Foam Control Using a Fluidized Bed

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This proposal is based on research by Guitián and Joseph [1996] which was carried out at the University of Minnesota. A patent application for foam control using a fluidized bed has been filed jointly by Intevep S.A. and the University of Minnesota. The paper "How bubbly mixtures foam and foam control using a fluidized bed" on which this proposal is based is appended to this proposal.

Part 1. Foam creation in a bubbly column

Here we consider projects associated with how bubbly mixtures foam, without particles, corresponding to Part 1 of the paper by Guitián and Joseph in the appendix. We shall use the same figure and equation numbers in the appendix.

1. Scale up

Is the foaming criterion

$$U_g = a + bU_l \qquad (2)$$

independent of the foam height H (see figure 1). The percentage of foam $f = h/H$ in the column depends on U_g for a fixed U_l and $f = 0$ when the U_l is larger than the threshold value given by (2) (see figure 2).

The coefficients a and b depend on the foaminess (surfactant) and foam quality (the distributor) is a factor

- Do a and b depend on H?

2. Foam Quality

In our video tape, we show that bubbling through a fixed bed produces a fine foam

- Determine a and b for fine foam

- Determine gas holding vs. gas velocity for fixed liquid velocities for fine foam. *Repeat the measurements in the appended paper for fine foam.*
- In the previous work we used pentanol-SDS mixtures to reproduce the foaming characteristics of a real reactor (figure 6). The pentanol is toxic, now we use butanol-SDS mixtures and the foam quality is visually different. Repeat the measurement in the appended paper for Butanol-SDS mixture.
- Seek a foaming system for organic, non-aqueous liquids which resemble commercial hydrocarbon reactors more closely.

3. Foam Rheology
We think that the rheology of foams may be initially confined to the determination of viscosity, yield stress, elasticity and normal stress in foam. We need to consider particles as a tool for characterizing the rheology of foams.

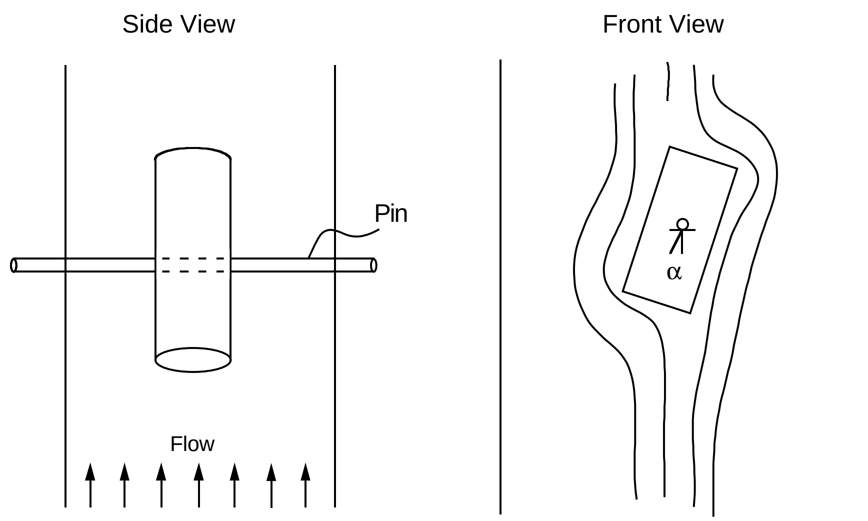
Viscosity. We used an ad hoc and foaming data to determine a formula (22) for the viscosity of foam shown in figure 7.

- Repeat the viscosity calculation for fine foams and butanol SDS - water foaming mixtures.
- Compare the formulas for viscosity that arise from our ad hoc analysis with literature expressions.

Yield stress. Small particles are trapped in foam; large particles are blocked from entering or if they enter the foam, they will not circulate and they drop out in linked chains as in figure 8.

- Determine the size and weight of particles that can be trapped in foam. Use this information to characterize the yield stress. It may be better to describe this property of foam as its *particle carrying capacity* rather than yield stress.
- How does the shape of particles and the size and weight distribution of a polydispersion effect the particle carrying capacity?

