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# Experimental Investigation on Co-Combustion Characteristics of Bituminous Coal and Semi-coke Blends in a 660 MW Utility Boiler

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## ABSTRACT

With the rapid development of the low-rank coal chemistry industry, the production of semi-coke has ever been increasing. However, the semi-coke is difficult to burnout and the $NO_x$ generation during semi-coke combustion is high. Therefore, the co-combustion of semi-coke and bituminous coal in utility boiler is considered as a promising approach to realize the efficient utilization of the semi-coke. Here, the co-combustion features of bituminous coal and semi-coke blends were investigated in a 660 MW utility boiler. The results show that the $NO_x$ generation decreases firstly and then increases with the rises of the load and the fraction of semi-coke. The effects of load and blending ratio of semi-coke are both obvious on burnout behavior than those on $NO_x$ generation. With the rise of oxygen concentration, the $NO_x$ generation rises and the unburned carbon in fly ash decreases. The Na-bearing mineral are better-preserved with the higher oxygen concentration. The experimental results may provide guidance for the realization of the utilization of the semi-coke in the utility boiler.

**Keywords:** co-combustion, semi-coke, 660 MW utility boiler, blends, bituminous coal

## NONMENCLATURE

| | |
|---|---|
| *Abbreviations* | |
| TGA | Thermogravimetric Analysis |
| BC | Bituminous Coal |
| SC | Semi-Coke |

## 1. INTRODUCTION

The semi-coke is the by-product of the low-rank coal chemistry industry. However, the firing features of semi-coke is poor due to its low volatile content. Some scholars put forward that the semi-coke could be burned in circulating fluidized bed boiler with preheated technology [1, 2]. However, the new equipment and/or much reconstruction are necessary for the boiler to fire semi-cokes. Therefore, the co-combustion of bituminous coal and semi-coke in boiler is considered as an efficient mean to consume the semi-coke by some studies [3-5].

Some scholars studied the chemical and physical characteristics of semi-coke [2, 6, 7]. Zhang et al. [8] studied the firing and NO formation features of semi-coke using TGA and drop tube furnace experimental system. The results implied that the reactivity of semi-coke could be improved by the addition of $CO_2$ and $O_2$. The NO generation and burnout ratio could be reduced significantly by addition of $O_2$. Liu et al. [6] studied the physical features like structure of the semi-coke. The experimental results indicated that the microwave radiation time and pyrolysis temperature both have obvious effects on complex relative permittivity and resistivity of the semi-cokes. However, these scholars mainly focused on the characteristics of semi-coke. And other studies concentrated on the co-firing features of bituminous coal and semi-coke blends [9-11]. Zheng et al. [12] investigated the ignition and burnout features of bituminous coal and semi-coke blends. The results showed that the co-combustion features were improved with the proportion of bituminous coal, and the midterm reaction process was enhanced with the temperature raised from 850 ℃ to 1050 ℃. Yao et al. [11] studied the oxy-fuel co-firing features of semi-coke and bituminous coal. The results implied that the burnout performance of blends was improved significantly in $O_2/CO_2$ atmosphere. While above scholars both studied the co-combustion characteristics of bituminous coal and semi-coke in laboratory. Few studies of co-combustion of bituminous coal and semi-coke have been performed in utility boiler, therefore the co-firing of bituminous coal with semi-coke in utility boiler need to be further discussed. Moreover, the interactions between bituminous coal and semi-coke are still unclear.

In the present, the co-combustion characteristics of bituminous coal and semi-coke blends were investigated in a 660 MW utility boiler. The $NO_x$ generation and burnout features of bituminous coal and semi-coke blends in utility boiler were revealed. In addition, the interactions between bituminous coal and semi-coke on co-firing features were further discussed. The experimental results may provide guidance for the co-combustion of bituminous coal and semi-coke in the utility boiler.

## 2. EXPERIMENTAL

The 660 MW supercritical once-through boiler, which was a single-furnace structure with a "π" construction, was utilized to investigate co-combustion behaviors of semi-coke and bituminous coal. The boiler adopted wall-type tangential combustion method in the main combustion zone, while the burners of separated over fire air were arranged at four corners of the water wall above the main combustion zone to achieve the staging combustion and reduce the $NO_x$ emission. The parameters under the boiler maximum continuous rate operating condition were used as design parameters, and the initial steam flow rate and the superheated steam outlet temperature were 2210 t/h 571 ℃, respectively. The boiler had 6 layers of burners, which could be fully loaded when 5 layers of burners were operating. The general diagram of the boiler and the arrangement of the burners are shown in Fig. 1. The value of $NO_x$ generation was measured at the outlet of the air preheater, and the value of unburned carbon content was collected from the fly ash at the outlet of the air preheater.

The proximate and ultimate analyses of bituminous coal (BC) and semi-coke (SC) are showed in Table 1. The volatile content of SC is below 1/3 volatile content of BC. Here, the effects of load, blending ratio of semi-coke and oxygen concentration were discussed. The experimental parameters and case conditions were shown in Table 2.

