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Experimental Study on Ammonia Injection Optimization for Denitration System for 1000MW Coal-Fired Unit

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Abstract: To improve NOx distribution uniformity at the SCR reactor outlet, reduce ammonia escape concentration, and minimize air preheater plugging risk, an ammonia injection optimization experiment was conducted on the SCR denitrification system of a 1000 MW coal-fired unit. After optimization, at 1000 MW load, the relative standard deviation of NOx concentration distribution at the A and B side SCR reactor outlets decreased from 53.8% and 78.9% to 17.5% and 18.0%, respectively, while the average ammonia escape concentration decreased from 1.92 mg/m³ to 1.39 mg/m³. Under different unit loads, ammonia escape remained stable between 1.39-1.61 mg/m³, NOx concentration distribution uniformity at the SCR outlet significantly improved, and ammonia escape concentration decreased to varying degrees, providing reference for the safe, stable, and economical operation of denitrification systems.

Keywords: Coal-fired unit; SCR; AIG; Ammonia escape.

1. Introduction

In recent years, with the implementation of a series of ecological and environmental protection policies[1], most coal-fired power plants in China have successively completed ultra-low emission or near-zero emission technology retrofits. By the end of 2020, 950 million kW of coal-fired units in China had achieved ultra-low emission standards, accounting for 88% of the total installed capacity of coal-fired units[2]. Among these technologies, Selective Catalytic Reduction (SCR) has been widely applied to existing coal-fired units due to its advantages of high denitrification efficiency, simple maintenance, and mature technology[3-5]. However, during actual operation, SCR denitrification systems often experience issues such as inlet NOx concentration deviating from design values, large outlet NOx concentration deviations, excessive ammonia injection, and localized ammonia escape exceeding standards due to factors including unit load, flue gas flow field, and denitrification catalyst. With the advancement of deep peak-shaving policies for thermal power units, the frequent load fluctuations of existing coal-fired units have become more intensive, further exacerbating these issues. These problems manifest as decreased denitrification efficiency, high ammonia escape concentration at the SCR reactor outlet, increased air preheater pressure differential, and other practical issues that severely constrain the safe and stable operation of the units[6-7].

Currently, relevant personnel have conducted extensive experimental research on ammonia injection optimization for coal-fired units. Gao Peng et al.[8] conducted ammonia injection optimization experiments on the SCR denitrification system of a 300MW unit. Through multiple optimization adjustments, the relative standard deviations of NOx concentration at both A and B side SCR denitrification reactor outlets were reduced to within 10%, and ammonia escape concentrations on both sides were significantly reduced, achieving good optimization results. Wang Yanpeng[9], Guo Lei[10], and others performed SCR ammonia injection optimization adjustments on a 600MW coal-fired unit. After optimization, the ammonia flow rates in each injection branch pipe became more reasonable, and the total ammonia injection flow rate under different operating conditions decreased significantly, substantially reducing annual liquid ammonia costs. Yu Xiaowei et al.[11] significantly reduced the non-uniformity of NOx distribution at the SCR outlet through ammonia injection optimization experiments, achieving an average non-uniformity of 18.5% and improving the problem of excessive local ammonia mass concentration. Chen Cheng et al.[12] systematically analyzed the impact of ammonia injection grid operation on denitrification systems by listing actual problems in the operation of SCR denitrification system ammonia injection grids, and discussed current experimental methods for ammonia injection grid optimization, providing theoretical support for ammonia injection optimization.

Currently, experimental research on ammonia injection optimization for coal-fired units is mostly concentrated on small and medium-sized units, with relatively scarce research on large coal-fired units. After long-term operation of the denitrification system of a 1000MW unit at a certain power plant, non-uniform NOx concentration distribution at the SCR outlet, significant deviation between the SCR reactor outlet NOx concentration meter readings and the NOx concentration meter readings at the chimney inlet, and localized excessive ammonia injection were observed. Therefore, this paper conducts ammonia injection optimization adjustments on the SCR denitrification system of this 1000MW unit to minimize the NOx concentration deviation at the denitrification system outlet and ammonia escape concentration to the greatest extent, accumulating experience for ammonia injection optimization experimental research on large coal-fired units.

