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Drying of Mixtures of Agricultural Wastes in a Conical Spouted Bed Contactor

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With the aim of determining the applicability of conical spouted beds for drying of mixtures of agricultural wastes, stable operation conditions at low temperatures in the range of 25-50ºC have been determined and the effect of moisture content and inlet gas temperature on bed stability has also been analyzed. The correlation already proposed for calculation of the minimum spouting velocity at room temperature has been proven to be valid at higher temperatures. The performance of the spouted bed dryer of mixtures of agricultural wastes has been analyzed as well as the effect of the operating conditions and the factors of greater influence in drying have been determined. Systems are stable in all studied experimental conditions. Spouted bed zone increases as moisture content decreases and as inlet gas temperature increases. In the temperature range of 40-50 ºC drying time decreases as inlet gas temperature increases and moisture content decreases.

1. Introduction

Agricultural exploitation generates a great amount of biomass wastes. The thermal treatment by drying would be the more suitable alternative because allows for reducing moisture content. Furthermore, drying is the first stage of the incineration.

Spouted bed technology is successful for wastes treatment (Olazar et al., 1994; San José et al., 2002, 2006, 2009, 2010a, 2010b). Therefore, this technology would be adequate for drying due to the ability to handle granular and fibrous materials and mixtures of different sizes and textures with the low segregation (Olazar et al., 1993, San José et al., 1994). In fact, the first application of spouted beds was drying of grain (Mathur and Gishler, 1955) and several authors have dried granular materials (Mujumdar, 1984; Passos et al., 1987; Strumillo et al., 1980; Viswanathan, 1986) and other materials (Cordeiro and Oliveira, 2005; Devahastin et al., 2006; Marmo, 2007; Nindo et al., 2003; Shuhama et al., 2003; Altzibar et al., 2007; San José et al., 2010c) in spouted beds.

In this paper, the treatment of biomass wastes of fruit trees at low temperatures (from room temperatures up to 50 ºC) has been carried out in spouted beds in different operating conditions.

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2. Experimental

The experimental unit design on a pilot scale, Figure 1, consists basically of a conical dryer; a blower that supplies a maximum flow rate of 300 Nm^3h^{-1} at a pressure of 15 kPa; two mass-flow meters in the ranges of 50-300 and 0-100 m^3h^{-1}, both being controlled by a computer to measure the flow rate; an electrical heater to heat gas before the inlet to the dyer; and thermocouples.

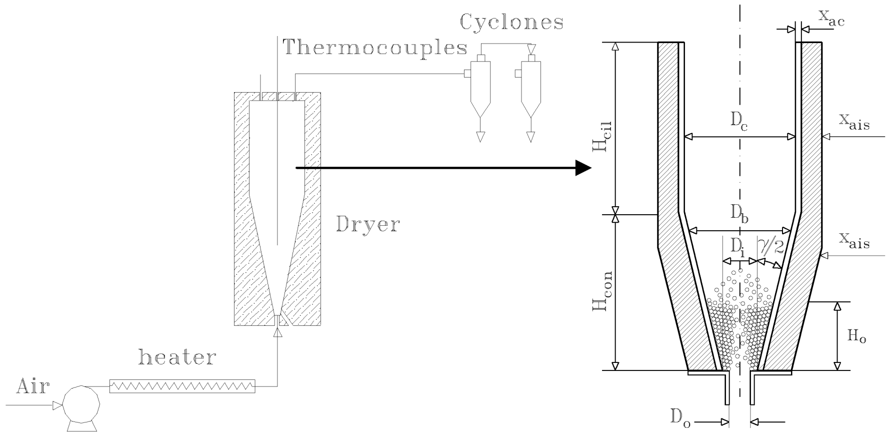

Figure 1: Experimental equipment and conical spouted bed dryer

The dryer utilized, Figure 1, is made of AISI-310S heat-resistant stainless steel and is externally insulated with 0.05 m quartz fibre. The dimensions of the reactor are: cone angle, γ of 45°; height of the conical section, H_{con}= 0.36 m; height of the upper cylindrical section, H_{cil}= 0.64 m; contactor inlet diameter, D_i= 0.06 m; gas inlet diameters, D_o, in the range of 0.03 and 0.05 and stagnant bed heights, H_o, between 0.05 and 0.25 m.

