Operating Conditions in Drying of Grapevine Wastes in a Novel Spouted Bed Dryer

María J. San José[1], Sonia Alvarez, and Raquel López

***Abstract*—**The applicability of conical spouted beds for drying of grapevine wastes, stable operation conditions at inlet gas temperature range of 25-120 ºC has been determined and the effect of inlet gas temperature on bed stability has also been analyzed. The evolution of biomass moisture content with time has been determined and the effect of inlet gas temperature and gas velocity over minimum spouting on solid drying time has been analyzed.

***Keywords*—**Drying, grapevine wastes, Spouted beds, thermal treatment.

I. Introduction

LIGNOCELLULOSIC materials such as agricultural wastes (e.g., wheat straw, sugarcane bagasse, corn stover), forest products (hardwood and softwood), and dedicated crops (switchgrass, salix) are renewable sources of energy. Agroforestal wastes are becoming interesting for energy production because they are renewable fuels that reduce CO_2 and sulfur emissions. These raw materials are sufficiently abundant and generate very low net greenhouse emissions. The high taxes on emissions of carbon dioxide from fossil fuels and the high price of fuel oil has biomass demand. At the Paris climate conference (COP21) 195 countries agreed a global action plan to put the world on track to avoid dangerous climate change by limiting global warming to well below 2°C above pre-industrial levels due to enter into force in 2020.

Biomass and agroforestal wastes usually have high humidity content. Consequently, it is necessary to reduce this one before the treatment methods, so it is necessary to make a previous drying to other treatment operations.

economic

The influence of operating conditions on thermal decomposition of or not materials has been widely studied [1]-[9].

Moreover, high moisture contents in the biomass can cause both storage and burning problems [10]. The level of moisture reduction needed depends on the requirements of the process that follows. A good drying process is essential for the processing of biomass. If the biomass is burned immediately, it may be sufficient to maintain an even moisture level after drying [11], in order that combustion problems caused by fluctuations in moisture content are reduced or eliminated. Storage with low substance losses and low mould growth requires moisture contents lower than 20% [12].

The excellent performance of spouted bed contactors with conical geometry in physic operations such as drying, as well as in chemical processes is due to the versatility of gas flow distribution [13], which allows for increasing the velocity of the characteristic cyclic movement of cylindrical spouted beds. This vigorous movement of the solid allows for handling of solids that are sticky, of irregular texture and with a wide particle size distribution and the break-up of agglomerates in the spout allows for attaining an efficient contact between the gas and the solid and for avoiding problems that are inherent to fluidized beds, as are segregation [13]. Furthermore, conical spouted beds allow for significantly reducing the amount of inert solid required in order to help fluidization of the solid to be treated or not using inert material.

Spouted beds performs well in operation and processes carried out at high temperature, such as drying of granular materials [14]-[17], and sludges [18]-[20]. The good performance of these contactors in physic operations as drying relies on the cyclic movement of the particles which avoids the disadvantages of handling of sticky solids, and/or wide particle size distribution.

In order to determine the optimum operating conditions and the applicability of this contact method to manage grapevine wastes, a hydrodynamic study has been carried out in a conical spouted bed reactor at pilot plant scale [21]-[22]. From the experimental study, stable operation maps have been obtained in a wide range of operating conditions from room temperature up to 120 ºC.

The results of drying at lower temperature than in the literature prove that conical spouted bed reactor with an optimal design is a suitable clean technology for thermal treatment of grapevine wastes.

II. Experimental

The experimental unit designed at pilot plant scale, Figure 1, allows to work with conical contactors of different geometry (contactor angle, and gas inlet diameter) and at different experimental conditions (stagnant bed height, particle diameter

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and gas velocity) and the optimal design for the treatment of biomass wastes has been obtained. It consists of a blower that supplies a maximum flow rate of 300 Nm^3h^{-1} at a pressure of 15 kPa, two high efficiency cyclones in order to collect fine particles and an electrical preheater located at the inlet of the contactor to heat air. The flow rate is measured by means of two mass flowmeters in the ranges of 50-300 and 0-100 m^3h^{-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 and their outputs are checked with U-type water manometer measurements. 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 reactor 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 36°; contactor inlet diameter, D_i= 0.03 m; gas inlet diameter, D_o, in the range of 0.01-0.03 and values of the stagnant bed height, H_o, in the range between 0.05 and 0.20 m.