2. Experimental Object and Method

2.1. Experimental Object

The 1000MW unit boiler at the power plant is an ultra-supercritical compound variable pressure once-through reheat single-furnace natural circulation boiler manufactured by Dongfang Boiler Co., Ltd. The boiler employs flue gas dampers to regulate reheat steam temperature, solid slag discharge, all-steel frame, fully suspended structure, balanced ventilation, outdoor arrangement, and front-to-back wall opposed firing. The flue gas denitrification system is installed between the boiler economizer outlet and the air preheater inlet, with two SCR reactors configured. The SCR catalyst is arranged in a "2+1" mode, with three layers of catalyst currently in operation. The SCR reactor inlet duct dimensions are 3.5m×18.29m. The denitrification system is designed for an inlet NOx concentration of 400mg/m³ (standard state, dry basis, 6% O_2), a denitrification efficiency of not less than 87.5%, resulting in a NOx emission concentration at the denitrification system outlet of not more than 50mg/m³ (standard state, dry basis, 6% O_2), and a design ammonia escape mass concentration not exceeding 2.28 mg/m³. The layout of the denitrification reactor is shown in Figure 1.

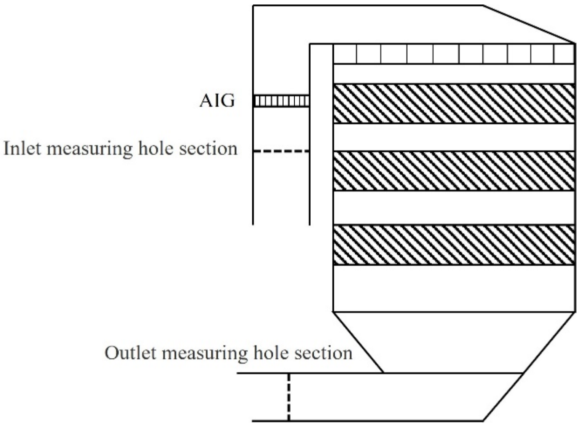

Figure 1. Measuring hole locations and arrangement diagram

2.2. Experimental Content and Operating Condition Design

According to the requirements of the power station boiler performance test procedure, this experiment includes three parts: baseline test, optimization adjustment test, and comparative test. To cover three conventional load levels of 100%, 75%, and 50%, these three parts of the experiment were conducted at load conditions of 1000MW, 750MW, and 515MW, respectively. First, the baseline test was conducted to measure the NOx concentration, O_2 concentration, and ammonia escape at the SCR reactor outlet, thereby calculating the NOx concentration distribution across each cross-section. Through the baseline test, detailed knowledge of the actual performance of the denitrification system and ammonia escape conditions was obtained, laying the foundation for the adjustment optimization test. Second, after completing the baseline test, the ammonia injection system optimization adjustment test was conducted by specifically adjusting the opening of manual valves on the ammonia injection branch pipes at the reactor inlet duct to maximize the uniformity of NOx concentration distribution at the outlet. Finally, after completing the adjustments, comparative tests were conducted under different load conditions to re-measure the NOx concentration, O_2 concentration, and ammonia escape at the SCR reactor outlet to verify the optimization adjustment effect.

2.3. Experimental Method and Data Processing

In this experiment, 10×3 test points were set up at the inlet and outlet cross-sections of both A and B side reactor ducts. The grid method was used to measure flue gas components, flue gas velocity, pressure, and temperature at each test point, with the grid arrangement following the test grid arrangement method in GB/T 16157. A German Rosemount NGA2000 infrared flue gas analyzer and flue gas pretreatment device were used to analyze NOx and O_2. Flue gas velocity was measured using an S-type Pitot tube and an electronic micromanometer. Ammonia escape samples were collected using the standard chemical solution method, and samples were analyzed within 12 hours using the indophenol blue spectrophotometric method. The relative standard deviation of NOx concentration distribution in each cross-section of the duct was calculated using the following formulas:

$$Cv = \frac{\sigma}{\overline{NOx}} \times 100 \tag{1}$$

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(NOx_i - \overline{NOx}\right)^2} \tag{2}$$

$$\overline{NOx} = \frac{1}{n}\sum_{i=1}^{n} NOx_i \tag{3}$$

Where,Cv is the relative standard deviation, %; σ is the standard deviation, mg/m³; $\overline{NOx}$ is the average NOx concentration (standard state, dry basis, 6% O_2) of the test cross-section, mg/m³; NOx_i is the NOx concentration (standard state, dry basis, 6% O_2) at point i of the test cross-section, mg/m³.

