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Short communication

Ash characteristics during oxy-fuel fluidized bed combustion of a Victorian brown coal

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ABSTRACT

This paper investigates, for the first time, the characteristics of ashes resulting from oxy-fuel fluidized bed combustion of a Victorian brown coal. The experimental results showed that the bed ash composition was independent of the reactor temperature and feed gas concentration in the combustion environment. No bed agglomeration was observed under oxy-fuel combustion conditions, even with the addition of steam, at 800–900 °C temperatures during the period of the tests. It is expected that agglomeration is unlikely to be a major problem during oxy-fuel fluidized bed combustion of this Victorian brown coal.

1. Introduction

In capturing CO_2 from coal-fired power plants, oxy-fuel fluidized bed (Oxy-FB) combustion has emerged as a promising technology due to its ability to produce highly concentrated CO_2 in the flue gas, which in turn allows easier and cheaper CO_2 separation from flue gas [1]. Moreover, Oxy-FB combustion potentially offers several technical, scientific and economic advantages over oxy-fuel pulverized fuel (Oxy-PF) combustion. These advantages include reduced capital and operating costs [2]. Furthermore, in Oxy-FB the transition from air-mode combustion to oxy-mode combustion is potentially easier relative to Oxy-PF, because fluidized beds contain large amount of inert bed material that also helps in controlling the bed temperature. Oxy-FB is also suited to operate at slightly over the atmospheric pressure, so diminishes the potential air in-leakage to the reactor [1]. Another major advantage of Oxy-FB combustion over Oxy-PF combustion is the lower furnace temperature, which aids in reducing the problems associated with high alkali ash, and overall plant efficiency. Furthermore, fuel flexibility, uniform temperature distribution, low NO_X and SO_2 emissions are the known advantages of Oxy-FB combustion [1,3].

In coal-fired fluidized bed combustion, the ash behavior is an important consideration as it could affect the design and operation of fluidized bed boilers. Though few researchers have studied the characterization of ashes resulting from Oxy-FB combustion using a variety of coals [4–7], prior studies used mainly bituminous and anthracite coals. To date no studies are available on ash behavior using brown coal in oxy-fuel fluidized bed combustion. Furthermore, the issue of agglomeration during coal combustion has important implications on the operation of Oxy-FB combustors using different types of coals. If agglomeration remains undetected, it may propagate to partial or total defluidization of the bed materials, which in turn may lead to a lengthy and expensive unscheduled shutdown [8]. Agglomeration is mainly caused by the compounds of various elements, such as alkali metals (Na and K), alkali earth metals (Mg and Ca), sulfur, chlorine, silicon, vanadium, and nickel [9]. Compared to the high-rank coals, the alkali and alkali earth metal elements are relatively higher in some low-rank coals which in turn may increase the possibility of bed agglomeration. The study on agglomeration characteristics using low-rank coal remains almost unexplored for Oxy-FB combustion. Therefore, it is important to know the tendency of agglomeration during Oxy-FB combustion using these coals.

Victoria has an abundant resource of brown coal with an estimated reserve of 430 billion tonne, expected to last for over 500 years at current consumption rate [10,11]. The ash characteristic data for Oxy-FB combustion using these valuable coals is non-existent, and hence this research aims to fill that void. In this present work, experiments were conducted in a bench-scale fluidized bed combustor under air and oxy-fuel combustion using one Victorian brown coal, Loy Yang. This paper presents the effects of feed gas composition and reactor temperature on the generated ash characteristics, and makes a preliminary assessment of ash-related mineral interaction towards bed agglomeration.

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Table 1
Composition of coal used in experiments.

	Loy Yang
Ultimate analysis (wt.% dry basis)	
Carbon	65.00
Hydrogen	4.60
Nitrogen	0.72
Sulfur	0.50
Oxygen	25.48
Ash	3.70
Minerals and inorganic (wt.% ash basis)	
SiO_2	56.90
Al_2O_3	20.64
Fe_2O_3	4.63
TiO_2	1.51
K_2O	1.31
MgO	3.63
Na_2O	4.73
CaO	1.61
SO_3	5.04

2. Material and methods

2.1. Feedstock

One air-dried Victorian brown coal (Loy Yang) with the particle size of 1–3 mm was used in these experiments; the composition is given in Table 1. Silica sand (350–400 μm) was also added as a bed material. In addition, during start-up char (77.97% C, 2.42% H, 1.29% N, 0.11% S, 15.77% O and 2.44% ash) of 1–3 mm was used. All chars were used up during heat-up.

2.2. Experimental method

Experiments were carried out in a 10 kW_{th} fluidized bed unit. The experimental facility and operating procedure were described in detail elsewhere [12], and therefore are briefly described here. The combustor has an overall height of 4 m, and an inner diameter of 0.1 m in the lower part and of 0.15 m in the upper part. All reacting gases — air/typical oxy-fuel gas composition (O_2, CO_2 and/or steam), were mixed prior to entering the reactor. The solids were fed using a screw feeder located just above the distributor. Flue gases passed through a primary and a secondary cyclone to separate from the solids before passing to the stack. After each experiment, the fly ash and bed samples were collected for analysis. Table 2 summarizes the experimental conditions. From the steady-state process model using Aspen Plus simulation on oxy-fuel fluidized bed combustion, 10–12% H_2O was observed in case of Victorian brown coal. Therefore, 12% H_2O was chosen as feed gas.

