Transient Fluidization and Segregation of Binary Mixtures of Particles

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Fluidization of binary mixtures of particles belonging to group B of the Geldart classification of powders was studied. Beds tested were prepared by mixing in different proportions particles with almost equal density ($\approx$ 2,500 kg/m^3) and dissimilar size (125 μm silica sand and 500 μm glass beads). Experiments were carried out using a segmented fluidization column equipped with multiple pressure transducers. Experimental procedures included continuous monitoring of pressure drop at different locations along the bed during quasi-steady or stepwise changes of gas superficial velocity, and characterization of particle-size distributions in each segment of the fluidization column after fluidization of the bed for given times. Three ranges of gas superficial velocity were recognized for each solids mixture. At low velocity the bed behaves as a fixed bed. At high velocity, it is fully and steadily fluidized. In an intermediate velocity range, transient fluidization takes place: an initially uniform fluidized bed eventually undergoes segregation, giving rise to a defluidized bottom layer rich in the coarser solids and to a "supernatant" fluidized layer where finer particles prevail. The thresholds between these velocity ranges are rather sharp and were characterized as functions of initial bed composition. Rates at which the defluidized solids layer builds up from initially uniform beds, and the ultimate compositions of the defluidized bottom and fluidized top layers are characterized for beds with different compositions at variable gas superficial velocity.

Introduction

Mixtures of solids characterized by broad distributions of size/or density are often processed in fluidized beds. Typical examples are: solid fuels combustors/gasifiers (Chen and Keairns, 1978); catalytic polymerization reactors (Khang and Lee, 1997); solids mixers (Fan et al., 1990) and classifiers (Gel'perin et al., 1964); and solids dryers (Mourad et al., 1994). Steady or transient fluidization of multidisperse powders can also be indirectly promoted by fast bulk particles motion, as in airslides (Dolgunin and Ukolov, 1995), chute flows, or during efflux from bins and hoppers. Nature provides additional examples of unsteady fluidized/aerated states of multidisperse particles associated with rapid flows, such as pyroclastic flows (Wilson, 1980; Di Pastena, 1997; Marzocchella et al., 1998) and snow avalanches.

An extensive literature has been published on the mixing/segregation behavior of aerated/fluidized beds of dissimilar solids. Attention has been focused mostly on the minimum gas superficial velocity necessary to fully and steadily fluidize multidisperse solids (Cheung et al., 1974; Chiba et al., 1979; Yang and Keairns, 1982; Thonglimp et al., 1984; Noda et al., 1986; Formisani, 1991; Hoffmann et al., 1993). Nienow and Chiba (1985) extensively reviewed the subject, pointing out the broad discrepancies existing among the criteria suggested by various authors to identify the minimum fluidization velocity of solids mixtures. A commonly accepted definition of this

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threshold is apparently lacking. Differences are often related to the different initial mixing state in which solids mixtures can be found. Correspondingly, the minimum fluidization velocity of the solids mixtures can span between the minimum fluidization velocity of the smaller/lighter (*flotsam*) particles ($U_{mf,F}$) and that of the larger/denser (*jetsam*) particles ($U_{mf,J}$) or even lay outside the $U_{mf,F}-U_{mf,J}$ range.

Beds composed of multidisperse solids fluidized at steady gas superficial velocity may display unsteady fluidization behavior if segregation of the various solids components occurs. Only relatively few studies (Chen and Keairns, 1975; Yoshida et al., 1980; Yang and Keairns, 1982; Hemati et al., 1990; Kozanoglu and Levy, 1992; Beeckmans and Agrawal, 1994; Hoomans et al., 1998; Zhang et al., 1998; Wu and Baeyens, 1998) considered the dynamics of particles segregation. In particular, Yang and Keairns (1982) pointed out that the time scale of particle segregation in steadily fluidized binary mixtures of particles, belonging to group B and D, is on the order of seconds to minutes, depending on the gas superficial velocity. Gel'perin et al. (1964), Chen and Keairns (1975), and Marzocchella et al. (1998) have shown the existence of transient fluidization regimes at gas superficial velocities intermediate between those at which the bed is in the fixed state and those at which full and steady fluidization of solids mixtures occur. Comprehensive analyses of mechanisms underlying mixing/segregation during fluidization of multidisperse solids are provided by Gibilaro and Rowe (1974) and by Naimer et al. (1982).

The present article concerns the transient fluidization behavior of binary solid mixtures. The following objectives are pursued: (a) defining, for a set of binary mixtures of dissimilar materials, the gas superficial velocity ranges corresponding to the fixed-bed state, to the steadily fluidized state, and that intermediate state at which transient fluidization is observed; (b) characterizing the time-scales over which buildup of a defluidized solids layer occurs in the transient fluidization regime; and (c) characterizing the ultimate axial solids concentration profiles established after transient fluidization.

