



Effect of a Device for Retaining Solids on the Fountain Height in the Nonporous Draft Tube Conical Spouted Bed

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Fine particle entrainment is a serious problem when dealing with fluidized and spouted beds. In the latter, it is even enhanced by the need for using draft tubes when dealing with fine particles, and therefore entrainment avoidance is a key aspect for process viability. A new device for retaining solids has been developed and the influence of geometric factors on the fountain height has been studied in draft tube conical spouted beds with materials of different density. A nonporous draft tube has been used combined with a solid retaining device. This internal device is placed above the bed and traps the particles of the fountain, modifying fountain shape and height. Thus, runs have been carried out in conical spouted beds of different geometry to ascertain the effect of the device on the fountain height. These runs have been conducted using different contactor angles, gas inlet diameters, solid densities, device diameters and distances from the bed surface to the lower end of the device. It can be concluded that all the factors studied affect the fountain height, with the smaller effect being that of distance from the bed surface to the lower end of the device.

1. Introduction

The spouted bed regime is an alternative gas-solid contact method to fixed and fluidized beds that has been successfully applied to systems where fluidization has yielded unsatisfactory results. Accordingly, the main difference with fixed and fluidized beds lies in their cyclic movement. Different modifications of the original spouted bed (cylindrical with conical base) are proposed in the literature to improve its performance (Epstein et al., 2011).

Spouted beds are gas-particle contactors in which the gas is introduced through a single nozzle at the centre of a conical or flat base. The air penetrates the bed of particles creating a central spout zone, a fountain above the spout and an annulus surrounding the spout. The gas passes upward through the spout, fountain and annulus, while the particles are conveyed up the fountain core and down the fountain periphery and annulus. The recirculation of particles between the spout and annulus is one of the more important characteristics of spouted beds.

Spouted beds with a fully conical geometry combine the features of cylindrical spouted beds (such as the capacity for handling coarse particles, small pressure drop, cyclic movement of the particles and so on) with those inherent to their geometry, such as stable operation in a wide range of gas flow rates (Olazar et al., 1992). The versatility of the gas flow rate allows handling particles of irregular texture, fine particles and those with a wide size distribution, as well as sticky solids, whose treatment is difficult using other gas-solid contact regimes. Moreover, the dilute spouted bed can operate with short gas residence times (as low as milliseconds). Furthermore, this technique has been applied in many processes, such as granulation (Borini et al., 2009), coating (Rocha et al., 2009), drying (Correa et al., 2012) and pyrolysis (Makibar et al., 2015).

Spouted beds of conical geometry have advantages compared to fluidized beds and to other gas-solid contact methods, especially for treatment of solids with a wide particle size distribution (Barcelos et al., 2006). Furthermore, the success of the use of spouted beds in applications as drying of vegetables seeds (Chielle et al., 2016) is attributable to the characteristics of circulation of the solids, which describe defined trajectories in the contactor with a defined residence time.

However, there are situations in which the gas-solid contact is not fully satisfactory due to the instability of the bed, especially at large scale. A crucial parameter that limits the scaling up of spouted beds is the ratio

between the inlet diameter and particle diameter. Olazar et al. (1992) observed that the inlet diameter should be smaller than 20-30 times the average particle diameter in order to avoid a slugging regime and achieve spouting status. Therefore, operation with fine particles (smaller than 1 mm particle diameter) requires the use of draft tubes.

Nevertheless, draft tubes modify the hydrodynamics and solid circulation flowrate of spouted beds. Thus, minimum spouting velocity, operating pressure drop, solid circulation pattern, particle cycle time (time required for a solid to complete the full cycle, crossing all the zones in the spouted bed), and gas distribution are influenced by the type of draft tube used. The performance of the lower conical section of the contactor is different when the draft tube is used, and largely depends on the bed geometry, draft tube diameter, length of the entrainment zone, and operating conditions (Nagashima et al., 2009).

The most used draft tubes are nonporous draft tube due to the great advantages they have (Ishikura et al., 2003): decrease the minimum spouting velocity, the peak pressure drop and operating pressure drop, better control of solid circulation, narrower residence time distribution, maximum spoutable bed height is avoided and higher bed stability is attained. Moreover, this kind of draft tube enables the operation with solids of any size or nature, such as sawdust (Saldarriaga et al., 2015), chickpeas (Estiati et al., 2015) or low-density solids (Olazar et al., 2004). Nevertheless, the use of nonporous draft tubes limits the access of the air to the bed (poor contact between gas and solids) decreasing heat and mass transfer rates, narrows the distribution of solids cycle times, decreases the degree of mixing, increases the risk of tube blockage and makes the design more complex.

