



Nitrogen evolution during the co-combustion of hydrothermally treated municipal solid waste and coal in a bubbling fluidized bed



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ABSTRACT

Nitrogen evolution was studied during the co-combustion of hydrothermally treated municipal solid wastes (HT MSW) and coal in a bubbling fluidized bed (BFB). HT MSW blending ratios as 10%, 20% and 30% (wt.%) were selected and tested at 700, 800, 900 °C. Emissions of NO and N₂O from blends were measured and compared with the results of mono-combustion trials. Moreover, concentrations of precursors like NH₃ and HCN were also quantified. The results are summarized as follows: NO emissions were predominant in all the cases, which rose with increasing temperature. The blending of HT MSW contributed to the NO reduction. N₂O emissions decreased with temperature rising and the blending of HT MSW also presented positive effects. At 30% HT MSW addition, both NO and N₂O emissions showed the lowest values (391.85 ppm and 55.33 ppm, respectively at 900 °C). For the precursors, more HCN was detected than NH₃ and both played important roles on the gas side nitrogen evolution.

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1. Introduction

With the development of human civilization, the solutions to waste disposal and energy crisis are emerging to be the most important tasks to be focused on. Recently co-combustion of municipal solid waste (MSW) and coal in coal-fired boilers (Boxiong et al., 2004; Lu et al., 2011a) have been paid attention to because of its possibility of simultaneous wastes disposal and coal consumption mitigation with low capital investment. Based on the considerations abovementioned, if some parts of the coal consumption could be substituted by MSW, it would be a great success for further sustainable development both on the energy balance and the waste treatment sides. However, the fulfillment of this task is not so easy because the characteristics of MSW full of biomass are very different from those of coal. The proportion of volatile matter contents in MSW are generally close to 60% whereas in coal it is only around 30% (Boxiong et al., 2004; Lu et al., 2011a). This means that with MSW the fuel char levels are lower, and the resultant chars tend to be more reactive in combustion processes, all of which set new demands for boiler process control and boiler design, as well as for combustion technologies, fuel blend control, and fuel handling systems.

Furthermore, because of possible flame instability, striated flow and other problems caused by MSW which has heterogeneous physical properties and high moisture content, it is extraordinarily

hard to directly put it into the coal firing system co-combusting with coal. As a result, in order to promote the utilization of MSW for co-combustion with coal, technologies for converting MSW to solid fuels are booming in the waste utilization field aiming at high-efficiency heat output. Among the pretreatment technologies, hydrothermal treatment (HT) is one of the most effective options (Lu et al., 2011a; Muthuraman et al., 2010a; Muthuraman et al., 2010b; Lu et al., 2011b; Muthuraman et al., 2010c) which utilizes high temperature and pressure steam (usually 220 °C, 2.2 MPa) posing as an environment-friendly waste-to-energy tool. The product produced from MSW through the HT is no longer presenting as MSW but slurry-like and has high natural-drying ability: the moisture content could be as low as around 10% after two days natural drying under sunshine (Lu et al., 2011b; Muthuraman et al., 2010c). The dried sample is easily to be grinded then presenting homogeneous physical characteristics comparable to coal. In addition, the heating value of the products are between 15 and 20 MJ/kg (Muthuraman et al., 2010c; Lu et al., 2010) which are close to that of moderate rank coals suggesting that the HT MSW is a promising alternative for primary solid fuels.

On the other hand, as a well-known fact, combustion of coal/biomass (MSW) particles produces significant amounts of NO_x (nitrogen oxides), including NO (nitrogen oxide) and NO₂ (nitrogen dioxide) which are unpleasant pollutants and strictly regulated by the corresponding rules and protocols. NO_x emissions play an important role in the atmospheric reactions that create harmful particulate matter, ground-level ozone (smog), and acid rain. In terms of formation mechanisms, NO_x is generally formed through

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three paths: (1) Thermal NO_x, requiring high reaction temperature for dissociation of the atmospheric diatomic species N₂ and O₂ (Oberberger, 1998); (2) Fuel NO_x, produced from the reaction of fuel bound N and combustion air (Demirbas, 2004; Leckner and Karlsson, 1993); (3) Prompt NO_x, emerging near the flame zone due to fast reactions involving N₂ and fuel bound hydrocarbon radicals, forming HCN as the most important intermediate reactant (Miller and Bowman, 1989; Grass and Jenkins, 1994). In order to control the NO_x concentration from coal-fired power plant, many efforts have been adopted including air staging, decoupling combustion, etc. (Li et al., 2009; Cai, in press). Among all these alternatives for NO_x emission control, fluidized bed (FB) is considered as one of the most effective technologies due to its low operating temperature (normally no higher than 900 °C) thus avoiding the formations of thermal and prompt NO_x (Li et al., 2011; Qian et al., 2011). Moreover, its flexibility and high efficiency in handling all kinds of fuel also make it popular in reality. Nevertheless, the low operating temperature of FB is known to be favorable for the formation of N₂O (Hiltunen et al., 1991) which belongs to the category of greenhouse gases. Moreover, nitrogen content in MSW may result in possible risk in the increment of N-containing gas emissions and also add uncertainty to the evolution of all kinds of N-containing gases which is of great concern during the co-combustion practice.