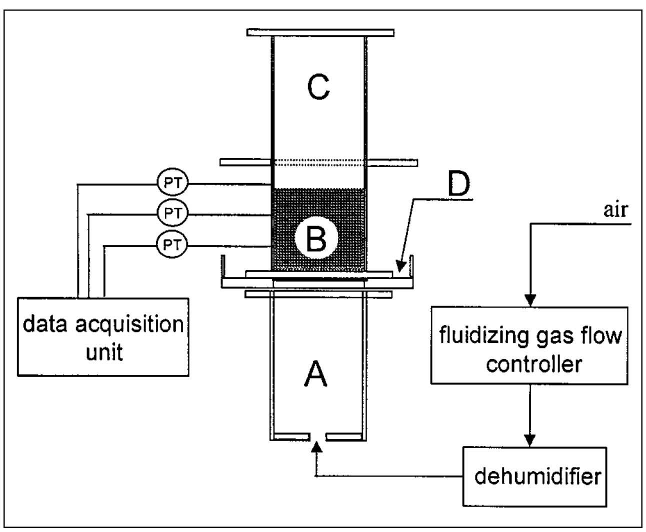

Figure 1. Experimental apparatus.

(A) windbox; (B) fluidized bed; (C) freeboard; (D) solids collection plate. PT: pressure transducer.

Experimental Studies

Experimental apparatus

The experimental apparatus is shown in Figure 1. It consists of a 0.120-m-ID Plexiglas fluidization column, 1.5 m high, equipped with a gas-flow controller, a dehumidifier, a set of electronic pressure transducers, and a data-acquisition unit (Di Pastena, 1997). The lower part of the column consists of an assembly of cylindrical segments 2.5 cm high, each equipped with a pressure tap connected to a transducer. The fluidizing gas is fed through a sintered brass distributor characterized by a high-pressure drop. The dehumidifier consists of a fixed bed of silica gel high enough to reduce the humidity in the fluidizing gas to less than 5%, as measured by a digital hygrometer. Pressure transducers were of the high-precision piezoelectric type. The data-acquisition unit consisted of a PC equipped with a 12 A/D data-acquisition board. Pressure time series were logged on at preset sampling frequencies (100–200 Hz) and for fixed time intervals (0.5–20 min).

Materials

Table 1 reports the main properties of solids. Beds consisted of binary mixtures of 125 μm silica sand (flotsam) and 500 μm glass beads (jetsam) in various proportions. Solids were chosen so as to meet the constraint that the terminal velocity of the flotsam be larger than the minimum fluidization velocity of the jetsam. The ratio between the minimum fluidization velocities of the jetsam and of the flotsam was about 13. The total mass of the bed was kept constant at 2.8 kg.

Fluidizing gas was technical air, dehumidified as just indicated. A few comparative tests, carried out with nondehumidified air, indicated that results are not significantly affected by moisture, at least in the range investigated.

Procedures

Bed solids were kept in the oven at 120°C for one hour to remove moisture, then mixed in the desired proportion for one hour in a rotary mixer prior to being poured into the column.

Two types of experimental procedures were followed:

(A). The gas superficial velocity, U, was quasi steadily increased, starting from the fixed-bed state until the bed be-

Table 1. Properties of Solids

Material	Silica Sand (flotsam)	Glass Beads (Jetsam)
Sauter mean dia., μm	125	500
Size, μm	100–150	400–600
Sphericity	≈ 1	1
Particle dens., kg/m^3	2600	2540
Geldart group	B	B
Terminal vel.,* m/s	0.80	4.1
Min. fluidiz. vel.,** m/s	0.017	0.22

*Value calculated according to Haider and Levenspiel (1989).
**Value calculated according to Leva (1959).

came fully fluidized. Then, the superficial gas velocity was slowly reduced until the bed returned to the fixed state.

(B). The gas superficial velocity was suddenly raised from zero to a preset value, where it was kept for periods ranging from 0.5 to 20 min. After the preset fluidization time expired, the bed was "frozen" by suddenly shutting off the fluidizing gas flow.

In both types of experiments, gas pressure (P) was continuously recorded at different levels in the bed. In some cases size distributions of solids in each segment were directly obtained by sieve analysis at the end of experiments. To this end, cylindrical segments were disassembled one at a time, gently pouring the bed solids contained therein into the collection, plate D of Figure 1, from where they were retrieved for subsequent sieving. The axial profile of the solids mixture fraction X_J along the bed could be determined accordingly. Here, X_J was defined as the volumetric fraction of the jetsam with respect to the solids mixture, not including interparticle voidage. The control volumes over which X_J could be measured were those of the cylindrical segments (ID 12.0 cm, height 2.5 cm). Therefore, they represented averages over each segment.

A few experiments were purposely carried out in which axial solids concentration profiles were assessed immediately after bed charging. It was found that no appreciable segregation occurred prior to the beginning of either type-A or type-B experiments.

