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Original Research Article

Technical Research on Widening the Adaptability of Coal Types after Low-nitrogen Combustion Transformation of 300MW Lean Coal Boiler

LIAN Guo-dong[1], LI Hao[2], JIANG Nan[3]

Hebei Huadian Shijiazhuang Yuhua Thermal Power Co.，Ltd.，Shijiazhuang 051430，China

Abstract: In view of the problems such as poor adaptability of coal types, frequent slagging of boilers, and difficulty in mixing and burning after low nitrogen combustion transformation of lean coal units, the boiler shall be transformed to improve the safety and economy of boilers by improving the boiler power field and combustion stability.

Keywords: Low nitrogen transformation; Coal quality fluctuation; Furnace fire extinguishing; Discharge standard.

1. Introduction

Affected by various factors such as the rise in international energy prices and the marketization of coal prices in recent years, various provinces across the country are facing a shortage of electric coal. Power plants are taking multiple measures to ensure the purchase of raw coal and to ensure the safe operation of the unit over a long period of time. Our factory has consumed approximately 1.54 million tons of raw coal in 2021. There are over 40 coal suppliers, with 10 types of coal entering the factory. There are multiple channels for purchasing coal, diverse coal sources, multiple types of coal, and poor coal quality stability. In response to the problems of mixed coal sources, multiple types of coal, poor coal quality stability, and deviation from design values in thermal power plants, each plant is exploring coal fired units to expand coal type adaptability technology, ensure the stability of boiler combustion adjustment and operation safety, and strive to meet emission standards.

Since 2015, due to low nitrogen transformation and coal quality fluctuations, our plant has experienced multiple furnace fire extinguishing incidents caused by severe slagging, resulting in MFT actions and subsequent tripping accidents, seriously affecting the safe and stable operation of the unit.

2. Boiler Operation Problems and Analysis

2.1 Boiler Overview

The 300MW unit boiler is manufactured by Shanghai Boiler Factory, with subcritical pressure parameters, natural circulation, primary intermediate reheating, single furnace balanced ventilation, solid slag removal, semi open-air layout, and a small steel frame drum furnace with four corner tangential combustion. The intermediate storage pulverization system adopts a steel ball mill and a hot air powder delivery system. The original design coal type of the boiler was Shanxi lean coal, and a low nitrogen burner transformation was carried out in 2014.

2.2 Current Situation Investigation

The technical backbone of the boiler profession organized a professional analysis meeting, established a research group, and proposed the main problems currently faced by the boiler:

Poor adaptability of coal types: Except for lean coal, serious slagging occurs during the co firing of anthracite and bituminous coal, and the melting point of all incoming coal ash is required to be no less than 1500, resulting in multiple boiler collapse and fire extinguishing accidents.

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Poor combustion stability: During the mixing of low volatile coal and low calorific value coal in the boiler, the combustion stability is poor, and there have been incidents of boiler fire extinguishing due to the simultaneous mixing of low volatile and low calorific value coal; Small negative pressure fluctuations can also easily cause boiler fire extinguishing.

Poor corrosion resistance: The water-cooled wall surface from the C-layer burner in the main combustion area to the upper part of the reduction zone is severely corroded due to high temperature, and there is a large number of pipe replacements on the water-cooled wall during maintenance.

2.3 Cause Analysis

In response to the above-mentioned problems, the boiler profession analyzed them from multiple aspects, including consulting theoretical materials and papers, consulting similar unit experiences, and leveraging the power of the Electric Power Research Institute to ultimately identify the crux of the problem.

2.3.1 Reasons for Poor Adaptability of Coal Types

The reducing atmosphere is relatively strong: after the low nitrogen combustion transformation, the oxygen content in the main combustion area of the boiler is insufficient, and the combustion lag is severe. During the co firing of low volatile coal, due to its low volatility and low ignition resistance, some coal forms a strong reducing atmosphere in the reduction zone, reducing the melting point of ash by 200-300 degrees. The ash in the center of the flame is in a molten state, making it easier to adhere to the water-cooled wall.

