Influence on combustion and ash characteristics during co-combustion of municipal solid waste and pelleted sewage sludge

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Abstract: Co-combustion of sewage sludge and municipal solid waste (MSW) in grate-type MSW incineration is a promising method to meet environmental requirement and reduce equipment investment. However, due to the high ash content of sewage sludge, co-combustion of sludge and MSW may increase the amount of fly ash and further aggravate the wearing and fouling corrosion of heated surface. In this study, combustion of dry sludge powder and sludge pellets with different diameter and compressive strength is investigated in a laboratory-scale tube furnace before further studies in larger-scale setups. The experimental results confirm that combustion of sludge pellets has a lower ratio of fly ash and a higher ratio of slag ash compared with powder, which is benefit to disposal of fly ash and storage of dry sludge. The addition of desulfurizer (CaO) in sludge pellets can reduce the average SO_2 emission concentration with the maximum 80% SO_2 removal rate in combustion section. Moreover, the clinker ignition loss of slag ash of sludge pellets may be as high as 11.92% under a low combustion temperature condition, so the temperature on grate should be higher than 800℃ to avoid incomplete combustion.

Keywords: municipal solid waste, sludge pellet, co-combustion, ash characteristics, grate-type incineration

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1. Introduction

According to the data of China statistical year book [1], the total sewage discharge reaches 71.62 billion tons in 2014, which has an increase rate of 2.99% over the same period last year. The daily capacity of sewage treatment plants was 13.88 million m^3 and the treatment rate of sewage reached 90.2%. However, the treatment capacity of sludge, a by-product of sewage treatment, has a huge gap. The total amount of sludge produced of cities and towns in China is 280.147 million tons, and the average growth rate is 11.57% from 2008 to 2014, while the harmless disposal rate of sludge is only 56%. At present, the disposal methods of sludge commonly used in the world mainly include sanitary landfill, land use, building materials, pyrolysis and incineration [2]. With the gradual reduction of urban land use and the strict requirements for environmental protection, incineration gradually becomes the mainstream method for the disposal of sludge. Compared with the construction of sludge incineration plant alone, co-combustion of coal or municipal solid waste with sludge in the local pulverized coal boiler [3] or garbage incineration power plants [4] is an alternative choice. This method can reduce constructions costs and transport costs of sludge without additional incineration and tail gas purification systems, and it can also provide thermal energy for the drying process of sludge.

In 2016, there are nearly 300 garbage incineration power plants in China, while the ratio of grate-type boilers is over 70%. Therefore, the researches and applications of sludge cooperative treatment in grate-type MSW (municipal solid waste) incineration is of great importance. So far, many studies on combustion characteristics and gaseous pollutants emission of co-combustion of sewage sludge and solid wastes has been carried out [5-7]. However, because of the high ash content of sludge, co-combustion of MSW and sludge in grate-type boiler may increase the amount of fly ash in the flue gas, thus aggravating the wearing of heating surface and fouling corrosion [8]. Besides that, dry sludge will cause dust problem during storage and transportation.

Although there have been many studies on co-combustion of sludge and MSW in circulating fluidized bed boilers [9-11], to our best knowledge, only few researches concern the co-combustion of MSW and pelletized sludge pellet in grate boilers. This study aims at the influence on combustion performance and ash characteristics from pelletized sludge particle with different particle size and compressive strength, especially the ratio of slag ash and fly ash and ignition loss rate of slag ash. At the same time, the effect of desulfurizer (CaO) on the gaseous pollutants SO_2 and NO_x emissions are studied to provide experimental data for further industrial applications. The experiment is carried out in a tube furnace with five independent heating sections which has a similar combustion profile as grate boilers.

2. Experimental section

2.1. Materials

The sewage sludge used in this experiment is provided by a domestic sewage treatment plant from eastern China; Through the drying of disc dryer, the moisture content of sludge is reduced to 28%. In order to solve dust problem during storage and transportation of dry sludge and investigate the effect of sludge pellets on ash characteristics, dry sludge is compressed into two kinds of cylindrical pellets that are 3 mm and 8 mm in diameter separately and 30 mm in length by annular pelletizers. As shown in Fig.

