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Influence of the Geometric Factors of Conical Contactors and Draft Tubes on the Performance of Draft Tube Conical Spouted Beds

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A hydrodynamic study of conical spouted beds equipped with draft tube has been carried out for Geldart group D particles. Based on a design of experiments, the performance of conical spouted beds provided with draft tube has been studied by measuring different hydrodynamic parameters (minimum spouting velocity, operation pressure drop, solid circulation rate) and the influence of the geometric factors of conical contactors and draft tubes (open-sided draft tubes), and particle properties on these hydrodynamic parameters. The results show that the factors studied (bed height, angle, inlet diameter, width of the draft tube faces, particle diameter) have great influence on the hydrodynamic parameters.

1. Introduction

Spouted beds are an alternative contact method to fixed and fluidized beds. They consist of only one orifice at the bottom of the bed and, therefore, the fluidizing gas opens a central spout in which particles ascend and a surrounding annulus in which particles descend. Accordingly, the main difference with fixed and fluidized beds lies in their cyclic movement.

In the past, spouted beds have been widely used for drying, granulating, and mixing, but attempts have recently been made to make better use of their flexibility by using them for gasification, pyrolysis, combustion and three phase reactions (Epstein and Grace, 2011).

Different modifications of the original spouted bed are proposed in the literature with the aim of improving its performance. These modifications mainly concern the geometry of the contactor and/or the gas inlet to the bed. Given the advanced knowledge of their hydrodynamics and applications, the following are worth mentioning: the spouted beds of rectangular section (also with rectangular gas inlet), the conical spouted beds and the spout-fluid beds, which combine the advantages of the spouted beds and bubbling fluidized beds. Thus, Freitas and Dogan (2000) proposed the spouted beds of rectangular section to overcome the scaling up difficulties of conventional spouted beds. Olazar et al. (1992) found that the hydrodynamics of conical spouted beds was different from that of the conventional spouted bed and prove that they are suitable for the handling of particles of large diameter, sticky solids and with size distribution. Povrenovic et al. (1992) developed a model for calculating the minimum spouting flow rate and pressure drop in these conical beds. Bi et al. (1997) developed a correlation to predict the minimum spouting velocity for small and pilot-scale conical spouted beds. Zhao et al. (1987) studied coal combustion in a half column spout-fluid bed combustor, Passos and Mujumdar (1989) the drying performance of spout-fluid beds dryers for different grains and Ye et al. (1992) the influence of hydrodynamic parameters in a half column spout-fluid bed at high temperatures.

A crucial parameter that limits scaling up of spouted beds is the ratio between the gas inlet diameter and particle diameter. In fact, the inlet diameter should be smaller than 20 - 30 times the average particle diameter in order to achieve spouting status. The use of a draft tube is the usual solution to this problem and causes changes in the hydrodynamics and solid circulation rate of spouted beds. Thus, Ishikura et al. (2003) studied the hydrodynamics of a spouted bed with a porous draft tube, Nagashima et al. (2009) the effect of the porous draft tube shape on gas and particle flow pattern, Neto et al. (2008) the effect of a draft tube on the fluid dynamics of a spouted bed and Zhao et al. (2006) the influence of the draft tube on

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particle velocity profiles. The performance of the lower conical section of the contactor is different when the draft tube is used.

Different draft tube configurations are reported in the literature: conventional non-porous draft tubes, porous draft tubes and open-sided draft tubes. The latter have been developed by our research group (Altzibar et al., 2008; Altzibar et al., 2009; Olazar et al., 2012) and they are especially suitable for vigorous contact.

