# Research proposal to GPRI from D.D. Joseph

## Project Title:

Particle transport in foams: underbalanced drilling, hole cleaning and propant transport.

## Summary.

The project is to correlate the properties of aqueous foams used in practice with the size, weight and hydrophobicity of particles. The impact of segregation of foamy liquids into bubbly mixtures and foams on transport and levitation of particles in horizontal, tilted and vertical holes is to be assessed. Holdup of particles, liquid and gas injected continuously in foaming slit flow loops will be measured. Methods of enhancing particle transport by creating foam downhole will be studied.

## Principles.

We carried out studies of aqueous foams, foam formation and segregation and the fluidization of hydrophobic and hydrophilic particles in foams and bubbly mixtures. These are described in three papers listed at the end and a little appendix on the shaker bottle. The experiments were carried out in a vertical bubble column of slit type described by Guitian & Joseph [1997] (figure 2).

The following ideas came out of the experiments

- There is a critical condition for foaming
- Foams segregate into bubbly mixtures below and foam above
- You can create foam downhole and in fixed beds
- You can control the size of the bubbles and foam with a good distributor
- You can suppress the formation of foam with a fluidized bed of hydrophilic particles and even more with hydrophobic particles
- The ability of a given foam to carry particles can be tuned to the size of particles; particles which are too large or too small cannot be well suspended.

## Explanations.

Foam appears above a bubbly mixture when the superficial gas velocity is greater than critical. In the case of continuous injection of gas and surfactant-water the bubbly mixture will not foam unless the gas velocity $U_g$ is greater than the value $U_g = aU_l+b$ where $a$ and $b$ depend on the foam and $U_l$ is the liquid velocity. At any fixed gas velocity $U_g$, foam may be eliminated by increasing $U_l$ so that $U_g < aU_l+b$. Foam is above because it contains much more gas, say 85% instead of 40% in the bubbly mixture; it's important to know when and where foams occur. You can foam *in situ*, without an interface, only if the gas holdup in the bubbly mixture reaches a close packed limit in which bubbles are forced together and change topology. Foam will stratify and then segregate; water falls out; when too much water is on the bottom the foam will change to bubbly mixture or even pure liquid.

Particles don’t really fluidize in foam; they can carry particles however. Particles are carried away by foam or they drop out of the foam, but they don’t circulate. Moreover, foams which will carry some particles will not carry others (see appendix). Aqueous foams carry hydrophilic particles better than hydrophobic.

## Implications.

The tendency of flowing foams to segregate means that in horizontal drilling the bubbly mixture below should have a harder time levitating particles off the bottom than if the hole were full of foam. Segregation and transport times should be known in practical applications. It is best to inject foam under particles because if particles enter the bubbly mixture below they will not get into the foam. This opens the strategy of downhole and in-situ foaming for hole cleaning of transport application. We would introduce foam by rapid bubbling of gas through liquid downhole, under the foam. It is necessary to recognize the type of particles, size, weight and degree of hydrophobicity, which can be suspended in the foam used in field application. Foams, and distributors controlling the size of bubbles in the foam can be tuned to the actual cuttings or propants being used. You ought to know what particles can be carried by your foam.

## Projects.

(1) Equip the Guitian-Joseph flow loop for continuous injection of particles. Measure particle holdup in the bubbly mixtures and foams used in field applications. Determine the difference in particle holdup for coarse and fine foams created by different distributors.

(2) Build a table top slit flow loop to test foam stratification and levitation of particles from the floor of the loop. Try to develop methods of downhole foam creation under the particles.

(3) Determine the optimum size, weight and degree of hydrophobicity of particles for transport by a given foam from shaker, sedimentation and fluidization tests.

## Deliverables.

These are specified just above and in the abstract.

D.D. Joseph, 1997, “Understanding foams and foaming”, *J. Fluid Engineering,* **119**:497-498.

J. Guitian and D.D. Joseph, 1997, “How bubbly mixtures foam and foam control using a fluidized bed,” *Int. J. Multiphase flow,* **24**(1):1-16.

C. Mata and D.D. Joseph, 1997, “Foam control using a fluidized bed of hydrophobic particles”, to appear in *Int. J. Multiphase Flow.*

## **Appendix: Shaker Bottles**

These are used to measure foaminess and stability of foams. You shake the foaming water in a controlled way; you get a foam head and the head height gives the foaminess. The rate of collapse of the head gives the foam stability. We can use this technique to test your oils.