1, dry sludge in the inner cavity is compressed into the opening holes with a certain diameter by the rolling wheel, and the diameter of sludge pellets can be adjusted by the diameter of opening holes in ring type die plate. Besides that, desulfurizer (CaO, mass ratio: 1%) is added to sludge to investigate its effect on pollutant emissions in flue gas. The proximate and ultimate analysis for sludge are shown in Table 1. The compressive strength of cylindrical pellets is tested by electronic universal material testing machine (AGS-X, Shimadzu), as shown in Table 2.

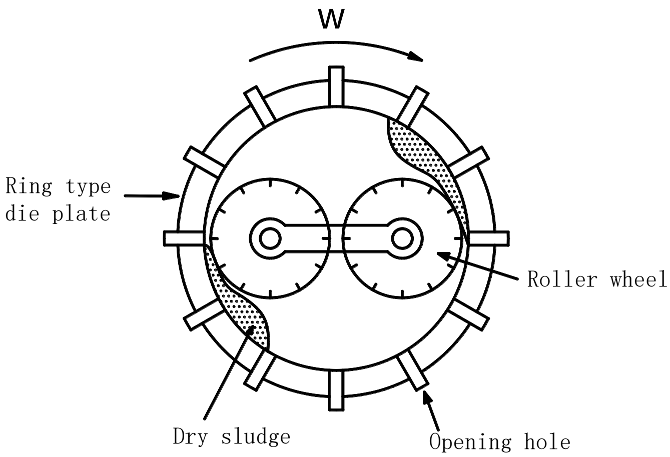

Fig. 1. Schematic diagram of granulation process

Table 1 Proximate and Ultimate Analysis for sewage sludge

Sample	Proximate analysis (mass %)					Ultimate analysis (mass %)				
	M_{ad}^{*}	A_{ad}	V_{ad}	FC_{ad}	$Q_{net,ad}$(J/g)	C	H	O	N	S
Sludge	0.77	48.6	32.2	18.4	11302	28.8	2.4	14.5	2.2	2.84

*ad: air-dried basis.

Table 2 Physical property of sludge pellets

Diameter(mm)	Compressive strength (kPa)	Density (g/cm^3)
8	2061.8	1.61
3	1286.2	1.49

2.2. Experimental system

The experiment is carried out in a tube furnace system as shown in Fig. 2. The inside diameter of the tube furnace is 52 mm. The main part of the system is divided into three sections: gas supply, tube furnace and flue gas analysis. The flow of reaction gas (air) is controlled by flowmeter in the range of 4~60 m^3/h. The working temperature range of air preheater can reach 300 °C and can be adjusted to different experimental conditions. The length of each heating section is 200 mm, with an electrical heating power 20 kW and temperature range from room temperature to 1200 °C.

During the experiment, the sludge sample in quartz boat is sent into the heating section 1 of the furnace, and the flow is adjusted to reach corresponding wind velocity. After the heating time of first period, the quartz boat is sequentially moved to heating section 3 and 5. The three heating sections are set at different constant temperature to simulate combustion condition in a three-section grate boiler. The air preheater is set to 180 °C for all experimental conditions. The concentration of CO, CO_2, NO_x, SO_2 in the flue gas are measured on-line using a Gasmet FT-IR (DX—4000, Finland Gasmet).

