Refereed Proceedings

The 12th International Conference on Fluidization - New Horizons in Fluidization Engineering

Engineering Conferences International *Year* 2007

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HYDRODYNAMIC CHARACTERISTICS OF A FLUIDIZED BED WITH ROTATING DISTRIBUTOR

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ABSTRACT

The performance of a novel rotating distributor fluidized bed is presented. The pressure drop and the standard deviation of pressure fluctuations, σ_p, were used to find the minimum fluidization velocity, U_{mf}, and to characterize the quality of fluidization at different rotational speeds of the distributor plate. Experiments were conducted in the freely bubbling regime in a 0.19 m i.d. fluidized bed, operating with Group B particles according to Geldart's classification. A decrease in U_{mf} is observed when the rotational speed increases. Frequency analysis of pressure fluctuations shows that fluidization can be controlled by the adjustable rotational speed at several excess gas velocities.

INTRODUCTION

The selection of an appropriate distributor plate is an important consideration in the design of fluidized beds. The aim of the distributor is to disperse the gas as uniformly as possible over the whole cross-section of the bed. Also, in applications which involve the processing of solids, its purpose is to promote the rapid mixing, particularly when the feed stream must be quickly dispersed. The inadequate design of gas distributors may be responsible for a substantial proportion of the difficulties encountered in fluidized bed processes; such as segregation, which can lead to defluidization, or the presence of undesired hot spots in fluidized bed combustors (1). One of the problems in conventional distributors is the deficiency in lateral mixing, since the fluidizing gas discharged possesses only axial momentum. In order to enhance the tangential or radial mixing, some improved designs have been tested. These are, among others, centrifugal beds, the horizontal injection of gas, as it is the case of the multihorizontal orifice plate (2), or the spiral (3) distributor and its different versions (4), specially suited for shallow beds, were the channelling of the fluid through the bed may prevent the fluidization.

The purpose of the present research is to evaluate a new type of bed support, called the rotating distributor plate (5, 6) and compare its characteristics such as pressure drop and quality of fluidization, with that of the same perforated plate without

The 12th International Conference on Fluidization - New Horizons in Fluidization Engineering, Art. 94 [2007]

rotation. The effect of the distributor plate rotation on the hydrodynamic characteristics of a fluidized bed was experimentally studied. The bed was operated with Group B particles in the bubbling regime. The rotating distributor offers the advantages found in the swirling designs, improving solid mixing and making the fluidization possible even for very shallow beds. With the new design, the minimum fluidization velocity decreases, as it is also found in the vibrating and sound assisted beds (7-10)

EXPERIMENTS

The experimental set-up, shown in Figure 1, consists of a 0.8 m high methacrylate column, with a 0.19 m i.d. diameter. The rotating distributor is a perforated plate with 2 mm diameter holes, giving a total open area ratio of 1 %. The plate is covered with a fine-mesh net to prevent particles from falling down through the plate into the wind-box. The holes are laid out in a hexagonal pitch of 15 mm. Group B silica sand particles with a density of 2600 kg/m^3 and a mean diameter of 300 μm were fluidized with air. The air velocity was controlled with a rotameter. The range of the gas velocity was 0 to 0.8 m/s (corresponding to volumetric flow rates ranging from 0 l/min to 1400 l/min).

