Project Title:

Foam control and suppression of foaming using fluidized bed

Brief Project Description:

The project is to apply newly discovered properties relating to foam formation and foam suppression using fluidized beds to problems arising in the recovery and production of foamy oil. Studies will also be carried out on foam rheology as it relates to transport of particles in foam workouts in underbalanced drilling, proppant transport in reservoir stimulation and in applications involving in-situ foaming as in acid diversion using foam.

(a) Background:

New ideas about foams are presented:

> J. Guitián and D.D. Joseph (GJ), "How bubbly mixtures foam and foam control using a fluidized bed", to appear in the *Int. J. of Multiphase Flow*, 1997.
>
> C. Mata & D.D. Joseph (MJ), Foam control using a fluidized bed of hydrophobid particles. Submitted for publication to *Int. J. Multiphase Flow*, 1997.

A short nontechnical essay on the generalization of concepts arising in these studies to foams generally is presented in article:

> D.D. Joseph, "Understanding foams and foaming," to appear in *J. Fluid Engineering*.

These three papers are appended to this preproposal. Videotapes of its experiments can be obtained from Patti Urbina at GRPI.

The new ideas we wish to exploit for applications are:

(1) Foam appears above a bubbly mixture when the gas velocity in the bubbly mixture 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

$$U_g = aU_l + b \qquad (1)$$

where *a* and *b* depend on foam quality and U_l is the liquid velocity. At any fixed gas velocity U_g foam may be eliminated by increasing U_l beyond the threshold given by (1).

It is very important to know where and when a bubbly mixture will foam in production. It seems not to be well understood; though it is obvious, that the foam is always on top and that a precise condition like (1), which could be framed in terms of a pressure drop in production, can be determined. Obviously the design of chokes and separators to alleviate foaming will depend on knowing where and when the bubbly mixture will foam.

(2) You can suppress foam using a fluidized bed of hydrophilic particles below the foam.

The cold slit reactor used by Guitián and Joseph was designed to study how solid particles could suppress foam. The motivation was that foam control in the patented HDH process could not be done with commercial defoamers like silicon oils which are degraded at the high pressures and temperatures at which these hydrocarbon crackers work. They found that solid particles would suppress formation of foam but did not understand the controlling features, size, weight and solids concentration. They thought, following the literature, that the mechanism by which solid particles suppress foam is by breaking foam and hydrophobic particles are required.

An entirely different mechanism of foam suppression was found by Guitián and Joseph [1997], foam control using a fluidized bed. Hydrophilic particles fluidized in the bubbly mixtures below the foam suppress foam formation dramatically without breaking the foam. The suppression is not perfectly understood but it occurs because the particles don't fluidize in the foam. The particles in the fluidized bed expand when the gas flow is increased, probably according to some rule of hindered settling. The expansion of the particles in the bubbly mixture pushes the liquid plus particles against the foam which at the same time is pushing down by increased foam formation due to more gas. The bed expansion opposes the foam formation and in some cases the expansion dominates and the foam retreats. Fluidized solid particles are at zero order, stationary objects like walls over which liquid must pass. Since these particles are hydrophilic the water “sticks” to them, increasing liquid holdup in the bed; it's all in the data.

Another effect of solid particles is to increase the effective density of the bubbly mixture. In this case the buoyancy is proportional to the difference between the gas density and the density of the fluid plus solid mixture, which is larger than what you might guess using the liquid density. The gas then is impelled to rise at a faster velocity, decreasing the holdup of gas. This mechanism works in bubbly mixtures whether or not foam is present, and it works even when the particles are hydrophobic.

(3) Fluidized hydrophobic particles attack foam.

Mata & Joseph [1997] have done some studies of foam control using fluidized beds of hydrophobic particles which can attack foam. They found an appreciable reduction in gas holdup when hydrophobic particles of the same concentration, size, shape and weight as hydrophilic particles were used. In one case the gas holdup in the bubbly mixture with no foam present increased because some gas sticks on the particles. In another case the gas holdup in the bubbly mixture actually decreased. We can probably assume that the further reduction of foam is due to breakup of foam with hydrophobic particles. The fluidized bed mechanisms of foam suppression are just enhanced by foam attack resulting in improved performance.