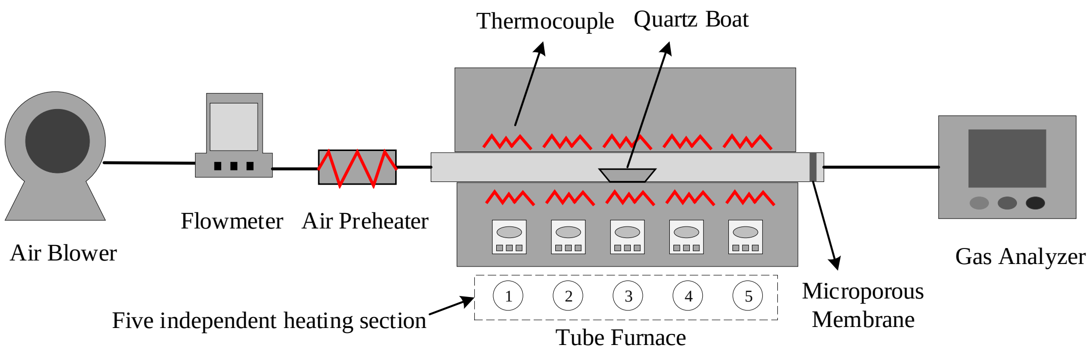

Fig. 2. Schematic diagram of tube furnace system

2.3. Experimental matrix

Taking the non-uniformity of temperature distribution in grate furnace into consideration, the experimental tests include two different temperature conditions, as shown in Table 3. The temperature, residence time and flow velocity of primary air is based on simulation calculation in a grate boiler [12]. The sampling and measuring process is repeated three times and the furnace is kept at high temperature for 1 h to perform high temperature cleaning after each experiment.

Table 3 Combustion Experiment Conditions in the Tube Furnace

Parameter	Drying section(sect.1)	Combustion section(sect.3)	Burn-out section(sect.5)
Flow velocity (m/s)	1.15	4.48	1.22
Residence time (min)	18	25	50
Temperature condition a (°C)	250	600	450
Temperature condition b (°C)	300	1050	700

To investigate the effect of different diameter and compressive strength, addition of desulfurizer and combustion temperature on the pollutant emissions in flue gas and ash characteristics, ten groups of experiment are carried out. Due to the large number of experimental groups, all experiments are numbered for ease of reading, as shown in Table 4.

Table 4 Code number of each experiment group

Sludge Diameter		powder	3mm	8mm	3mm (1% CaO)	8mm (1% CaO)
28% moisture content	Condition a	a-1	a-2	a-3	a-4	a-5
	Condition b	b-1	b-2	b-3	b-4	b-5

3. Result and discussion

According to standard for pollutant control on the municipal solid waste incineration (GB 18485-2014), in the subsequent analysis all the gaseous pollutant emission concentrations are converted to 11% baseline oxygen content. Besides that, all results given in the following parts are the average value of the three replicated experiments.

3.1. Flue gas emission

In the flue gas, CO, NO, NO_2 and SO_2 emissions concentrations at different experimental conditions are shown in Fig. 3. Fig. 3 illustrates that under temperature condition a, most of samples have low concentration of pollutants due to the low temperature in drying section; In the combustion section, sludge sample is heated rapidly and burned violently, while it produces high concentration of CO, NO and SO_2. The concentration of CO decreases sharply in a short period of time (3~6 min); In the burnout section, the flue gaseous pollutants produced by most sludge samples tend to zero. But a small part of sludge pellets is burned and broken into small particles, thus further combustion produces a certain concentration of pollutants (Fig. 3. a-3, a-5). Under temperature condition b, the temperature of drying section is much higher than that of condition a, and it reaches the ignition point of some combustible substances in sludge. The combustion of some substances produces certain concentration of CO, NO and other flue gaseous pollutants (Fig. 3. b-2, b-3). In the combustion and burnout section, the pattern of emission under condition b is similar to that of condition a.