Poor combustion organization: Team members inspected the burning situation of the burner nozzle in the furnace and found that there was burning damage in the upper two layers of burners. The rigidity of the coal powder airflow was poor, and due to the turbulence of the flow field near the nozzle, the coal powder quickly diffused when it rushed out of the nozzle, causing some coal powder to burn against the wall, resulting in boiler corrosion and slagging.

Aggravated slagging increases furnace temperature: After slagging in the boiler, the furnace temperature will significantly increase, and the central temperature of the combustion zone will exceed 1500 degrees Celsius, causing the ash to melt and further exacerbating slagging.

2.3.2 Reasons for Poor Combustion Stability

The design of the primary air burner is unreasonable: Our factory's primary air burner adopts a concentration dilution separation burner with a conical blunt body at the outlet. The tangential direction of the lean side coal powder is the same as that of the secondary air, while the tangential direction of the concentrated side coal powder is opposite to that of the secondary air. The collision between the concentrated side coal powder and the secondary air weakens the rigidity of the secondary air, and causes the concentrated side coal powder to be thrown near the water-cooled wall and burn against the wall.

Insufficient rigidity of secondary air: After the transformation of low nitrogen combustion, the secondary air volume in the main combustion area is significantly reduced, and the area of the secondary air nozzle is significantly reduced. Under low secondary air pressure, it cannot form a good combustion tangent circle, making it difficult to ensure tangent rigidity and poor flame anti-interference ability.

The interference of the lower third air on boiler combustion: Our factory's lower third air is supplemented as secondary air between the CDE burners in the main combustion area, and a large amount of high-speed and low-temperature tertiary air carries coal powder into the central combustion area of the furnace, reducing the stability of boiler combustion.

Burner burnout: There are phenomena of blunt body and nozzle burnout and cracking in the E and F layer nozzles, as well as some secondary air outlets. Blunt body burnout can damage the reflux zone formed after the blunt body, which is not conducive to high-temperature flue gas reflux to the flame root, affecting the ignition and stable combustion of coal powder airflow.

2.3.3 Reasons for Poor Corrosion Resistance

Poor combustion organization: Burn damage at the burner nozzle leads to poor combustion organization in the furnace. The upper layer of coal powder is in an unorganized combustion state, and some partially unburned coal powder adheres to the water-cooled wall, resulting in a reducing atmosphere near the wall. Mixing with sulfur in the fuel causes high-temperature corrosion.

Low nitrogen combustion impact: Low nitrogen combustion causes severe oxygen deficiency in the reduction zone, but the temperature is very high, which meets the necessary conditions for high-temperature corrosion.

In summary, after the transformation of low nitrogen combustion, the main reasons for poor adaptability, slagging, poor corrosion resistance, and unstable combustion of coal are the concentrated reducing atmosphere, severe burning loss of the burner in the furnace, and poor organization of the aerodynamic field.

3. Measures Taken

3.1 Optimizing Combustion Organization

3.1.1 Combustion Tangent Argument

(1) Effect of tangential diameter on O_2 concentration in the furnace

Figure 1 shows the overall O_2 concentration distribution cloud map of the boiler, and Figure 2 shows the O_2 concentration distribution cloud map of the central section inside the boiler. It can be seen that in the boiler furnace, the area with high O_2 concentration is the burner inlet area, and the O_2 concentration at the geometric center of the boiler is almost zero. This is because the reaction rate between O_2 and coal powder is extremely high, and O_2 is completely consumed in a short period of time. In the burn out wind area, a large amount of air is used to burn the CO and residual coke produced in the combustion and reduction zones. Due to the excess air coefficient greater than 1, the O_2 input from the burn out wind cannot fully participate in combustion, resulting in an increase in O_2 concentration in the flue gas.

