The influence and optimization of air distribution method on the boiler burns high-sulfur coal

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Abstract. A large amount of H₂S will be generated during the operation of power plants mixed combustion with high-sulfur coal, causing high-temperature corrosion of the boiler water-cooled wall. In order to prevent it from pipes bursting due to high temperature corrosion during the operation of the unit, Air distribution was adjusted on a 350MW subcritical pulverized coal combustion boiler, especially for the opening of the secondary air valves of each layer of the burner, so as to reduce the volume fraction of H₂S in the furnace and lower the corrosion of the water-cooled wall. The research results show that by adjusting the air distribution, the volume fraction of CO and O₂ in the flue gas of the furnace is changed, and at the same time, it also has an influence on the change of the flue gas temperature in the furnace, and effectively inhibits the generation of H₂S, alleviating the high temperature corrosion of water wall.

1. Introduction
Coal with a sulfur content of more than 3% is called high-sulfur coal [1]. It not only produces a large amount of SO₂ and pollutes the environment, but also generates excessive H₂S, which intensifies the high temperature corrosion of the water-cooled wall. In severe cases, the pipeline bursts which affects the safe operation of the boiler and the power grid [2].

The high temperature corrosion caused by H₂S gas is mainly caused by the formation of FeS and other sulfides in a reducing atmosphere of the furnace [3]. Relevant studies have shown that when the volume fraction of H₂S in boiler flue gas is greater than 220mg/Nm³, and the volume fraction CO content is greater than 30,000 μL/L, it has the effect of aggravating the high temperature corrosion of the water-cooled wall [4].

At present, the main measures to solve the high temperature corrosion of the water-cooled wall are to optimize the operation of the air distribution; install wall-mounted air; apply anti-corrosion and anti-wear thermal spraying to the water-cooled wall to reduce the generation of H₂S or to protect the metal wall [5]. The method used in this article is to monitor the fluctuation of H₂S before and after changing the air distribution in real time by setting the online monitoring equipment in the furnace, and at the same time monitor the volume fraction of CO and O₂, and identify the influence of air distribution on the reducing atmosphere in the furnace [6].

During the test, the flue was tested for NOₓ, and unburned carbon in slag and flue dust under three air distribution methods were taken for testing to ensure the burnout rate and environmental protection requirements.
2. Experimental method

Sampling pipes are opened on the fins of the four water-cooled walls between the burning out wind and the combustion zone [7]. It is planned to install 10 sampling pipes evenly on each wall, and sample and measure \( \text{H}_2\text{S} \), CO and \( \text{O}_2 \) at multiple points simultaneously. The overall reduction monitoring data of the boiler constructed by this method is used to study the influence of the opening of the secondary air valves and the combustion air valves on the volume fraction of \( \text{H}_2\text{S} \), CO and \( \text{O}_2 \) by adjusting the air distribution, and use the test data analysis to find out the optimal damper control strategy. The operating persons carry out operation optimization and adjustment [8].

The overall numbering of measuring points is to face each wall, and number from 1 to 10 from left to right. The numbering form is "Fn" which is the nth measuring point on the front wall, and "Ln, Rn and Bn" respectively represent the nth measuring point on the left wall, right wall and back wall. The specific layout is shown in Figure 1.

![Figure 1. Schematic diagram of measuring point layout of water wall atmosphere.](image)

3. Test results and analysis

3.1. Test coal quality and test methods

The coal quality analysis used during the test is shown in Table 1.

| Project                        | Symbol | unit | design coal type | check coal type |
|--------------------------------|--------|------|------------------|-----------------|
| Low calorific value of received basis |        |      | 16777            | 16334           |
| Air dry basis moisture         |        |      | 24.50            | 6.76            |
| Dry ash free volatile         |        |      | 37.62            | 35.24           |
| Moisture as received basis     |        |      | 33.10            | 23.53           |
| Ash as received basis          |        |      | 21.08            | 15.02           |
| Carbon as received basis       |        |      | 42.28            | 41.70           |
| Hydrogen as received basis     |        |      | 3.45             | 3.29            |
| Oxygen as received basis       |        |      | 12.08            | 12.62           |
| Nitrogen as received basis     |        |      | 1.73             | 1.29            |
| Sulfur as received basis       |        |      | 2.39             | 2.55            |

