FLUIDIZATION OF INITIALLY SEGREGATED EQUI - DENSITY BINARY SYSTEMS

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Abstract Fluidization of initially segregated binary mixtures has been investigated for narrowly sized particle systems of the same material. This paper reports experiments conducted in 0.055m diameter fluidizes bed for binary mixtures composed of sands whose sizes ranged from 450 to 1450μm. An empirical relationship, $U_{tf} = 0.95\ U_F\ (d_R)^{0.87}$, was derived in terms of the minimum fluidization velocity of the smaller particle, U_F, and particle diameter ratio, d_R, for predicting the velocity at commencement of total fluidization. This expression was found also suitable for estimating the take-over velocity of equi-density binary systems which enables good prediction of mixing behaviour. The corresponding expression for pressures drop at the commencement of total fluidization was formulated as $\Delta P_{tf} = \exp\ (1.7\ U_F(d_R)^{0.13})$.

Key Words Fluidization, Fluidized Bed, Minimum Fluidizing Velocity, Take-over Velocity

چکیده سیال‌سازی مخلوط های دوجزئی از ماسه با ابعادی در محدودهٔ ۴۵۰ تا ۱۴۵۰ میلی میکرون در یک سر سیال به قطر ۰/۰۵۵ متر مطالعه شده است. یک رابطهٔ تجربی به صورت زیر به منظور تخمین سرعت آغاز سیالیت تمام قطعات، برحسب حداقل سرعت سیالیت قطعات کوچکتر U_F، و نسبت قطر ذرات d_R، بدست آمده است: $U_{tf} = 0.95\ U_F\ (d_R)^{0.87}$ این رابطه در تخمین سرعت جابجائی سیستم های دوجزئی هم جرم ویژه نیز مفید است و امکان پیش بینی چگونگی عمل اختلاط را میسر می‌سازد. رابطهٔ دیگری نیز برای تعیین افت فشار در آغاز سیالیت تمام مواد به‌شکل زیر حاصل شده‌است:

$$\Delta P_{tf} = \exp\ [1.7\ U_F\ (d_R)^{0.13}]$$

INTRODUCTION

Tow basic features commonly observed in the fluidization of multisized systems are mixing and segregation phenomena. Both processes of which the mechanisms have been well studied [1-17] play a vital role in the industrial application of fluidized bed technology. Good mixing brought about by efficient circulation and uiform agitation of the bed materials is desirable in processes where localized not spots and stagnant regions should be avoided such cases exist in industrial boilers where clinkering, caking or both must be prevented. This is also important in fluid catalytic cracking operations where the continous circulation of the catalyst between the reactor and the regeneration units is necessary. On the other hand, in fluidized bed reactors for solid waste treatments and dry mineral processing, segregation mechanism is employed to achieve separation of different species. Both mixing and segregation of solids during fluidization are caused by the action of bubbles a well bubbling gas, fluidized bed particle mixing is good and rapid, but strong segregation can also occur if the bed contains particles of different physical properties. Segregation is more sensitive to density difference than size difference [9]. While a fairly wide particle size difference can be tolerated without appreciable segregation, a small density difference readily leads to the settling of the denser particles [2]. Cape & Sutherland [16] have noted that segregation is most efficient with gas velocities just above the required value for incipient fluidization. However, for binary particles of the same density, the primary variables affecting particle segregation are the minimum fluidization velocities of the individual solids and the gas velocity. For equi-density multicomponents system, the criterion for particle segregation for consecutively-sized solid is given as:

$$U_J/U_F > 2$$

while no particle mixing occurs [18] at gas velocity up to 1.2 U_{mf}.

In binary systems, mixing and segregation mechanisms compete, and in a freely bubbling bed, a stable equilibrium of solids (i.e segregation pattern) is reached in a very short time (10 to 20 sec) [9]. The time required for a complete turnover of a bed contents has been estimated by Rowe [19]. Takeover velocity, U_{To}, is widely used to characterize the region where the physical forces promoting mixing take over or begin to dominate segregation[13]. Knowledge of U_{To} is important in the evaluation of the degree of mixedness through the correlations

$$M = X_J/\bar{X}_J = 1/(1+e^{-F})$$

where, M is the mixing index,

F is dimensionless velocity term difined as

$$F = [(U - U_{To})/(U - U_F)] \exp(U/U_{To}),$$

X_J is the mass fraction of the larger particle size (jetsam) in the uniform upper bed, and $\bar{X}_J$ is the overall jetsam mass fraction.