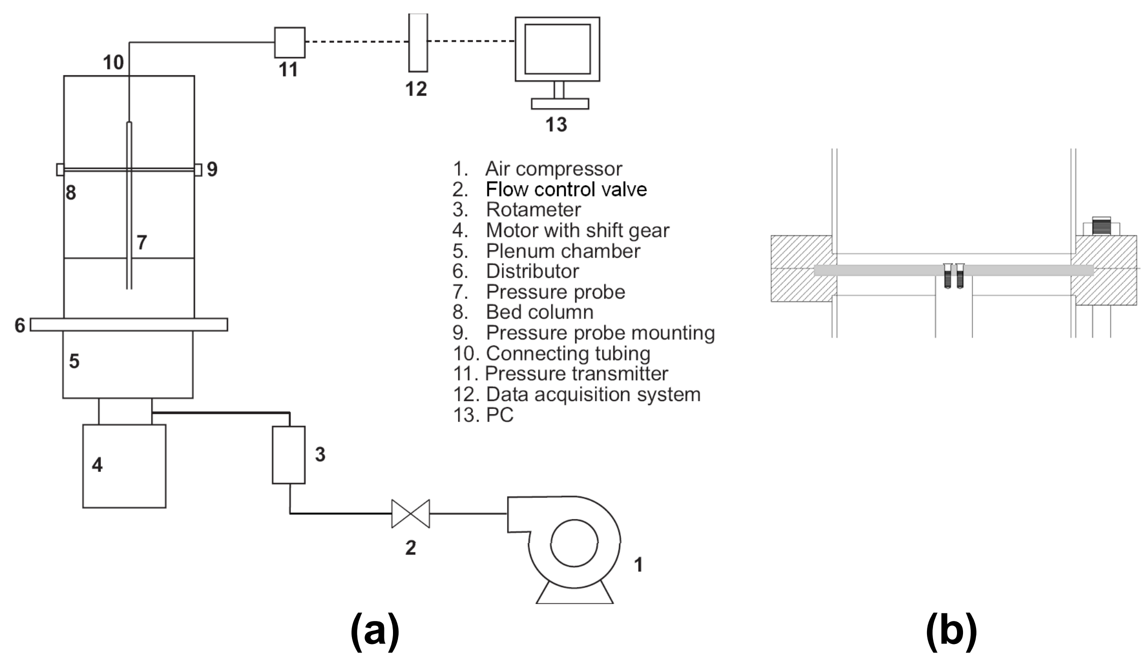

Figure 1. (a) Schematic diagram of the experimental fluidized bed. (b) Detail of the mechanical set-up of the distributor in the bed

In order to promote the rotation, the distributor axis was coupled with the driveshaft of an AC electric motor, as shown in Figure 1. A frequency inverter was used to control the rotational speed of the distributor plate, which can be varied from 0 to 100 rpm.

Pressure measurements were taken in the bed. In order to avoid the influence of the rotation on the pressure measurements, the pressure sensor was not placed flush to the bed wall but it was mounted at the bed axis (11). The pressure drop across the bed and the pressure oscillations were measured with an Omega PX 291 piezoresistive differential pressure transmitter (0-5 in H_2O) with a 1% full scale accuracy. The sensor was mounted on a 5 mm i.d. steel probe and silicone connecting tubing of 4 mm i.d. and the whole set-up had a length of about 2 m. The measurements were taken about 5 cm below the bed surface, roughly in the middle of the bed height. The high pressure port was placed at this point and the low pressure port was exposed to atmosphere. The data were recorded with a 12 bits ICP DAS PCI-1802H data acquisition board assembled in a PC. The resultant accuracy in pressure measurements was approximately ±12 Pa. Time series of 12000 data points measured with a sample frequency of 200 Hz were processed to obtain standard deviations and power spectral density functions.

RESULTS AND DISCUSSION

In this work, the influence of the rotational speed of the distributor plate on the hydrodynamic behavior of the fluidized bed was studied for a wide range of gas velocities in the bubbling regime. Several aspects were analyzed: the pressure drop across the bed; the minimum fluidization velocity, U_{mf}; the quality of fluidization characterized by the standard deviation of pressure fluctuations, σ_p, and the bed response in the frequency domain.

Minimum Fluidization Velocity

The pressure drop across the bed was measured at a range of superficial gas velocities, U, beginning with a vigorously fluidized bed and reducing to zero velocity (12).

The distributor plate was rotated at different speeds up to 100 rpm. Figure 2 compares the measured pressure drop for the distributor plate rotating at the maximum rotational speed (n = 100 rpm) with the measurements without rotation (static distributor hereafter).

A moderate increase in the pressure drop is found when the distributor plate rotates at 100 rpm, for gas velocities below $2U_{mf}$. The rise in the pressure drop is in agreement with the results of other investigators (5). However, when operating at higher gas flow, the difference in the pressure drop operating with the rotating distributor and that with the static distributor is hardly noticeable. This can be explained by a predominant influence of the axial gas velocity at higher gas flows, as opposed to the tangential velocity imparted by the distributor rotation to the bed. Moreover, a decrease in U_{mf} was observed when rotating the distributor plate.

