



# Experimental study on preheating and combustion characteristics of pulverized anthracite coal



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## HIGHLIGHTS

- Proposing a method of preheating pulverized anthracite coal in CFB.
- Comparing the inner pore structure of preheated anthracite and raw coal.
- Analyzing coal-N transformation mechanism in preheating and combustion.
- Discussing the limiting regimes of preheated anthracite combustion.

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## ABSTRACT

Anthracite, with low volatile content, has difficulties in ignition, stabilization, and burn out, especially under conditions of low boiler load. A new technique for preheating pulverized anthracite by a circulating fluidized bed was adopted. Experiments on preheated anthracite combustion were carried out in a down-fired combustor. Process of anthracite preheating, combustion characteristics, and NO<sub>x</sub> emissions were studied. The results show that preheated anthracite has a smaller mean size with a larger specific surface area. There is a uniform temperature profile along the axis of the down-fired combustor, and the combustion efficiency is 96.5%. The NO<sub>x</sub> emission in the exhaust is 256 mg/N m<sup>3</sup> (@ 6% O<sub>2</sub>) and the conversion ratio of fuel-N to NO<sub>x</sub> is 24.3%.

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## 1. Introduction

In some thermal power plants, anthracite is widely used as fuel supplied to the boiler. However, it is difficult to ignite and burn out due to its low volatile and high fixed carbon content, especially under conditions of low boiler load. Therefore, stabilizing anthracite combustion and improving combustion efficiency have been a focus of research for a long time [1–3].

At present, some methods for boiler design and operation to solve these problems include optimizing burners, increasing combustion temperature, and prolonging residence time. One such method involves tangential combustion with an optimized burner to preheat anthracite using flue gas recirculation and a W-shaped flame to prolong residence time by a complicated configuration. However, NO<sub>x</sub> emissions in tangentially fired boilers and W-shaped flame boilers are high, generally 850–1300 mg/N m<sup>3</sup> (@ 6% O<sub>2</sub>) due to high combustion temperature [4–6]. Moreover, both tangentially fired boilers and W-shaped flame boilers have difficulties in stabilizing combustion, especially at low boiler load.

A new technique for preheating pulverized anthracite by a circulating fluidized bed was adopted. Anthracite preheated to a temperature of nearly 900 °C was pneumatically transported into a down-fired combustor to achieve highly efficient and stable combustion.

A bench-scale rig of pulverized anthracite combustion was built, and a series of experiments were carried out. This paper outlines the process of anthracite preheating, the combustion characteristics, and the NO<sub>x</sub> emissions from this system.

## 2. Experiment

### 2.1. Test rig

The test rig diagram shown in Fig. 1 is composed of a circulating fluidized bed which is abbreviated to CFB, a down-fired combustor which is abbreviated to DFC, and an auxiliary system. A horizontal tube 48 mm in diameter and 500 mm in length is used to guide the preheated anthracite from the CFB to the DFC.

The riser of the CFB is 90 mm in diameter and 1500 mm in height. The coal feeding port is 240 mm above the air distributor on the riser, and the air, defined as primary air, is supplied to the

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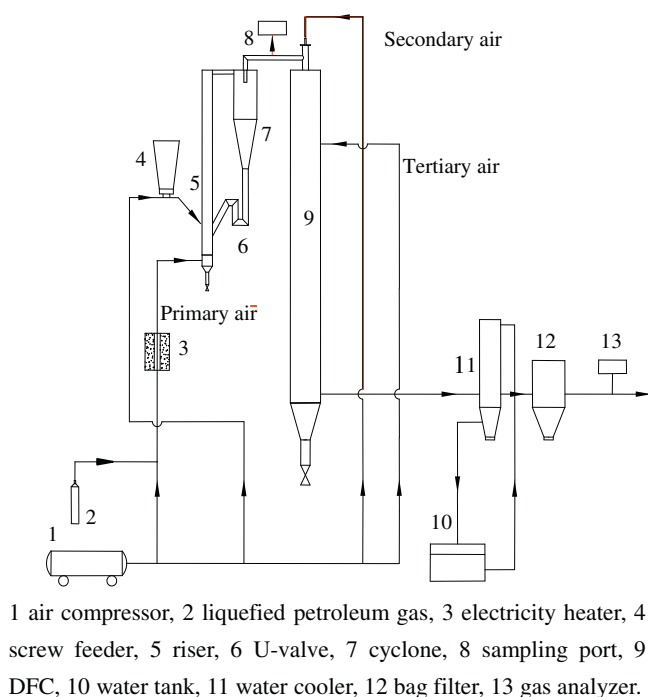


Fig. 1. Schematic diagram of the test rig.

