Study on the Validity of NOx Uniformity Thermal State Optimization Adjustment Strategy for SCR Denitration Unit of Coal-fired Power Plant

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Abstract. In order to make the NOx stable discharge standard after the ultra-low emission reform of coal-fired power plants, SCR denitration unit safe and economical operation. Taking a 600MW unit as the research object, the effectiveness of the NOx uniformity thermal state optimization adjustment strategy at the outlet of the denitration unit was studied, and the denitration unit inlet and outlet flow fields and NOx concentration field were tested to analyze the existing problems and formulate an optimization plan. The thermal state optimization adjustment, the NOx uniformity of the denitration unit outlet is significantly improved, the standard deviation of the NOx concentration at each outlet of the load section is reduced to below 15% and the ammonia escape concentration is reduced to be low 3ppm. The research shows that the thermal optimization adjustment strategy is reliable and effective for improving the NOx uniformity of the SCR denitration unit, and the unit can operate safely and economically.

1. Introduction

NOx is one of the main atmospheric pollutants emitted by coal-fired power plants. NOx emitted into the atmosphere reacts with hydrocarbons under light conditions, causing secondary pollution and endangering human health [1-2]. China has established strict standards and policies to limit NOx emissions from coal-fired power plants. Currently, ultra-low emission limits require NOx concentrations below 50 mg/Nm³. In order to meet more stringent standards, domestic coal-fired power plants widely use SCR denitration technology [3]. With the operation of the device, the problem of SCR denitration unit gradually appeared. Among them, the typical problem was uneven concentration of NOx at the outlet of SCR denitration unit [4], and the hazard was mainly reflected in the excessive escape of ammonia, increasing the clogging and corrosion risk of the downstream air preheater device [5-7]. According to the analysis, the uniformity of NOx at the outlet of the SCR denitration unit is poor, mainly due to the uneven flow field at the inlet of the denitration unit and the uneven ammonia-nitrogen molar ratio, which leads to insufficient mixture of flue gas and NOx in the reactor, which ultimately leads to the concentration of NOx at the outlet not uniform [8, 9]. Therefore, it is necessary to optimize and adjust the denitration unit to ensure safe operation of the device and stability of the NOx.

In general, optimization adjustments can be divided into cold state and thermal state according to the operation of the unit. The cold state adjustment is to analyze the flow field and adjust the angle of
the guide plate when the unit stops running, so as to achieve the goal of uniform inlet flow field and ammonia-nitrogen molar ratio in the denitration unit. Many scholars [10-12] have carried out in-depth research on the cold state adjustment, optimized and adjusted the denitration unit by establishing a model and simulating the flow field, and achieved good results. However, it is insufficient that the above optimization and adjustment should be completed when the unit was stops running; the thermal adjustment strategy makes up for the deficiency. So the thermal adjustment strategy is relative to cold adjustment strategy, it based on the flow field on the flue gas denitration unit inlet section, NO\textsubscript{X} concentration field, such as testing, testing the outlet NO\textsubscript{X} concentration field at the same time, according to the test result to adjust the ammonia injection grid opening size, eliminate local excessive ammonia escape peak, improve the distribution of the reactor inlet ammonia nitrogen molar ratio deviation, improve the uniformity of the denitration unit outlet NO\textsubscript{X} concentration. At the same time, the ammonia escaping amount at the reactor outlet is reduced, and the liquid ammonia consumption is reduced, so as to guarantee the efficient and safe operation of the denitration unit. In this study, a 600MW unit of a coal-fired power plant was taken as an example, and the uniformity of NO\textsubscript{X} at the outlet of SCR denitration unit was optimized by adopting the thermal adjustment strategy, and its effectiveness was analyzed to achieve the purpose of improving the safe and stable operation of the unit.

2. Overview of SCR denitration unit
The object of study for a coal-fired power plant 600MW unit SCR denitration unit, layout after the economizer, economizer to reactor flue has more than 90° angles, installed in the reactor catalyst layer 3, its decorate a form as shown in figure 1.

![Figure 1 SCR reactor structure](image1)

![Figure 2 Ammonia grid structure diagram](image2)

Ammonia injection grilles are set at the inlet of each reactor, and 9 groups of ammonia injection pipelines are set along the width of the furnace in the flue of the vertical section of the inlet. Upper and lower 2 layers of branch pipes for each group are installed at different depths. Manual regulating valves are set for each layer of branch pipes to control the amount of ammonia injection. The structure and layout of the ammonia spray grille are shown in figure 2.