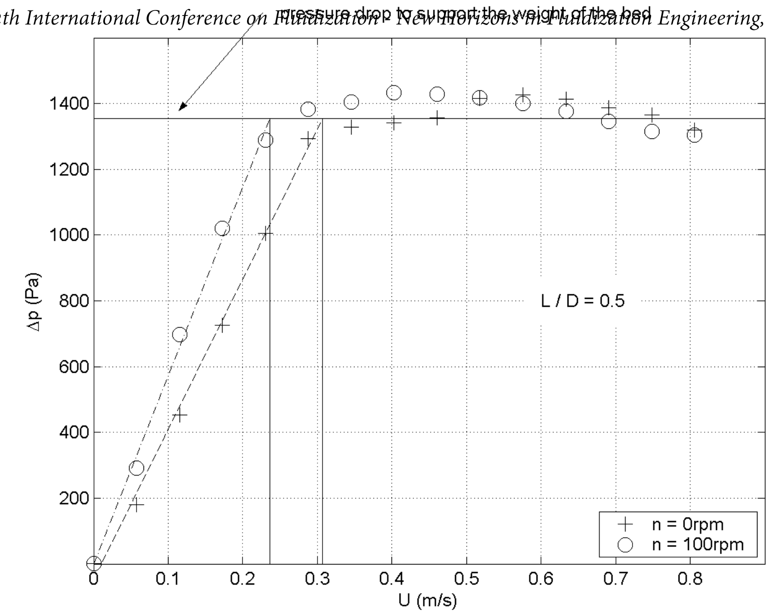

Figure 2. Pressure drop across the bed, Δp (Pa), vs. superficial gas velocity, U (m/s), for n = 0 rpm and n =100 rpm.

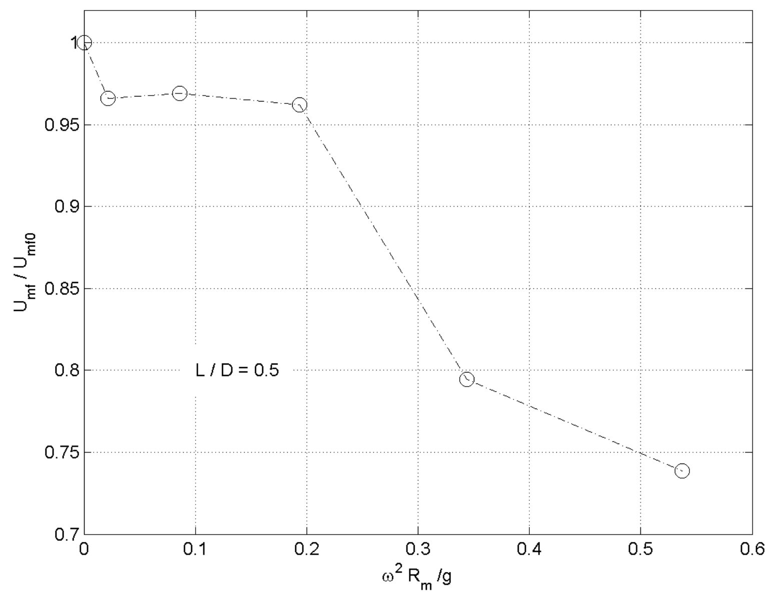

Figure 3. U_{mf}/U_{mf0} against the non-dimensional centripetal acceleration of the distributor plate, $\omega^2 R_m/g$.

The U_{mf} trend when increasing the rotational speed for the speed range studied in this work (0-100) rpm is shown in Figure 3. The values of U_{mf} at each rotational speed, nondimensionalized using U_{mf} for the static distributor configuration, U_{mf0}, are plotted against the centripetal acceleration, $\omega^2 R_m$ (ω is the angular velocity of the distributor plate and R_m its average radius), nondimensionalized using the gravitational acceleration, g. The value $\omega^2 R_m/g$ is proportional to the quotient between the centrifugal force and the buoyancy force acting on the bubbles during the bubble detachment of the perforated plate. For low values of ω ($\omega^2 R_m/g < 0.2$) a negligible effect was found.

