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CHARACTERIZATION OF THE FLUIDIZATION AND MIXING OF BINARY MIXTURES CONTAINING BIOMASS AT LOW GAS VELOCITIES

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ABSTRACT

To judge qualitatively the effect of biomass properties on its fluidizability and mixing tendency with sand particles at low fluidization velocities, local pressure gradients in the top and bottom of the bed were compared for all investigated systems. It was found that changing the mass fraction and the size of biomass impacted the onset of bubbling and the size of bubbles across the bed, which, in turn, affected the mixing/segregation of the bed content.

INTRODUCTION

Biomass, living and recently dead biological material, is known as one of the highly potential renewable sources of energy. Biomass materials stand as the third energy resource after oil and coal due to their abundance and rapid replenishment. Producing energy from biomass results in the mitigation of greenhouse gas emissions making biomass an outstanding substitution for fossil fuels. Nowadays, a variety of thermo-chemical processes, e.g., combustion, gasification, and pyrolysis, are being developed worldwide to convert biomass to energy and added-value fuels (1). Due to the unique advantages of fluidized beds, they are widely used as the heart of nearly all of the above-mentioned processes. Nevertheless, fluidization of biomass particles alone is a problematic or even impossible task due to their peculiar sizes, densities, and shapes. The most widespread solution for this problem is adding inert materials, such as sand particles commonly used in regular fluidized beds. Highly different properties of biomass and bed material particles, in terms of hydrodynamics, result in some shortcomings, e.g., segregation, which negatively affects fluidization performance. In spite of the noticeably different characteristics of mixing and segregation in the biomass-sand mixture from that of a common binary mixture, a few studies have been devoted to examine the mixing dynamics of systems, including biomass particles (2-4). On the other hand, the scarcity of phenomenological studies on the mixing/segregation behavior of biomass particles hinders the industry from applying general solutions for biomass fluidization.

In general, the difference between the density, size, and/or shape of components of fluidizing solids causes segregation and, as a consequence, particles of each component tend to accumulate at the top (flotsam) or bottom (jetsam) of the bed. Early investigations addressed mainly segregation patterns in binary mixtures of particles of equal size but with different densities. More recent studies have been carried out on the equal density and different size systems. Only a few works have considered mixing and segregation phenomena in systems dealing with particles differing in both size and density; however, such systems have a vast application not only in biomass processing, but also in pharmaceutical and chemical industries (5).

To understand the phenomena underlying segregation in mixtures dealing with biomass, the main objective of the present work is devoted to scrutinizing the binary fluidization behavior of relatively light biomass and dense sand particles at comparatively low superficial gas velocities, namely, around the limit required for complete fluidization. In particular, the analysis of the mixing/segregation trend of binary mixtures consisting of biomass particles with two different sizes and/or mass fractions has been attempted on the basis of mechanisms governing the mixing/segregation in binary mixtures of granular solids.

EXPERIMENTAL

Apparatus

The experiments were conducted in a cold conventional fluidized bed consisting of a Plexiglas fluidization column 1.5 m high and 0.152 m in diameter. A perforated plate containing holes 1 mm in diameter and arranged in a triangular pitch was used as a distributor. Three graduated scales spaced at 120° around the column wall were used to determine the bed height. The dynamic pressure fluctuations were monitored along the bed via a couple of pressure transducers mounted flush with the wall of the bed. One of the pressure transducers was used to register the pressure fluctuations of the whole bed (PT1). The local pressure signals corresponding to the low and high levels of the bed were obtained by two pairs of differential pressure transducers, namely PT2 and PT3, respectively. The position and configuration of all pressure transducers has been shown in Figure 1. The pressure data were acquired at a sampling frequency of 400 Hz for 180 seconds through a 16 bit A/D data acquisition board with the help of the Labview 9.0.1® program. The pressure signals were low-pass filtered at 100 Hz to remove the signal noises. This frequency is sufficiently higher than the frequency of typical phenomena taking place at low velocities (1-10 Hz), thus it seems unlikely to affect the signal fluctuations.

