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Evaluation of a flue gas cleaning system of a circulating fluidized bed incineration power plant by the analysis of pollutant emissions

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ABSTRACT

Air pollution caused by flue gas from municipal solid waste (MSW) incineration is becoming increasingly serious. There are many harmful products in flue gas, such as acid gases (SO_2, NO_x, and HCl, etc.), particulate matter (PM), heavy metals, and organic compounds. For controlling emission of toxic substances, the choice of the flue gas cleaning system plays an important role in the operation of an incinerator plant. In this study, a flue gas cleaning system of a power plant with circulating fluidized bed (CFB) incinerators of MSW located in Shandong Province (eastern China) was evaluated. The investigation included the removal of organic pollutants, PM, acid gases, and heavy metals. According to data of pollutants in the flue gas, the emission level of these items was under control and met the required domestic regulations. In order to comply with relevant international standards and the zero-release project, the selective non-catalytic reduction (SNCR), calcium magnesium acetate (ACM), catalytic filtration (CF), and secondary bag filter systems were suggested to optimize the existing flue gas cleaning system. The application of CFB incinerators with a semi-dry scrubber, activated carbon injection, and a bag filter to small and mid-sized cities in China serves as an example for developing countries in MSW management.

1. Introduction

The rapid urbanization and industrialization of China have increased the quantity of municipal solid waste (MSW). The total amount of MSW collected and transported was 172 million tons in 2013 [1]. This figure is projected to reach 210 million tons in 2015 and 480 million tons in 2030 [2,3]. Facing the increasing volume of MSW, governments and citizens are becoming especially aware and concerned about how wastes are managed. With a lack of appropriate landfill sites, waste-to-energy (WTE) processes are viewed as the preferred methods to reduce the amount of waste going to landfills, while biological and thermal treatments of waste, such as composting and incineration are becoming more widespread. WTE processes refer to the energy from waste through either direct combustion or production of combustible fuels. China, the world's second largest consumer of energy and the third largest importer of energy, faces massive demands for energy in order to catch up with its economic growth. Discarded MSW as an energy source can be transformed into electricity and/or steam for heating. Therefore, WTE incineration is gaining increasing popularity in China. It not only reduces the volume of MSW that requires landfilling or composting, but also lessens the country's dependence on fossil fuel, which contributes to the reduction in greenhouse gas (GHG) emission [4].

Currently, four types of MSW incinerators (stoker, fluidized bed, pyrolysis, and rotary kiln) are widespread all over the world. As shown in Table 1, each kind of incineration technology has its advantages and disadvantages [5–7]. In a fluidized bed incinerator, the combustion ash and other materials are suspended in an upward flowing airstream, which promotes uniform mixing and heat transfer. As one type of fluidized bed reactors, the circulating fluidized beds (CFB) have higher gas velocities and the entrained particles can be separated by a cyclone and returned to the bed for continuous and complete combustion [8]. Because of high investments and high calorific value for incineration, the stoker is usually adopted by large and coastal areas in China. While in small and mid-sized cities with a poor garbage classification system, CFB incinerators are popular from the point of economy, reliability, and applicability [6,9]. The reasons for this phenomenon are:

(i) In the small and mid-sized cities, MSW are produced with high moisture contents and low calorific values, which are consistent with residents' standard of living and are importantly allowed in CFB incinerators because of the additional coal mixed with waste to achieve complete combustion.

Abbreviations: MSW, municipal solid waste; PM, particulate matter; CFB, circulating fluidized bed; WTE, waste-to-energy; GHG, greenhouse gas; ESP, electrostatic precipitators; PCDD/Fs, polychlorinated dibenzo-ρ-dioxins and dibenzofurans; EC, European Community; I-TEQ, International Toxic Equivalence Quantity; I-TEFs, International Toxic Equivalence Factors; SNCR, selective non-catalytic reduction; CMA, calcium magnesium acetate; CF, catalytic filtration.

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Table 1
Comparison of characteristics of various furnace types [4–6].

Type	Stoker	Fluidized bed	Pyrolysis	Rotary kiln
Pre-treatment	Big pieces need to be crushed	Wastes need to be crushed to less than 15 cm	Wastes with low calorific values need pre-treatment	Big pieces need to be crushed
Residence time in the furnace	Solid refuse: 1–3 h; gas: seconds	Solid refuse: 1–2 h; gas: seconds	Solid refuse: 3–6 h; gas: seconds	Solid refuse: 2–4 h; gas: seconds
Temperature in the furnace	Garbage layer surface temperature: 800 °C; flue gas temperature: 800–1000 °C	The fluidized bed combustion temperature: 800–900 °C	The first combustion chamber: 600–800 °C; the second combustion chamber: 800–1000 °C	Rotary kiln temperature: 600–800 °C; secondary furnace: 1000–1200 °C
The capacity of single furnace	Large scale: >200 t/d	Small and medium scales: <150 t/d	Small and medium scales: <150 t/d	Large and medium scales: >200 t/d
PM content in flue gas	Low PM content in flue gas	High PM content in flue gas	Low PM content in flue gas	High PM content in flue gas
Comprehensive assessment	This kind of incinerators with a better processing performance for MSW has a good environmental performance, and low maintenance and operating costs	Additional coal is usually mixed with MSW to achieve complete combustion, and environmental pollutants produced during incineration are not easy to control	A large amount of ashes that are generated in the combustion process creates a serious threat to the local environment	MSW with high calorific values are required, while at the same time, these incinerators have high operating costs

(ii) Considering the difficulty of garbage classification in small and mid-sized cities, CFB incinerators with high heat exchange efficiency are able to mix all kinds of garbage for satisfactory combustion.
(iii) CFB incinerators need relatively lower investment and maintenance costs than stoker incinerators. Consequently, MSW incineration power plants in small and mid-sized cities prefer CFB technology.
(iv) Electricity and steam for heating produced during incineration can be purchased at a reasonable price in small and mid-sized cities.