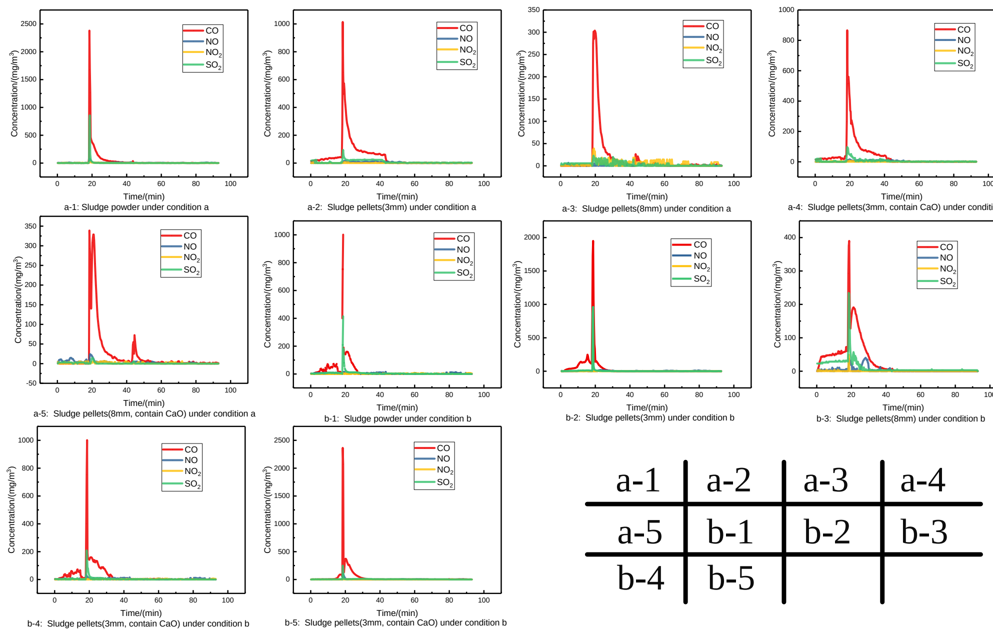

Fig. 3. Gaseous pollutants emission at different experimental conditions

In Zhang's research [13], the feasibility of co-combustion of CaO-conditioned sludge (Sc-CaO) and coal is discussed. The results show that adding 30% Sc-CaO into co-combustion strengthened the procedure of devolatilization and volatiles combustion (220–380 °C), and Conditioner CaO could capture almost all the SO_2 during sludge mono-combustion and 15.8–48.4% of SO_2 during co-combustion. To investigate the effect of addition of desulfurizer (CaO) on emission of SO_2 in flue gas, the desulfurizer is added to sludge pellets with mass ratio of 1%, and SO_2 emission during three sections are shown in

Fig. 4. It shows that the addition of desulfurizer can reduce the average SO_2 emission concentration in each section. Taking the combustion section with the highest SO_2 emission concentration as an example, the SO_2 removal rate can reach 51-79% under working condition a and 32-63% under working condition b. It can be drawn that the addition of desulfurizer during granulation process is beneficial effect on the removal of SO_2.

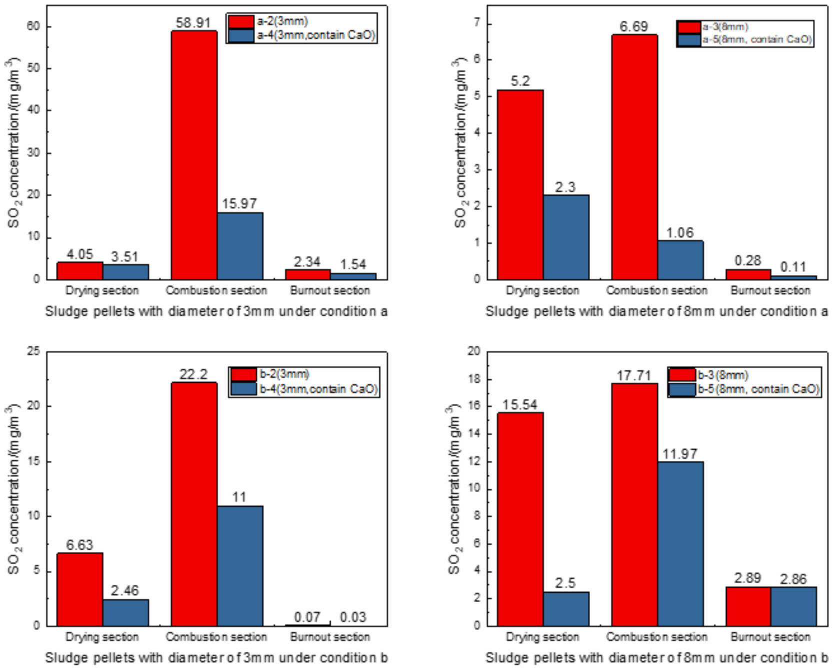

Fig. 4. SO_2 emission of three sections at different experimental conditions

3.2. Ash characteristics

Due to the high ash content of sewage sludge, the ratio of fly ash will increase during co-combustion of sewage sludge and municipal solid waste, which increases the cost of fly ash disposal. Besides that, the clinker ignition loss of slag ash is required to be less than 5% (GB 18484—2001). Thus, the proportion of fly ash and slag ash and the clinker ignition loss of slag ash are of eminent importance for sludge pellets.