Local bed density (ρ_b) under fluidized conditions has been calculated as $\rho_b = (\Delta P / g \Delta z)$ where g is the acceleration due to gravity, and Δz the distance between pressure taps. For particles of equal density (ρ_s), the voidage (ϵ) can be evaluated as $\epsilon = 1 - (\rho_b/\rho_s)$.

Mixing index

Nonuniformity of solids composition in the bed has been frequently expressed by the ratio of the jetsam concentration in the upper layer of the bed to the average jetsam fraction X_{J0} (Nienow and Chiba, 1985). However, experimental evidence (Hemati et al., 1990; Marzocchella et al., 1998) suggests that, in general, the solids composition profile along the bed is not uniquely related to this ratio. Schofield (1976) surveyed definitions of the mixing quality of a particulate solids mixture and highlighted the drawbacks of basing mixing indexes on pointwise measurements. It was suggested that mixing indexes should rather be based on integral parameters of the solids composition profile. Consistently with this advice and similarly to Hemati et al. (1990), the mixing index M has been defined here as

$$M = \frac{\int_0^{H^*} |X_J^* - X_J| \, dz}{\int_0^{H^*} |X_J^* - X_{J0}| \, dz}, \tag{1}$$

where H^* is the static bed height in the completely segregated state (Figure 2). According to the definition, M is a measure of the deviation between the actual solids composition profile and that associated with the completely segregated state, $X_J^*(z)$: jetsam particles segregated at the bed bottom ($X_J^* = 1$) and flotsam particles at the top ($X_J^* = 0$) (see Figure 2). The index M, normalized with respect to the condition of completely mixed state ($X_J = X_{J0}$ throughout the bed), ranges between 0 and 1, which correspond to completely segregated and to well-mixed beds, respectively (Figure 2).

Results

The static-bed voidage of binary solids mixtures

The static-bed height was recorded at the beginning of each experiment and worked out in order to calculate the voidage of the thoroughly mixed bed under fixed conditions. This is reported as a function of the average jetsam fraction X_{J0} in Figure 3. In agreement with previous experiments (Formisani, 1991; Zhang and Peng, 1995), the static-bed height is maximum for monocomponent beds. It passes through a minimum (13.5 cm in the present investigation) at $X_{J0} = 0.50$. Correspondingly the fixed-bed voidage of the well-mixed bed was minimum at $X_{J0} = 0.50$ and maximum for monocomponent beds. The ability of finer particles to occupy the interstices between coarser particles is usually invoked to explain trends like that in Figure 3.

Type-A experiments: "Transient Fluidization" regime

Figure 4 reports the pressure vs. gas superficial velocity curves measured at different levels in the bed during a typical type-A experiment. Pressure profiles resemble those obtained by previous investigators (Boland, 1971; Knowlton, 1977; Yoshida et al., 1980; Yang and Keairns, 1982). It is noted in particular that, as gas velocity is increased quasi-

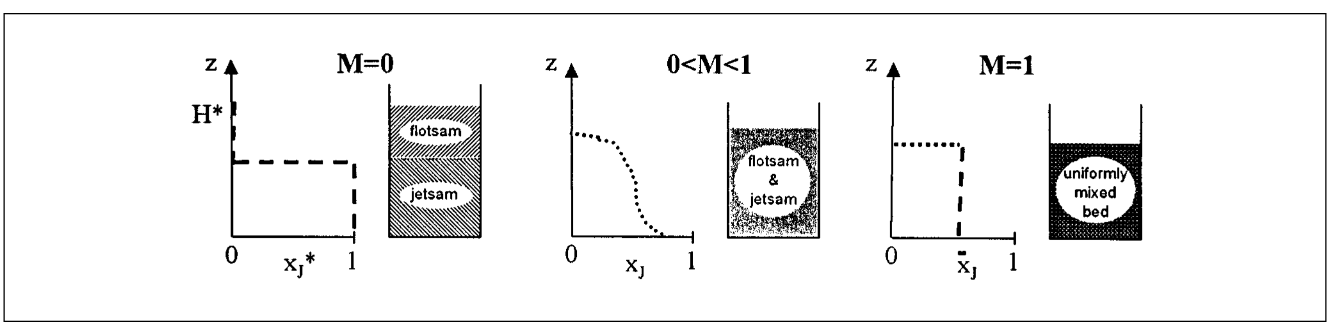

Figure 2. Mixing index.