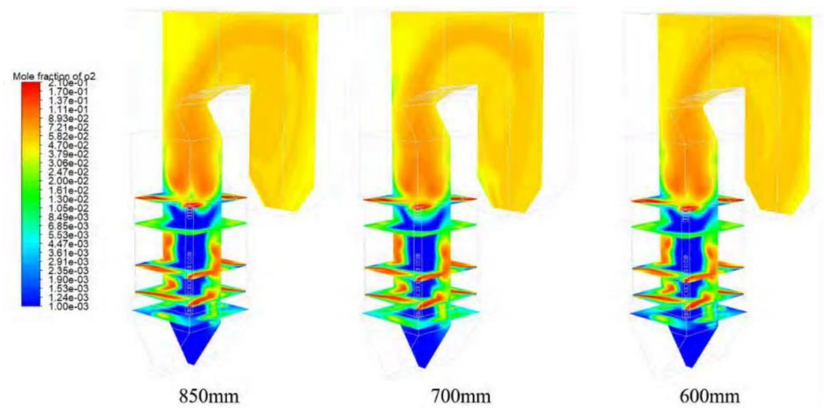

Figure 1 Cloud diagram of overall oxygen concentration distribution in the boiler.

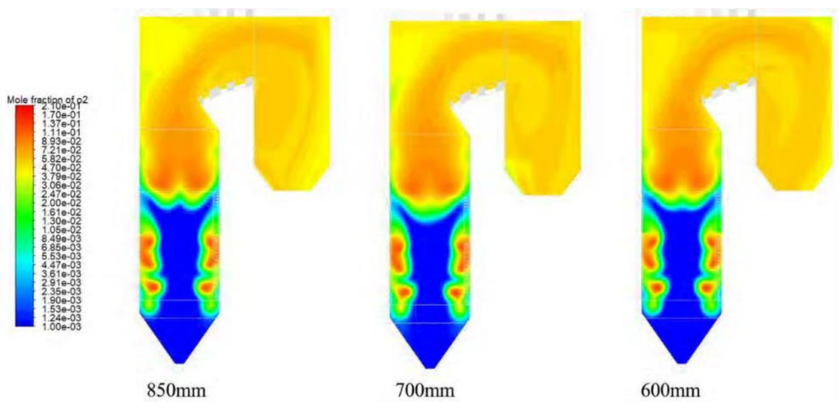

Figure 2 Cloud diagram of oxygen concentration distribution at the center section of the boiler.

Compare the changes in O_2 concentration under different tangential diameter working conditions. It can be seen that under the condition of a tangential diameter of 850mm, the rate of O_2 concentration reduction is higher than other conditions. This is because as the diameter of the tangential circle increases, the coal powder jet is closer to the furnace wall, making it easier for the coal powder flame to reach the adjacent coal powder inlet, which is conducive to coal powder ignition. Therefore, increasing the diameter of the tangent circle leads to earlier ignition of coal powder, which is beneficial for its ignition.

(2) The influence of cutting circle diameter on the temperature inside the furnace

Figures 3 to 7 show the overall temperature distribution of the boiler and the temperature distribution of some burner layers. Due to the thermal expansion of the airflow inside the furnace and the impact of the upstream airflow, the actual size of the tangent circle generally expands to 6-8 times that of the imagined tangent circle. From the temperature distribution cloud map of the boiler, it can be seen that after the boiler burner generates a tangential circle, a low-temperature zone will appear in the central area of the boiler. Figure 4 shows that after the tangential diameter of the boiler is reduced from 850mm to 600mm, the area of the central low-temperature zone decreases, and the temperature of the central low-temperature zone increases, indicating that the reduction of the tangential area causes the flame to move towards the center of the furnace. From the red line in Figure 4, it can be seen that as the tangential diameter decreases, the low-temperature zone at the outlet of the A-layer burner increases. This indicates that the decrease in tangential diameter is not conducive to the movement of the adjacent flames in the A-layer to the root of the coal powder airflow, promoting the rapid devolatilization and ignition of coal powder. At the same time, it can also be explained that the decrease in tangential diameter leads to an increase in the ignition distance of coal powder, which is not conducive to the ignition of coal powder. The diameter of the cut circle decreases, and the area of the high-temperature area on the cross-section decreases. Reducing the diameter of the tangential circle increases the difficulty of coal powder ignition, reduces combustion stability, and results in combustion delay, especially at low loads, which can easily cause combustion instability and stalling. When the diameter of the cut circle is large, the difference in flame temperature decreases, the temperature is more uniform, and the coal powder airflow is prone to ignition. Therefore, from the perspective of tangency, when it comes to the ignition and burnout of coal powder, the diameter of the tangency decreases, the difficulty of coal powder ignition increases, the stroke in the furnace is small, and the burnout performance is poor.