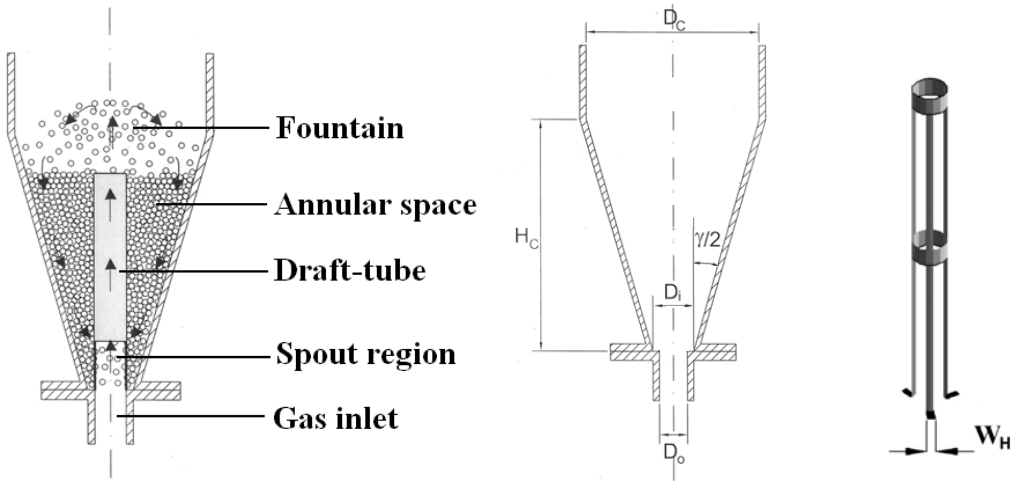
Regarding the performance of the spouted bed regime, previous works (Altzibar et al., 2008; Altzibar et al., 2009) show that open-sided draft tubes perform much better than conventional non-porous tubes, and the solid circulation rate (turbulence) is much higher with open-sided draft-tubes, which is due to the solid cross-flow from the annulus into the spout at any level in the bed, although their operating pressure drop and air flowrate required are higher. Furthermore, open-sided draft tubes allows for an optimum gas distribution in the bed, and consequently, open-sided draft tubes are the best option for drying processes (Altzibar et al., 2007; Altzibar et al., 2008; Altzibar et al., 2011; Olazar et al., 2012).

There are three different zones in the conical spouted bed with conventional draft tube, namely, spout, annulus and fountain. Figure 1 shows these different zones.

In this paper, a study has been carried out on the hydrodynamics of conical spouted beds with open-sided draft tubes. Thus, the performance of conical spouted beds provided with open-sided draft tube has been studied by measuring different hydrodynamic parameters (minimum spouting velocity, operating pressure drop and solid circulation mass flowrate) and the influence of the geometric factors of conical contactors and draft tubes, as well as the particle properties have been determined.

2. Experimental

The experimental unit used is described in previous paper (Altzibar et al., 2013). The study has been carried out using contactors of different angles (γ) and inlet diameters (D_0) (Figure 1b). These contactors are made of polymethyl methacrylate. The dimensions of each contactor depend on the contactor angle. Thus, the column diameter is the same for the different angles used, D_c, 0.36 m. The height of the conical section, H_c, is 0.60, 0.45 and 0.36 for the angles of 28, 36, and 45°, respectively. The gas inlet diameters used are, D_0, 0.04 and 0.05 m.



(a) (b) (c)

Figure 1: a) Zones in the conical spouted bed with conventional draft tube, b) geometric factors of the conical contactors and c) open-sided draft tube configuration.

The internal devices used for operation are the open-sided draft tubes. Figure 1c shows the configuration of open-sided draft tubes. Three open-sided draft tubes have been used in this work, which differ on the width of the faces (W_H = 0.01, 0.018, 0.025 m), related to the aperture ratio of the tube.

Coarse materials (glass beads of 0.002 and 0.004 m of diameter and of 2420 kg m^{-3} of density) have been used for operation, which belong to group D of Geldart classification. The stagnant bed height (H_0) is varied between 0.14 and 0.30 m.

3. Results

Experimental runs have been carried out by combining the factors and their levels mentioned in the experimental section (γ, D_0, H_0, W_H, d_p). In each experimental run, the evolution of bed pressure drop with air velocity has been monitored from the fixed bed to the spouting regime. Figure 2 shows the results for a given system as an example.

A very pronounced hysteresis is noteworthy, which is due to the fact that peak pressure drop is much higher than operating pressure drop and, furthermore, a much higher velocity than the minimum one is required to break the bed and open the spout.

Furthermore, it is observed that, at first, as air velocity is increased, pressure drop increases to a maximum value. Subsequent to the maximum value, when air velocity is increased, the fountain is created and pressure drop decreases. Subsequently, air velocity is decreased in order to obtain the values of operating pressure drop and minimum spouting velocity. From each figure, the minimum spouting velocity (u_{ms}) and operating pressure drop (ΔP_S) are determined.