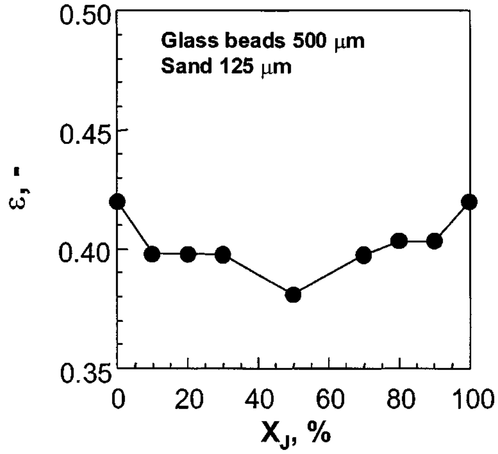

Figure 3. Static bed voidage as a function of the volumetric jestam fraction in the solids mixture.

steadily, the pressure measured at the bed bottom ($z = 0.6$ cm) first reaches a value corresponding to the bed weight per unit cross-sectional area (about 22 mbar) at a velocity $U_1 \cong 2.5$ cm/s, to suddenly drop thereafter. This pattern is repeated several times as U is increased, giving rise to a sawlike pattern of the pressure drop curve up to the gas superficial velocity $U_2 \cong 10$ cm/s. Beyond this value the pressure drop across the bed levels off to the value corresponding to the fluidized state, namely 22 mbar. Similar behavior is observed at pressure taps located at different levels in the bed, with the exception that the ultimate pressure level increases even beyond $U \cong U_2$, because of the increasingly large amount of bed solids that are brought above the pressure taps as the bed expands. The pressure measured during the defluidization process exhibits the hysteresis typical of broadly distributed solids (Nienow and Chiba, 1985).

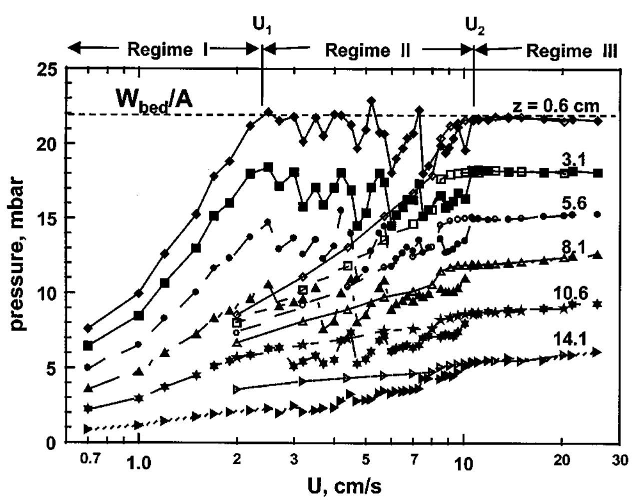

Figure 4. Pressure drop as a function of gas superficial velocity at different tap locations measured during type-A experiments.

Closed symbols: increasing gas velocity; hollow symbols: decreasing gas velocity. $X_{J0} = 0.5$.

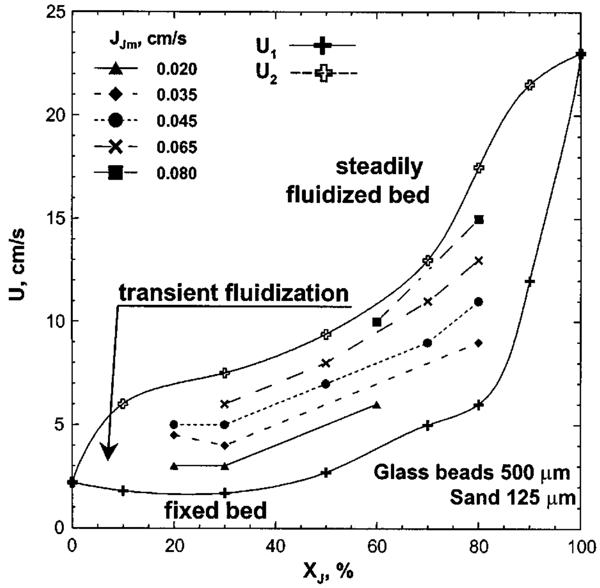

Figure 5. Gas superficial velocities at the lower (U_1) and upper (U_2) thresholds of the transient fluidization regime as functions of the average volumetric jetsam fraction in the solids mixture.

Contour lines corresponding to different drift flux J_{Jm} are plotted in the transient fluidization region.

Three ranges of gas superficial velocity can be recognized in Figure 4:

Regime I. $U < U_1$, the granular bed is in the *fixed-bed* state.

Regime II. $U_1 < U < U_2$, the granular bed undergoes *transient fluidization*: the whole bed is initially fluidized. Segregation of the jetsam and partial defluidization of solids eventually occur at the bottom of the bed.

Regime III. $U > U_2$, the bed is steadily fluidized, effective bed mixing overtaking defluidization at the bed bottom.

It must be noted that no direct relationship exists between U_1 and the minimum fluidization velocity of the flotsam, nor between U_2 and the minimum fluidization velocity of the jetsam. Gas velocity U_1 can be even lower than the minimum fluidization velocities of the flotsam particles, while U_2 lies in between the minimum fluidization velocities of the flotsam and of the jetsam particles. From the practical standpoint, U_2 is the minimum superficial gas velocity to be established in order to fully and steadily fluidize the solids mixture.