U_{To} is arbitararily defined as the superficial gas velocity at M = 0.5.

Nienow and Ghiba [10] and Peeler and Huang [13] have reviewed the various correlations available for predicting U_{To}. Notably among these are Equations 1 to 3 according to Nienow, et al., [12] Rice, et. a [15], and the modified version by Peeler, et al. [13].

$$U_{To}/U_F = (U_J/U_F)^{1.2} + 0.9\,(\rho_R - 1)^{1.1}(d_R)^{0.5} - 2.2\,\bar{X}_J^{0.7}(1-e^{-R_a})^{1.4} \tag{1}$$

$$U_{To} = (U_F U_J)^{0.5}(2R_a)^{-0.2} \tag{2}$$

$$U_{To} = 0.27\,(U_J U_F)^{0.5}(d_R)^{0.5}(D_b)^{-0.21} \tag{3}$$

In these equations R_a is the bed aspect ratio (H/D), ρ_R is the density ratio and D_b is the bubble diameter at the take-over velocity. These equations have been found useful in interpreting solids mixing and segregation mechanisms during fluidization of binary systems.

If the bed materials were to be segregated initially before the commencement of fluidization, it might be likely that U_{To} would be the same as the superficial gas velocity at which mixing commences in earnest as the bed becomes totally fluidized. The present work investigates the velocity at total fluidization for binary sand mixtures with particle size ratios upto 3.22. It also attempts to develop empirical relationship between the total fluidization velocity, particle size ratio, and minimum fluidization velocities of the components in the mixture.

EXPERIMENTATION

Experiments were carried out in a conventional fluidization column made of pyrex, 0.055m internal diameter and 0.75m high. The bed was supported by a standard synthetic grid distributor of equal-sized micropores. The pressure drop across the distributor and the bed was measured using U-tube mercury manometer.

A high powered compressor supplied the air for fluidization. The air flow rate was measured using a pre-calibrated gasometer. The bed material used for the experiments was sand particles with density of 0.81×10^3 kg/m³ and sizes ranging from 450 to 1450µm.

The sand particles were first demagnitized to remove ferrous impurities, then thoroughly washed several times to remove dirts and other soluble impurities, and finally oven dried at 40°C for about 10 hours. The sand was then classified into six test samples (A to F) of different sizes by method of sieve analysis.

Five binary mixtures were prepared from the six test samples such that the particle diameter ratio of the larger particles relative to the smaller ones, d_R, varied from 1.22 to 3.22.

Studies were first conducted at constant bed weight of 200gm for each of the six test samples. Then they were repeated for the same bed weight using each of the binary mixtures whose static bed height varied between 0.051m to 0.053m. The variation depended on the fractional composition of each particle component in the mixture. The jetsam was placed at the bottom of the bed and overlayed with the finer particles (flotsam) and then gradually fluidized.

The basic measurements made were the superficial gas velocity and the pressure drop across the distributor and the bed at various fluidizing velocities.

RESULTS AND DISCUSSION

It was observed that as the air velocity was gradually increased to a certain value, the flotsam at the top of the bed began to fluidize at the velocity of beginning fluidization, U_{bf}, while the jetsam remained packed. With further increase in U, the packed jetsam began to fluidize as well. At this point particle segregation at the jetsam/flotsam interface started to break down and mixing across the interface began. This is characterized by a point on the plot of log ΔP versus log U at which ΔP reaches maximum and sharply falls before rising again. Hence fluidization at this instance is in downward direction, from top to bottom.

As the gas velocity was decreased at the end of the fluidization, partial mixing of the materials was observed. Some of the flotsam remained at the top of the bed while some were found at the bottom. The jetsam had the same experience. The degree of mixing was higher for systems with smaller particle size ratios.

Log - log plots of the pressure drop across the bed versus the superficial gas velocity, U, were prepared and used to determine (a) the minimum fluidization velocities of the monosize test samples (U_J and U_F), (b) the total fluidization velocity, U_{tf}, and (c) their corresponding pressure drops. Tables 1 and 2 show data obtained from the analysis.

Binary mixtures of constant size ratio had the same value of U_{tf} which was higher than U_F but lower than U_J of its constituent bed materials. This is consistent with the result of other works [9,10]. However the effect of variation in the fractional

TABLE 1: Minimum Fluidization Velocity, U_{mf}, of Particle Size.

