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Characterization of Multiphase Fluid Flow During Air-Sparged Hydrocyclone Flotation by X-Ray CT

Thirteenth Quarterly Report
14 August - 13 November, 1993

DOE Contract No. DE-FG22-90PC90311

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REPORT FOR THIRTEENTH QUARTER
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The research activities during this quarter of the DOE project, "Characterization of Multiphase Fluid Flow During Air-Sparged Hydrocyclone Flotation", involved a detailed parametric study of the flotation response of the ASH, establishing an empirical correlation between flotation response and operating variables and development of a phenomenological description of the observed responses. In these experiments with quartz particles flotation response is essentially characterized by recovery of the solids to the overflow. In this regard, dimensionless variables such as A^* - the ratio of overflow opening area to underflow opening area, Q^* - the ratio of air flow rate to slurry flow rate, percent solids in the feed suspension, particle size, inlet velocity (i.e. slurry pressure) all are of paramount importance. A series of experiments were designed to systematically study the effects of these variables on the flotation response. For each experimental condition the system response was quantified.

The variables studied were A^* , Q^* , slurry pressure (P), percent solids in feed (ϕ) and particle size. In all these experiments narrow-sized quartz particles were used. The reagents dosages were maintained at the same level of 40 ppm (water basis) of MIBC frother and 800 g of dodecyl amine collector per ton of dry solids in the suspension. At room temperature, quartz is intrinsically hydrophilic while addition of the amine collector renders the quartz particles hydrophobic. The absence of collector will be referred to as the hydrophilic case and the presence of

collector will be referred to as the hydrophobic case.

Samples were collected for a specified time from the overflow and underflow streams for various experimental conditions, followed by filtering and drying. Recovery values were calculated from the weights of the solids in each sample. Some of these results are presented graphically in Figures 1 through 4 illustrating the effects of the above-mentioned variables on the ASH flotation response.

Figure 1(a) shows the effect of A^* on recovery when the 100 x 200 mesh quartz particles are made hydrophobic by collector addition. It is evident from this figure that A^* has a strong influence on recovery, especially when the solids content of the feed is high (15%). In the range of A^* values studied, clearly, recovery increases with an increase in A^* . For a constant overflow opening area, a lower value of A^* means a larger underflow opening area. This affects the pressure drop and in turn, the flow reversal, thus decreasing the recovery. Since quartz particles are hydrophilic in the absence of collector, all the solids are expected to report at the underflow stream. Figure 1(b) shows that the recovery of the solids to the overflow is indeed very small in the case of hydrophilic particles.

Figure 2 shows the effect of slurry pressure on recovery of 100 x 200 mesh quartz particles for (a) 5% solids in feed and (b) 15% solids in feed, for various values of Q^* . The similarity between Figures 2(a) and 2(b) indicates that percent solids in the feed has negligible effect on recovery when the A^* value is maintained at 1.00. It can be seen from these figures that to

achieve maximum recovery, there is an optimum level both with respect to slurry pressure and Q^* . Recovery increases with Q^* up to a certain point and then it drops. The same trend is observed with slurry pressure too. This observation can be explained by the fact that the bubble-particle assembly can withstand a certain centrifugal force or a certain degree of turbulence in the ASH beyond which it breaks down and thus the recovery of solids to the overflow is reduced. In this regard, it may be expected that an increase in both slurry pressure and Q^* should increase the eddy dissipation of energy in the ASH.

Interesting results were obtained when the particle size in the feed slurry was lowered. These results are shown in Figure 3 for both 100 x 200 mesh and 200 x 325 mesh particle size. Examination of this figure reveals that in case of smaller particles (200 x 325 mesh), the slurry pressure beyond which the recovery starts to fall is higher. For these smaller particles, the attachment between the bubble and particle is much stronger and can withstand a higher centrifugal force or a higher degree of turbulence. It can also be observed from this figure that fine particle flotation efficiency is relatively higher and fairly insensitive to the levels of slurry pressure and Q^* over a broad range.

Based on the results of these tests an empirical model has been developed correlating recovery with the operating variables. This is presented below.

$$R=K(A^*)^\alpha \left(1+\frac{1}{(A^*)^2}\right) (Q^*)^\beta (P)^\gamma \exp(\delta \phi)$$

where, $K=2.7$; $\alpha=0.6+0.45\phi$

$$\beta=-0.5+0.2P-0.01P^2$$

$$\gamma=0.5; \delta=0.002$$

The recovery values calculated from this model compare fairly well with the values observed experimentally. This is presented graphically in Figure 4. The correlation coefficient was found to be 0.913.

Of course, the radial density distribution profiles obtained from x-ray CT measurements (presented in earlier quarterly reports) reflect the fluid flow behavior of the ASH to a great extent. It is intended to correlate those density distribution profiles, and thus fluid flow behavior of the ASH, with the flotation responses. This will provide a more complete understanding of the ASH flotation.

With regard to the phenomenological explanation of the ASH flow behavior, a computer code has been developed to calculate the bubble slip velocities at every point of the computational domain. The mathematical equations were formulated by balancing the forces acting on the bubble as it moves. The calculations are now being done for the two phase air-water system. Completion of these calculations will generate the steady state concentration profiles in the ASH for a two phase system, which will be compared with the experimentally observed radial density profiles obtained from x-ray

CT measurements for the case of no solids in the feed. It is intended to carry these calculations further for the three phase system at a later stage and thus develop a more complete understanding of the ASH flotation.

Figure 1 : Recovery of solids (100 x 200 mesh) to the overflow as a function of A^* for (a) hydrophobic and (b) hydrophilic quartz particles. $Q^* = 4.55$, slurry pressure = 12 psi.

Figure 2 : Recovery of hydrophobic quartz particles (100 x 200 mesh) to the overflow as a function of slurry pressure for various Q^* values and for two different solids percent in the feed.

Figure 3 : Variation in the recovery of hydrophobic quartz particles to the overflow with slurry pressure for various values of Q^* and two different particle sizes.

Model Equation :

$$R = K(A^*)^\alpha \left(1 + \frac{1}{(A^*)^2}\right) (Q^*)^\beta (P)^\gamma e^{\delta\phi}$$

$$K = 2.7 ; \quad \alpha = 0.6 + 0.45\phi$$

$$\beta = -0.5 + 0.2P - 0.01P^2$$

$$\gamma = 0.5 ; \quad \delta = 0.002$$

Figure 4 : Comparison between experimental recovery and the recovery calculated from the empirical model.

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