Applicability of the spouting regime for drying of biomass wastes in conical spouted beds with a draft tube

M.J. San José, S. Alvarez, A. Ortiz de Salazar, A. Morales, J. Bilbao

Department of Chemical Engineering, University of the Basque Country, P.O. Box 644. 48080 Bilbao, Spain

Abstract

The operating conditions in spouted bed regime of uniform beds consisting of different biomass wastes dry and wet have been studied to determine the applicability of conical spouted beds with a draft tube in the drying of biomass wastes. This experimental study has been carried out at room temperature and the effect of the solid humidity on the stability of beds of biomass wastes has been determined.

Keywords: conical spouted beds, draft tube, wastes, drying

1. Introduction

Due to the increasing costs of fossil fuels, interest has grown in the use of biomass wastes. Different methods can be followed for the use of the biomass feedstocks, as combustion, gasification and pyrolysis. Since biomass and agroforestal wastes usually have high humidity content is necessary to reduce this one before the treatment methods, so it is necessary to make a previous drying to other treatment operations. The spouted bed technology is very useful for applications where a vigorous movement of the solids is required, as happens in the handling of solids that are sticky, of irregular texture and with a wide particle size distribution (San José et al., 1993). The first application of spouted beds was drying of grain. Several authors (Strumillo et al., 1980; Mujumdar, 1984; Viswanathan, 1986; Passos et al., 1987) have used spouted bed in drying of granulated materials.

The spouted bed method has certain advantages over the contact method of fixed or fluidized bed: easy construction and the non-requirement of distributor plate or any other gas distributor device, lower pressure drop than a fluidized bed, better gas-solid contact than in a fluidized bed, materials that are difficult to handle can be processed, especially those that must be in vigorous contact with the fluid phase.

Although the conical spouted bed operating in the transition regime is very versatile, as it allows for operation to be carried out in a wide range of operating conditions, especially of air flowrates (from the minimum to more than ten times this value), there are situations in which the bed is unstable. In order to enlarge the stable operating regime central draft tubes of different length have been tried.

It has been proven that by means of an appropriate design of internal devices, a very wide size distribution of one to ten thousand (from a few microns to centimetres) may be handled without any instability or operation drawbacks. Furthermore, the length of draft tube required is only of a few millimetres located in the lower section of the bed, which means that the function of this device is simply to guide the air and so avoid the instabilities created near the bottom of the contactor.

The introduction of a central draft tube in a spouted bed provokes great changes in the hydrodynamics of the spouted beds. Buchanan and Wilson (1965) were the first to use this device in order to overcome the limitations of the spouted for operating with small particles and for improving gas-solid contact. Certain advantages for the use of this central draft tube are: greater flexibility in the operation; lower pressure drop; solids of any size or nature may be treated; narrower residence time distribution; lower flow rate; lower pressure drop; better control of solid circulation; avoids maximum spoutable bed height. Consequently, solid circulation may be controlled by changing independently column diameter, stagnant bed height or particle diameter. Of the disadvantages the following are worth mentioning: lower mixing degree; complexity of design; risk of tube blockage.

Khoe and Van Brakel (1980, 1983) used the draft tube for drying and thermal disinfection of wheat in order to attain a better control of the residence time and improve process economy. Pallai and Nemeth (1972) used a porous draft tube, which allowed for the passage of air from the spout to the annulus without particle cross-flow from the annulus into the spout. The ultrapyrolysis of heavy oils in a spouted bed provided with draft tube is an efficient method for degrading these hydrocarbons to low viscosity liquids with a reduced coke deposition (Vogiatzis, 1988).

