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PRESSURE DROP CORRELATION FOR THE DESIGN OF OPEN-SIDED DRAFT TUBE CONICAL SPOUTED BEDS

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Abstract. A hydrodynamic correlation has been proposed for calculating the operation pressure drop in conical spouted beds equipped with open-sided draft tubes as a function of dimensionless moduli that take into account the geometric factors of the contactor and draft tube, particle characteristics and operating conditions. A statistical analysis of the data obtained shows that stagnant bed height, width of the faces of the tube and contactor angle are the parameters of greater influence.

INTRODUCTION

The spouted bed regime is an alternative contact method to fluidized bed regime. Different modifications of the original spouted bed (cylindrical with conical base) are proposed in the literature with the aim of improving its performance (1). These modifications concern mainly the geometry of the contactor and/or gas inlet to the bed.

Spouted beds with fully conical geometry combine the features of the 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 (2). This versatility in the gas flow-rate allows for handling particles of irregular texture, fine particles and those with a wide size distribution and sticky solids, whose treatment is difficult using other gas-solid contact regimes (3, 4).

A crucial parameter that limits scaling up of spouted beds is the ratio between the 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 (2). The insertion of a draft tube is the usual solution to this problem and was used for the first time by Buchanan and Wilson (5). Nevertheless, a draft tube causes changes in the hydrodynamics and solid circulation flowrate of spouted beds (6). Thus, minimum spouting velocity, operating pressure drop, solid circulation pattern, particle cycle times 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 a draft tube is used, and largely depends on bed geometry, draft tube geometry, and operating conditions (6).

The use of a draft tube gives way to advantages in the operation with spouted beds (6, 7), i.e., greater flexibility, lower gas flow and pressure drop, solids of any size or nature may be treated, narrower residence time distribution, better control of solid circulation, a maximum spoutable bed height can be avoided, and higher bed stability is attained.

Consequently, the draft tube is an interesting option for optimizing the hydrodynamic performance of spouted beds, especially when scaling up, given that it is simple, of low cost and greatly increases flexibility.

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

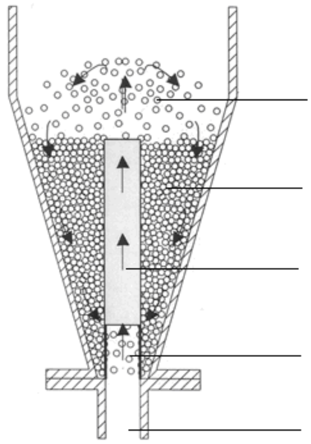

Figure 1. Zones in the conventional non-porous draft tube conical spouted bed.

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 in our research group for operating in conical spouted beds with fine particles, and they are especially suitable for a vigorous contact (8, 9). Thus, it was observed that the minimum spouting velocity required and operating pressure drop are higher with open-sided tubes than non-porous and porous draft tubes for the same contactor geometry and operating conditions. Nevertheless, the regime is more vigorous and solid circulation is higher with this type of tube. Recently, Nagashima et al. (10) developed porous and non-porous draft tubes of conical-cylindrical geometry and observed that gas-solid contact and solid circulation rate were considerably improved using the porous one**.**

The main aim of this work is to obtain a correlation to determine the operating pressure drop in conical spouted beds equipped with open-sided draft tubes.

EXPERIMENTAL

The experimental unit used is described in previous papers and allows for operating with contactors of different geometry (8). The blower supplies a maximum air flow-rate of 300 $Nm^3 h^{-1}$ at a pressure of 1500 mm of water column. The flow-rate is measured by means of two mass flow-meters in the ranges 50-300 $m^3 h^{-1}$ and 0-100 $m^3 h^{-1}$, both being controlled by computer. The blower supplies a constant flow-rate and the first mass flow-meter controls the air flow that enters the contactor (in the range 50-300 $m^3 h^{-1}$) by acting on a motor valve that reroutes the remaining air to the outside. When the flow required is lower than 50 $m^3 h^{-1}$, it crosses the first mass flow meter and is regulated by the second one placed in series, which also acts on another motor valve that regulates the desired flow-rate. The accuracy of this control is 0.5% of the measured flow-rate.