Experiments carried out with mixtures characterized by X_{J0} ranging between 0 and 1 displayed the same general phenomenology. In particular, for any value of X_{J0} it was possible to identify a range of gas superficial velocities $[U_1, U_2]$ corresponding to the transient fluidization regime. Figure 5 reports U_1 and U_2 as functions of the initial jetsam concentration in the mixture. Both velocities depend on X_{J0} and, in agreement with previous findings (Chen and Keairns, 1975; Nienow and Chiba, 1985), they are more sensitive to X_{J0} as it approaches 1: the fluidization behavior of coarse particles is strongly affected by the addition of even small amounts of fines. The width of the velocity range within which transient

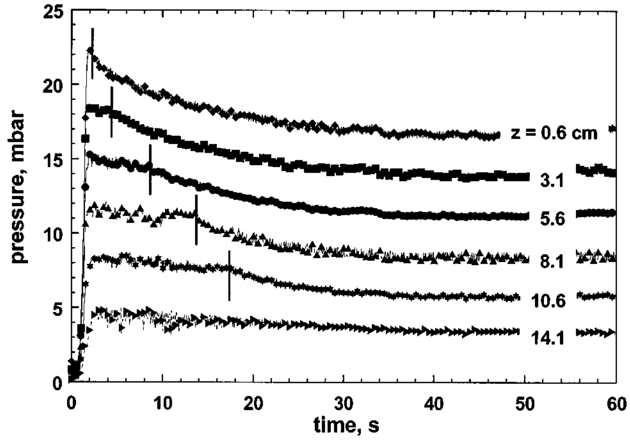

Figure 6. Time series of pressure drop measured at different tap locations during type-B experiments: $U = 5$ cm/s; $X_{J0} = 0.5$; fluidization time—1 min.

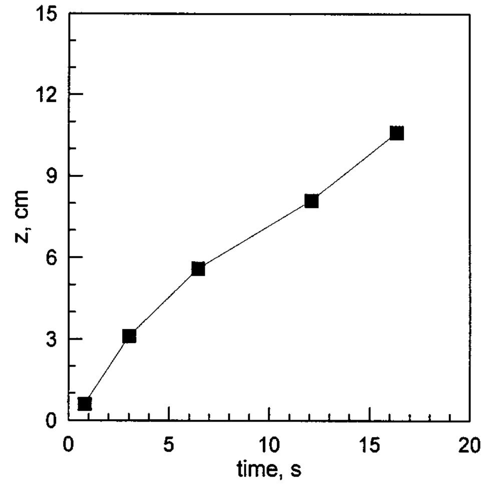

Figure 7. Axial position of the defluidization front as a function of time during type-B experiments: $U = 5$ cm/s; $X_{J0} = 0.5$.

fluidization is observed is variable with X_{J0}, being broadest around 80% at X_{J0}. Chen and Keairns (1975) and Yang and Keairns (1982) arrived at similar plots when reporting the minimum fluidization velocity for mixtures of dolomite and acrylic particles characterized by strong differences in minimum fluidization velocities of the components (larger than by a factor of 2).

Type-B experiments: dynamics of particle segregation

Figure 6 reports time-resolved pressure signals measured along the bed during a typical type-B experiment carried out with a solids mixture ($X_{J0} = 0.5$) at a gas superficial velocity ($U = 5$ cm/s) well within the transient fluidization regime. As soon as gas is fed to the column, pressure drop jumps to a value equal to the weight of the bed material above the pressure-tap level divided by the bed cross-sectional area. The pressure drop remains at that level for a time interval t^* that is longer, the higher the tap level. At time t^*, pressure rather abruptly starts decreasing until a new, lower steady value of the pressure is established, whose value depends on the location of the tap. Visual observation showed that the bed was fully fluidized at the beginning of the test. Eventually particles were observed to migrate either to the top (flotsam) or to the bottom (jetsam) of the bed and the suspension became progressively defluidized from the bottom. Voidage of the suspension appeared substantially uniform throughout the bed and close to 0.45 as long as the solids were fluidized.

Pressure profiles obtained in type-B experiments have been worked out by assuming that the point at which pressure drop starts decreasing at each pressure tap (highlighted in Figure 6) marks the time t^* at which a defluidization wave is moving upwards beyond the pressure tap level. Figure 7 is obtained after analysis of the profiles in Figure 6, and reports the axial position at which the defluidization front was observed as a function of time t^* at which its passage was recorded. The speed V_s at which the defluidization wave travels across the bed turns out to be 0.6 cm/s in the case considered in Figure 7. Values of V_s measured at different gas superficial velocities U and initial solids mixture concentration well within the transient fluidization regime (Figure 5) X_{J0} were always on the order of few millimeters per second.