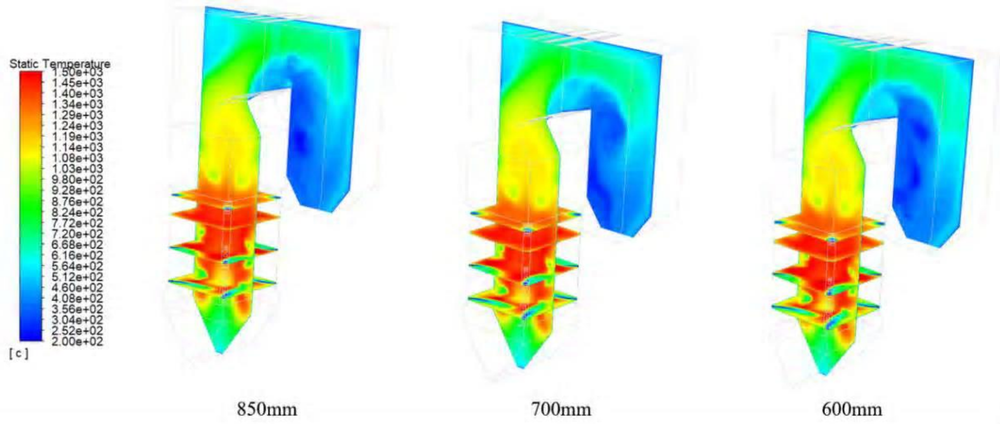

Figure 3 Cloud map of boiler temperature distribution.

From Figure 4, it can be seen that as the tangential circle increases from 600mm to 700mm, the overall temperature of the flame zone increases. This is because the increase in tangential circle leads to earlier ignition of coal powder. As the diameter of the tangent circle increases, the overall temperature of the flame zone slightly decreases from 700mm to 850mm. This is mainly because as the diameter of the tangent circle increases, the central low-temperature zone increases, and the flame will entrain more central low-temperature gas. From the red circle in Figure 5, it can be seen that as the tangential angle increases, the temperature at the end of the adjacent flame decreases, mainly due to the low-temperature gas in the center of the entrainment (Figure 4).

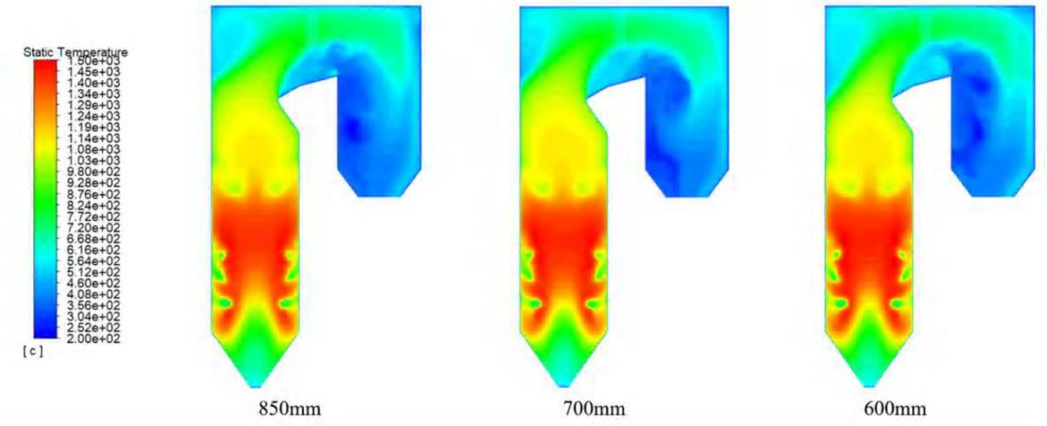

Figure 4 Cloud map of temperature distribution at the center section of the boiler.