A new internal device has been developed by our research group called device for retaining solids which influences the fountain of conical spouted beds. This device is placed above the bed and traps the particles in the fountain, changing the shape of the fountain (narrower and higher) and forcing the air to make a longer trajectory. Thus, it stabilizes the system and avoids the entrainment of fine particles. It is a cylindrical tube (made of polymethyl methacrylate) with the upper outlet closed. Therefore, it is possible to operate at high values of gas flowrate without bed losing and improving solid circulation rate.

Thus, the main aim of this work is to analyze the effect of a solid retaining device on the fountain height using nonporous draft tubes with particles of different density (glass beads of 2 mm diameter and black peas of 3 mm diameter). This work is a preliminary one on the hydrodynamics of draft tube conical spouted beds equipped with a solid retaining device.

2. Experimental

Different runs have been carried out in a pilot plant shown in Figure 1.

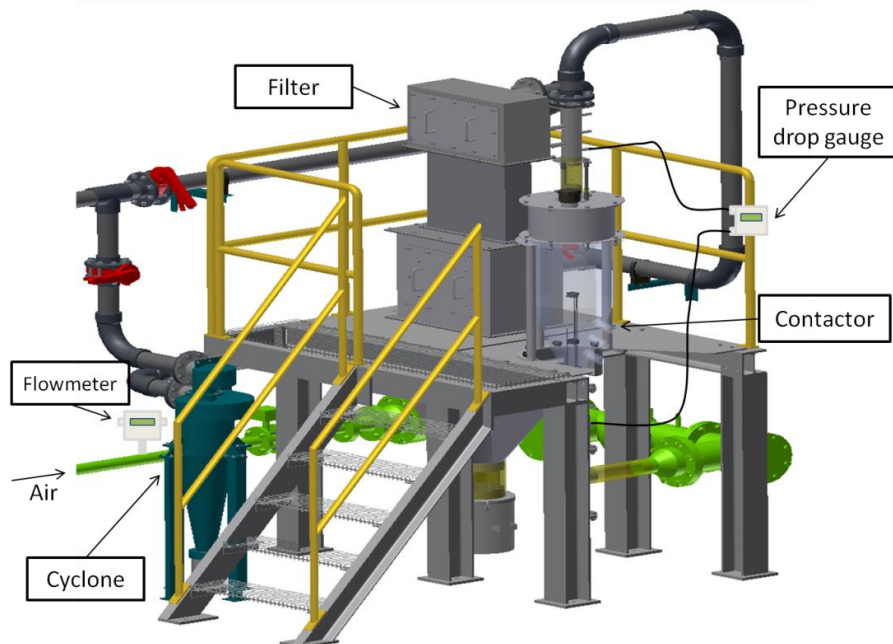


Figure 1. Diagrammatic representation of the pilot plant.

This plant is composed by a blower, flowmeter, pressure drop gauge, contactor, filter and cyclone. The blower has a power of 5.5 kW and supplies air to the contactor. The gas flow is measured by means of a flowmeter, which is used in the range of 0-600 Nm³/h. The blower supplies a constant flowrate, and the flow that enters in the contactor is controlled by acting on a motor valve that reroutes the remaining air to the outside or changing the frequency of the motor of the blower if strict control is necessary. The pressure measurements are carried out by means of two pressure taps, which are connected to the input and output of the contactor. In order to separate the solids dragged by the air, a filter and a cyclone are connected in parallel. The filter traps fine particles meanwhile the cyclone separates coarser particles from the air.

Moreover, the unit allows operating with contactors of different geometry. These contactors are made of polymethyl methacrylate and have a conical geometry. Figure 2a shows the geometric factors of these contactors. The column diameter and the base diameter are the same for the different angles used, D_c , 0.36 m and D_i , 0.068 m, respectively for the angles (γ) of 28, 36 and 45°. Different gas inlet diameters have been used: 0.03, 0.04 and 0.05 m.