The anomalous results on the effects of fluidizing hydrophobic particles in bubbly mixtures without foam have not yet been clarified. It is probable the degree of hydrophobicity of particles matters for foam attack - but the degree of hydrophobicity is irrelevant to the fluidized bed mechanism.

It is well known, through studies using shaker bottles, that hydrophobic particles break aqueous foam. However, shaker bottles are not useful for production but fluidized beds are.

(4) Rheology and transport properties of foam.

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 underbalanced drilling. The foam flows, so there is some kind of viscosity for flow after yield but particles won't circulate in the foam and the foam itself does not circulate as an ordinary fluid. Heavy particles, driven into the foam by turbulence in the bubbly mixture fall out of the foam in a chain of linked particles characteristic of polymer solution. This shows that the foams have viscoelastic properties like polymeric solutions.

(b) Description of Project

The project focuses on experiments using aqueous foams. The applications to production targets suppression of hydrocarbon foams like those that arise in well completions using foamy oils and in aqueous foams like those used for underbalanced drilling, hole cleaning and acidizing. When dealing with fluidized particles in hydrocarbon foams the reader should replace the words “hydrophilic” and “hydrophobic” with “oleophilic” and “oleophobic.” Our intention is to carry out research in close cooperation with our sponsors; ideally the production problems are identified by sponsors and the laboratory models to tackle these problems at Minnesota.

Some experiments we want to do which look useful for applications are listed below.

i. Foam suppression of aqueous foams using hydrophobic particles which are effective foam fighters even in small concentrations. At the same time we want effective oleophobic particles to fight hydrocarbon foams.

ii. Measure the volume flow rates of foam leaving the Guitián-Joseph slit reactor. The suppression of the volume of flow in a reactor, due to increased liquid hold-up does not necessarily imply a reduction in the volume flow rate of foam; in applications we seek such a reduction.

iii. Development of experiments modeling gas release in foamy oils in well completions. Here bubbles are released by cavitation as the hydrostatic pressure is reduced. It may be possible to simulate such a release in pressure controlled cells or by controlled injection of gas. It is necessary to understand and model chokes and separators where foam production is a problem.

iv. The use of fluidized particles to suppress foam can be utilized in production separators. We can conceive of a screened box containing particles through which the gas and liquid flow. The work on using hydrophobic particles to suppress foam can also lead us to better designs. We can possibly use different materials in our internals to suppress foam.

v. Adapt the Guitián-Joseph slit reactor to accommodate continuous rather than batch solids loadings. This is a very practical topic of study since foam drilling must accommodate the continuous generation of cutting and 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. 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.

vi. *Proppant transport and underbalanced drilling using foams.* Our foaming reactor already simulates some properties of foam drilling muds in vertical holes. With GPRI funding I would construct an apparatus of similar type that could be tilted to study particle transport in deviated holes. We are going to use those slit see-through devices which encourage us to believe by seeing. Tilt slit devices are good models for cracks in reservoirs. Crucial to these applications is the modification of the slit reactor to allow for continuous injection of particles at controlled rates, simulating the injection of cuttings at the drill bit. An important quantity to understand and measure when particles are continuously injected is the solids hold-up. The performance of any multiphase flow in conduits is controlled by the hold-up.

Foam rheology may also be better understood in the controlled environment in our slit reactor. In applications involving cuttings and proppant transport it is very important to know the rheological properties of the suspending fluid. Foams exhibit viscoelastic properties that impact strongly not only the particle carrying capacity of foams but the forces that govern the cross stream migration of particles.

vii. *In situ foaming.* The foaming criterion (1) 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.

