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NOx AND ULTRAFINE PARTICLE EMISSION CHARACTERISTICS IN A NEW STEEL SLAG MODIFICATION DEVICE

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Two density-separated Chinese coals and steel slag were prepared and then combusted in a modification furnace with different excess air ratio. Non-staged and Fuel-staged combustion experiments were compared under different pulverized coal mixing ratios. Thus, in the fuel-staged combustion experiments, the concentration of NOx in the flue gas was found to greatly decrease under a bitumite: anthracite mixing ratio of 1:1 and an air excess coefficient of 1,2 under the fuel-staged ratio is 15:85. The flue gas temperature was as high as 1 615ºC, while the NOx concentration in the flue gas was as low as 320 mg/m^3. Compared with the other types of burners, the experimental combustion device designed herein efficiently reduced the NOx emissions ca. 80 %. Fuel-staged combustion has a significant effect on reducing particulate matter (PM) emissions, and a suitable coal ratio was also beneficial for reducing particulate matter emissions.

Key words: steel slag modification, NOx emission, particulate matter (PM), coal swirl combustion

INTRODUCTION

Steel slag has become the main solid waste of the steel industry in China, with an annual production as high as 107 million tons (2016). However, since the content of free CaO (f-CaO) in steel slag is relative high, poor volume stability of steel slag will be caused, and not qualified [1, 2]. In addition, high content of metallic iron which leads to the poor grindability of steel slag, and its volume stability is not qualified [3]. Coal-based swirl combustion reforming furnace is a new type of devices allowing steel slag modification [4, 5]. The operation flow is as follows: pulverized coal and steel slag are first mixed, and then the amount of the mixed are controlled by the screw feeder, which enter into the furnace combustion from the primary outlet with air as a carrier. Currently, most of the researches in domestic and international on thermal modification of steel slag focus on using waste heat of steel slag to melt additive or modifying agent, in order to adjust the physical and chemical properties of steel slag. However, for other previously reported similar steel slag reforming devices, their thermal efficiency, NOx emission and the particulate size distribution are not systematically reported up to now. It increasing its thermal efficiency and reducing NOx emissions are important prerequisites for its industrialization [6-8].

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EXPERIMENTAL FACILITY AND MATERIALS

The proximate and ultimate analysis of bitumite and anthracite are presented in Table 1. The composition of slag steel is also shown in Table 1.

Table 1 **Physical properties of the steel slag, bitumite, and anthracite materials**

The test project	Bitumite	Anthracite	
Proximate analysis /wt.%, as received			
Moisture	2	2,04	
Ash	12,02	15,48	
Volatile matter		32,23	8,5
Fixed carbon		53,75	73,98
Net calorific value /kJ/kg		29620	29440
Ultimate analysis /wt.%, dry ash free			
C		70,7	73,86
H		4,43	3,01
S		2,06	2,35
N		1,39	1,1
O		7,4	2,16
Composition /wt. %, dry basis		Steel slag	
CaO		36,8	
SiO_2		15,4	
MgO		7,56	
Al_2O_3		0,87	
Fe_2O_3		17,43	
FeO		9,48	
MFe		3,43	
TFe		23	

