Study on coking of High Moisture Lignite in coal fired boiler

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Abstract: The coking problem of coal-fired boiler seriously affects the economy and safety of the boiler. At the same time, the work of poking coke after coking in the boiler poses a great threat to the personal safety of poking coke personnel, which violates the purpose of establishing ”intrinsic safety” in the power industry. Therefore, it is very important to analyze the factors affecting the coking of coal-fired boiler and effectively prevent the coking of coal-fired boiler. This paper studies the coking situation of High Moisture Lignite in a certain type of coal-fired boiler, calculates the characteristics of lignite, analyzes the causes of coking, and puts forward the optimization scheme of blending combustion and the research direction of burner adjustment in operation, so as to improve the coking situation in the process of operation.

1. Introduction
As the power equipment of coal, boiler is prone to coking, which affects the safety and economy of coal-fired boiler. A large number of researches have been carried out on the coking problem of coal-fired boilers at home and abroad, mainly focusing on the coal quality factors and external conditions. When the boiler is running, the pulverized coal is burned in the furnace, and the melted or partially melted particles are entrained in the flue gas. They exchange heat with the water wall, convection tube and burner in the furnace, and release heat together with the flue gas to lower the temperature. Before approaching the water wall, burner and inner wall of the furnace, if the temperature of the softened ash particles decreases and condenses, a loose ash layer will be formed on the heating surface, it can be removed by soot blowing. When the combustion area is overheated at high temperature, part of the ash is in the state of melting and semi melting without enough cooling and heat release before contacting the water wall. At this time, the ash has relatively high viscosity and is easy to be adsorbed on the water wall, burner and water wall. The adhered particles are easy to adhere to other ash particles and make the slagging surface continue to expand[1]. Therefore, improving the fusibility of coal ash is an effective way to prevent coal-fired boiler from coking. In this paper, the coking reasons of High Moisture Lignite in the combustion process of a specific boiler are analyzed in detail. The fusibility of lignite coal ash is calculated and analyzed. The preliminary scheme of coal blending and combustion adjustment which can reduce coking is put forward. This paper can provide reference for how to operate safely when lignite is fired from coal fired boiler.

2. General situation
The engineering boiler of 660MW Unit in a power plant is a type of boiler with ultra supercritical parameters, spiral furnace, primary reheat, balanced ventilation, solid slag discharge, all steel frame and tight closed layout. The boiler is equipped with built-in start-up system without start-up
circulating pump. The design coal of boiler is lignite, and the check coal is lignite. The boiler adopts medium speed mill direct blowing pulverizing system, front and rear wall opposed combustion mode, and is equipped with B & W hpax-x ultra-low NOx swirl burner and OFA nozzle. The tail of the boiler is equipped with a flue, and the flue gas temperature regulating baffle is used to regulate the outlet steam temperature of the reheater. Two three compartment rotary air preheaters are set under the boiler shaft[2].

