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Characteristics of distinct ash flows in a biomass thermal power plant with bubbling fluidised bed combustor

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ABSTRACT

Characteristics of biomass used as fuel and distinct ash flows in a thermal power plant with BFBC (bubbling fluidised bed combustion) technology were studied. An integrated approach involving chemical composition, microscopy analysis, mineralogy, and thermal behaviour were used to characterize the ash. The ashes have a low unburned content, typically below 3 wt.% (dry basis), with higher values in ash from the electrostatic precipitator. The chemical element present in higher concentration in the several ash flows is Si (>20 wt.%, dry basis). The fly ash from the electrostatic precipitator are enriched in heavy metals when compared to other ash, and Zn is the heavy metal found in higher concentration (but <225 ppm wt., dry basis), followed by Cr, Pb, Cu and Ni in decreasing order of abundance. The distinct ash produce leaching solutions with pH values in range 11.9–12.8, and conductivity in the range 4.7–19.5 mS/cm, with higher values in ash from electrostatic precipitator. Ca is the element in higher concentration in the ash leachates, followed by K, Na and Cl. The concentration of heavy metals in the leachates is relatively low. The biomass quality influences the ash characteristics, and an appropriate management of biomass and ash is need to improve the performance of thermal power plants.

1. Introduction

The use of biomass to produce heat and power has been increasing in recent years and is part of the energetic strategies of developed and developing countries.

An important issue during thermochemical conversion of biomass to energy is related to the ashes produced, their characteristics and management (both operating and environmental aspects). The ash management has important consequences, both economic and environmental, considering the sustainability of the biomass to energy policies. For example, the ashes contain the main nutrients needed for plants growing up, and thus, the management strategies must consider the ashes as a nutrient source, and an important issue on forest sustainability.

Some countries, for example, Austria, Denmark, Finland, Germany, and Sweden, have guidelines for appropriate management of ashes from biomass combustion, namely by recycling the ashes in forest soil [1–6]. Nevertheless, published research shows that several applications for the ashes from biomass combustion can be explored [1,2,7,8], in order to make the valorisation of this material and save natural resources.

The industry, together with local and national environmental authorities, recognizes the need of guidelines for the appropriate management of the ashes from biomass combustion. However, the particular characteristics of each ash flow in a thermal plant, and also between thermal plants using distinct conversion technology, fuels and operating conditions, sometimes makes difficult to establish management practices of general application. Also, some management practices, e.g. the application as fertilizing on the forest soil, are restricted by the local characteristics of the soil, biota and water resources.

Characterization of ashes from biomass combustion is of major importance, considering the impact of ashes on the technology performance and on ashes management. Important physical–chemical parameters of the ash to be known include particle size distribution, particle morphology and microstructure, density

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and porosity, particle specific surface area, pH, leaching, chemical composition, and mineralogy.

Aspects that influence the characteristics of the ashes produced during biomass combustion include the biomass properties, the conversion technology and the operating conditions.

Biomass characteristics can vary widely [9,10], influencing both the quantity and chemical composition of ashes produced during biomass combustion in thermal plants. Biomass with high content of inorganic material will produce higher amount of ashes. Biomass ashes with high content of Na and K will be more problematic considering operating issues, such as problems of bed agglomeration and defluidization during fluidised bed combustion [11].

The technology used for biomass combustion also influences the quantity and characteristics of the ashes produced. In a biomass thermal plant distinct flows of ashes can be identified, and in general are classified in two major categories [12]: bottom ashes and fly ashes. The fly ashes can be divided in distinct flows, namely the fly ashes collected in super-heaters, economizers and air pollution control devices (e.g., cyclones, bag filters, and electrostatic precipitators). However, often distinct ash flows in a thermal plant are mixed and managed together, although it can be observed that ashes can have distinct characteristics depending on the thermal plant operating variables [6,13–20]. The relative amount of distinct ash flows produced in a thermal plant, namely bottom ash and fly ash, depends on the technology used. During fixed bed combustion, as in grate furnaces, the major mass fraction is bottom ash [1], whereas during fluidised bed combustion the fly ash represent the major mass fraction [6,13,14,16]. However, the same technology operated under distinct conditions, for example, fuel with distinct characteristics, can produce distinct relative amounts of bottom ash and fly ash. For example, the bottom ashes from BFBC (bubbling fluidised bed combustion) can represent the major mass fraction of ashes produced [21], and that is a result from the low quality of the biomass used as fuel and related to a high content of inert (forest soil) material fed mixed [22].

The operating conditions (e.g., temperature, stoichiometry, air staging, additives) influence the characteristics of the ash produced, because they can influence the transformation and association of the chemical elements during combustion of the biomass fuel [23], and thus, their partition between bottom ash and fly ash.