3. Experimental Results and Analysis

3.1. Baseline Test

At a unit load of 1000MW, the NOx concentration field distributions measured at the SCR inlet and outlet ducts during the baseline test are shown in Figures 2-5. The test measured an average NOx concentration of 339mg/m³ at the A side inlet, with a relative standard deviation of 5.4% after conversion, and an average NOx concentration of 356mg/m³ at the B side inlet duct, with a relative standard deviation of 6.3% after conversion, indicating uniform inlet concentration distribution. The average NOx concentration at the A side outlet was 25mg/m³, with a relative standard deviation of 53.8% after conversion, and the average NOx concentration at the B side outlet duct was 24mg/m³, with a relative standard deviation of 78.9% after conversion. The maximum deviation of NOx mass concentration at the B side outlet cross-section reached 69 mg/m³, indicating extremely non-uniform NOx concentration distribution.

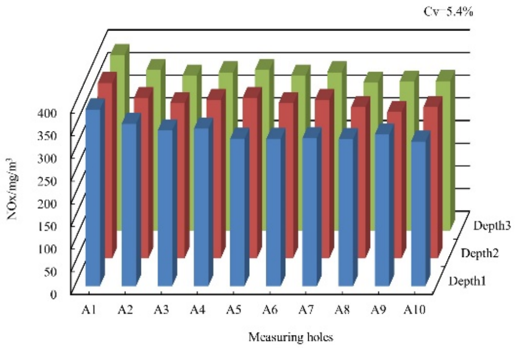

Figure 2. NOx concentration distribution at SCR A-side inlet under 1000MW baseline condition

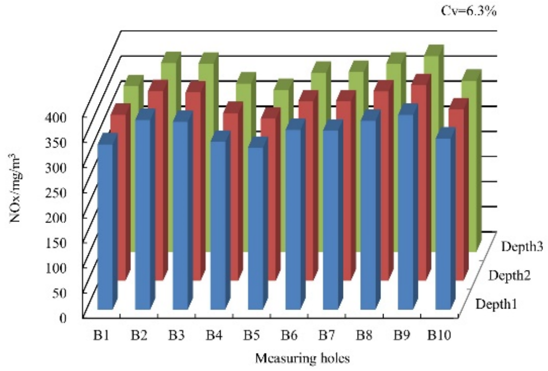

Figure 3. NOx concentration distribution at SCR B-side inlet under 1000MW baseline condition

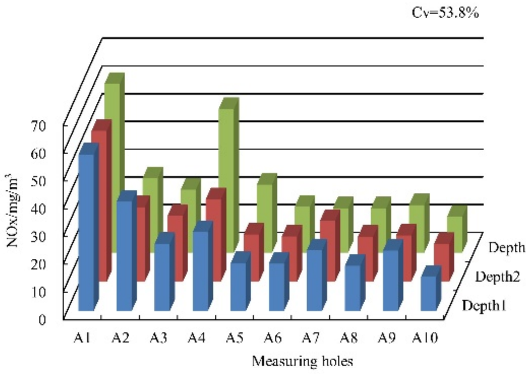

Figure 4. NOx concentration distribution at SCR A-side outlet under 1000MW baseline condition

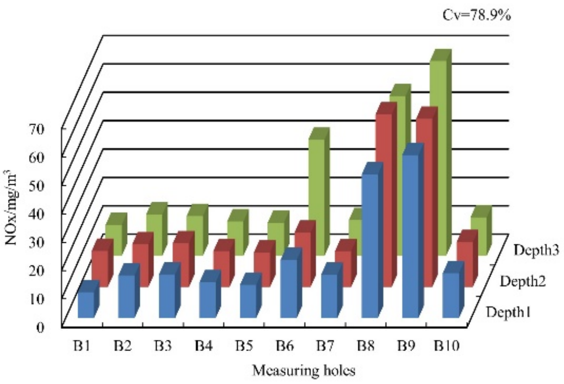

Figure 5. NOx concentration distribution at SCR B-side outlet under 1000MW baseline condition