In the installation measurement plan, infrared laser online flue gas analyzer, flue gas preprocessor and flue gas flow diluter are used to measure the volume fraction of \( \text{O}_2 \), CO and \( \text{H}_2\text{S} \) in the flue gas near the water-cooled wall and the wall temperature of this layer. Among them, \( \text{O}_2 \) and CO are
extracted by a sampling pump, and then sent to the flue gas analyzer after pretreatment such as dust removal, dehumidification, and cooling. H₂S needs to be quenched and diluted before being sent to the flue gas analyzer to obtain the atmosphere near the wall. A nickel-chromium-nickel-silicon thermocouple is placed near the wall of the sampling tube to measure the wall temperature and flue gas temperature of the measuring point [9].

3.2. Test results and analysis
The unit adopts equal air distribution method under the 350MW load. By adjusting the opening of the secondary air valves of the burners of each layer, the air distribution method of the boiler is changed to the tower-shaped air distribution method and the inverted tower-shaped air distribution method, and compared with the equal air distribution method before the experiment. Finally, an air distribution method that effectively inhibits high temperature corrosion is obtained. And carry out NOx volume fraction and burn-out rate tests, and finally get the most ideal air distribution method.

Taking into account that the opening of the four corners of the boiler is basically the same, the three air distribution modes in the combustion zone are shown in Table 2. A burner is located at the bottom, and the E burner is at the top.

Table 2. Opening degree of secondary air regulate valves under three air distribution modes (%).

|                        | AA | A  | BB | B  | BC | C  | CC | DD | D  | DE | E  | EE |
|------------------------|----|----|----|----|----|----|----|----|----|----|----|----|
| equal air distribution | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| the tower-shaped air    | 30 | 30 | 25 | 25 | 25 | 20 | 20 | 15 | 15 | 15 | 15 | 15 |
| distribution method     | 20 | 20 | 20 | 20 | 20 | 25 | 25 | 30 | 30 | 30 | 30 | 30 |

During the test, the volume fraction of O₂ at the outlet of the furnace was maintained at 3%. The test results of O₂, CO and H₂S concentrations at the measuring points of the unit in the equal air distribution method, the tower-shaped air distribution method and the inverted tower-shaped air distribution method are shown in Table 3, Table 4 and Table 5.

Table 3. The volume fraction of O₂, CO and H₂S under equal air distribution method (%).

|       | F1  | F2  | F3  | F4  | F5  | F6  | F7  | F8  | F9  | F10 |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| O₂    | 0.42| 0.21| 0.52| 0.23| 0.25| 0.31| 0.33| 0.25| 0.33| 0.45|
| CO    | 2.83| 3.56| 2.61| 3.78| 3.45| 3.01| 3.44| 3.63| 3.90| 2.97|
| H₂S   | 0.028| 0.032| 0.022| 0.038| 0.033| 0.030| 0.029| 0.031| 0.023| 0.025|
|       | L1  | L2  | L3  | L4  | L5  | L6  | L7  | L8  | L9  | L10 |
| O₂    | 0.34| 0.20| 0.32| 0.31| 0.34| 0.22| 0.39| 0.30| 0.41| 0.34|
| CO    | 3.31| 3.16| 2.71| 4.07| 3.45| 3.51| 3.12| 3.15| 2.98| 2.85|
| H₂S   | 0.029| 0.030| 0.032| 0.035| 0.029| 0.036| 0.027| 0.031| 0.025| 0.028|
|       | B1  | B2  | B3  | B4  | B5  | B6  | B7  | B8  | B9  | B10 |
| O₂    | 0.31| 0.37| 0.35| 0.40| 0.23| 0.29| 0.21| 0.32| 0.33| 0.25|
| CO    | 3.90| 3.33| 3.32| 2.99| 4.01| 4.24| 4.31| 3.52| 3.60| 3.07|
| H₂S   | 0.034| 0.030| 0.029| 0.021| 0.039| 0.032| 0.037| 0.029| 0.031| 0.024|
|       | R1  | R2  | R3  | R4  | R5  | R6  | R7  | R8  | R9  | R10 |
| O₂    | 0.44| 0.39| 0.32| 0.35| 0.31| 0.28| 0.30| 0.32| 0.34| 0.42|
| CO    | 2.01| 3.56| 3.51| 3.66| 2.98| 4.52| 3.18| 3.35| 3.56| 2.79|
| H₂S   | 0.025| 0.024| 0.029| 0.030| 0.035| 0.037| 0.034| 0.030| 0.031| 0.027|
Table 4. The volume fraction of $O_2$, CO and $H_2S$ under the tower-shaped air distribution method (%).

