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Drying of wastes of almond shells in conical spouted beds

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Abstract

The goal of this study was to prove the feasibility of a conical spouted bed dryer for the drying of wastes of almond tree fruit. The drying operating regimes ranges in sspouted beds contactors were determined. The drying tests were conducted in the spouted bed regime under determined experimental conditions. Beds consisting of almond shells were dried at drying air temperatures ranging from room temperature to 140 ºC. The drying behaviour was assessed based on the decrease in moisture content of almond shells with the time and the effect of drying air temperature on the drying process was analyzed.

Keywords: *Almond shells wastes; conical spouted beds; biomass wastes; drying*

1. Introduction

World energy consumption has increased by 28% in 2017 and renewable fuels are the world's fastest-growing energy source, predicting an increase of 2.3%/year between 2015 and 2040 [1]. Biomass is a key renewable resource, which supplies 14% of the world's energy consumption. Since biomass wastes usually have high moisture content, in order to increase the yield of thermal valorization of these wastes, it is advisable to reduce the moisture content previously.

Almond nut production annually generates more than 4,800 dry tons of by-products per 1,000 acres of harvested almond trees [2]. This biomass wastes including shells, hulls, and pruning, composed mainly by cellulose, lignin and hemicelluloses are suitable for energy production. The most common treatments for these wastes are landfills, compostage, recycling and direct burning [3]. However, there is little research of energy uses for waste from almond processing including gasification, pyrolysis, and combustion or co-firing [2]. World production of almonds was estimated about 3.2 million tonnes in 2016, being the United States the largest producer with 2 million tonnes. Spain is the second world's almond producer, with a yearly production around 200 thousand tonnes [4]. Almond shell is the hard layer between the hull and the almond nut, which protects the almond from insects while on the almond tree (*Prunus dulcis*).

Spouted beds technology can be an appropriate alternative for energy exploitation of renewable biomass wastes, with a previous reduction of moisture content of biomass wastes by drying, due to the high mass and energy transfer. Conical spouted beds have been applied for drying biomass wastes such as agricultural wastes [5-6], vineyard pruning wastes [7] sludge wastes [8-11], of yeast [12].

2. Materials and Methods

The experimental unit used, Fig. 1, comprises a conical dryer, a blower, two high efficiency cyclones, an electrical preheater and thermocouples. The conical dryer (Fig. 1) made of AISI-310S stainless steel is externally insulated to reduce heat loss, has an angle of 36º, base diameter of 0.03 m and inlet gas diameter to inlet dryer diameter ratio, D_o/D_i, 1/2, 2/3 and 1. The geometric factors of this dryer are listed in Table 1.

The drying air velocity was determined by the air flow rate measured by mass flowmeter, installed at the inlet pipe, and controlled by a computer to an accuracy of ±0.5%.

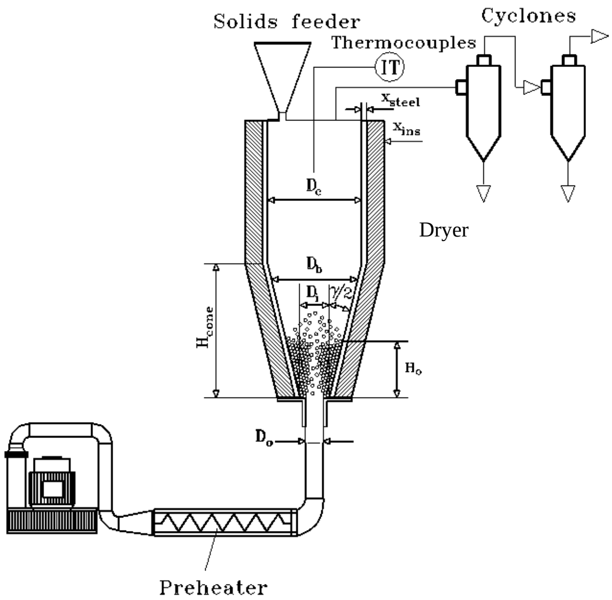

Fig. 1 Schematics of the experimental plant and of the conical spouted bed dryer with an outline of solid particles movement in the spouted bed regime.

