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Effect of temperature on the sintering behavior of Zhundong coal ash in oxy-fuel combustion atmosphere

Bin Zhou, Hao Zhou *, Jianyang Wang, Kefa Cen

Zhejiang University, Institute for Thermal Power Engineering, State Key Laboratory of Clean Energy Utilization, Hangzhou 310027, PR China

HIGHLIGHTS

- Digital image technique was used to monitor the morphology of sintered ash samples under oxy-fuel combustion atmosphere.
- The change in height and area of sintered ash samples with time was obtained through image processing system.
- Layer structure of the sintered samples with different colors was analyzed.
- Mineralogy, chemical compositions, and microstructure of layer structure of sintered samples were analyzed.

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ABSTRACT

This paper was addressed to evaluate the sintering behavior of coal ash at different temperatures under oxy-fuel combustion (O_2/CO_2 combustion) atmosphere. A lignite (Zhundong coal) characterized by high sodium level has been applied as the fuel material. The raw ash was heat treated at four different temperatures: 1350, 1300, 1250, and 1200 °C, respectively. In addition, two atmospheres has been applied to as the reaction atmosphere: (1) 30 vol.% O_2/70 vol.% CO_2 (oxy-firing); (2) air (reference). Meanwhile, the shape of the sintered ash samples during the sintering process was monitored by charge coupled device (CCD). The shrinkage of height and area of sintered samples can be obtained by the image processing system. In addition, the microstructure and chemical compositions of the sintered samples were analyzed by a scanning electron microscope (SEM) equipped with energy dispersive X-ray spectrometry (EDX). Moreover, the distribution of mineral phases in the sintered samples was identified by X-ray diffraction (XRD). The results show that the sintering degree of the samples increases with temperature. In addition, all the samples are characterized by layer structure with different colors. Meanwhile, the XRD results reveal that the oxy-fuel combustion atmosphere did not change dramatically the kinds of mineral phases, but did influence the relative amount of crystalline phases.

1. Introduction

It is well known that oxy-fuel combustion (O_2/CO_2 combustion) can give rise to an easy recovery of CO_2 [1]. This is attributed to a significantly high concentration of CO_2 in flue gas in the oxy-fuel conditions [2–6]. Meanwhile, the cost of CO_2 capture in oxy-firing conditions will be less than that in conventional air firing combustion [7,8]. In consequence, the oxy-fuel combustion technology has been recognized as the most promising technology for controlling CO_2 emission in coal-fired boiler [9]. Furthermore, it was investigated that oxy-fuel combustion could cause the substantial reduction of NO_X, Hg emissions and unburned carbon in fly ash [10–12]. Nevertheless, oxy-fuel combustion also results in high concentration of SO_2 in flue gas [13] and the corresponding corrosion problems [14].

In recent years, many studies have been carried out which cover experimental and engineering issues on application of this technology, for instance, combustion characteristics [15], emissions of pollutant [16], heat transfer characteristics [17], flame ignition [18], and so on. But only a few researches have been conducted on ash-related topics in oxy-fuel combustion atmosphere. Li et al. [19] demonstrated that O_2/CO_2 combustion atmosphere gave rise to the higher fine particulate formation, lower ash deposition and finer bulk ash particle formation. Zheng et al. [20] investigated the fly ash deposition during Oxy-fuel combustion in a bench-scale fluidized-bed combustor. The results revealed that the deposition rate followed this order: 21% O_2/79% CO_2 < air < 30% O_2/70% CO_2. According to Chen et al. [21], increasing the O_2 concentration decreases the amount of the fine ash

* Corresponding author. Tel.: +86 571 87952598; fax: +86 571 87951616.
E-mail address: zhouhao@cmee.zju.edu.cn (H. Zhou).

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Table 1
The analysis of ZD Coal ash produced at 550 °C.

		ZD coal
Ash content (wt.%, dry basis)		12.3
Ash melting temperature, (°C)	IT	1213
	ST	1218
	HT	1221
	FT	1231
Chemical compositions		
(as oxides wt.%, dry basis)	Na_2O	7.60
	MgO	2.90
	Al_2O_3	14.50
	SiO_2	27.43
	P_2O_5	0.03
	SO_3	3.82
	Cl	10.72
	K_2O	0.33
	CaO	27.461
	TiO_2	0.87
	MnO	0.07
	Fe_2O_3	4.26

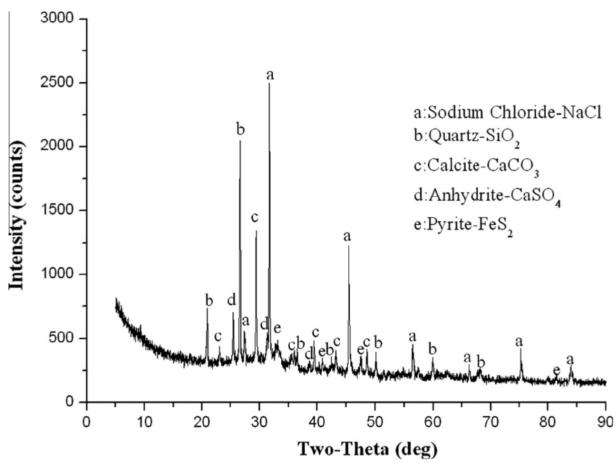

Fig. 1. XRD patterns of coal ash samples prepared at 550 °C.

particles in both O_2/CO_2 and O_2/N_2 atmospheres. The effect of oxygen concentration on the concentration of major and trace elements in coal bottom ash was conducted by Oboirien et al. [22].