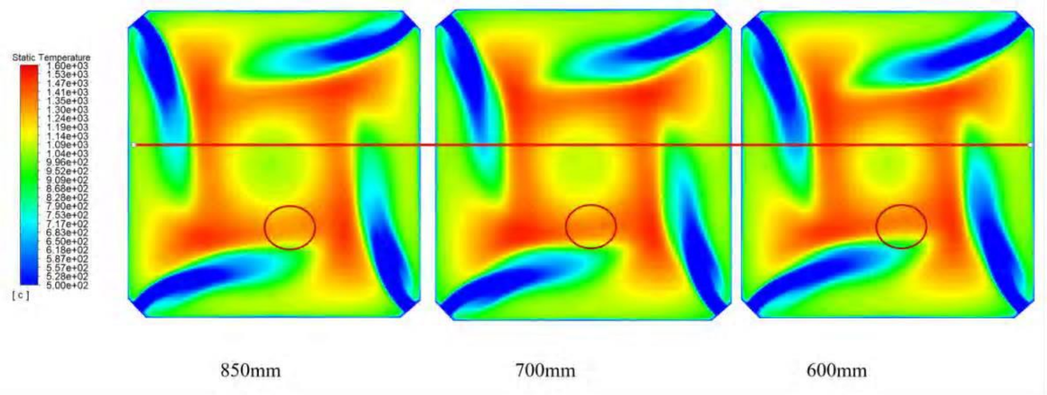

Figure 5 Temperature distribution cloud map of burner layer A.

Figures 6 and 7 show the temperature distribution of burner F layer and burner SOFA2 layer, respectively. It can be seen that as the tangential angle decreases, the temperature in the central area of the boiler increases. This is because the coal powder flame is close to the geometric center of the furnace under low tangential angle conditions.

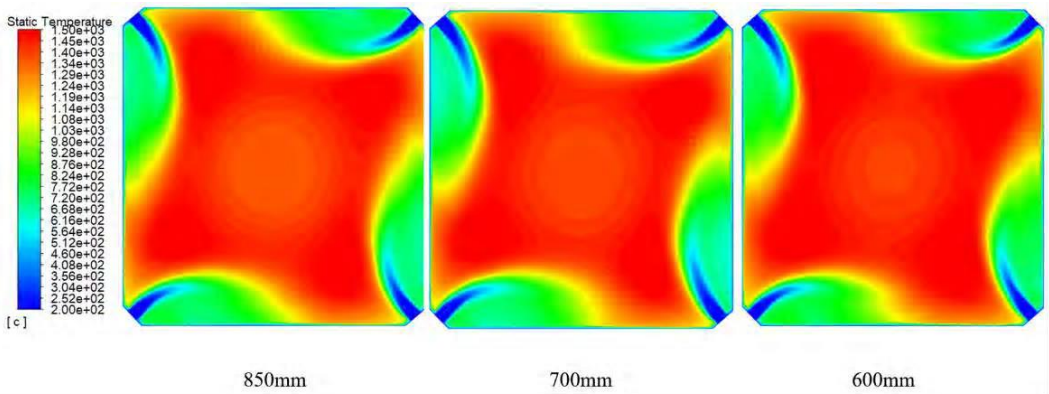

Figure 6 Temperature distribution cloud map of burner F layer.

Contact Xi'an Thermal Power Institute to use numerical simulation to model and calculate the temperature field in the furnace of the burner area after modifying the tangential diameter. Taking into account the influence of the tangential layout of the burner on the ignition of coal powder airflow, the temperature distribution and airflow movement of the upper and middle layer burners, it is recommended to arrange the tangential diameters of the first, second, and third air burners according to the original design value of 700mm.