The value of V_s can be directly related to the drift flux J_{Jm} of the jetsam with respect to the jetsam/flotsam mixture, defined according to Wallis (1969):

$$J_{Jm}(X_{J0}) = \left\{\left[(1-\epsilon)\cdot X_J\right]_B - \left[(1-\epsilon)\cdot X_J\right]_0\right\}\cdot V_s, \quad (2)$$

where subscripts B and 0 refer to the properties of the defluidized bottom layer and of the original solids mixture, respectively. Values of the jetsam-mixture drift velocity J_{Jm} are reported in Figure 5 as constant$-J_{Jm}$ contours in the transient fluidization region. Since V_s is zero at $U \leq U_1$, the contour line corresponding to $J_{Jm} = 0$ coincides with the curve $U = U_1(X_{J0})$. The closer U is to U_2, the smaller the extent of the defluidized solids layer that is ultimately formed. This, together with relatively fast segregation rate, makes determination of V_s and J_{Jm} increasingly difficult as U_2 is approached.

Experimental values of J_{Jm} are on the order of tenths of millimeters per second. Similar values were found, using different experimental techniques, by Beeckmans and Agrawal (1994) in the fluidization of binary mixtures of group B powders. Both sets of data are indicative of values of the drift flux significantly smaller (by about one order of magnitude) than values of the segregative fluxes predicted according to the theory of Naimer et al. (1982), based, in turn, on experimental work by Tanimoto et al. (1980). When analyzing this discrepancy, however, it should be considered that the Naimer et al. (1982) procedure was admittedly restricted to conditions of full-bed fluidization. The authors warned about applying the same procedure to conditions in which defluidized solids layers could be established. It is likely that inhibited solids mobility under transient fluidization conditions is responsible for the relatively small values of the drift velocities found in the present work, as well as by Beeckmans and Agrawal (1994).

Type-B experiments: ultimate solids segregation profile

Analysis of pressure profiles, like those in Figure 6, indicated that segregation during transient fluidization is completed after tens of seconds, for the bed heights and the fluidization conditions of the experiments, provided that $(U-U_1)/(U_2-U_1)$ is larger than about 0.2. Similar figures were obtained in previous studies on the dynamics of segregating fluidized beds (Chen and Keairns, 1975; Yoshida et al., 1980; Yang and Keairns, 1982; Hemati et al., 1990; Kozanoglu and Levy, 1992; Zhang et al., 1998; Wu and Baeyens, 1998). Accordingly, it was assumed that the solids concentration profiles measured after type-B experiments lasting 1 min could be taken as the ultimate solids segregation profiles, $X_J(z)$ at $(U-U_1)/(U_2-U_1)>0.2$.

Ultimate axial profiles of jetsam concentration X_J are reported in Figure 8 for runs carried out with solids mixtures having $X_{J0}=0.5$. Profiles are relative to different gas superficial velocities U within the transient fluidization interval $U_1(X_{J0})<U<U_2(X_{J0})$. Data are qualitatively similar to those obtained by previous investigators using different techniques (Chiba et al., 1979; Yang and Keairns, 1982; Hemati et al., 1990; Hoffmann et al., 1993). It is worth noting that, according to Figure 8, the bed displays at first increasing, then declining degrees of segregation as gas velocity is increased from U_1 (2.5 cm/s) to U_2 (10 cm/s). Even at gas superficial velocities at which segregation phenomena are significant, they never result in fully segregated layers of either pure jetsam ($X_J=1$) or flotsam ($X_J=0$). Profiles qualitatively similar to those in Figure 8 were measured with solids mixtures characterized by X_{J0} in the range between 0.1 and 0.8.

Solids composition profiles have been worked out to estimate the mixing index M according to Eq. 1. Figure 9 reports M as a function of the dimensionless superficial velocity $(U-U_1)/(U_2-U_1)$ for each X_{J0} investigated. Notably, the mixing index has a nonmonotonic trend as a function of gas superficial velocity: it equals 1 when U is either too small to give rise even to transient fluidization, $U<U_1(X_{J0})$, or when it is so large that mixing phenomena overtake segregation, $U>U_2(X_{J0})$. In between, it passes through a minimum at a gas superficial velocity that depends on the initial jetsam concentration.