My student Ling Jiang has used shaker bottles to test stability of foams when particles are present. She did one test with different size particles. Small and large particles fall out of the foam. Intermediate size particles do not fall out. There is an optimal size for which the solids fraction of particles stuck in foam to the total volume of particles (fixed and the same for all tests). So a given size cutting will be effectively removed by a foam drilling mud, with removal of other sizes being less good (see Figure 1).

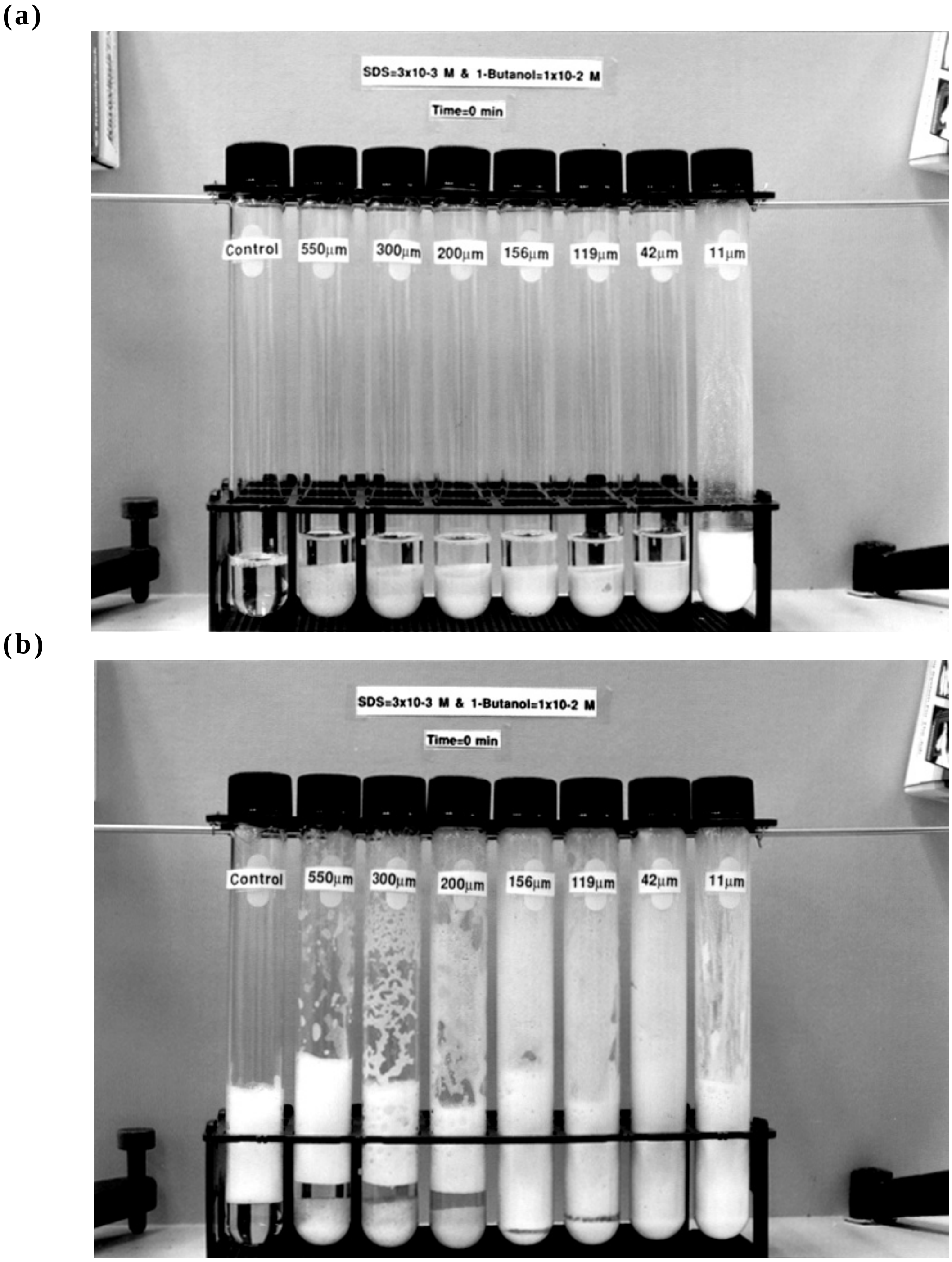

**Figure 1** *(continues, next two pages)*. 10 gms of glass of different sizes marked on the bottles are put in 7cc of surfactant solution (a) before shaking, (b) just after shaking, (c) 15 min. later, (d) 30 min. later, (e) 1 hour later. The optimal size of cutting for this foam is $d$ = 156 μm.

