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Influence on gaseous pollutants emissions and fly ash characteristics from co-combustion of municipal solid waste and coal by a drop tube furnace

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Co-combustion experiments of municipal solid waste and coal were carried out in a drop tube furnace at high temperature 1300 °C. The effect of different simulated municipal solid waste (SMSW) added proportion (0, 7.5, 15, 20 and 25 wt%) in the blend fuels on the characteristics of gaseous pollutants emissions, e.g. CO, HCl, SO_2, NO_x, and heavy metals, and fly ash were studied. The results indicated that CO and CH_4 emission concentrations were at a low level under all conditions. With the increasing proportion of SMSW, the combustion efficiency decreased slightly, the HCl emission increased obviously at 25% conditions while at lower proportion conditions the change was not significant; the NO_x emission concentration showed a tendency to rise first and then decrease, while the SO_2 showed an exactly opposite trend; besides, Fe, Cl and S content in the fly ash increased obviously. Under all experimental conditions, only a small amount of heavy metals were emitted in the flue gas while most of the heavy metals were retained in the fly ash. The leaching results showed that Ni leaching concentration was beyond the national standard which means the fly ash needs further treatment before they can be disposed of by landfill, while the HCl, NO_x and SO_2 emissions can easily reach the national emission standard under the desulfurization and denitrification system operating conditions in real power plants. These findings are helpful for the further development of co-combustion with renewable energy in coal-fired incinerators, yet more investigation on heavy metal emission in fly ash is still required to be further conducted in the future.

1. Introduction

In recent years, due to the rapid development and expansion of the cities in China, the amount of municipal solid waste generation increased rapidly. According to the data of China statistical yearbook (NBSC, 2012–2015) as shown in Table 1, the generation volume increased from 164 million tons at 2011–191.4 million tons at 2015; although the incineration disposal capacity and harmless disposal rate increased year by year, it can be seen that the landfill still occupy the main position due to the lack of capacity for other disposal methods. Recently, centralized incineration disposal is considered to be the most suitable way to deal with municipal solid waste due to the obvious volume reduction, wide adaptability and high disposal efficiency. In EU, the materials and energy recovery from waste was considered to be the second most popular option just after the prevention of waste production in European Community Strategy for Waste Management, COM (96)/399.

Co-combustion is an effective method to use waste fuels replace part of fossil fuels and achieve harmless thermal treatment of waste (Leckner, 2007), and it has been has been successfully applied in many cases (Alipour et al., 2015; Kumar and Ingh, 2017; Lu et al., 2016; Rajczyk et al., 2014). At the same time, due to the biogenic fraction in the municipal solid waste (or solid recovered waste and refuse derived fuel from municipal solid waste), co-combustion can significantly reduce the greenhouse gas CO_2 emission (Astrup et al., 2009; Garg et al., 2009). At present, the installed capacity of coal fired power generation in China was 1005.5 GW in 2015 (NBSC, 2012–2015), which is a very large capacity. Besides, according to the latest electric power development in China (NDRC and NEA, 2016), more than 20 GW outdated thermal power plants (capacity less than 300 MW) will be eliminated. If part of these outdated power boilers could be transformed for co-combustion of municipal solid waste, the incineration disposal capacity will get a substantial development and the status of municipal solid waste disposal will be greatly improved. So far, many studies on co-combustion have been carried out and the types of waste materials being studied included sewage sludge

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Nomenclature

CFB	circulating fluidized bed boiler
C_{CO2}	concentration of CO_2 in flue gas
C_{CO}	concentration of CO in flue gas
MSW	municipal solid waste
PCDD/Fs	polychlorinated dibenzo-p-dioxins/furans
RDF	refuse derived fuel
SEM	scanning electron microscope
SMSW	simulated municipal solid waste
XRF	X-ray fluorescence

(Cenni et al., 1998; Chen et al., 2014; Seames et al., 2002; Wang et al., 2009), municipal solid waste (MSW) (Amand and Kassman, 2013; Fan et al., 2008; Lee et al., 2008; Peng et al., 2016) and solid recovered fuels (SRF) (Beckmann and Ncube, 2007; Hilber et al., 2007a, 2007b, 2007c).

