Analysis and Discussions on the Nonuniformity Problem of SCR Denitration Equipment NO_x Concentration Distribution in a 600MW Coal-fired Unit

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Abstract. Combining with an engineering example, from the aspects of SCR inlet NO_x concentration distribution, flue gas velocity uniformity, ammonia injection valve opening, ash deposit, abrasion and flue arrangement, the uniformity problem of SCR denitration equipment outlet NO_x concentration distribution is analyzed and discussed in a 660MW coal-fired unit. The results show that the uneven distribution of NO_x concentration is caused by the combined action of many factors. In the cause analysis and solution formulation, the influence factors need be overall consideration. By adjusting the ammonia injection valve opening, the uniformity of SCR outlet NO_x concentration increases by about 30%, the performance of SCR denitration equipment is obviously improved. At the same time, rationalization proposals and solution measures for the improvement of outlet concentration uniformity are given in order to ensure the safe and stable operation of denitration equipment.

1 Introduction

Nitrogen oxides is one of the main pollutants in flue gas emissions from coal-fired units, and excessive emissions will seriously deteriorate environmental air quality and have adverse effects to human health^[1]. Therefore, controlling the emission of nitrogen oxides has become one of the main tasks in the construction of a beautiful ecological environment in China. SCR flue gas denitrification technology is currently the most widely used and mature flue gas treatment technology. With the hours of equipment operation increasing, the operation state of denitrification facilities such as the diversion device, the rectifier device, the ammonia spraying grid has changed, which caused the flue gas flow field to change, resulting in the uneven distribution of NO_x concentration at the outlet of denitrification equipment. This will further lead to problems and deterioration of ammonia escape rate increasing, air preheater blockage, catalyst wear and other, which will adversely affect the safe and stable operation of the denitrification equipment and even the unit, and will also lead to the phenomenon of "upside down" of NO_x at the outlet of the denitrification equipment and the chimney discharge port, there is the risk of excess nitrogen oxide emissions, which has become an important technical problem to be solved by coal-fired power generation enterprises at present^[2].

2 RESEARCH OBJECT

2.1 Overview of SCR denitrification equipment

The 680MW unit boiler is designed and manufactured by Harbin Boiler Plant Co., Ltd. The boiler is ultra-supercritical variable pressure running once-through boiler, which use low NO_x main burner grading combustion technology and MACT-type low NO_x grading air supply combustion system, reverse tangential burning. The flue gas denitrification equipment uses SCR denitrification process, honeycomb catalyst, liquid ammonia as reducing agent. The unit design parameters of SCR denitrification are shown in table 1.

Table 1. The design parameter of SCR de-NO_x equipment

Item	Design Parameter
The flue gas parameters	
Flue gas volume flow rate /(m ³ ·h ⁻¹)	2062799
flue gas temperature/°C	365
The inlet NO _x of SCR /(mg·m ⁻³)	400
The dust concentration /(mg·m ⁻³)	38.8
The performance parameters	
The outlet NO _x of SCR/(mg·m ⁻³)	50
Ammonia escape/(mg·m ⁻³)	2.28
Denitrification efficiencies /%	87.5

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The denitrification equipment was put into operation at the end of March 2013, with the initial loading of two layers catalyst. The ultra-low emission transformation is completed at the end of 2016, and the initial loading of two layers catalyst is replaced. The denitrification ammonia-spraying grille (AIG) adopts zoning control, that is, the inlet flue section is divided into 14 regions, seven regions of the single side reactor, two ammonia-spraying pipes are set up in a single area to control the amount of ammonia sprayed at different depths, and each pipe is connected with three ammonia-spraying branch pipes, each of which can be adjusted separately to distribute the ammonia-spraying flow.

2.2 Inlet and outlet flue monitoring points of denitrification equipment

The reactor inlet NO_x concentration and flue gas flow rate monitoring points are located at the upper horizontal flue between economizer outlet and SCR reactor inlet. The monitoring point arrangement is shown in Fig.1. The NO_x concentration and flue gas flow rate distribution were measured by grid method. The number of monitoring points in the reactor A to B direction was 1A1,1A2...1A9,1B1,1B1,1B2....1B9, total 18 monitoring holes; the depth of flue gas sampling points in each hole was 1,2,3,4,5m, and the number was 1P1,1P2,1P3,1P4,1P5; and 90 monitoring points for the inlet flue section^[3].

