Recycling of Wastes From Wood Processing in a Conical Spouted Bed Combustor

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ABSTRACT: Conical spouted bed incineration has been proven a feasible technology for thermal treatment of beds consisting of wastes from wood processing. The objective has been to evaluate the combustion efficiency and gas products from wastes from wood processing such as shavings, sawdust and wood chips. The spouted bed regime has been obtained up to velocity corresponding to low bed pressure drop fluctuations. Experiments have been carried out from 450 to 550°C. The combustor has been operated with an average excess air (20%) regarding minimum spouting gas flow, and the efficiency has been in 68-90% range.

KEYWORDS: Conical Spouted bed; combustion; thermal treatment; wastes from wood processing

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INTRODUCTION

Lignocellulosic materials such as wastes from wood processing are becoming interesting for energy production, to replace fossil fuels, because they are renewable fuels with low CO_2 and sulphur emissions, which contribute to the greenhouse effect (Ramanathan & Feng, 2009), one of the main causes of global warming. In the last Paris Climate Conference, COP21, the most of the countries signed an agreement to keep global temperature increase below 2ºC above pre-industrial levels and better lower than 1.5 ºC.

In combustion process of biomass is important to remove water content prior to burn, due to the fact that moisture content can cause problems due to moisture fluctuations (Bahadori *et al.*, 2012). In fact, drying is the first step of the combustion.

Biomass consists of the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste (Directive 2009/28/EC). The main types of biomass are summarized in Table 1 (Lomas *et al.*, 2001). The heterogeneity of biomass, is both a fundamental characteristic and as a source of problems for development due to the peculiarities of each type of waste.

In recent years, there has been an increasing research emphasis on the application of spouted bed technology in processes at high temperature such as combustion of biomass wastes (Olazar *et al.*, 1994; San José *et al.*, 2006a, 2006b, 2010a, 2010b, 2013a, 2013b, 2014a, 2014b). Spouted bed technology is gas-solid contact method characterized by a recirculatory movement of the solid. In the spouted bed regime in the conical Spouted Bed combustor three zones can be distinguished in the bed. 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. In the annulus, particles go downwards and incorporate from the annular zone to the spout zone mainly at the combustor bottom, but also at every longitudinal position of the spout-annulus interface, mainly at the combustor bottom. Then solid particles rise through the spout zone again. The particle movement in spouted bed regime is shown in Figure 1. Whereas in the spout zone gas-solid contact is concurrent, in the annular zone is counter current. The good gas-solid contact avoids problems such as segregation (San José *et al*., 1994) and defluidization.

Table 1. Types of biomass.

Sector	Type	Example
Agroforest	Wastes from clearing, pruning and cutting	Bark; wood chips, branches
Agricultural wastes	Woody	Pruning of olive, fruit trees, vineyard, grapevine
	Herbaceous	Straw of maize, cereal, rice
	Energy crops	Wheat, thistle, sorghum
Livestock wastes	Manure	Solid manure Liquid manure
Industry	Wood processing	Bark, sawdust, wood chips, off-cuts
	Food industry	Wastes from olive oil, canning industry, nuts.
	Urban and industrial wastes	Municipal wastes, sewage sludge, paper sludge

In order to increase combustion efficiency, conditions that allow obtaining spouted bed regime have been determined by measurements of gas pressure drop fluctuations by increasing gas velocity from 0 to a maximum value. The gas-flow range in spouted bed regime has been determined and plotted in maps in temperature range of combustion.

The results of combustion at lower temperature than in the literature validate the feasibility of conical spouted bed technology for thermal exploitation of wastes from wood processing.

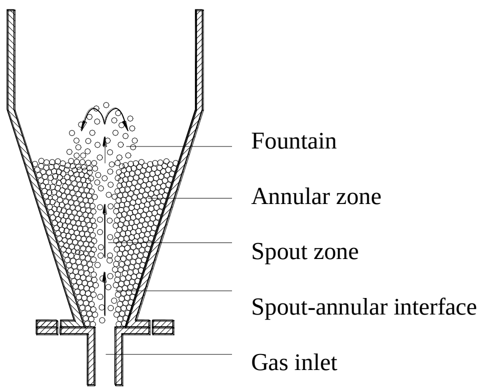

Figure 1. Zones in the conical spouted bed reactor and outline of particle movement

METHODOLOGY

The thermal treatment of biomass wastes from wood processing has been conducted in a conical spouted combustor at temperatures from 450 to 550 ºC. Figure 2 depicts the experimental pilot plant, designed at purpose, which has been described in details in previous papers (San José *et al*., 2013a, 2013b, 2014a, 2014b), is provided with a blower, an electric resistance to preheat the air, a worm gear to regulate and control the solid feeding system, several thermocouples, two high efficiency cyclones, and three rotameters used in the range of 20-250 Nm^3/h. measure the air flow rate.