CFB with about 10–30% of theoretical air. The primary air fluidizes the bed materials and provides oxygen for partial pyrolysis, gasification, and combustion of anthracite, to achieve and maintain a bed temperature of nearly 900 °C. Due to the strong reducing atmosphere throughout the CFB, the gas outflow the CFB is mainly comprised of  $N_2$ ,  $CO_2$ ,  $CO$ ,  $CH_4$ , and  $H_2$ ; this is similar to the composition of coal gas. Therefore, the gas at the outlet of the CFB is defined as high-temperature coal gas. In this system, the function of the CFB is to preheat pulverized anthracite by consuming a small amount of air.

Preheated anthracite and high-temperature coal gas enter a nozzle at the top center of the DFC with 260 mm in diameter and 3000 mm in height. Secondary air at room temperature is supplied to the nozzle at a velocity of 18 m/s to provide oxygen for preheated anthracite combustion. Tertiary air, still at room temperature, is supplied to the DFC at a position 600 mm below the nozzle to provide extra oxygen for complete combustion. A reducing atmosphere, favorable to the reduction of nitrogen oxides, is present between the secondary air port and the tertiary air port.

There are eight thermocouples in the test facility, three Ni–Cr/Ni–Si thermocouples in the CFB, and five Pt/Pt–Rh thermocouples in the DFC. Eight sampling ports are set: one is at the outlet of the CFB for sampling preheated anthracite and high-temperature coal gas; one is at the outlet of a bag filter for sampling fly ash; and the other six ports are 100, 400, 900, 1400, 2400, and 3000 mm below the nozzle. All the gas samples are dried and filtered before they enter individual online analyzers. High-temperature coal gas is measured using a MAIHAK S710 analyzer, and other gases in the DFC are measured using a Gasmet FTIR DX-4000 analyzer.

Noticeably, the gas composition and temperature at the nozzle of the DFC are those of the high-temperature coal gas from the CFB.

## 2.2. Coal characteristics

Raw anthracite coal from China (proximate and ultimate analyses listed in Table 1) was used in the experiments to investigate

Table 1

Proximate and ultimate analysis of the raw anthracite.

Items	Data
Proximate analysis (wt%)	
Moisture <sup>a</sup>	3.40
Volatile matter <sup>b</sup>	7.58
Fixed carbon <sup>a</sup>	81.38
Ash <sup>a</sup>	8.55
Ultimate analysis <sup>b</sup> (wt%)	
Carbon	92.27
Hydrogen	3.52
Oxygen	1.92
Nitrogen	1.33
Sulfur	0.79
Low heating value <sup>a</sup> (MJ/kg)	30.70

<sup>a</sup> As received.

<sup>b</sup> Dry ash free basis.

preheating, combustion, and  $NO_x$  emissions. The diameter of the raw anthracite is smaller than 0.355 mm, with mean particle diameter,  $d_{50} = 82 \mu m$ . Quartz sand with a diameter ranging from 0.1 to 0.5 mm was added to the CFB as bed material.

## 2.3. Experimental conditions

Experimental conditions are listed in Table 2.

The air equivalence ratio in the CFB is defined as  $\lambda_{CFB}$ , and the air equivalence ratio in the reducing zone of the DFC is defined as  $\lambda_{RZ}$ :

$$\lambda_{CFB} = \frac{A_I}{A_{stoi}}; \quad \lambda_{RZ} = \frac{A_I + A_{II}}{A_{stoi}}; \quad A_{stoi} = \frac{A_I + A_{II} + A_{III}}{\lambda} \quad (1)$$

$A_I$  is the primary air flow,  $A_{II}$  is the secondary air flow,  $A_{III}$  is the tertiary air flow,  $A_{stoi}$  is the air flow in stoichiometric combustion for pulverized coal, and  $\lambda$  is the excess air ratio.

In the experiment,  $\lambda_{CFB}$  is set to 0.3, i.e., about 30% of theoretical air is supplied to the CFB.  $\lambda_{RZ}$  is set to 0.6, i.e., about 60% of theoretical air is supplied to the DFC ranging from the nozzle to 600 mm below the nozzle. The excess air ratio is 1.3 and the coal feed rate is 3.0 kg/h.

## 3. Results and discussions

### 3.1. Preheating process in the circulating fluidized bed

The temperature variation with time in the CFB is shown in Fig. 2. It is obvious that preheated anthracite with a temperature of 880 °C can be obtained steadily and continuously by partial pyrolysis, gasification, and combustion of anthracite in a low air equivalence ratio in the CFB.

The particle size distribution of the preheated anthracite is tested by a Malvern Mastersizer 2000 laser analyzer, and the diam-

Table 2

Experimental conditions.

Items	Unit	Data
Pulverized anthracite feed rate	kg/h	3.0
The primary air flow	$N m^3/h$	7.5
The primary air temperature	°C	20
$\lambda_{CFB}$	–	0.3
The secondary air flow	$N m^3/h$	8
The primary air temperature	°C	20
$\lambda_{RZ}$	–	0.6
The tertiary air flow	$N m^3/h$	16
The primary air temperature	°C	20
$\lambda$	–	1.3

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