The slag ash and fly ash are collected and measured to get the ratio to samples. The clinker ignition loss of slag ash is calculated by keeping the slag ash heated in 600 ℃ for 3 hours. As shown in Fig. 5, when the diameter and compressive strength of sludge pellet increase, the ratio of slag ash increases and the ratio of fly ash decreases correspondingly. Besides that, the clinker ignition loss of slag increases with diameter of sludge pellets. There are two main reasons leading to the results: 1) with the increase of diameter of sludge pellets, the specific combustion surface area of sludge pellets decreases which causes the decline of combustion efficiency. 2) with the increase of compressive strength of sludge pellets, the fly ash inside the pellets is hard to escape from pellets, and it leads to a lower ratio of fly ash. Compared with sludge powder, the ratio of fly ash of sludge pellets with diameter of 8mm decreases 0.3% and 1.6% under condition a and b, respectively. And the ratio of slag ash increases 0.8% and 0.7% under condition a and b, respectively. Thus, the combustion of sludge pellets has lower ratio of fly ash and higher ratio of slag ash, which reduces the cost of fly ash disposal.

It is noteworthy that the combustion of sludge pellets (under temperature condition a) has a quite high clinker ignition loss of slag ash which is over the limit (5%). But under temperature condition b, a much higher combustion temperature, the clinker ignition loss of slag ash is below 2% for all experimental conditions, which indicates sludge pellets need temperature more than 900 ℃ to avoid incomplete combustion.

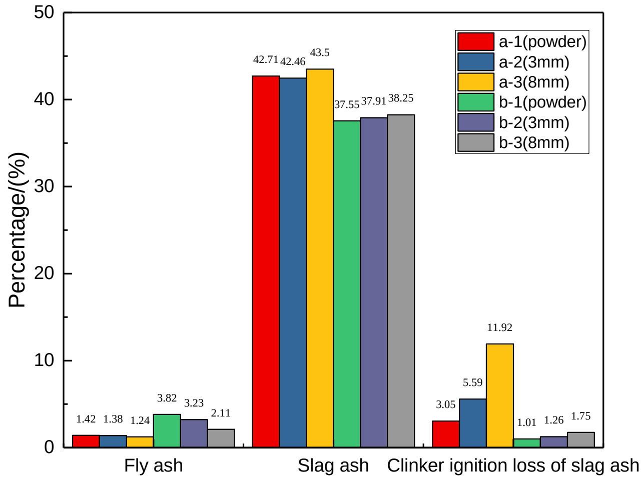

Fig. 5. Ash characteristics at different experimental conditions

4. Conclusions

Combustion of sludge powder and pellet is carried out in a tube furnace system. We mainly investigate combustion characteristics, ash behaviour and flue gas emission. The main conclusions are listed as follows:

1) The addition of desulfurizer (CaO) in sludge pellets can reduce the average SO_2 emission concentration in each section. During the combustion section with the highest SO_2 emission concentration, the maximum SO2 removal rate can reach 80%.
2) With the increase of diameter and compressive strength, the combustion specific surface area of sludge pellets decreases and the fly ash inside the pellets is hard to escape from the pellets, the ratio of fly ash decreases and the ratio of slag ash increases, which is of benefit to the disposal of fly ash.
3) Under a low combustion temperature condition (600℃), the clinker ignition loss of slag ash of sludge pellets may be as high as 11.92%. Since the clinker ignition loss of slag ash in grate-type municipal solid waste incineration is required to be less than 5%, the temperature on grate should be higher than 800℃ so as to avoid incomplete combustion.

Acknowledgements

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