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Expansion of uniform beds of wastes in clean technology of conical spouted beds with a draft tube

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The expansion of uniform beds in conical spouted beds with a draft tube has been studied experimentally with different geometrical factors of the contactor (contactor angle and gas inlet diameter) of the draft tube (diameter and height of the entrainment zone) and in different experimental conditions (gas velocity and stagnant bed height). The results of expansion obtained in conical spouted beds with a draft tube have been compared with the expansion of other beds studied in the literature, fluidized beds, cylindrical spouted beds of conical base, spouted beds of flat base and conical spouted beds without a draft tube.

1. Introduction

Spouted bed technology is suitable for thermal treatment in order to obtain energy, to reduce wastes volume and to obtain different products. Applications of conventional spouted beds with a draft tube cover a wide range of operations and chemical processes including: drying, combustion, pyrolysis, ultrapyrolysis, pneumatic conveying, and mixing (Ishikura, 2003).

In spite of the versatility of the conical spouted beds, there are situations in which the gas-solid contact is not fully satisfactory due of the bed instability. The insertion of a draft tube in a conventional spouted bed overcomes the limitations of the spouted for improving gas-solid contact.

The study of expansion with a draft tube is of special interest for the design, in conical spouted beds contactors, because flexibility of operation is one of the main qualities of the regimes and their application limit lie precisely in the voidage and consequently in the gas flow rate.

In this paper, the expansion of uniform beds with a non-porous draft tube has been studied in conical contactors. Operation has been carried out in stable operation conditions (San José et al., 2007), increasing velocity from fixed bed to diluted spouted bed, the minimum spouting velocity and diluted spouted bed velocity.

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2. Experimental equipment

The experimental unit design on a pilot scale consists basically in a blower which supplies a maximum air flow rate of 300 $Nm^3\ h^{-1}$ at a pressure of 15 kPa, two mass flow meters to measure the flow rate, with both being controlled by a computer. The accuracy of this control is 0.5% of the measured flow rate (Olazar et al., 2004).
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 (Olazar et al., 2004). 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 the software AMR-Control. The software AMR-Control also registers and processes the air velocity data, which allows for the acquisition of continuous curves of pressure drop against air velocity.
The experimental measurements of bed voidage have been carried out by determining the upper level of the expanded bed by means of a photographic technique video equipment and by visual observation.
Conical contactors made of poly(methyl methacrylate), Figure 1, have been used whose dimensions are as follows: column diameter, D_c, 0.36 m; contactor angle, γ, 28, 33, 36, 39 and 45°; height of the conical section, H_c, from 0.60 to 0.36 m; gas inlet diameter, D_o, in the range of 0.03-0.06 m. The values of the stagnant bed height, H_o, used are in up to 0.10 m.

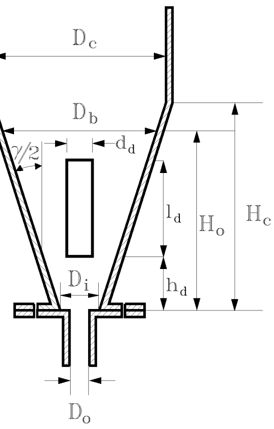

Figure 1. Schematic diagram of a conical spouted bed contactor and of the draft tube.

The draft tube, Figure 1, is a cylindrical tube made of poly(methyl methacrylate) inserted centrally at the bottom of the contactor, locating the top of the draft tube at the same level that the upper bed surface centrally. The diameter of the draft tube, d_d, is varied from 0.03 m to 0.05 m, and the entrainment zone, distance between the base of the contactor and the lower base of the device, h_d, is in the range 0.01-0.09 m. The length of the draft tube, l_d, has been calculated as $l_d = H_o - h_d$. and it is in the range 0.02-0.34 m. The range of the geometric factors of the draft tube has been determined

experimentally in conical spouted beds with a non-porous draft tube, from a viewpoint of stability and to avoid clogging (San José et al., 2007).
The solids studied are glass spheres, which corresponds basically to the D group of the Geldart classification (Geldart 1973, 1986) and their properties are set out in Table 1.

Table 1 Properties of the solids used

Material	d_p, mm	ρ_S, kg/m^3	ϕ	ε_0	Geldart Classification
Glass spheres	1	2420	1	0.322	B
	2			0.328	D
	3			0.345	D
	4			0.355	D
	5			0.358	D
	6			0.361	D
Wood wastes	8	560	0.9	0.470	D

3. Expansion

The states of incipient spouted bed and diluted spouted bed (jet spouted bed) have been determined in detail from the total bed pressure drop vs. air velocity curves. In Figure 2, a general outline of these curves is shown and in Figure 3 an outline of the evolution of particle population in the different regimes is shown.

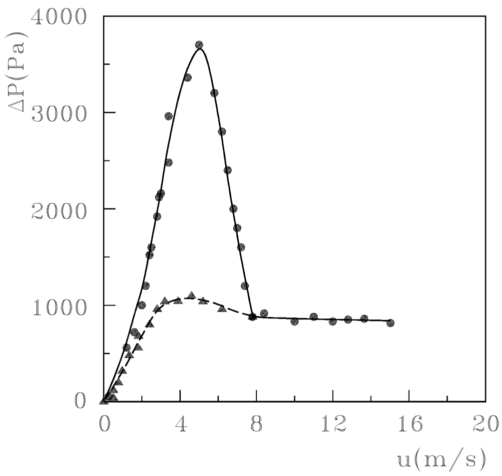

Figure 2. Pressure drop evolution with air velocity. System: γ= 45º; D_o= 0.03 m; glass spheres d_p= 4mm; d_d= 0.04m; h_d= 0.05 m; l_d= 0.05 m.