In China, MSW is generally composed of kitchen waste, plastics, garden waste, textile, glass, metal, and dust. The specific components and heat of combustion are usually determined by the development level of the local economy, and the heating value of MSW is generally below 4.50×10^6 J/kg in small and mid-sized cities [10]. Compared with other incinerators, CFB incinerators have more benefits for MSW disposal. However, different from developed countries, incineration in China has caused heavy environmental pollution, which is becoming more serious and has raised vast public concern [11]. The original composition and concentration of pollutants in flue gas, as one type of emission from the incineration process, are determined by the components of MSW and the combustion mode. These air pollutants including heavy metals, acid gases, and toxic organic compounds pose serious threats to the surrounding environment and human health [12]. When a flue gas cleaning system is chosen, the efficiency of cleaning up of pollutants in exhaust gases should be considered. In order to restrict the emission level within related standards, the best available control technologies are supposed to be used for effective control of hazardous air pollutants. At present, acid gases such as SO_x, HCl, and HF are removed by means of alkaline reagents: dry neutralization with $Ca(OH)_2$, dry neutralization with $NaHCO_3$, semi-dry neutralization with $Ca(OH)_2$, and wet scrubbing [13]. NH_3 or urea can be used for NO_x removal including two processes: selective non-catalytic reduction (SNCR) or selective catalytic reduction (SCR) [14]. Activated carbon injection is normally adopted for removal of dioxins and heavy metals [15]. Many technologies are available for dust removal: electrostatic precipitators, bag filters, centrifugal sedimentation, and wet scrubbing. As the environmental requirement is stricter, in terms of the dust removal efficiency and emission standard, the effect of bag filters is better than electrostatic precipitators [16,17]. Therefore, standard CJJ90-2009 [18] made a regulation that fabric filters are the necessary dust removal device of MSW incineration, as they have been widely used in Australia, United States, and South Africa [13,19]. For both economic and environmental benefits, it is indispensable to optimize flue gas cleaning systems. The major aim of this paper is to evaluate an existing flue gas cleaning system of a CFB incinerator power plant including the removal of organic pollutants, particulate matter, acid gases, and heavy metals, which would contribute to optimizing flue gas cleaning technologies in continually emerging economic markets. In addition, a comparison and analysis of emissions data and pollutants with relative higher emission concentration are noted, which offers a clear direction for the needed improvement of this system to meet international standards and the zero-emission goal.

2. Experimental

2.1. Plant description

The CFB incinerator power plant investigated was in one of the small and mid-sized cities of Shandong Province. It has three sets of CFB incinerators and was put into operation in July 2007. Since then, stable operation of this plant has continued, running throughout the year for more than six years. The actual heating capacity is 3.60×10^5 tons a year and the power generation capacity is 1.70×10^8 kW·h. The process flow of MSW incineration is shown in Fig. 1. The CFB power plant includes four main sections: the MSW pre-treatment section, CFB combustion section, heat and electricity generation section, and flue gas treatment section. Specifications of the main equipment and environmental protection facilities of this plant are listed in Table 2. Silica sand is the bed material of the CFB incinerator, and MSW is used as the main fuel with coal used as the auxiliary fuel.

The MSW that is sorted and crushed, along with the auxiliary coal is put into the incinerator at a ratio 9 to 1. The main ingredients of MSW were kitchen waste, plastic, glass, paper, and wood, and the low calorific value was 5.28×10^6 J/kg. The analysis of MSW and coal is listed in Table 3. The moisture content of coal was 6.53% and the low calorific value was 2.09×10^7 J/kg, which complied with the relevant standard (≤8%, $>1.65 \times 10^7$ J/kg) [20]. For power generation, water is heated to superheated steam under a certain pressure and temperature, and the generator produces electricity driven by steam in a turbine. After being separated by the cyclone from combustion flue gas at high temperature, particles with larger sizes are fed back to the furnace through the return loop, while relatively small ash particles are sent to the desulfurization and dust removal system after being cooled by the air heater. Finally, purified flue gas is emitted into the atmosphere through a chimney with a height of 100 m. The techniques for air pollution control mainly include a semi-dry scrubber, activated carbon injection, and fabric filter. In this process, lime slurry is the absorbent in the flue gas cleaning system, and is added to the reaction tower to absorb acid gases. Then the fly ash and the reactants are removed when the flue gas passes through the baghouse. In addition, a separate activated carbon injection entrance is at the inlet of the bag filter to adsorb toxic substances such as dioxins and heavy metals.