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Experimental investigation of ash deposits on convection heating surfaces of a circulating fluidized bed municipal solid waste incinerator

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ABSTRACT

Incineration of municipal solid waste (MSW) is a waste treatment method which can be sustainable in terms of waste volume reduction, as well as a source of renewable energy. During MSW combustion, increased formation of deposits on convection heating exchanger surfaces can pose severe operational problems, such as fouling, slagging and corrosion. These problems can cause lower heat transfer efficiency from the hot flue gas to the working fluid inside the tubes. A study was performed where experiments were carried out to examine the ash deposition characteristics in a full-scale MSW circulating fluidized bed (CFB) incinerator, using a newly designed deposit probe that was fitted with six thermocouples and four removable half rings. The influence of probe exposure time and probe surface temperature (500, 560, and 700°C) on ash deposit formation rate was investigated. The results indicate that the deposition mass and collection efficiency achieve a minimum at the probe surface temperature of 560°C. Ash particles are deposited on both the windward and leeward sides of the probe by impacting and thermophoretic/condensation behavior. The major inorganic elements present in the ash deposits are Ca, Al and Si. Compared to ash deposits formed on the leeward side of the probe, windward-side ash deposits contain relatively higher Ca and S concentrations, but lower levels of Al and Si. Among all cases at different surface temperatures, the differences in elemental composition of the ash deposits from the leeward side are insignificant. However, as the surface temperature increases, the concentrations of Al, Si, K and Na in the windward-side ash deposits increase, but the Ca concentration is reduced. Finally, governing mechanisms are proposed on the basis of the experimental data, such as deposit morphology, elemental composition and thermodynamic calculations.

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Introduction

In modern industrialized societies, large quantities of waste are produced. The disposal of municipal solid waste (MSW) is one of the more serious and controversial urban issues facing local governments, globally. Compare to landfilling, incineration of MSW has many advantages including a significant reduction in volume (about 70%–90%), recovery of energy and complete disinfection. Therefore, incineration of MSW has been adopted in many countries, such as China, Japan, the US and several European countries. Compared to more traditional incinerators such as grate furnaces and rotary kilns, fluidized bed combustion has shown to be a versatile technology, capable of burning practically any waste combination, with lower emissions (De Boom et al., 2011). The significant advantages of fluidized bed combustors over conventional combustors include their compact furnace, simple design, effective burning of wastes with low calorific value, relatively uniform temperature and the ability to reduce emissions of nitrogen oxide and sulfur dioxide gases (Van Caneghem et al., 2012). In China, circulating fluidized bed (CFB) boilers are playing an important role in MSW combustion and electrical power generation. However, MSW often contains large proportions of ash (25%), which can be deposited on the heat transfer surfaces, and ash-related problems like deposit formation, corrosion and erosion are usually responsible for the malfunctioning of combustion systems (Mu et al., 2015; O'Hagan et al., 2015; Phongphiphat et al., 2011; Wang et al., 2008). These problems may have implications for heat transfer rates and hence decrease the efficiency of the boilers or even render the incinerators unmanageable (Garba et al., 2012; Teixeira et al., 2012; Wieland et al., 2012; Zbogar et al., 2009).

Ash deposition phenomena can be influenced by many physical and chemical processes, such as ash chemical composition, distribution of mineral matter in ash, ash fusion temperatures, furnace temperature, ash particle temperature, surface temperature of heat-exchanger tubes, tube materials, the flow field in the furnace, and ash transport mechanisms (Phongphiphat et al., 2011; Wieland et al., 2012). A number of reviews relating to ash deposition characteristics have already been reported (Reichelt et al., 2013; Teixeira et al., 2012). The formation of deposits depends strongly on the boiler type, the fuel and the temperature in the system. Deposits in coal combustion plants are formed at high temperatures above 900°C and show a large amount of amorphous phases, anhydrite, hematite and silicates (Kostakis, 2011). In biomass-fired FBC boilers, the vaporization and condensation of alkali metal elements, in particular potassium, play an important role in the ash deposition process (Bashir et al., 2012; Garba et al., 2012). Potassium is dispersed in biomass in different forms, *e.g.*, organometallics and salts, while silicon occurs primarily as hydrated silica grains (Li et al., 2013).

MSW differs from coal or pure biomass, such as wood and straw. MSW is a very complex and heterogeneous fuel, containing several individual material fractions (paper, plastics, food waste, metals, glass *etc.*) with different physical and chemical characteristics. MSW is a mixture of inhomogeneous materials which contains large concentrations of sulfur, chlorine, alkali and earth alkali metals and, in minor amounts, heavy metals like lead or zinc (Pfrang-Stotz et al., 2004). Currently, major research on MSW ash deposition has focused on the morphology or compositions of the collected ash deposit, especially in grate firing boilers. Ash deposits from MSW grate firing boilers are mainly composed of silicates and alumino–silicate minerals with low solubility, and the fly ash contains considerable amounts of soluble salts of alkali and alkaline earth metals. The major components of fly ash and bottom ash are SiO_2, CaO, Al_2O_3, Fe_2O_3, Na_2O, and MgO (Chou et al., 2009; Cobo et al., 2009; Thipse et al., 2002). Phongphiphat's work includes the analysis of bottom ash, deposits from the superheater and the fly ash from the economizer and fabric filters in a large-scale MSW grate firing incinerator in terms of particle size, unburned carbon, elemental composition and surface morphology. According to this study, the main components of the deposits on the superheater are Ca–Si–Al and/or Si–K–Al, likely to be present as amorphous silicates (Phongphiphat et al., 2011). Based on the fouling behavior of three different grate incinerators, Reichelt's study suggests that directly on the tube itself, a primary deposit is formed very rapidly due to mineralogical reactions. It contains sulfates and higher contents of chlorides, which both act due to their low melting points as glue for the secondary deposits (Reichelt et al., 2013).