubbly mixture across which the topology, gas fraction and velocities are sharply discontinuous. Foam fractions can be reduced to zero by increasing the liquid or decreasing the gas velocity to values below the foam threshold. The factors controlling the formation and position of such an interface are unknown. Even the interface below a head of beer drops when the beer foams strongly; beer drinkers know that there is a lot of liquid in the head stabilized by the alcohols and other surfactant in the beer. The so called “foamy” oils which produce anomously high rates of primary oil recovery are something like a very viscous beer in which the gas bubbles rise very slowly; when the bubbles rise fast enough, foam appears at the well head (2). Since foams have ever so much gas, they are much lighter and rise to the top or are centrifuged to the center.

What is the difference between foaminess and stability?

Creation and maintenance of foams are different; the former relates to foaminess and the latter to stability. Bad champagne foams even more strongly than beer under mild depressurization; but the champagne foams don't last long. We can get the same head on beer and champagne initially on depressurization, but champagne foam is much less stable. Devices for measuring foaminess have been described but theories for these devices are not known (3,4). Though there is a huge literature on the stability of foams, many questions remain unanswered.

Surface Tension vs. Gibbs Elasticity

It is thought that small surface tension is required for good foaming systems but good foamers appear to correlate more strongly with the rate at which surface tension changes than how much it changes. People who study the stability of foams have come to realize that "Gibbs elasticity", which is related to surface tension gradients and Maragnoni effects, is even more important than the value of the tension (1,4). Gibbs elasticity measures the change of surface tension with area; a change in area induces a change of concentration, so that the measure combines deformation with material properties. The lowest tension in a surfactant mixture is realized when it saturates the surface. In the highly turbulent surfactant mixture the stretched portions of bubble surfaces desaturate and can absorb more; the saturation condition (CMC) seems not to enter into the dynamics. Many material properties enter into the creation and stability of foams; viscosity, density, diffusion and film thickness of the bulk liquid as well as a number of interfacial properties other than tension are relevant. It can be said that the collective action of all these factors is not understood.

How are foams controlled with solid particles?

Defoaming literature (5) focuses on the action of hydrophobic liquids and solids in breaking aqueous foams. Silicon oils are effective but they degrade at the high temperatures found in commercial reactors. Hydrophobic particles break foam in laboratory tests, but even hydrophilic particles will suppress foam by fluidized bed mechanisms recently discovered (1). The solid particles fluidize in the bubbly mixture below the foam, but not in the foam, they increase liquid holdup by bed expansion and greater wetted area. Suppression of foam with a fluidized bed is a new and practical idea which needs further study. The beneficial effects of fluidized particles are even greater when hydrophobic particles are used (6).

Foams are non-Newtonian. What are their rheological properties?

Foam rheology is another important subject for applications which is not well understood. Foams can trap and immobilize small and light particles, showing that foams have an effective yield stress. This property makes foam a good drilling fluid for carrying away cuttings in oil-field drilling. When foam flows there is some kind of viscosity after yield, but particles won't circulate in the foam, and the foam itself does not circulate as an ordinary fluid. Foams have viscoelastic properties like polymer solutions; heavy particles driven into the foam by turbulence in the bubbly mixture fall back out of the foam lined up in a vertical chain of linked particles, characteristic of particle solutions. This kind of particle migration has not been discussed before. Complex and exotic, the true nature of foams has yet to be revealed.

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