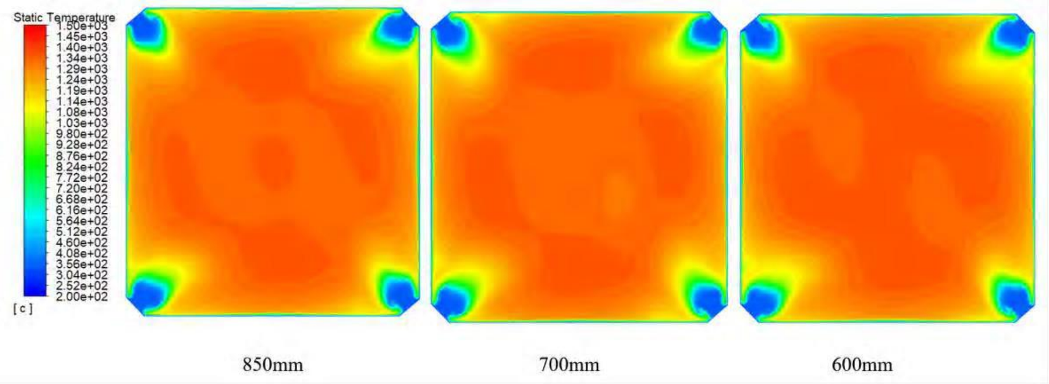

Figure 7 Temperature distribution cloud map of SOFA2 layer in burner.

3.1.2 Burner Replacement

During the maintenance period of the unit, a total of 6 severely burned primary air nozzles were replaced, namely 2D, 3D, 1E, 3E, 4E, and 4F. At the same time, the lower two layers of burnt out air nozzles at the four corners were replaced. After adjustment, all burners in the furnace meet the original design requirements.

3.1.3 Combustion Tangential Adjustment

During the maintenance period of the unit, a laser was used to measure the tangent circle of each nozzle inside the furnace, and the nozzle diameter was adjusted to deviate from the normal value. The specific adjustment results are shown in Tables 1 and 2.

Table 1 Circumferential cutting of each layer before adjustment.

Burner	#1	#2	#3	#4
OFA	-6100	-6300	-6900	-6500
HH	1010	760	700	630
H	-3850	-3820	-3400	-3880
G	-3820	-3680	-3380	-3850
FF	1040	400	700	620
F	600	760	800	Replace
EF	960	560	400	700
E	Replace	490	Replace	Replace
DE、h	1020	610	650	580
D	835	Replace	Replace	589
CD、g	960	750	770	770
C	740	810	700	700
BC	765	708	545	600
B	750	750	700	500
AB	1020	800	850	560
A	750	810	900	800
AA1	980	700	820	610
AA2	940	700	700	620

Before the round cutting adjustment, there were a total of 11 primary air nozzles and 19 secondary and tertiary air burners in the burner of furnace 1 whose round cutting diameter did not meet the design requirement of 700mm; After adjustment, the hypothetical tangential diameter of each layer of burner basically reaches the design value, with a deviation of about 50mm, meeting the requirements of design and numerical modeling calculation.

Table 2 Circumferential cutting of each layer after adjustment.

Burner	#1	#2	#3	#4
OFA	6100	-6300	-6900	-6500
HH	710	760	700	630
H	-3850	-3820	-3400	-3880
G	-3820	-3680	-3380	-3850
FF	720	700	700	720
F	700	700	670	730
EF	690	700	710	700
E	730	690	700	720
DE、h	720	610	650	680
D	690	700	750	690
CD、g	760	750	770	770
C	700	710	650	720
BC	765	708	720	700
B	680	680	670	660
AB	720	800	700	700
A	750	780	700	740
AA1	730	700	820	710
AA2	740	700	700	720

3.1.4 Conduct Cold Dynamic Field Tests

After the burner was replaced and the tangential adjustment was normal, our factory conducted a cold power field test on the boiler. By cold leveling, the deviation of wind speed in each of the first and third layers is controlled within 5%. Under cold ventilation conditions, the uniformity of the first, second, and third wind speeds on each floor is good, and the tangent circle is centered. During hot ventilation, it is not easy to have the problem of slag accumulation on a certain wall. The aerodynamic field inside the furnace is well organized, and the burner is located at the center of the furnace with a tangential circle. There is no skewed airflow brushing against the wall, and the wall adhering wind speed is low, making it less prone to coal powder airflow burning against the wall and causing slagging.

3.1.5 Hot State Adjustment Test

After the tangential adjustment of the burner in the boiler, it can be seen from the operating situation that the impact of boiler coking on operational safety is no longer the main problem in boiler operation. Through combustion adjustment and soot blowing optimization, the safe and stable operation of the boiler can be guaranteed.