Materials

Biomass particles were provided from birch cylindrical rods with two different diameters cut into identical lengths of tiny particles. The bed material used had a continuous normal size distribution ranging from 100 to 1000 μm. Table 1 reports more details of all materials used in this investigation.

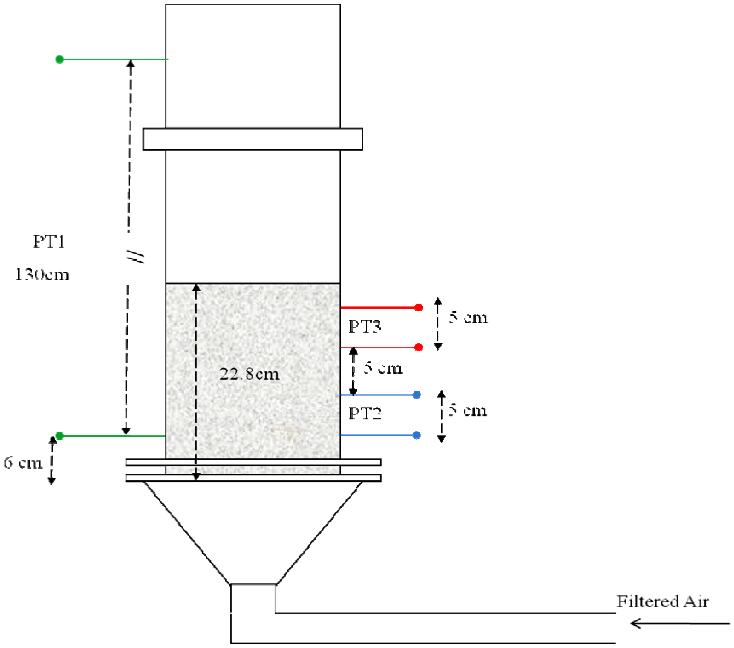

Figure 1. Schematic diagram of experimental setup.

Table 1. Properties of materials used

Material	*Shape*	*d_p(mm)*	*h_p(mm)*	*ρ_p(kg/m^3)*	*ρ_b(kg/m^3)*	*ε (-)*
Sand	Spherical	0.381	-	2865	1632	0.43
Biomass 1	Cylindrical	3.175	6.350	670	331.5	0.50
Biomass 2	Cylindrical	6.350	6.350	670	332	0.50

Procedure

To investigate the effect of the cross section size and mass fraction of biomass particles four different mixtures of bed material and biomass, whose properties are mentioned in Table 2, were studied. In each experiment, the height of the static bed was set at 225 mm (H/D=1.5). To gain insight into the fluidization behavior of the bed material used in the mixtures, the sand alone was fluidized first under the same conditions as the other experiments. In an attempt to make the mixing state of the systems uniform before starting the experiments, the binary mixture was vigorously fluidized for about 15 min. Experiments were conducted at ambient pressure and temperature. Starting from the fixed bed state, the superficial gas velocity was quasi-steadily increased until it reached the desired value. Then, the bed was slowly defluidized until it returned to a fixed state.

Table 2. Properties of binary mixtures investigated

System	*Biomass type*	*Sand mass (kg)*	*Biomass mass (kg)*	*Wt.% of biomass*	*Vol.% of biomass*
System 1	Biomass 1	5.363	0.282	5	20.58
System 2	Biomass 2	5.364	0.282	5	20.55
System 3	Biomass 1	4.365	0.485	10	35.36
System 4	Biomass 2	4.367	0.484	10	35.33

Analysis Methods

Processing the time-series signals reflecting the pressure fluctuations in the different vertical positions of the bed was the main method used to characterize the fluidization and mixing of particles. In this regard, the time-averaged value of all 72000 data collected during each run was considered as the static pressure of the relevant section. Moreover, signals were analyzed dynamically in time and frequency domains. In terms of statistical analysis in the time domain, the mean amplitude or standard deviation (σ) of the fluctuation signals over the bed has an intense interrelation with mean bubble size. The standard deviation of pressure data is calculated as follows (6):

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(P_i - \bar{P})^2} \tag{1}$$

where N is the number of data points at the intended time interval and $\bar{P}$ is the average of recorded P_i s.