After the state of fixed bed, (Figure 3a), the velocity becomes the value corresponding to the maximum pressure drop. By increasing gas velocity stable regime of spouting is obtained, Figure 3b, increasing the velocity both annular and spout zones become progressively confused (transition zone), Figure 3c, and increasing gas velocity jet spouting regime (dilute spouted bed) (San José et al., 1991, 1992) is reached, Figure 3d.

Maximum pressure drop obtained by decreasing the gas velocity is much lower than that measured by increasing the air flow. Therefore, the hysteresis is more pronounced in conical spouted beds with draft tube than the observed in the same experimental conditions without draft tube (Olazar et al., 1992).

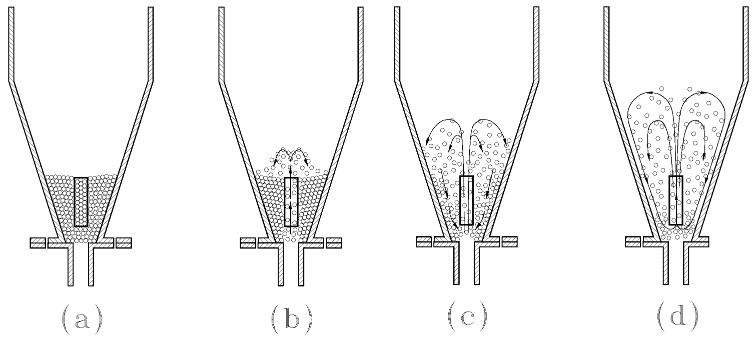

Figure 3. Particle states in the contactor for the different regimes.

In Figure 4, the experimental values of bed voidage, ε, have been plotted against the ratio of drag to gravitational forces, F_D/F_G, for a conical spouted bed with a draft tube system taken as an example, of contactor angle, γ= 36°, gas inlet diameter, D_o= 0.04 m, with a bed of glass spheres of particle diameter, d_p= 4 mm, stagnant bed height, H_o= 0.10 m, with a draft tube of diameter d_d= 0.04 m, length, l_d, = 0.05 m, and height of the entrainment zone, h_d= 0.05 m. As it is observed, in the expansion from the fixed bed to dilute spouted bed (jet spouted bed) regime, bed voidage increases as the ratio of drag to gravitational forces is increased.

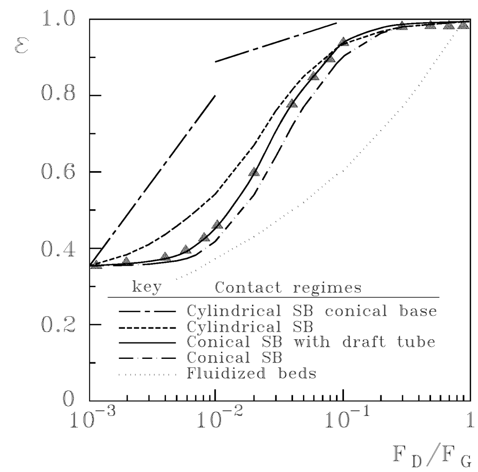

Figure 4. Bed expansion for different gas-solid contact regimes in different gas-solid contact systems. Glass spheres d_p= 4mm.

In order to compare the expansion of conical spouted beds with a draft tube with the expansion of other beds studied in the literature, in this Figure, the expansion curves for fluidized beds (Richardson and Zaki, 1954) for cylindrical spouted beds of conical base (Kimiec, 1975), for cylindrical spouted beds (San José, 1991), for conical spouted beds without a draft tube (San José et al., 1993) and for cylindrical spouted beds of conical base with a draft tube have been plotted too. The expansion curves have been calculated using the same values of the common geometric factors: for fluidized beds and for spouted beds of different geometries, H_o= 0.10 and D_c= 0.13 m; for a cylindrical spouted bed of conical base, γ_b= 36º; for a conical spouted bed, γ= 36º. Comparing conical spouted beds with and without draft tube, it is observed that bed expansion is greater with this device.

Conclusions

The expansion with a draft tube is of special interest for the design, in conical spouted beds contactors. The system passes from the spouted bed regime to a dilute spouted bed (jet spouted bed) after a transition regime.
Bed expansion of uniform beds in conical spouted beds with a draft tube has been increases as the ratio of drag to gravitational forces is increased. From the comparison of bed expansion in conical spouted beds with and without draft tube is determined, that bed expansion is greater with draft tube.

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Nomenclature

D_b, D_c, D_i, D_o	top diameter of the stagnant bed, diameter of the column, of the contactor base, and of the gas inlet, respectively, m
d_d	diameter of the draft tube, m
d_p	particle diameter, m
F_D/F_G	ratio between the drag and gravitational forces
h_d	height of the entrainment zone, m
H_c, H_o	height of the conical section and of the stagnant bed, respectively, m
l_d	length of the draft tube, m
u	velocity of the gas referred to D_i, ms^{-1}
Greek Letters	
ϕ	sphericity, dimensionless
ε, ε_o	voidage of bed and of the static bed
γ, γ_b	cone angle and angle of the conical base of the contactor, deg
ρ_s	density of the solid, kg m^{-3}

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