Fig.1. Monitoring points of flue inlet

The reactor outlet NO_x concentration and flue gas flow rate monitoring points are located at the upper horizontal flue. The NO_x concentration and flue gas flow rate distribution were measured by grid method. The number of monitoring points in the reactor A to B direction was 2A1,2A2...2A12,2B1,2B1,2B2....2B12, total 24 monitoring holes; the depth of flue gas sampling points in each hole was 1,2,3,4m, and the number was 2P1,2P2,2P3,2P4; and 96 monitoring points for the inlet flue section. The order of the monitoring points is the same as the import.

2.3 Evaluation criteria

The uniformity of NO_x concentration and flue gas flow rate at inlet and outlet of denitrification reactor are evaluated by standard deviation coefficient (Cv.), which is defined by the following formula^[4-5]:

$$C_v = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2} / \bar{x} \times 100\% \quad (1)$$

Where $\bar{x}$ is the average value of measured data;
 x_i is the monitoring value of monitoring point.

3 Distribution of outlet flow field of denitrification equipment

3.1 Distribution of NO_x concentrations

Fig.2 shows NO_x concentration distribution at outlet of denitrification reactor. From Fig.2, it can be seen that the maximum value of NO_x concentration at the outlet section of A side reactor is 95 mg/m³, the minimum value is 10 mg/m³, the relative standard deviation of NO_x concentration distribution is 57.58%; the maximum value of NO_x concentration at the outlet section of B side reactor is 80 mg/m³, the minimum value is 12 mg/m³, the relative standard deviation coefficient of NO_x concentration distribution is 45.07%; and the mean value of relative standard deviation coefficient at the outlet of two reactors is 51.37%^[6]. It can be seen that the outlet NO_x concentration distribution is highly heterogeneous, the NO_x concentration distribution along the reactor width direction obviously presents the distribution characteristics of the flue lateral high and the medial low, and the middle concentration is the lowest; the depth direction presents the distribution characteristics of the upper layer concentration of the flue and the lower layer gradually decreases.

Fig.2. Distributed situation of outlet NO_x concentration

3.2 Distribution of ammonia escape rates

The ammonia escape rate is an important operation

parameter of SCR system, which reflects the spray amount of ammonia, the degree of mixing uniformity between NO_x and ammonia, and the catalytic chemical reaction on the catalyst surface. Fig.3 shows the ammonia escape rate distribution at the outlet of the denitrification reactor. It can be seen that the maximum ammonia escape concentration in the flue section of the reactor outlet is 1.45 mg/m^3 and the minimum value is 0.59 mg/m^3 . The ammonia escape rate of each monitoring point is within the control guaranteed value range. However, from the distribution situation, it can be seen that the outlet ammonia escape concentration unevenness is high, mainly showing the trend of high in the two sides and low in the middle of the flue, which is basically consistent with the concentration distribution of NO_x .

Fig.3. Distributed situation of ammonia escape

4. Analysis and Discus distribution of outlet NO_x concentration sions on the uniform

4.1 The distribution of NO_x concentration in the inlet

The distribution of inlet NO_x concentration in the denitrification system is directly related to the spray amount of ammonia in the flue. The more uniform the NO_x concentration distribution is, the more stable the denitrification efficiency and ammonia escape rate are. Fig.4 shows the NO_x concentration distribution at the inlet of the denitrification reactor. From Fig.4, it can be seen that the maximum NO_x concentration of inlet flue section of A reactor is 332 mg/m^3 , the minimum value is 262 mg/m^3 , the relative standard deviation of NO_x concentration distribution is 6.08%; the maximum NO_x concentration of outlet flue section of B reactor is 315 mg/m^3 , the minimum value is 261 mg/m^3 , and the relative standard deviation of NO_x concentration distribution is 5.05%, which is maintained near the standard deviation design value (5%) of inlet NO_x concentration. It can be seen that the NO_x concentration uniformity of the inlet flue of the denitrification equipment is relatively good, and the concentration distribution of each region of the inlet flue is more uniform, only a relatively high concentration distribution appears on both sides of the flue. In the case of the same

inlet flue gas flow rate, ammonia spray and so on the influence of the inlet NO_x concentration distribution on the uniformity of the outlet NO_x concentration distribution is relatively small.

