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Research article

Experimental study on combustion, flame and NO_X emission of pulverized coal preheated by a preheating burner

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ABSTRACT

Experimental researches on combustion characteristics of pulverized Ningdong bitumite preheated by a preheating burner were carried out in a 0.2 MW coal preheating combustion test rig, and the effects of preheating temperature, secondary air equivalence ratio and the positions of tertiary air nozzles on combustion, flame and NO_X emissions of preheated fuels were studied. The results showed that the 0.2 MW coal preheating combustion test rig can operate stably and the combustion efficiency can be higher than 97% while the NO_X emissions are lower than 100 mg/Nm^3. With the increase of preheating temperature, NO_X emissions increase, and the combustion efficiency does not change obviously. With the increase of secondary air equivalence ratio, the combustion efficiency increases, and NO_X emissions increase as well. With the increase of the distance between the tertiary air nozzle and the preheated fuel nozzle, NO_X emissions decrease, and the combustion efficiency decreases as well. The flame characteristic is not sensitive to preheating temperature, but closely related to the air distribution of down-fired combustor. With reasonable air supply positions, flameless combustion can be realized.

1. Introduction

As the main resource, coal is dominant in the energy structure of China. Combustion for power and heat generation is the two most commonly use form of coal. However, the combustion of coal may produce amounts of pollutants, especially NO_X, which is very toxic to our ecosystem. How to realize the high-efficient and clean utilization of coal is a big problem.

In consideration of the hazard of NO_X, de-NO_X technologies have been developed rapidly in recent years. From air-stage combustion technology [1–3] to flameless combustion technology [4–6], the NO_X emission levels have been in decline. However, with the increasingly stringent environmental protection requirements, the standards for NO_X emission of coal-fired boilers are getting harsh, and the denitrification of boilers is aggravated. The existing low-NO_X combustion technologies cannot fully meet the requirements of reducing NO_X emissions.

Based on the problems above, coal preheating combustion technology is proposed as a novel low NO_X combustion technology, and a lot of researches have been carried out. Zhang Hai [7] designed a novel burner to achieve the preheating of pulverized coal. All Russia Thermal Research Institute [8,9] proposed a novel technology, in which the hot flue gas generated from gas combustion was used to preheat pulverized coal. The technology was finally testified to be high-efficient and effective for NO_X reduction. Changchun Liu [10,11] further developed the gas-fired coal preheating technology and carried out some experiments to study the influence of burner type and air distribution on NO emissions in a drop-tube furnace. A new coal preheating technology which is based on the circulating bed (CFB) was proposed by Institute of Engineering Thermophysics, Chinese Academy of Science [12–14], and a 30 kW bench test rig was constructed. The main feature of this technology is that the fuel can be preheated up to above 800 °C by its partial combustion in the preheating burner and then enters into the down-fired combustor for complete combustion under the method of air-stage. A series of researches have been implemented in the bench test rig and the results show that the test rig can run stably and the combustion efficiency can be high up to 99% with low NO_X emission.

In order to achieve the amplification of this technology and its industrial application and promotion, a 0.2 MW pulverized coal preheating combustion pilot test rig has been constructed. Ningdong bitumite is used as the test fuel to study the operating characteristics of the preheating burner, the characteristics of preheated fuel combustion, the flame and NO_X formation, and the factors affecting the NO_X emission. The aim of this paper is to explore the influence of different factors on combustion and NO_X emission, which will be beneficial to further

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Table 1
Proximate and ultimate analyses of the Ningdong bitumite coal.

Items	Data
Ultimate analysis (wt%, air dry)	
Carbon	54.01
Hydrogen	3.21
Oxygen	14.26
Nitrogen	0.58
Sulfur	0.54
Proximate analysis(wt%, air dry)	
Moisture	5.48
Ash	26.27
Volatile matter	30.34
Fixed carbon	37.91
Low heating value (MJ/kg)	20.09

improve the preheating burner and the system design principles, and reduce NO_X emission with coal preheating technology.

2. Experimental

2.1. Fuel analysis

The fuel used in the experiments is bitumite coal from Ningdong, and the properties of the Ningdong bitumite coal are listed in Table 1. The particle size of the Ningdong bitumite coal ranges from 0 to 100 μm with 50% cut diameter d_{50} = 18.38 μm.

2.2. Test rig and experiments

0.2 MW coal preheated combustion test rigs consists of a preheating burner, a down-fired combustor (DFC), a gas cooler and other auxiliaries, and the flow chart of the test rigs is shown in Fig. 1.

