



Ash transformation by co-firing of coal with high ratios of woody biomass and effect on slagging propensity



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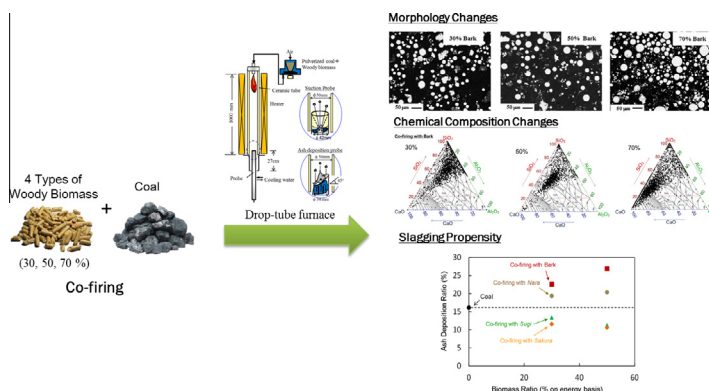
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HIGHLIGHTS

- Co-firing 4 types of woody biomasses with coal were conducted in a DTF.
- CCSEM and ternary phase diagram are used to elucidate the ash formation mechanism.
- Co-firing using high-ash biomass produces significant changes in ash properties.
- The interaction between biomass ash and coal ash was discussed.
- Co-firing using high-ash biomass results in a rapid increase of slagging tendency.

GRAPHICAL ABSTRACT



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ABSTRACT

The co-firing of coal with biomass is a promising method for reducing net CO₂ emissions from existing coal-fired power plants, as well as for the utilization of forest resources. This present study examined the effect of the co-firing of coal with woody biomass on the produced combustion ash and slagging propensity under different conditions representative of the wall furnace region of pulverized-coal boilers. The slagging tests were conducted in a drop-tube furnace by inserting a water–air-cooled deposition probe to the point where the inner furnace temperature was 1300 °C. Bituminous coal was mixed with up to 70% (energy basis) of four different Japanese woody biomasses, namely; *sakura* wood (*Prunus* spp.), *sugi* (*Cryptomeria japonica*), *nara* (Japanese oak), and bark of *sugi* respectively. For comparison purposes, pure coal firing was also performed. The collected combustion ashes and ash deposits were characterized by computer-controlled scanning electron microscopy analysis while the slagging propensity was evaluated by determining the ratio of the deposited ash to the fuel ash, the so-called ash deposition ratio. The results showed no increase in the ash deposition ratio or significant change in the properties of the ash for co-firing using up to 50% of the low-ash (0.4 wt%) biomasses (*sugi* and *sakura*). In contrast, there was significant change in the properties of the ash and an increase in the ash deposition ratio with increasing biomass ratio for co-firing using the high-ash (>1.0 wt%) biomasses (*nara* and bark of *sugi*). The significant transformation of ash with regard to its morphology and chemical composition,

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together with the formation of eutectic calcium mineral mixtures in the deposit layer enhanced the slagging propensity during the co-firing process, particularly when using the high-ash biomasses. The use of a low-ash biomass was found to be suitable for preventing severe slagging during the co-firing process.

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1. Introduction

Co-firing technology, which involves the addition of some biomass to the coal used in coal-fired power plants, is a promising means of reducing greenhouse emissions, especially considering its lower additional investment requirement compared with CO₂ capture technology [1]. Co-firing has been widely introduced particularly in the EU, with the ratio of the added biomass reaching more than 30% (energy basis) [2]. It has also been implemented in several coal-fired power plants in Japan, although the biomass ratio in the country is still low, being <3% [3]. However, Japan has large woody biomass resources, particularly coppice forests, which remain unutilized. The country has the ambitious target of reducing its 2030 total greenhouse gas emission to 26% of 2013 level [4]. The heavy application of biomass co-firing in coal-fired power plants in the country will not only contribute substantially to the achievement of this goal, but will boost the utilization of the national forest resources.

Despite that woody biomasses generally have lower ash content compared to coal, they contain larger amounts of alkaline and alkali earth metals (AAEMs) such as potassium and calcium [5]. This high AAEM content may have an undesirable effect on the boiler operation during combustion. The interaction of AAEMs with the discrete coal minerals may reduce the melting point of the mineral particles [6], leading to severe deposition (slagging and fouling), which reduces heat transfer and causes corrosion and erosion problems under the high-temperature boiler conditions. Majority of coal-fired power plants in Japan and elsewhere, use a pulverized coal (PC) boiler as the steam generator. Compared to a circulating fluidized bed (CFB)-type boiler, which is mainly used for biomass combustion, a PC boiler operates at higher temperatures, with the furnace wall temperature reaching 1100–1400 °C. Thus, the effect of the inorganic component of the biomass on ash deposition in a PC boiler, particularly the slagging propensity, is a potential cause of concern regarding the use of high co-firing ratios.