From Table 1, it can be seen that the relative standard deviations of NOx concentration at the A and B sides of the SCR reactor inlet ducts under three different load conditions fluctuated around 6%, with a maximum of only 7.6%, indicating excellent uniformity of NOx at the inlet ducts. However, the relative standard deviations of NOx concentration at the A and B sides of the SCR outlet ducts under the three load conditions were all very large, with a maximum of 81.1% and a minimum of 53.0%, indicating extremely non-uniform NOx concentration distribution at the outlet ducts.

Table 1. NOx distribution non-uniformity at SCR inlet and outlet ducts before optimization

Item	1000MW		750MW		515MW	
	A side	B side	A side	B side	A side	B side
Inlet *Cv*	5.4	6.3	5.7	7.6	6.0	6.3
Outlet *Cv*	53.8	78.9	53.0	80.7	65.0	81.1

The ammonia escape concentrations at the SCR reactor outlet under the three load conditions are shown in Figures 6-8. Under the 1000MW baseline condition, the average ammonia escape at the A side outlet of the SCR reactor was 2.00mg/m³, and 1.92mg/m³ at the B side outlet. Under the 750MW baseline condition, the average ammonia escape at the A side outlet of the SCR reactor was 2.11mg/m³, and 2.18mg/m³ at the B side outlet. Under the 515MW baseline condition, the average ammonia escape at the A side outlet of the SCR reactor was 1.96mg/m³, and 2.00mg/m³ at the B side outlet. Although the average ammonia escape concentrations at the A and B sides of the SCR reactor outlet under the three load conditions did not exceed the standard, most values were high, and some individual test point values exceeded the design value for ammonia escape (2.28mg/m³). The peak ammonia escape concentration at the test port reached 2.90 mg/m³ at 750MW, and the average ammonia escape concentrations at both A and B sides were approaching the design value. This analysis indicates that non-uniform mixing of NH_3 and NOx occurred at both the A and B sides of the SCR reactor during reaction, causing NH_3 to be excessive or insufficient in some areas of the reactor, resulting in high average ammonia escape concentrations.

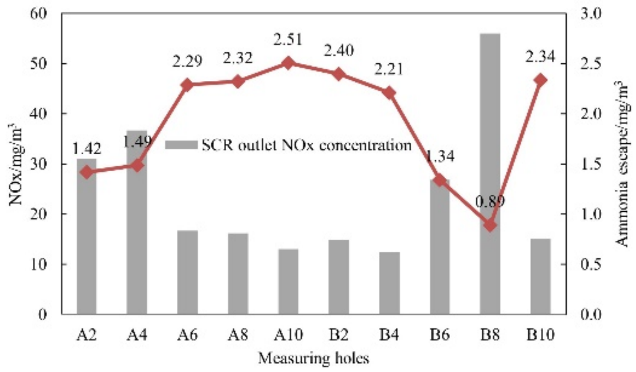

Figure 6. Ammonia escape concentration distribution at SCR outlet under 1000MW baseline condition

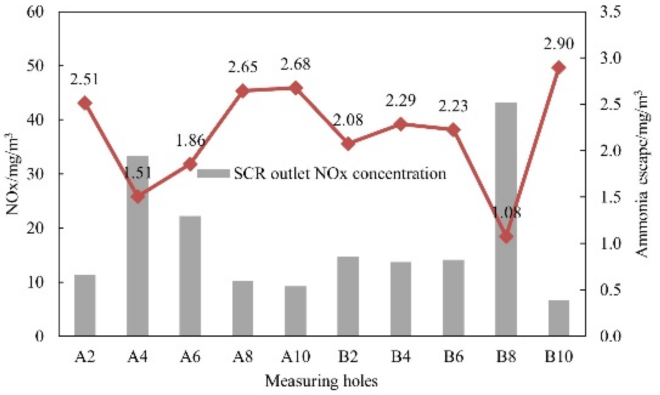

Figure 7. Ammonia escape concentration distribution at SCR outlet under 750MW baseline condition