RESULTS AND DISCUSSION

The most common method for identifying the fluidization status at different velocities is studying the whole bed pressure drop as a function of superficial gas velocity. This method is not, however, sufficient to distinguish the phenomenological differences between the fluidization behavior of mixture components and, despite the diversities existing between the systems investigated in the present work, their overall pressure drops versus gas velocity show more or less a similar trend during fluidization and defluidization, correspondingly.

As observed, the bed pressure drop increases initially in the fixed bed mode. It is well known that for the ideally mono-sized and homogenous particle systems transition from fixed to fluidized state takes place at a specific gas velocity known as minimum fluidization velocity (U_{mf}). Realistically speaking, U_{mf} is determined by finding the superficial gas velocity, which corresponds to the intersection of the pressure drop line of the fixed bed with that for the fluidization state. Unlike the monodispersed systems, for the binary solids mixtures the transition from fixed to fully fluidized occurs gradually at a gas velocity interval beginning with initial fluidization velocity (U_{if}) and ending at complete fluidization velocity (U_{cf}). U_{if} is located at the point where ΔP first deviates from the fixed bed curve. In relation to U_{mf} of sand alone, the values of U_{if} of investigated binary systems were slightly lower. This is due to the difference between the packing extent and bulk densities of sand alone and sand mixtures containing biomass.

For the systems investigated, particles might stay in a bubble-free fluidization regime during the transition from initial to complete fluidization mode. In other words, deviation from the fixed bed state did not necessarily result in the immediate formation of bubbles. The occurrence of such phenomenon is the first departure of the fluidization behavior of binary mixtures whose components differ in density from that of uniform particles (7).

A further increase in the gas velocity brought about the appearance of bubbles in the bed. It should be noted that before bubbles became large enough to move upward along the entire height of the bed, bubbling might take place just occasionally and locally at the bed depending on the mixture properties. The velocity corresponding to the onset of bubbling across the entire bed is defined as the initial bubbling velocity (U_{ib}). In the present work, U_{ib} was considered as the velocity at which a sudden jump was observed in the dominant frequency of the signal representing the pressure fluctuations of the whole bed (PT1 signal). It is noteworthy that U_{ib} is always located between U_{if} and U_{cf}.

U_{cf} is defined as the velocity beyond which no considerable change in the total bed pressure drop can be observed. Indeed, the essence of the U_{cf} is the same as that of U_{mf} defined for the fluidization of homogeneous particles; however determination of U_{cf} is not as straightforward as the aforementioned method used for finding the U_{mf} of monodispersed particle systems.

In spite of the similar features of whole bed pressure drop for systems containing different sizes and/or amounts of biomass particles, pressure drop profiles of low (PT2) and high (PT3) levels are meaningfully different for the investigated systems. As shown in Figure 2, the discrepancy between up and down pressure drops of the bed in systems 1 and 2 is lower than those of systems 3 and 4, signifying the inferior segregation propensity of sand and biomass particles in systems having less biomass mass fraction. Notably, it seems that biomass particles with a small cross section (system 3) are subject to an intensified segregation at a very low superficial gas velocity compared to biomass particles having a larger cross section (system 4).

Comparing the local pressure drops of systems composed of the same biomass particle but differing in the mass fraction of components (systems 1 & 3 or 2 & 4) reveals that the change of the biomass mass fraction considerably changes the behavior of the systems at low gas velocities. For example, increasing the biomass content of the mixture could result in a delay in the formation of bubbles in the bed. As a result, the bed content stayed in a bubble-free mode at a range of very low gas velocities. Local segregation was extremely severe in this bubble-free fluidization regime due to the percolation effect.