Several studies have been conducted on the use of wood-derived fuels in low-ratio co-firing [7–9]. It was generally found that such conditions had a modest effect on the ash deposition. In contrast, there have been limited studies on co-firing using high woody biomass ratios, and on the effect of such on ash deposition especially in PC boiler applications. Moreover, there are different types of woody biomasses with varying ash contents, and few studies have investigated the effect of the type of woody biomass on the ash transformation during co-firing. In the present study, the effects of high-ratio co-firing and the woody biomass types on the ash transformation and slagging propensity in a drop tube furnace (DTF) were investigated.

2. Experimental

2.1. Solid fuels

Pulverized bituminous coal was mixed with four different types of Japanese woody biomasses (30%, 50%, 70% on energy basis), namely, *sakura* wood (*Prunus* spp.), *sugi* (*Cryptomeria japonica*), *nara* (Japanese oak), and bark of *sugi*, respectively. *Sakura* wood and *sugi* were used as examples of low ash biomasses, while *nara*

and bark of *sugi* were used as examples of high-ash biomasses. The biomass samples were dried at 105 °C for 1 day and then pulverized and shredded to less than 200 μm before use. The properties of the samples are presented in Table 1.

2.2. Combustion procedure

The combustion tests were conducted in a drop tube furnace (DTF) (see Fig. 1). The DTF used in this study consisted of a ceramic tube of length 1000 mm and ID 50 mm. It comprised three zones, all which were heated electrically by siliconit heating elements. The temperature in all the zones could be raised up to 1400 °C. The samples were continuously supplied at a rate of 173 W (ex. coal: 0.35 g/min) through a table feeder and burnt together with air in the ceramic tube, which had been pre-heated to 1350 °C. The flow rate of the air was 3 L/min and the excess air ratio was 1.2.

2.3. Ash collection

The combustion ashes (ashes) were collected during the combustion by a water-cooled suction probe inserted 270 mm beyond the furnace outlet. The ashes and flue gas passed through the inner tube of the suction probe and were then rapidly cooled to halt further combustion. The cooled ashes, including the char, were then trapped by a filter.

The ashes were also collected in 400 mm beyond the furnace outlet where the slagging tests were conducted. The ashes were then subjected to thermogravimetric (TG)-differential thermal (DT) analysis to determine the combustion efficiency, which was always found to be higher than 95%. It was thus appropriate to conduct the slagging test at this location.

Table 1
Properties of tested samples.

Property	Coal	<i>Sugi</i>	<i>Sakura</i>	<i>Nara</i>	Bark of <i>sugi</i>
High heating value (MJ/kg)	29.5	20.8	21.2	18.7	18.2
<i>Proximate analysis (wt% db)</i>					
Ash	12.7	0.4	0.4	1.1	5.3
Volatiles	30.9	84.6	82.2	81.9	71.1
Mixed carbon	56.4	15.0	17.4	17.0	17.4
<i>Ultimate analysis (wt% daf)</i>					
C	81.51	51.01	50.81	48.21	52.23
H	5.61	5.83	5.86	5.94	5.90
N	2.06	0.15	0.15	0.14	0.51
O	10.19	43.00	43.18	45.70	41.32
S	0.63	0.01	0.01	0.01	0.04
<i>Ash analysis (wt% ash)</i>					
SiO ₂	64.2	13.6	5.6	0.8	15.1
Al ₂ O ₃	21.4	5.5	1.4	1.5	3.89
TiO ₂	1.13	0.3	0.0	0.1	NA
Fe ₂ O ₃	4.45	6.3	2.2	0.8	2.51
CaO	1.02	44.2	51.7	79.1	55.2
MgO	0.88	14.5	17.2	5.3	2.99
Na ₂ O	0.58	1.6	0.6	0.0	0.74
K ₂ O	1.52	8.5	4.4	4.5	1.96
P ₂ O ₅	0.19	1.7	2.9	1.6	1.46
SO ₃	0.81	2.9	9.3	1.5	NA

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