Research on ammonia injection optimized adjustment test of selective catalytic reduction denitrification device for 600MW coal-fired unit

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Abstract: After the ultra-low emission reform of the coal-fired power plant, the ammonia slip at the outlet of the Selective Catalytic Reduction(SCR) denitrification device increases, resulting in abnormal air preheater resistance, which affects the economic and safety of the unit. The optimized adjustment test was carried out on the ammonia injection system of the SCR denitration device for 600 MW coal-fired unit. Under the premise of meeting the ultra-low emission of the unit, the NOx and ammonia escape at the outlet of the denitration device are controlled by adjusting the ammonia injection manual door to reduce the NOx distribution deviation of the outlet. The test shows that the standard deviation of the NO concentration distribution at the outlet of the reactor A reduced from 27.72% before adjustment to 12.53% after adjustment. The standard deviation of the NO concentration distribution at the outlet side B decreased from 55.78% before adjustment to 14.52% after adjustment. The uniformity of the NOx distribution in the outlet zone of the reactor is significantly improved, thereby effectively controlling the escape of ammonia.

1. Introduction
In recent years, the state has put forward further requirements for wordy environmental protection work of coal-fired power plants. In July 2011, the Ministry of Environmental Protection released the latest “Air Pollutant Emission Standard for Thermal Power Plants” GB13223-2011[1]. In September 2014, the National Development and Reform Commission, the Ministry of Environmental Protection and the National Energy Administration jointly formulated and issued the "Action Plan for Energy Saving and Emission Reduction and Reconstruction of Coal-Fired Power Generation (2014-2020)" [2]. On this basis, most provinces, municipalities and power generation enterprises in China have successively formulated coal-fired ultra-clean emission targets [3] in order to further reduce the total pollutant emissions of coal-fired power plants, and the NOx emission limit is 50mg/m3. This emission limit is used as the “ultra-low emission” standard for nitrogen oxide emissions from coal-fired boilers [4].

The introduction of ultra-low emission standards poses an enormous challenge for coal-fired power plants. In order to meet the requirements of national policies and achieve ultra-low emission of atmospheric pollutants, most coal-fired power plants have carried out ultra-low emission conversion of existing environmental protection facilities such as denitrification systems. Because of the lack of sufficient understanding of the operating characteristics for the Selective Catalytic Reduction(SCR) denitration system, the ammonia escape rate at the denitrification reactor outlet is high, resulting in
abnormal air preheater resistance. The unit had to reduce the load operation, and even caused the abnormal shutdown of the unit [5-8]. Therefore, it is necessary to carry out optimization adjustment of ammonia injection to find the better correspondence between ammonia injection, NO\textsubscript{x} emission and ammonia slip concentration, which is necessary to improve the economical efficiency and reliability of unit operation.

2. Occurrence and harm of ammonia escape
The principle of SCR denitration technology is the reaction of ammonia with NO\textsubscript{x} in the flue gas to convert NO\textsubscript{x} into nitrogen and water vapor to reduce NO\textsubscript{x} emissions. The main reactions are as follows:

\begin{align*}
NO + NH_3 + O_2 &\rightarrow N_2 + H_2O \\
NO_2 + NH_3 + O_2 &\rightarrow N_2 + H_2O
\end{align*}

In the SCR reactor, since the injected ammonia gas and the flue gas cannot be entirely uniformly mixed, in some regions, the volume fraction of ammonia gas is higher than the volume fraction of NO\textsubscript{x} in flue gas, thus causing a relative excess of ammonia, that is escape of ammonia\cite{9}. At the same time, part of the SO\textsubscript{2} in flue gas is oxidized to SO\textsubscript{3} under the action of the catalyst. With the existence of water, the escaped ammonia in the SCR reacts with the SO\textsubscript{3} in the flue gas to form the by-product. The possible reaction is as follows:\cite{10-12}:

\begin{align*}
NH_3 + SO_3 + H_2O &\rightarrow NH_4HSO_4 \\
NH_4HSO_4 + NH_3 &\rightarrow (NH_4)\_2SO_4 \\
2NH_3 + SO_3 + H_2O &\rightarrow (NH_4)\_2SO_4 \\
SO_3 + H_2O &\rightarrow H_2SO_4 \\
H_2SO_4 + NH_3 &\rightarrow NH_4HSO_4
\end{align*}