Upon the emergence of bubbles in the bed, sand particles moving with the bubble wake can penetrate to the top flotsam-rich layer and partially offset the segregation. Accordingly, as seen in the curves denoting system 3, the difference between up and down pressure drops decreases sharply. A progressive increase of the gas velocity brings about the formation of bubbles at lower layers of the bed content. Thus, one can consider a downwardly moving front for the bubbling fluidization regime whose movement is significantly slower for system 3 in comparison with system 1.

On the other hand, comparing the standard deviations of systems 1 & 3 or 2 &4 at corresponding velocities (Figure 3) verifies that the increase of biomass concentration in the mixture leads to a decrease of pressure fluctuation amplitude (standard deviation, σ, Eq. (1)). Since the standard deviation of pressure fluctuations as a function of gas velocity correlates with the bubble diameter (6), it can be concluded that the size of bubbles decreases when the portion of biomass particles increases in the bed. Therefore, it is not surprising that the 'well mixing' of the bed inventory caused chiefly by strong and energetic bubbles is achieved at the higher gas velocities.

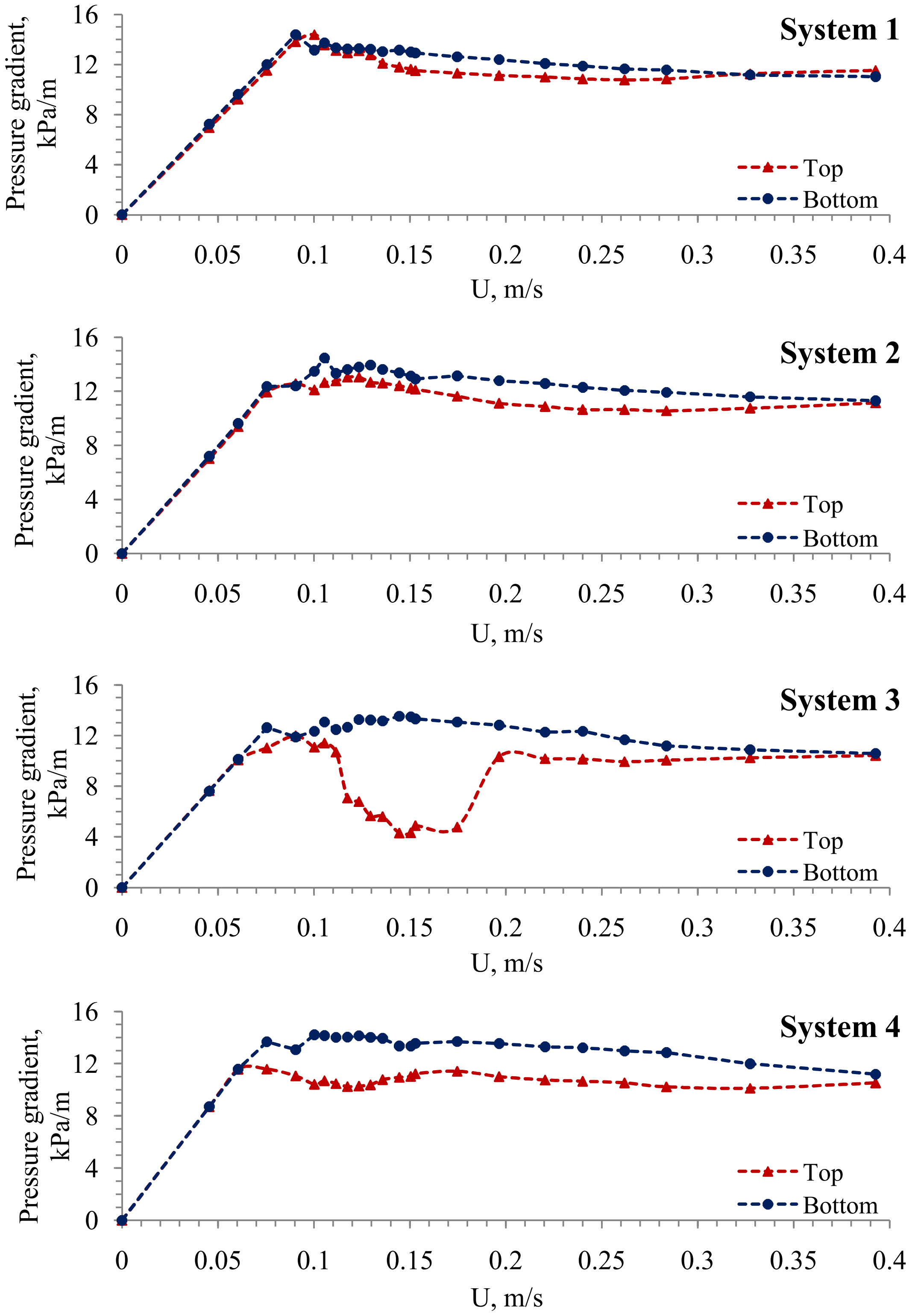

Figure 2. Bottom and top pressure drop gradients of systems investigated at increasing values of the superficial gas velocity (Top and bottom curves obtained via time-averaging the pressure fluctuations recorded by PT2 and PT3, respectively.)