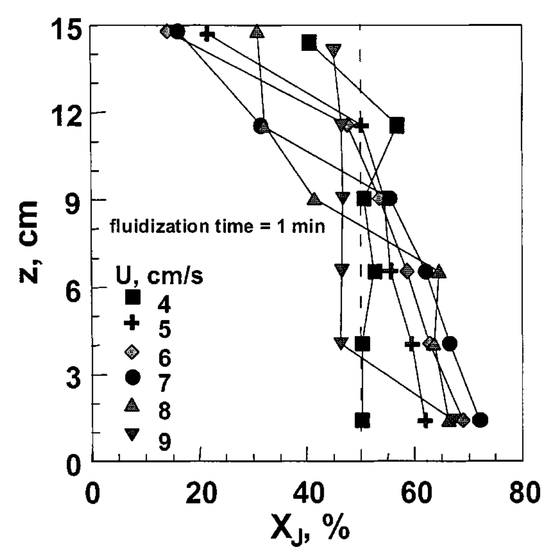

Figure 8. Axial profiles of solids concentration measured after fluidization for 1 min in type-B experiments for different gas superficial velocity: $X_{J0}=0.5$.

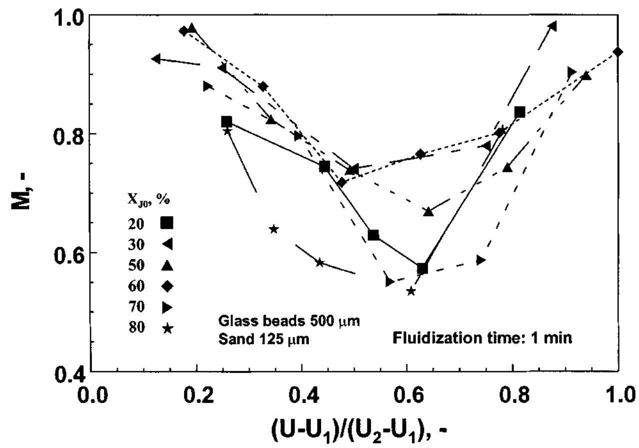

Figure 9. Mixing index as a function of dimensionless gas superficial velocity after 1 min fluidization in type-B experiments for different values of X_{J0}.

It is worth noting that the shape of profiles in Figure 9, and in particular the apparent nonmonotonic trend of M vs. $(U-U_1)/(U_2-U_1)$ are strictly related to the well-mixed state of the bed that was chosen as the starting point of the experiments. A different choice of the mixing/segregation starting conditions would have resulted in a different shape of profiles; Nienow et al. (1978) recorded a monotonically increasing trend of the mixing parameter M throughout the fluidization range. Though not explicitly indicated in the experimental procedure, it is inferred that experiments were carried out starting from the fully segregated state of the bed.

Type-A and -B experiments: "loci" of top (fluidized) and bottom (defluidized) layer compositions

Chen and Keairns (1975) first noticed that beds fluidized at gas superficial velocities smaller than the complete fluidization velocity (i.e., U_2) ultimately gave rise to a top (fluidized) and a bottom (defluidized) layers whose compositions (respectively, X_{JT} and X_{JB}) were relatively uniform within each zone. As a criterion to establish for a clearcut interface between top and bottom layers, they suggested that the ratio of the jetsam to the flotsam incipient fluidization velocities should be larger than 2. The analogy between segregation of multidisperse powders and phase-transition equilibria was put forth in the pioneering work of Gel'perin et al. (1964) to explain experimental findings: according to this analogy, the gas superficial velocity plays a role similar to that of temperature, that is, the larger U is, the larger the concentration of the "heavy" jetsam found in the fluidized upper layer.

Results of the present work are in agreement with those of Chen and Keairns (1975). Relatively uniform jetsam volumetric fractions were measured in the top fluidized layer (X_{JT})

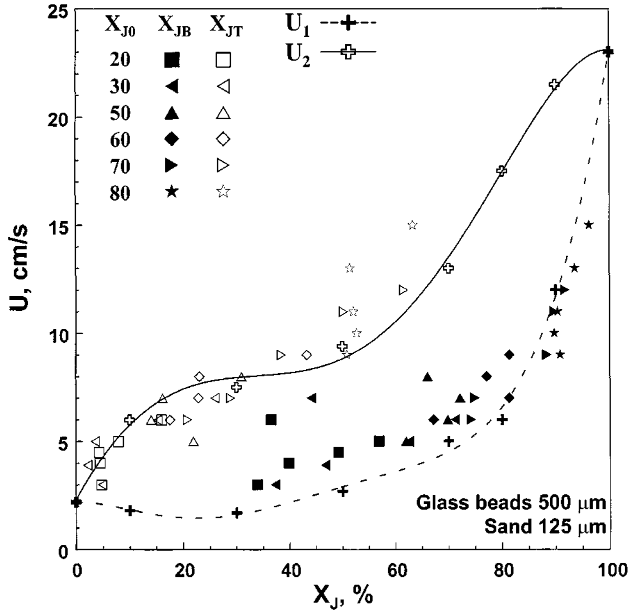

Figure 10. Loci of the jetsam volume fractions in the top fluidization layer (X_{JT}) and in the bottom defluidized layer (X_{JB}) as functions of gas superficial velocities for different values of X_{J0}.

