



Foam control using a fluidized bed of hydrophobic particles

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Abstract

Applications of foams and foaming are found in many industries such as the flotation of minerals, enhanced oil recovery, drilling in oil reservoirs, insulation, construction and refining processes such as vacuum distillation and delay-coker reactors. However, foaming and defoaming are not yet understood. Foams trap gas, and are not wanted in many applications. It has been found that foaming may be strongly suppressed by fluidizing hydrophilic particles in the bubbly mixture below the foam, in a cold slit bubble reactor. This suppression is achieved by increasing the wetted area of the solid's surface (walls and particles), by bed expansion and by decreasing the gas hold-up by increasing the effective density of the liquid–solid mixture.

Never before has a fluidized bed been used to study the antifoam action of hydrophobic particles. In this work, we fluidized hydrophobic and hydrophilic versions of two different sands in a slit bubble reactor. We found that the hydrophobic sands suppress the foam substantially better than their hydrophilic counterparts. We also observed that, when foam is not present in the reactor (i.e. at high liquid velocities), the gas hold-up in the bubbly mixture was higher for the hydrophobic version of one sand. This result may be explained in terms of attachment of the particles onto the air bubbles, which increases the residence time of the gas phase. On the other hand, the gas hold-up in the bubbly mixture for the hydrophobic version of the other sand was smaller. A possible explanation is that the bubble adhesion to a non-wettable particle, leads to a decrease in the apparent density of the particle, which in turn is responsible for a larger bed expansion and smaller gas hold-up compared with wettable particle systems. These results suggest that the degree of hydrophobicity matters.

Hydrophobic particles appear to break, and not only suppress foam; and they may have a wider application. © 1999 Published by Elsevier Science Ltd. All rights reserved.

Keywords: Foam suppression; Fluidized bed; Hydrophobic particles

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1. Introduction

Applications of foams and foaming are found in many industries such as the flotation of minerals, enhanced oil recovery, drilling in oil reservoirs, insulation, construction and refining processes such as vacuum distillation and delay-coker reactors. In hydrocracking and other foaming reactors, the foam rises to the top because it has a higher gas fraction than the bubbly mixture from which it comes. The high gas hold-up in foams is undesirable in chemical reactors because it strongly decreases the liquid residence time and in hydrocracking reactors also promotes formation of coke. However, foaming and defoaming are not yet well understood.

Guitian and Joseph (1998) made a literature review of the modern theory of foams, which will not be repeated here. To study foams, they built a cold slit bubble reactor which gives rise to foam when used with aqueous anionic surfactants. It partitions into two regions: a bubbly mixture below and foam above; we call this a *two phase, two phase flow*. The bubbly mixture is dispersed gas in water plus surfactant; the phase above is a foam through which large gas bubbles rise. This reactor reproduces some of the foaming processes which are characteristic of the commercial system CANMET from Petro-Canada, which have been studied by Pruden (1993). Guitian and Joseph discovered a critical condition for foaming; when the gas velocity exceeds a critical value, which depends on the liquid velocity, a foam interface appears at the top of the reactor, with foam above a bubbly mixture below. The interface is very sharp and it moves down the reactor as the gas velocity is increased at a constant liquid velocity. This is the way reactors foam, with the bubbly mixture being consumed by foam. The foam may be destroyed by increasing the liquid velocity backing up against the foaming threshold. They derived constant state theories for the bubbly mixture, the foam and the position of the foam interface and presented semiempirical correlations. They also found that foaming may be strongly suppressed by fluidizing hydrophilic particles in the bubbly mixture below the foam. They suggest that the suppression is achieved by increasing the wetted areas of solids surface (walls and particles), by bed expansion and by decreasing the gas hold-up by increasing the effective density of the liquid solid mixture.

Frye and Berg (1989) studies the antifoam action of hydrophobic particles using two different tests, but they did not use a fluidized bed. They first analyzed the rupture times of a single foam film formed by dipping a thin wire loop (diameter approx. 1 cm) into the test solution; a small rod (radius approx. 1 mm) was then pushed through the film. They called this technique particle-induced film rupture. The second test was the foam shake test.

Armstrong et al. (1976) studied adhesion of air bubbles to non-wettable or hydrophobic particles (6 mm Teflon-coated glass beads) fluidized in water. They suggested that the phenomenon of bubble adhesion to the non-wettable particle led to a decrease in the apparent density of the particle, which in turn was responsible for a larger bed expansion and smaller gas hold-up compared with wettable particle systems. Tsutsumi et al. (1991) studied the characteristics of water–air–solid fluidization with hydrophobic particles and classified the flow pattern according to the motion of the particle-bubble aggregates. They also used Teflon coated glass beads of 774 μm in diameter. In their experiments, the superficial gas velocity varied from 5.7 to 7.6 cm/s and the liquid velocity varied from 2.6 to 4.5 cm/s.

In this work, we fluidized hydrophobic and hydrophilic versions of two different sands in the same slit bubble reactor Guitian and Joseph (1998) used. Our goal was to compare the effect of the particles affinity to the aqueous solution, if any, on the foam control process.

2. Experimental setup

2.1. Bubble column reactor

The bubble column reactor was constructed in a narrow slit geometry which reproduces existing data from the literature on non-foaming systems and cylindrical bubble columns. The slit geometry allows us to observe the flow pattern and to determine the presence of foam. Details on this apparatus are given by Guitian and Joseph (1998). The superficial gas velocity U_G and liquid velocity U_L are prescribed data which we control. The total average gas fraction $\varepsilon_G = 1 - V_L/V$ in steady flow is determined by direct measurement of the liquid volume fraction V_L/V after the gas and liquid flow are simultaneously stopped. Steady states are recognized by visual observation of the foam interface. When particles are present in the reactor, the total average gas fraction becomes $\varepsilon_G = 1 - (V_L/V) - (V_S/V)$, where V_S/V is the solid's volume fraction.

2.2. Foaming system

We used a 0.06% wt. SDS plus 1.0% wt. 1-butanol in water solution. This solution was usually prepared the same day or the day before the test was carried out to ensure maximum freshness and a standard foamingness. This property of the solution was measured at the beginning and after each test and did not show any significant change; the mean value of the foamingness was 0.85. Although this was not the foaming system used by Guitian and Joseph (1998), it reproduced the CANMET process, as shown in Fig. 1.

2.3. Particles

We used hydrophobic and hydrophilic versions of two different kinds of sands. One of them was provided by Science Kit & Boreal Laboratories and the other one by STIM-LAB. In both cases, hydrophobic particles were obtained by treating the surface of ordinary sand, which happens to be hydrophilic. Science Kit & Boreal Laboratories treated theirs with very reactive *chlorinated silanes*. On the other hand, at STIM-LAB, they coat their sand with a very thin layer of resin, which does not wash away. We summarize the particles' properties in Table 1.

In order to verify the particles affinity to the 0.06% wt. SDS plus 1.0% wt. 1-butanol in water solution, we estimated the contact angles of a drop of the surfactant solution sitting on flattened surfaces of the two kinds of sands we used; at least for the hydrophobic versions of each kind of sand, since the surfactant solution would just be absorbed by the hydrophilic sands, like the sea water on the beach. The contact angles are clearly greater than 90° , as shown in Fig. 2. There is no doubt that these sands are hydrophobic.

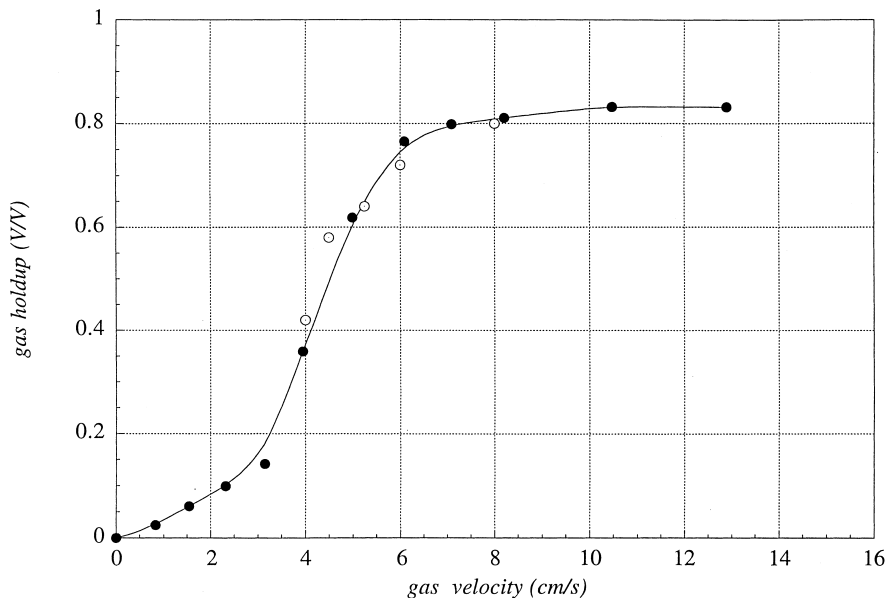


Fig. 1. Gas hold-up as a function of gas velocity, for a 0.06% wt. SDS + 1.0% wt. 1-butanol solution at a liquid velocity of 0.154 cm/s (solid circles) and the CANMET process, which liquid velocities are in the range 0.1–0.2 cm (open circles).

Another way of characterizing the used particles is by simple observation. The density of sand varies from 2.2 g/cm^3 to 2.7 g/cm^3 . If one pours ordinary sand in a container with water, it will smoothly, and grain by grain, fall to the bottom. If one does the same thing with hydrophobic sand, a different scenario follows: some of the grains stay at the surface, even though their density is greater than 1 g/cm^3 ; most of them fall to the bottom in large aggregates covered with a thin layer of air (see Fig. 3); and some will fall in the form of particle–bubble aggregates. They are so uncomfortable in water, that no matter how, they want to stick to air.