Ash from biomass combustion are alkaline, and pH in the range 11–13 has been found in ash from BFBC [6,16,22]. The bottom ash from BFBC is coarser in size when compared to fly ash [6,13,14,16]. Fly ash have lower density and higher specific surface area when compared with bottom ash [1,22].

During biomass combustion in grate furnaces, the ash results from the intrinsic inorganic content (ash) of the biomass and exogenous inert material (e.g. forest soil) fed mixed with the biomass. During FBC (fluidised bed combustion) of biomass the ashes are composed by particles from the original sand bed, intrinsic inorganic content (ash) of the biomass, and exogenous inert material (e.g. forest soil) fed mixed with the biomass. The ashes might also contain unburned organic material, as a consequence of incomplete conversion of the fuel during the combustion process. The bottom ash from FBC results from periodic discharges of the bed, among other reasons, related to: i) bed renovation and replacement in order to avoid bed agglomeration and defluidization, ii) discharge of excess bed solids in order to maintain the optimal bed height, iii) bottom bed replacement by fresh sand with appropriate particle size distribution, to guarantee proper hydrodynamic conditions of the bubbling bed. For this reasoning the bottom ash from FBC are composed mainly of Si compounds, with values as high as 90 wt.% (expressed as SiO_2) [9,14,21,22,24]. Usually the fly ashes from biomass combustion are enriched in chemical elements typical of the inorganic content of the biomass, including heavy metals (e.g., Cr, Cd, Zn, Pb), when compared to bottom ash [1,6]. The fly ashes can also contain organic compounds with environmental relevance (e.g., PAH (polyaromatic hydrocarbons), PCDD/F (polychlorinated dibenzodioxins/furans)) [1,25].

Ashes from biomass combustion are classified as a solid waste, according to the European List of Wastes [26], and usually are managed accordingly; a common practice is ash disposal in landfill. However, disposal in landfill is not sustainable, and has economic and environmental drawbacks; environmental policies penalize this practice as management operation, with increasing costs associated.

In Portugal, the amount of biomass used for heat and power production in industrial combustion installations has been increasing in the last decade, and most facilities with higher power installed capacity include BFBC technology [27]. The country has no guidelines for biomass ash management. The ash is classified as a solid waste [28], and distinct codes are assigned depending on the origin of the ash in a thermal plant, e.g., slags (code 100101), fly ash (code 100103), bottom ash from fluidised beds (code 100124), and managed accordingly. Nevertheless, some industries are trying to manage the ash in a sustainable way, attempting its valorisation; this might involve the recycling on the forest soil or as secondary raw material in the building industry.

In this context, detailed knowledge about the properties of distinct ash flows in a thermal plant is of major importance in order to understand and prevent ash related operating drawbacks, and to support the development of suitable ash management operations, namely in the scope of alternatives for its material valorisation. This will be crucial, considering the sustainability of forest biomass to energy policies.

However, most of the knowledge and published work related to characteristics of ash from biomass combustion in industrial installations with bubbling fluidized bed technology refers to the main two flows usually named as bottom ash and fly ash [6,13,14,16,45,46] or only to fly ash [39,49]. The fly ash are often referred as from the electrostatic precipitator [6,16,45,46]. In fact, it is not taken into account that other fly ash flows can be collected in result of thermal plant configuration, namely at superheater and economizer hoppers. Thus, it is important to study these distinct ashes, because they can have different characteristics and diverse implications on operating issues and environmental management impacts. Also, it is observed that existing studies often offer a very limited set of information about the operating conditions of the thermal plants where ashes are produced; for example, indicating only the type of furnace and designation of the fuel [45], the type of furnace/installed power and designation of the fuel [49], type of furnace/installed power, designation of the fuel and general operating temperature [6,16,39,46]. Thus, restricting the analysis between ash properties and operating conditions of the thermal plant.

In this context, and intended to suppress some lacks on the subject, this work provides new knowledge about properties of specific ashes according to the location where they are collected (namely, at the discharge of bottom bed, superheater, economizer, electrostatic precipitator) in a biomass thermal power plant with BFBC technology and the relation with biomass fuel properties and operating conditions. Some insights related to the influence of distinct ash on the thermal plant performance are also analysed. It was selected as study case an industrial facility located in Portugal, comprising a thermal power plant using BFBC technology and fuel composed of residual forest biomass common in the Iberian Peninsula. An integrated approach, including acquisition of new experimental information and data analysis, related to characteristics and operating conditions of the thermal power plant, and detailed physical–chemical properties (particle size and