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Investigation into high-temperature corrosion in a large-scale municipal waste-to-energy plant

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ABSTRACT

High-temperature corrosion in the superheater of a large-scale waste-to-energy plant was investigated. A comparison of nickel-/iron-based alloys and austenitic stainless steel probes placed in the furnace demonstrated that temperature and particle deposition greatly influence corrosion. Nickel-based alloys performed better than the other metal alloys, though an aluminide coating further increased their corrosion resistance. Sacrificial baffles provided additional room for deposit accumulation, resulting in vigorous deposit-induced corrosion. Computational modelling (FLUENT code) was used to simulate flow characteristics and heat transfer. This study has shown that the use of aluminide coatings is a promising technique for minimising superheater corrosion in such facilities.

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1. Introduction

A sustainable management strategy for municipal solid waste (MSW) includes reducing the amount of waste generated and reusing certain materials, as well as making use of recycling and energy recovery processes, followed by the environmentally-sound disposal of any residues. MSW consists of a putrescible fraction, along with paper, plastics, textiles, metals, glass and other miscellaneous materials. After recovering valuable recyclables by segregation, the waste can be thermo-chemically treated. Among the many technologies available for energy recovery, mass-burn incineration is well established. Coal-fired power stations have efficiencies in the region of 35%. While typical efficiencies for waste-to-energy (WTE) facilities are in the range of 25–30% for electricity generation only, when heat and power production are combined, much higher overall efficiencies can be achieved. Furthermore, more than two thirds of the carbon in MSW is greenhouse gas-neutral.

1.1. High-temperature corrosion in waste-to-energy facilities

High-temperature corrosion of heat exchangers is one of the most important factors that limits the efficiency of various energy systems [1–4]. In combustion processes utilising biomass or MSW, the steam temperatures are usually kept lower than 450 °C to avoid corrosion problems [5]. Raising the steam temperature by an additional 50 °C can result in significant increases in the corrosion rate in a biomass power plant [2,6]. Such problems become amplified by: (i) the use of fuels containing alkali metals, heavy metals, Cl and S; (ii) fluctuations in the flue gas flow; (iii) the high velocity, particle-bearing flue gas; and finally (iv) deposit (combustion residues) accumulation [3,5,7,8]. High-temperature corrosion can be amplified by a range of factors. Problems related to flue gas fluctuations and particle trajectory, for example, can be predicted, controlled and prevented using computational fluid dynamics (CFD) modelling. This has proved to be an effective tool for simulating and optimising flow conditions, heat transfer and particle trajectories inside the furnace [8]. As stated above, overall efficiencies for WTE plants are relatively low, thus methods to prevent or control high-temperature corrosion in such plants must be investigated in order to improve efficiencies.

Abbreviations: CFD, computational fluid dynamics; MSW, municipal solid waste; SEM, scanning electron microscopy; SP1, sampling probe 1; SP2, sampling probe 2; WTE, waste-to-energy.

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Unfortunately, WTE facilities are more susceptible to severe corrosion than other types of energy systems due to the presence of deposits containing alkali and heavy metals (such as Na, K, Pb, Zn and Cd), as well as Cl and S. These elements originate in the fuel and lead to the formation of eutectic compounds with low-melting points [3,5,7–10]; fuel composition is the main factor determining high-temperature corrosion in WTE plants. Liquid phase corrosion or hot corrosion is highly likely to take place on superheater tubes, resulting in high annual repair and replacement costs. Reliable and cost-effective methods to control corrosion in these plants must, therefore, be explored. One corrosion control method is the use of high-grade alloys, however, this is not generally cost-effective. Approaches that are more popular are to use coatings or sacrificial baffles. Aluminide coatings, which form a protective oxide layer of Al_2O_3, and chromized coatings (Cr_2O_3), have been found to be effective in minimising high-temperature corrosion [11–13]. An aluminide coating on cheaper stainless steels may provide engineers with a high corrosion resistance material at an affordable price.

1.2. Aims and objectives

The main objectives of this research were: (i) to investigate the corrosion behaviour of three high temperature super-alloys in a large-scale WTE plant; (ii) to evaluate the performance of aluminide coatings and sacrificial baffles in this facility; and (iii) to recommend appropriate techniques for corrosion minimisation in the superheater.

