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On the minimum fluidization velocity in 2D fluidized beds

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ABSTRACT

In the present study, a new correlation for the determination of the minimum fluidization velocity in 2D fluidized beds was developed. The proposed correlation was based on the experimental results obtained in 2D fluidized beds with different particle sizes, bed thicknesses and bed heights. Thus, the proposed correlation depends only on the nondimensional variable t/d_p, where t is the bed thickness and d_p is the particle size. The proposed correlation was compared with other experimental results that can be found in the literature, and two different trends were observed. Namely, one set of experimental results was in accordance with the proposed correlation, while the other set deviated from the theoretical results. In particular, the minimum fluidization velocities of the experimental results were greater than the predicted values of the proposed correlation. In view of the differences in the experimental conditions, the observed discrepancies may be attributed to the effects of electrostatic charge and particle shape. In addition, the experimental fluidization–defluidization curves were compared to the theoretical results of Jackson's model, and the parameters were fitted to the experimental data. However, Jackson's model is based on a 1D bed; thus, general parameters could not be obtained for a bed with a fixed particle size and thickness due to the two dimensional voidage distribution in the bed and bed cohesion effects, which are a result of electrostatic forces and are not considered in Jackson's model.

1. Introduction

The study of fluidized beds dynamics is a complex task. Thus, different experimental techniques have been developed to evaluate the characteristics of fluidized beds, including pressure, capacitance, optical and/or heat transfer probes [1–3]. In addition, imaging techniques have been used to observe the interior of the bed. Simons [4] reviewed the use of radiation and capacitance imaging, and studies on the application of magnetic resonance imaging (MRI) for the determination of the time average particle velocity [5], time average voidage [6] and/or the mean length of jets in perforated plate distributors have been conducted [7].

Alternatively, 2D fluidized beds have been used to study fluidized bed hydrodynamics since the pioneering studies of the early 60's [8–11]. For example, Trsiakti et al. [12] and Pallarès and Johnsson [13] monitored the motion of an artificial fuel particle in a 2D fluidized bed with a camera to characterize fuel dispersion and fuel motion within the bed. In addition, Shen et al. [14] and Busciglio et al. [15] measured the size and velocity of bubbles along the height of the bed, and Santana et al. [16], Müller et al. [17] and Almendros-Ibáñez et al. [18] applied Particle Image Velocimetry (PIV) to obtain the instantaneous particle velocity around erupting bubbles in 2D fluidized beds. Similarly, Almendros-Ibáñez et al. [19] combined PIV techniques with numerical calculations to characterize particle–fluid motion around bubbles, and Link et al. [20] and Busciglio et al. [21] compared the experimental results obtained in 2D fluidized beds to those of numerical simulations.

Thus, 2D fluidized beds have been successfully used to study particle–fluid dynamics in fluidized beds, and important qualitative information has been obtained. Moreover, high speed video cameras can be easily employed in 2D fluidized beds [15–19], and higher spatial and temporal resolution than techniques commonly used in 3D beds (radiation and capacitance imaging and MRI) can be obtained. Nevertheless, it is unclear how the results obtained in 2D fluidized beds can be quantitatively extrapolated to 3D beds [22,23]. For instance, Geldart [24] and Clift [25]] observed that the bubble size distribution in 2D fluidized beds could not be directly applied to 3D beds due to differences in bubble coalescence and the presence of wall effects. More recently, the experimental results of Shen et al. [14] corroborate these wall effects. In a different study, Briongos and Guardiola [26] proposed a new method based on chaos scale-up techniques to scale 2D hydrodynamics.

The minimum fluidization velocity U_{mf} is an important parameter of a fluidized bed. Ramos Caicedo et al. [27] fluidized glass ballotoni (density $\rho_s = 2550\ kg/m^3$ particle size $d_p = 250 - 400\ \mu m$) and demonstrated that the minimum fluidization velocity in 2D fluidized

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beds was dependent on the thickness and height of the bed. Thus, significant differences in the U_{mf} (up to 500%) were detected when the bed height was varied from $h = 8$ *cm* to $h = 60$ *cm* (bed thickness $t = 6$ *mm*). Ramos Caicedo et al. [27] proposed a correlation for the extrapolation of the U_{mf} in 2D fluidized beds to the U_{mf} of a 3D bed; however, the constant in the proposed correlation was dependent on the particle size. Thus, the correlation could not be used when different experimental conditions were applied. Moreover, Geldart [24] demonstrated that the minimum fluidization velocity increased with an increase in the fixed bed height; however, only a 43% increased in the U_{mf} was observed when the bed height was increased from 5 to 80 *cm*. In theory, the minimum fluidization velocity does not depend on the height of the bed; thus, the observed differences in the U_{mf} were attributed to wall effects.

In the present study, a new correlation was proposed to quantify the effect of the 2D geometry on the minimum fluidization velocity, and the results indicated that the minimum fluidization velocity in a 2D bed increases with an increase in the ratio of the particle size to the bed thickness (d_p/t) Alternatively, negligible differences were observed when the fixed height of the bed was varied (in contrast to the results obtained by Ramos Caicedo et al. [27]). In addition, the proposed model by Jackson [28] was used to characterize wall effects; however, due to the 1D assumptions of the model (the voidage varies with the bed height $\varepsilon(z)$) , general conclusions could not be obtained because the voidage distribution during the fluidization–defluidization process varies with the height and the width ($\varepsilon(x,z)$) of the bed.