The municipal solid waste is a kind of complex mixture materials, so co-combustion will have an impact on combustion conditions and pollutant emissions. In Li and Xing's researches (Li et al., 2017; Xing et al., 2017), the combustion efficiency decreased obviously when the particle size of the blend fuels increased, and the fuel particles (<106 μm) was very sensitive to the combustion gas atmosphere. At the same time, since the composition of MSW is very different from that of coal, in Karlsson's research (Karlsson et al., 2015) co-combustion significantly affected the emissions of gaseous pollutants e.g. CO, NO_x, SO_2, HCl. In Desroches-Ducarne's research (Desroches-Ducarne et al., 1998), it was found that the addition of MSW resulted in lower N_2O and SO_2 emissions while the HCl and NO concentrations increased with the higher amount of MSW, and the CO emissions slightly decreased when the MSW proportion was low. Lee's results (Lee et al., 2007) indicated that the CO, NO_x, SO_2 and HCl emissions at the good practical conditions were below government environmental licence limits. In addition, the influence of excess air and secondary air on the CO, SO_2 and NO_x emission was also very important (Suksankraisorn et al., 2004). Moreover, the organic pollutants emissions during co-combustion of MSW are also highly concerned including PCDD/Fs (Agraniotis et al., 2010; Zhong et al., 2006) and PAHs (Peng et al., 2016). Furthermore, the different operational conditions in the real disposal process also have great impact on the performance of the furnace, e.g. waste materials injection position (Agraniotis et al., 2010). In a series of co-combustion experiments in Germany (Thiel and Thome-Kozmiensky, 2012), it should be noticed that although many successful tests were carried out for continuous co-combustion of waste material in different types of boilers, there are still some failure cases which were mainly caused by problems of firing technique (incomplete burnout or collapses of combustion) in pulverized coal firings and slag tap firings, or serious chlorine corrosion in CFB firings.

Although there have been many studies on MSW co-combustion in CFB boilers, only few researches concern the co-combustion of MSW in suspension firing boilers. This study focused on exploring the feasibility of coal and MSW co-combustion in suspension firing boilers at high temperatures. At the same time, the effect of co-combustion on the gaseous pollutants CO, HCl, SO_2, and NO_x emissions, heavy metals emission in flue gas, and fly ash composition and leaching characteristics are studied to provide experimental data for further industrial applications. The experiment was carried out in a drop tube furnace which has a similar combustion profile as suspension firing boilers.

2. Experimental section

2.1. Materials

The coal used in this experiment is provided by a power plant from eastern China; it is a mixture of Shenmu coal and Indonesian coal in accordance with the mass ratio of 1:1. Shenmu coal is a typical homemade bituminous coal and Indonesian coal is a typical imported brown coal, and these two fuels in a 1:1 mixing ratio are widely used in Shanghai. The municipal solid waste (MSW) in Shanghai has been widely investigated (Dong et al., 2015; Liu et al., 2005; Zhang and Yang, 2000). Due to the composition of original municipal solid waste is complex and difficult to be pretreated, in this experiment we use simulated municipal solid waste (SMSW) samples as shown in Table 2. The components of simulated municipal solid waste were determined according to national standard CJ/T 313-2009, including kitchen waste, plastic, paper, textile, wood bamboo, metal and noncombustible materials. According to Wang's research (Wang et al., 2017) the primary component of municipal solid waste in Shanghai (wet basis) is Kitchen waste (40.65%), the secondary is Plastic (24.20%) and the subsequent is paper (22.85%). Through the calculation of moisture content in the municipal solid waste in Shanghai, the dry basis of the waste can be determined and the composition of SMSW used in this test was chosen as shown in Table 2. The proximate and ultimate analysis for mixed coal and SMSW are shown in Table 3. According to previous study (Zhao et al., 2007) the volatilization of some specific components in municipal solid waste was very high (plastic >90%, textile > 85%, sawdust >75% and paper >65%), so the relative high volatile of SMSW was mainly due to the high plastic, paper, textile and kitchen waste (organic) content. The Cl content in both fuels are analyzed and determined through high temperature combustion hydrolyzing method (GB/T 3558-2014) and an ion chromatography method (Dionex Integrion HPIC, Thermo Scientific). It is obvious that the moisture content, ash content, fixed carbon and calorific value of SMSW are lower compared to mixed coal; besides, the O, N, S and Cl content of SMSW are higher. Table 4 shows the heavy metal contents for mixed coal and SMSW. It can

Table 1
generation and harmless disposal of municipal solid waste in 2011–2015, China.

Year	Generation/(million tons)	Harmless disposal capacity/(million tons)			Harmless disposal rate/%
		Landfill	incineration	other	
2015	191.4	114.8	61.8	3.5	94.1
2014	178.6	107.4	53.3	3.2	91.8
2013	172.4	104.9	46.3	2.7	89.3
2012	170.8	105.1	35.8	3.9	84.8
2011	164.0	100.6	26.0	4.3	79.7