Table 1. Geometric factors of the conical spouted bed dryer

Conical spouted bed dryer		
Diameter of the cylindrical section	D_c (m)	0.23
Cone angle	γ (deg)	36
Gas inlet diameter	D_o (m)	0.015, 0.02 and 0.03
Diameter of the cone bottom	D_i (m)	0.03
Upper diameter of the stagnant bed	D_b (m)	$D_i + 2\ H_o \tan(\gamma/2)$
Height of the conical section	H_{cone} (m)	0.31
Stagnant bed height	H_o (m)	between 0.03 and 0.20
Thickness of the dryer wall	X_{steel} (mm)	2
Thickness of the insulation	X_{ins} (mm)	14

During the drying process, solids were sampled by a suction pump, and the solids moisture content was measured by Mettler Toledo HB43-S Halogen hygrometer. Room temperature, the relative air humidity and air humidity at the inlet and the outlet were measured using Ahlborn MT8636-HR6 thermal conductivity detectors (accuracy ± 2% relative humidity). The drying air temperature was measured by a K-type thermocouple (relative error: the greater ± 0.75% or ± 2.2°C) located at the inlet to the dryer.

Biomass wastes studied, Fig. 2, were almonds shells. In the industry almonds are washed before peeling. Almonds shells have a density of 1220 kg/m^3, particle sizes 5-8 mm and moisture content 25-30 wt%. Bed masses of almond shells used are 100-400 g. Solids moisture content is measured by Mettler Toledo HB43-S Halogen hygrometer (accuracy ± 0.01 %).

(a) (b)

Fig. 2 (a) Grinded wet almond shells wastes inside the feeder. (b) Grinded dry almond shells wastes inside the conical spouted bed dryer.

3. Results and discussion

The performance of conical spouted beds for drying of beds formed from almond shells and operation conditions at inlet gas temperature at room temperature and at 105 ºC have been established in this paper. Likewise, the evolution of solids moisture content has been measured with the time, and effect of operating conditions on drying time has been analyzed.

In order to prove the feasibility of the conical spouted bed dryer for thermal exploitation of almonds shells, the range of the stable operating regimes of homogeneous beds formed from wastes of almond shells was determined. The minimum air flow rate necessary to achieve the spouted bed regime was characterized by pressure drop fluctuations with a standard deviation less than 10 Pa [13]. The experimental values of minimum air velocity corresponding to the spouted bed regime are shown in Fig. 3 for beds consisting of wastes of almond shells with stagnant bed height (H_o) in the range of 0.02-0.14 m along with an outline of solid particles in the stagnant bed and in the spouted bed regime for a system taken as example. Starting in the stagnant bed, increasing stagnant bed height, the air velocity necessary to reach the spouted bed regime increases, therefore the velocity operating range over the minimum spouting flow is narrower. The spouted bed regime is reached in all studied systems, characterized by the vigorous cyclic movement as is shown inside the conical dryer, Fig. 1.

With the aim of determining the drying behaviour of the conical spouted bed dryer, beds consisting of the almond shells waste were dried under different experimental conditions.

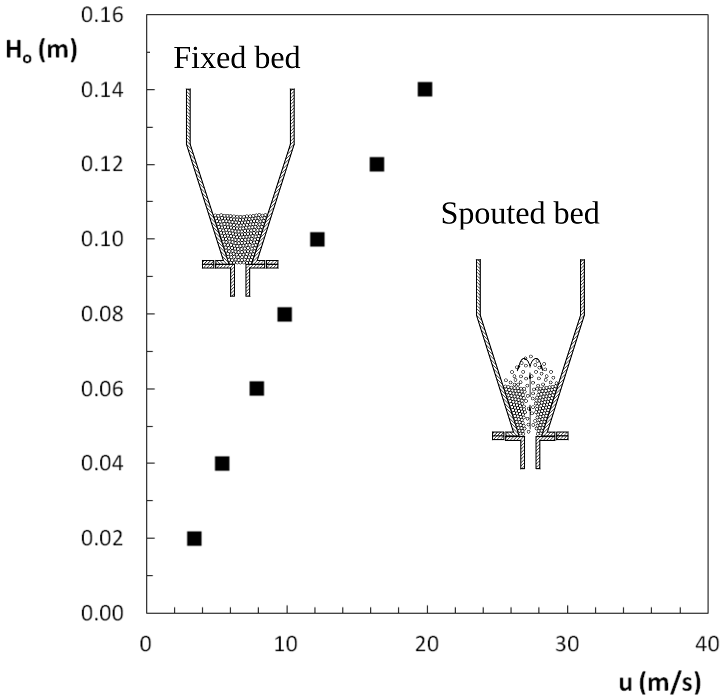

Fig. 3 Operating map of stagnant bed height versus the gas velocity. Experimental system: γ= 36º D_o= 0.03 m, almond shells of d_S= 5.6 mm.