Normal Stresses and elasticity of foams. The orientation of cylinders settling in viscoelastic are sensitive indicators of the normal stresses developed in flow. In situations, in which cylinders with round ends fall with their long axis parallel to gravity, cylinders with flat ends will tilt and the angle of tilt is greater when the normal stresses are greater. We propose to use this property to construct a device to determine the magnitude of normal stresses in foam, shown below in cartoon form.



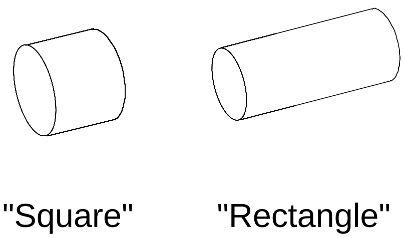
The cylinder center is fired by a pin through its center and is anchored on the side wall. It is tilted normal stresses in flow of foam and measurements of the tilt angle correlate with the intensity of the normal stresses.

4. Foam suppression with hydrophilic particles

More data of the type collected by Guitián and Joseph needs to be collected. The effects of size, weight and concentration of monodisperse particles in batch should be thoroughly documented. New types of data should be collected.

- Polydisperse particle. The foam should act as a filter removing small and light particles. The effect on the gas hold up and foam height should be determined. We are getting 12 different proppant sands used in well fracturing from Stimlab. These sands are polydisperse and have other differences which may enter into foam suppression.

- Shape effects can enter into properties of fluidized beds used to suppress foam. The bed expansion could be controlled to a degree by the shape of particles. We propose to make cylinder with flat ends from feed stock.



Particles like these can be made cheaply in our shop from different feedstock size and weight. The drag on these particles is greater than the drag on an equivalent spherical leading to less foam through enhanced bed expansion.

- It is known (see figure 14) that the liquid hold up will increase with size of monodisperse spheres of fixed density and concentration only up to a certain size; for larger sizes the liquid hold up decreases.
- Determine the optimum size of monodisperse particles of fixed density and concentration.

Since

$$1 = \epsilon_l + \epsilon_s + \epsilon_g$$

large spherical particles can increase liquid hold up even when they decrease gas hold up.

There are probably many criteria for optimization of different mechanisms of foam suppression which will emerge.

5. Continuous injection of particles

This is a very practical topic of study since most reactors use continuous rather than batch injection of particles. Injected particles must go out of or accumulate in the reactor.

- Determine size, weight and injection rate of particles for which steady state conditions, without accumulation may be established.
- The limiting factor in particle transport is the foam. We expect to see large hold up of particles in the bubbly mixture with only small amounts of particles held up in the foam. This hold up will depend on the foam but more strongly on the particles.

- Determine hold up properties of foam and bubbly mixtures under steady conditions corresponding to different rates of particles (3). The light and small particles of a polydisperse slurry will be driven out with the foam. The foaming reactor can be used in this way as a particle demixer, like a flotation device, which needs documentation.

6. In situ foaming

The foaming criterion (2) works also in a packed bed. We may create foam in a packed bed by injecting gas and liquid at rates above critical. This creates an opportunity for foam injection. The surfactant or foaming solution is injected, then gas is forced through at a rate fast enough to create foam. The foam is created in situ, instead of injecting foam we create it down-hole.

There are many opportunities for in situ foaming; acidizing to name one. It would be useful to see if foam could be created in fluid filled tightly packed sands.

7. Foam suppression and destruction using hydrophobic particles.

Though no reference to the use of fluidized beds appears in the vast literature on defoaming, there are discussions of foam breaking using hydrophobic particles. Guitián & Joseph studied foam suppression with glass and plastic (hydrophilic) particles. Hydrophobic particles also can be fluidized in the bubbly mixture and perhaps they will attack foam at the interface where foam appears. The reduction or destabilization of foam above a bed of hydrophobic particles fluidized in a bubbly mixture is a new topic worthy of study.

The study of foam breaking or destabilization is different than foam suppression. The suppression of foaming in a reactor means less foam is in the reactor, but the rate of foam production does not necessarily decrease. For many applications, foam suppression is not enough, the foam should be destroyed or destabilized to the greatest extent. For this, we look to the fluidization of hydrophobic particles.

It is certain that not all hydrophobic particles are alike. A classification based on size, weight, concentration and degree of hydrophocity (contact angle) should be established along the lines in the appended paper. Continuous injection of hydrophobic particles should also be considered.