2.1. Coal quality analysis of boiler design coal and check coal

| Serial number | Name                        | Symbol | Unit | Design coal type | Check coal type |
|---------------|-----------------------------|--------|------|------------------|----------------|
| 1             | As received carbon          | Car    | %    | 40.89            | 37.95          |
| 2             | As received hydrogen        | Har    | %    | 2.77             | 2.44           |
| 3             | As received oxygen          | Oar    | %    | 9.87             | 10.04          |
| 4             | As received nitrogen        | Nar    | %    | 0.52             | 0.42           |
| 5             | As received sulfur          | St,ar  | %    | 0.21             | 0.35           |
| 6             | Ash content of as received basis | Aar | % | 10.24 | 17.50 |
| 7             | As received basis moisture  | Mt     | %    | 35.50            | 31.30          |
| 8             | Air drying based moisture   | Mad    | %    | 9.32             | 9.69           |
| 9             | Dry ash free volatile matter | Vdaf | % | 48.26 | 44.26 |
| 10            | Low calorific value of as received basis | Qnet,ar | MJ/kg | 14.690 | 13.500 |
| 11            | Grindability coefficient    | HGI    |      | 58               | 63             |
| 12            | Silicon dioxide             | SiO2   | %    | 52.51            | 56.83          |
| 13            | Aluminum oxide              | Al2O3  | %    | 19.76            | 17.53          |
| 14            | Ferric oxide                | Fe2O3  | %    | 5.87             | 5.71           |
| 15            | Calcium oxide               | CaO    | %    | 12.57            | 9.84           |
| 16            | Titanium oxide              | TiO2   | %    | 0.49             | 1.14           |
| 17            | Potassium oxide             | K2O    | %    | 1.23             | 1.05           |
| 18            | Sodium oxide                | Na2O   | %    | 1.63             | 1.39           |
| 19            | Magnesium oxide             | MgO    | %    | 1.45             | 1.86           |
| 20            | Sulfur trioxide             | SO3    | %    | 3.78             | 3.65           |
| 21            | Other                       |        | %    | 0.68             | 0.95           |
| 22            | Ash deformation temperature | DT     | °C   | 1190             | 1230           |
| 23            | Ash softening temperature   | ST     | °C   | 1220             | 1240           |
| 24            | Gray Hemisphere temperature | HT     | °C   | 1230             | 1250           |
| 25            | Ash fusion temperature      | FT     | °C   | 1250             | 1290           |
3. Calculation and analysis of coking causes

3.1. Summary of boiler coking causes

The coking of pulverized coal boiler can be divided into local coking and uniform coking in the whole furnace. No matter what kind of coal coking, and whether the coking part is local or the whole furnace, their coking mechanism or direct cause is relatively clear, mainly depends on two aspects. On the one hand, it is the ash melting characteristics of coal, that is, different coal quality has specific deformation temperature DT, softening temperature St, hemispherical temperature HT and melting temperature Ft. Generally, the softening temperature st of coal ash is used as the main index to measure its fusibility in industry. On the other hand, in the process of coal combustion in the furnace, due to the design of combustion equipment and the actual combustion organization, the actual temperature level of coal ash in different areas of the furnace is formed. When the temperature of coal powder and coal ash in the furnace or combustion reaches the characteristic temperature of coal ash softening temperature st, the coal ash reaches the temperature level of coking. According to the operation experience of pulverized coal boiler, if the softening temperature st of coal ash is less than 1350 °C, it may cause furnace coking and affect the safe operation of boiler.

3.2. Calculation on coking of lignite

According to the design parameter table of the boiler, the design coal and check coal of the boiler are high moisture lignite, the softening temperature of the design coal is 1220 °C, the melting temperature is 1250 °C, the softening temperature of the check coal is 1240 °C, and the melting temperature is 1290 °C. In the actual operation, the power plant is a coal mine pit power plant, which uses a large number of single coal, and the coal parameters are similar to the check coal.

Since the softening temperature of coal ash is 1240 °C, it can be preliminarily determined that the actual coal is slagging coal. The difference between softening temperature st and deformation temperature DT is \(S_t - DT\) = 1240 - 1230 = 10 °C. It is generally considered that the difference between ST and DT is long slag at 200 ∼ 400 °C and short slag at 100 ∼ 200 °C. Because the temperature interval is very small, the viscosity of ash changes sharply with the temperature, and only slagging will be formed in a short time.

### Table 2. Criteria for slagging index

| Parameter                     | Slight slagging | Medium slagging | Serious slagging |
|-------------------------------|-----------------|-----------------|------------------|
| Acid base ratio B / A         | <0.206          | 0.206 ∼ 0.400   | >0.400           |
| Silicon ratio G               | >0.788          | 0.661 ∼ 0.788   | <0.661           |
| Si / Al ratio C               | <1.87           | 1.87 ∼ 2.65     | >2.65            |
| Iron calcium ratio D          | <0.3 or >3.0    | 0.3 ∼ 3.0       | Close to 1       |
| Comprehensive slagging index R| <1.5            | 1.5 ∼ 2.5       | >2.5             |

