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The investigation of the coal ignition temperature and ignition characteristics in an oxygen-enriched FBR

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ABSTRACT

Oxygen-enriched circulating fluidized bed (CFB) technology is considered as one of the low carbon emission power generation technologies. By recycling the flue gas into the furnace, the CO_2 concentration in the exhaust gas can reach over 90%. The coal ignition temperature and ignition characteristics are important factors for boiler design and for choosing the feeding temperature during the transition from air-firing to oxy-firing. The ignition and combustion processes of five types of coal under four different atmospheres (air, O_2 27%, O_2 40%, O_2 53%) were measured in a laboratory scale fluidized bed reactor (FBR) with an under-bed preheat system. Using thermocouples and a gas analyzer, the changes in bed temperature and the concentrations of different components, such as O_2, CO_2 and CO, in flue gas were directly measured to determine the coal ignition temperature, T_i^F. It was found that T_i^F decreases with increasing O_2 concentration. At lower bed temperatures, two-stage ignition processes were observed in certain ranges of initial bed temperature and oxygen concentration. The influence of initial bed temperature on volatile release and the SO_2 emission in the ignition processes were also discussed.

1. Introduction

As one of the 'Green House' gases, in recent years, CO_2 is considered as one of the main reasons of the climate change. More and more attention was paid to reduce CO_2 emission. As the main releasing source of CO_2, coal combustion burdens much pressure on the climate change, while, the increasing world population and energy demand make coal an essential and stable energy source in the near future [1].

Contrary to the traditional air combustion technology, oxygen-enriched combustion in a pulverized coal fired (PC) boiler is considered as one potential technology to reduce CO_2 emission [2–4]. By recycling the flue gas, the CO_2 concentration in the exhaust gas could reach over 90%, which makes it easier to realize the application of carbon capture and storage (CCS) technology.

Circulating fluidized bed (CFB) combustion technology has the features of good fuel flexibility, low NO_X emission and high SO_2 absorption efficiency with limestone injected into the furnace. These advantages make the oxygen-enriched CFB combustion technology more convenient for CCS [5].

An oxygen-enriched CFB is superior to the traditional CFB [6]. The high oxygen concentration in the furnace will improve the combustion efficiency and cause the significant reduction in the gas flow volume, which will decrease the boiler size greatly [7]. Comparably, the recycle ratio of flue gas in an oxygen-enriched CFB boiler is much lower than that of the oxy-fuel PC boiler by using external heat exchanging system, which can maintain higher oxygen concentration in the furnace and reduce the auxiliary power simultaneously [5,8]. In the view of industrial application, there are still many problems to be solved for oxygen-enriched CFB, such as the coal ignition temperature and coal combustion characteristics in the CFB boiler.

Abbreviations: CFB, circulating fluidized bed; CCS, carbon capture and storage; FBR, fluidized bed reactor; SPSS, statistical product and service solutions.

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Nomenclature

f_{SO2}	sulfur conversion rate, mol/s	T_i^F	coal ignition temperature in FBR, °C
M_S	the molecular weight of sulfur, g/mol	U	fluidizing air velocity, m/s
S^V	mass of the converted sulfur from volatile	U_{mf}	minimum fluidizing air velocity, m/s
S^{Char}	mass of the converted sulfur from char	V_{daf}	volatile content as base of dry free of ash, %
T_b	bed temperature, °C		
T_i	the bed temperature used in the ith test during the determination of the coal ignition temperature		

Coal ignition temperature in a CFB boiler, T_i^F, defined as the lowest bed temperature required for stable coal combustion, is an important parameter for boiler design and automatic control during the startup process. When the coal is fed into a furnace at a temperature lower than T_i^F, the coal will not ignite and the furnace temperature will decrease even more. As the coal particles accumulate in the furnace, once the fuel concentration and temperature in the furnace reach critical conditions, the mixture will flash and the furnace temperature will suddenly increase, which leads to overheating problem. Determining the ignition and combustion characteristics of certain coal type are necessary for the safety of the boiler operation.

Though there are many studies on ignition temperature of coal in air condition [9–12], the investigations on that in oxygen-enriched condition are still far from enough. In oxygen-enriched conditions, the influences of CO_2 on the reactions of char, the releasing of volatile and the heat transfer are still unclear [4].

