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Investigation of chloride deposit formation in a 24 MWe waste to energy plant

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HIGHLIGHTS

- The chlorine balance in a WTE plant was firstly calculated.
- Chlorine distribution in terms of ash deposit formation/growth was detected.
- Deposits and corrosion characteristics were studied in different locations in the WTE plant.

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ABSTRACT

Waste-to-energy (WTE) plants are widely utilized for the production of heat and electricity from municipal solid waste (MSW) and refuse-derived fuel (RDF). However, there is the potential for high temperature corrosion to occur on the heat transfer surface due to a high chlorine content (0.5–1.0 wt.%) in MSW. Therefore, a full scale investigation was conducted in a WTE plant located in Tianjin, China, to study the corrosion mechanism and deposit chemistry that occurs during engineering projects. Deposit and corrosion probes were inserted and exposed to flue gas at five different locations for nine months then two different alloy probes were removed and analyzed. The chlorine flow in the incinerator was also investigated via stack sampling and the analysis of the composition of the residual. The results demonstrate that fly ash dominates the output for chlorine mass flow, accounting for 40.3% of total chlorine. Bottom ash accounts for approximately 6.7%, semi-dry scrubber and bag filter ash 31.4%, stacks 2.75% and leachate 18.6%. Using the back-calculation method, the chlorine content is 0.92 wt.% which is consistent with the elemental analysis that considers alkali salts soluble in the leachate resulting from MSW storage prior to boiler combustion. All deposits have a high concentration of sulfur and calcium but the potassium and chlorine concentrations suddenly decrease with flue gas flow. The deposit growth can be classified into three layers: the outer layer, the inner layer and the interface. The sodium and sulfur contents are high in the interface while the silicon and magnesium are high in the inner layer and calcium and chlorine are considerably high in the outer layer. The results are valuable for a better understanding of chlorine characteristics in large-scale WTE plants thereby assisting in reducing chlorine corrosion.

1. Introduction

Along with continued urbanization and economic development, municipal solid waste (MSW) quantities in China have rapidly increased in last 30 years from 31.3 million tons in 1980 [1] to 170.8 million tons in 2012 [2]. Waste to energy (WTE) plants now play an increasing role in the MSW management chain, as they are considered advantageous to reduce the volume of MSW significantly whilst also recover heat and generating power.

Around 130 million tons of MSW are incinerated worldwide in over 600 WTE plants [3]. 138 MSW incinerators run with a total disposal capacity of 122,649 tons per day in China, accounting for 27.5% of total MSW treatment [2] by the end of 2012. Currently, 50 WTE plants are under construction or are planned to be built in China. However, due to the desire to improve the electrical efficiency of WTE plants by raising the steam temperature, potential high temperature corrosion problems on the heat transfer surface have been introduced. This constitutes significant operational issues which have caused a loss of material, frequent shut-downs for maintenance and high operational costs in WTE plants [4]. It is well known that the high chlorine content of MSW induces a significant volume of deposit and high corrosion rates on the

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downstream super-heater tube. Previous research produced findings on chlorine origin, distribution, thermal behaviors as well as its influence on deposit and corrosion formation.

Our previous study identified chlorine in MSW originates mainly from polyvinyl chloride (PVC) and sodium chloride (NaCl) [5,6]. Chang and Huang [7] investigated the chlorine flow in two MSW incinerators with different air pollution control devices in Taiwan and concluded that approximately 60 wt.% chloride compounds were removed in the baghouse and electrostatic precipitator while the remaining 40wt% discharged into bottom and cyclone ash. Persson et al. [8] studied high temperature corrosion in a WTE plant by varying feedstock with additional PVC and compared the corrosion rates of five different alloys. The biomass-fired boilers also suffered from similar problems and it has been demonstrated that alkali chlorides are critical to corrosion [9,10]. Albina et al. [11] studied the effects of feed composition on boiler corrosion through the use of thermodynamic calculations and concluded that an increase in chlorine content of the fuel led to higher release of gaseous HCl, KCl and NaCl and condensed phases of NaCl and KCl which were proposed to be the precursors of corrosion. The corrosion of the superheater tubes is related to the tube material as well as the chemical composition of the deposit formed on the tubes. Furthermore, fuel chemistry may affect the corrosion mechanism through altering deposit chemistry but little information can be found in the literature, in particular from the point of industrial-scale operations. Thus, study relating chlorine flow and its relationship with deposit chemistry and possibly corrosion rates in a WTE plant is necessary to understand the corrosion mechanism and therefore result in forming corrosion preventative measures.