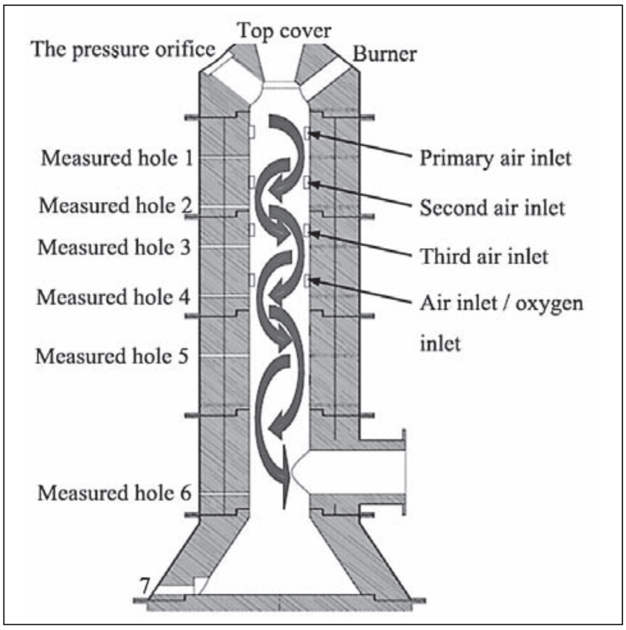

Figure 1 Schematic diagram of the combustion system

Experiments were conducted in a swirl one-dimensional, self-designed, down-fired coal combustor, with 240 mm ID (Inner Diameter) and 3,5 m height. The detailed descriptions of this facility as well as operation procedures were shown in Figure 1 and Table 2. The coal feed style was divided into a non-staged and fuel-staged. Non-staged feed means that all the coal and steel slag enter from the primary air outlet into the furnace. But for the fuel-staged feed, the coal and steel slag with a certain percentage separately enter from the primary air outlet and the secondary outlet into the furnace combustion.

Each gas-sampling hole was equipped with a sampling tube, and all sampling tubes were connected with the main sampling tube connected to a gas analyzer. By switching the valve between each sampling tube and the sampling main tube, the gas coming out each sampling hole can be individually analyzed. The measurements of the species present in the flue gas were carried out by a NOVA PLUS-S enhanced flue gas analyzer (German MRU Company). The aerosol monitor equipment (DustTRAKTM II) was used to measure the particle size of PM_1, $PM_{2.5}$, PM_4, PM_{10} and inhalable particles produced during the combustion process.

Table 2 **The coal ratio of non-staged and fuel-staged**

Quantity	100 %	3:2	1:1	2:3
Non-staged	a b c	a b c	a b c	a b c
Fuel-staged	a b c	a b c	a b c	a b c

Note: a, b, c, represents the air excess coefficient of 1,4, 1,2, 1,0, respectively. 100 %, 3:2, 1:1, and 2:3 represent the ratio of bitumite and anthracite.

RESULTS AND DISCUSSION

Figure 2 suggested that the concentration of NOx increased gradually with the decreased air excess coefficient. When the ratio of bitumite to anthracite was 1:1 and the air excess coefficient was 1,2, the NOx concentration in the flue gas was relatively low. In the case of 1,2 and the fuel-staged ratio of 15:85, the flue gas temperature was 1 615 °C, and the minimum NOx concentration in the flue gas was 320 mg/m^3 (Figure 2b). The NOx concentration in the flue gas was minimum in the measured hole 6. The above results demonstrated that flue gas NOx concentration obtained herein was significantly lower than those obtained by other similar combustion devices.

