Research on Nox Formation and SCR Denitration System Control by Smoke Mixing Under Low Load

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Abstract. With 2 × 330MW subcritical coal-fired boiler as the research object, the influence of two kinds of primary air flue gas recirculation schemes on the combustion of pulverized coal and the formation of NOX were studied by numerical simulation software. The variation law of SCR inlet fume temperature was studied with boiler thermodynamic calculation. The calculation results show that the reasonable smoke mixing method can effectively improve the SCR inlet flue gas temperature and reduce the furnace outlet NOX concentration. The optimal proportion was 20% with the primary air mixing smoke while maintaining constant air mass. The results of numerical simulation and thermodynamic calculation show that SCR inlet flue temperature can be increased by 15℃, the concentration of NOx emission can reduce by 18.29mg/Nm³.

1. Introduction

In recent years, more and more large-capacity coal-fired thermal power units are facing increasing challenges in peak load regulation. During the peaking period, the units are running under low load for a long time, which brings up the oxygen content of the furnace outlet and the NOx generated by combustion [1]. At present, the operating temperature of the SCR denitration catalyst usually ranges from 300 to 420℃. When the load is reduced to 50% ~ 60%, the economizer outlet smoke temperature may be lower than the SCR denitration requirement. When the smoke temperature is too low, catalyst is less active and ammonia slip rate will be up, which will increase the risk of clogging of ammonium sulphate in the air preheater. At the same time, ammonium sulphate formed by the reaction between ammonia and flue gas will deposit on the catalyst surface and catalyst will be deactivated. Catalyst deactivation will make the denitration system fail to work at low load, making the nitrogen oxide emission exceeding the standard, which will bring difficulties to peak load regulation [2].

In this paper, the influence of primary air-smoke mixing flue gas recirculation technology on NOX generation and SCR denitration control in coal-fired boilers is discussed. The numerical simulation software Fluent is used to simulate the temperature distribution and NOx generation in case of the primary air-smoke mixing. Besides, the change characteristics of furnace outlet flue gas temperature and other heating surfaces temperature are calculated by coupling into the whole boiler system, focusing on the change characteristics of SCR inlet flue temperature.
2. Study Object
The study object is a 2×330MW subcritical coal-fired boiler in Tianjin (HG-1102/17.5-YM33). The boiler is an intermediate reheating and natural circulation steam drum furnace with a DC burner, which is divided into 5 layers. It is a tangentially fired boiler furnace with a Π type arrangement. It is made of steel frame structure featuring balanced ventilation and solid slag discharge. The furnace height, width, depth are respectively 61.35m, 14.018m, and 14.019m. The height of furnace’s smoke outlet window is 11.392m. The main design parameters of the boiler are shown in Table 1.

| Parameters                  | Units  | numbers |
|-----------------------------|--------|---------|
| Superheater flow            | t/h    | 1101.6  |
| Superheater outlet pressure  | MPa.g  | 17.5    |
| Superheater outlet temperature | ℃     | 541     |
| Reheater flow               | t/h    | 909.7   |
| Reheater outlet pressure     | MPa.g  | 3.617   |
| Reheater outlet temperature  | ℃      | 541     |
| Reheater inlet pressure      | MPa.g  | 3.797   |
| Reheater inlet temperature  | ℃      | 329.9   |
| Feedwater temperature       | ℃      | 280     |
| Feedwater pressure          | MPa.g  | 19.392  |
| Total coal consumption      | t/h    | 139     |
| Boiler calculation thermal efficiency | %     | 93.48   |

3. Calculation methods

3.1. Numerical Simulation
The numerical model is simplified by Gamit according to the prototype of the boiler, and the whole furnace is modeled and meshed. Since the combustion mainly occurs in the burner area, in order to reduce the generation of pseudo-diffusion, the mesh division should be adapted to the streamline [3]. To improve the calculation accuracy, the main burner section is encrypted, and the distribution of the grid is radiated along the burner nozzle to ensure that most of the streamline enters the control body in a vertical direction.

3.2. Thermal Calculation
According to The Standard Calculation Method of Thermal Boiler Unit [4], the overall thermal calculation of the boiler is carried out under 100% load based on the steam water and flue gas flow. On this basis, different proportions of primary air smoke mixing under low load are applied to carry out overall thermal calculation.

3.3. Calculation conditions
The flue gas recycling scheme adopted in this paper is to mix the smoke of the air preheater with the primary air through the recirculation duct and the recirculation fan, and replace the original primary air for drying and conveying the coal powder. In order to compare the effects of different primary air smoke mixing methods on NOx generation and inlet flue gas in SCR denitrification system, two kinds of smoke mixing schemes were proposed.