At this point, the reader must be wondering what happens to the hydrophobic particles when they are submerged in an aqueous solution for long periods of time. After each experiment with hydrophobic particles in the slit bubble reactor, we observed they had the

Table 1
Properties of the particles used

| Provider | Water affinity | Surface treatment | Density (g/cm^3) | Size distribution (μm) |
|---------------------------|----------------|---------------------|-----------------------------|-------------------------------------|
| STIM-LAB | Hydrophilic | None | 2.65 | 600–850 |
| | Hydrophobic | Resin coating | 2.65 | 600–850 |
| STIM-LAB | Hydrophilic | None | 2.65 | 500–600 |
| | Hydrophobic | Resin coating | 2.65 | 500–600 |
| Science Kit & Boreal Labs | Hydrophilic | None | 2.4 | 300–425 |
| | Hydrophobic | Chlorinated silanes | 2.4 | 300–425 |

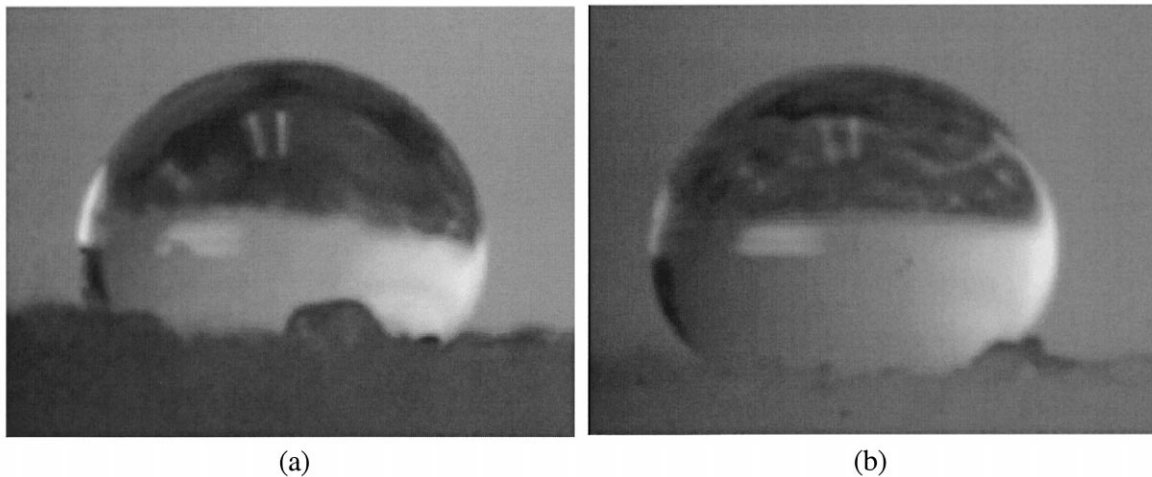


Fig. 2. Drops of 0.06% wt. SDS + 1.0% wt 1-Butanol solution sitting on top of flattened surfaces of hydrophobic particles; (a) resin coated particles from STIM-LAB; $\rho = 2.65$ g/cc; mean size = 500–600 μm , and (b) hydrophobic sand from Science Kit and Boreal Labs.; $\rho = 2.4$ g/cc, mean size = 300–425 μm . It is clear that the contact angles are $> 90^\circ$. It is not possible to get the same pictures on flattened surfaces of hydrophilic sands, because the surfactant solution is rapidly absorbed by the hydrophilic sand.

behavior described in the previous paragraph, making it very difficult to wash them with pure water for sorting and further use. Samples of hydrophobic and hydrophilic sands that were taken during the washing procedure are shown in Fig. 4.

3. Results

Fig. 5 shows the gas hold-up and foam fraction as a function of the gas velocity at a liquid velocity of 0.205 cm/s, for the surfactant solution without particles; freshly prepared and after having been used with the hydrophobic and hydrophilic sands, provided by Science Kit & Boreal Labs (mean size = 300–425 μm). We observe no difference at all, which means that the presence of surface treated particles does not modify the foaming properties of the surfactant solution. For a 10% volume fraction of the mentioned sands, Figs. 6 and 7 show gas hold-up and foam fraction as a function of the gas velocity at liquid velocities of 0.205 and 0.411 cm/s, respectively. We observed that the hydrophobic particles suppressed the foam substantially better than their hydrophilic counterparts. Evidently the fluid mechanics of foam suppression with hydrophilic particles are enhanced by a direct attack on the foam by hydrophobic particles.

A similar series of experimental results is presented in Figs. 8 and 9; this time for a 10% volume fraction of the uncoated and resin coated sands with a mean size of 600–850 μm provided by STIM-LAB. Again, we observe a better foam suppression by the hydrophobic particles (resin coated sand) for the two lowest liquid velocities (0.205 and 0.411 cm/s), and also a better gas hold-up reduction for all the liquid velocities, including the case for which there is no foam. Fig. 8(a) looks at foam suppression in a different way; the liquid fraction is

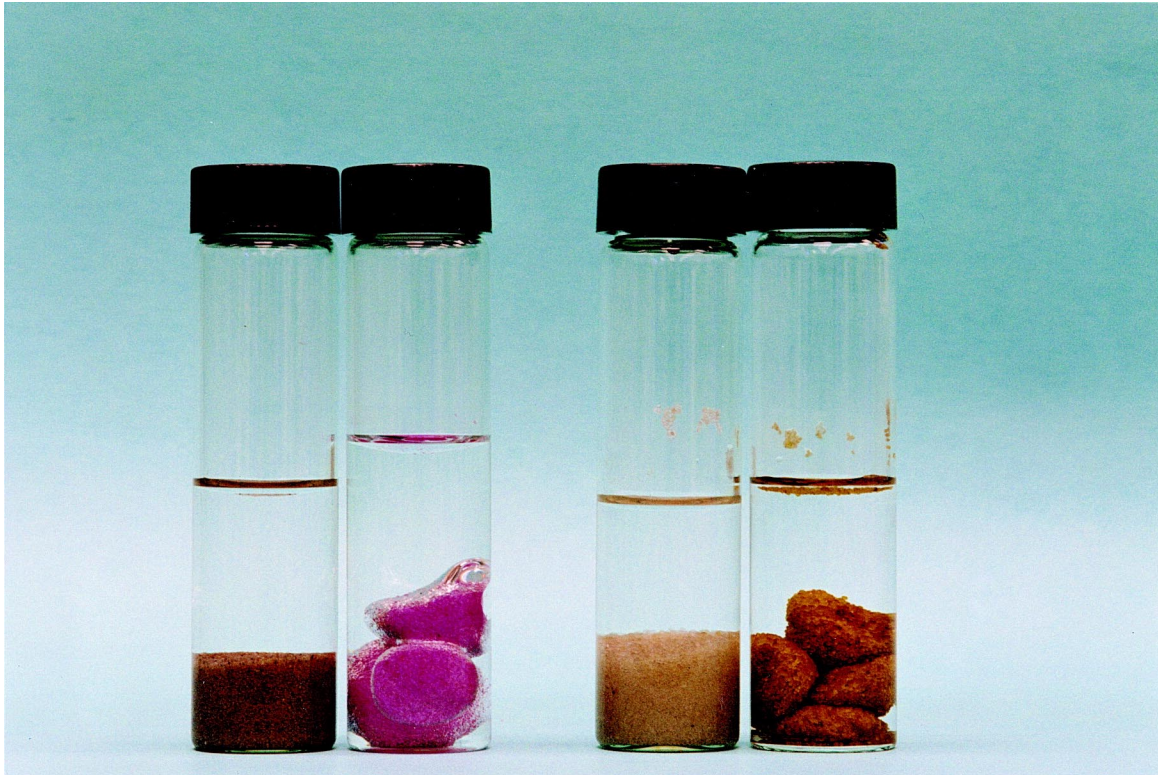


Fig. 3. Comparison of the behavior of hydrophilic and hydrophobic versions of the same kind of sand when they are poured in a container with water. Two pairs of vials are presented; one pair (left) contains hydrophilic and hydrophobic sands from Science Kit and Boreal Labs. ($\rho = 2.4 \text{ g/cm}^3$ and mean size = 300–425 μm); the other pair (right) contains uncoated or hydrophilic particles and resin coated or hydrophobic particles from STIM-LAB ($\rho = 2.65 \text{ g/cm}^3$ and mean size = 500–600 μm). The hydrophilic versions of each kind of sand settled down smoothly and grain by grain; whereas their hydrophobic counterparts settled down as large aggregates covered with a thin layer of air.

plotted as a function of the gas velocity when $U_L = 0.411 \text{ cm/s}$. At gas velocities below 5.0 cm/s there is no foam in the reactor (Fig. 10(b)) and the volume occupied by the solids reduces the amount of liquid in the reactor. When the reactor starts foaming, the liquid fraction with hydrophobic particles rapidly surpasses the liquid fraction with no particles and even with hydrophilic particles. Obviously, after this threshold hydrophobic sands are more effective in retaining liquid (destroying foam) than the hydrophilic sands.

A different scenario is illustrated in Fig. 10, where the gas hold-up is plotted as a function of the gas velocity at a high value of the liquid velocity, $U_L = 0.822 \text{ cm/s}$. There is no foam in the reactor at this liquid velocity. The corresponding solids' volume fraction is 10%. In the case shown in Fig. 10(a), the fluidized particles were provided by Science Kit & Boreal Labs ($\rho = 2.4 \text{ g/cm}^3$, mean size = 300–425 μm). The hydrophilic particles did a better job in reducing the gas hold-up. This led us to think that the hydrophobic particles stick to the passing gas bubbles in the bubbly mixture, which promotes an increased gas hold-up in this phase. This explanation is supported by Tsutsumi et al.'s work (1991).

