Analysis of NO emission characteristics of low-order blended fuels

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Abstract. Two kinds of typical coal (HSQ bituminous coal and LY anthracite coal) were selected as the object of research, and in the fixed bed reactor a series of research was carried to make a thorough inquiry on NO emission characteristics of coal combustion under different blending modes. The results of coal blended combustion show that: Improving the ratio of bituminous coal can advance the ignition and burnout, and improve the combustion performance of coal. When two kinds of coal burn blended, NO emission is between the concentration of these two kinds of single coal, and the NO conversion rate increases gradually with the growth of the proportion of anthracite; the interrelationship between these two kinds of coal has influence on NO emission, which is showed as form of inhibition or promotion when ratio of mixed coal is changed.

1. Introduction

Many power station boilers adopt the method of blending anthracite or lean coal with other coal types [1] at present, which improves the utilization rate of coal, especially low-quality coal, saves high-quality coal resources, and brings significant economic benefits [2-4].

Two typical coals with different coal quality were selected as experimental coals in this work. The combustion characteristics of the blended coal were analyzed by thermogravimetric experiments. Then the NO emission characteristics of mixed coal combustion under different proportions were carried out on a fixed bed reactor. The experimental study investigated the relationship between the combustion performance of mixed coal and NO emission characteristics, in order to reveal the interaction between the combustion characteristics of mixed coal and the emission characteristics of NO pollutants.

2. Material and methods

2.1. Coal sample

Two coal types with different coal quality and similar nitrogen content were selected as representative coals for experimental research, namely HSQ bituminous coal and LY anthracite. Table 1 gives the industrial and elemental analysis results for the two coals.

As known from Table 1, the difference in basic characteristics of the two types of coal is very obvious. The volatile matter content of LY anthracite coal is low and the ash content is high, while HSQ bituminous coal is opposite. However, the difference in nitrogen content between the two coals is small,
which reduces the influence of nitrogen content on NO emission characteristics in the coal combustion experiment.

Table 1. Industrial analysis and elemental analysis of experimental coal samples

| Coal sample | Industrial analysis, wt.% | Elemental analysis, wt.% |
|-------------|--------------------------|-------------------------|
|             | Vad          | Mad         | Aad         | FCad        | Cad         | Had         | Oad         | Nad         | Sad         |
| HSQ         | 24.91        | 14.34       | 6.85        | 53.9        | 63.0        | 4.10        | 10.38       | 0.66        | 0.67        |
| LY          | 5.68         | 3.59        | 34.46       | 56.27       | 56.97       | 1.95        | 1.77        | 0.75        | 0.51        |

2.2. Combustion characteristic experiments

The combustion characteristics of the blended coal were tested on a STA8000 thermogravimetric analyzer. The TG-DTG method [5] is used to determine the ignition temperature $T_i$ of the pulverized coal combustion, the maximum weight loss rate $DTG_{\text{max}}$, and the temperature $T_{\text{max}}$ corresponding thereto, and the temperature at which the sample weight loss accounts for 98% of the total weight loss (burnout temperature $T_b$).

The blended coal samples HSQ/LY with various blending mass ratios (0, 30, 50, 70 and 100 wt.%) of HSQ bituminous coal were prepared and mixed well before carrying out the experiment. Coal samples with a particle size of 75μm~90μm are heated from 30°C to 1000°C in an air atmosphere at a heating rate of 50 K/min, and the air flow rate is 100 ml/min.

2.3. NO emission characteristics experiments

The main research and comparison in this work is the emission concentration of NO, because the amount of N₂O produced by pulverized coal combustion is small (the volume concentration is generally less than 20 ppm) when the combustion temperature reaches 1000°C [6-7]. Figure 1 is a system diagram of the fixed bed gantry used in this experiment, which mainly includes components such as a gas distribution system, a heating vertical furnace, a reactor, and measurement and analysis instruments.

![Diagram of fixed bed bench system for mixed coal combustion](image)

**Figure 1.** Diagram of fixed bed bench system for mixed coal combustion

As Figure 1 shows, the mixed gas is blown into the reactor from below. The screen below the reactor is used to place the coal, while the screen at the gas outlet above the reactor acts to prevent the pulverized coal from being carried out of the reactor by the gas stream.

The NO emission characteristics of the blended coal were studied with various blending mass ratios (0, 30, 50, 70 and 100 wt.%) of HSQ bituminous coal. The coal sample is fed into the reactor firstly for a total amount of 200 ± 0.5 mg. The reactor is purged with a mixed gas of 1.0 L/min (79% N₂ and 21% O₂) for 5 mins, and the airtightness has been checked to ensure good sealing. The experimental
temperature is set to 1000°C by the temperature controller and the temperature field of the furnace should be evenly distributed. The reactor is then quickly placed in the furnace to rapidly heat up the combustion reaction. After treated by the drying dust removal device, the exhaust gas is detected online using a flue gas analyzer, and the NO concentration change curve is recorded. The flue gas analyzer has a pumping force of 1.0 L/min, which is equal to the feed gas flow rate to keep the combustion under pressure equilibrium.

3. Results and discussion

3.1. Combustion characteristics of mixed coal

In order to systematically compare the combustion characteristics of blended coal with different blending ratios, a discriminant index proposed in many literatures, namely the combustion characteristic index S [8], is cited:

\[ S = \frac{(dw/dt)_\text{max} \times (dw/dT)_\text{mean}}{T_i \times T_b} \]  

\((dw/dt)_\text{max}\) is the maximum burning rate (ie, the absolute value of the maximum weight loss rate of the pulverized coal mass); \((dw/dT)_\text{mean}\) is the average weight loss rate; \(T_i\) is the ignition temperature; and \(T_b\) is the burnout temperature.