|       | F1   | F2   | F3   | F4   | F5   | F6   | F7   | F8   | F9   | F10  |
|-------|------|------|------|------|------|------|------|------|------|------|
| $O_2$ | 0.29 | 0.17 | 0.17 | 0.20 | 0.22 | 0.30 | 0.24 | 0.19 | 0.18 | 0.30 |
| CO    | 4.48 | 5.24 | 5.18 | 5.07 | 4.99 | 4.03 | 4.55 | 5.53 | 5.25 | 4.81 |
| $H_2S$| 0.022| 0.043| 0.045| 0.039| 0.032| 0.029| 0.031| 0.040| 0.044| 0.028|
| L1    | L2   | L3   | L4   | L5   | L6   | L7   | L8   | L9   | L10  |
| $O_2$ | 0.30 | 0.21 | 0.24 | 0.19 | 0.17 | 0.26 | 0.27 | 0.21 | 0.16 | 0.27 |
| CO    | 4.56 | 5.32 | 5.09 | 5.54 | 5.61 | 4.78 | 4.26 | 4.19 | 4.99 | 4.25 |
| $H_2S$| 0.020| 0.038| 0.035| 0.040| 0.043| 0.032| 0.031| 0.038| 0.047| 0.022|

Table 5. The volume fraction of $O_2$, CO and $H_2S$ under inverted tower wind distribution method (%).

|       | F1   | F2   | F3   | F4   | F5   | F6   | F7   | F8   | F9   | F10  |
|-------|------|------|------|------|------|------|------|------|------|------|
| $O_2$ | 0.098| 1.03 | 1.00 | 1.34 | 1.87 | 1.31 | 1.38 | 0.88 | 1.21 | 0.78 |
| CO    | 0.009| 0.013| 0.009| 0.015| 0.019| 0.011| 0.010| 0.008| 0.012| 0.008|
| $H_2S$| 0.70 | 0.52 | 0.66 | 0.50 | 0.48 | 0.52 | 0.71 | 0.65 | 0.55 | 0.67 |
| L1    | L2   | L3   | L4   | L5   | L6   | L7   | L8   | L9   | L10  |
| $O_2$ | 1.00 | 1.28 | 1.17 | 1.46 | 1.39 | 1.27 | 0.87 | 0.98 | 1.11 | 0.99 |
| CO    | 0.010| 0.016| 0.011| 0.013| 0.018| 0.013| 0.009| 0.012| 0.017| 0.010|
| $H_2S$| 0.64 | 0.60 | 0.69 | 0.39 | 0.45 | 0.36 | 0.59 | 0.68 | 0.64 | 0.71 |
| B1    | B2   | B3   | B4   | B5   | B6   | B7   | B8   | B9   | B10  |
| $O_2$ | 1.19 | 1.21 | 1.02 | 1.39 | 1.48 | 1.75 | 1.22 | 0.93 | 1.10 | 0.68 |
| CO    | 0.011| 0.013| 0.011| 0.016| 0.013| 0.015| 0.012| 0.011| 0.010| 0.008|
| $H_2S$| 0.64 | 0.60 | 0.69 | 0.39 | 0.45 | 0.36 | 0.59 | 0.68 | 0.64 | 0.71 |
| R1    | R2   | R3   | R4   | R5   | R6   | R7   | R8   | R9   | R10  |
| $O_2$ | 0.77 | 0.73 | 0.63 | 0.56 | 0.49 | 0.58 | 0.61 | 0.70 | 0.71 | 0.77 |
| CO    | 0.90 | 1.10 | 1.23 | 1.78 | 1.77 | 1.51 | 1.30 | 0.97 | 0.78 | 0.82 |
| $H_2S$| 0.007| 0.009| 0.012| 0.014| 0.019| 0.014| 0.013| 0.010| 0.011| 0.009|

According to the data in Tables 3, 4, and 5, the volume fraction of $O_2$, CO and $H_2S$ in the flue gas under the three air distribution methods are drawn, as shown in Figure 2, Figure 3 and Figure 4 and compared.