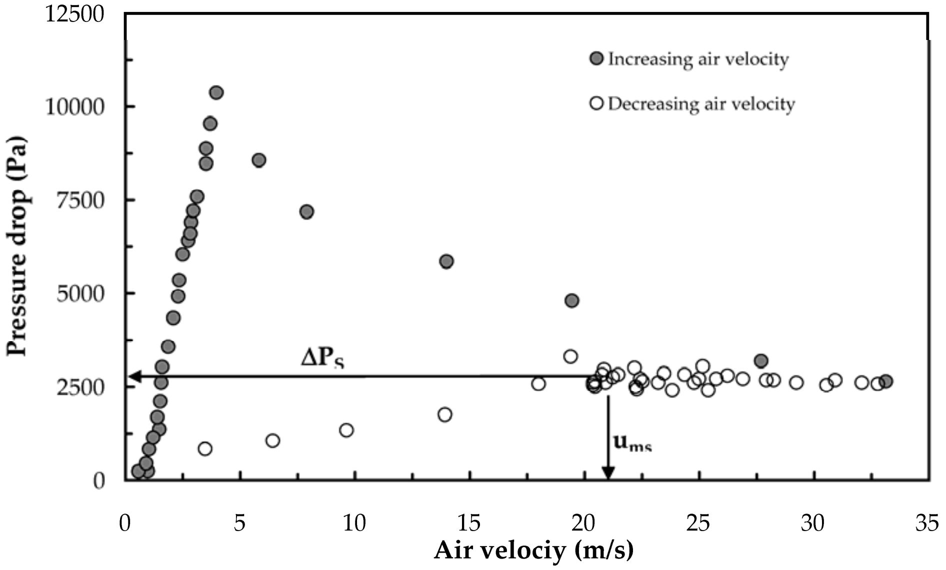


Figure 2: Evolution of the bed pressure drop with air velocity for a given system: Experimental conditions: γ = 45°; D_0 = 0.04 m; H_0 = 0.22 m, W_H = 0.010 m, d_p = 0.004 m.

Furthermore, the solid circulation rate (W_S) has been determined for each run by measuring the solid cycle time (monitoring a marked particle of the same material and with visual observation in the fountain through the transparent wall) and the bed mass. Thereby, the solid circulation rate is the ratio of the bed mass and the solid cycle time. Based on repetitions, a relative error of 8% has been estimated for these values.

In order to study the quantitative and qualitative influence of the geometric factors of conical contactors and open-sided draft tubes, and particle properties on the hydrodynamic parameters, the values of the different responses vs. the factor levels have been plotted.

Figures 3 and 4 show typical trends observed in the experimental runs carried out, for given systems as an example. In these Figures plots, average values of the responses (u_{ms}, ΔP_S and W_S) are plotted for each level considered, i.e., each average corresponds to all the data with the same value of the level.

Figure 3 shows the change in minimum spouting velocity (a), operation pressure drop (b) and solid circulation rate (c) caused by the gas inlet diameter (D_0).

It can be observed that an increase in gas inlet diameter gives way to a decrease in minimum spouting velocity (a), and an increase in operating pressure drop (b) and circulation rate (c).

Figure 3a shows that the minimum spouting velocity decreases as the gas inlet diameter is increased. This trend is similar to that qualitatively observed for conical spouted beds with non-porous draft tube (San José et al., 2007) and without tubes (Aguado et al., 2005). It should be noted that although the minimum spouting velocity referred to the inlet diameter decreases, the inlet flow rate increases due to the increase in the inlet cross-sectional area.

