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Treatment and use of bottom bed waste in biomass fluidized bed combustors

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ABSTRACT

Bottom bed waste (BBW) from combustion of forest biomass residues was characterized aiming its use as partial substitute of fresh bed sand (FBS) in industrial bubbling fluidized bed combustors (BFBC).
BBW particle size distribution, elemental composition (mainly Si, Ca, Al, Na, K, P and Mg) and mineralogy were evaluated considering also the influence of the characteristics of the biomass used as fuel.
Biomass combustion experiments were developed using a pilot-scale bubbling fluidized bed combustor. The operating conditions during the experiments were monitored, namely the flue gas composition (CO_2, O_2 and CO), temperature and pressure, and compared with data collected from BFBC located in two industrial biomass thermal power plants.
Physical, chemical and mineralogical characteristics of the FBS and BBW revealed that practices related with biomass handling at the forest strongly influence the BBW properties, in terms of not only coarse soil particle addition (>1.0 mm) but also mineralogically. However, the results obtained here indicate that by sieving of BBW it is possible to recover almost 60% of the original BBW particles (size between 0.3 and 1.0 mm), which have properties that allow its reuse as substitute of FBS for bed make-up in industrial BFBC.

1. Introduction

Fluidized bed combustion (FBC) is recognized as the most suitable technology for biomass combustion. FBC plants can deal with distinct fuel mixtures (e.g. different types of biomass) but might show some operating problems when the particle size distribution and type/amount of impurities in the fuel are not adjusted [1]. The combustion temperature inside the bed must be kept relatively low (usually 700–900 °C) in order to prevent ash sintering. Even so, this technology assures high conversion efficiency [2,3]. Problems that might appear during biomass combustion are related to the amount of ashes being generated and their properties, with potential reflex on the energy conversion efficiency. Slagging, fouling, corrosion, and bed agglomeration are unwanted episodes. Additionally, the generated ash also requires a proper environment [4,5].

Several authors consider agglomeration of bed particles as the major problem during biomass combustion in FBC [6–9]. According to Bartels et al. [10] the inappropriate fluidization caused by agglomeration could lead to the fluidized bed collapse. The bed material agglomeration and sintering are related with the sticky coatings on bed particle formation [10].

These coatings are formed by multiple layers of ash or ash-rich compounds. The internal layers seem to be a sign of the composition of the bed material (sand), while the outer layers are essentially defined by the ash characteristics [11]. In addition, certain element segregation to the ash layers on bed sand particles has been observed [12].

The volume of ashes, their characteristics and management have been considered one of the most important issues during thermochemical conversion of biomass to energy. The type of biomass in use (i.e., forest wastes, wood, herbaceous, domestic wastes), the amount/nature of impurities (i.e., soil, inorganics), the technology and the operating conditions (e.g., bed material residence time, and temperature) determine the amount and characteristics of the ashes produced during combustion. According to Vassilev et al. [13] approximately 480 million ton of ash from biomass combustion could be generated worldwide annually. This quantity is becoming comparable to that of coal ash, namely 780 million ton produced per year at present [14].

During biomass combustion in bubbling fluidized bed combustors (BFBC) two main types of ashes are produced: bottom bed and fly ashes. The bottom bed ashes are basically composed by a mixture of sand (mainly quartz) particles from the original bed, and by inert/inorganic components (forest soil and small stones) included in the biomass. Additionally unburnt organic components might also

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Table 1
Characteristics of the residual forest biomass used as fuel in the combustion experiments.

Proximate analysis	(wt.%, as received)	Ultimate analysis	(wt.% dry basis)
Moisture	5.82	Ash	1.41
Volatile matter	73.01		
Fixed C	19.84	C	51.7
Ash	1.33	H	6.72
Heat value	$M * kg^{-1}$	N	0.29
LHV (lower heating value)	20.34	S	0.02
HHV (higher heating value)	21.81[a]	O (by difference)	39.86

[a] Thipkhunthod et al. [27].

Table 2
Thermal power plant mass flows of biomass fuel, FBS, BBW and FA quantities and associated costs.