Plan A: Incorporating smoke into primary air, whose amount in the primary air is reduced by the same amount, so that the total amount of primary air remains unchanged while ensuring that the secondary air volume does not change.
Plan B: Mixing smoke in primary air and reducing the amount of air in the primary air by the same amount while increasing the same amount of secondary air to ensure that the total air volume remains unchanged.

The 40% load is selected as the calculation condition. Through the numerical simulation, the proportion of smoke in the air is gradually increased to find out the safe range of mixing the pulverized coal combustion in the furnace. Importance has been attached to study the trend of furnace outlet temperature, NOx emission and SCR inlet smoke temperature with the smoke ratios being rising. Meanwhile, the inlet and outlet smoke temperature, working fluid parameters, exhaust gas temperature and boiler efficiency of each heating surface have also been studied.

4. Calculation results and analysis
4.1. The effects of flue gas recirculation on combustion

![Temperature distribution curves with different smoke ratios.](image)

(a) A decrease in the smoke amount in primary air     (b) No change in the smoke amount in primary air

Fig. 1. Temperature distribution curves with different smoke ratios.

Fig. 1(a) is a graph showing the temperature distribution in the furnace along the height of the furnace in the method of smoke mixing. The temperature distribution curve is relatively stable when the smoke ratio is less than 20%, indicating that the combustion state in the furnace is stable. Compared with the temperature distribution curves with smoke ratios being 10% and 20% in the primary air, the temperature in the non-smoke furnace in the combustion zone is higher than those in the smoke mixing furnace. In the area above secondary air outlet, the temperature in the smoke mixing furnace is higher than that in the non-smoke one. Therefore, it can be found from the curve that after the furnace height is higher than 27m, the temperature inside the smoke mixing furnace is higher than the non-smoke curve, and the temperature difference increases with the height of the furnace. The lower smoke temperature of outlet with the 20% smoke ratio is 18.5℃, higher than that of non-smoke one. When the smoke mixing ratio is up to 30%, the temperature curve of the combustion zone fluctuates greatly. When the smoke ratio is 40%, the temperature in the furnace is significantly lower than that of the non-smoke one and the temperature difference in the combustion zone is quite large. It is likely that the furnace has been extinguished in actual operation.

Fig. 1(b) is a graph showing the temperature distribution in the furnace along the height of the furnace by the method of plan B. The flow velocity of the primary air jet is the same in both Plan A and Plan B. Besides, due to the delay of pulverized coal ignition caused by smoke mixing, the position of the flame center moves up. The larger the proportion of smoke, the larger the amount of smoke in the furnace, the higher the value of flue gas taken away from the furnace, so the temperature field in the upper is significantly increased compared with non-smoke mixing, which is better than Plan A. When the proportion of smoke mixing reaches 30%, the combustion of pulverized coal in the furnace is affected to some extent, and the temperature of the combustion zone fluctuates. But the
fluctuation range is smaller than the 30% smoke-mixing curve of Fig. 1(a). At the same ratio of smoke mixing, the increase of the secondary air volume in Plan B enhances the disturbance to the pulverized coal. When the oxygen required in the initial stage of pulverized coal combustion is insufficient, the secondary air oxygen diffuses to the combustion zone at a faster rate, so that the oxygen concentration is increased to benefit the pulverized coal combustion. When the proportion of smoke mixing reaches 40%, it can be found from the overall furnace temperature is still maintained at a higher temperature, indicating that the method of smoke mixing is more conducive to the stable combustion of pulverized coal.

4.2. Analysis of the change characteristics of flue temperature at outlet of the furnace

Figure 2 shows the simulation results of the flue temperature of the furnace outlet under two kinds of smoke mixing ratios. When the smoke ratio is 10%, the flue temperature of the outlet is up to 884.9℃. When the smoke-mixing ratio ranges from 35% to 40%, the flue temperature at the outlet suddenly drops, boiler flame failure may occur. In plan A, the flue temperature at outlet increases with the proportion of smoke mixing at 0%-20%. When the ratio is 20%, the flue temperature is 36.6 ℃ higher than that of non-smoke mixing. When the ratio is higher than 20%, the flue temperature at the outlet gradually decreases. When the smoke ratio is 40%, the temperature of the outlet still maintained relatively high.