2. Materials and methods

2.1. The waste-to-energy plant

This investigation was conducted at a large-scale WTE facility – a commercial mass-burn MSW incinerator. The waste, which is fed by ram feeders, undergoes combustion on the grate in the combustion chamber with primary air for about 60–80 min, at temperatures of 1000–1200 °C. The temperature (over 800 °C) and oxygen (over 10 wt.% dry) measurements acquired directly from the bed using a novel measuring technique showed very large fluctuations during combustion, due to the heterogeneous nature of the waste particles, solid particle mixing and the channelling of air through the waste particles. Secondary air is injected in the form of jets at each side-wall above the bed in order to aid turbulent mixing and supply additional oxygen to the combustion gases. Due to the furnace geometry and secondary air injection, the gas flow field has a high velocity (7–12 m/s) at over 1000 °C, developed from above the bed to the exit of the radiation shaft and is thus likely to carry large amounts of particles to the heat exchangers. The gases pass through a pendant superheater, a vaporiser, a multi-tubular heat exchanger and economisers for energy recovery. The gas temperature at the superheater inlet is about 800 °C and drops to 230 °C at the boiler exit.

The gas then enters the air pollution control system. Here, injections of hydrated lime sorbents are used for the removal of acid gases and activated carbon is used to capture heavy metals and organic compounds. The amounts of lime and activated carbon injections are about 9 and 0.2 kg/ton-waste, respectively. The residual particulate matter is removed from the gas stream using bag/fabric filters. The temperatures at the economiser exit and at the fabric filter exit are about 135 and 120 °C, respectively. Fig. 1 shows a schematic diagram of a typical WTE plant.

2.2. Experimental probe fabrication and placement

Two air cooled sampling probes, SP1 and SP2, were fabricated for this study. They were placed in the furnace, via existing viewing ports, for approximately 800 h. A schematic diagram of the probe locations is presented in Fig. 2. The main structure of the probes was made from a 1.5 m-long tube of Inconel 625 – a nickel-based alloy. This had an inner diameter of 25.4 mm and an outer diameter of 31.75 mm, resulting in a wall thickness of 3.175 mm. Three identical sets of alloys rings were welded onto the main tube at 0.59 m (wall-section), 0.87 m (mid-section) and 1.16 m (end-section) from the furnace wall. Each set of rings was composed of three individual rings made of 2 nickel-based alloys (alloys 59 and 625) and an iron-based alloy (alloy 556).

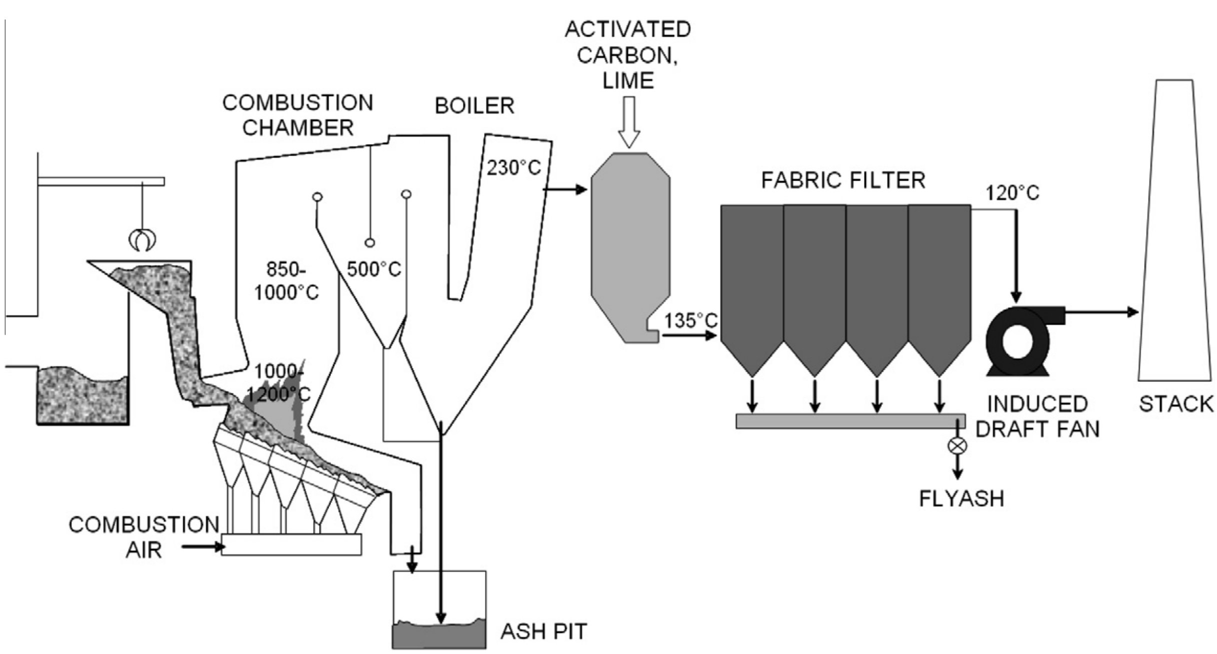

Fig. 1. A schematic overview of a typical municipal solid waste (mass-burn) incineration process at an energy-from-waste facility.

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