3. Optimization adjustment plan
In this study, based on the operating history of the unit for nearly one year, 100% BMCR was determined as the main adjustment condition, and the main optimization adjustment was performed under this load. In addition, two typical loads, medium load (75% BMCR) and low load (50% BMCR) were selected as the verification conditions for the optimized adjustment. The specific optimization and adjustment work should be carried out according to the following steps.

1) Pre-commissioning: Under the main load, test and evaluate the SCR reactor inlet and outlet flow fields, NO\textsubscript{X} concentration field and ammonia escape concentration.

2) Optimization and adjustment of ammonia injection: Under the main load, according to the evaluation results of pre-commissioning, adjust the opening of the ammonia injection grid regulating
valve of the SCR inlet, adjust the amount of ammonia injected into each part, and make the SCR reactor outlet NO\textsubscript{X} uniform distribution.

(3) Verification test: After optimization of ammonia injection, the SCR reactor outlet NO\textsubscript{X} concentration and ammonia slip concentration were tested under medium load and low load conditions to verify the NO\textsubscript{X} uniformity of the SCR reactor outlet.

The above steps are all based on the premise of ensuring denitration efficiency.

4. Analysis of uniformity effect

4.1 Pre-adjustment test

4.1.1 SCR denitration unit inlet flow field. The grid flow method was used to test the inlet flow field of the SCR denitration unit, and the measuring points were arranged in 8×4. The maximum of the A-side reactor appeared at the measurement point A8P3 (16.2 m/s), the maximum of the B-side reactor appeared at the measurement B1P4 (15.1 m/s); the minimum flow rate of the A-side reactor appeared at the measurement A2P4 (9.3 m/s), the minimum flow rate of the B-side reactor appeared at the measuring A3P3 (7.9m/s), the flow rate deviation of the A-side reactor was 12.57%, and the flow deviation of the B-side reactor was 15.34%. The specific test results as shown in figure 3. According to the test results, the flow rates of the reactors on both sides of A and B are different in the horizontal and vertical directions, showing a tendency of high on both sides and relatively low in the middle, and irregular distribution in the longitudinal direction.

![Figure 3 Test results of flue gas flow velocity at the inlet of SCR reactor](image)

The deviation of the flue velocity of the inlet of the reactor is mainly determined by the characteristics of the flue. The flue gas is collected at the downstream end of the variable diameter due to the inertia, which leads to the uniformity of the lateral flue gas, which is caused by high flow velocity at both ends and low intermediate flow velocity [13]. In the longitudinal direction of the flue gas, due to the change of the 90° direction upstream of the inlet of the reactor, the horizontal flow direction of the flue gas changes and the vertical flow direction is not changed. Similarly, due to the inertia and insufficient length of the deflector, the horizontal movement direction of the flue gas cannot be completely changed to vertical. In the direction of motion, the flue gas in the horizontal running direction is mixed with the flue gas phase in the vertical moving direction, resulting in uneven distribution of the longitudinal velocity of the inlet flue gas in the reactor[14].

4.1.2 SCR denitration unit inlet and outlet NO\textsubscript{X} concentration. The grid method was used to test the inlet flow field of SCR denitration unit. The test results are shown in figure 4. The average concentration of NO\textsubscript{X} at the reactor inlet at side A is 281 mg/Nm\textsuperscript{3}, with the relative standard deviation of 3.64%. The average concentration of NO\textsubscript{X} at the reactor inlet at side B is 282 mg/Nm\textsuperscript{3}, with the relative standard deviation of 6.97%.
The outlet NO\textsubscript{X} test results are shown in figure 5. The relative standard deviation of the A side is as high as 69.45\%, the relative standard deviation of the B side is 46.32\%, and the relative standard deviation of the NO\textsubscript{X} concentration on both sides is greater than 15\%. The concentration of NO\textsubscript{X} at the outlet of each side of the one-sided reactor varies widely. The maximum NO\textsubscript{X} concentration of the A-side reactor outlet reached 57 mg/Nm\textsuperscript{3}, exceeding the ultra-low emission concentration limit, the minimum value was as low as 6 mg/m\textsuperscript{3}, with a difference of 54 mg/Nm\textsuperscript{3}; the NO\textsubscript{X} at the outlet of the B-side reactor reached a maximum of 72 mg/Nm\textsuperscript{3}, the minimum value is as low as 12 mg/Nm\textsuperscript{3}, the difference is 60 mg/Nm\textsuperscript{3}, the concentration of NO\textsubscript{X} at the outlet of the SCR reactor is extremely uneven, indicating that the ammonia injection amount in the areas A1~A6 and B2~B6 is too large, this results in a low concentration of NO\textsubscript{X} in the corresponding area.