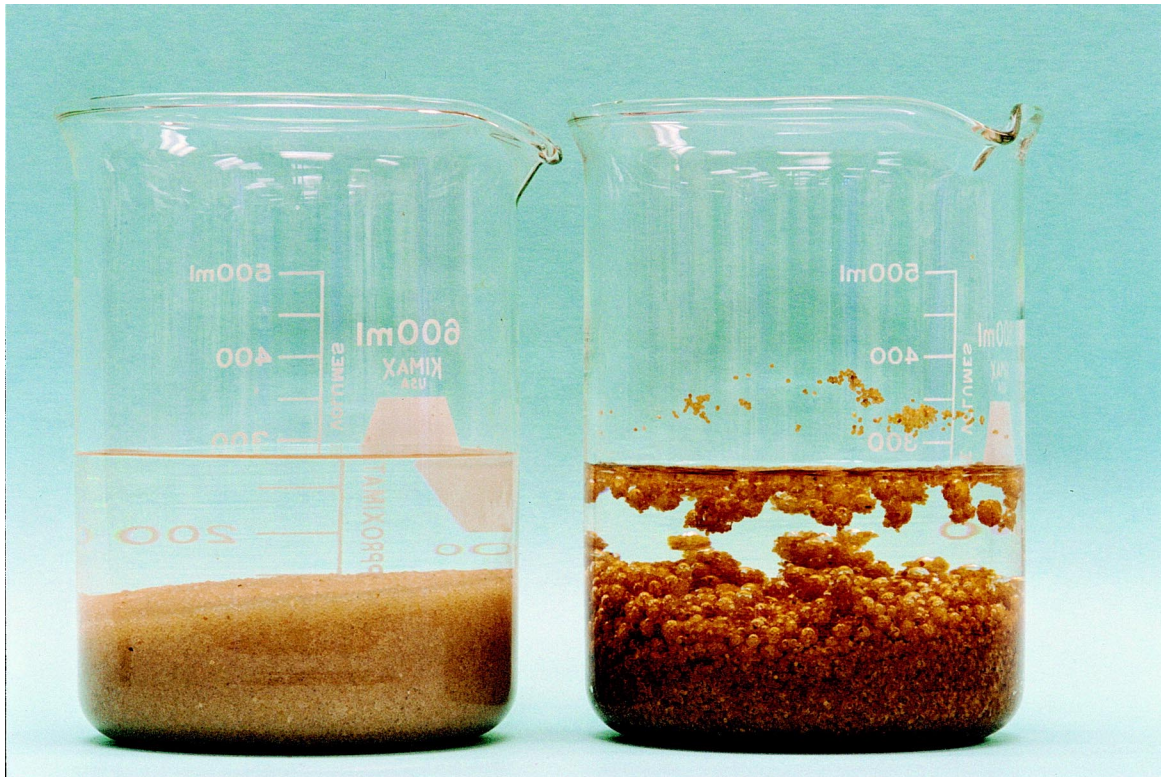
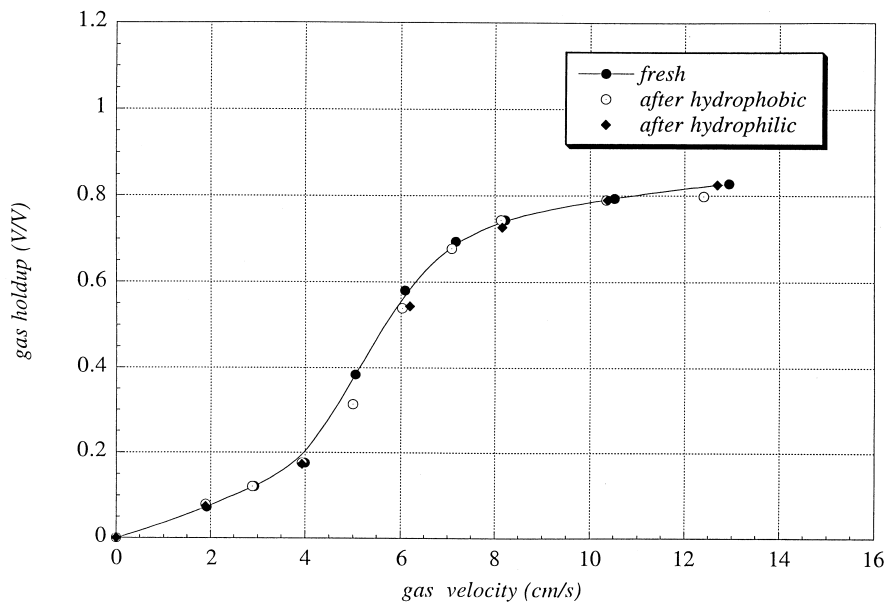


Fig. 4. Samples of particles from STIM-LAB ($\rho = 2.65 \text{ g/cm}^3$ and mean size = $600\text{--}850 \mu\text{m}$) that were taken during the washing process after they were exposed to the 0.06% wt. SDS + 1.0% wt. 1-butanol in water solution, inside the reactor for a long period of time. One beaker contains uncoated or hydrophilic particles (left); the other beaker contains resin-coated or hydrophobic particles (right). Resin coated particles stick to air bubbles that float or sink, depending on their effective density.

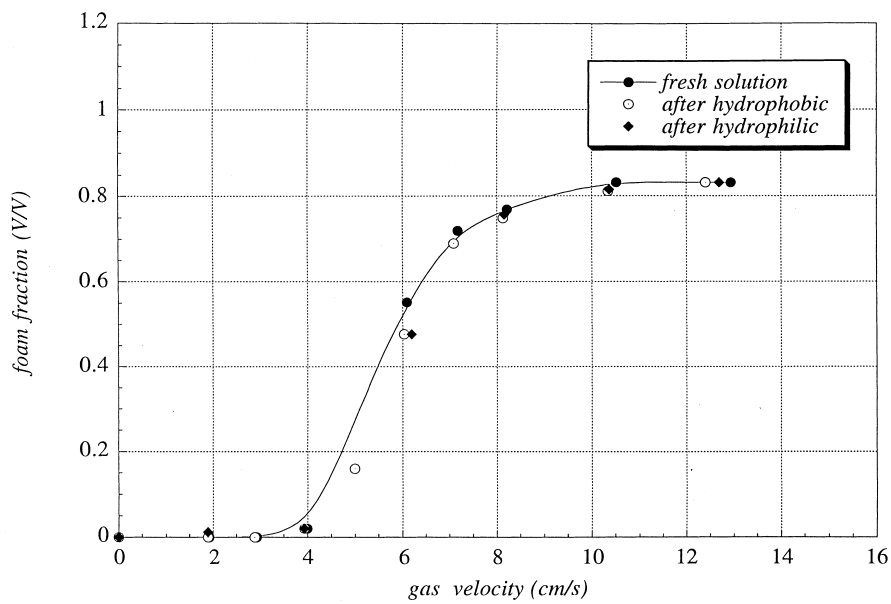
Fig. 10(b), compared with Fig. 10(a), shows a puzzling and unexpected result. This time, the fluidized particles were provided by STIM-LAB ($\rho = 2.65 \text{ g/cm}^3$, mean size = $600\text{--}850 \mu\text{m}$). To our surprise, the hydrophobic particles reduced the gas hold-up better than their hydrophilic counterparts. However, Armstrong et al.'s (1976) findings are in agreement with ours. We think more experiments have to be done in order to understand the, so far, unpredictable behavior of different kinds of hydrophobic particles, when there is no foam in the reactor.

Figs. 11 and 12 show the gas hold-up and foam fraction as a function of the gas velocity at liquid velocities of 0.103 and 0.205 cm/s, respectively, for the surfactant solution without particles and with 10% volume fraction of uncoated and resin-coated sand from STIM-LAB, with a mean size of $500\text{--}600 \mu\text{m}$. As expected, the hydrophobic particles suppress the foam (and gas hold-up) substantially better than their hydrophilic counterparts. Because of the large accumulation of hydrophobic particles at the top of the column, it was impossible to get steady measurements of gas hold-up and foam fraction for gas velocities above 8 cm/s.

In Fig. 13, the gas hold-up and foam fraction as a function of the gas velocity at a liquid velocity of 0.205 cm/s are compared for two mean size ranges; $500\text{--}600$ and $600\text{--}850 \mu\text{m}$, for the resin-coated or hydrophobic sand. As expected the smaller particles better-suppressed the

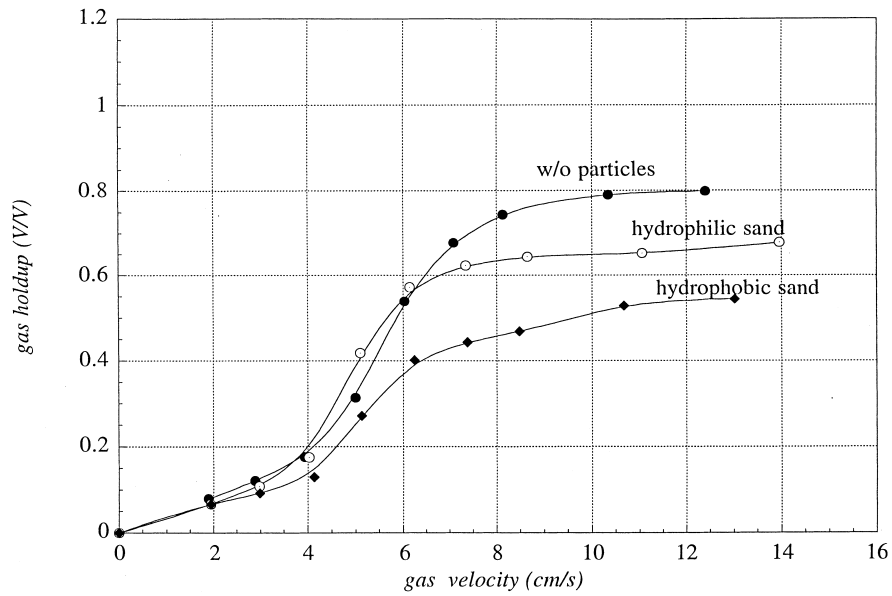


(a)

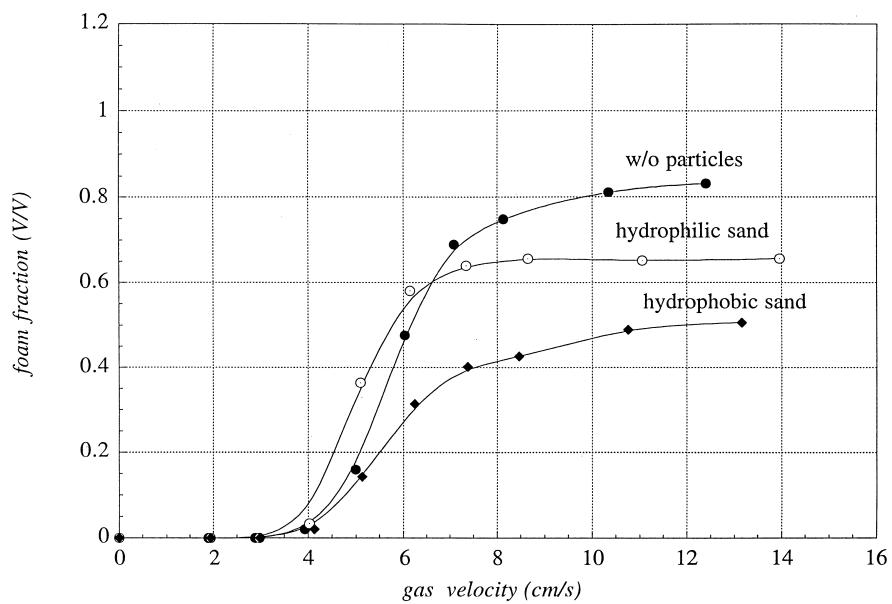


(b)

Fig. 5. (a) Gas hold-up as a function of gas velocity; and (b) foam fraction as a function of gas velocity, at a liquid velocity of 0.205 cm/s, for a 0.06% wt. SDS + 1.0% wt. 1-butanol without particles; fresh solution (solid circles), after having been used with hydrophobic particles (open circles) and hydrophilic particles (solid lozenges), from Science Kit & Boreal Labs.

