Conical Spouted Bed Combustor for Combustion of Vine Shoots Wastes

M. J. San José, S. Alvarez, R. López

***Abstract*—**In order to prove the applicability of a conical spouted bed combustor for the thermal exploitation of vineyard pruning wastes, the flow regimes of beds consisting of vine shoot beds and an inert bed were established under different operating conditions. The effect of inlet air temperature on the minimum spouted velocity was evaluated. Batch combustion of vine shoots in a conical spouted bed combustor was conducted at temperatures in the range 425-550 ºC with an inert bed. The experimental values of combustion efficiency of vine shoot calculated from the concentration the exhaust gases were assessed. The high experimental combustion efficiency obtained evidenced the proper suitability of the conical spouted bed combustor for the thermal combustion of vine shoots.

***Keywords*—**Biomass wastes, thermal combustion, conical spouted beds, vineyard wastes.

I. INTRODUCTION

WORLD energy demand is supplied mainly by fossil fuels, whose combustion contributes to the global pollution. Development of technology for exploitation of renewable non-fossil fuels, such as biomass, is necessary to replace fossil fuels. The extension of vineyard lands in Spain is the largest in the world, with a 13% of the world land in 2013 [1]. Vineyard pruning generates above 1 ton of waste per hectare [2], mainly composed of cellulose and lignin with a low moisture content and high C/N ratio, which is suitable for energy valorization.

Biomass combustion has low CO_2 and sulfur emissions in general. Thermal valorization of vineyard wastes by Spouted Bed technology is a clean alternative for thermal exploitation of these wastes. Recent studies have reported the thermal processing of biomass in spouted beds by drying [3], [4] and by combustion [5]-[7].

In this paper, spouted bed technology in conical geometry has been applied for thermal combustion of vine shoot wastes with an inert bed. Behaviour of beds consisting of mixtures of vine shoots and inert particles has been studied in spouting regime. Combustion of vine shoots has been conducted with an inert bed in order to determine the influence of the inert material. The effect of the inlet gas temperature on combustion efficiency has been determined.

II. EXPERIMENTAL

The experimental study has been carried out in a unit, Fig. 1, designed at purpose, detailed in previous papers [3]-[7], which consists of a blower, an electric resistance, thermocouples, two rotameters, two mass flow-meters, two high efficiency cyclones and the reactor. The combustor used, Fig. 2, is made of AISI-310 stainless steel, it has a cone angle of $\gamma = 36^{o}$, and it is thermally insulated to reduce heat loss. The geometric factors of this dryer are listed in Table I.

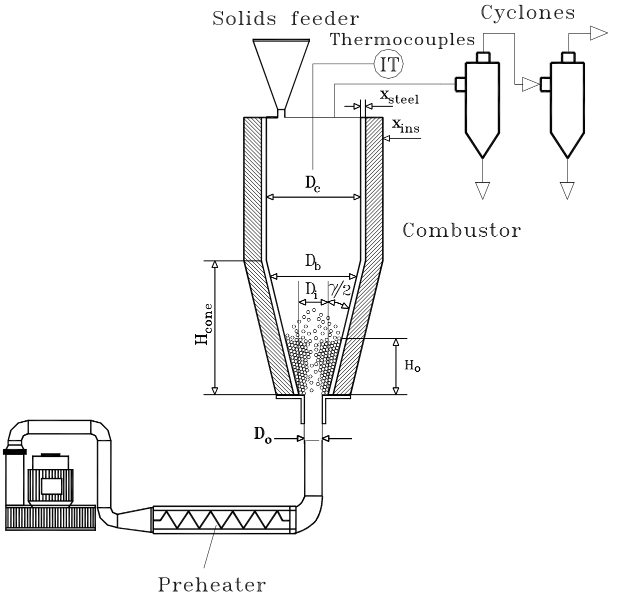

Fig. 1 Schematic diagram of the experimental plant and of the conical spouted bed combustor

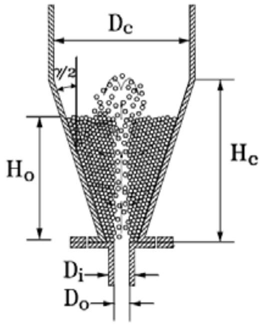

Fig. 2 Conical spouted bed combustor with vine shoots particles in the spouted bed regime

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TABLE I
GEOMETRIC FACTORS OF THE COMBUSTOR

Conical spouted bed combustor		
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_c (m)	0.31
Stagnant bed height	H_o (m)	0.03-0.20
Thickness of the combustor wall	X_{steel} (mm)	2
Thickness of the insulating	X_{ins} (mm)	14

The air flow rate used in the combustion process was measured by a mass flowmeter located at the inlet pipe and controlled by a computer with an accuracy of ±0.5% [4]-[7]. Inlet gas temperatures were measured by a K-type thermocouple (maximum relative error of ± 0.75% or ± 2.2 °C) located at the inlet of the combustor.