Estimated data	Input		
	TPP_1	TPP_2	Unit
Inerts fed with biomass (dry base)[a]	31.7	29.0	t/day
Biomass ash content (loss on 550 °C — dry base)	10.8	14.0	t/day
Mass of fresh bed sand input (dry base)[b]	2.6	4.4	t/day
Total	45.1	47.3	t/day
	Output (a)		
Real data supplied by the industry	TPP_1	TPP_2	
BBW — discharge (dry base)[b]	20.9	17.6	t/day
FA — discharge (dry base)[b]	20.5	29.8	t/day
FA — discharge (dry base)[a]	24.2	29.7	t/day
Total[b]	41.4	47.4	t/day
Total[a]	45.1	47.3	t/day

[a] Estimated values based on bench tests and industry values.
[b] Industry data.

be present in the ash. The components of the fly ashes are similar to the previous ones, but finer enough to be aspired by the exhaustion system of the combustor. The bed sand fraction is normally much lower than in the bottom ash, since only the original finer particles or the ones resulting from attrition and abrasion phenomena are present. During BFBC, the bottom bed ashes often represent the lower fraction of the total ashes produced: around 5 wt.% [15,16], 10 wt.% [17], and 17 wt.% [18]. However, in some Portuguese thermal plants with BFBC, the relative amount of bottom bed ashes can be as high as 50–60 wt.% [19].

The bottom bed waste is generated when periodic discharges of the bed are performed: i) trying to maintain the particle size distribution and to avoid agglomeration, in order to assure the suitable fluidity and hydrodynamic conditions of the bubbling bed; ii) to discharge the excess of solids (ash) and keep the height constant. In general, the relative high level of inert material present in the biomass used in Portuguese BFBC plants [20] enhances the frequency of bed discharges, meaning that bottom bed ashes have low residence time (<5 days — see Tables 1 and 2) in the BFBC when compared with results reported for other installations using BFBC [15,16]. Since around 60 wt.% of discharged bottom bed waste is composed by sand particles having sizes in the range of 0.5–1.0 mm, the mentioned increase of discharge frequency will imply a stronger make-up with fresh sand, while increases the volume of waste being generated.

The bottom bed waste from BFBC has the code 100124 according to European List of Wastes [21] and the search for recycling or reuse alternatives of such residue is a hot topic and a serious need. We should also look to other relevant environmental indications like the one given by Hoffman [22] that concluded that around 90% of the beaches in the world are losing ground due to excessive sand extraction for distinct uses.

Previous studies demonstrated that the use of bottom bed waste from biomass burning in BFBC as substitute of the conventional sand used as coarse aggregate in the formulation of industrially-prepared rendering-mortars is technologically feasible [23]; in general this substitution does not induce negative effects on the relevant properties and material accomplishes with required specifications. However, other applications for such waste must be found and one obvious option is the recirculation or reuse of the material in the same BFBC. Apparently easy, this way requires the pre-adjustment of particle size distribution,

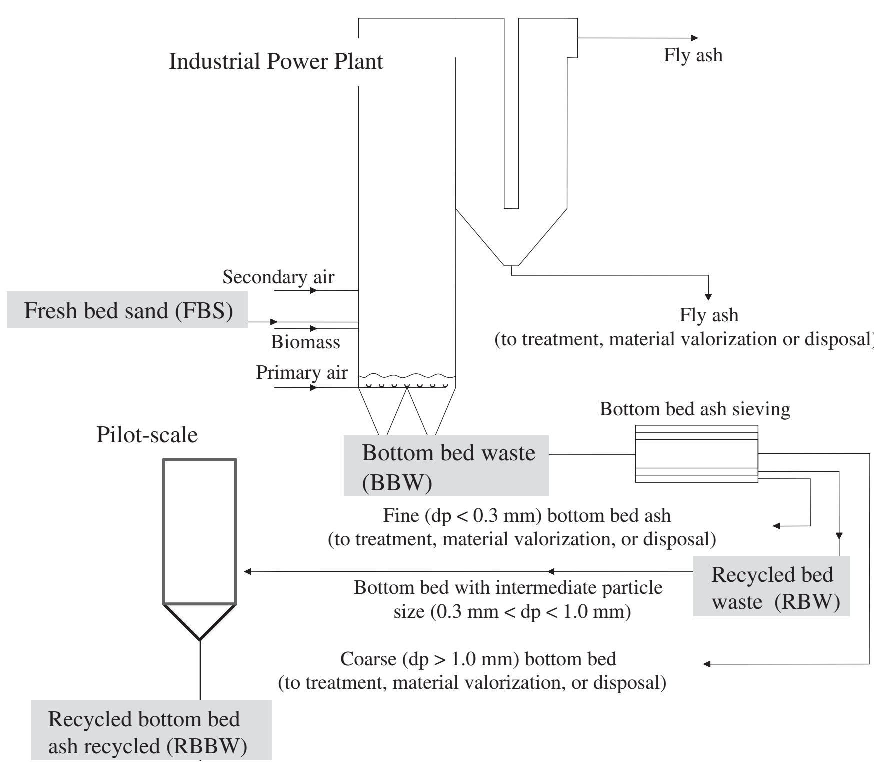

Fig. 1. Schematic diagram of the main ash flows in a thermal plant with BFBC and the respective samples used in this study.