Fig.4. Distributed situation of inlet NO_x concentration

4.2 Distribution of inlet velocity field

The inlet flue gas flow rate of denitrification equipment is one of the important factors affecting the mixing of flue gas and ammonia [7]. Fig.5 shows the inlet velocity field distribution of the denitrification reactor. The grid method is used to measure the dynamic pressure of each measuring point of the inlet flue. According to the test results, the average flue gas velocity of the inlet flue of the A and B side reactor is 11.87 m/s and 12.30 m/s , the relative standard deviation of the flue gas velocity distribution is 35.8% and 28.9%, the difference value of maximum and minimum flow velocity is 14 m/s , and the velocity distribution deviation is large, the velocity field is relatively uneven, showing the characteristics of high on both sides and low in middle of the flue. And the relative standard deviation of the inlet flue gas flow rate of the ammonia spraying grille on both sides of A and B is higher than the design requirement of 15%, which is mainly limited by the construction conditions of the site, the steering of the outlet flue of the economizer causes the air flow to deflect, or the installed diversion device is offset, that leads to the increase of the unevenness of the flue gas flow rate. In the case of uniform NO_x concentration distribution at the inlet of the denitrification equipment, the flue gas flow rate is high and the flue gas flow rate is large, and the outlet concentration of the denitrification reactor is higher under the same amount of ammonia injection [8]. In

conclusion, it is found that the inhomogeneity of inlet flue gas velocity field is one of the reasons for the uneven distribution of NO_x concentration at the outlet.

Fig.5. Distributed situation of inlet flue gas velocity

4.3 Number of ammonia injection control valve

Opening of ammonia injection control valve is the key factor affecting the size of ammonia spray. The opening is large, the spray amount of ammonia is large, and the NO_x concentration at the outlet of the corresponding area is low. Fig.6 shows the regulating valve opening and ammonia injection pressure of each ammonia injection branch. From Fig.6, it can be seen that the overall change trend of valve opening and ammonia injection pressure of ammonia injection regulation is basically the same, the pressure of ammonia injection at each point is above 1200Pa, the circulation of ammonia gas in the area is good, and the possibility of blockage of ammonia injection pipeline is low. The opening of the ammonia spraying pipe at both ends is relatively small, the amount of ammonia spraying is relatively low, and the outlet NO_x concentration is higher; the opening of the middle area of the flue is relatively large, the amount of ammonia spraying is large, and the outlet NO_x concentration is lower. In general, the valve opening of ammonia regulating valve has a strong correlation with the distribution of NO_x concentration at the outlet.

Fig.6. Opening of ammonia injection control valve

4.4 Catalyst wear and ash deposition

The denitration equipment adopts high dust arrangement, and the motion impact of fly ash particles in the flue will produce deposition and bypass phenomenon in the local area of the reactor [9]. When the content of alkaline metal oxides (e.g. K₂O and Na₂O) in ash is high, it is easier to form ash in the nozzle, flue, flow-sharing device and catalyst layer. When the catalyst layer appears ash deposition, the chemical reaction between NO_x and ammonia on the catalyst surface is prevented, and the NO_x removal cannot be realized. At the same time, it causes the change of flow field in the reactor, intensifies the occurrence of catalyst wear problem, and when serious, the catalyst is worn through, resulting in a significant increase in the concentration of NO_x outlet in this area. The study shows that the ratio of SiO₂ and Al₂O₃ in the chemical components of fly ash is usually used as an important index to measure the wear characteristics of fly ash, the larger the ratio, the more serious the wear. When the ratio exceeds 60%, the wear will be significantly aggravated [10]. According to the results of fly ash analysis (as shown in table 2), the ratio of SiO₂+Al₂O₃ accounts is about 80% of fly ash, and the wear of fly ash is relatively strong, and there is a risk of catalyst wear problem.

Table 2. The analysis of ash components

Item	Analysis Result
SiO ₂ /%	49.70
Fe ₂ O ₃ /%	6.56
Al ₂ O ₃ /%	28.49
CaO/%	6.94
MgO/%	1.07
TiO ₂ /%	0.62
SO ₃ /%	3.11
P ₂ O ₅ /%	1.10
Na ₂ O/%	1.57
K ₂ O/%	0.84

Fig.7 shows the outlet velocity distribution of the denitrification reactor. As can be seen from Fig.7, the

flow rate of the flue gas outside the A-side and B-side reactors is lower, especially the B-side is obvious. A single lower flue gas flow area appears in the middle part of the A-side and B-side reactors, considering the presence of beams at the front end of the monitoring area, which affects the flue gas flow. By calculation, the relative standard deviation of flue gas velocity is 25.8% and 29.5%, and the overall uniformity of flue gas velocity distribution is poor. Combined with the distribution of outlet NO_x concentration, considering the possibility of ash deposition and wear in the catalyst near the outer part of the reactor, it is easy to cause the local area flue gas flow to increase, and beyond the catalytic removal capacity of the catalyst to cause the increase of the emission concentration in the region. Therefore, it is suggested to check the ash and wear of the catalyst in the reactor during the maintenance period and dispose of it in time.