Sand Sample	Average Diameter d_p , µm	u_{mf} , cm/s
A	450	4.42
B	550	5.37
C	725	6.82
D	1015	8.84
E	1290	11.24
F	1450	13.57

TABLE 2: U_{tf} for Binary Mixtures for Size Ratio Upto 3.22.

Mixture of a with	Diameter Ratio d_R	U_{tf} cm/s	Log ΔP_{tf} KPa/m²
B	1.22	4.99	3.36
C	1.61	6.31	3.49
D	2.26	8.08	3.63
E	2.87	10.35	3.74
F	3.22	12.56	3.84

composition of the particles in the mixture for jetsam-rich systems ($X_F < 0.5$) did not change U_{tf} of the individual binary mixture. This shows that U_{tf} was independent of flotsam composition (X_F). This is contrary to the observations for binary systems which involve materials having different densities [10]. It seems, therefore, that U_{tf} is more sensitive to size ratio differences than to variations in fractional composition of the bed materials in equi-density binary systems. The observed fluidization in the downward direction is in agreement with the results of earlier works [7,20]. Of course, it is expected since the velocity of the fluidizing air is higher at the top of a fluidizing bed than it is at the bottom due to pressure differential. The non-uniformity in the porosity of the materials along the bed accounts [21] for the existence of a range of velocities for which a relatively packed (mostly jetsam) and the top fluidizing (largely flotsam) regions exist simultaneously.

From the results it is obvious that for a homogeneous binary system having the same density, the total fluidization velocity, U_{tf}, depends on the size ratio, d_R, and the minimum fluidization velocity of the flotsam component. This can be related through an expression of the form

$$(U_{tf} / U_F) \propto (d_R)^{\eta} \quad (4)$$

Appropriate values for the power dependence (η) and the proportionality constant were evaluated using data fitting regressional technique which yielded the expression;

$$U_{tf} = 0.95\ U_F\ (d_R)^{0.87} \quad (5)$$

Equation 5 shows a reasonable fitting with the experimental data and has coefficient of correlation of the order of 0.998. By using values in Table 2 and adopting the procedure mentioned above, the following expression was developed for estimating the pressure drop at the commencement of total fluidization:

$$\Delta P_{tf} = \exp\ [1.7\ U_F\ (d_R)^{0.13}] \quad (6)$$

Equation 6 gives a good fit with the experimental dàta as can be seen in Figure 1.

Equation 5 was compared with Equations 1 to 3 for U_{T_o} and tested with literature data spanning a wider particles size range. Table 3 shows the computed values for U_{T_o} and U_{tf} using data extracted from the work of others [13]. Equation 5 has a maximum deviation of 37% compared to values of 136%, 60% and 14%, respectively, for Equations 1, 2 and 3. Also its average absolute deviation of 22% is considerably lower than 39% and 97% for Equations 2 and 1, respectively.

Equation 1 which was originally proposed for non-equal density systems was adapted for equidensity calculations which had to be accounted for the very high estimation error. However, Equation 5, proposed in this work, compares reasonably well with Equation 3 relative to the others and has values of the

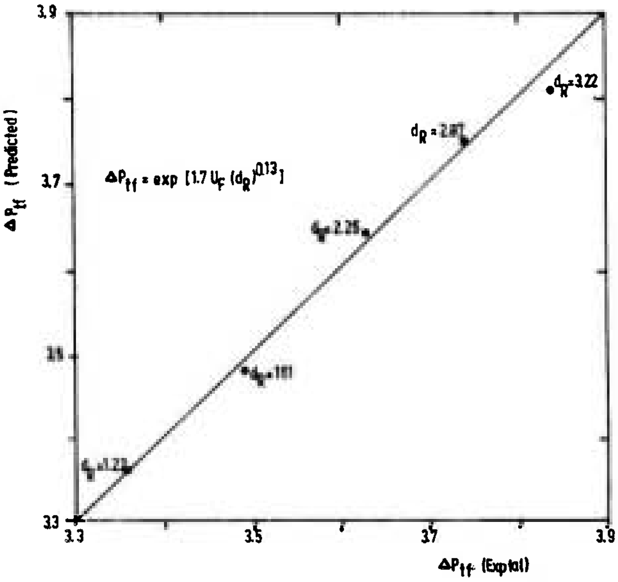

Figure 1. Crossplot for pressure drop at commencement of total fluidization

TABLE 3: Calculated Values of Take-Over Velocity Using Literature[13] Data for Eq. (1 to 5)