In a spouted bed reactor, Figure 2, solid particles ascend through the spout zone up to the fountain, and fall onto the upper surface of the annular zone at different radial positions. Subsequently, particles descend through the annulus and incorporate from the annular zone to the spout zone at every longitudinal position of the spout-annulus interface. Then solid particles rise through the spout zone again.

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.

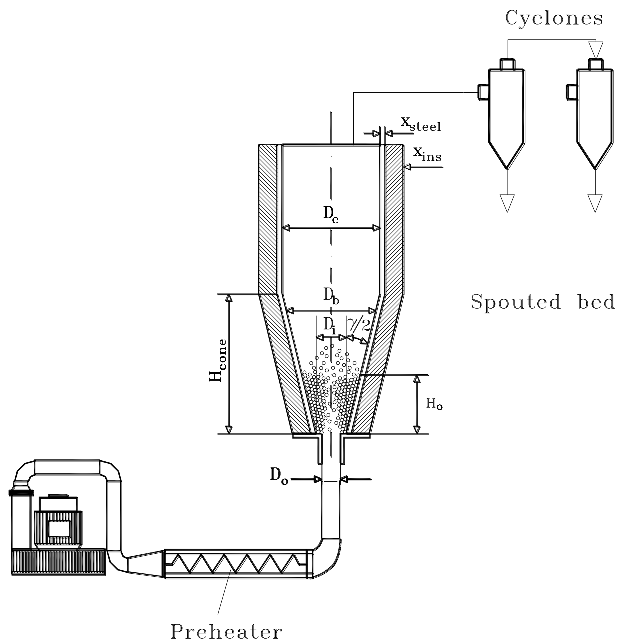

Fig. 1. Experimental equipment with the conical spouted bed reactor

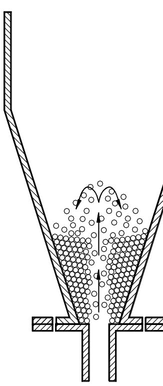

Fig. 2. Spouted bed regime

The biomass wastes studied have been agroforestal wastes, grapevine branches (Figure 2) of density, ρ_s, 560 kg/m^3 and moisture content between 15 to 60 wt%. The different particles sizes of the biomass have been obtained by means of a grinding mill (Fritzch Pulverizette) and have been sieved by means of meshes. Table 1 shows the properties of biomass wastes.

Fig. 3. Grapevine branches

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TABLE I
PROPERTIES OF THE MATERIAL

Material	Size range (mm)	d_S (mm)	ϕ	ε_o	Geldart classification
Grapevine	0.8-1.0	0.95	0.81	0.50	A
	1.0-2.0	1.5	0.80	0.56	B
	3.0-4.7	4.2	0.80	0.62	D

During the drying of grapevine bed, 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 HB43-S hygrometer. Solid moisture results have been checked with those obtained by the oven drying method at 105 ºC up to constant weight.

III. RESULTS AND DISCUSSION

A. Operating Conditions

To delimit the conditions of stable operation and the operating regimes of uniform beds made up of grapevine wastes at high temperatures (up to 150 ºC), an experimental study on stability has been carried out by increasing gas velocity from static bed, at different solid properties (particle diameter and sfericity) and experimental conditions (gas velocity).

In Figure 4 an operation map together with an outline of the evolution of particle population in fixed bed and in spouted bed regimes is shown as an example in plot of temperature, T, vs. gas velocity, u. The points drawn have been obtained experimentally for a bed mass of a quarter of kilogram (0.25 kg). The border between the different regimes, drawn with solids line, has been obtained by linking the experimental points.

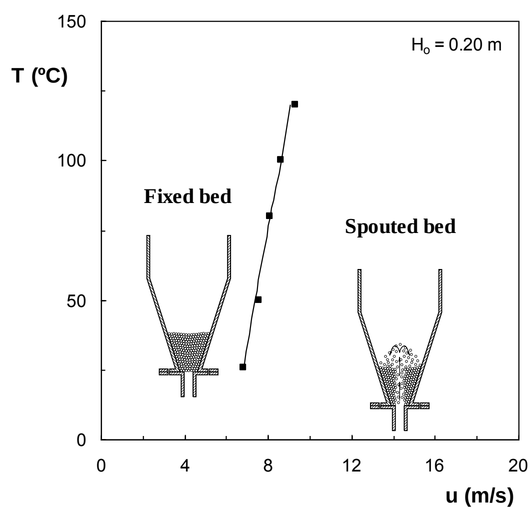

Fig. 4. Effect of the inlet gas temperature on the spouting regimes of beds consisting of grapevines of d_S = 4.2 mm with moisture content of 60 wt % (dry basis). Experimental system: γ= 36º, D_o= 0.02 m, H_o= 0.20 m.