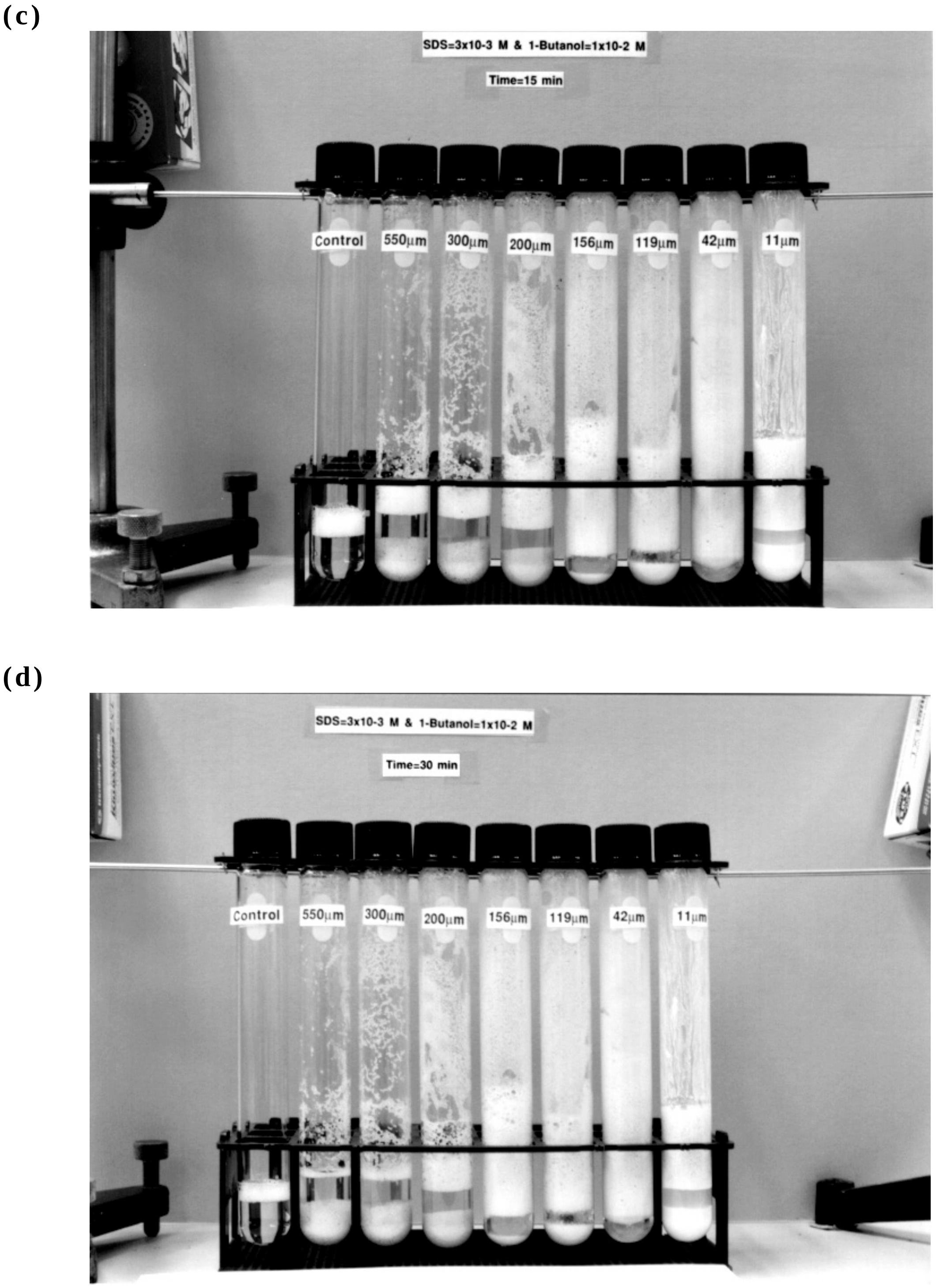

***Figure 1,*** *cont.*

**(e)**

***Figure 1,*** *cont.*