Furthermore, Wang et al. [23] investigated the effect of additives on the sintering behaviors of biomass ash. Jing et al. [24] used a high pressure thermogravimetric analyzer apparatus to research the influence of pressure and temperature on the mineralogical and fusion characteristics of coal ash. Additionally, the melting behavior of typical ash particles in reducing atmosphere was conducted by Wang et al. [25]. However, these investigations cannot monitor the shape of ash samples online and simulate the ash sintering on the surface of water wall tube in pulverized coal boiler. Meanwhile, to date, there is still a lack of experimental study with respect to the ash melting behaviors in oxy-firing conditions. Consequently, fundamental research is needed to conduct to understand the changes of ash melting behaviors between oxy-fuel combustion and conventional air-fired combustion.

The aim of this study was addressed to evaluate the sintering behaviors of ash particles on an oil-cooled deposition probe in oxy-fuel and air (reference) combustion atmosphere. Moreover, application of CCD to observe the shape of the ash samples online at different temperature. Meanwhile, the method used by this paper is a limited applicability as far as sintering in pulverized coal boilers.

2. Experimental

2.1. Preparation and analysis of ash samples

A representative lignite coal (Zhundong coal) characterized by high sodium in the ash was selected as the experimental material for this study. Before the experiments, the coal was ground to less than 70 μm. Due to the high level sodium in the coal ash, the coal samples were ashed at 550 °C for 10 h in a muffle furnace. The coal ash composition is given in Table 1. Meanwhile, the concentration of the crystalline phases in the coal ash is illustrated in Fig. 1. It can be observed that the ZD coal ash contains a large quantity of NaCl, which is in accordance with the relatively high Na_2O concentration—7.60 wt.% in ash presented in Table 1. In addition, the coal ash was also rich in quartz, calcite, and anhydrite. Meanwhile, less pyrite is found in the XRD pattern, it reveals that Fe is mainly bound to inorganic sulfur to form pyrite. To evaluate the change of ash sample dimension before and after sintering, the powdery ash was pressed into cubical ash block (length 25 mm, width 15 mm, height 15 mm).

2.2. Experimental setup and procedure

The schematic diagram of the sintering furnace system is illustrated in Fig. 2. It is mainly composed of a gas system, an image

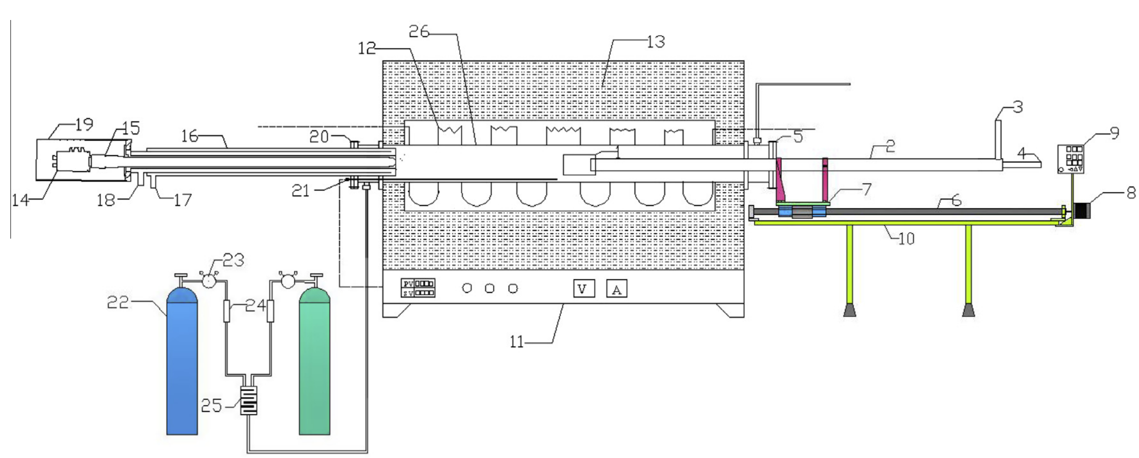

Fig. 2. Schematic diagram of the sintering furnace system. 1: Sintering probe; 2: Sintering tube; 3: Outlet of conduction oil; 4: Inlet of conduction oil; 5: Sealing flange; 6: Screw rod; 7: Sliding table; 8: Motor; 9: Control panel; 10: Supporting platform; 11: Shell; 12: Heater; 13: Refractory matter; 14: CCD camera; 15: Optical lenses; 16: Protective tube; 17: Outlet of cooling water; 18: Inlet of cooling water; 19: Camera shield; 20: Sealing flange; 21: Thermocouple; 22: Gas cylinder; 23: Pressure reducing valve; 24: Mass flow meter; 25: Mixing device.