The smoke temperature in the cold end portion of the air preheater is just in the liquid phase of NH\textsubscript{4}HSO\textsubscript{4}, and the liquid NH\textsubscript{4}HSO\textsubscript{4} is a highly viscous substance, which easily adheres to the fly ash in the flue gas, thereby causing an increase in the resistance of the air preheater, even blocking the air preheater \cite{13}.

According to the study\cite{14}, when the ammonia escape concentration is less than 1μL/L, the amount of ammonium hydrogen sulfate is low, the resistance of the air preheater is not obvious. When the ammonia escape concentration increases to 2μL/L, the resistance increases by roughly 30% after half an hour of operation. When the ammonia escape concentration increases above 3μL/L, the resistance increases by about 50% after half an hour of operation, which seriously affects the safe and economic operation of the unit.

3. optimization adjustment test

3.1. Equipment overview
The coal-fired power plant is a 600 MW unit, and the boiler boiler is a supercritical DC furnace produced by Harbin Boiler Co., Ltd., which is a reheating, wall tangential combustion, balanced ventilation, tight-sealing, solid-state slagging, all-steel frame, full suspension Structure II type boiler. The combustion equipment design coal type and the check coal type are both Shanxi Hequ bituminous coal. The burner uses a horizontal faint low NO\textsubscript{x} pulverized coal combustion system.

The flue gas denitrification technology of the power plant adopts a SCR denitration process. The boiler is provided with two sets of SCR reactors, using liquid ammonia as a reducing agent, and the
SCR reactor is located between the boiler economizer and the air preheater. After the flue gas flows out of the economizer, it enters two reactors A and B respectively, and each reactor is equipped with three layers of honeycomb catalyst, as shown in Fig. 1.

![SCR structure diagram](image)

Figure 1. SCR structure diagram

At the beginning of the ultra-low emission reform, the SCR of the plant is able to meet the design requirements for its NOx emission value and ammonia slip concentration. After 2 years of ultra-low emission modification, the ammonia slip concentration of the dial exceeded the standard significantly, and the air preheater resistance increased significantly, which seriously affected the economic and safe operation of the boiler.

3.2. Spray ammonia optimization adjustment test

We refer to the relevant SCR spray ammonia optimization adjustment test [15,16] for the adjustment test of this project. By adopting a method of adjusting the ammonia flow rate of each branch pipe of the ammonia injection system one by one, the local excessive ammonia escape peak is eliminated, the distribution deviation of the ammonia nitrogen molar ratio at the inlet of the reactor is improved, the uniformity of the ammonia concentration distribution is improved, and NH3 and NOx are sufficiently mixed. The ammonia escape amount at the outlet of the reactor is reduced, thereby avoiding the high ammonia escaping concentration due to excessive ammonia injection, and the resulting NH4HSO4 causes air preheater blockage and cold-end corrosion, which provides guarantee for efficient and safe operation of the denitration device.

In the SCR ammonia optimization adjustment test, by adjusting the ammonia injection amount of the system, the NOx/O2 concentration at the inlet and outlet of the reactor is measured after the denitration efficiency of the denitration device reaches the system design value. According to the NOx concentration of the outlet section of the reactor and the concentration distribution of the outlet NH3, the opening degree of each ammonia gas nozzle valve is adjusted to match the flow rate of each ammonia gas nozzle with the NOx content to be reduced in the flue gas, so as to avoid partial ammonia injection excess. Due to certain deviations between the design and the actual situation, it is necessary to adjust the ammonia distribution valve according to the actual distribution of the inlet nitrogen oxide concentration and the outlet nitrogen oxide concentration. The measurement of its distribution is measured by the grid method. The adjustment process is an iterative process. The NO data was tested at the SCR flue outlet test port using a portable flue gas analyzer, and the flow rate of the ammonia dispensing valve was adjusted according to the data to balance the NOx content at the outlet test port.

