HOLDUP CORRELATIONS IN SLURRY-SOLID FLUIDIZED BEDS

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The use of slurry-solids fluid beds plays an important role in the development of synthetic fuels and the hydrogen processing of petroleum resid. In the H-Coal process in particular, coal oil slurries are processed over extrudates of hydrodesulfurization catalyst. The objective of this note is to present a model which describes the volume fraction occupied by the slurry phase. The accurate prediction of the liquid holdup is important not only for the calculation of the bed height in liquid solid fluidized beds, but also is required for the development of a model predicting the holdup in three-phase fluidized beds.

Although several correlations have been considered in the literature (Richardson and Zaki, Ramamurthy and Sabbaraju) for pure liquids, very little has been published for slurry systems. The objective of this paper is to extend the work of previous investigators for systems of particular interest to the H-Coal process. A summary of correlations describing liquid-solid fluidized beds has been presented elsewhere (Vasalos, et al., 1979, 1980).

In the present publication, the application of two correlations is considered: 1) the Richardson and Zaki; and 2) Ramamurthy and Sabbaraju. The first relates the liquid volume fraction (ϵ_1) due to bed expansion to the ratio of the superficial velocity (U_1) to the terminal velocity of a single particle (U_t):

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$$\epsilon_1^n = U_1/U_t \quad (1)$$

The second is based on an empirical approach where a function of Reynolds and Galileo numbers is related to the function $[1 - 1.21(1 - \epsilon_1)^{2/3}]^{-1}$. This function relates the velocity of a fluid in minimum cross-section of the bed to the superficial velocity. It is derived by assuming that the particles are arranged in an imaginary node of a simple cubical lattice.

Experimental

Data used in this work were obtained in a cold flow unit, details of which have been reported elsewhere (Vasalos, et al., 1979). The unit consists of a glass reactor 15 cm in diameter and 5 m in height. Extrudates of hydrodesulfurization catalyst (1.8 mm diameter, 5.1 mm length) were fluidized with coal fines-kerosene slurries and mineral oil. The density and viscosity of these fluids are reported in Table I. It has been found that this slurry has about the same viscosity as the H-Coal liquids at actual operating conditions.

For each set of conditions, the bed height was measured by scanning the entire reactor length with an elevator on which was mounted a 10 mc gamma-ray source and a detector. From the change in the gamma-ray absorption, the bed height can easily be inferred. The liquid or slurry holdup is then determined from the equation:

$$1 - \epsilon_1 = M/\rho_c A H \quad (2)$$

Results and Discussion

The application of the Richardson and Zaki correlation to coal char-kerosene slurries and mineral oil is shown in Figures 1 and 2, respectively. From plots of this type the particle terminal velocity, U_t , and the exponent, n , are derived with the application of standard techniques. The extrapolated particle terminal velocities and the calculated particle Reynolds and Galileo numbers are listed in Table II. For this calculation of the dimensionless groups (Re_t , Ga), the equivalent particle diameter (defined as the diameter of a sphere having the same volume) is used. The terminal velocity Reynolds number was found to depend on Galileo number with the following correlation, which is also illustrated in Figure 3:

$$Re_t = 0.132 Ga^{0.714} \quad (3)$$

$$\text{where: } Re_t = d_s U_t \rho / \mu \quad (4)$$

$$Ga = d_s^3 \rho (\rho_s - \rho) g / \mu^2 \quad (5)$$

Figure 3 indicates that both coal slurry and mineral oil data fall in the same line, supporting an earlier conclusion (Vasalos, et al., 1979) that coal char-kerosene slurries behave as a simple liquid of similar viscosity.

From Equation 3, the particle terminal velocity is easily derived by the following equation:

$$U_t = 0.132 g^{0.714} d_s^{1.142} (\rho_s - \rho)^{0.714} / \rho^{0.286} \quad 0.428 \quad (6)$$

The range of Re_t and Ga covered is:

$$25 < Re_t < 100$$

$$10^3 < Ga < 10^5$$

Equation 6 is similar to that reported by Lewis and Bowerman (1978) for spheres; however, it is necessary to include the effect of particle sphericity. Sphericity is defined as:

$$\phi_s = (\text{surface area of sphere} / \text{surface area of particle})_{\text{both of the same volume}} \quad (7)$$

In this study the sphericity factor was 0.67.

Following the determination of the particle terminal velocity, the exponent n was related to Re_t by the following correlation:

$$n = 4.64 (Re_t)^{-0.055} \quad (8)$$

The small change of n with Re_t as previously reported by Richardson and Zaki is expected for a range of Reynolds numbers of 1 to 200.