Fig.7. Distributed situation of outlet flue gas velocity

4.5 Flue arrangement

Figure 8 is the flue arrangement of SCR denitrification equipment. As can be seen from Fig.8, from the ammonia-spraying grid to the upper catalyst, there are 1 abrupt cross section and 3 flue elbows in the whole flue gas strike. The flow field distribution is uneven due to the abrupt change in the flow line of the flue gas through the abrupt cross section, especially near the outside of the flue (no gradual expansion section on the inside of the flue). At the same time, when the flue gas flows through the first flue elbow, the flue gas is pressed to the outside of the elbow by centrifugal force, so that the low-speed triangle zone appears on the inside, resulting in uneven distribution of the flow field. When flue gas

diffuses from horizontal into reactor, it will flow along the flue wall, that is easy to form a high-speed scour zone on the outside of the reactor and a reflux zone on the inside, which seriously affects the flow field uniformity and the residence time of the flue gas in the catalyst layer, and then leads to the decrease of denitrification efficiency and the increase of ammonia escape rate, which is one of the reasons why the upper concentration of the outlet flue is higher than that of the lower part.

Fig.8. The plan of flue arrangement

4.6 Operation after ammonia injection adjustment

In view of the uneven distribution of NO_x concentration at the outlet of the SCR denitrification equipment of the unit, the adjustment test of the opening of the valve for regulating ammonia injection in the field was carried out [11]. Figure 9 shows the effect of the adjusted outlet NO_x concentration distribution. As can be seen from figure 9, the maximum concentration of NO_x in the outlet flue of the A-side reactor is 33 mg/m^3 and the minimum is 15 mg/m^3 ; the maximum concentration of NO_x in the outlet flue of the B-side reactor is 34 mg/m^3 and the minimum value is 15 mg/m^3 ; the relative standard deviation of the A-side and B-side reactors is 23.06% and 22.01%, which optimizes the operation of the denitrification equipment to some extent, alleviates the inhomogeneity of the outlet NO_x concentration, effectively improves the denitrification efficiency and reduces the ammonia consumption. However, only adjusting the valve opening of ammonia injection cannot meet the uniformity requirements of the design, the uneven coefficient of outlet concentration distribution is still large, and there is still a high concentration area in the local area. In order to further improve the uniformity of the outlet NO_x concentration, it is suggested that the next step should be to make use of the downtime inspection period to comprehensively check the possible problems from the aspects of ammonia spraying grille (nozzle), ash deposition in the flue, the change of the arrangement of the flow-sharing device, the ash deposition and wear of the catalyst, and formulate the corresponding solutions.

Fig.9. Distributed situation of outlet NO_x concentration after ammonia injection adjustment

5 Conclusion

The results show that the uneven distribution of NO_x concentration at the outlet of SCR denitrification plant is caused by the joint action of imported NO_x concentration, flue gas flow rate, ammonia spray regulating valve opening, ash deposition and wear, and flue arrangement, etc. The specific gravity of each factor should be taken into account in the cause analysis to find the most appropriate solution. By adjusting the opening of the valve with ammonia injection in different regions, the uniformity of the NO_x concentration field at the SCR outlet was significantly improved, and the uniformity was improved by about 30%. To further improve the uniformity of the outlet concentration, we can consider starting from the establishment of numerical simulation and cold state physical model test of denitrification equipment, re-accounting for the SCR flow field distribution, reasonably adjusting the number and layout of the diversion and rectifier units, and replacing the severely worn catalyst, and so on. In addition, in order to improve the accuracy of the on-line monitoring data and avoid the problem of inconsistency between the NO_x concentration at the denitrification outlet and the total outlet, we can consider changing the existing single point on-line monitoring mode to multi-point or matrix sampling mode to expand the online monitoring range.

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