Samle	dp µm	U_{mf} mf m/s	d_R for S_1 mixtures with	U_{To}, Take-over Velocities, m/s [13]								
				Experimental	Eq. (5) Nienew et al [12]	% error	Eq. (6) Rice et al [15]	% error	Eq. (3) Peeler et al [13]	% error	Eq. (5) This work	% error
S_1	208	0.032	-	-	-	-	-	-	-	-	-	-
S_2	440	0.165	2.1	0.057	0.079	+38	0.057	0	0.065	+14	0.058	+1.7
S_3	680	0.340	3.3	0.11	0.19	+72	0.082	-33	0.12	+5	0.086	-22
S_4	1340	0.750	6.4	0.21	0.49	+133	0.12	-43	0.22	+5	0.15	-27
S_5	2030	1.05	9.6	0.35	0.73	+108	0.14	-60	0.32	-9	0.22	-37
S_6	2850	1.25	13.7	0.38	0.90	+136	0.16	-58	0.39	+3	0.29	-23
				A.A.D	-	97	-	38.8	-	7.2	-	22.14

$$A.A.D. = (1/n) \sum_{i=1}^{n} /E_i/$$

where A.A.D. - Average Absolute Deviation

$E_i = [(X_{exp} - X_{est}) / X_{exp}]_i \times 100$, for i = 1, 2.... n

here X_{exp} and X_{est} represent the experimental and estimated values respectively and n is the number of data.

order of U_{To}.

Therefore, it appears that even though U_{tf} in this study has not been measured and defined in terms of the equilibrium mixing index, M, as is the case with U_{To} determination [9,10], it is the same characteristic velocity as that often termed take-over velocity for binary systems [10,12-13,15]. This is more so since both velocities display no dependence on X_F for equidensity binary systems as seen in Equations 2 and 3. Thus U_{tf}, as measured in this work, typifies the superficial gas velocity at which a transition from particles segregation to particles mixing occurs. It corresponds to that gas velocity at which the pressure drop in the bed reaches maximum and suddenly falls before rising again. From repeated runs, it was evident that the peak pressure drop could be evaluated straight from the manometer readings without any recourse to the conventional method of plotting the data. This considerably simplifies the procedure for estimating U_{tf}; also the non-inclusion of bubble diameter term, D_b at the take-over velocity, in the expression is an added advantage in using proposed Equation 5.

COLCLUSIONS

Fluidization in initially segregated binary mixtures in which the coarser particles are overlayed with finer ones of the same materials is in downward direction. The velocity at beginning of total fluidization is constant for a given particles diameter ratio, d_R, and does not depend on the fractional composition of the constituent bed materials, at least for d_R up to 3.22. The equation formulated for velocity at the commencement of total fluidization, $U_{tf} = 0.95\ U_F \times (d_R)^{0.87}$, was also found suitable for predicting the take-over velocity of equi-density binary mixtures. This equation has been shown to fit reasonably well the experimental data spanning wide particle size range (upto 13.7) and to a greater extent it is superior to some of the existing expressions for the take-over velocity. Similarly the equation developed for pressure drop at the commencement of total fluidization $\Delta P_{tf} = \exp[1.7U_F(d_R)^{0.13}]$ correlated well with the experimental values.

NOMENCLATURE

D - Bed diameter, m
D_b - Bubble diameter, m
d_F - Diameter of flotsam, m
d_j - Diameter of jetsam, m
d_p - Diameter of particle, m
d_R - Particles diameter / size ratio, d_J/d_F
H - Bed height, m
R_a - Bed aspect ratio, H/D
U - Superficial gas velocity, m/s
U_{bf} - velocity at beginning of fluidization, m/s
U_F - Minimum fluidization velocity of flotsam, m/s
U_J - Minimum fluidization velocity of jetsam, m/s
U_{mf} - Minimum fluidization velocity, m/s
U_{tf} - Total fluidization velocity, m/s
U_{To} - Take-over velocity, m/s
X_F - Weight fraction of flotsam
X_J - Weight fraction of jetsam
ΔP - Pressure drop across the bed, KN/m^2
ρ_R - Particle density ratio, ρ_J/ρ_F

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