Furthermore, a nonporous draft tube has been used and Figure 2b shows a scheme of this device. The dimensions of the nonporous draft tube are: length of the tube $L_T = 0.27$ m; height of the entrainment zone (distance between the gas inlet nozzle and bottom of the draft tube) $L_H = 0.07$ m; diameter of the tube $D_T = 0.04$ m.

Furthermore, a new device has been used to avoid solid entrainment from the bed and it is shown in Figure 2c. This solids retaining device is a cylindrical tube made of polymethyl methacrylate with the upper outlet closed. The dimensions of this device are as follows: length of the device $L_{RS} = 0.5$ m; diameter of the device $D_{RS} = 0.19$ and 0.15 m. A stainless steel cone is coupled at the top of the device to avoid the deposition of the solid on the device, i.e., the solids deposited on the cone slip and fall down onto the bed. The device is placed above the bed (Figure 2d) and traps the particles in the fountain. Thus, it is possible to modify the distance from the bed surface to the lower end of the device. Different values of this distance have been tested to ascertain the effect it has on the minimum spouting velocity; $H_{RS} = 0, 0.01$ and 0.02 m.

The materials used for operation are glass beads and black peas. The first one has 2 mm particle diameter and 2420 kg/m³ density. The black peas have 3 mm particle diameter and 1230 kg/m³ density. Both materials have similar particle diameter, which allows studying the influence of solid density on the fountain height. The static bed height used is 0.27 m.

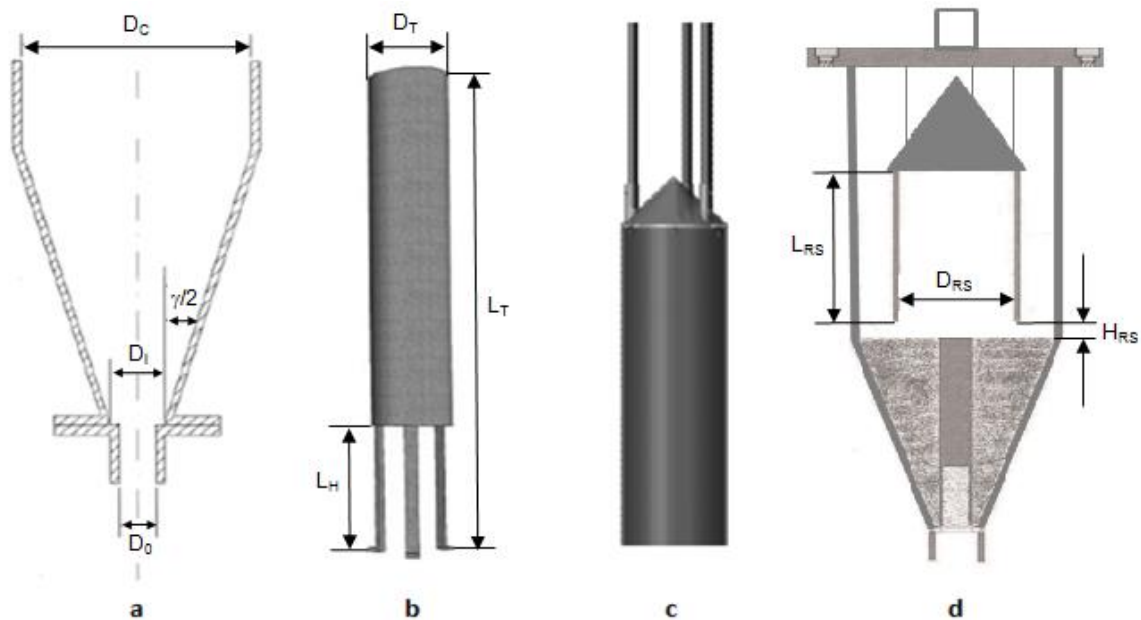


Figure 2. a) Geometric factors of conical spouted bed contactors, b) nonporous draft tube configuration, c) device for retaining solids and d) its location in a conical spouted bed.

3. Results

3.1 Design of experiment

Experimental runs have been carried out in conical spouted beds of different geometry following a design of experiments. The purpose of this design has been to study the effect on the fountain height of the insertion of a device for retaining solids, the device configuration and the different factors of the contactor and particle system. Thus, runs have been carried out by combining all these factors corresponding to the contactors (γ , D_0), solids retaining device (D_{RS} , H_{RS}) and materials (ρ_s). Approximately 110 experimental runs have been carried combining all mentioned factors.