Standard Deviation

The analysis of the pressure fluctuations across a fluidized bed is a convenient, if rough, way of evaluating the quality of fluidization (3, 9, 13). In Figure 4 the standard deviation of pressure fluctuations, σ_p, is plotted against the excess gas, U/U_{mf}. The magnitude U/U_{mf} has been chosen to compare the rotating distributor and the static distributor configurations, since it is assumed that the additional flow above the amount for incipient fluidization passes through the bed as bubbles (12). Therefore, comparing the performance of the bed operating with the same gas excess U/U_{mf}, beds working at the same fluidization state are being compared. On the contrary, if two beds with the same flow rate of gas U are compared, they will not operate with the same rate of gas above the minimum needed to fluidize the bed, because the bed with the rotating distributor has a lower U_{mf}.

For a given U/U_{mf} value, very similar amplitudes of pressure fluctuations, σ_p, are found for the different rotational speeds. Therefore, the rotation of the distributor plate can be used as an independent parameter to control the dynamics of the bed. However this similarity tends to disappear for an excess gas about U/U_{mf} = 1.6.

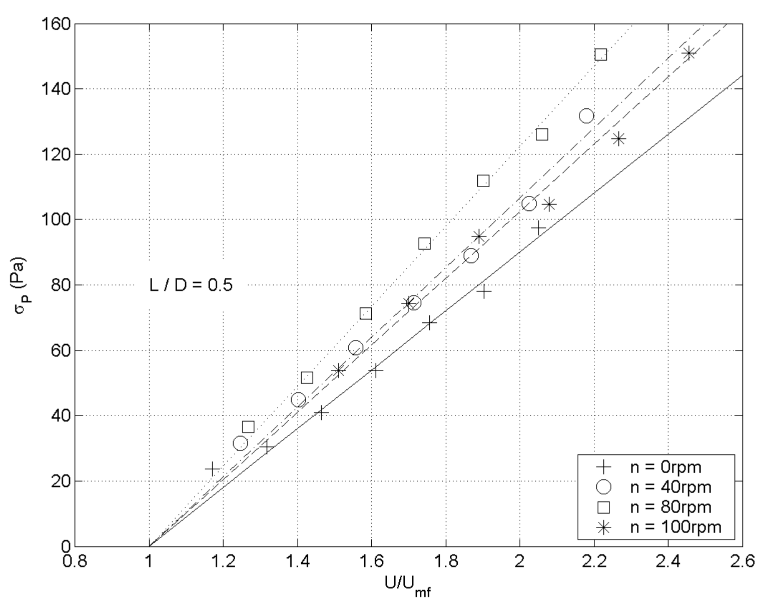

Figure 4. Standard deviation of pressure fluctuations, σ_p, for several rotational speeds, n, against gas excess, U/U_{mf}.

Frequency Domain Analysis

Analysis of the frequency distribution of pressure time series is discussed in this section in order to give a different approach of that of the time domain analysis, which sometimes can be misleading when attempting to explain the dynamics of the flow (14). Welch method is used for power spectrum estimation (15). A hamming window is chosen as window function. All sub-spectra are based on 4096 samples yielding an average of 8 sub-spectra.

The influence of the rotational speed on the bed dynamics can be explained in terms of the relation between the tangential velocity, ωR_m, imparted to the flow by the distributor rotation and the superficial gas velocity, U, which has an axial direction. The average tangential velocity of the gas in contact with the distributor plate, ωR_m, is about 0.5 m/s when the plate rotates at 100 rpm. This velocity value is about $1.6U_{mf}$. Accordingly, operating with gas velocities U above $1.6U_{mf}$, the gas would have a predominantly axial direction. Otherwise, that is $U<1.6U_{mf}$, the effect of the tangential velocity imparted to the gas by the distributor would be dominant. Figure 5 compares the power spectrum of pressure fluctuations at U/U_{mf} = 1.2 (Figure 5a) and U/U_{mf} = 2 (Figure 5b) for the static distributor, with the corresponding power spectrum of the distributor rotating at 100 rpm. If the tangential velocity is of the same order of the superficial gas velocity, the same amplitude of the pressure signal can be observed regardless of the rotational speed (Figure 4). Moreover, attending to frequency domain tools, it is shown that a smaller peak in the power spectrum is found when the rotating distributor is used (Figure 5a).