The combustion characteristic index under the five blending ratios was calculated according to the formula, and the results are shown in Fig. 1.

![Figure 1. Index of combustion characteristics of two coals at different ratios](image)

Figure 2. Index of combustion characteristics of two coals at different ratios

When the blending ratio of bituminous coal is increased, the index of combustion characteristics of the blended coal gradually increases, which indicates that blending bituminous coal with anthracite and increasing the proportion of bituminous coal can improve the combustion performance of the coal powder. The combustion performance of the blended coal is between the two single coals, but the combustion characteristics of the blended coal are not a simple superposition of the single coal components. The combustion characteristics of the blended coal are significantly different from those of the single coal, which will inevitably lead to differences in the emission characteristics of pollutants such as NO\(_x\) from coal combustion.

3.2. NO emission characteristics of mixed coal

The NO emission characteristic curve obtained from the experimental study of NO emission characteristics is shown in Figure 3.
The time for the emission of NO from bituminous coal is very short, and the peak of NO appears earlier than anthracite, indicating that the release of NO from coal with high volatile content is relatively rapid. The anthracite coal has a higher NO peak than the bituminous coal, which is because the coal with a higher volatile content usually has a higher hydrogen content. As shown by elemental analysis, the hydrogen content of HSQ bituminous coal is about twice that of LY anthracite, so in the early stage of combustion, more NOx precursors such as HCN and NH3 are formed during the precipitation of volatiles. These NOx precursors play an important role in the reduction and control of NO, which leads to the fact that the peak of NO emission of anthracite is higher than that of bituminous coal although the nitrogen content of the two coals is similar. At the same time, the bituminous coal with a relatively low degree of coalification generates a large amount of volatiles during the combustion process, which increases the porosity and the surface area of the char, thereby enhancing the char activity and the reduction effect on NO.

In the combustion process of mixed coal, the component coals have both relative independence and interaction between coal types. In order to judge whether the degree of nitrogen conversion to NO in the fuel is affected by the mixing ratio, the NO conversion rate is calculated according to formula (1) [9].

$$\text{NO conversion rate} = \frac{\int_0^t \left( \omega \times V \times P / RT \right)}{M_{(\text{fuel})} \times Y_{(N,\text{fuel})} / M(N)}$$ (2)

$\omega$ is the volume fraction of NO measured by the flue gas analyzer at a certain time in the exhaust gas; $V$ is the volumetric flow rate of the flue gas; $P$ is the atmospheric pressure; $R$ is the ideal gas constant; $T$ is the absolute temperature of the flue gas; $M_{(\text{fuel})}$ is the mass of coal sample; $Y_{(N,\text{fuel})}$ is the content of nitrogen; $M(N)$ is the relative atomic mass of nitrogen.

Although the trend of actual NO conversion rate shows the effect of mixing ratio on fuel nitrogen conversion, it may also be linearly affected only by the proportional change. Assuming that there is no interaction between the two coals and the respective N conversions are independent, the theoretical NO conversion rate is calculated for comparison with the actual NO conversion:

$$\text{Theoretical NO conversion rate} = \frac{A \times \omega_1 + B \times \omega_2}{M \times Y_1(N,\text{fuel}) \times \omega_1 + M \times Y_2(N,\text{fuel}) \times \omega_2}$$ (3)

$A$ and $B$ are respectively the nitrogen quality of NO emitted from bituminous coal and anthracite combustion; $\omega_1$ and $\omega_2$ are respectively the proportion of bituminous coal and anthracite in the blended coal; $Y_1(N,\text{fuel})$ and $Y_2(N,\text{fuel})$ are respectively the mass fraction of nitrogen in bituminous coal and anthracite.
As shown in Figure 4, it can be explained that the NO emission concentration and NO conversion rate of bituminous coal are lower than that of anthracite combined with the NO emission characteristic curve, and the increase of bituminous coal ratio can reduce NO emission concentration and NO conversion rate of blended coal.

The actual NO conversion rate is significantly different from the theoretical NO conversion rate. When the proportion of anthracite is larger, the actual NO conversion rate is higher than the theoretical value, while the opposite is true when the proportion of bituminous coal is higher. It is indicated that for the NO emission of coal-blending combustion, the two coals have a certain effect on each other, which could be performed as inhibition or promotion as the mixing ratio changes. The competition of these two interactions determines the combustion characteristics of the blended coal in the combustion process of mixed coal. The promotion effect is reflected in that the preferential combustion of bituminous coal improves the local temperature in the initial stage of combustion, promotes the ignition of the flame-retardant anthracite coal, accelerates the pyrolysis of the heterocyclic structure and tar in the coal char, and increases the fuel nitrogen converted into the gas phase. In the presence of quantitative O\textsubscript{2}, the fuel nitrogen is more likely to react with O\textsubscript{2} to form NO. The inhibition is reflected in the premature combustion of bituminous coal, which leads to the consumption of a large amount of oxygen and the anthracite burning in an under-oxidized state. Although the fuel nitrogen converted to the gas phase increases, HCN and NH\textsubscript{3} in the carbon black and the gaseous fuel nitrogen have a reducing effect on NO at lower oxygen concentrations. The interaction has obvious influence on NO emission characteristics because of the obvious difference between the two kinds of coal.

4. Conclusion

1) Mixing bituminous coal in anthracite can improve the combustion performance of pulverized coal.

2) The peak value of NO emission curve of anthracite combustion is higher than that of bituminous coal, and the release of NO from bituminous coal is relatively rapid.

3) The NO emission of mixed coal combustion is between that of the two kinds of single coal, and NO conversion rate increases gradually with the increase of blending ratio of anthracite. The interaction between the two kinds of coal has a certain effect on NO emission from blended coal combustion, which is reflected in the promotion when the bituminous coal proportion is low, and vice versa, the inhibition.

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