2.3. Analytical measurements

The major inorganics in ashes were determined by ICP-AES (inductively coupled plasma-atomic emission spectrometry) following borate fusion and acid dissolution according to the standard method AS 1038.14.1. And, the crystalline mineral phases in ashes are analyzed by X-Ray diffraction (XRD), using a Rigaku Miniflex 600 XRD model, at voltage of 40 kV and a current of 15 mA. These XRD measurements were repeated two times, and the average of the data was reported in the paper. The qualitative analysis of XRD patterns is conducted using MDI Jade 5.0 software. Each analysis was repeated three times and the average of the data was reported in the paper.

Table 2
Operating conditions used in experiments.

Run	Combustion atmosphere (% Volume)	Gas velocity (m/s)	Bed temperature (°C)	Steady-state period (hr)	Coal feed rate (g/h)
1	Air	0.80	840 ± 10	4.50	650
2	15% O_2 + 85% CO_2	0.80	840 ± 10	3.25	850
3	21% O_2 + 79% CO_2	0.80	840 ± 10	3.50	850
4	30% O_2 + 70% CO_2	0.80	845 ± 5	3.75	800
5	15% O_2 + 85% CO_2	0.75	820 ± 10	3.25	785
6	15% O_2 + 85% CO_2	0.80	880 ± 10	2.00	855
7	15% O_2 + 73% CO_2 + 12% H_2O	0.75	860 ± 10	2.00	840

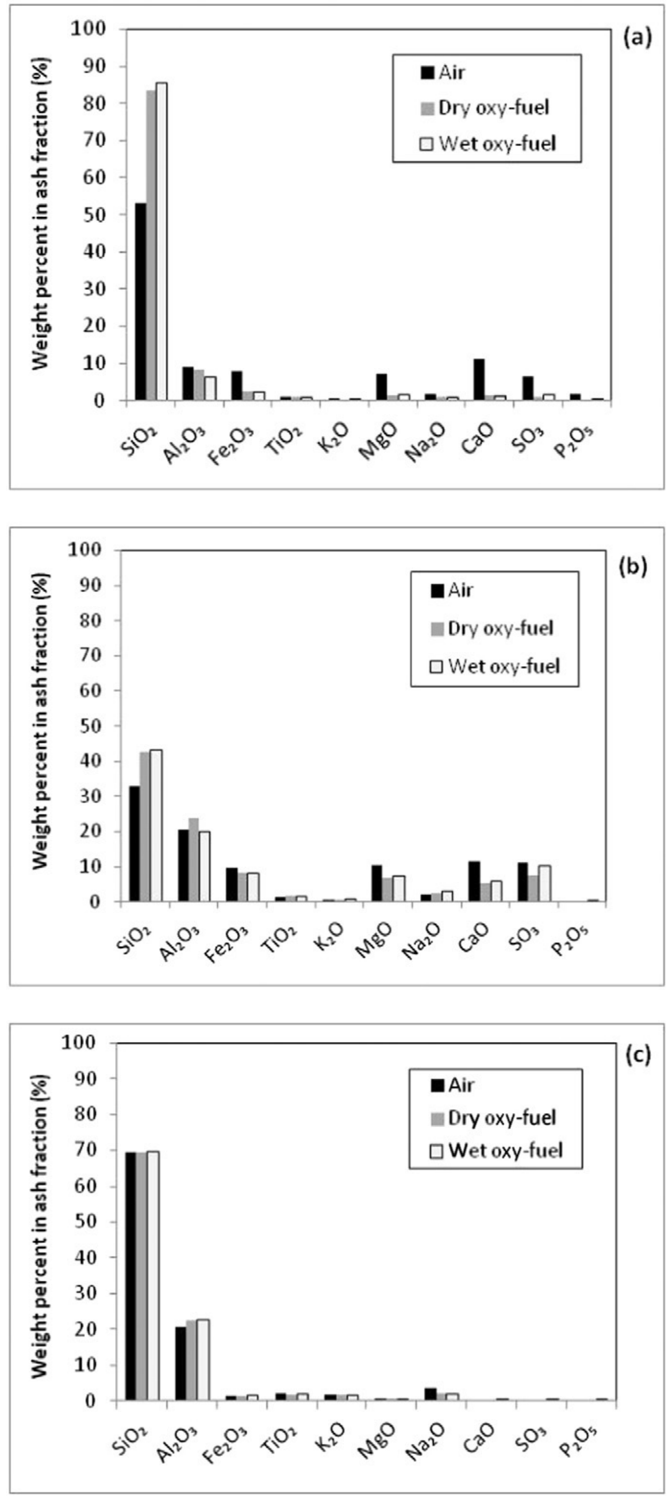

Fig. 1. Comparison of (a) primary cyclone ash, (b) secondary cyclone ash and (c) bed ash under different combustion environments.