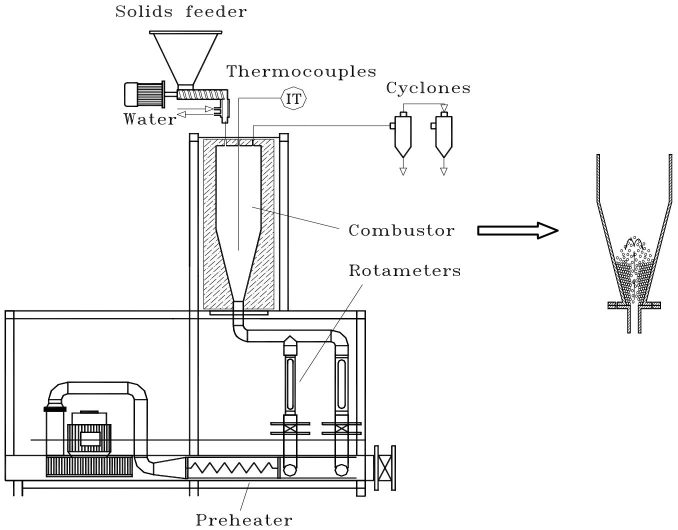

Figure 2. Experimental pilot plant with the conical spouted bed combustor.

Figures 1-3 show the spouted bed combustor used with a conical zone of operating and a cylindrical freeboard. The combustor is made of AISI-310S heat-resistant stainless steel and has an external insulation of 0.05 m of quartz fibre. The geometric factors of the combustor are: cone angle, ◎ = 36º; contactor inlet diameter, D_c = 0.20 m, D_i= 0.03 m; gas inlet diameter, D_o, between 0.01 m and 0.03 m and stagnant bed height values, H_o, from 0.05 to 0.20 m.

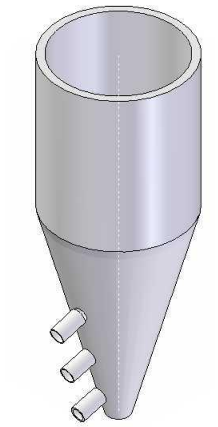

Figure 3. Conical Spouted bed combustor

The biomasses used are wastes from wood processing sawdust, branches, wood chips and shavings (Figure 4) (LoW, list of waste code 03 01 04) (Commission Decision of 18 December 2014) of density, $◎_s$, 540 kg/m^3, and of different particle sizes obtained by grindring (Fritzch Pulverizette) and sieving. Table 2 shows the properties of biomass wastes of different particle diameter and sphericity.

Figure 4. Biomass wastes. (a) sawdust; (b) shavings; (c) branches; (d) wood chips

Table 2. Properties of the materials.

Material	Size range (mm)	d_S (mm)	[illegible]	[illegible]	Geldart classification
Sawdust	0.8-1.0	0.95	[illegible]	[illegible]	A
	1.0-2.0	1.5	[illegible]	[illegible]	B
	3.0-4.7	4.2	[illegible]	[illegible]	D
Branches	2.0-6.4	4.05	[illegible]	[illegible]	D
Shavings	3x8x0.3-12x27x0.3		[illegible]	[illegible]	B
Wood chips	4.8-5.2	4 5	[illegible]	[illegible]	D

In order to obtain pressure drop curves against air velocity, bed pressure drop and air velocity data are measured by a differential pressure transducer (Siemens Teleperm), connected to a computer where the data are processed by AMR-Control software (San José *et al*., 2013b, 2014a, 2014b). Minimum spouting and minimum diluted spouted bed (jet spouted) velocities have been delimited by visual observation of the bed (San José *et al*., 2015).

Gas temperatures are measured by two thermocouples located at the combustor inlet and at the outlet (San José *et al*., 2013b, 2014a, 2014b). Moreover, air moisture content is measured by thermal conductivity detectors (Alhborn MT8636-HR6) at both inlet and outlet.

With the aim of carrying out combustion of wastes from wood processing, conical spouted bed combustor is heated by heat air and once the desired temperature in the range 440-550 ºC is attained, wastes from wood processing are fed. Air flow rate is in excess of the stoichiometric condition, and the rate fed ranges from the corresponding minimum spouting velocity up to 20% above this value.