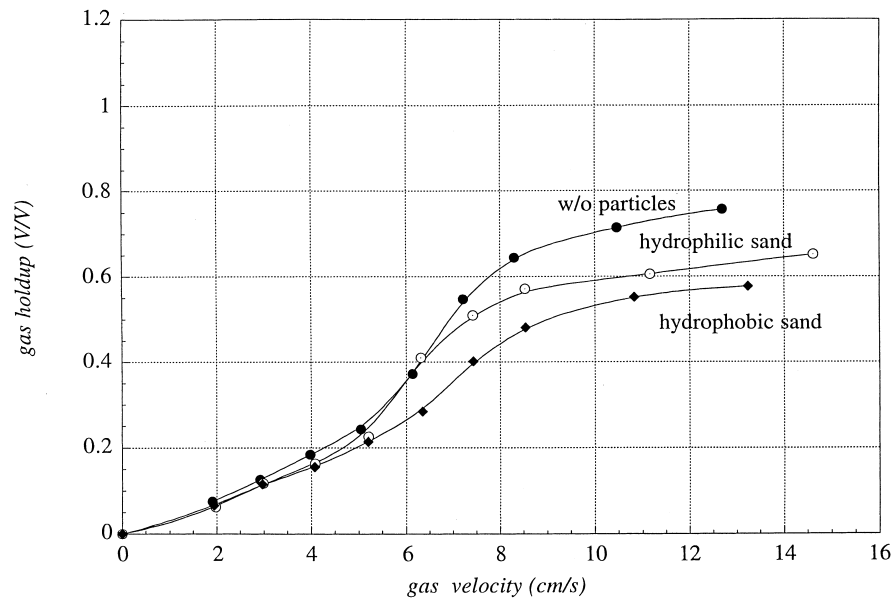


(a)

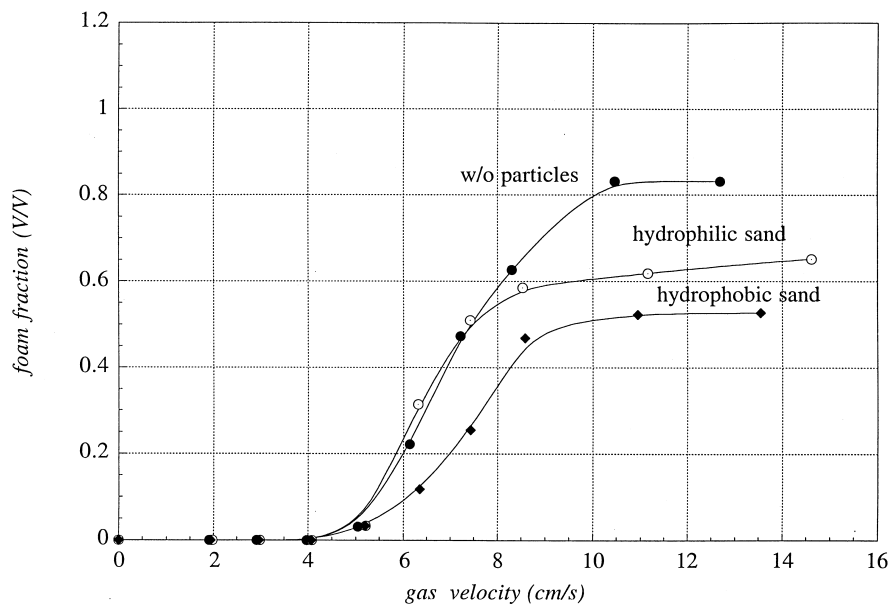


(b)

Fig. 6. (a) Gas hold-up as a function of gas velocity; and (b) foam fraction as a function of gas velocity, at a liquid velocity of 0.205 cm/s, for a 0.06% wt. SDS + 1.0% wt. 1-butanol solution, without particles (solid circles) and, with 10% volume fraction of solids (from Science Kit & Boreal Labs., $\rho = 2.4 \text{ g/cm}^3$, mean size = 300–425 μm); hydrophilic sand (open circles) and hydrophobic sand (solid lozenges).

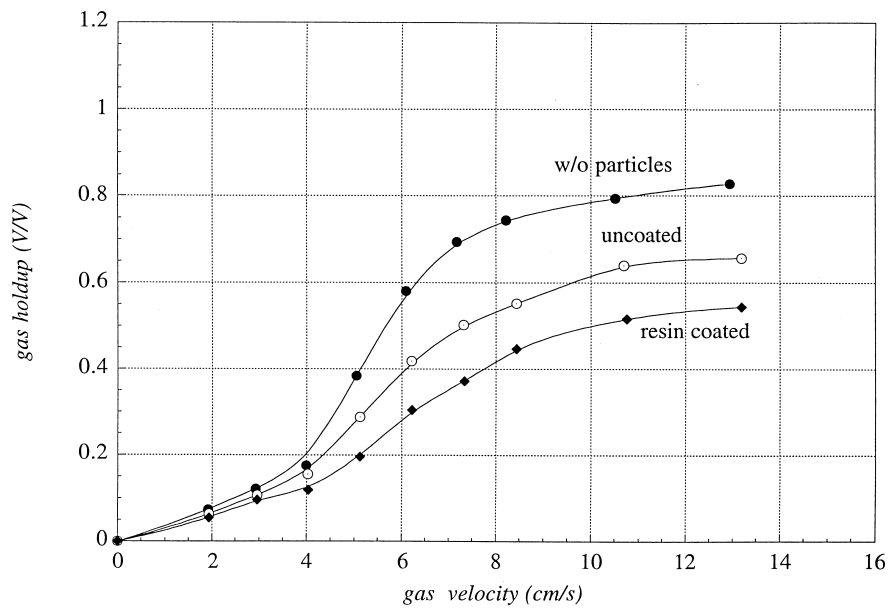


(a)

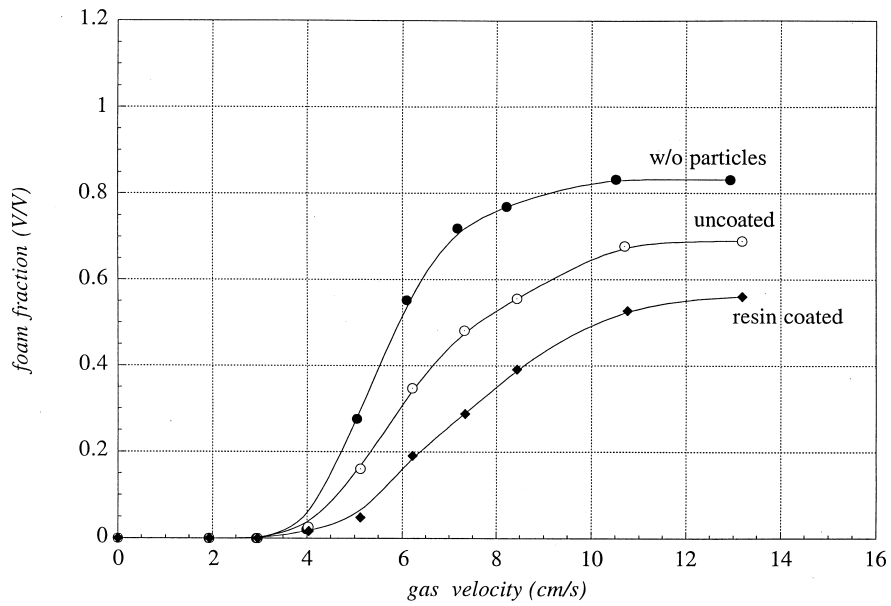


(b)

Fig. 7. (a) Gas hold-up as a function of gas velocity; and (b) foam fraction as a function of gas velocity, at a liquid velocity of 0.411 cm/s, for a 0.06% wt. SDS + 1.0% wt. 1-butanol solution, without particles (solid circles) and, with 10% volume fraction of solids (from Science Kit & Boreal Labs., $\rho = 2.4 \text{ g/cm}^3$, mean size = 300–425 μm); hydrophilic sand (open circles) and hydrophobic sand (solid lozenges).