The temperatures of the air supplied by the blower before entering the contactor and at the exit are measured by two thermocouples located at the bed inlet and outlet. In addition, there are thermal conductivity detectors (Alhborn MT8636-HR6) for measuring air moisture content at both inlet and outlet. Temperature and air moisture contents are also stored in the Alhborn Almeno 2290-8 data logger, which allows monitoring of their evolution over time.

During the batch drying, air temperature and moisture have been measured and solid sampling has been carried out by means of a suction pump, with the time. Solid moisture has been measured by means of Mettler Toledo hygrometer and by AQUA-Boy KPM HM III hygrometer. Solid moisture results have been checked with those obtained by the oven drying method at 105 ºC up to constant weight.

The solids used have been different mixtures of branches, leaves and bark wastes of fruit trees of density ρ_s= 560 kg/m^3 and of different Sauter mean diameter, $\overline{d_S}$, between 1.3 and 4.26 mm.

3. Results

In order to determinate the applicability of conical spouted beds for drying of agricultural wastes, a hydrodynamic study has been carried out at temperatures from room temperatures up to 50 ºC, stable operating conditions and stable operating regimes have been determined with beds consisting of mixtures of agricultural wastes.

Operation maps are shown as an example in Figures 3 and 4, in plots of stagnant bed height, H_o, vs. air velocity, u for a bed consisting of agricultural wastes for a contactor angle of 45º and gas inlet diameter, D_o= 0.04 m. The points between the different regimes have been obtained experimentally by increasing gas velocity for each stagnant bed height.

Figure 3 corresponds to an operation map of beds consisting of branches of Sauter mean particle diameter, $\overline{d_S}$ = 3.2 mm with moisture of 20 and 60 wt%. As it is observed, beginning in the fixed bed, increasing gas velocity, the minimum spouting velocity is obtained and stable spouted bed regime is reached. An increase in stagnant bed height gives way to an increase in minimum spouting velocity. Furthermore, the gas velocity necessary to reach the spouted bed regime increases slightly, with moisture content and this increasing is more pronounced as stagnant bed height increases, so the spouted bed zone decreases.

The effect of gas inlet temperature is shown in Figure 4, for beds consisting of branches of Sauter mean particle diameter, $\overline{d_S}$ = 3.2 mm with moisture of 60 wt% in dry basis at gas inlet temperatures of 30 and 50 ºC. As it is observed in this Figure, as inlet gas temperature increases, minimum spouting velocity increases slightly, so the spouted bed zone decreases and this effect is more appreciable at stagnant bed heights from 0.15 m. It is noticeable that these systems are stable at all studied stagnant bed heights.

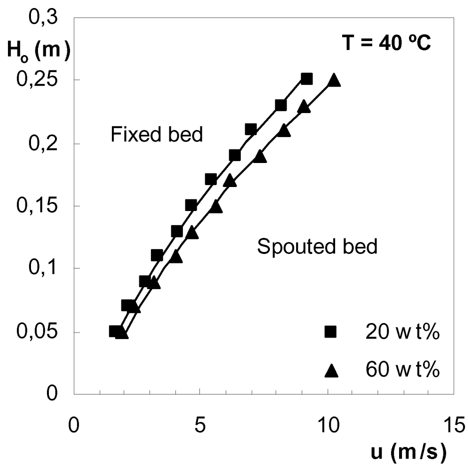

Figure 3. Operation map for beds consisting of branches of $\overline{d_S}$ *=3.2 mm with moisture content of 20 and 60 wt% (dry basis). Experimental system* γ*= 45º,* D_o*= 0.04 m.*