Another approach was also followed in correlating the data. It is based on the use of the Galileo and Reynolds numbers as previously discussed by Ramamurthy. In relating a function of Re and Ga with $[1 - 1.21(1 - \epsilon_1)^{2/3}]^{-1}$, it is expected that as $\epsilon_1 \rightarrow 1$ the correlation should approach Equation 3. for this reason, all data were correlated using the function $Re/(0.132 \times Ga^{0.714})$. The results are shown in Figure 4. It is observed that the following correlation exists:

$$Re/0.132 Ga^{0.714} = \phi \epsilon^{-1.514} \quad (9)$$

$$\text{where: } \phi = [1 - 1.21 (1 - \epsilon_1)^{2/3}]^{-1} \quad (10)$$

This relationship is slightly different from that reported by Ramamurthy and Sabbaraju (1973) for the intermediate flow region.

A comparison of the Richardson and Zaki approach with Equation 9 was made for a bed of catalyst particles (1.8 mm x 5.1 mm) fluidized with mineral oil at 80°C. At these conditions, the density and viscosity of mineral oil were found equal to 0.81 g/cc and 4.2 cp, respectively. Using Equations 6 and 8, the particle terminal velocity and index n were found equal to 14.2 cm/sec and 3.65, respectively. A comparison of experimental values of ϵ_1 with the correlations presented in this study is shown in Table III. Although both correlations predict the liquid holdup fairly accurately, Equation 9 offers a more general approach for those cases where n changes rapidly with Reynolds number and other systems parameters.

Because these correlations are based on only one particle size, future work will investigate the effect of sphericity factor ϕ_s on the structure of the equations.

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NOMENCLATURE

		<u>Typical Units</u>
A	Cross-sectional area of reactor	cm ²
d	Particle diameter	cm
d _s	Equivalent diameter of a sphere	cm
g	Acceleration of gravity	cm/sec ²
Ga	Galileo number	
H	Catalyst bed height	cm
M	Mass of dry catalyst to reactor	g
Re _t	Particle Reynolds number based on U _t	--
U _l	Superficial liquid velocity	cm/sec
U _t	Terminal velocity of an isolated particle	cm/sec

Greek

ε _l	Volume fraction of liquid	--
ρ	Density of liquid or slurry	g/cm ³
ρ _c	Density of a dry catalyst particle	g/cm ³
ρ _s	Density of liquid-soaked catalyst particle	g/cm ³
μ	Liquid or slurry viscosity	Poise
Φ	Correlation parameter (Equation 10)	--
Φ _s	Sphericity of catalyst particle (Equation 8)	--

Subscripts

n	Richardson-Zaki index n or exponent

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TABLE I
SUMMARY OF EXPERIMENTAL RUNS

<u>Run No.</u>	<u>Liquid</u>	<u>Fines, Vol%</u>	<u>Temp, °C</u>	<u>Density, g/cc</u>	<u>Particle Density*</u>	<u>Fluid Viscosity, cp</u>
204	Kerosene	5.1	21	0.835	1.63	3.5
211	"	17.8	26	0.952	1.70	8.2
214	"	15.5	65	0.927	1.69	6.7
422	Mineral Oil	0	65	0.820	1.61	6.1
428	"	0	53	0.830	1.61	9.1

*Soaked with liquid.

TABLE II
PARTICLE TERMINAL VELOCITIES

<u>Run No.</u>	<u>U_t, cm/Sec</u>	<u>Re_t</u>	<u>Ga</u>
204	15.37	99	10,405
211	9.78	31	2,033
214	10.63	39	2,985
422	11.52	42	3,342
428	10.14	25	1,501

TABLE III
COMPARISON OF RICHARDSON-ZAKI WITH EQUATION 1:
LIQUID--MINERAL OIL

<u>U₁, cm/Sec</u>	<u>ε₁, Experimental</u>	<u>ε₁ Predicted R-Z</u>	<u>Eq. 8</u>
2.5	0.60	0.62	0.58
3.0	0.65	0.65	0.61
4.5	0.73	0.73	0.70
6.0	0.82	0.79	0.78
1.6	0.51	0.55	0.49

Figure 1

Application of Richardson-Zaki Correlation to Coal-Char kerosene slurry/catalyst

Figure 2

Application of Richardson-Zaki correlation Mineral oil/catalyst

Figure 3

Terminal Velocity Reynolds Number

Figure 4

Correlation of liquid holdup data