Biomass wastes used were vine shoots, Fig. 3, of density $\rho_s = 540$ kg/m^3, mean Sauter diameters, d_S, 25-65 mm obtained by grinding mill (Fritzch Pulverizette) and sieved by meshes in a Filtra FTI-0300 sieving machine. The moisture content of the vine shoots was 25 wt% (dry basis), determined by thermogravimetry (Mettler Toledo HB43-S Halogen hygrometer, accuracy ± 0.01%). The physical properties of the vine shoots used are shown in Table II. Ultimate and proximate analyses, together with the lower heating value (LHV) of the vine shoots were reported in a previous paper [3]. The inert material used as bed material has been silica sand, with two fractions: fine fraction (d_p<1 mm) and coarse fraction (d_p≥1 mm), whose properties are summarized in Table II.

Fig. 3 Vine shoots

TABLE II
PHYSICAL PROPERTIES OF THE SOLIDS

Material	*Sauter average diameter* d_S (mm)	*Density* ρ_S (kg/m^3)	*Shape* ϕ
Vine shoots	25	540	0.72
	30		0.71
	36		0.69
	65		0.65
Silica sand	0.88	2650	0.80
	1.28		0.75

Combustion was conducted in the spouting bed regime at gas inlet temperatures ranging from 450 to 550 ºC. The bed of inert material (sand) was preheated by air flow, measured by mass flowmeter, by passing through an electrical resistance located at the inlet pipe of the combustor. Once the set temperature of the sand bed was reached, the vine shoots were fed to the combustor.

Concentrations of CO_2 and CO (% volume) in the flue gases were measured by Testo 350 gas analyzer. Experimental combustion efficiency was calculated from the concentration of CO_2, CO (% volume) gases. With the purpose of improving the combustion efficiency, the moisture content of the vine shoots was diminished by previous drying.

III. RESULTS

The experimental values of air velocity required to carry out the thermal process with beds made up of binary mixtures of vineyards and the inert particles in the spouted bed regime were determined by pressure drop fluctuations obtained by increasing the gas velocity from 0 to maximum value [8]. The spouted bed regime was reached when the standard deviation of the pressure drop fluctuations was lower than 10 Pa [8].

The influence of stagnant bed height and air temperature on the experimental values of minimum spouting velocity corresponding to the beginning of the spouted bed regime is plotted in Fig.ure 4, along with an outline of the particles population inside the combustor at each operating regime. As it is observed, minimum spouting velocity increases with the stagnant bed height. Moreover, an increase in inlet air temperature leads to higher air velocity and this effect is more pronounced at higher temperatures. The spouted bed regime is reached in all studied systems.

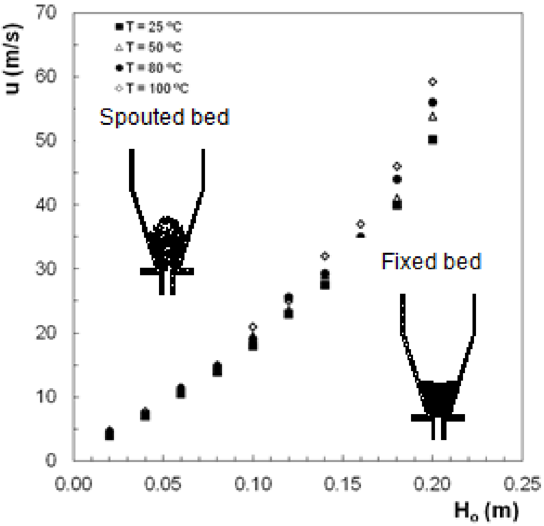

Fig. 4 Effect of inlet air temperature on operating regimes for mixtures of vine shoots and silica sand in a conical spouted bed combustor. Experimental system: γ= 36º D_o= 0.03 m, vine shoots of d_S= 25 mm, T= 25, 50, 80, 100 ºC

In Fig. 5 temperature profiles at the axis of the conical spouted bed combustor in beds of stagnant bed height of 0.08

m of inert material (silica sand) of Sauter mean diameter of 1.28 mm at inlet gas temperatures T= 400 and 500 ºC are plotted. As it is observed, axial temperature profiles decrease from the base of the contactor towards the surface of the bed, and these profiles are more pronounced at the lowest region in the contactor.

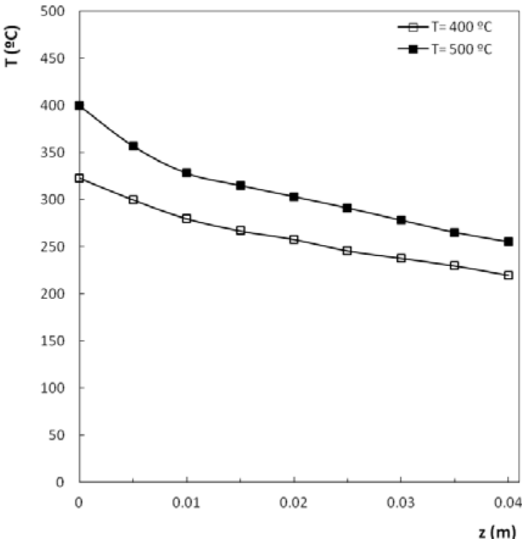

Fig. 5 Longitudinal temperature profiles at different levels of the combustor axis in beds of inert material (sand) at different inlet gas temperature T= 100, 200, 300, 400, 600 and 700 ºC. Experimental system: γ= 36º, D_o= 0.03 m, bed of 380 g (H_o= 0.08 m) inert material (silica sand) of d_S = 1.28 mm