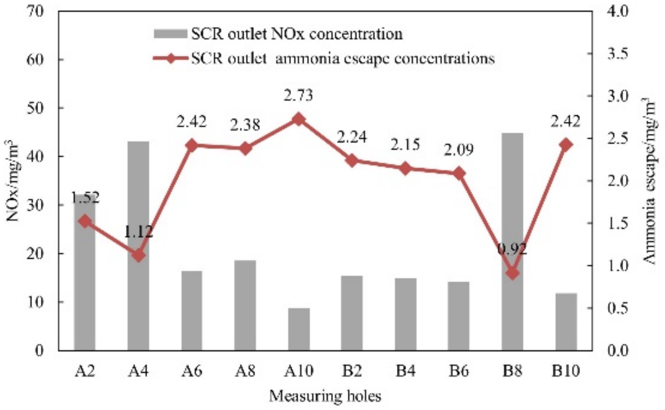

Figure 8. Ammonia escape concentration distribution at SCR outlet under 515MW baseline condition

3.2. Optimization Adjustment Test

Based on the baseline test results in Section 2.1, multiple rounds of optimization adjustments were made to the opening of the manual valves on the ammonia injection branch pipes to maximize the uniformity of NOx concentration distribution at the reactor outlet. The opening of each ammonia injection branch pipe manual valve before and after optimization adjustment is shown in Table 2. Each side of the SCR reactor corresponds to 26 valves, numbered A1-A26 (on-site nameplate numbers) and B1-B26 (on-site nameplate numbers). The valves are handle butterfly valves with an opening range of 0-10, where 0 is fully closed and 10 is fully open.

Table 2. Summary of ammonia injection branch pipe manual valve openings

Item	Record of valve opening of ammonia injection branch pipe								
Valve number	A1	A2	A3	A4	A5	A6	A7	A8	A9
Original opening	5	7	7	8	7	6	4.5	5	5
opening after adjustment	5.5	6	6	7	6	6	5	6	6
Valve number	A10	A11	A12	A13	A14	A15	A16	A17	A18
Original opening	6	7	6	7	5	6.5	6.5	5.5	5.5
opening after adjustment	6	6	6	6	5	5	6	5	5.5
Valve number	A19	A20	A21	A22	A23	A24	A25	A26	
Original opening	5	4.5	4.5	5	4.5	5	4.5	5	
opening after adjustment	4	5	4	5	5	5	5	5	
Valve number	B1	B2	B3	B4	B5	B6	B7	B8	B9
Original opening	5	6	5	6	5	5	5	5	5.5
opening after adjustment	4	4	4	5	5	4	5	4	5
Valve number	B10	B11	B12	B13	B14	B15	B16	B17	B18
Original opening	5	5	5	5	5.5	5.5	5	5	5
opening after adjustment	4	4	4	5	4	5	5	6	6
Valve number	B19	B20	B21	B22	B23	B24	B25	B26	
Original opening	5	5	5	5.5	5	6	5	5	
opening after adjustment	7	7	10	10	10	10	5	5	

3.3. Comparative Test

After completing the optimization adjustment test, comparative tests were conducted at 1000MW, 750MW, and 515MW conditions. At a unit load of 1000MW, the NOx concentration field distributions measured at the SCR outlet ducts during the comparative test are shown in Figures 9-10. As shown, the average NOx concentration at the A side outlet was 25mg/m³, and 27mg/m³ at the B side outlet. The relative standard deviations of NOx concentration after conversion at the SCR A side outlet and SCR B side outlet were 17.5% and 18.0%, respectively, showing significant improvement in NOx uniformity compared to the baseline test.