Measuring probes for deposit and corrosion were therefore exposed to different locations in a 24 MWe WTE plant in Tianjin, China. After long-term exposure, the probes were removed and analyzed by a scanning electron microscope (SEM) and an energy dispersive spectrometer (EDS) to obtain the chemical composition and micro structure of the deposit. Meanwhile, the chlorine flow in the waste incinerator was also investigated via sampling stacks and analyzing the residue's composition. The objective of this work is to: (1) obtain information concerning chlorine distribution in the WTE plant and (2) characterize the chemical composition of deposit at different locations and identify deposit chemistry. The results aim to provide useful information to better understand the chlorine characteristics in large-scale WTE plants and furthermore result in reducing the chlorine corrosion.

2. Experimentation

2.1. Materials

The MSW has been sourced from two downtown districts and one urban district in Tianjin, China. Table 1 shows the waste composition in Hexi District per month in 2009. The food fraction in Tianjin, similar to other Chinese cities, takes the largest weight proportion (~48.4 wt.%) whereas in developed countries paper and cardboard make up the largest fraction (~20.6 wt.%) [12]. The paper and plastic fractions contribute 40 wt.% to total waste which differs from major representative Chinese cities. The weight proportion of these two fractions in Beijing is 23.7 wt.% [13], Shanghai of 27.0 wt.% [14], Hangzhou of 26.8 wt.% [15], and Guangzhou of 14.4 wt.% [16]. The high content of paper and plastics may be attributed to high living standard of residents in the Hexi District. Moreover, recyclable fractions like metal and glass account for less than 5 wt.% in waste streams since they are highly sought after by waste pickers before centralized collection due to their high value.

Our previous paper identified that food residues and plastics as the main source of chlorine, containing high chlorine concentrations of 0.9 wt.% and 0.5–6.3 wt.% respectively [5]. Due to the large food residue and plastic proportion the chlorine content of combustible MSW in Tianjin is severely high, up to 1.13 wt.% (Table 2), which may easily result in chlorine-induced high temperature corrosion for the WTE plant. Furthermore, the large proportion of food residues also leads to a high moisture content (~46.7 wt.%) in waste.

2.2. Plant introduction

Experiments were conducted in a 24 MWe WTE plant (operated by TEDA Environmental Protection Co., Ltd.) in Tianjin, China. This

Table 1
Waste composition per month in Hexi District, Tianjin, China, 2009 (wt.%).

Month	Organic		Inorganic		Recyclable						Others[a]
	Food	Shell	Ash	Bricks	Metals	Glasses	Paper	Plastics	Textiles	Grass	
1	52.4	0.2	1.5	0.1	0.1	6.7	18.6	14.4	2.4	1.3	2.6
2	51.9	0.3	0.9	0.1	2.2	7.9	17.4	15.1	2.0	1.2	1.0
3	30.4	0.1	0.6	0.2	0.4	5.7	26.5	30.8	0.8	4.4	0.2
4	43.6	1.4	0.6	0.4	0.2	0.1	17.5	25.8	0.0	0.1	0.4
5	50.3	0.1	1.5	0.5	0.2	0.4	21.8	21.8	2.2	0.9	0.5
6	48.3	1.0	0.1	0.7	1.0	1.6	21.1	22.3	2.0	0.1	2.0
7	48.3	0.3	0.5	1.3	0.1	7.5	11.9	20.2	5.4	2.0	2.4
8	54.9	0.2	1.9	1.9	0.2	3.1	14.6	17.2	0.2	2.7	3.2
9	48.2	1.5	0.8	0.2	0.3	0.5	22.6	24.0	0.1	0.3	1.6
10	48.3	0.2	0.3	0.3	0.4	6.7	22.9	18.0	1.3	0.9	0.8
11	53.4	0.4	0.9	0.2	0.3	3.5	20.9	17.4	0.1	2.0	0.6
12	50.2	0.9	0.5	0.2	0.4	5.9	16.1	17.4	1.8	6.6	0.1
Average	48.4	0.5	0.8	0.5	0.5	4.1	20.2	20.4	1.6	1.9	1.3

[a] By difference.

Table 2
Proximate analysis and ultimate analysis of combustible waste in Tianjin.

	Proximate analysis (wt.%)					Ultimate analysis (wt.%)					
	Moisture	Volatile	Ash	Fixed carbon[a]	Low heating value (kJ/kg)	C	H	O[a]	N	S	Cl
MSW	41.8	41.4	11.9	4.9	6480	43.26	7.87	45.21	2.45	0.08	1.13

[a] By difference.