The measurement of the bed pressure drop is sent to a differential pressure transducer (Siemens Teleperm), which quantifies these measurements within the 0-100% range. This transducer sends the 4-20 mA signal to a data logger (Alhborn Almeno 2290-8), which is connected to a computer where the data are registered and processed by means of AMR-Control software. This software also registers and processes the air velocity data, which allows for the acquisition of continuous curves of pressure drop vs. air velocity.

Three conical contactors made of polymethyl methacrylate have been used. Figure 2 shows the geometric factors of these contactors. The dimensions of these contactors are: column diameter, D_c, 0.36 m; contactor angle, γ, 28, 36 and 45º; height of the conical section, H_c, 0.60, 0.45 and 0.36 m. Three inlet diameters , D_0, have been used with each contactor: 0.03, 0.04 and 0.05 m.

Different open-sided draft tubes have been used, Figure 3. The dimensions of these draft tubes are: width of the faces of the tube (aperture ratio of the tube), W_H, 0.010, 0.018 and 0.025 m; diameter of the tube, D_T , 0.04 and 0.05 m. The stagnant bed heights used are, H_0, 0.14, 0.20, 0.25 and 0.30 m.

The materials used for operation have been glass beads of different size (2 and 4 mm of diameter) and building sand (0.71 mm of diameter), both of 2358 kg m^{-3} of particle density and of D group in Geldart classification.

Runs have been carried out by combining all contactor, draft tube and operating condition factors.

In all runs, pressure drop evolution in the bed with air velocity from fixed bed to spouted bed has been studied and the values of the operating pressure drop have been obtained.

RESULTS

In order to illustrate the general characteristics of pressure drop evolution in the bed with air velocity from fixed bed to spouted bed, the results for a given system are shown in Figure 4. From each system analysed, the performance of the spouted bed regime and the operating pressure drop (ΔP_s) have been determined.

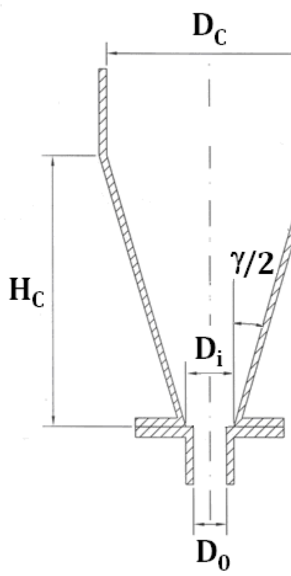

Figure 2. Geometric factors of the draft tube conical spouted beds.

Figure 3. Open-sided draft tube configuration.

Figure 4 shows 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 to a value that remains constant for a wide range of air velocities. This pressure drop is called as the operating pressure drop (ΔP_s). When air velocity is decreased from stable spouting, there is a slight increase in pressure immediately below minimum spouting velocity.

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.

From these plots, the operation pressure drop has been determined for a wide range of systems.

In order to ascertain the influence of the different variables on the operating pressure drop, an analysis of variance (ANOVA) has been carried out by means of a standard statistical program (SPSS 12.0). The significance order of the factors analysed (95% confidence interval) is shown in Table 1.