In this study, nitrogen evolution (N-containing gas emissions) during the co-combustion of the HT MSW and coal in a laboratory-scale bubbling fluidized bed (BFB) was clarified. In the previous studies, the blending ratio of HT MSW could hardly be elevated more than 30% in terms of CO emissions and combustion efficiencies (Lu et al., 2012), so HT MSW blending ratios as 10%, 20% and up to 30% were selected in this research work. Blends were then tested at 700, 800, 900 °C in order to clarify the combustion characteristics at different co-combustion degrees. Emissions of NO_x (NO) and N₂O were measured during the co-combustion and compared with the results of the mono-combustions of individual HT MSW and coal to verify the effects of the addition of HT MSW into the coal combustion system on the formations and the distributions of N-containing gases. In addition to that, the concentrations of NH₃ and HCN as important precursors responsible for the formation of NO_x and N₂O were also quantified to provide more details on the nitrogen evolution in the gas side during the co-combustion.

2. Experimental

2.1. Material sources

The MSW sample composed of organics, plastics and wood wastes was pretreated in a batch scale HT facility in Nagoya city, Japan. The experimental specification is shown in Table 1. The HT can convert MSW with high moisture content, irregular shapes and low bulk density into homogeneous solid powder product (Fig. 1).

The HT MSW was dried in an oven for 2 days and then sieved between mesh 10 and 40 (0.83–1.7 mm) Muthuraman et al., 2010a. For coal sample, one typical lignite coal was chosen for the co-combustion experiment because it is widely used in power

plants in China. The coal sample was also prepared following the same way as the HT MSW but without the HT. Blends of HT MSW and coal at the blending ratio at 10%, 20% and 30% MSW were mixed thoroughly before fed into the BFB reactor.

The fuel analysis of the samples is listed in Table 2. In view of ultimate analysis, obviously, coal is usually high in carbon content because of its mature carbonization which also leads to less hydrogen and oxygen contents. Also coal has relatively high sulfur content deriving from the depositional environment. On the other hand, due to the carbohydrate structure, biomass is strongly oxygenated compared with the conventional fossil fuels. In the case of HT MSW used here, high carbon contents and high HHV can be ascribed to both the hydrothermal carbonization process facilitated by high temperature and pressure and original plastic fraction, although which also adds the chlorine ratio to the sample. With respect to nitrogen contents, MSW shows higher value compared to coal, which may be ascribed to abundant wood wastes and organics. For proximate analysis, coal is higher in fixed carbon (FC) whereas HT MSW as biomass is richer in volatile matter (VM) indicating the introduction of HT MSW into the coal-fired system might change the original combustion characteristics in BFB. Additionally, the ash content of well separated MSW is far lower than that of coal.

2.2. Bubbling fluidized bed

A laboratory-scale coal-based BFB reactor (Fig. 2) was adopted for the co-combustion behavior investigation to verify the feasibility of the replacement of coal with MSW at different levels without major furnace modification. The BFB was made of a 77 mm i.d. corundum ceramic tube, with a total height of 1100 mm. An electrical heater with 3 temperature zones was used for adjusting and maintaining the furnace temperature. The minimum fluidization velocity was 0.15 m/s at room temperature and the operating temperatures were 700, 800, 900 °C. The excess air in this research was 1.3 which is normal for coal combustion and the residence time was kept ranging 1.5–2.0 s. Contents of flue gas such as O₂, CO, SO₂, NO_x, N₂O, HCN and NH₃ were analyzed by a GASMET™ DX-4010 FT-IR Gas Analyzer and the data was recorded continuously at the interval of 5 s.

3. Results and discussion

3.1. NH₃ and HCN emissions

As important precursors responsible for the formation and destruction of the N-containing species, the concentrations of NH₃ and HCN during the co-combustion are to be discussed in this section. Figs. 3 and 4 show the NH₃ and HCN emissions as a function of the temperature respectively. It is obvious that for mono-combustion of coal, no NH₃ emission was detected whereas the HCN concentration of coal was the highest among all the trails which implies that the nitrogen compounds of coals were essentially contained in aromatic heterocycles which were released as HCN rather than NH₃ during the combustion (Desroches-Ducarne et al., 1998). On the other hand, because the main nitrogen compounds of HT MSW components (wood, organics) were simple proteins known to release ammonia, the NH₃ concentration from mono-combustion of HT MSW, therefore, showed the highest value. Nevertheless, the burning of HT MSW generated small amount HCN as well. Studies also suggested that the dominant nitrogenous volatile species in biomass are NH₃ and HCN, and their concentrations depend on the devolatilization and combustion temperature (Jensen et al., 1995).

Table 1
Experimental specification of the HT.

Parameter	Value
Loading volume (m ³)	10
Operating temperature (°C)	190
Operating pressure (MPa)	1.5
Holding time (h)	0.5

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