Measure the NOx content at the inlet of the air heater, and take ash and slag samples for burnout rate testing. The specific data are shown in Tables 6 and 7. The measuring point number of the flue is represented by 1–6.
Figure 2. The volume fraction of O\textsubscript{2} in three air distribution modes.

Figure 3. The volume fraction of CO in three air distribution modes.

Figure 4. The volume fraction of H\textsubscript{2}S in three air distribution modes.

Table 6. The volume fraction of NO\textsubscript{x} at the inlet of the air preheater (ppm).

| Measuring point number | 1    | 2    | 3    | 4    | 5    | 6    |
|------------------------|------|------|------|------|------|------|
| equal air distribution method | 41   | 42   | 41   | 43   | 43   | 36   |
| the tower-shaped air distribution method | 49   | 53   | 51   | 48   | 45   | 45   |
| inverted tower wind distribution method | 39   | 42   | 41   | 42   | 41   | 39   |

Table 7. Unburned carbon in slag and flue dust under three air distribution methods (%).

|                         | unburned carbon slag | Unburned carbon flue dust |
|-------------------------|----------------------|---------------------------|
| equal air distribution method | 1.26                 | 0.84                      |
| the tower-shaped air distribution method | 1.21                 | 0.85                      |
| inverted tower wind distribution method | 1.20                 | 0.80                      |

From Figures 2, 3 and 4, it can be seen that the volume fraction of O\textsubscript{2} concentration in the center of the furnace is lower than that on both sides, and the relative volume fraction of CO and H\textsubscript{2}S are higher. Because the temperature point of the flame center in the furnace is usually higher than the
surroundings, and the temperature has a certain promotion effect on the formation of H\textsubscript{2}S, and the fuel burns at the flame center in the furnace is concentrated and the required O\textsubscript{2} concentration is higher, which is easy to produce CO. The reducing atmosphere eventually leads to a high concentration of H\textsubscript{2}S.

By comparing the before and after states of the air distribution, it can be seen that the positive tower-shaped air distribution is prone to produce a reducing atmosphere and increase the H\textsubscript{2}S concentration. While the inverted tower air distribution generates an oxidizing atmosphere and inhibits the increase in the H\textsubscript{2}S concentration. Because the inverted tower air distribution increases the opening of the upper secondary air valves, the O\textsubscript{2} concentration at the upper burner is sufficient, to ensure that the fuel burns completely and excess contain O\textsubscript{2} to produce oxidizing atmosphere, which effectively inhibits the generation of H\textsubscript{2}S and high temperature corrosion in the furnace.

Under the rated load of the unit, keep the O\textsubscript{2} content of the furnace outlet at 3%. Adjust the opening of the upper secondary air valves to make the overall air distribution in the furnace an inverted tower air distribution and appropriately open the secondary air valves of the lower burners to ensure sufficient O\textsubscript{2} concentration in the furnace to fully burn the pulverized coal. This optimized air distribution method can not only create an oxidizing atmosphere in the furnace, inhibit high-temperature corrosion of the water-cooled wall, but also ensure the exhaustion of pulverized coal and reduce the incomplete combustion heat loss.

4. Conclusions
The temperature at the center of the flame inside the furnace is high, which is the main combustion area of the fuel. It consumes a lot of O\textsubscript{2} and has a high CO content. When the rigidity of the primary and secondary air is not enough, it is easy to generate H\textsubscript{2}S and cause high temperature corrosion of the water-cooled wall;

Among the three air distribution methods, the order of the volume fraction of O\textsubscript{2} in the flue gas near the water-cooled wall is: inverted tower air distribution > equal air distribution > tower-shaped air distribution; the order of the volume fraction of CO is: tower-shaped air distribution > equal Air distribution > inverted tower air distribution; the volume fraction of H\textsubscript{2}S is: tower-shaped air distribution > equal air distribution > inverted tower air distribution;

According to the experimental data, the inverted tower air distribution is beneficial to suppress the reducing atmosphere near the water-cooled wall, thereby inhibit the high temperature corrosion of the water-cooled wall;

During the operation of the boiler, it is necessary to ensure that the fuel is fully busted, and that the water-cooled wall does not appear high temperature corrosion. Therefore, while increasing the opening of the upper secondary air valves, the lower secondary air valves is also opened appropriately to supplement sufficient O\textsubscript{2} for the fuel in the furnace to burn out.

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