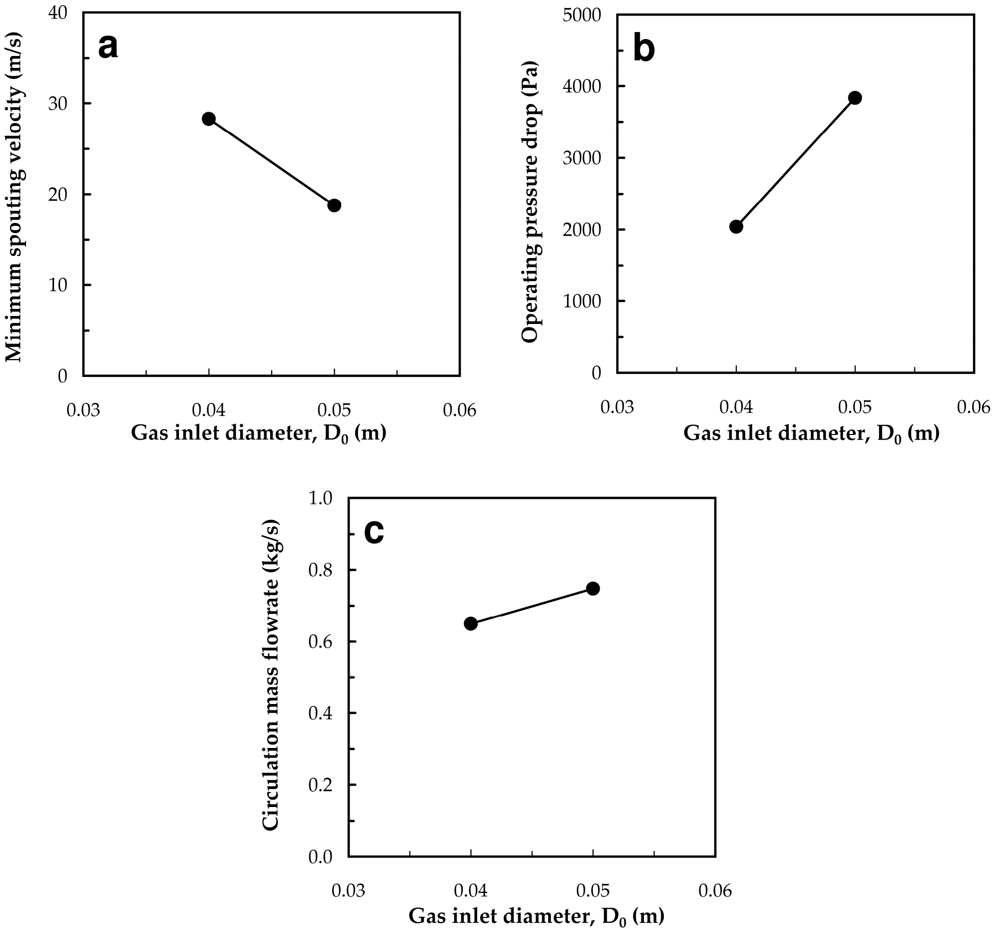


Figure 3: Influence of gas inlet diameter on the minimum spouting velocity (a), operation pressure drop (b) and solid circulation mass flowrate (c). Experimental conditions: $\gamma = 45°$; $H_0 = 0.27$ m, $W_H = 0.018$ m, $d_p = 0.004$ m.

Regarding the operating pressure drop, Figure 3b shows that the operating pressure drop increases with an increase in gas inlet diameter. The explanation lies in the higher air velocity required to operate with stable performance, and the higher air fraction crossing the bed through the annulus.

Figure 3c shows that the solid circulation rate increases with an increase in gas inlet diameter. This trend is as a consequence of a higher inlet air flowrate required as gas inlet diameter is increased, and as the air fraction rising through the annulus is higher, the bed is loosen, and the solid circulation rate is increased. This trend is similar to that Cheong et al. (1986) observed in slotted spouted beds.

Figure 4 shows the change in minimum spouting velocity (a), operation pressure drop (b) and solid circulation rate (c) caused by the width of the faces (W_H) of the draft tube.

As observed in Figure 4, an increase in the width of the faces of the tube (i. e., aperture ratio of the tube is decreased) gives way to a decrease in the minimum spouting velocity (a), operating pressure drop (b) and circulation rate (c).

Figure 4a shows that the minimum spouting velocity decreases as the width of the faces is increased. The reason for that lies in a lower fraction of the gas that percolates from the spout into the annulus as the width of the faces is increased, and consequently, a lower air velocity is required. This trend is similar to that already observed qualitatively by Altzibar et al. (2009) and Altzibar et al. (2013) in previous works.

Regarding the operating pressure drop, Figure 4b shows that as the width of the faces is increased the operating pressure drop decreases due to the smaller aperture ratio of the tube. Consequently, the amount of solid that enters the spout and the gas fraction that percolates from the spout into the annulus is lower.

Furthermore, as a consequence of a lower amount of solid entering the spout, solid circulation rate decreases as the width of the faces (Figure 4c) is decreased.

Although the results are not shown here, particle diameter, contactor angle and bed height also influence the hydrodynamic parameters studied. Typical trends observed show that the minimum spouting velocity goes through a minimum with contactor angle. Thus, it decreases as contactor angle is increased from 28 to 36 degrees and then increases as the level of the factor is increased further. Regarding the bed height, the minimum spouting velocity increases sharply with bed height. In the case of particle diameter, an increase in particle diameter gives way to an increase in minimum spouting velocity.

Furthermore, the operating pressure drop increases significantly with bed height and decreases slightly with contactor angle and particle diameter. The solid circulation rate increases with bed height, contactor angle and particle diameter.