3.2 Add Anti Slag Blower

Considering the insufficient arrangement of soot blowers in the burner area and reduction area of the boiler, three layers of soot blowers are installed in the middle and upper burner areas and reduction areas to achieve full coverage of soot blowing in areas prone to slagging and effectively remove slagging on the water-cooled walls of the furnace burner area and reduction area. According to the modification of the soot blower, the “Technical Measures for Boiler Soot Blowing” have been modified to meet the anti-slagging function while avoiding water wall blowing damage. The specific installation location is shown in Figure 8.

After the boiler renovation was completed, the unit operated continuously at high load and its operational safety was effectively verified. From the amount and type of slag in the slag scraper, it can be seen that the current slag is mostly loose type. During the operation of the newly added third layer (lower part of the burnout air) and B-layer soot blower, there are occasional slag blocks exceeding 5cm, but the hardness of the slag is not high and it is easy to crush. During high load continuous operation, the amount of slag is relatively large when the D layer burner is put into operation from the B layer above the reduction zone and the upper C layer soot blower. During low load continuous operation, the areas prone to slagging are mainly located in the D and G layers of the burner layer, the lower part of the burnout air blower layer, and the B and C layers of the blower area. The frequency of soot blowing can be targeted based on the type and amount of slag.

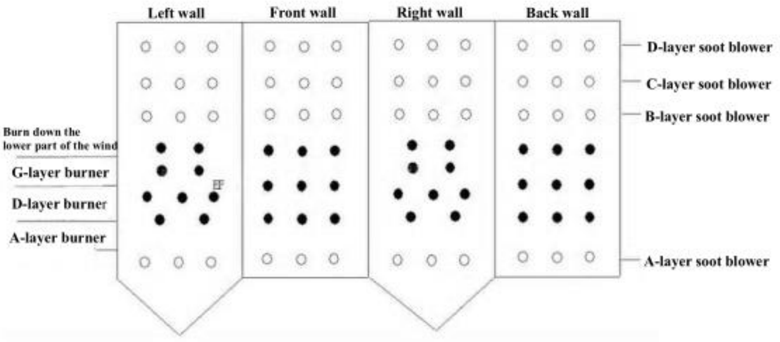

Figure 8 Schematic diagram of the installation position for the renovation of the soot blower.

3.3 Optimize Combustion Adjustment

(1) Reasonably control the primary air pressure: Adjust the primary air pressure according to the coal type, and try to reduce the primary air pressure as much as possible when conditions permit to reduce the impact of the primary air on combustion.

(2) Improving the rigidity of secondary air: During operation, it is required to ensure that the pressure of the secondary air box is not less than 0.5kPa to ensure tangential rigidity, and at the same time, the oxygen content in the main combustion zone is supplemented to avoid excessive reducing atmosphere in the reducing zone, reducing high-temperature corrosion.

(3) Reduce the impact of tertiary air combustion: During operation, it is required that the opening of the recirculation air door of the powder making system should not be less than 60%, and the tertiary air volume entering the furnace should be reduced. At the same time, open the secondary air door nearby to make up for the lack of oxygen in the boiler caused by the decrease in tertiary air.

4. Analysis of the Effect after Renovation

Through the above transformation, the boiler combustion tangential circle has been restored to the design level, and no burning damage has been found at the nozzle and secondary air outlet of each burner. The combustion organization in the furnace has been significantly improved, and the boiler slagging has been controlled. The combustion stability has been significantly enhanced, and high-temperature corrosion has been significantly reduced. The adaptability of coal types has been greatly expanded. Throughout the year, a total of 341000 tons of inferior coal were co burned, achieving good economic benefits.

5. Conclusion

After the renovation, our factory conducted mixed firing tests on various types of coal. During the mixed firing period, there was no slagging, high-temperature corrosion, or combustion fluctuation in the boiler, fundamentally solving a series of problems that existed after the low nitrogen combustion renovation, ensuring energy supply safety and unit operation safety, and cultivating technical talents.

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