The advantage of *in situ* foaming is that it is easier to inject gas and water separately and produce foam in place than to mix and transport the foam to place. A technology for *in situ* foaming required separate liquid and gas lines. Two possible applications of *in situ* foaming are acidizing and down-hole cleaning of drilling hole. For acidizing we want to block the more permeable undamaged cracks with foam so that we acidize damaged cracks. Flood the reservoir with surfactant and water. Then inject gas fast enough to foam; the most conductive cracks will foam first. Then the acid will flow into the less conductive (damaged) cracks. This idea could be tested in small scale laboratory experiments. For hole cleaning the main problem is how to pump in the gas. One idea is to use an annular drill string, or a drill string with an auxiliary gas line.

(c) Objectives and Deliverables

The University of Minnesota team will deliver knowledge and data from experiments and theory. Devices and technology are deliverables arising from collaborations between Joseph's team and company sponsors.

- Determine the parameters of the most effective hydrophobic particles for the suppression of aqueous foam and the most effective oleophobic particles for the suppression of hydrocarbon foam.

- Consider the problems of redesign of chokes and separators to suppress foam with fluidized particles and by manipulation of the foaming criterion.

- Modify the Guitián-Joseph reactor to accomodate the continuous injection of solids and the measurement of solids hold-up separately in the bubbly mixture and in the foam.

- Construct a slit “see-through” device with two degrees of orientational freedom to simulate a reservoir crack in any orientation. This device will be equipped for continuous injection of gas, liquid and particles. We are already building a benchtop device at Intevep in VZ to use on foams and aerated muds targeting underbalanced drilling.

There are huge gaps in understanding the nature of foams and foaming, especially in the case of hydrocarbon foams which impede production. Besides the item specific studies mentioned here already, we propose to deliver new understandings to applications involving foams.

(d) Timetable with milestones

We are aiming to have all the new equipment and enhancements finished in year 1. We will start our discussions of production problems with sponsors in year one with the goal of collecting data and applying results to processes and technology in year two.

(e) Cost and benefits

The idea of foam control using a fluidized bed is new and has a high potential for application upstream and downstream.

(f) The research scientists are all at the University of Minnesota site. No subcontracts are planned.

(g) These terms are specified in the body.

(h) Shell and Exxon

	Year1	Year 2	TOTAL
Salary			
- Joseph 3.0 mos.	41,284	43,348	**84,632**
- Fortes 12 mos. 100%	50,000	52,500	**102,500**
- Jose 1 mos.	4,200	4,410	**8,610**
- Bai 12 mos. 50%	24,000	25,200	**49,200**
- Post Doc. Assoc. 12 mos. 100%	24,500	25,725	**50,225**
- Graduate Student 12 mos. 50%	13,800	14,490	**28,290**
Salary TOTAL	157,784	165,673	**323,457**
Fringe Benefits			
- Senior Personnel :Yr. 1@ 27.1%,Yr 2 @ 27.7%	32,380	34,752	**67,132**
- Post Doc Assoc.: Yr. 1 @ 14.0%, Yr.2 @ 14.5%	3,430	3,730	**7,160**
- Graduate Student @ 68.0%	9,384	9,853	**19,237**
Fringe Benefits TOTAL	45,194	48,335	**93,529**
Travel	6,000	6,000	**12,000**
Supplies	15,000	15,450	**30,450**
Equipment	40,000	40,000	**80,000**
Machine Shop	20,000	20,600	**40,600**
Direct Cost TOTAL	283,978	296,058	**486,507**
Overhead @ 47% of TDC less Equip & Grad Fringe	110,259	115,716	**225,975**
Grand TOTAL	**394,237**	**411,774**	**712,482**

Personnel Information:

- Antonio Fortes: Associate Professor, Department of Mechanical Engineering, University of Brasilia
  Received his Ph.D. in 1986

- Jose Guitian: Research Manager, Intevep, S.A. , Caracas, Venezuela
  Received his Ph.D. in 1996

- Runyuan Bai: Research Associate, Aerospace Engineering & Mechanics, University of Minnesota
  Received his Ph.D. in 1996