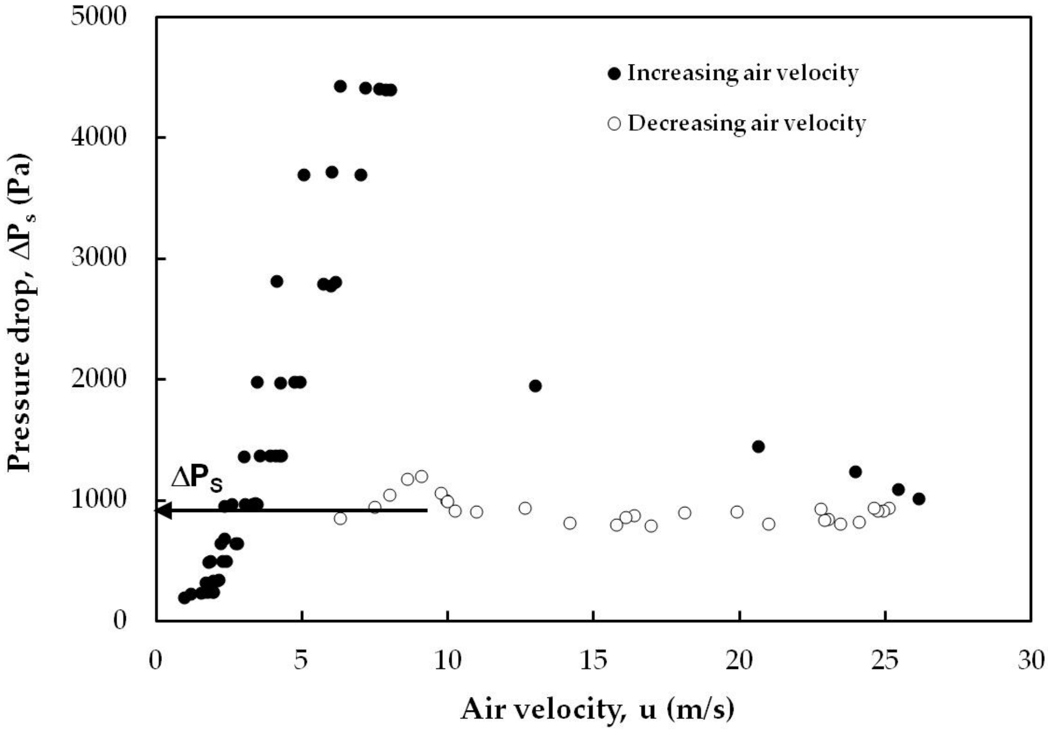

Figure 4. Evolution of the bed pressure drop with air velocity for a given system: dp=0.002 m; γ=36º; D_T=0.04 m; W_H=0.025 m; D_0=0.04 m; H_0=0.14 m

Table 1. The significance order of the factors.

Material	**Significance order**
Sand	$H_0 > W_H > \gamma > \gamma x H_0 > \gamma x W_H > \gamma x D_0$
Glass beads	$H_0 > W_H > \gamma > D_0 > D_0 x H_0 > d_p$

As observed, the stagnant bed height, the width of the faces of the tube and the contactor angle are the parameters of greater influence on the operating pressure drop for fine (sand) and coarse particles (glass beads).

The quantitative influence of the variables may be observed by plotting the operating pressure drop vs. the factors. As an example, Figures 5, 6, and 7 show the change in operating pressure drop caused by a change in the level of these factors (stagnant bed height, width of the faces of the tube and contactor angle).

As observed in Figures 5, 6 and 7, an increase in H_0, and a decrease in W_H and in γ gives way to an increase in operating pressure drop.

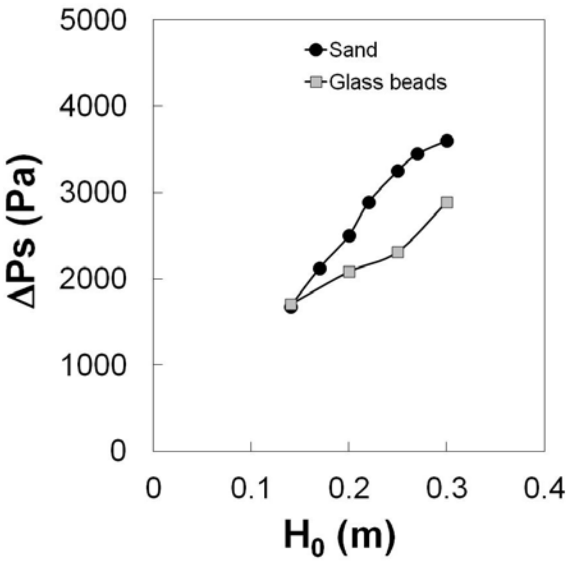

Figure 5. Influence of stagnant bed height on the operating pressure drop.

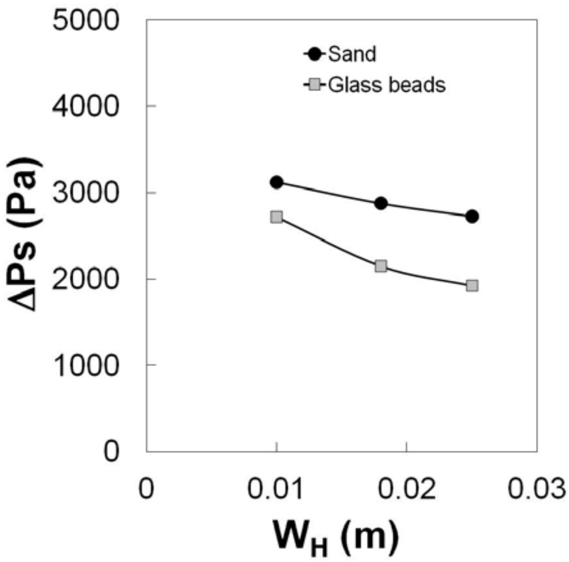

Figure 6. Influence of width of the faces on the operating pressure drop.