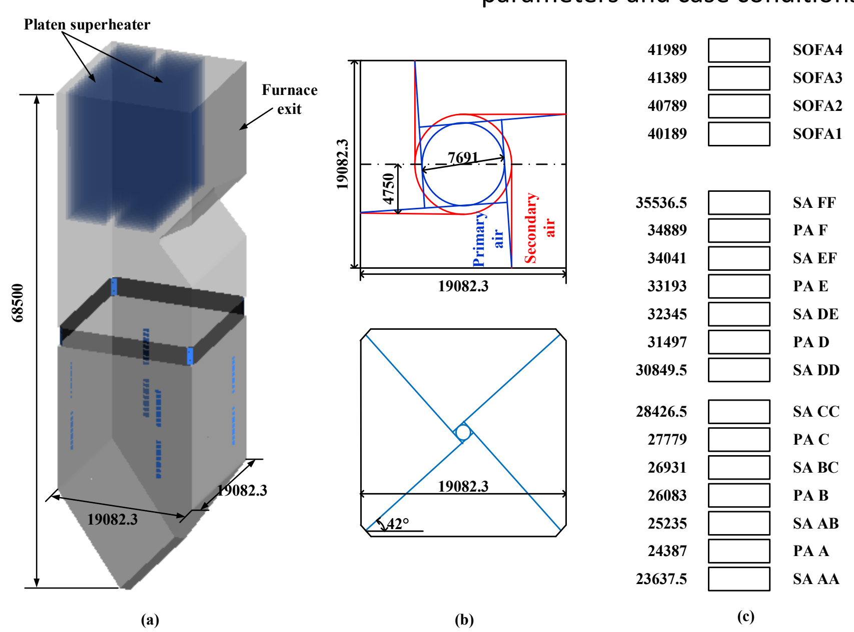


Fig.1 The Schematic diagram of the 660 MW utility boiler experimental system (a) the general diagram of the boiler, (b) and (c) the arrangement of the burners

Table 1. The chemical properties of three samples

| Sample | Proximate analysis (*wt*%, ar) | | | Ultimate analysis (*wt*%, ar) | | | | | $Q_{net,ar}$ ($MJ \cdot kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| | *w*(V) | *w*(A) | *w*(FC) | *w*(C) | *w*(H) | *w*(N) | *w*(S) | *w*(O)[a] | |
| BC | 23.27 | 35.49 | 41.24 | 44.56 | 3.12 | 0.76 | 1.48 | 8.59 | 17.54 |
| SC | 7.62 | 9.73 | 82.65 | 75.33 | 1.48 | 1.12 | 0.28 | 0.02 | 25.51 |

[a] calculated by difference

Table 2. Experimental parameters and case conditions

| Parameters | Cases |
|---|---|
| Load | 450 MW, 550MW, 660MW |
| Blending ratio of semi-coke | 20%, 40%, 50% |
| Oxygen concentration | 3.2%, 3.5%, 3.8% |

## 3. RESULTS AND DISCUSSION

### *3.1 Effects of load*

The loads of 450 MW, 550 MW and 660 MW were investigated in the experiment. As shown in Fig. 2, the unburned carbon in fly ash is raised with the load. The $NO_x$ generation reduces firstly and then rises with the load. The change of $NO_x$ generation with load is insignificant, while the change of unburned carbon in fly ash is obvious. When the load is raised from 450 MW to 660 MW, the unburned carbon content in fly ash is raised by 42.92%, and that of $NO_x$ generation is increased by 5.31%. It could be concluded that the effects of load is more significant on burnout behavior than $NO_x$ generation.

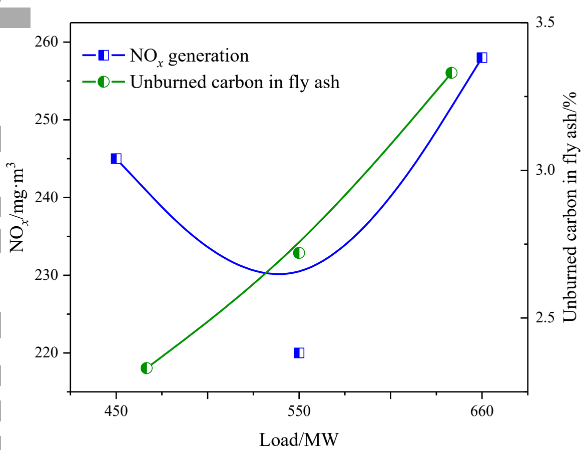


Fig. 2 Change of $NO_x$ generation and unburned carbon content in fly ash with the load

### *3.2 Effects of blending ratio of semi-coke*

In order to clarify the effects of blending ratio of semi-coke on co-firing features, the semi-coke proportions of 20%, 40% and 50% were studied. As depicted in Fig. 3, the unburned carbon in fly ash increases with the blending ratio of semi-coke, while the $NO_x$ generation decreases firstly and then rises with the increase of the semi-coke proportion. The volatile content of semi-coke is lower than that of bituminous coal, therefore the combustion features could be weakened with the rise of blending ratio of semi-coke. Moreover, the effects of blending ratio on burnout behavior are more obvious than that on $NO_x$ generation.