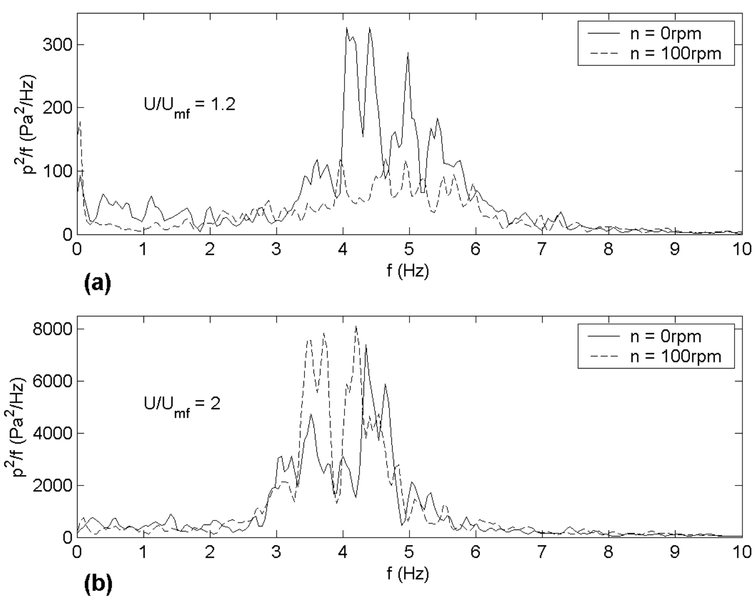

Figure 5. Power spectra for an excess gas: (a) U/U_{mf} =1.2, (b) U/U_{mf} = 2 and a fixed bed height L/D = 0.5.

Nevertheless, the improvement in the quality of fluidization achieved with the novel distributor tends to disappear when the tangential velocity, ωR_m, becomes smaller than the gas velocity. In Figure 5b, at an excess gas U/U_{mf} = 2, the gas flow supplied to the bed with the rotating distributor is such that $U > \omega R_m$. In this case the standard deviation of pressure fluctuations has a higher amplitude for the rotating distributor configuration (Figure 4). However, using frequency domain analysis, power spectra of the same energy are found for both the static and the rotating distributor configurations. The range of characteristic frequencies observed is also the same. Comparing Figure 5a and Figure 5b, a rise in the characteristic frequencies can be observed for both cases when the gas velocity increases.

CONCLUSIONS

The novel fluidized bed proposed in this paper presents some contributions that can be useful in some applications: lower gas flow is needed to fluidize the bed, the fluidization state is reached more easily and the bed dynamics can be controlled by adjusting the rotational speed of the distributor plate without loosing the quality of the fluidization, for superficial gas velocities $U < 2U_{mf0}$.

The main differences found between the hydrodynamics of the rotational distributor bed and the classical static distributor bed are:

(a) If $\omega^2 R_m > 0.2g$ the minimum fluidization velocity decreases when the rotational speed increases. The ratio between U_{mf} when the distributor rotates at the given rotational speed and U_{mf} for the static distributor, decreases from a value of 96% at $\omega^2 R_m = 0.2g$ (n = 60 rpm) up to 74% at $\omega^2 R_m = 0.55g$ (n = 100 rpm).

(b) If $\omega R_m = U$ the same fluidization quality is found not depending on the rotational speed.

(c) If $\omega R_m < U$ the effect of the plate rotation on the bed dynamics disappears due to the dominant influence of the axial gas velocity with respect to the tangential velocity caused by the distributor rotation.

Further work could investigate the performance of the rotating distributor in Geldart A and C particles which are more difficult to fluidize. Moreover, similar experiments could be carried out encouraging the effect of the rotation by increasing the rotational speed above 100 rpm, or modifying the holes layout on the distributor.

NOTATION

D	Bed diameter (m)
g	Acceleration of gravity (m/s^2)
L	Height of fixed bed measured from the distributor (m)
n	Rotational speed of the distributor plate (rpm)
$R_m = D/4$	Average radius of the distributor plate (m)
U	Superficial gas velocity (m/s)
U_{mf}	Minimum fluidization velocity (m/s)
U_{mf0}	Minimum fluidization velocity for the static distributor plate (m/s)
Δp	Pressure drop across the bed (Pa)
σ_p	Standard deviation of pressure fluctuations (Pa)
$\omega = 2\pi n/60$	Angular velocity of the distributor plate (s^{-1})

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