In each experimental run, fountain height has been measured using a ruler by visual observation through the transparent wall. All the runs have conducted at the minimum spouting velocity and each experimental run has been repeated three times in order to obtain three values of fountain heights for each system. The first step for determining the minimum spouting velocity lies in loosing the bed until the fountain is formed. As the inlet air velocity is increased, the pressure drop increases to a maximum values. Subsequently to the maximum value, when air velocity is increased, the fountain is formed and the pressure drop of the system sharply decreases. Once the fountain has been formed, the air velocity is decreased until the minimum spouting velocity is obtained. This velocity is the lowest possible for which the fountain remains constant and stable. Our polymethyl methacrylate contactors allow observing the contactor inside, and therefore determining precisely the minimum air velocity.

Although the nonporous draft tube stabilizes the system, preliminary runs have shown that the insertion of the solids retaining device stabilizes the system and decreases the minimum spouting velocity, stable pressure drop and fountain height. Therefore, different device diameters (D_{RS}) and device heights (H_{RS}) have been used to analyze the changes in the fountain height.

3.2 Experimental results

Figure 3 shows the trends of the fountain height when the levels of the factors are changes. In each figure, different systems are plotted (different angle, Ang ; gas inlet diameter, D_0 ; systems without device, WOD; device diameter, D_d ; distance between device and bed surface, D_h ; solid density, glass and peas) and the trends observed are similar in all the systems studied for each individual factor.

Figure 3a shows the evolution of the fountain height (H_f) as the level of contactor angle is changed. This figure shows a minimum value for an intermediate value of contactor angle (36°), but wider angles (45°) and narrower ones (28°) lead to higher values of fountain height. This factor is related to the minimum spouting velocity.

Figure 3b shows that, as the diameter of the device is greater, the fountain height increases. This is due to the low pressure that is generated in the device using the device of greater diameter, and therefore, the fountain generated is higher. Even so, Figure 3b shows that at low values of the distance from the bed surface to the lower end of the device, the effect of device diameter on the fountain height is greater than for high values of this distance.

Figure 3c shows that the influence of the distance from the bed surface to the lower end of the device on the fountain height is not significant. As the distance is higher the fountain height obtained is greater, leading to less stable systems. Thus, low distances are preferable for stable operation. Nevertheless, the difference of the fountain height between three distances (0, 10 and 20 mm) are not too significant, which means greater values of this distance should be investigated.

Figure 3d shows that as the gas inlet diameter is increased, the fountain height is lower, which is due to the lower minimum spouting velocity required when gas inlet diameter is greater (Altzibar et al., 2013). Moreover, San José et al. (2005) observed that the diameter of the spout decreases when the gas inlet diameter is decreased, i.e., less quantity of solids access to the spout from annulus, which leads to slim and high fountains. Furthermore, the insertion of the device attenuates the effect of the gas inlet diameter on the fountain height.

Finally, as observed in Figure 3e, materials with a greater density lead to higher fountains. The explanation lies mainly in the minimum spouting velocity required by denser particles, i. e. heavier particles need higher air velocities to attain stable operation. Thus, operation with glass beads leads to higher fountain heights. Furthermore, Figure 3e shows the effect of solid density is similar to the systems without solid retaining device and the higher fountains heights are obtained with the denser solids and greater diameter devices.