The uniformity of the NOx concentration distribution at the outlet of the denitration reactor is usually expressed by the standard deviation $C_v$ of the outlet NO concentration, and its value is generally controlled within 15%[15]. The calculation method is:
\[ C_i = \frac{\sigma \times 100\%}{\bar{x}}, \quad \sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2}, \quad \bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \]

In the formula, \( x_i \) is the NO concentration at a certain point of the denitration reactor outlet; \( \sigma \) is the standard deviation of the NO concentration at the outlet of the denitration reactor; and \( \bar{x} \) is the average value of the NO concentration at all points of the measurement section at the outlet of the denitration reactor.

### 3.3. Measurement methods

#### 3.3.1. NOx concentration distribution

In the inlet and outlet flue sections of the SCR reactor, the flue gas sampling points are arranged by the equal-section grid method, and the flue gas is taken out to the flue through the sampling gun and connected to the flue gas analyzer for analysis. Using two sets of flue gas analyzers, the flue gas samples are collected point by point at the inlet and outlet of the reactor, and the NO content in the flue gas is analyzed to obtain the NOx concentration distribution of the flue section.

#### 3.3.2. NH3 concentration distribution

At the exit section of the SCR reactor, a grid method is used to arrange the flue gas sampling points. The flue gas is connected to the Fourier infrared flue gas analyzer by a sampling gun to detect the content of NH3 in the flue gas.

### 3.4. Adjustment method

The NO and oxygen of the 18 test holes were tested under the fixed load of the unit, and then the ammonia valves were adjusted according to the measured data, and adjusted according to the dilution air volume, ammonia injection amount and outlet NO value.

- Analysis of the arrangement of the ammonia spray nozzle.
- Analyze the outlet of the reactor to measure the arrangement of the grid points.
- According to the above arrangement and the corresponding relationship, the cross section of the flue is divided into corresponding small areas, analyzing the relationship between the valve and the small area.
- Under the condition of stable operation of the unit and a certain amount of ammonia injection, measure the NOx concentration at the outlet of the reactor to understand the distribution of the NOx concentration field at the outlet.
- Measure the NOx concentration at the outlet of the A and B reactors, and calculate the relative standard deviation of the NOx concentration at the outlets of the A and B reactors. If \( > 15\% \), fine-tune the ammonia-operated manual door in the region with a large deviation. Then, the NOx concentration at the outlet of the A and B reactors is tested, and the test results are compared and analyzed with the previous test results.
- Calculate the average value \( C_a \) of the NOx concentration field at the exit of the A and B reaction zones, calculate the average value of the NOx concentration in each small zone, and set it to \( C_i \) \((i = 1, 2, 3, 4, \ldots)\), compare \( C_i \) and \( C_a \). If \( C_i > C_a \), open the \( i \) valve. If \( C_i < C_a \), open the \( i \) valve and the value is close. It can be fine-tuned or not adjusted.
- Repeat steps 4 to 6 to compare the NOx concentration data at the A and B reactor outlets until the relative standard deviation of the outlet NOx concentration is \( < 15\% \), and the NOx concentration uniformity is significantly improved.
3.5. Optimization results and analysis

3.5.1. Testing
Basic test before optimization adjustment in SCR. Each of the 9 holes of the A and B reactor outlets is tested from the outside of the flue A to the center line of the furnace at the measuring point. The distribution results of NOX distribution in the denitrification outlet before the ammonia injection optimization of the unit are shown in Table 1.

| Number | Subject                  | Side A flue Data of SCR Export | Side B flue Data of SCR Export |
|--------|--------------------------|--------------------------------|--------------------------------|
| 1      | O₂(%)                    | 2.89                           | 2.22                           |
| 2      | NH₃ Avg(µL/L)             | 0.59                           | 0.67                           |
| 3      | NOₓ Avg(mg/m³)           | 32.1                           | 20.7                           |
| 4      | NOₓ Max(mg/m³)           | 46.9                           | 43.0                           |
| 5      | NOₓ Min(mg/m³)           | 21.3                           | 6.0                            |
| 6      | NOₓ Std Dev(mg/m³)       | 9.06                           | 11.78                          |
| 7      | NOₓ Cv(%)                | 27.72                          | 55.78                          |