During the previous combustion step, solid is dried at 105 ºC up to constant weight is obtained. Solid moisture content has been determined by Mettler Toledo HB43-S hygrometer at different times. Concentration of flue gas (O_2, CO_2, CO, NO, and SO_2) has been analyzed by Testo 350 gas analyzer, in order to characterize combustion with the time. Each experiment has been repeated three times to calculate mean gas concentrations.

TRANSACTIONS ON SCIENCE AND TECHNOLOGY

RESULT AND DISCUSSION

Operating Conditions

Spouted bed regime in beds of wastes from wood processing in conical spouted bed combustor is determined by pressure drop evolution with gas velocity when standard deviation of pressure fluctuations are lower than 10 Pa (San José *et al*., 2015). Operating pressure drop has been measured in conical spouted beds at different geometrical factors of the spouted bed reactor (angle and gas inlet diameter) and different solid properties (particle diameter and sphericity, moisture content) and experimental conditions (bed mass and gas velocity).

Figure 5 shows pressure drop evolution with air velocity, u, for an experimental system taken as an example of cone angle ◎ = 36º, contactor inlet diameter D_o= 0.03 m, stagnant bed height H_o= 0.20 m for a bed consisting of wood chips, sawdust and shavings with a moisture of 60 wt % in dry basis at inlet gas temperature of T= 60 ºC. As can be observed, as gas velocity is increased, pressure drop increases up to a maximum and subsequently decreases sharply up to pressure corresponding to stable spouted bed regime. Evolution obtained as gas velocity is decreased, dotted line, shows a pronounced hysteresis due to a very much lower maximum pressure. As can be seen in the Figure, maximum pressure drop and the corresponding gas velocity are greater for sawdust than for wood cubes and the last values are greater than those corresponding to shavings. Stable pressure drop and the corresponding gas velocity for wood chips are greater than for branches and the last values are greater than the corresponding to shavings.

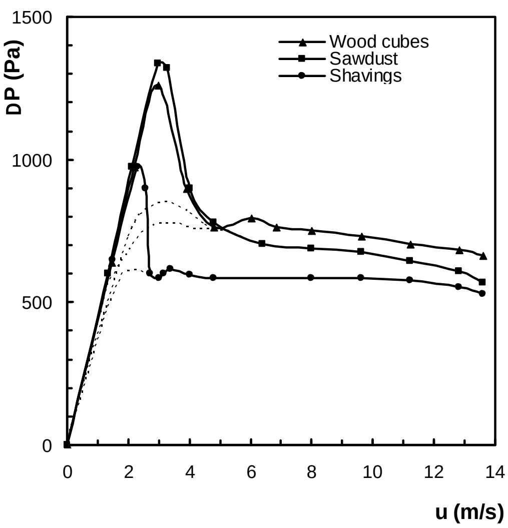

Figure 5. Pressure drop evolution with gas velocity for beds of shavings, branches and sawdust with moisture of 60 wt % (dry-wt. basis). Experimental conditions: ◎ = 36º, D_o= 0.04 m, H_o= 0.20 m and inlet gas temperature of 60 ºC.

Air-flow range for combustion process of wastes from wood processing in conical spouted bed combustor is determined at each bed mass by increasing gas flow from the condition of minimum spouted bed velocity, determined by pressure drop fluctuations, up to the velocity at which spout and annular zones of the bed are mixed.

Operating map of stagnant bed height, H_o, against air velocity is shown in Figure 6 for beds made up of shavings, sawdust, branches and wood chips of moisture content of 60 wt % (dry basis), u at inlet gas temperature of 105 ºC.

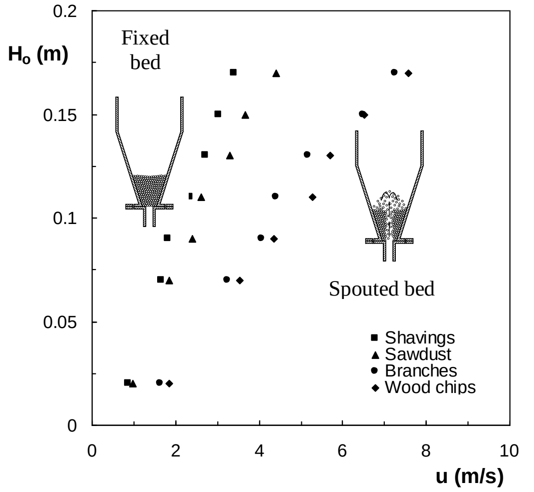

Figure 6. Operation map for beds of biomass of moisture content of 60 wt% (d.b.). Experimental system ◎ = 36º, D_o= 0.03 m. beds of shavings, sawdust, branches and wood chips at inlet gas temperature of 105 ºC.