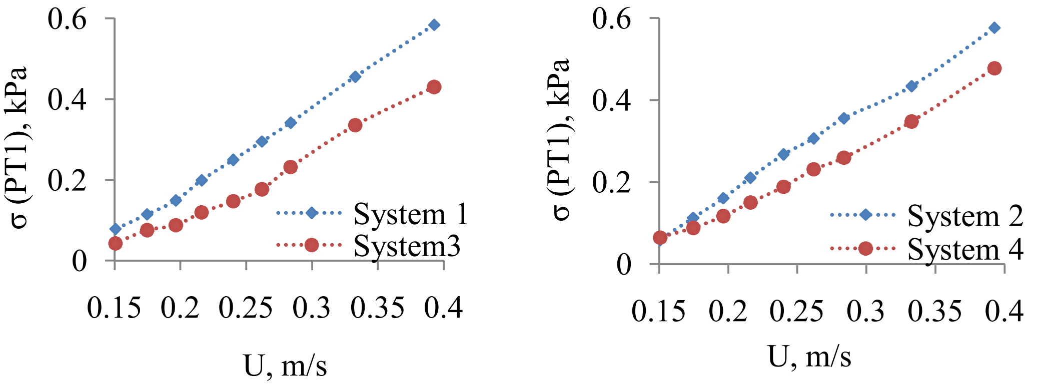

Figure 3. Comparison of standard deviation of signals representing the global pressure fluctuation in systems differing in mass fraction of biomass (σ_{PT1})

The analysis of pressure signals shows that the bubble-free transient condition persists only at a short range of low gas velocities for system 4. Since the number of biomass particles in this case is about ¼ of those in system 3 (because both of these systems contain 10% wt. biomass but the cross section of biomass particles is four times bigger in system 4), the particle packing is less loose. Therefore, in relation to large biomass particles, remarkable multiplicity of small biomass significantly intensifies segregation in the early stages of fluidization; however, this condition can improve easily in favor of mixing by the bubbles passing through the bed. The effect of a higher number of biomass particles can be seen during the defluidization of systems. For example, as seen in Figure 4, the larger discrepancy between top and bottom pressure drop profiles in system 3 with respect to those of system 4 (especially at the transition zone from fluidized to fixed state) expresses the higher sensitivity of system 3 to a gradual decrease of gas velocity. In other words, for system 3 biomass particles possess greater potential to be segregated from sand during the defluidization. Consequently, the system falls into the fixed bed state earlier.