At the 580 MW load of the unit, the NOₓ content was tested at the A-side SCR outlet, the average NOₓ content was 32.1 mg/m³, and the standard deviation was 27.72%. The average content of NOₓ at the B-side SCR outlet was 20.7 mg/m³, and the standard deviation was 55.78%. According to the data, the NOₓ concentration at the outlet of the two reactors is uneven along the width and depth of the flue, especially in the outer wall of the B side flue. The NOₓ concentration in the deep position is high, and the shallow position is low. The lateral outlet maximum is 46.9 mg/m³ and the minimum is 21.3 mg/m³. The B side outlet has a maximum value of 43 mg/m³ and a minimum value of 6.0 mg/m³.

![Figure 2. NOₓ distribution of denitrification export before ammonia injection optimization](image)

3.5.2. Optimized adjustment of ammonia injection
According to the measured distribution of NOₓ concentration in the outlet section of the reactor, the manual valve opening degree of the ammonia branch pipe is adjusted several times to maximize the uniformity of NOX concentration distribution at the outlet of the reactor. The SCR is optimized for the test when the boiler is loaded at 580 MW. The optimized NOₓ concentration distribution at the outlet of the reactor after adjustment is shown in Table 2.
Table 2. NOx distribution results of denitration export after ammonia injection optimization

| Number | Subject       | Side A flue Data of SCR Export | Side B flue Data of SCR Export |
|--------|---------------|--------------------------------|--------------------------------|
| 1      | O2(%)         | 2.61                           | 3.25                           |
| 2      | NH3 Avg(μL/L) | 0.48                           | 0.32                           |
| 3      | NOx Avg(mg/m^3) | 53.8                    | 47.7                           |
| 4      | NOx Max(mg/m^3) | 68.1                  | 56.4                           |
| 5      | NOx Min(mg/m^3) | 42.2                   | 36.9                           |
| 6      | NOx Std Dev(mg/m^3) | 6.74       | 6.92                           |
| 7      | NOx Cv(%)     | 12.53                          | 14.52                          |

Figure 3. NOx distribution of denitration export after ammonia injection optimization

The distribution of NOx concentration at the outlet of the reactor after optimized ammonia injection is shown in Figure 3. After repeated tests and adjustments, the standard deviation of the NOx concentration distribution at the outlet of the reactor showed a decreasing trend, and the NOx concentration distribution gradually became uniform.

3.5.3. Ammonia escape

During the ammonia spray optimization adjustment test, ammonia slip concentration tests were performed on the A and B sides of the SCR outlet. The test results show that the ammonia slip concentration of the A and B sides of the SCR outlet is reduced after the ammonia-adjusted adjustment test. The ammonia slip concentration of the A-side SCR outlet is reduced from 0.59 μL/L to 0.48 μL/L, which is reduced by 18.6%. The ammonia slip concentration at the B-side SCR outlet was reduced from 0.67 μL/L to 0.32 μL/L, which was reduced by 52.2%.

4. Conclusion

4.1. After multiple measurements of the denitration outlet data and multiple adjustments of the distribution valve, the standard deviation of the A side is reduced from 27.72% before the adjustment to 12.53% after the adjustment. The standard deviation of the B side is reduced from 55.78% before the adjustment to 14.52% after the adjustment. The uniformity of NOx distribution at the outlet section of the reactor was significantly improved, and the ammonia escape is effectively controlled.

4.2. The uneven flow field inside the SCR and the structure of the ammonia spray grid will affect the distribution of NOx mass concentration at the SCR outlet. The design should be optimized in the later stage, and the improved ammonia spray grid structure and its arrangement should be implemented to realize the zone adjustment and improve the internal flow field distribution[17].
4.3. It is recommended to carry out the optimization experiment of ammonia injection on a regular basis to reduce the ammonia escape amount at the outlet of the denitration device and reduce the blockage of the air preheater.

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