The preheating burner is designed based on a circulating fluidized bed, and the riser is 1500 mm in height and 160 mm in inner diameter, respectively. Before starting the experiments, 10 kg quartz sand with the size of 0.5–1 mm is added into the preheating burner as the bed material. The coal feeding port is at the position of 285 mm above the air distributor of the riser. Around 15%~30% of the theoretical air (defined as primary air) is supplied into the riser from the bottom. The cyclone separator is designed to only allow particles smaller than 20 μm to escape out, thus the bed material is circulating in the preheating burner all the time as the heat source and the coal particles will not escape from the cyclone separator unless they are small enough. Once the pulverized coal enters into the preheating burner, it is preheated up to a high temperature by the high temperature bed material and the volatile matter is released. Since the combustion air is insufficient, gasification reactions should be taken into consideration, and the coal gas (mainly consists of CO, H_2, CO_2 and N_2) and high temperature char are generated in the process, which can be named as high temperature preheated fuel. The high temperature preheated fuel enters into the DFC for complete combustion through the nozzle installed on the top of the DFC.

The DFC is cylindrical, with the height of 6000 mm and the inner diameter of 700 mm. Air-staged method is adopted. The secondary air nozzle is set on the top of the DFC, and ten layer tertiary air nozzles are installed along the axis of the DFC, the positions of which are 300 mm, 600 mm, 900 mm, 1200 mm, 1500 mm, 1800 mm, 2100 mm, 2400 mm, 2700 mm and 3000 mm below the secondary air nozzle. The tertiary air nozzles can be denoted as N1 to N10. Each tertiary air nozzle has a separate valve and flowmeter, which are used to control the injecting position and measure the flow of the tertiary air.

Four k-type thermocouples are set inside the preheating burner, and one k-type thermocouple is set at the outlet of the preheating burner; fifteen S-type thermocouples are set along the axis of the DFC. Flue gas sampling port is set at the outlet of the DFC, and a Gasmet DX4000 gas analyzer is used to measure the concentration of NO, N_2O, NO_2, CO, CO_2 and other compositions online. The gas analyzer is set to collect data every 5 s, and each measurement last 30 min to obtain more accurate data. A flame detection probe is installed inside the DFC at the position of 6000 mm below the secondary air nozzle to obtain flame

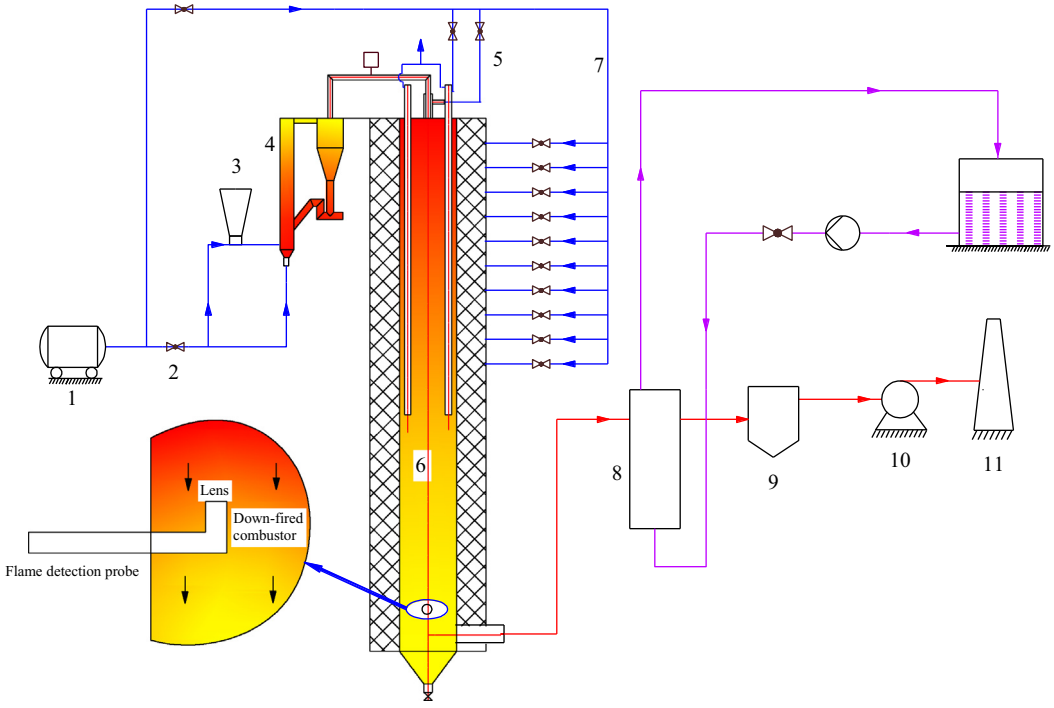

Fig. 1. The flow chart of 0.2 MW coal preheating combustion system (1, air compressor; 2, primary air; 3, coal feeder; 4, preheating burner; 5, secondary air; 6, down-fired combustor; 7, tertiary air; 8, gas cooler; 9, bag filter; 10, inducer; 11, chimney).