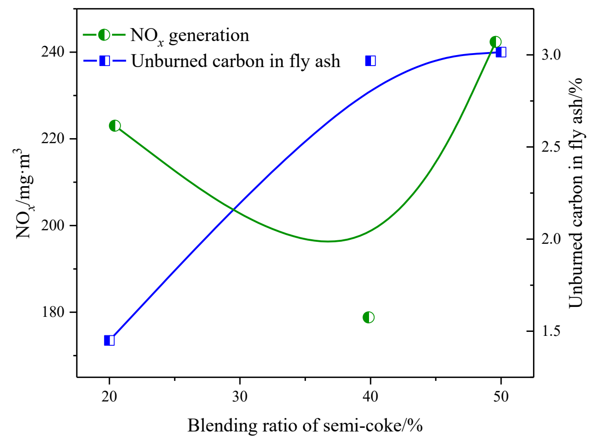


Fig. 3 Change of $NO_x$ generation and unburned carbon content in fly ash with the blending ratio of semi-coke

### *3.3 Effects of oxygen concentration*

The oxygen concentration was measured before the air preheater. In the present, the oxygen concentrations of 3.2%, 3.5% and 3.8% were investigated. With the rise of oxygen concentration, the $NO_x$ generation increases and the unburned carbon in fly ash reduces. When the oxygen concentration is raised from 3.2% to 3.5%, the $NO_x$ generation is increased by 19.57% and the unburned carbon in fly ash is reduced by 24.12%. Therefore, the effects of oxygen concentration are more significant on burnout performance than that on $NO_x$ generation with the rise of oxygen concentration.

The ash composition of fly ash is shown in Table 3. With the rise of oxygen concentration, the changes of oxides are unobvious. The fraction of $Na_2O$ reduces with the increasing oxygen concentration. Therefore, the Na-bearing mineral are better-preserved with the higher oxygen concentration.

Table 3. Ash composition of the fly ash

| Oxides | Oxygen concentration | | |
|---|---|---|---|
| | 3.2 | 3.5 | 3.8 |
| CaO | 5.75 | 5.3 | 5.8 |
| MgO | 0.684 | 0.627 | 0.716 |
| $SO_3$ | 1.09 | 1.16 | 1.13 |
| $Na_2O$ | 0.566 | 0.553 | 0.545 |
| $Al_2O_3$ | 36.6 | 36.2 | 37.4 |
| $SiO_2$ | 42.5 | 41.3 | 43.6 |
| $Fe_2O_3$ | 3.57 | 3.06 | 3.62 |
| $TiO_2$ | 1.39 | 1.3 | 1.38 |
| $K_2O$ | 0.915 | 0.851 | 0.918 |

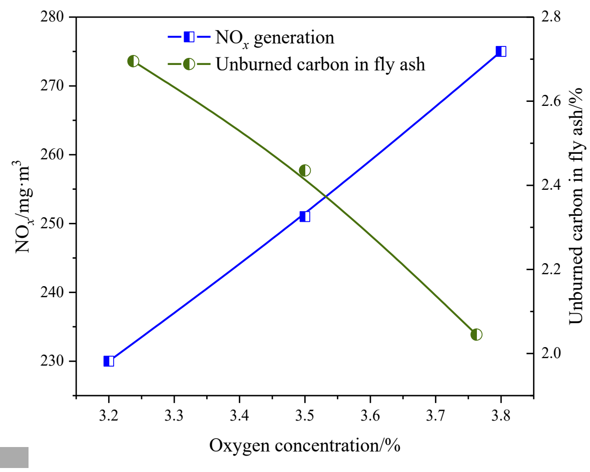


Fig. 4 Change of $NO_x$ generation and unburned carbon content in fly ash with the oxygen concentration before the air preheater

## 4. CONCLUSION

Here, the co-firing features of bituminous coal and semi-coke blends in a 660 MW utility boiler were investigated. The burnout performance and $NO_x$ generation characteristics of blends were discussed. Moreover, the effects of interactions between bituminous coal and semi-coke on co-firing features were further discussed. The main conclusions are as follows:

The $NO_x$ generation reduces firstly and then rises with the increases of the load and the fraction of semi-coke. The effects of load and blending ratio of semi-coke are both obvious on burnout performance than those on $NO_x$ generation. With the rise of oxygen concentration, the $NO_x$ generation rises and the unburned carbon in fly ash decreases. The Na-bearing mineral are better-preserved with the higher oxygen concentration.

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