The experimental results for the time evolution of the moisture content of almonds shells, X, from the initial moisture content of 40 wt % (d.b.) to the equilibrium moisture content are plotted in Fig 4 for a bed consisting of 400 g of wet almond shells with drying air temperatures of 25 and 105 ºC. The air flow rate, was high enough, so that the outlet air humidity was lower than saturation humidity, resulting in a driving humidity gradient. The drying process was assumed concluded when the difference between two consecutive measurements of solids moisture content did not exceed ±0.05 wt%.

At the beginning of the process the decrease in the moisture content is more pronounced, almost proportional, controlled by evaporation of free moisture. At the end of the drying process, variation of almond shells moisture content is asymptotic until the moisture content reaches its equilibrium value.

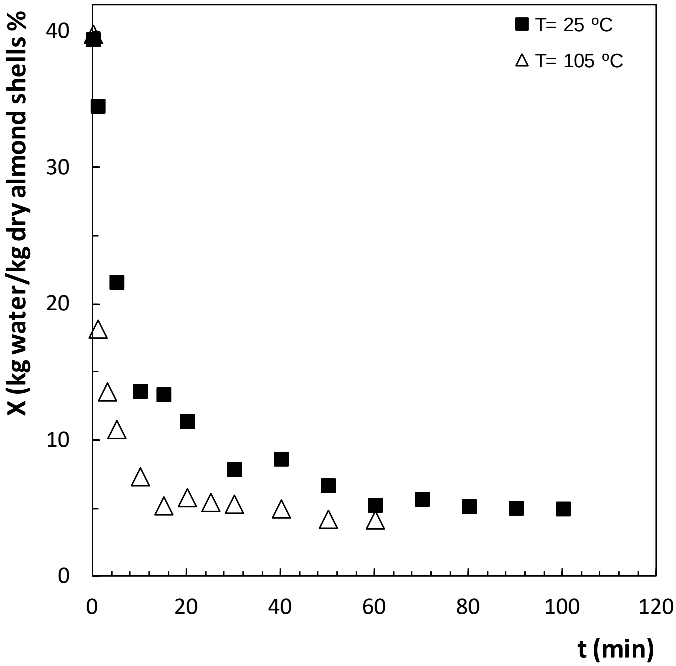

Fig. 4 Time evolution of the moisture content of a bed of almond shells. Experimental system: γ= 36º; D_o= 0.03 m, M= 400 g, d_S = 5.6 mm, initial moisture content 33 wt % (d.b.), u= 1.10 u_{ms}; T= 25 and 105 ºC.

As the inlet air temperature is increased, the solids moisture content decreases faster, with shorter drying time to reach the moisture equilibrium content, which depends on the inlet air temperature and the relative humidity. In drying of almonds shells, as inlet air temperature is increased 80 ºC, from 25 to 105 ºC, drying time is decreased by around 75% from 60 to 15 minutes.

4. Conclusions

The feasibility of a conical spouted bed equipment for thermal exploitation of almond shells wastes by drying in the spouted bed regime has been proven at low air temperatures. The range of operating regimes beds consisting of almond shells has been determined under different experimental conditions.

The moisture content of almond shells decreases almost proportionally with time from the initial moisture content to equilibrium moisture content, and this disminishing is more noticeable at the beginning of the drying process, at high moisture content. The drying time to reach the equilibrium moisture content decreases with increasing drying air temperature around 75% with a temperature increase of 80 ºC.

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5. Nomenclature

D_b	upper diameter of the stagnant bed, $D_b = D_i + 2\ H_o \tan(\gamma/2)$	m
D, D_i, D_o	diameter of the cylindrical section, of the dryer base, and of the gas inlet	m
d_S	mean Sauter diameter	m
H, H_c, H_o	height of the cylindrical section of the dryer, of the conical section and of the stagnant bed	m
t	time	min
T	temperature	ºC
M	solids mass	kg
X	solids moisture content (dry basis),	kg water/kg dried sludge, %
X*	equilibrium solids moisture content (dry basis),	kg water/kg dried sludge, wt %
X_{steel}, X_{ins}	thickness of the dryer wall and of the insulation	m
u, u_{ms}	velocity of the air and air minimum spouting velocity	m/s

Greek letters

γ	angle of the conical section of the dryer	deg
ρ_s	density of solids	kg /m^3

Subscripts

d	drying
ms	minimum spouting

6. References

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