2. Experimental

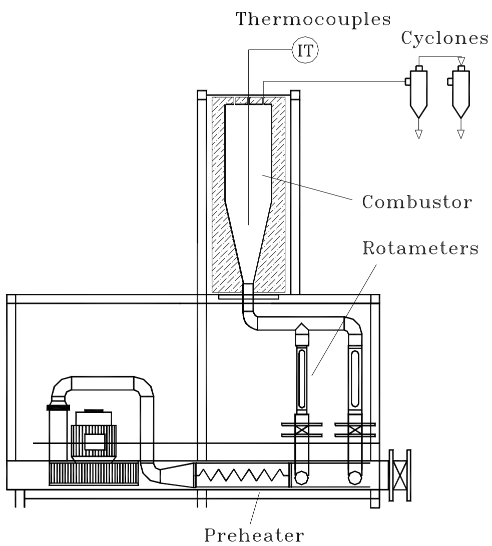

Figure 1. Experimental equipment

The experimental unit designed at pilot plant scale, shown in Figure 1, allows for operation with contactors of different geometry basically consists of a blower that supplies a maximum flow rate of 300 Nm^3h^{-1} at a pressure of 15 kPa, a worm gear to regulate and control the solid feeding system and two high efficiency cyclones in order to collect fine particles. The flow rate is measured by means of two mass flowmeters in the ranges of 50-300 and 0-100 $m^3\ h^{-1}$, both being controlled by a computer. 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 the software AMR-Control. This software also registers and processes the air velocity data, which allows for the acquisition of continuous curves of pressure drop evolution with air velocity (San José et al., 2005).

Five conical contactors made of poly(methyl methacrylate) have been used. Figure 2 shows the geometric factors of these contactors, 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, 0.60, 0.50, 0.45, 0.42, and 0.36 m; gas inlet diameter, D_o, 0.03, 0,04, and 0.05 m. They are provided with central draft tubes and a conical baffle (cap) over the bed, as those shown in Figure 2.

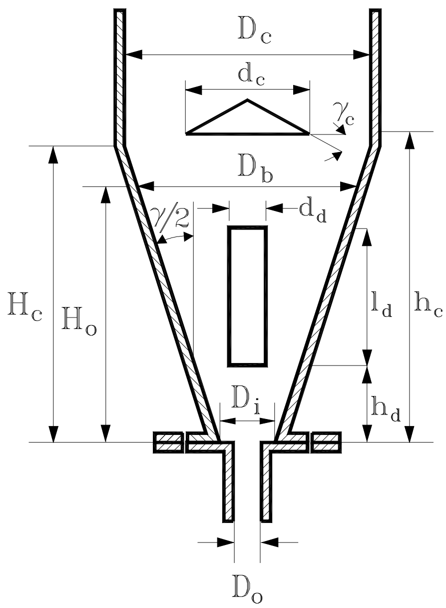

Figure 2. Geometric factors of the contactor and of the internal devices.

Their dimensions are the following: central draft tube of diameter, d_d: 0.03, 0.04, 0.05 and 0.06 m and length, l_d, variable; distance between the base of the contactor and the lower level of the device, h_d; cap of lower diameter, d_c: 0.08 m; angle, γ_c: 30 º; distance between the base of the contactor and the lower level of the device, h_c: from 1.2 H_o to 2.0 H_o. The values of the stagnant bed height, H_o, used are in the range between 0.05 and 0.35 m. Operation has been carried out at the minimum spouting velocity and at velocities 20 and 30 % above this value.
The solids used are pine sawdust and pine bark, whose properties are set out in Table 1**.**

Table 1. Properties of the solids used

Material	size range, mm	Density ρ_s, kg/m^3	Shape ϕ	Voidage ε_o	Geldart Classification
Pine sawdust	1.5 3.5	540	0.90 0.82	0.60 0.70	B D
Pine bark	1.5 3.5	520	0.90 0.90	0.65 0.70	B D

Solid moisture has been measured by means of a hygrometer AQUA-Boy KPM HM III. This device uses for moisture measurement an electrical resistance calibrated to 20ºC according to norm DIN 52183 with accuracy of ± 0,1% and reproducibility of ± 0.2%. In order to measure moisture of sawdust beds samples in the spout zone and in the annular zone have been taken by means of a suction pump.

3. Results

The hydrodynamic study of conical spouted beds provided with internal devices has been carried out using draft tubes of varying diameter and length. They are located at different distance from the base of the contactor. Furthermore, conical baffles or caps over the fountain have also been tried.

The evolution of pressure drop with air velocity is different from that observed for other materials (Olazar et al., 1992). It is peculiar that once the bed has been spouted, when the air flow is cut, the random order of the particles is not restored, but the particles stay reordered in the same situation as in the spouting regime, which is due to the fact that a central crater created in the spouting operation has remained. As a consequence of this behaviour, the maximum pressure drop that is obtained in a second spouting operation is much lower than the measured in the first operation. This phenomenon does not affect the measurement of stable pressure drop, which is the same as in the first operation. This hydrodynamics peculiarity has its origin in the deficient fluidity of sawdust and in cross-linkage between particles due to the fact that they are mainly long and irregular.

In order to obtain a reproducible measurement of pressure drop evolution, avoiding the previously mentioned problem, the measurements have been carried out once the solid was fed for a sufficiently high altitude (1 m). These measurements are totally reproducible.