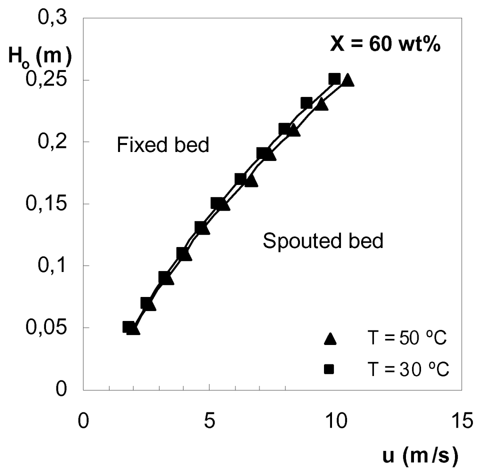

Figure 4. Operation map for beds consisting of branches of $\overline{d_S}$ *=3.2 mm with moisture content of 60 wt% (dry basis). Experimental system* γ*= 45º,* D_o*= 0.04 m, inlet gas temperature, T= 30 and 50 ºC.*

The experimental results of minimum spouting velocity have been fitted to the equation proposed in previous papers for granular materials (Olazar et al., 1992) and for mixtures (Olazar et al., 1993, 1994):

$$(Re_o)_{ms} = 0.126\, Ar^{0.50}\, (D_b / D_o)^{1.68}\, [\tan(\gamma/2)]^{-0.57} \quad (1)$$

where $$(Re_o)_{ms} = \overline{d_S}\, u_o\, \rho / \mu \quad (2)$$

The good fitting of the experimental results of minimum spouting velocity to eq. (1) are shown in Figures 3 and 4. The regression coefficient of all the experimental data is r^2= 0.98, and the maximum relative error is ±7%. The accurate fitting proves the general applicability of eq. 1 in a wide range of contactor geometries, and operating conditions.

The effect of gas velocity and gas inlet temperature on drying of mixtures of agricultural wastes in conical spouted beds has been analyzed. It is obtained that as gas velocity and gas inlet temperature are increased, drying time decreases noticeable, being gas inlet temperature the factor of greater influence followed by gas velocity.

4. Conclusions

The good behaviour of the spouted bed dryer of mixtures of agricultural wastes has been proven on the basis of on a wide experimental study on stability in a pilot plant in a wide range of operating conditions at a temperature range from room temperature to 50 ºC.

The experimental systems studied are stable at a range of gas inlet temperatures 25-50 ºC. The minimum spouting velocity increases as stagnant bed height is increased. The increasing of moisture content and inlet gas temperature increase minimum spouting velocity, so stable operation zones decrease slightly.

The correlation already proposed for calculation of minimum spouting velocity for granular materials and mixtures at room temperatures is valid for beds of agricultural wastes, in a wide range of operating conditions at temperatures over room temperature (at a temperature range of 25-50ºC). Increasing in gas velocity and inlet gas temperature gives rise to a noticeable decrease in drying time, being the effect of inlet gas temperature on drying time greater than the effect of gas velocity.

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6. Nomenclature

Ar	Archimedes number, $Ar = g\, dp^3\, \rho\, (\rho_S - \rho)/\mu^2$
D_b, D_i, D_o	upper diameter of the stagnant bed, of the bed base and of the gas inlet, m
$\overline{d_S}$	Sauter mean diameter, m
H_{cil}, H_{con}, H_o	height of the cylindrical section, of the conical section and of the stagnant bed, m
$(Re_o)_{ms}$	Reynolds of minimum spouting referred to D_o, -
T	temperature, ºC
x_{ac}, x_{ais}	thickness of the reactor wall and of the insulating, m
u, u_o	velocity of the gas referred to D_i, and minimum spouting velocity of the gas referred to D_o, m s^{-1}

Greek Letters

γ	angle of the contactor, deg
ρ, ρ_s	density of the gas and of the solid, kg m^{-3}
μ	gas viscosity, kg m^{-1} s^{-1}

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