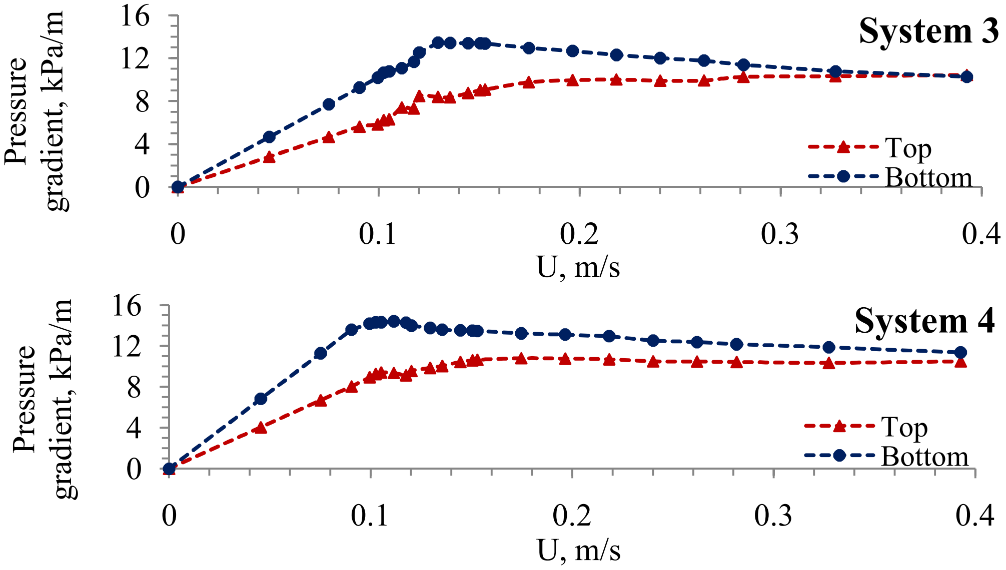

Figure 4. Bottom and top pressure drop gradients of systems 3 and 4 at decreasing values of the superficial gas velocity

CONCLUSION

To investigate the effect of biomass properties on its fluidization behavior in the presence of bed material, four mixtures of woody biomass and sand particles differing in biomass size and mass fraction were investigated. The applied characterization method was measuring the global and local pressure drops of the bed by means of pressure transducers mounted along the bed. The intensity of segregation in different systems was analyzed by comparing the time-averaged amplitude of signals representing pressure fluctuations at the top and bottom of the bed. Through comparing the profiles of local pressure drops for the mixtures investigated, it can be concluded that since varying the mass fraction of biomass particles changes the distribution of inlet gas between the bubble and emulsion phases, it can considerably affect the mixing/segregation extent, particularly, at low gas velocities. Besides, it seems that for a given mass fraction of biomass, the number of biomass particles can influence the sensitivity of mixtures towards mixing/segregation at least for the range of gas velocities studied.

REFRENCES

1. Khan, A., De Jong, W., Jansens, P.J. and Spliethoff, H., 2009. Biomass combustion in fluidized bed boilers: Potential problems and remedies. Fuel Processing Technology 90 (1), 21-50.
2. Zhang, Y., Jin, B., Zhong, W., 2008. Fluidization, mixing and segregation of a biomass-sand mixture in a fluidized bed. International Journal of Chemical Reactor Engineering 6, A88.
3. Zhang, Y., Jin, B., Zhong, W., 2009. Characterization of fluidization andsegregation of biomass particles by combining image processing and pressurefluctuations analysis. International Journal of Chemical Reactor Engineering 7,A81.
4. Zhang, Y., Jin, B., Zhong, W., 2009. Experimental investigation on mixing and segregation behavior of biomass particle in fluidized bed. Chemical Engineering and Processing 48, 745-754.
5. Joseph, G. G., Leboreiro, J., Hrenya, C. M., Stevens, A. R., 2007. Experimental segregation profiles in bubbling gas-fluidized beds. AIChE Journal 53 (11), 2804-2813.
6. Johnson, F., Zijerveld, R. C., Schouten, J. C., Van Den Bleek, C. M., Leckner, B., 2000. Characterization of fluidization regime by time series analysis of pressure fluctuation. Int. J. Multiphase Flow 26, 663–715.
7. Olivieri, G., Marzocchella, A., and Salatino, P., 2004. Segregation of fluidized binary mixtures of granular solids. AIChE Journal 50 (12), 3095-3106.