Acid base ratio of coal ash
\[ B/A = \frac{\omega(Fe_2O_3) + \omega(CaO) + \omega(MgO) + \omega(Na_2O) + \omega(K_2O)}{\omega(SiO_2) + \omega(Al_2O_3) + \omega(TiO_2)} = 0.263 \]  \hspace{1cm} (1)

Silicon ratio \( G = \frac{\omega(SiO_2)}{\omega(SiO_2) + \omega(Fe_2O_3) + \omega(CaO) + \omega(MgO)} = 0.765 \)  \hspace{1cm} (2)

Si / Al ratio \( C = \frac{\omega(SiO_2)}{\omega(Al_2O_3)} = 3.24 \)  \hspace{1cm} (3)

Iron calcium ratio \( D = \frac{\omega(Fe_2O_3)}{\omega(CaO)} = 0.58 \)  \hspace{1cm} (4)

Comprehensive slagging index \( R = 5.415 - 1.9G + 1.237B/A - 0.002ST + 0.282C = 2.72 \)  \hspace{1cm} (5)
Table 3. Calculation results analysis of coal ash slagging index

| Project    | B/A  | G    | C    | D    | R    |
|------------|------|------|------|------|------|
| Numerical  | 0.263| 0.765| 3.24 | 0.58 | 2.72 |
| Slagging   | Medium slagging | Medium slagging | Serious slagging | Medium slagging | Serious slagging |

It can be seen from the calculation results in Table 3 that there are three "medium" and two "serious" judgment indexes for this kind of coal, with strong slagging property.

3.3 Boiler coking
In actual operation, the furnace outlet temperature is about 710 °C - 780 °C. There is serious coking around the furnace burner and OFA nozzle. The coking is shown in Figure 1 and Figure 2. There are four cold ash hoppers at the bottom of the furnace, among which the 1 and 4 cold ash hoppers near the left and right furnace walls have a large amount of coke drop during operation. It can be judged that boiler slagging is caused by the fact that the actual temperature level of some areas in the furnace is higher than the characteristic temperature of coal ash softening temperature due to the design of combustion equipment and actual combustion organization, resulting in boiler coking.

Comprehensive analysis shows that there are two causes of coking in this boiler. The first is the coal ash used in boiler, which has low melting temperature and strong slagging. The second reason is that the local temperature inside the furnace is too high and local coking is formed due to the combustion organization and adjustment in the actual operation process.

4. Description of adjustment plan
4.1 Improving the fusibility of coal ash
Because the power plant is a pithead power plant, using a single coal type, the existing coal type can not be changed, and the surrounding coal types are all high moisture lignite, and the coal property parameters have little difference. Therefore, in the case that the existing coal type can not be changed, there are only two ways to increase the ash fusion temperature of the existing pulverized coal by using chemical coke remover in operation or adding additives into the coal into the furnace. Due to the high
cost of using decoking agent and the safety risk of manual operation, it is not recommended to use it. The feasibility of adding additives to pulverized coal is high, which is discussed in this paper.

Because the melting temperature of acidic components (SiO$_2$, Al$_2$O$_3$, TiO$_2$) of coal is generally higher than that of basic components (Fe$_2$O$_3$, Cao, MgO, K$_2$O, Na$_2$O), it is generally believed that the more acidic components in coal, the higher the melting temperature of coal ash, the less slagging. According to Table 2, SiO$_2$, Al$_2$O$_3$ and Cao are the main components of coal ash, and the melting point is high, which plays a major role in the melting temperature of coal ash. At the same time, the influence of SiO$_2$ on the melting temperature of coal ash is complex. After the combination of SiO$_2$ and Al$_2$O$_3$ to form kaolin (Al$_2$O$_3$.SiO$_2$), the melting point is higher. If there is excessive, the co crystal will be formed by the combination of Cao and MgO, which will lead to the decrease of the fusibility of coal ash. So how to enlarge the difference of acid-base oxide in ash is the key to improve the melting temperature of ash. According to the calculation in 2.2, it can be found that the coking of coal ash can be effectively improved by adding SiO$_2$ or Al$_2$O$_3$ rich substances in coal to improve the melting temperature of ash. Compared with various materials, quartz sand is a suitable additive in SiO$_2$ or Al$_2$O$_3$ rich materials. It can be added with a certain proportion of quartz sand in coal to improve the fusibility of coal ash and improve the coking condition of boiler. Due to the limited conditions, the proportion of quartz sand addition can be obtained by further test.