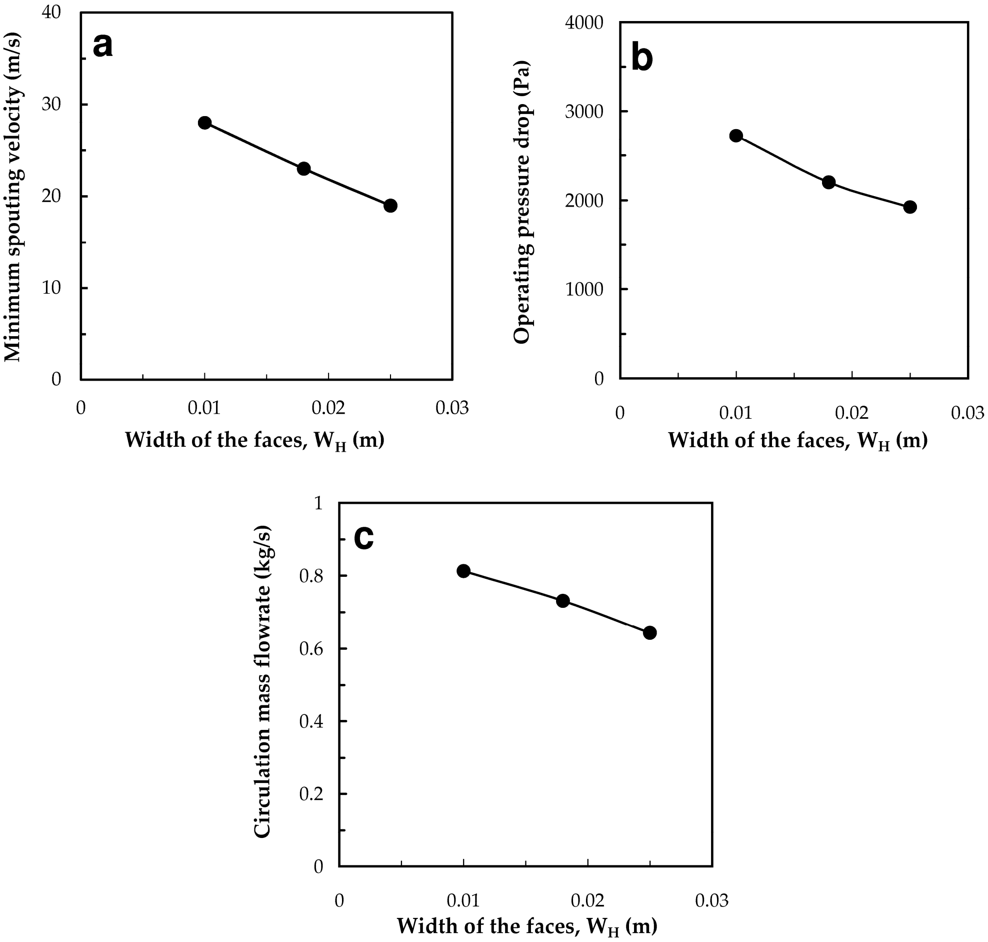


Figure 4: Influence of width of the faces on the minimum spouting velocity (a), operation pressure drop (b) and solid circulation rate (c). Experimental conditions: γ = 36°; D_0 = 0.04 m; H_0 = 0.17 m, d_p = 0.002 m.

4. Conclusions

A hydrodynamic study of open-sided draft tube conical spouted beds has been carried out for Geldart group D materials. The influence of the geometric factors of conical contactors and open-sided draft tubes, and particle properties on the hydrodynamic parameters (u_{ms}, ΔP_S, W_S) have been studied following the evolution of bed pressure drop with air velocity in a wide range of conditions.

A very pronounced hysteresis, much higher than in conventional conical spouted beds, is obtained in the evolution of pressure drop with air velocity.

The results show that the hydrodynamics of conical spouted beds with open-sided draft tube is influenced by the geometric factors of the contactor and draft tube, as well as the operating conditions.

The values of the minimum spouting velocity are increased by increasing particle diameter and bed height, and decreasing the width of the faces of the tube and the gas inlet diameter.

Regarding the operating pressure drop, its values are increased by increasing the gas inlet diameter and the bed height, and decreasing the width of the faces, the particle diameter and the contactor angle.
Finally, the values of the solid circulation rate are increased by increasing particle diameter, gas inlet diameter and bed height, and decreasing the width of the faces.

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