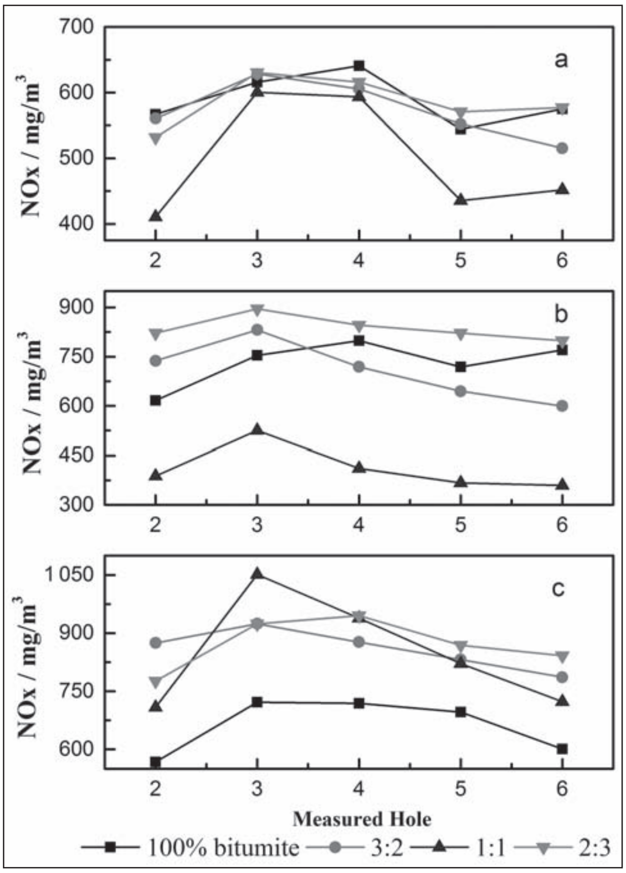

Figure 2 Variation of the concentration of NOx for each measured hole under different coal ratios and fuel-staged is 15:85. a) Air excess coefficient of 1,4. b) Air excess coefficient of 1,2. c) Air excess coefficient of 1,0.

The burnout ratios of the non-staged experiments and the average values of the different fuel-staged burnout ratios with different coal ratios are shown in Figure 3. As can be seen, the burnout ratios of the fuel-staged experiments were higher than those of their non-staged counterparts under various ratios. The burnout ratios obtained for both non-staged and fuel-staged experiments were equal or better than those achieved by other burners.

Our previous studies have indicated that the emission concentration of NOx, SO_2 and particulate matter will have the lowest value when the fuel-staged ratio is 15:85. Therefore, the particulate matter is the object of the following part under the condition of different coal ratios and fuel-staged ratio of 15:85.It can be seen from Figure 4 that the concentration of particulate matter

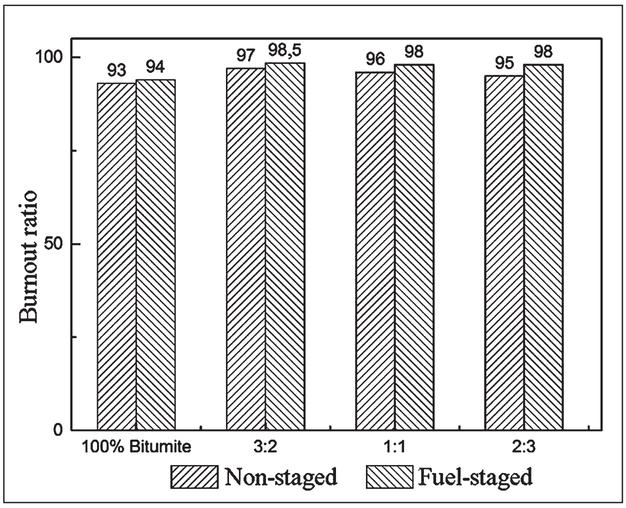

Figure 3 Burnout ratios for the different coal ratios under non-staged and fuel-staged conditions