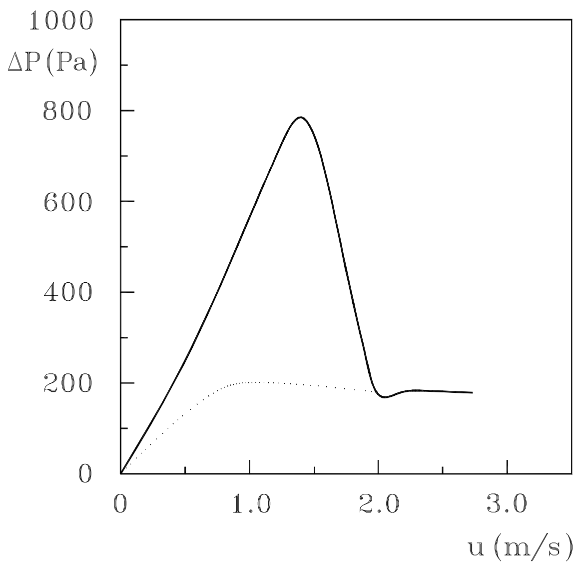

Figure 3. Evolution of pressure drop wit air velocity for a sawdust fraction of particle size between 1.0 and 2.0 mm at moisture of 50 wt %. γ= 45º, D_o= 0.04 m, H_o= 0.13 m, d_d= 0.04 m, l_d= 0.10 m, h_d= 0.03 m.

Figure 3 shows an example of the evolution of pressure drop with air velocity for the experimental system of cone angle γ= 45º, a bed made up of moist sawdust (with a wt % 50) of particle size between 1.0 and 2.0 mm, contactor inlet diameter D_o= 0.04 m, stagnant bed height H_o= 0.13 m, diameter of the central draft tube d_d= 0.04 m, draft tube length, l_d= 0.10 m. The draft tube is located at a distance from the contactor base h_d= 0.03 m. The dotted line corresponds to the values of pressure drop obtained by decreasing air velocity. As is observed, there is a pronounced hysteresis in the evolution of pressure drop with air velocity, which is as pronounced as in the bed without any internal device (Olazar et al., 1994).

With the aim of proving the applicability of the spouting regime for drying of biomass wastes in conical spouted beds with a draft tube operation maps are shown as an example in Figure 4, in plots of stagnant bed height vs. air velocity. The results correspond to beds of sawdust of particle diameter between 1 and 2 mm with different moisture content at the minimum spouting velocity, contactor angle γ= 36º and inlet diameter, D_o= 0.04 m, diameter of the central draft tube d_d= 0.04 m, varying draft tube length, $l_d = H_o - h_d$, height of the entrainment zone $h_d = 0.03$ m. It is observed the great stability of beds of moist sawdust (up to wt % 50) and that system stability decreases as solid moisture increases.

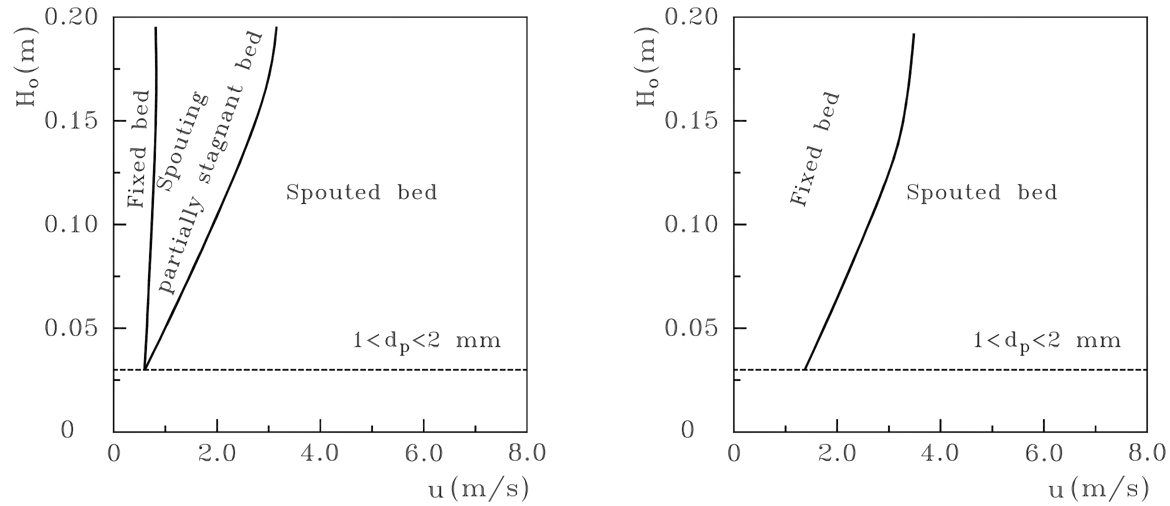

Figure 4. Operation map for a sawdust fraction of particle size between 1.0 and 2.0 mm. $\gamma = 36^o$, $D_o = 0.04$ m. a) at the equilibrium moisture; b) at moisture of 50 wt %. $d_d = 0.04$ m, $l_d = H_o - h_d$, $h_d = 0.03$ m.