To determine the coal ignition temperature, there are several different methods used in previous literatures, such as the thermogravimetric analysis (TG) ignition measurement [13], thermogravimetric-derivative thermogravimetric analysis (TG-DTG) combination method [15] and so on. A laboratory-scale fluidized bed reactor (FBR) with a under-bed preheating system was used in this study, in which the reaction condition (heat and mass transfer) is much closer to that in the industrial CFB boilers.

In this work, ignition temperatures and ignition characteristics of five different coals under four different atmospheres (air, O_2 27%, O_2 40%, O_2 53%, CO_2 as balance gas) were taken into account. The ignition characteristics of the coals can be described by a revised ignition index F_i [12], which is defined as:

$$F_i = \Delta T/(t_2 - t_1)$$

where ΔT is the difference between the initial furnace temperature and the maximum temperature, t_1 is the time to reach the lowest temperature after the coal sample was injected, and t_2 is the time to reach the maximum temperature.

The bed temperature was monitored by a thermocouple. The components in the exhaust gas was detected by an O_2 analyzer and a mass spectrometer. The tests results were combined to determine the coal ignition temperature and the combustion characteristics.

2. Experimental setup

The measurements were carried out in a laboratory-scale FBR with an under-bed preheating system, shown in Fig. 1. The combustion chamber is made of quartz glass with height of 70 cm and inner diameter of 65 mm. Quartz sand with narrow size range of 0.275–0.3 mm was used as bed material. The static height of the bed material in the chamber was set as 40 mm. CO_2 and O_2 were pre-mixed in the mixer with three different ratio, and the gaseous mixers with different O_2 concentrations were used as inlet gases. The pre-mixed gas was heated in the preheating system underneath the combustion chamber, and delivered into the combustion chamber. Coal particles were injected into the combustion chamber through the feeding tube above the reactor. The flue gas was cleaned through the cyclone and then introduced into the gas analyzers. The superficial gas velocity in the combustion chamber was about three times of U_{mf}. The operating condition in this work is specified in Table 1.

The proximate and ultimate analyses of five coal types are listed in Tables 2 and 3. The particle size of the coal sample was in the range of 1–2 mm and the mass used in each batch experiment was about 2 g. The temperature in the dense bed was measured by thermocouple online. An O_2 analyzer and a mass spectrometer were used to measure the concentration changes of the gas compositions (especially O_2, CO_2, H_2, CH_4, CO and SO_2) in the flue gas.

To investigate the influences of the volatile release on the ignition characteristics, the devolatilization processes under Ar atmosphere were carried out in the FBR, and the porosities of original coal particles and the chars that formed during the devolatilization processes were measured.

3. Experoment procedure

After the chamber was electrically heated to the selected temperature, T_b, the coal particles were injected into the chamber.

The bed temperature was then recorded by the data acquisition system. After the coal particles were injected into the chamber, the whole process was observed through the view port. If flame was observed and the coal particles started to glow, it was considered that the coal particles ignited. If the coal particles ignited, the chamber temperature was reduced to a lower temperature T_{i+1} and steps 1 and 2 were repeated until the coal particles did not ignite.

If the coal particles did not ignite, T_b, was set to be half between T_i and T_{i-1} and the process was repeated. The process was terminated when $|T_i - T_{i-1}| < 5$ °C. Then T_i was considered as the ignition temperature, T_i^F.

In the investigation, every single test carried out in this work was repeated for five times, and the results of each five tests were averaged as the final result to insure the reproducibility of the data.

4. Results and discussion

4.1. Coal ignition temperature

Following the procedure described in Section 3, the coal ignition temperatures of 5 coal types under air and oxygen-enriched atmospheres (O_2 27%, O_2 40%, O_2 53%, CO_2 as balance gas) were determined, shown in Fig. 2. It can be observed that the oxygen enriched technology is capable of decreasing the coal ignition temperature comparing with that in air condition. To find out the factors that might influence the coal ignition characteristics, the influences of several parameters (bed temperature, volatile content, oxygen concentration) are discussed in the following sections.