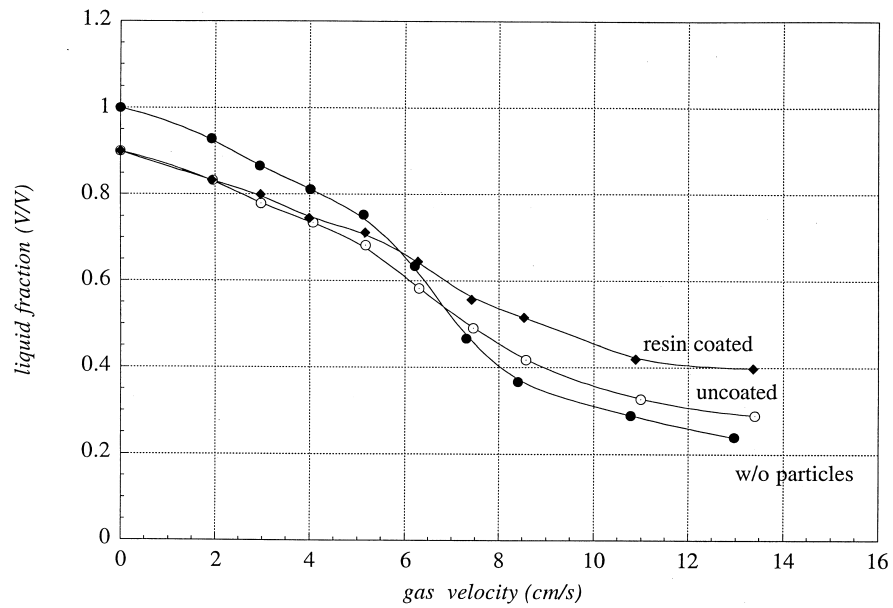


(a)

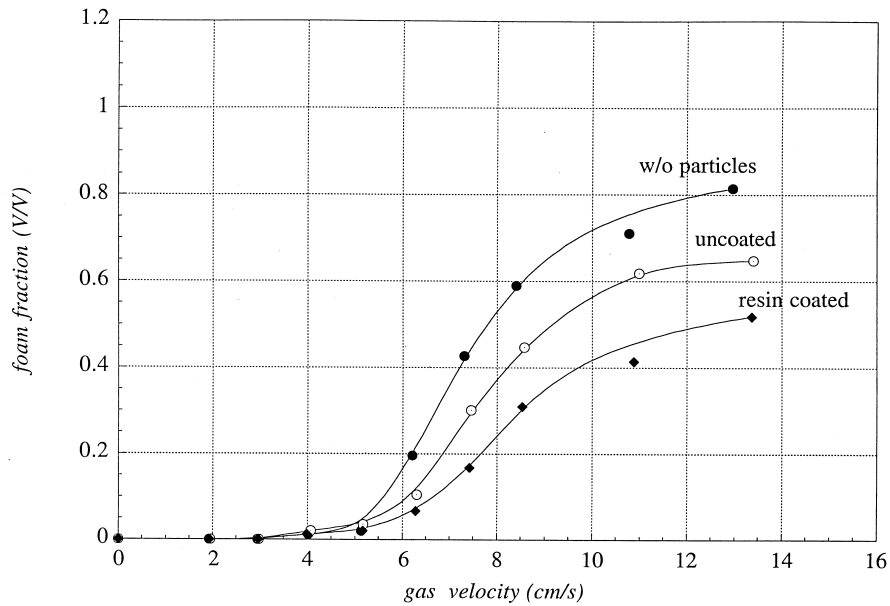


(b)

Fig. 8. (a) Gas hold-up as a function of gas velocity; and (b) foam fraction as a function of gas velocity, at a liquid velocity of 0.205 cm/s, for a 0.06% wt. SDS + 1.0% wt. 1-butanol solution, without particles (solid circles) and, with 10% volume fraction of solids (from STIM-LAB, $\rho = 2.65 \text{ g/cm}^3$, mean size = 600–850 μm); uncoated or hydrophilic sand (open circles) and resin coated or hydrophobic sand (solid lozenges).



(a)



(b)

Fig. 9. (a) Liquid fraction as a function of gas velocity; and (b) foam fraction as a function of gas velocity, at a liquid velocity of 0.411 cm/s, for a 0.06% wt. SDS + 1.0% wt. 1-butanol solution, without particles (solid circles) and, with 10% volume fraction of solids (from STIM-LAB, $\rho = 2.65 \text{ g/cm}^3$, mean size = 600–850 μm); uncoated or hydrophilic sand (open circles) and resin coated or hydrophobic sand (solid lozenges).

foam formation. The gas hold-up and foam fraction seemed to reach a plateau (and even a change of slope in the foam curve) at a gas velocity of approximately 8 cm/s. They expanded so well and penetrated the foam so easily, that a large accumulation of particles was observed.

Figs. 14 and 15 show the gas hold-up and foam fraction as a function of the gas velocity at liquid velocities of 0.205 and 0.411 cm/s, respectively, for the surfactant solution without particles and with 20% volume fraction of uncoated and resin-coated sand from STIM-LAB, with a mean size of 600–850 μm . As observed, the hydrophobic particles suppress the foam (and gas hold-up) considerably better than their hydrophilic counterparts. They readily expanded and, again, because of the large accumulation of hydrophobic particles at the top of the column it was impossible to get steady measurements of gas hold-up for gas velocities above 8 cm/s at the highest liquid velocity ($U_L = 0.411$ cm/s). In this case, no foam was created for gas velocities below 8 cm/s.

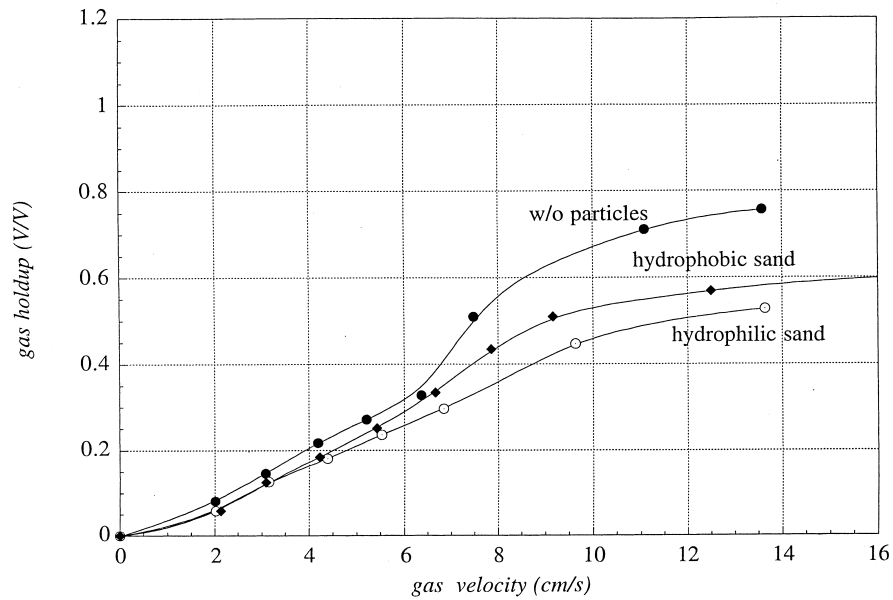
In Fig. 16, the gas hold-up and foam fraction as a function of the gas velocity at a liquid velocity of 0.205 cm/s are compared for two different volume fractions (10 and 20%) of the resin coated or hydrophobic sand with a mean size of 600–850 μm . As expected, the foam suppression was favored by the presence of the highest solid fraction.

A qualitative description of the differences in the bed expansion of the hydrophobic and hydrophilic particles is of interest. Hydrophobic particles expand more readily than the corresponding hydrophilic particles. More of the hydrophobic particles penetrate the foam and rise to the screen at the top of the reactor. When the flow is stopped, hydrophobic particles accumulate at the foam interface, because of trapped air as in flotation. At the same time, particles trapped by the foam break in a particular sequence in which the drier foam at the top breaks first. Fig. 17 illustrates some of these features; it shows collapsing foam and foam interfaces above a fluidized bed after turning off the gas and liquid velocities; the particles settle to the bottom and the bubble in the bubbly mixture disappear. The surfactant solution used was a 0.06% wt. SDS + 1.0% wt. 1-butanol in water solution and the particles (mean size = 600–850 μm) were provided by STIM-LAB. Before turning off the flows, the liquid and gas velocities were 0.411 cm/s and about 13 cm/s, respectively. Fig. 17(a) shows foam collapse when the particles were uncoated or hydrophilic; no particles are in the foam. Fig. 17(b) shows the foam–water plus surfactant interface for the case described above. No particles stick in the foam–water plus surfactant interface. Fig. 18 shows foam collapse and foam–water plus surfactant interface when the particles were coated with resin or hydrophobic; particles are levitated in the foam by attached air bubbles and are trapped in the interface by the same mechanism.

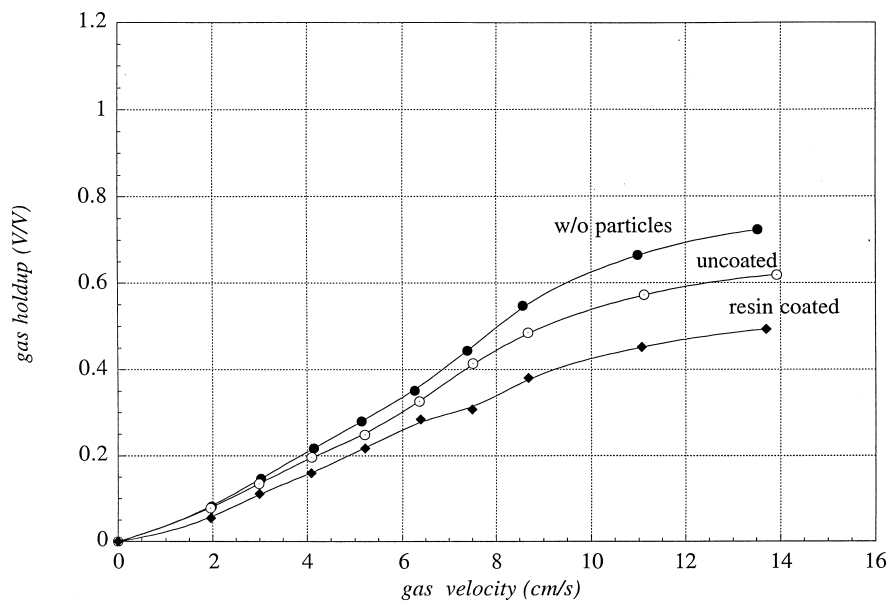
We believe that hydrophobic particles suppress foam in the same way as hydrophilic particles, but in addition act to collapse the foam at the interface between the foam and bubbly mixture. These qualitative features are captured in a video available on request.

4. Concluding remarks

The presence of surface treated particles does not modify the foaming properties of the surfactant solution.