In Figure 5 the experimental values of the minimum spouting velocity for the spouted bed regime with the humidity have been plotted vs. the sawdust humidity for a bed consisting of moist sawdust fraction (with a wt % 50) of particle size between 1.0 and 2.0 mm, for the contactor angle of $\gamma = 45^o$, contactor inlet diameter $D_o = 0.04$ m, for different values of stagnant bed height $H_o = 0.10$, 0.15, 0.18 m, diameter of the central draft tube $d_d = 0.04$ m, varying draft tube length, $l_d = H_o - h_d$. The draft tube is located at a distance from the contactor base $h_d = 0.03$ m. As it is observed in Figure 5, as sawdust humidity is increased the minimum spouting velocity increases and this effect is more important as the stagnant bed height is lower.

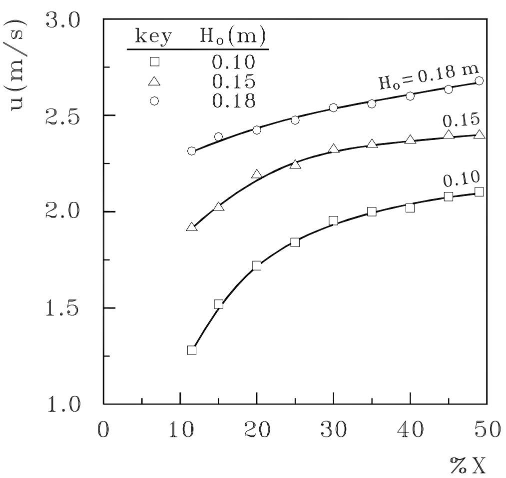

Figure 5. Minimum spouting velocity for a moist sawdust fraction (up to wt % 50) of particle size between 1.0 and 2.0 mm. $\gamma = 45^o$, $D_o = 0.04$ m, $H_o = 0.10$, 0.15, 0.18 m, $d_d = 0.04$ m, $l_d = H_o - h_d$, $h_d = 0.03$ m.

4. Conclusions

The good behaviour of conical spouted beds provided with internal devices for the drying of biomass wastes coming from activities related to wood manufacturing (sawmills, carpentries, furniture factories and so on) has been proven.
The general hydrodynamics of sawdust in conical contactors is peculiar and different from the hydrodynamics of granular materials and of glass spheres. The pressure drop obtained for beds consisting of moist sawdust has a very sharp peak value and there is a great hysteresis in the evolution of the pressure drop with the velocity.
The great stability of beds of moist sawdust shows the applicability of the spouting regime for drying of biomass wastes in conical spouted beds with a draft tube operation maps and that system stability decreases as solid moisture increases. The minimum spouting velocity increases as sawdust humidity stagnant bed height are increased.

5. Nomenclature

D_b: upper diameter of the stagnant bed, m
D_c, D_i, D_o: diameter of the column, of the bed base, and of the inlet, respectively, m
d_p: particle diameter, m
H_c, H_o: heights of the conical section, and of the stagnant bed, respectively, m
d_C, d_d: base diameter of the conical cap and diameter of the draft tube, respectively, m.
h_C, $h_{d,}$: distance from the bottom of the contactor to the lower end of the cap and from the bottom of the contactor to the lower end of the draft tube, respectively, m.
$l_{d,}$: length of the draft tube, m.
u, u_{ms}: velocity and minimum spouting velocity of the gas, respectively, m s^{-1}
Greek Letters
ε_o: voidage of the static bed
ϕ: sphericity
γ: angle of the contactor, deg
γ_C: angle of the conical cap, deg
ρ_s: density of the gas and of the solid, kg m^{-3}
ΔP: Pressure drop, kg m^{-3} s^{-2}.

6. Acknowledgements

This work was carried out with the financial support of the Ministry of Industry of the Basque Government (Project SPE06IKA02).

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