Aiming to determine the lowest temperature at which thermal combustion of vine shoots can be conducted and to improve the combustion efficiency, batch combustion tests were carried out from 400 to 550 ºC with inert bed. During the combustion process, concentration of CO_2 and CO (% volume) were measured in the exhaust gases by Testo 350 gas analyzer with the time. Fig. 6 illustrates the experimental results for the time evolution of the CO_2 and CO concentration (% volume) in the bath combustion of vine shoots in the inert bed at the inlet gas temperature of 450 ºC and at minimum spouting velocity, for a system taken as example. As displayed, the profiles of CO_2, CO gases rise from zero to a maximum value and then it decreases up to zero. The maximum value of CO_2 is more than fivefold higher than the maximum of CO.

The experimental values of combustion efficiency of thermal combustion of vine shoot in a conical spouted bed combustor were calculated from the mean concentration of CO_2 and CO (% volume) in the flue gas, (1) [5]-[7]:

$$\eta = \frac{CO_2}{CO + CO_2} \tag{1}$$

In order to assess the effect of the inert bed use and of the air temperature on the combustion efficiency, the mean of the experimental data of combustion efficiency of vine shoots with inert bed and without the sand particles conducted in triplicate at temperatures in the range 425-550 ºC were compared. The minimum combustion temperature was 425 ºC. At lower temperatures, the vine shoots were dried, but they were not burned. The combustion efficiency with inert bed increases with the inlet temperatures from 90% at 450 ºC and from 500 ºC, the combustion yield is asymptotical. The use of sand bed homogenized the bed temperature. Besides, combustion efficiency for vine shoots with inert bed is higher than that obtained without this bed [5], at each temperature, with the largest difference of 4% at 500 ºC.

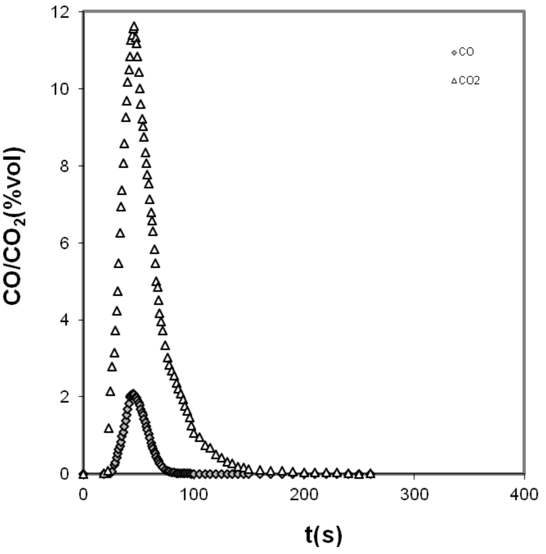

Fig. 6 Time evolution of CO_2 and CO concentration (% volume) in the exhaust gases during the batch combustion process of vine shoots with in inert bed at inlet gas temperature of 450 ºC at minimum spouting gas flow

IV. CONCLUSIONS

The range of operating conditions in the spouted bed regime of beds of vine shoots and an inert bed in a spouted bed combustor were determined at temperatures in the range 425-550 ºC under different operating conditions. Beds consisting of vine shoots and sand particles were stable and the spouted bed regime was reached under the experimental conditions studied. Minimum spouting velocity increased with the stagnant bed height and the inlet air temperature.

The conical spouted bed combustor has been proven to be feasible for thermal exploitation of vineyard pruning wastes with an inert bed, combustion efficiencies higher than 85%, calculated from measured concentrations of CO_2 and CO in the exhaust gases in the combustion. In addition, the increase in the inlet gas temperature promoted higher combustion efficiency.

The use of a bed of inert material homogenizes the bed temperature resulting in a higher combustion efficiency of vine shoots in a conical spouted bed combustor. The thermal combustion of vine shoots occurred at lower temperature than without inert bed. VOC generation was decreased and consequently combustion efficiency obtained by using sand particles was higher than without the inert bed at each inlet air temperature. Therefore, the appropriate performance of a conical spouted bed combustor for the thermal exploitation of vine shoots was demonstrated based on the high combustion efficiency obtained.

ACKNOWLEDGMENT

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NOMENCLATURE

D_b	upper diameter of the stagnant bed
D, D_i, D_o	diameter of the cylindrical section, of the dryer base, and of the gas inlet, respectively, 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, respectively, m
t	time, s
T	temperature, ºC
M	solids mass, kg
X_{steel}, X_{ins}	thickness of the dryer wall and of the insulation, respectively, m
u, u_{ms}	velocity of the air and air minimum spouting velocity, respectively, m/s
Greek Letters	
ϕ	Shape, -
γ	angle of the conical section of the dryer, deg
η	combustion efficiency
ρ_s	density of solids, kg /m^3
Subscripts	
d	drying
ms	minimum spouting

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