The experimental data, which delimit the condition of spouted bed regime, characterized by cyclic movement which gives the high contact efficiency, have been measured by increasing gas velocity at each stagnant bed height. As can be noticed in the Figure, minimum spouting velocity corresponding to wood chips is the greatest and the values corresponding to shavings are the smallest.

Combustion of wastes from wood processing

Combustion experiments of wastes from wood processing have performed in the spouted bed range delimited by minimum spouting velocity corresponding to each bed height. In the previous combustion step, drying, moisture content decreases from initial 60 wt% up to equilibrium moisture content, corresponding to each waste. Efficiency of combustion process of wastes from wood processing has been calculated based on mean values of concentration of CO_2, CO (% volume) gases in the flue flow at each studied temperature by means of the following equation (San José *et al.*, 2013a, 2013b, 2014a, 2014b).

$$\eta = \frac{CO_2}{CO + CO_2} \quad (1)$$

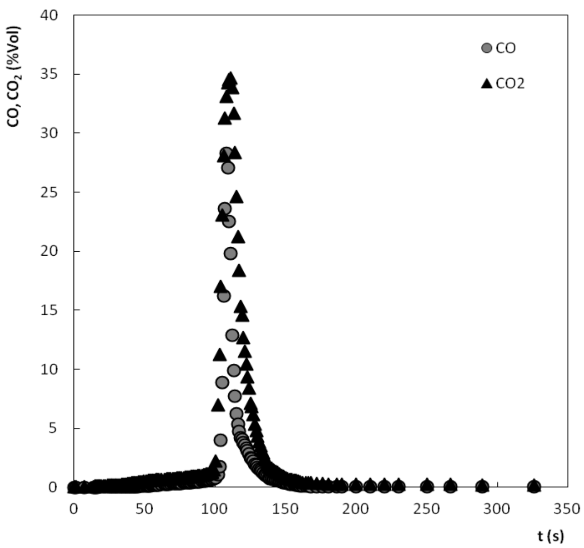

Figure 7. Evolution of CO_2, CO (% volume) concentration in flue gases with the time in combustion of sawdust at gas temperature of 550 °C.

The evolution of concentration of CO_2, CO (% vol) in the exhausted gas flow has been monitored with the time during the combustion process. In Figure 7 concentration evolution of these gases is outlined for combustion of sawdust at 550 ºC. As can be seen, both CO_2 and CO concentrations maintain constant at the beginning, subsequently increase pronouncedly describing a narrow peak, and later decrease sharply. However, CO_2 concentration is higher than CO concentration.

The experimental results of combustion efficiency obtained in combustion process of wastes from wood processing at inlet gas temperatures of 450-550 ºC are summarized in Table 3. Combustion efficiencies for sawdust wastes ranged from 68 to 88 % for inlet gas temperature between 450 and 550 ºC, as global efficiency for all wastes from wood processing studied. Combustion efficiencies obtained for sawdust are the highest and those corresponding to shavings are the lowest. As shown in Table III as inlet gas temperature is increased, efficiency increases. The high values of combustion efficiency for beds of wastes from wood processing and the low amount of ashes, lower than 3.6% confirm the suitability of the conical spouted bed combustor in recycling by combustion of wastes from wood processing.

Table 3. Combustion efficiency of wastes.

Biomass	T (º C)	Size range (mm)	d_S (mm)	◎ ◎
Sawdust	450	1.0-2.0	1.5	0.68
Sawdust	475	1.0-2.0	1.5	0.74
Sawdust	500	1.0-2.0	1.5	0.82
Sawdust	550	1.0-2.0	1.5	0.88
Wood chips	550	4.8-5.2	4.0	0.87
Branches	550	2.0-6.4	4.02	0.85
Shavings	550	3x8x0.3-12x27x0.3	--	0.83

CONCLUSION

Spouted bed regime, corresponding to minimum spouting velocity, has been delimited based on low pressure drop fluctuations, lower than 10 Pa. Air-flow range for combustion process of wastes from wood processing is determined from this velocity up to the velocity at which spout and annular zones are intermingled.

Recycling of wastes from wood processing (sawdust, branches, wood chips and shavings) by combustion in a conical spouted bed combustor has been proven to be suitable for inlet gas temperature between 450 and 550 ºC. High global values of combustion efficiency for all wastes from wood processing have been obtained, ranging 68-90% mainly for sawdust.

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