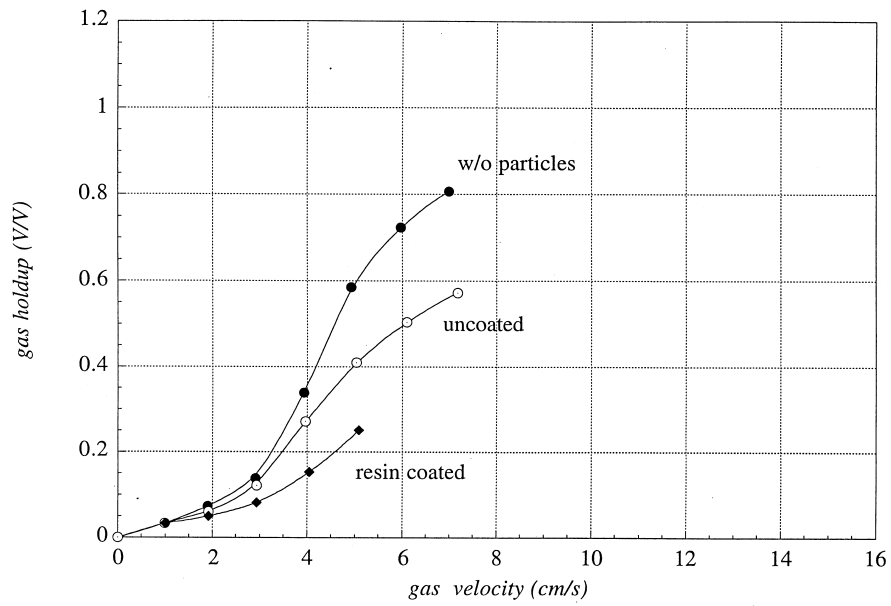


(a)

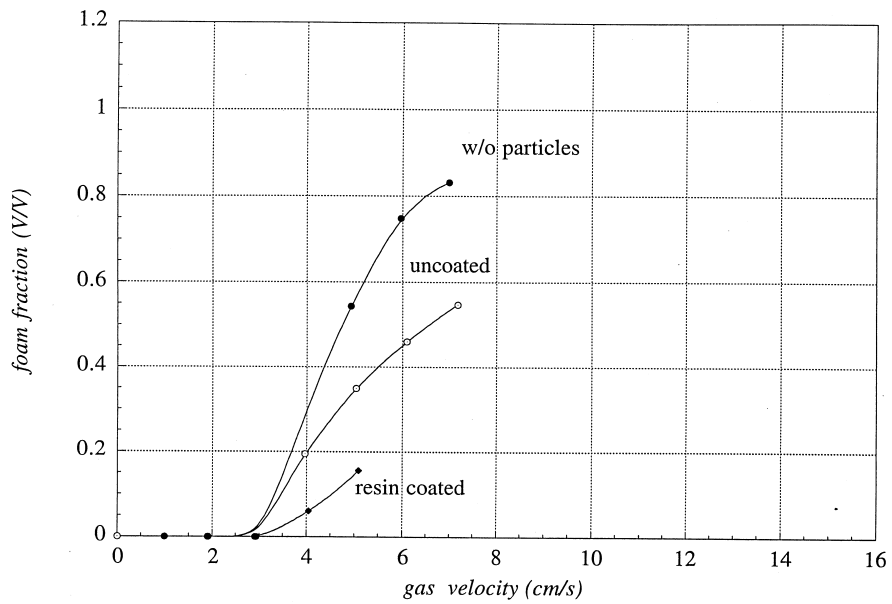


(b)

Fig. 10. Gas hold-up as a function of gas velocity, at a liquid velocity of 0.8216 cm/s, for a 0.06% wt. SDS + 1.0% wt. 1-butanol solution, without particles (solid circles) and, with 10% volume fraction of solids from two different providers. At this liquid velocity, there is no foam. (a) Hydrophilic sand (open circles) and hydrophobic sand (solid lozenges) from Science Kit & Boreal Labs. ($\rho = 2.4 \text{ g/cm}^3$, mean size = 300–425 μm). These results agree with Tsutsumi et al.'s findings (1991). (b) Uncoated or hydrophilic sand (open circles) and resin coated or hydrophobic sand (solid lozenges) from STIM-LAB ($\rho = 2.65 \text{ g/cm}^3$, mean size = 600–850 μm). This time, the results are supported by Armstrong et al.'s findings (1976).

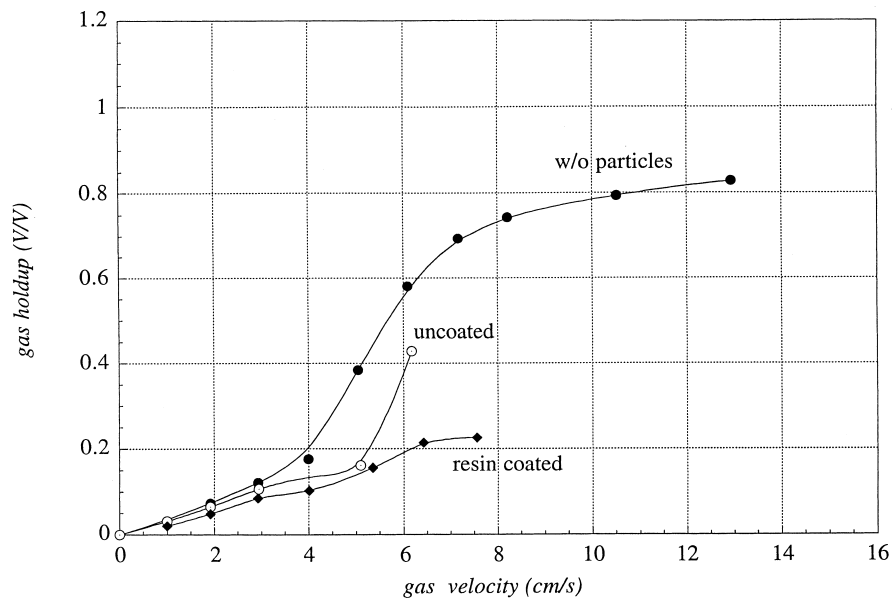


(a)

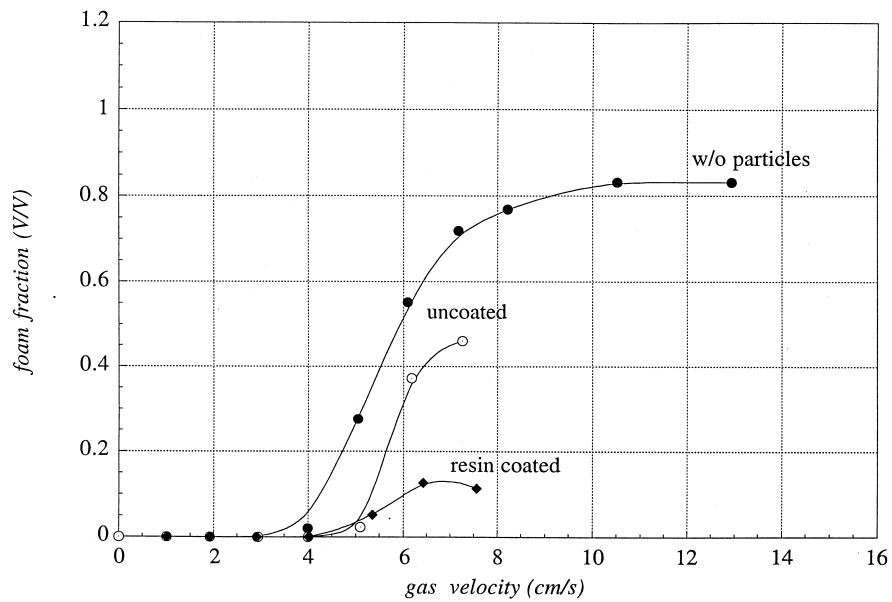


(b)

Fig. 11. (a) Gas hold-up as a function of gas velocity; and (b) foam fraction as a function of gas velocity, at a liquid velocity of 0.103 cm/s, for a 0.06% wt. SDS + 1.0% wt. 1-butanol solution, without particles (solid circles) and, with 10% volume fraction of solids (from STIM-LAB, $\rho = 2.65 \text{ g/cm}^3$, mean size = 500–600 μm); hydrophilic sand (open circles) and hydrophobic sand (solid lozenges).

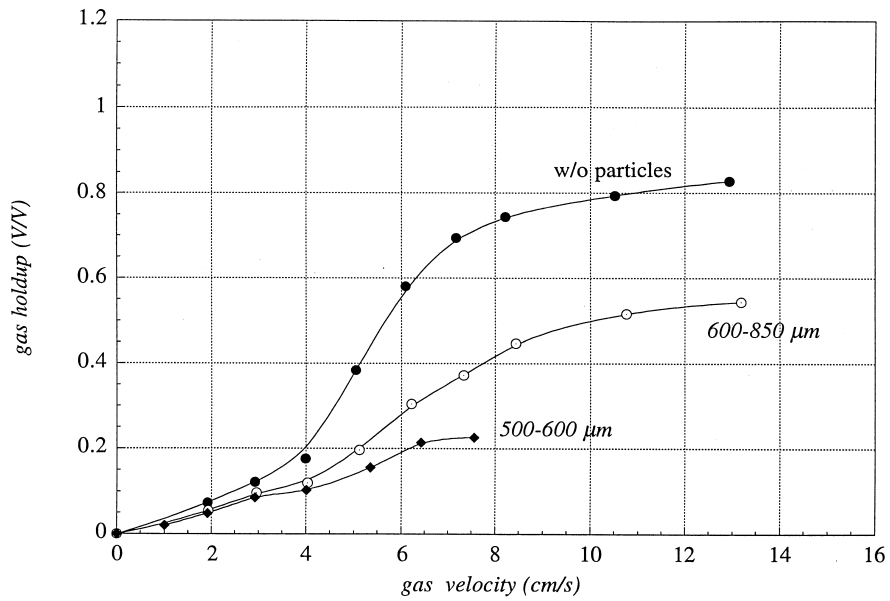


(a)

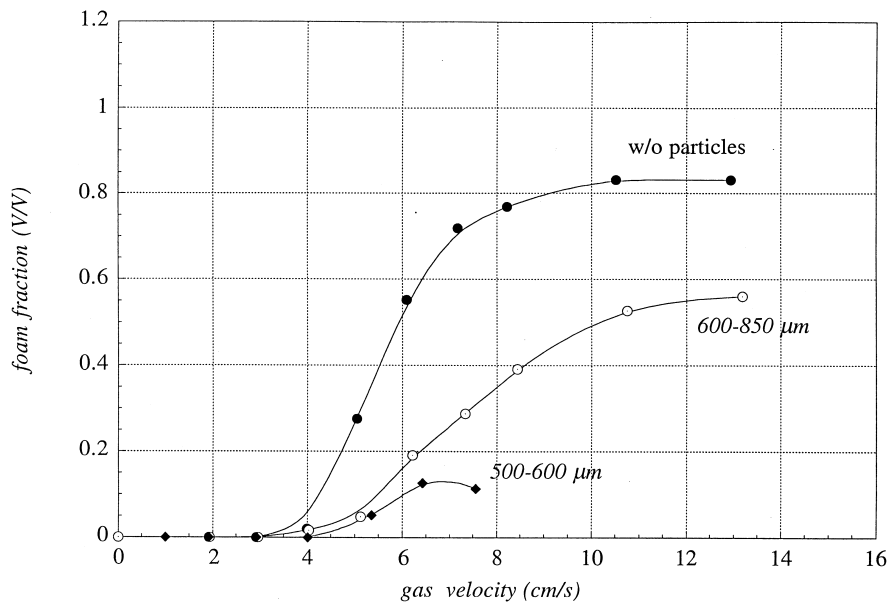


(b)

Fig. 12. (a) Gas hold-up as a function of gas velocity; and (b) foam fraction as a function of gas velocity, at a liquid velocity of 0.205 cm/s, for a 0.06% wt. SDS + 1.0% wt. 1-butanol solution, without particles (solid circles) and, with 10% volume fraction of solids (from STIM-LAB, $\rho = 2.65 \text{ g/cm}^3$, mean size = 500–600 μm); hydrophilic sand (open circles) and hydrophobic sand (solid lozenges).