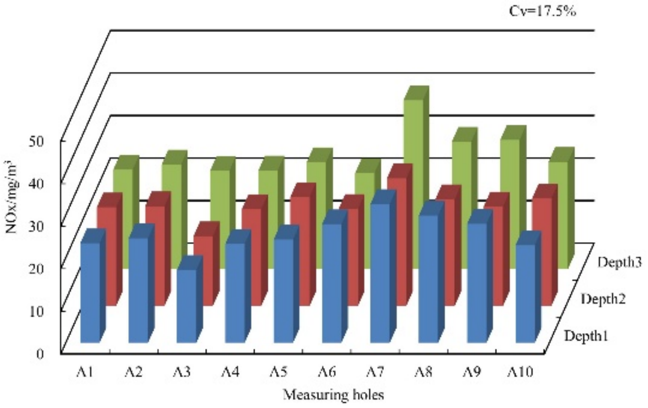

Figure 9. NOx concentration distribution at SCR A-side outlet under 1000MW comparative test

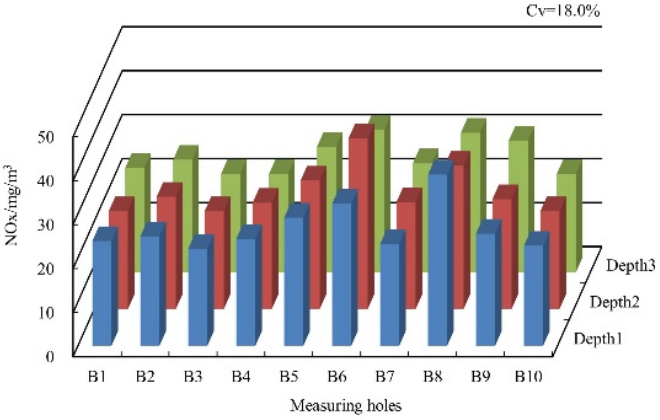

Figure 10. NOx concentration distribution at SCR A-side outlet under 1000MW comparative test

The relative standard deviations of NOx concentration at the SCR inlet and outlet ducts measured in the comparative test are shown in Table 3. The relative standard deviations of NOx concentration at the inlet ducts under the three load conditions in the comparative test were all small. After optimization, the relative standard deviations of NOx concentration at the outlet ducts ranged from 17.5% to 19.4%, showing significant improvement compared to the pre-optimization range of 53.0% to 81.1%.

Table 3. NOx distribution non-uniformity at SCR inlet and outlet ducts after optimization

Item	1000MW		750MW		515MW	
	A side	B side	A side	B side	A side	B side
Inlet *Cv*	4.6	4.4	5.7	6.8	6.5	6.9
Outlet *Cv*	17.5	18.0	17.7	18.0	18.4	19.4

The ammonia escape concentrations at the SCR reactor outlet under the three load conditions in the comparative test are shown in Figures 11-13. Under the 1000MW condition, the average ammonia escape at the A side outlet of the SCR reactor was 1.42mg/m³, and 1.36mg/m³ at the B side outlet. Under the 750MW condition, the average ammonia escape at the A side outlet of the SCR reactor was 1.63mg/m³, and 1.59mg/m³ at the B side outlet. Under the 515MW condition, the average ammonia escape at the A side outlet of the SCR reactor was 1.53mg/m³, and 1.47mg/m³ at the B side outlet. The average ammonia escape concentrations at both the A and B sides of the SCR reactor outlet under the three load conditions decreased significantly compared to before ammonia injection optimization, particularly after optimization adjustment, when ammonia escape concentrations remained stable between 1.39-1.61 mg/m³ and maintained good uniformity under different loads. This indicates that after adjustment, the mixing of NH_3 and NOx at both the A and B sides of the SCR reactor was uniform, the NOx concentration field was basically coupled with the ammonia injection amount, and the NOx distribution at the reactor outlet cross-section was more uniform. By comparing operational data, after the optimization adjustment test, the deviation between the NOx concentration values at the SCR reactor outlet and the NOx concentration data at the chimney total discharge outlet was minimal, further indicating that the NOx concentration distribution at the SCR denitrification reactor outlet cross-section has gradually become uniform under different load conditions.