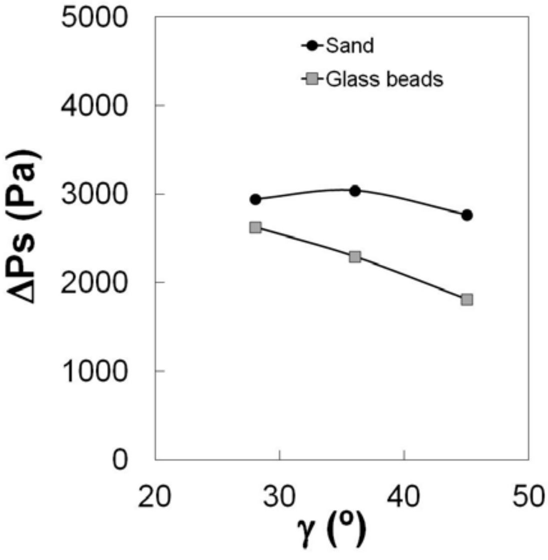

Figure 7. Influence of the contactor angle on the operating pressure drop.

Based on dimensional and statistical analysis, a hydrodynamic correlation for calculating the operating pressure drop in open-sided draft tube conical spouted beds has been determined as a function of dimensionless moduli that take into account the geometric factors of the contactor and draft tube, particle characteristics and operating conditions. The hydrodynamic correlation previously obtained by our research group for conical spouted beds without draft tubes (11) has been taken as a starting point, and a dimensionless modulus related to the aperture ratio of open-sided draft tubes has been introduced.

A correlation proposed for calculating the operating pressure drop (regression coefficient, r^2=0.95):

$$-\frac{\Delta P_s}{H_o \rho_b g} = 0.74\left[\tan\left(\frac{\gamma}{2}\right)\right]^{-0.68} (Re_o)_{ms}^{0.02} \left(\frac{H_o}{D_o}\right)^{-0.46} \left(\frac{A_o}{A_T}\right)^{0.60} \quad (1)$$

The applicability ranges of this equation are: 28º<γ<45º, 4000<Re<8000, 2.2<(H_0/D_0)<10, 0.42<(A_0/A_T)<0.78.

This correlation provides adequate predictions, especially for coarse particles.

Finally, open-sided draft tube conical spouted beds have been proven to be a good system to operate with particles as fine particles with size distribution that causes stability problems in plain spouted beds.

CONCLUSIONS

The results obtained based on an experimental design show that the hydrodynamics of conical spouted beds equipped with an open-sided draft tube is influenced by the geometric factors of the draft tube, contactor and operating conditions.

The stagnant bed height, the width of the faces of the tube and the contactor angle are the parameters of greater influence on the operation pressure drop for fine and coarse particles.

The hydrodynamic correlations in the literature for conical spouted beds cannot give satisfactory prediction results for the draft tube system used in the present study. Consequently, a new correlation has been developed for open-sided draft tube conical spouted beds, with fine and coarse particles in a wide range of operating conditions. This correlation is based on a previous correlation by including the corresponding moduli related to the factor defining the tube.

ACKNOWLEDGMENT

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NOTATION

A_0, A_T = open lateral area of the tube and total lateral area of the tube, m^2
D_0, D_i = gas inlet diameter and contactor base diameter, m
D_T , D_C = draft tube diameter and column diameter, m
d_p = particle diameter, mm
g = gravity constant, m s^{-2}
H_c, H_0 = height of the conical section and height of the stagnant bed, m
W_H = width of the faces of the tube, m
$(Re_o)_{ms}$ = Reynolds number of minimum spouting, $\rho u_{ms} d_p/\mu$
u, u_{ms} = fluid velocity and minimum spouting velocity through inlet orifice, m s^{-1}
γ = included angle of the cone, deg
ρ, ρ_s, ρ_b = density of the gas, particle and bed density, kg m^{-3}
μ = viscosity, kg $m^{-1}s^{-1}$
ΔP_S = operation pressure drop, Pa

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