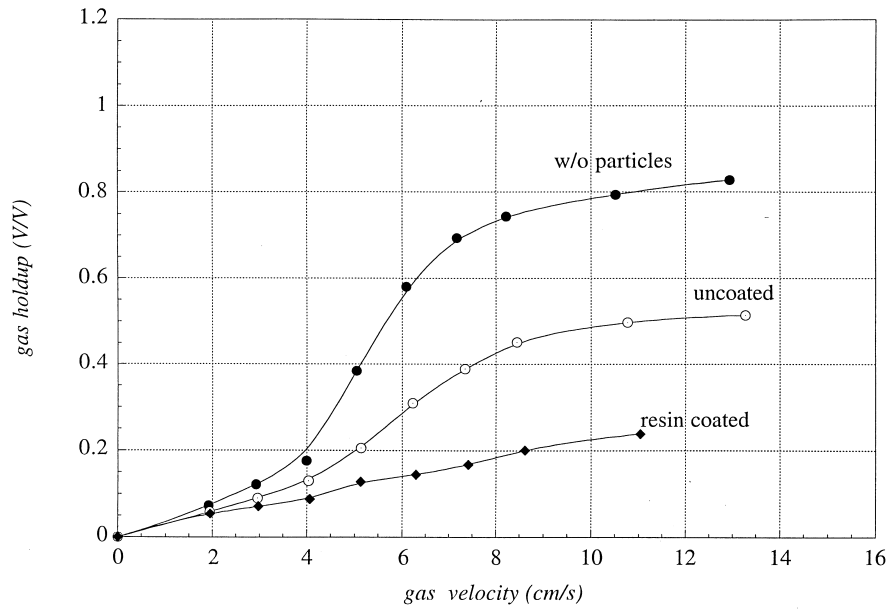


(a)

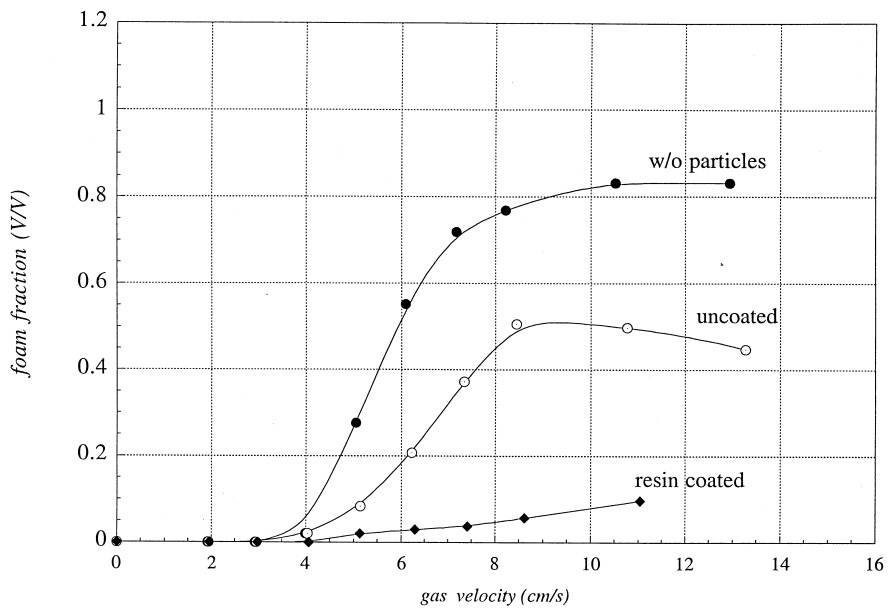


(b)

Fig. 13. (a) Gas hold-up as a function of gas velocity; and (b) foam fraction as a function of gas velocity, for a 0.06% wt. SDS + 1.0% wt. 1-butanol solution, at a liquid velocity of 0.205 cm/s; without particles (solid circles) and with 10% volume fraction of resin-coated or hydrophobic sand from STIM-LAB, $\rho = 2.65 \text{ g/cm}^3$; mean size = 600–850 μm (open circles) and mean size = 500–600 μm (solid lozenges).

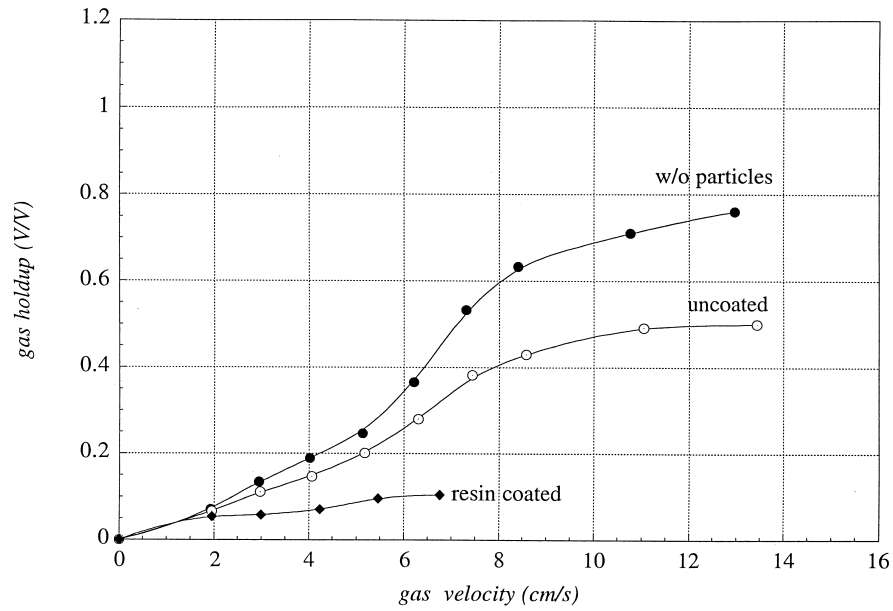


(a)

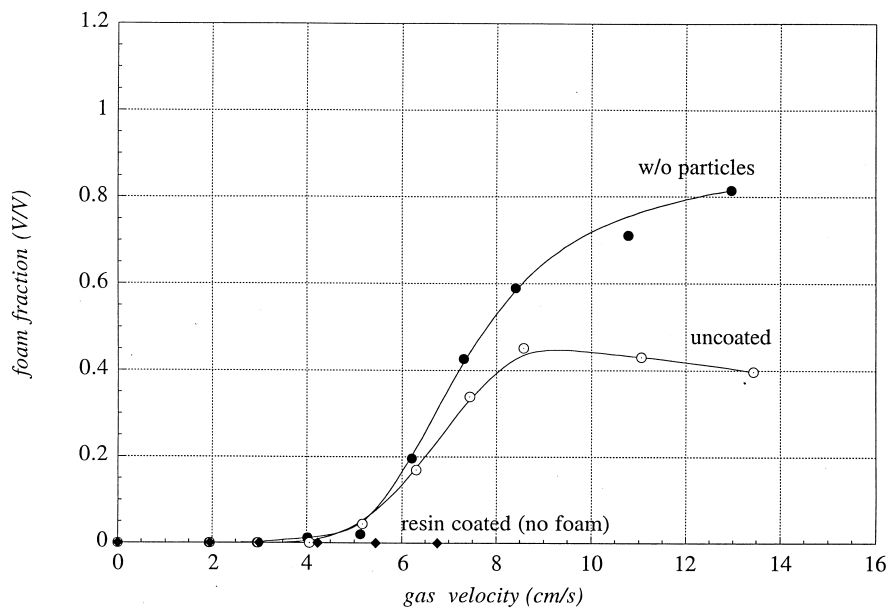


(b)

Fig. 14. (a) Gas hold-up as a function of gas velocity; and (b) foam fraction as a function of gas velocity, at a liquid velocity of 0.205 cm/s, for a 0.06% wt. SDS + 1.0% wt. 1-butanol solution, without particles (solid circles) and with 20% volume fraction of solids (from STIM-LAB, $\rho = 2.65 \text{ g/cm}^3$, mean size = 600–850 μm); hydrophilic sand (open circles) and hydrophobic sand (solid lozenges).



(a)



(b)

Fig. 15. (a) Gas hold-up as a function of gas velocity; and (b) foam fraction as a function of gas velocity, at a liquid velocity of 0.411 cm/s, for a 0.06% wt. SDS + 1.0% wt. 1-butanol solution, without particles (solid circles) and with 20% volume fraction of solids (from STIM-LAB, $\rho = 2.65 \text{ g/cm}^3$, mean size = 600–850 μm); hydrophilic sand (open circles) and hydrophobic sand (solid lozenges).