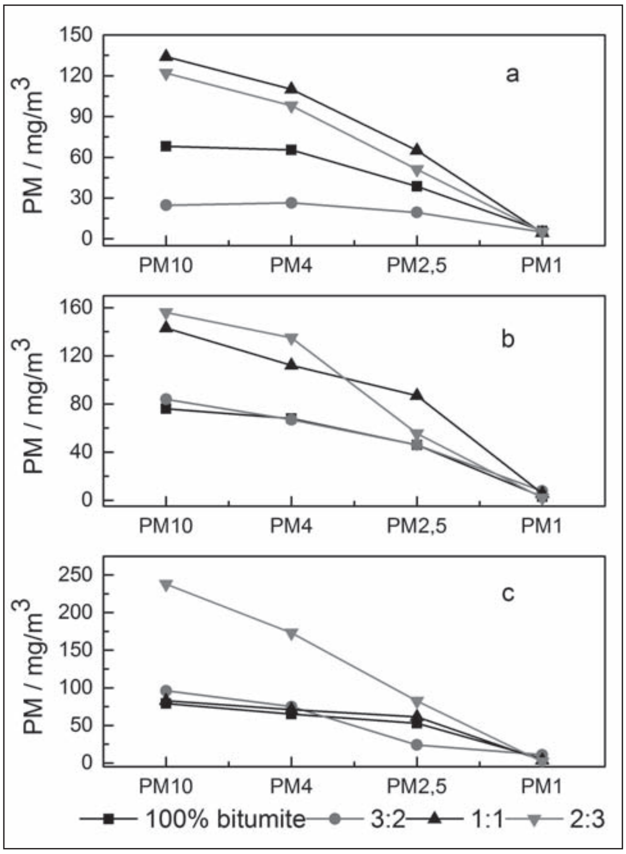

Figure 4 Particulate matter concentrations under different coal ratios and fuel-staged ratio of 15:85 conditions. a) Air excess coefficient of 1,4. b) Air excess coefficient of 1,2. c) Air excess coefficient of 1,0.

(PM_1, $PM_{2,5}$, PM_4, and PM_{10}) is not at the highest value under 100 % bitumite and fuel-staged combustion. At the same time, the concentration of particulate matter released with the fuel-staged combustion is lower than that of non-staged combustion under different air excess coefficients. Visible fuel-staged combustion has a significant effect on reducing particulate emissions. On the one hand, the fuel-staged combustion can make the furnace temperature higher than the non-staged combustion, and high temperature can make the particles better melt and gather in the ash, and finally reduce fly ash particulate matter emissions. On the other hand, under high temperature condition, alkali metals and other elements are more volatile, form more submicron particles smaller than 1 mm, and thus reduce the proportion of PM_1, $PM_{2.5}$, PM_4, and PM_{10}. When the coal ratio is 3:2, the emission concentration of each particle size is in low level, which indicates that the appropriate coal ratio is also beneficial to reduce the emission of particulate matter.

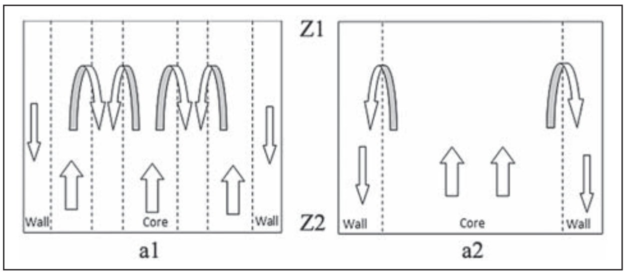

Figure 5 Air flow field from Z1 (measured hole 1) to Z2 (measured hole 4) cross-section

In the device between the Z1 and Z2 cross section, the main existence of the above two air flow state. As shown in Figure 5, air flow state is more conducive to hot experiments in mixing coal and prolonging burning time. This is beneficial to improve combustion efficiency and reduce pollutant emissions. At the same time, it can reduce the particulate matter emission.

CONCLUSIONS

When the ratio of bitumite to anthracite was 1:1 and the air excess coefficients were 1,4 and 1,2 under fuel-staged combustions, the NOx concentration in the flue gas was low. Under air excess coefficient of 1,2 and a fuel-staged ratio of 15:85, the flue gas temperature reached 1 615 ºC, while the minimum NOx concentration in the flue gas was 320 mg/m^3.

The concentration of particulate matter under the condition of three excess air coefficients (1,4, 1,2, and 1,0) has the following relationship: $PM_{10} > PM_4 > PM_{2.5} > PM_1$, indicating coal particles are more likely to produce large particulate matter during the swirling combustion process. 100 % bitumite combustion can be clearly seen PM_{10}, PM_4, $PM_{2.5}$, PM_1 emission concentration higher than other coal ratio combustion particulate matter emission concentration. The difference of the particulate matter emission concentration under the other three kinds of coal ratio (3:2, 1:1, and 2:3) and non-staged combustion conditions is small.

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Note: The responsibile for English language is the lecturer from University of Science and Technology, Beijing