From the numerical simulation results, it can be found that to obtain a higher furnace flue temperature and ensure the stable combustion, the reasonable range of smoke mixing should be controlled within 20%.

![Figure 2](image2.png)  
**Figure 2.** Change of the outlet furnace temperature  
![Figure 3](image3.png)  
**Figure 3.** NOX concentration at furnace outlet

4.3. Analysis of NOX Formation Characteristics at Furnace Outlet

It can be seen from fig.3 that when there is a decrease in the amount of smoke mixed primary air, the concentration of NOX at the outlet decreases gradually with the increase of the ratio of smoke mixing. With the ratio being 20%, the corresponding NOX concentration is 21.26mg · Nm⁻³ less than that of non-smoke mixing. When there is no change in the amount of smoke mixed in primary air, the NOX change trend of the furnace outlet is the same as that of Plan A, but the NOX concentration of the furnace outlet is slightly lower. With the ratio being 20%, the NOX concentration is 18.29 mg · Nm⁻³ less than the non-smoke mixing.

In these two plans, with the increase of the proportion of smoke incorporation, the concentration of NOx at the furnace outlet shows a decreasing trend. Under the same proportion of smoke mixing, Plan A’s reduction of NOX concentration is greater than that in Plan B. In Plan B, the amount of air remains constant, and the oxygen concentration in the furnace is large under the same proportion of smoke mixing, and the pulverized coal in the furnace is more completely burned, so the amount of
fuel-type NOx is large. The heat-type NOx generation is particularly sensitive to temperature, and the low temperature will inhibit the generation of thermal NOx. Under the same proportion of smoke mixing, the oxygen content in the combustion zone of Plan B is more sufficient, so is the combustion of coal powder. The temperature field of Plan B is higher than that of Plan A, so the amount of thermal NOX generated is relatively large. Due to the low overall temperature field in the furnace under low load, the fuel type has an advantage over the thermal NOx production. Compared with the non-smoke mixing case, the fuel type NOx production is greatly inhibited, which leads to a large deduction in the concentration of NOx emission at the furnace outlet.

4.4. Analysis of Inlet Flue Temperature Change Characteristics of SCR

Fig.4 is a graph showing the change of the flue temperature of the economizer outlet with changes of the temperature of the primary air mixed with smoke. The calculation results show that with the increase of the primary air smoke mixing ratio, the inlet flue temperature does not change significantly in Plan A. In Plan B, with the increase of the ratio, the temperature of SCR inlet smoke gradually increases. With the smoke-mixing ratio being 20%, the SCR inlet flue temperature increases by 15℃ compared with the non-smoke mixing. This will facilitate the operation of the SCR denitration unit. The main reason for the increase in flue temperature at the SCR inlet is that the flue temperature at the outlet is increased after the smoke is added. As the proportion of smoke is increased, the amount of smoke increases, so that more high-temperature smoke is sent to the tail flue. At the same time, the amount of desuperheating water increases, there is a decrease in the low temperature convection superheater in the flue tail and the working fluid flow in the economizer. Therefore, the absorbed convection and radiant heat decrease in different extents, so does the heat exchange of the convective heating surface of the overall tail flue, which eventually brings up the SCR inlet flue temperature significantly.

According to above calculation, to maintain the stable combustion of the pulverized coal, the flue temperature at the outlet should be increased as much as possible, and the NOx concentration at the outlet should be reduced to ensure that the inlet temperature of SCR is greatly increased to meet the safe operation requirement of the denitration system.

5. Conclusion

(1) The adoption of primary air-smoke mixing recirculation technology can affect the ignition of the furnace. The different ways of smoke mixing have a great impact on the combustion of pulverized coal in the furnace. Excessive proportion of smoke mixing may cause boiler flame failure in the furnace. Plan B, namely to mix smoke in primary air while maintaining total air volume remains unchanged, is more effective in improving the outlet flue temperature.
(2) Smoke mixing can effectively reduce the NO\textsubscript{x} emission concentration. With the same smoke mixing ratio, reduced air amount in primary air is more conducive to decreasing the NO\textsubscript{x} formation. Meanwhile, using the primary air-smoke mixing to maintain the overall air volume unchanged can also produce obvious effect.

(3) The key to improving the inlet flue temperature of SCR is to increase the flue temperature of the furnace and reduce the heat absorption of the convective heating surface before the SCR denitration system. In Plan B, when the proportion of smoke is 20\%, the SCR inlet flue temperature can be greatly improved, which is more favorable to put into SCR denitration device into operation to reduce NO\textsubscript{x} emissions.

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