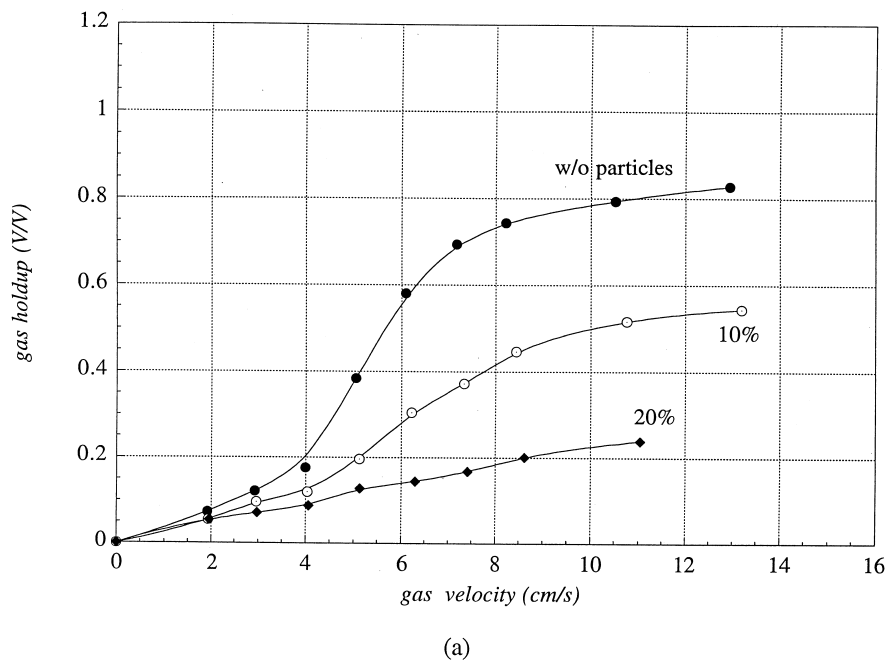


Fig. 16. (a) Gas hold-up as a function of gas velocity; and (b) foam fraction as a function of gas velocity, for a 0.06% wt. SDS + 1.0% wt. 1-butanol solution, at a liquid velocity of 0.205 cm/s; without particles (solid circles) and with resin-coated or hydrophobic sand from STIM-LAB, $\rho = 2.65 \text{ g/cm}^3$, mean size = 600–850 μm . The volume fractions are 10% (open circles) and 20% (solid lozenges).

The fluid mechanics of foam suppression with hydrophilic particles are enhanced by a direct attack on the foam by hydrophobic particles.

Hydrophobic particles are more effective in retaining liquid (destroying foam) than the hydrophilic particles.

For a fixed solids volume fraction (i.e. 10%), the 500–600 μm hydrophobic particles are more effective in retaining liquid (destroying foam) than the 600–850 μm hydrophobic particles. They expand so well and penetrate the foam so easily, that a large accumulation of particles at the top of the reactor is produced.

Owing to the large accumulation of the 500–600 μm hydrophobic particles at the top of the reactor, even for a liquid velocity as small as 0.103 cm/s, it was not possible to test them when there is no foam in the reactor, for a wide range of gas velocity (i.e. liquid velocity of 0.411 or 0.822 cm/s).

For a fixed particle size (i.e. 600–850 μm), the greater the volume fraction of hydrophobic particles (20% compared with 10%), the more effective is the foam suppression.

More research is needed in order to understand the behavior of different kinds of hydrophobic particles when there is no foam in the reactor.

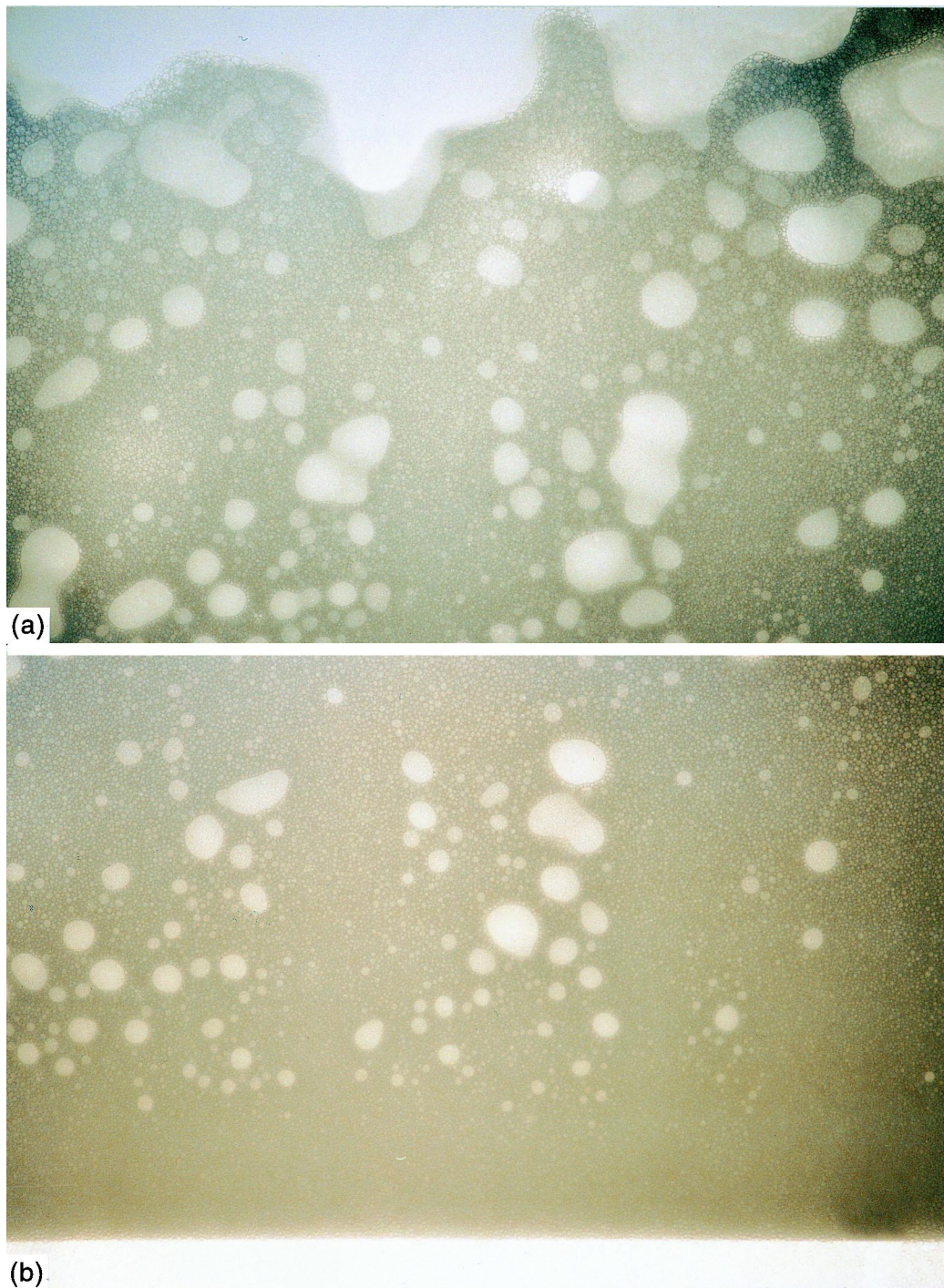


Fig. 17. Collapsing foam and foam interface above a fluidized bed after turning off the gas and liquid velocities (before 0.411 cm/s and about 13 cm/s, respectively); the particles settle to the bottom and the bubbly mixture disappears. The surfactant solution used was a 0.06% wt. SDS + 1.0% wt. 1-butanol in water solution. (a) Foam collapse when the particles were hydrophilic (uncoated sand from STIM-LAB; $\rho = 2.65 \text{ g/cm}^3$; mean size = 600–850 μm) no particles are in the foam. (b) Foam–water plus surfactant interface for the case described above. No particles stick in the foam–water plus surfactant interface.

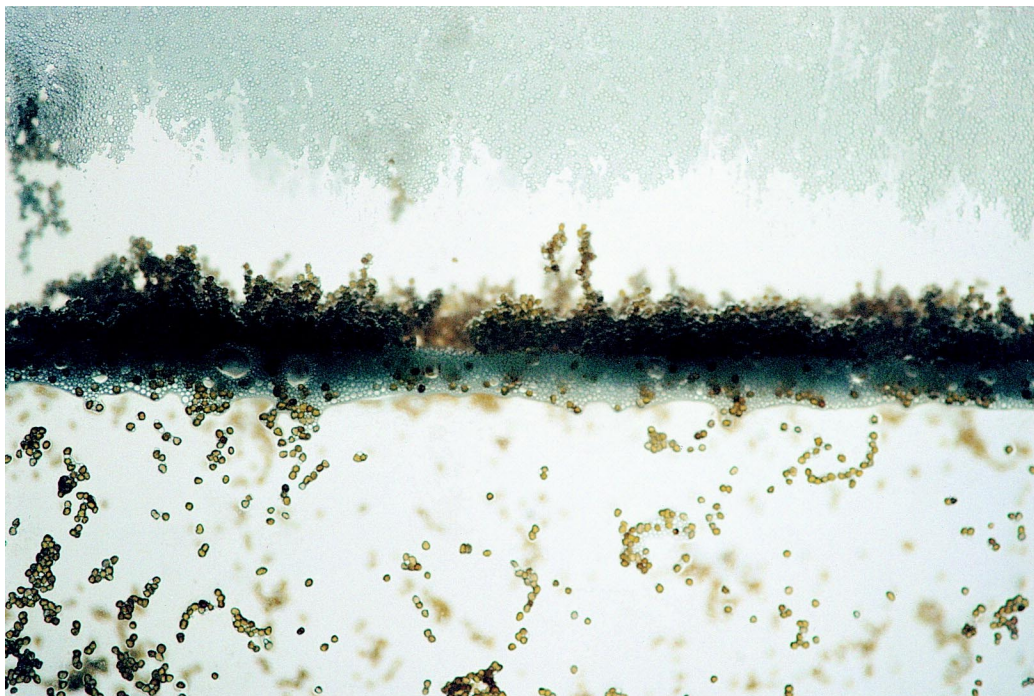


Fig. 18. Foam collapse and foam–water plus surfactant interface above a fluidized bed after turning off the gas and liquid velocities (before 0.411 cm/s and about 13 cm/s, respectively). The surfactant solution used was a 0.06% wt. SDS + 1.0% wt. 1-butanol in water solution. The particles used were hydrophobic (resin coated sand from STIM-LAB; $\rho = 2.65 \text{ g/cm}^3$; mean size = 600–850 μm). Most of the particles settle to the bottom and the bubble in the bubbly mixture disappear. Here, particles are levitated in the foam by attached air bubbles and are trapped in the interface by the same mechanism.

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