Solid and dashed lines report U_1 and U_2 as functions of X_{J0}, respectively.

and in the bottom defluidized layer (X_{JB}) in type-B experiments provided that the initial mixture fraction X_{J0} and the gas superficial velocity U fell within the transient fluidization range. Figure 10 depicts X_{JB} and X_{JT} as functions of U and of the initial mixture fraction X_{J0}. It can be seen that whatever the gas superficial velocity and regardless of X_{J0}, data points are fairly aligned along two loci: the upper locus, corresponding to the composition of the fluidized top layer X_{JT}, and the lower locus, corresponding to the composition of the defluidized bottom layer, X_{JB}. This finding implies that the compositions of the two solids layers to which transient fluidization ultimately gives place depend on the gas superficial velocity, but do not keep memory of the initial composition of the solids mixture. Of course, conservation arguments suggest (and experimental results confirm) that the extension of the upper fluidized and the bottom defluidized layers does depend on the initial mixture solids fraction, X_{J0}.

An even more intriguing feature of the loci emerges when they are compared with the boundaries of the transient fluidization region, that is, the U_1 vs. X_{J0} and U_2 vs. X_{J0} profiles in Figure 5. Notwithstanding some data scatter, the comparison suggests that to a reasonable approximation the upper locus is coincident with the U_2 vs. X_{J0} curve, and the lower locus with the U_1 vs. X_{J0} curve. Transient fluidization of an initially thoroughly mixed bed ends up with a segregated state having the following properties:

- The concentration, X_{JB}, of the bottom layer is such that $U = U_1(X_{JB})$. This implies that the bottom layer is in the defluidized (fixed) state, but on the verge of fluidization. In other words, the bottom layer is at the maximum concentration of flotsam compatible with the fixed state for the given gas superficial velocity U. In a dynamic perspective, segregative flux in this region is "frozen" by the locally fixed state of the bed.
- The concentration X_{JT} of the top layer is such that $U = U_2(X_{JT})$. This implies that the top layer is at the maximum jetsam concentration compatible with the full and steady fluidization of this layer. In a dynamic perspective, further segregation within the top layer is effectively overtaken by axial solids mixing.
- Any layer at jetsam concentration intermediate between X_{JB} and X_{JT} is bound to be dynamically unstable. It falls in the transient fluidization region of Figure 5, where segregation mechanisms are at work. Flotsam migrates to the top, jetsam to the bottom until the layer vanishes.

From the practical standpoint, the property that, for any given U belonging to the transient fluidization region, $U = U_1(X_{JB})$ and $U = U_2(X_{JT})$ provides an indirect but straighforward procedure for determining the ultimate concentrations of the top and bottom segregated layers after transient fluidization. Simple type-A quasi-steady fluidization experiments with mixtures of different initial composition, instead of much lengthier type-B experiments, would provide results that, once worked out, yield the $X_{JT}(U)$ and $X_{JB}(U)$ loci.

Conclusions

Fluidization and segregation of binary mixtures of solids have been studied by means of a combination of experimental techniques. Transient fluidization takes place at gas superficial velocities intermediate between those at which the bed is in the fixed state and those at which the bed is fully and steadily fluidized. Regions corresponding to the fixed, to the transient fluidization, and to the steadily fluidized states of the bed have been mapped in the gas-velocity/solids-concentration phase plane.

Transient fluidization is characterized by a defluidization front traveling across the bed, corresponding to the build up of a defluidized layer at the bottom of the bed. Rates at which the defluidization front moves across the bed have been experimentally determined by means of a novel experimental technique based on the analysis of the time series of the pressure drop recorded at different levels in the bed. Defluidization velocities on the order of some millimeters per second are observed in the range of gas superficial velocity and with the solids mixtures considered in the study. These results yield the drift flux of the jetsam with respect to the solids mixture. In agreement with results obtained by others, values of the drift flux smaller than those predicted from correlations valid for fully fluidized beds are found.

Axial solids concentration profiles and mixing indexes of initially uniform binary mixtures that result after prolonged fluidization in the transient fluidization regime have been experimentally determined. Loci representing the ultimate solids concentrations in the fluidized top layer and in the defluidized bottom layer have been obtained from data corresponding to different initial-mixture composition and gas superficial velocity. These loci display two distinctive features: they barely depend on the initial mixture concentration; and they coincide, to a good approximation, with the boundaries of the transient fluidization regime in the gas-velocity/solids-concentration phase plane.

Acknowledgment

This work is part of a wider project aiming at the characterization of the behavior of pyroclastic flows. Financial support for this project from MURST, CUGRI and GNV is acknowledged.

Notation

A = cross-sectional area of the fluid bed, m^2
H = bed height, cm
W = total weight of the bed material, kg
z = axial bed coordinate, m

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Manuscript received July 9, 1999, and revision received Apr. 20, 2000.