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Biomass combustion systems: A review on the physical and chemical properties of the ashes

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ABSTRACT

Biomass as an energy source contributes to a decrease in the dependence on imported fossil fuels, while at the same time, adding value to the countries where biomass fuel sources thrive, in addition to providing a source of renewable energy. Knowledge of the behaviour of fuel is essential in order to design and operate equipment safely and efficiently. In particular, knowledge about mineral content is essential because the ashes play an important role in the dynamics of the generation system. Through knowledge of the chemical composition and physical properties of the ashes, it is possible to predict the tendency to form deposits in the boiler components, as well as their potential to cause corrosion, erosion and abrasion. The behaviour of the ashes in the system is highly dependent on fuel, particularly when it comes from industrial waste or energy crops. These fuels have a higher mineral content, particularly sodium (Na), potassium (K), phosphorous (P) and chloride (Cl). They also have higher ash content with a low melting point and high corrosion potential. This paper focuses on the characteristics of the ashes derived from the combustion of biomass, with particular attention paid to the chemical transformations at high temperatures, as well as its effect on the combustion equipment. Emphasis is placed on the potential problems that occur when biomass-burning technologies are used for energy crops, in order to avoid catastrophic failures. It concludes with recommendations for the management, control and prevention of problems associated with ash.

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1. Introduction

In today's world, there is a growing interest in the use of biomass for energy purposes [1–5]. The reasons include economic, political and environmental concerns, as well as the need to provide energy using renewable resources, reduce dependence on foreign fossil fuels, create more jobs per unit of energy produced and considerably reduce the environmental impact [6–10]. The majority of biomass waste products actually available are deprecated and may potentially be used as an energy source. In addition, many types of biomass forms can be grown as energetic crops to be consumed on-site, eliminating the dependence on third parties to supply raw materials [11].

To achieve a stable energy generation system, the requirements imposed by the fuel should be well known in order to allow for the adaptation of the burning technologies, particularly when it concerns industrial waste biomass forms or energy crops that, by its chemical composition, have different behaviours than other biomass types [12]. These fuels have a higher content of minerals, including sodium (Na), potassium (K), phosphorous (P) and chloride (Cl), a high ash content with low melting point and a high corrosion potential [13].

The objective of this paper is to present a review about the development of the research related to biomass ashes and its effects in thermal conversion equipment. The ashing process and its physical and chemical characteristics, as well as the mechanisms of ash deposition and metallurgical damage caused by chloride gas combustion active corrosion are described. Ways to prevent or minimise the problems caused by ash deposition in biomass-fuelled boilers are also presented and analysed.

Fig. 1. Ash formation over a furnace grate fuelled with wood pellets.

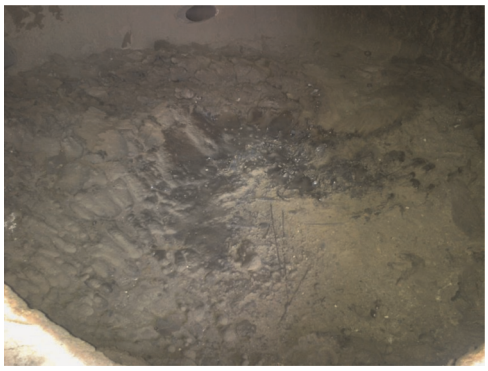

Fig. 2. Vitrified bottom ashes in a burner fuelled with sawdust.

2. Ash formation mechanisms

The elements that form the ashes are present in biomass as salts that are chemically bonded to the carbon structure (inherent ash), or they can come with biomass as mineral soil particles that have been caught during growth or are swiped during harvest and transport (foreign ash) [14]. The inherent ash components are homogeneously distributed in the fuel and are much more mobile than the trapped ash compounds, and therefore, they react chemically during combustion [15]. A fraction of these ash-forming compounds are volatilised and become part of the gas phase [16]. The volatilised amount depends on the characteristics of the fuel, the atmosphere surrounding the particle and the burner technology [17]. For example, a high combustion temperature and a reducing atmosphere enhance the volatilisation of environmentally relevant elements, such as heavy metals (Zn, Pb, etc.) [18].

Metals and metal oxides are partially evaporated at high temperatures within the fuel particles, and they become an active part of the reactions during the gas phase [19]. During its tour in the boiler fire, channels will precipitate at low temperatures and will nucleate on the surface as fine particles of CaO. They then become part of the gases in what is called “fly-ash” (size < 1 μm). Due to a reoxidation–nucleation–coalescence process, these particles agglomerate, composing an ash type larger than 10 μm known as coarse fly-ash [20]. Fig. 1 shows the typical grate furnace with bottom ashes being formed.

Non-volatile ash compounds that remain in the still-combusting particles may be melted and coalesced on or in the surface of the particle, depending on the temperature and chemical composition of both the particle and the surrounding gases [21]. This results in ash particles that have a wide range of compositions, sizes and characteristics related to the original mineral. Depending on the density and size of these particles, the technology used and the speed of the gases, a fraction of these ashes can be entrained by the gases, but in general, the majority is deposited on the grid, forming the so-called “grate ashes” [22], as seen in Fig. 2.

3. Chemical composition of the ashes

The ash content of different forms of biomass is varied, and can be as low as 0.5% on a dry basis for some species of pulpade wood, or up to 20% for some cereal or forestry and agriculture waste, particularly if they are contaminated with inert materials like small stones or rock dust [23]. The ash composition is dominated by SiO_2 and CaO, and less oxides of Mg, Al, K and P. The ash from plants with long reproductive periods, such as trees, by the dynamic flow of nutrients to the soil, have a very different mineral composition than plants that are harvested several times a year, such as energy crops or cereals. The latter contain large quantities of oxides with low melting points, particularly K and P [24], and also contain substantially lower levels of heavy metals [25]. Table 1 presents the ash average composition obtained from the combustion of some of the most common biomass forms available in Portugal.