In the following sections of the present manuscript, the experimental set-up and the particles employed in the experiments are described in detail. In addition, the experimental results are presented and discussed, and the main conclusions of the investigation are described in the final section.

2. Experimental set-up

The experiments were carried out in a 2D cold fluidized bed with a width *(w)* and height (H) of 500 and 2000 mm [29], respectively. The thickness of the bed (t) was varied by adding or removing columns along the frame of the bed, and three different bed thickness were evaluated (5, 10 and 20 mm). The gas flow was introduced through both sides of the plenum to properly distribute the gas flow. Fig. 1 shows a schematic depiction of the 2D bed.

Three different distributors were employed, and the type of distributor used in the bed was dependent on the bed thickness. The distributors consisted of perforated plates with 1*mm* holes at 1*cm* intervals. The ratio between the open area and the total area of the three distributors in each bed were identical, and the open area of the beds was set to 1.57% As a result, for all of the beds, the characteristic curves of the distributors ($\Delta P_{dist} - U$) were identical. Fig. 2(a) shows a schematic depiction of the distributors, and Fig. 2(b) shows the characteristic curves of the distributors.

The gas pressure drop was measured with a pressure transmitter (PTX 1400 model, GE industrial) at an operating pressure of 0–6 *atm*. The transmitter was connected to a probe, which was situated in the plenum (see Fig. 1), and a sample frequency of 100 Hz was applied. Two types of particles with different sizes were employed in the present study, spherical glass particles with a density of $\rho_p = 2500$ kg/m^3 (type B according to Geldart's classification [30]). Both particle size distributions were normal, and the mean particle size and standard deviation are shown in Fig. 3.

In addition to the 2D measurements, several measurements were obtained from a 3D bed that was similar to the one described in the literature [31]. These data were used to obtain the minimum fluidization velocity in a 3D bed.

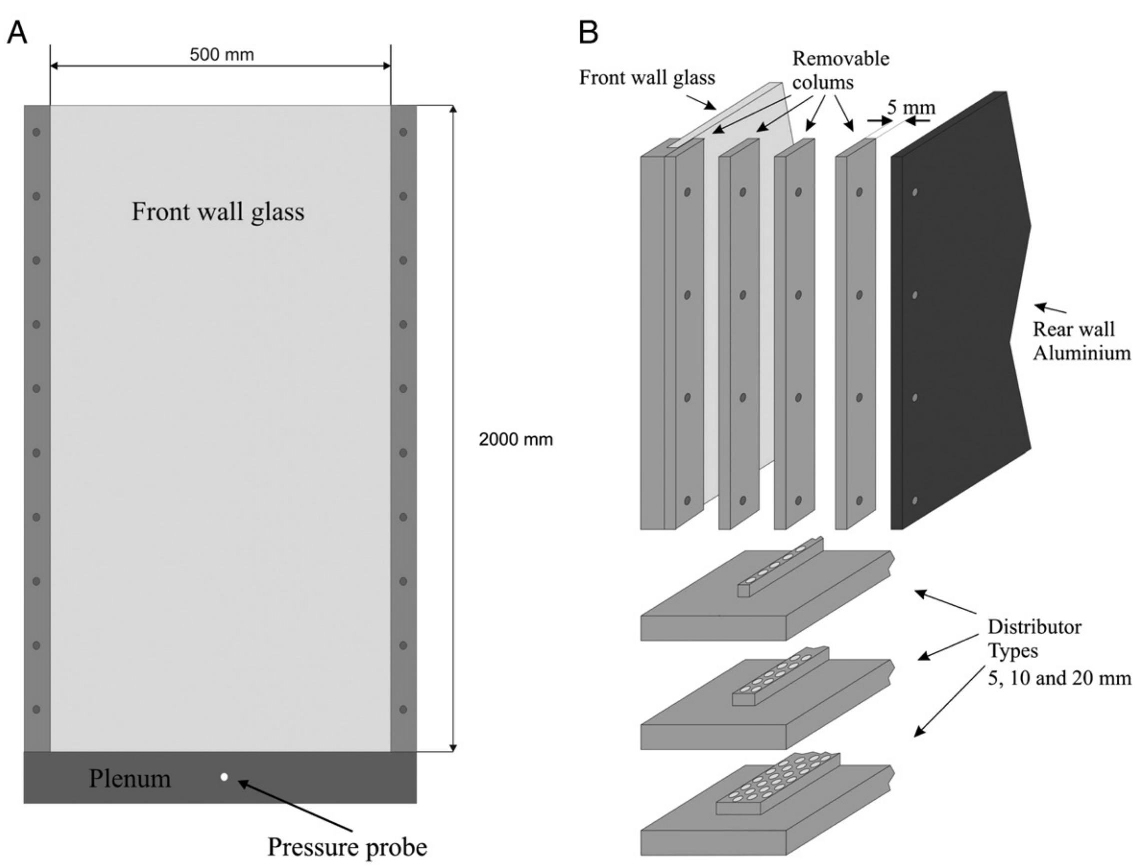

Fig. 1. Schematic depiction of the 2D fluidized bed.