4.2. Adjustment of combustion equipment and operation parameters

The combustion system of the boiler is composed of HPAX-X low NOx dual air swirl burner, OFA nozzle, air box of front and rear wall compartment, fuel oil system in front of the boiler, micro oil ignition system equipment, local ignition equipment in front of the boiler and flame detector. 35 HPAX-X pulverized coal burners are respectively arranged on the front and rear walls of the boiler, including three layers of front wall and four layers of rear wall, with 5 burners in each layer. There are 7 OFA nozzles on the front and rear walls (14 in total). According to the combustion characteristics of lignite with high moisture content and high primary air rate, combined with the requirements of boiler efficiency and NOx emission, HPAX-X low NOx dual air swirl burner is adopted in the power plant, and OFA nozzle is added at the same time. The NOx emission can be further reduced by distributing part of the combustion air of the main burner to the OFA nozzle by means of staged air supply.

According to the above boiler coking situation, the amount of coking around burner and OFA nozzle, left and right sides of furnace is large. Regardless of the influence caused by the installation position error of burner equipment, the study on the structure of this type of burner shows that the shape of the outlet air flow of swirl burner, the size of the recirculation zone, the swirl intensity of the external secondary air and the burnout air have a great influence on the regional slagging. The recirculation flow pattern is conducive to the ignition of pulverized coal flow and enhances the combustion stability. However, due to the combustion of pulverized coal particles carried by high temperature flue gas around the burner, a local high temperature zone is formed, and a large amount of unburned pulverized coal is contained, which causes slagging in the above zone. Therefore, the opening of internal and external secondary air blades should be appropriately increased, Reducing swirl intensity is an effective measure to reduce local coking. According to the structure of this type of burner, the adjustable blade is used in the burner to form a stable backflow zone at the root of the pulverized coal flame. The blade angle is usually set at about 40 degrees. If the opening angle is greater than 50 degrees, the stability of ignition will be reduced. If the opening angle is less than 30 degrees, the dust will accumulate in the internal secondary air zone, resulting in air flow blockage, and the burner may overheat. The external secondary air regulating blade is usually set at about 60 degrees. If the opening angle is greater than 70 degrees, the ignition stability will be reduced, and if the opening angle is less than 50 degrees, the flame shape will be destroyed. The setting position of all burner blades shall be consistent as far as possible.

After burner adjustment, the OFA nozzle should be adjusted. These adjustments need to be carried out when the boiler is in full load operation, that is, when the air flow into the OFA nozzle is relatively large. For uniform air distribution, the regulating sleeve, central regulating disc and swirl blade of
OFA nozzle need to be adjusted respectively. The specific adjustment method and the opening of internal and external secondary air blades need to be further studied and determined through the operation process adjustment.

5. Conclusion
In recent years, with the increasing load of power plant, the pressure level of boiler is also higher and higher, the combustion temperature of pulverized coal boiler furnace is high, and the coking situation of furnace is more sensitive to the change of coal quality. The internal cause of boiler slagging is coal ash melting characteristic, and the external cause is furnace structure, burner structure, primary and secondary air volume regulation, burner area heat load, burner area volume heat load and wall heat load. In this paper, through the research and calculation of High Moisture Lignite and its coking state in a specific type of boiler combustion, some suggestions and directions to improve the furnace coking are put forward, hoping to provide help for the actual operation and further research of power plant.

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