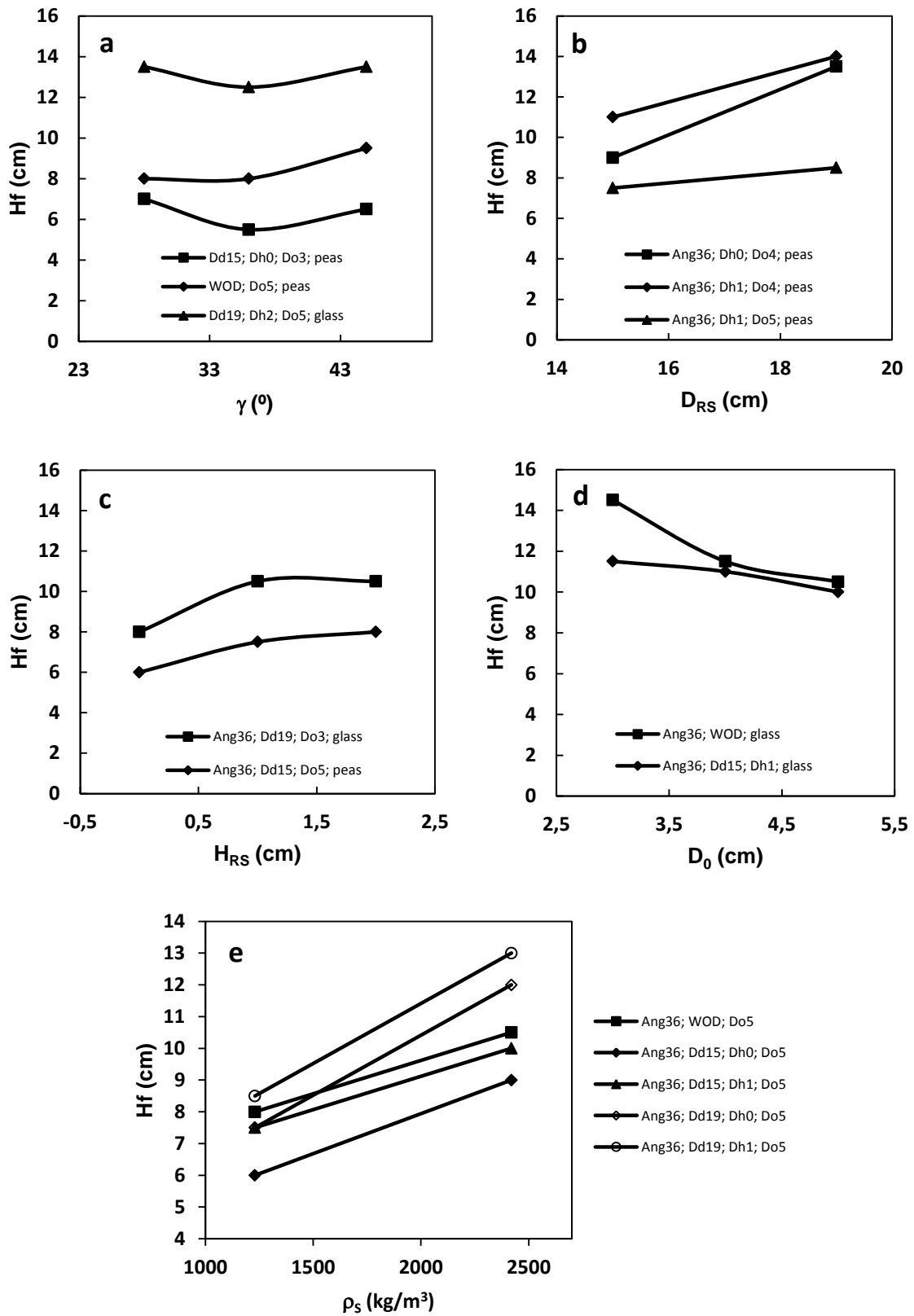


Figure 3. Influence of contactor angle a), device diameter b), distance of the device from the bed surface to the lowest end of the device c), gas inlet diameter d) and solid density e) on the fountain height.

4. Conclusions

A hydrodynamic study of conical spouted bed equipped with nonporous draft tube and a device for retaining solids has been carried out for two different solids; 2 mm diameter glass beads and 3 mm diameter black peas. Fountain height has been measured in draft tube conical spouted beds for different geometric factors of the contactor (γ , D_0), solid retaining device (D_{RS} , H_{RS}) and material density (ρ_S).

The results obtained based on an experimental design show that the fountain height is influenced by all the factors studied, but the distance from the bed surface to the lower end of the device does not affect greatly.

The effect of contactor angle, gas inlet diameter and solid density on the fountain height is closely related to the minimum spouting velocity required. Thus, the lower fountain height is obtained for an intermediate angle (36°), and the fountain height decreases as the gas inlet diameter is increased and increases when beds made up of dense solids are used.

Furthermore, the fountain height increases when the diameter of the device is increased, which must be attributed to the low pressure within the device. Nevertheless, the distance from the bed surface to the lower end of the device hardly affects the fountain height, which is due to the rather low distances used in the runs. Therefore, greater distances should be analysed in future studies to ascertain its influence on fountain height.

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