Minimum spouting velocity has been determined by expanding the bed by decreasing the gas flow from the maximum bed pressure drop condition. As is observed, beginning in the fixed bed, increasing gas velocity, minimum spouting velocity is obtained and stable spouted bed regime is reached. Furthermore, gas velocity necessary to reach the spouted bed regime increases, with gas inlet temperature. It is noticeable that this system is stable at all studied stagnant bed heights.

B. Drying of grapevine branches

The evolution of drying of grapevine wastes has been determined from measurement of moisture of solid sampled with time in experiments carried out at different the operating conditions. In Figure 5, the experimental results of the evolution of moisture content grapevine branches with time are shown. Results of Figure 5 correspond to a system taken as an example of reactor of angle γ= 36º, gas inlet diameter, D_o= 0.02 m for beds consisting of a quarter of kilogram (0.25 kg) of grapevine branches of Sauter mean particle diameter, d_S = 1.5 mm and initial moisture content of 60 wt % (dry basis) at drying gas temperatures of 60, 100 and 120 ºC and at 20% higher than minimum spouting velocity corresponding to each temperature.

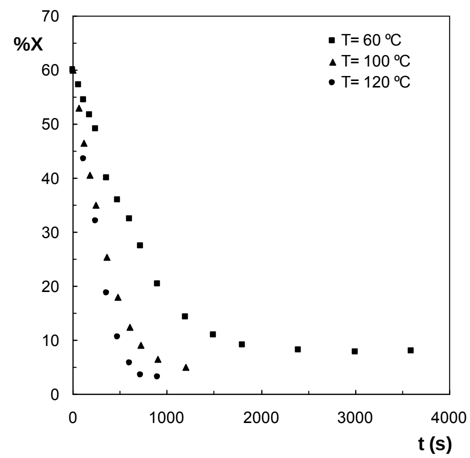

Fig. 5. Evolution of the moisture content of beds of 0.25 kg of grapevine branches with the time in drying process. Experimental system: γ= 36º; D_o= 0.02 m initial moisture content of 60 wt % (dry basis), u= 1.20 u_{ms}, d_S = 1.5 mm, drying gas temperatures of T= 60, 100º C and 120 ºC

IV. CONCLUSIONS

The good performance of the conical spouted bed dryer, based on a wide experimental study, allows to valid the applicability of this contact method in biomass drying at low temperatures, below 120 ºC.

The experimental systems studied are stable at a range of gas inlet temperatures 25-120 ºC. Minimum spouting velocity increases as stagnant bed height is increased.

The increasing of inlet gas temperature gives way to an increase in minimum spouting velocity.

The moisture content of grapevine wastes decreases with time and this decrease is more pronounced at shorter times. Moisture content decreases quicker as inlet air temperature is increased.

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V. UNITS

D_b, D_c, D_i, D_o	diameter of the top diameter of the stagnant bed, of the column, of the bed bottom, and of the bed inlet, respectively (m)
$\overline{d}_S$	Sauter mean diameter (m)
H_{cone}	height of the conical section (m)
H_o	height of the stagnant bed (m)
T	temperature (ºC)
t	time (s)
u	velocity of the gas referred to D_i (m s^{-1})
u_{ms}	minimum spouting velocity of the gas referred to D_i (m s^{-1})
x_{steel}, x_{ins}	thickness of the reactor wall and of the insulating (m)
X	moisture content at any time, in % dry basis, respectively (dry basis) (kg/kg)

Greek Letters

ε_o	loose bed voidage
ϕ	sphericity, (-)
γ	angle of the contactor (deg)
μ	air viscosity (kg m^{-1} s^{-1})
ρ, ρ_s	density of the air and of the solid, respectively, kg /m^3

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