4.1.3 SCR denitrification unit outlet ammonia escape concentration. While testing the NO\textsubscript{X} concentration field at the outlet, the ammonia escape concentration at the corresponding measuring point was thoroughly tested, and the test results are shown in figure 6. Ammonia escape concentration and NO\textsubscript{X} concentrations can be seen that the results of the test, an inverse correlation between the two, namely the area of high concentration of ammonia escape NO\textsubscript{X} concentration is low, such as A2, which the mean concentration of NO\textsubscript{X} in eight side of A reactor, the lowest point of 8 mg/Nm\textsuperscript{3}, but the highest concentration of ammonia escape instead, reached 6.1ppm, is beyond the control range of 3ppm [15], illustrate the large amount of ammonia injection of the area, have too much gas ammonia did not react with NO\textsubscript{X}. As can be seen from figure 6, ammonia escape concentrations in regions with low NO\textsubscript{X} at the outlet are all relatively high, which also increases the probability of NH\textsubscript{4}HSO\textsubscript{4} formation, increases the risk of blockage of downstream air preheater, and adversely affects the safe operation of the coal-fired unit.
4.2 Optimization and adjustment

Performed the initial adjustment according to the reactor inlet flow field, the outlet SCR NOX concentration field and the ammonia slip concentration field were tested and evaluated by the pre-adjustment test. By adjusting the ammonia injection grid to adjust the manual adjustment of the flow regulating valve, reduce the ammonia volume of A1~A6, B2 and B6, reduce the corresponding valve opening, and appropriately increase the ammonia volume of A7, A8, B1, B7, B8, and adjust The result is shown in figure 7. After initial adjustment, the NOX concentrations of A1~A6 were significantly increased, the minimum A2P1 side of B2 and B6 areas was adjusted from 6 mg/Nm³ to 25 mg/Nm³, and the maximum A8P4 points decreased by 57 mg/Nm³ to 46 mg/Nm³, the minimum B4P1 on the B side decreased from 12 mg/Nm³ to 28 mg/Nm³, the maximum B8P4 decreased to 72 mg/Nm³ to 46 mg/Nm³, the relative deviation on the A side decreased to 21.63%, and the relative standard deviation of the B side was 17.56%, compared with the standard deviation of 69.45% on the A side and 46.32% on the B side before the initial adjustment, there was a significant decrease, indicating that the adjustment strategy was correct. Although the uniform distribution of the NOX concentration at the outlet after initial adjustment was significantly improved, the relative standard deviations on both sides were still greater than 15%. According to the existing strategy, fine adjustment is performed to reduce the relative deviation of NOX on both sides to less than 15% to improve the uniformity of NOX at the outlet. The test results after fine tuning are shown in figure 8.
Relative standard deviation to 12.14%, below are reached 15%, compared to adjust outlet NO\textsubscript{X} before uniformity has improved significantly, from left to right side of A reactor NO\textsubscript{X} concentration increased trend basically eliminated, B side reactor among low NO\textsubscript{X} concentration distribution trend also eliminate high on both sides.

![Figure 9 Test results of NO\textsubscript{X} concentration and ammonia escape concentration at the outlet of SCR reactor after adjustment](image)

The refined ammonia escape concentration after the fine adjustment was tested, and the test results are shown in figure 9. After two adjustments, the ammonia slip concentration was significantly improved, the maximum value was reduced from 6.1ppm before adjustment to 2.4ppm, and the ammonia escape concentration at both reactor outlets was reduced to below 3ppm. The distribution trend and NO\textsubscript{X} concentration were the reverse correlation indicates that the optimization and adjustment strategy is feasible and effective.

4.3 Verification test

Since the optimization and adjustment test is carried out under the condition of full load, this study chooses to test the outlet NO\textsubscript{X} under medium load (75\%BMCR) and low load (50\%BMCR) to verify the uniformity of outlet NO\textsubscript{X} under medium and low load. The test adopts the same layout mode as the main debugging condition, and the test results are shown in figure 10 and figure 11.