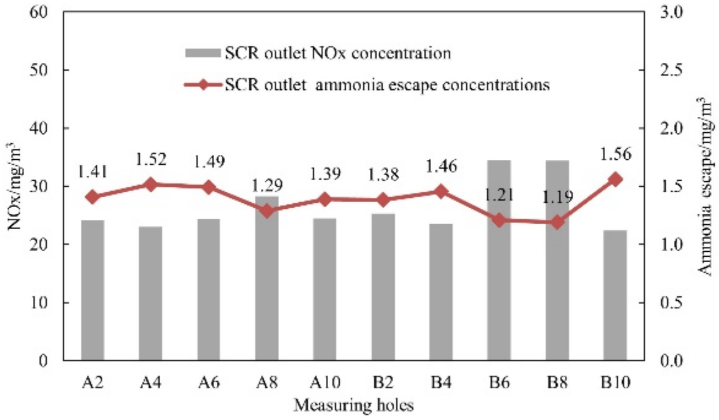

Figure 11. Ammonia escape concentration distribution at SCR outlet under 1000MW comparative test

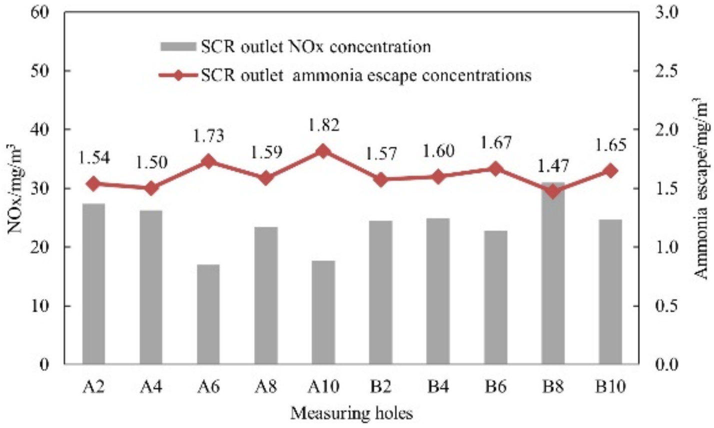

Figure 12. Ammonia escape concentration distribution at SCR outlet under 1000MW baseline condition

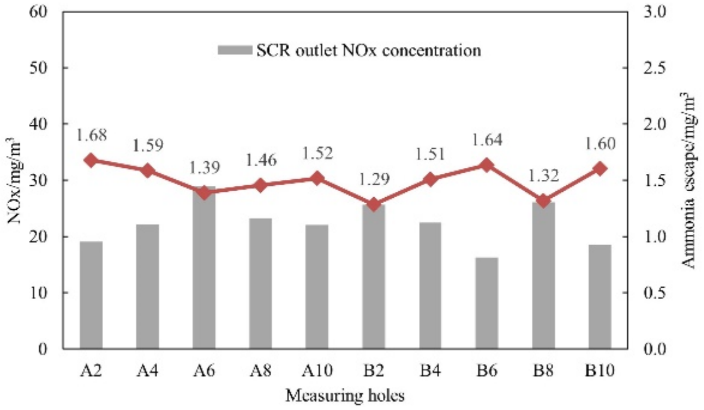

Figure 13. Ammonia escape concentration distribution at SCR outlet under 1000MW baseline condition

4. Summary

(1) During the baseline test of the 1000MW unit, the NOx concentration distribution at the SCR reactor inlet duct was uniform, but the NOx concentration distribution at the reactor outlet duct was extremely non-uniform, with the highest relative standard deviation of NOx concentration reaching 78.9%. The average ammonia escape concentration was high, with the peak ammonia escape concentration at the test port reaching 2.90 mg/m³ at 750MW load, and the average

ammonia escape concentrations at both A and B sides approaching the design value.

(2) Under 1000MW, 750MW, and 515MW load conditions, optimization adjustment tests of the ammonia injection grid can effectively reduce the non-uniformity of NOx distribution at the SCR reactor outlet while reducing ammonia escape concentration. Comparative tests showed that ammonia escape concentrations remained stable between 1.39-1.61 mg/m^3 and maintained good uniformity under different loads. The deviation between the NOx concentration data at the reactor outlet and the NOx concentration data at the chimney total discharge outlet was reduced.

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