![Figure 10 Verification test results of NO\textsubscript{X} concentration at outlet of medium load SCR reactor](image)

![Figure 11 Verification test results for NO\textsubscript{X} at outlet of low load SCR reactor](image)

According to test results can be seen in figure 10 and figure 11, the medium load and low load condition, the reactor outlet NO\textsubscript{X} concentration distribution rule and NO\textsubscript{X} concentration of outlet of the reactor after optimization adjustment distribution rule, and the load and low negative and NO\textsubscript{X} concentration of outlet of the reactor in the cases of relative standard deviation less than 15%, shows
that optimum adjustment unit can adapt to various typical load period, optimization strategy basic effective adjustment.

4.4 NO\textsubscript{X} uniformity analysis of SCR denitration unit outlet

According to the test results of NO\textsubscript{X} at the reactor outlet under various working conditions, the mean value of NO\textsubscript{X} at the horizontally measuring points of the reactor was compared and analyzed. It can be clearly seen from figure 12, before the optimization adjustment, the NO\textsubscript{X} of the A and B side reactor outlets is extremely uneven. The minimum NO\textsubscript{X} concentration of side A is 8 mg/Nm\textsuperscript{3}, and the maximum concentration exceeded the emission limit to 54.5 mg/Nm\textsuperscript{3}, with a difference of 46.5 mg/Nm\textsuperscript{3}. The minimum NO\textsubscript{X} concentration of side B is 15 mg/Nm\textsuperscript{3}, and the maximum concentration has also exceeded the emission limit, reaching 50.5 mg/Nm\textsuperscript{3}, with a difference of 35.5 mg/Nm\textsuperscript{3}. Optimized adjustment, outlet NO\textsubscript{X} uniformity had significantly improved, after adjusting for the corresponding area for ammonia valve opening, to optimize the spray amount of ammonia, A side reactor outlet minimum NO\textsubscript{X} concentration increased to 31.8 mg/Nm\textsuperscript{3}, the maximum concentration fell to 40.8 mg/Nm\textsuperscript{3}, a difference of 9 mg/Nm\textsuperscript{3}, B side reactor outlet minimum NO\textsubscript{X} concentration increased to 30.8 mg/Nm\textsuperscript{3}, the maximum concentration fell to 38.5 mg/Nm\textsuperscript{3}, a difference of 7.7 mg/Nm\textsuperscript{3}. Under the conditions of medium load and low load verification, the distribution law of NO\textsubscript{X} at the outlet is consistent with the adjusted distribution law. The concentration of NO\textsubscript{X} at the outlet is basically distributed between 20 mg/Nm\textsuperscript{3} and 41 mg/Nm\textsuperscript{3}, and the relative standard deviation is all below 15%. This shows that, after optimization and adjustment, the NO\textsubscript{X} uniformity at the outlet of the unit under various typical load conditions has been significantly improved, significantly higher than before the adjustment.

5. Conclusion

After optimization and adjustment, the relative standard deviation of NO\textsubscript{X} at the SCR denitration unit reactor outlet can be reduced from 69.45% to 11.02%, and can reach below 15% at all load segments, with significantly improved uniformity. Ammonia escape concentration decreased significantly, after adjustment, the maximum ammonia escape concentration at the outlet decreased from 6.1ppm to 2.4ppm, and the ammonia escape concentration at each measuring point decreased to below 3ppm. This study shows that the thermal state adjustment strategy is effective and reliable for improving the NO\textsubscript{X} uniformity of the SCR denitration unit. It can make up for the shortcomings of the cold state optimization adjustment strategy that requires the unit to stop operation. The NO\textsubscript{X} uniformity of SCR denitration unit outlet can be optimized during the operation of the coal-fired units, and the thermal state optimization adjustment strategy can be carried out at any time. It can effectively improve the uniformity of SCR denitration unit outlet NO\textsubscript{X} concentration, and reduce the risk of blockage of downstream air preheater, ensure stable discharge of NO\textsubscript{X}, and safe, stable and economic operation of the coal-fired unit. However, it should be pointed out that thermal optimization adjustment cannot guarantee the uniformity of NO\textsubscript{X} at the outlet for a long time due to the operating state of the
coal-fired unit and the change of coal quality and other factors. Therefore, thermal optimization adjustment should be carried out regularly, preferably once a year.

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