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Experimental research on performance test after SCR denitration system ultra-low emission retrofit in a 600 MW coal-fired unit

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Abstract. A systematic performance test was carried out for the ultra-low emission modification project of the Selective Catalytic Reduction (SCR) denitration system of a 600 MW coal-fired unit in a thermal power plant. Terms of the performance tests include denitration efficiency, ammonia escape rate, and SO_2/SO_3 conversion rate. The distribution of gas velocity and NO_x concentration in flue gas of SCR inlet and outlet were summarized. The effect of unit load and gas velocity to denitration efficiency, ammonia escape rate and SO_2/SO_3 conversion rate were discussed after the test. The result favours design and retrofit of the ultra-low emissions coal-fired power unit in China. Through technical trials, a set of practical test methods suitable for the actual situation was concluded.

1 Introduction

China set up strict standard to the emission of pollutant form coal-fired power station for environment protection. All-sided implementation of retrofit for ultra-low emission and energy-saving to coal-fired power station (Huanfa[2015]164) were published by the Ministry of Ecology and Environment, the National Development and Reform Commission, and the National Energy Administration of China for all existing coal-fired units with the condition to retrofit[1]. The ultra-low emissions standard requires emission pollutant concentration such as fly ash, SO_2 and NO_x with mass concentrations no higher than 10 mg /Nm^3, 35 mg /Nm^3 and 50 mg /Nm^3 respectively (6% reference oxygen dry flue gas) [2,3].

NO. 2 coal-fired unit of a thermal power plant was retrofit to achieve the ultra-low emission standard. A systematic performance test was carried out to evaluate the effect of alteration. Terms of the performance test include denitration efficiency, ammonia escape rate, and SO_2/SO_3 conversion rate. The distribution of gas velocity and NO_x concentration were summarized. Effects of unit load, and gas velocity to denitration efficiency, ammonia escape rate and SO_2/SO_3 conversion rate were discussed after the test. The result favours design and retrofit of the ultra-low emissions coal-fired unit in China. A feasible measurement method for the test of ultra-low emissions unit was summarized.

2 Unit Equipment

The 600 MW subcritical water-cooling unit was built in the first construction period of the thermal power plant. The unit was put into operation in 2003, which was equipped with a boiler with boiler maximum continuous rating (BMCR) of 2008 t/h. The original denitration device of the unit equipped a “high-dust arrangement” SCR system. The reducing agent of the SCR system was prepared from liquid ammonia. The SCR reactor was equipped in two flue, and there was no economizer bypass flue. It is required that the outlet NO_x concentration should be lower than 80 mg/Nm^3, the total denitration efficiency should be no less than 80%, the ammonia escape rate was no more than 3 ppm, and the SO_2/SO_3 conversion rate was lower than 1% under the BMCR condition for the treatment of 100% flue gas volume with design coal. The number of SCR catalyst layers was designed according to (2+1) scheme, that’s, two layers of operation while one layer is used as backup. The catalyst was honeycomb-type, and supplied by Ningbo Ruiji Corporation.

In this retrofit project, plate-type catalyst was added into the backup layer of the SCR. The purpose of this retrofit project requires the denitration efficiency of SCR no less than 90%, and the outlet NO_x content should be lower than 40 mg/Nm^3 under the BMCR condition with the NO_x content of the SCR inlet of 400 mg/Nm^3 and flue gas volume flow of 2×10^6 Nm^3/h (dry basis, standard state, 6% oxygen).

3 Experimental Setup and Method

The main test items of this test include denitration efficiency, flue gas flow velocity distribution, inlet and outlet NO_x concentration distribution, ammonia escape rate, and SO_2/SO_3 conversion rate of SCR. The technical standards and test specifications of the performance are summarized in Table 1.

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Table 1. Technical standards and test specifications of the performance

NO.	Serial number	Name
1	GB 13223-2011	Emission standard of air pollutants for thermal power plants [4]
2	DL/T414-2012	Specification for environmental monitoring of thermal power plants [5]
3	DL/T260-2012	Performance checkup test for flue gas denitration equipment of coal-fired power plants [6]
4	GB/T16157-1996	Determination of particulates and sampling methods of gaseous pollutants from exhaust gas of stationary source [7]

The instruments and equipment involved in the experiment are listed in Table 2.

Table 2. Experimental setup

NO.	Manufacturer	Name	Type	Quantity
1	Qingdao lonying Environmental Technology (China)	Automatic Stack Dust Sampler/Flue Gas Analyzer	3012H	2
2	MRU gauges for flue gases and environmental protection GmbH (Germany)	NO(X)-MESSUNG GEMÄSS 44. BIMSCHV	MRU NOV A PLUS	2
3	Unisearch Associates Inc. (Canada)	TDLAS Ammonia Gas Analyser	M-NH3	1

4 RESULTS AND DISCUSSION

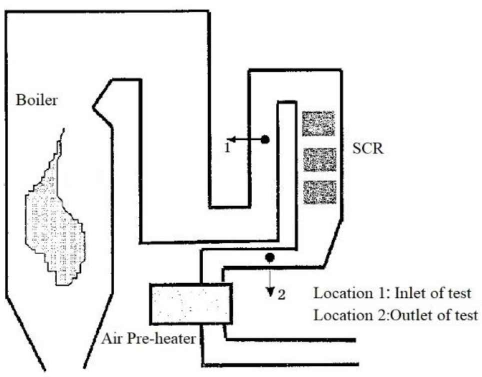

Fig.1. Location of the experimental test

In the experiment, the unit have two flues named A and B for the flow of flue gas. Five sampling holes were chosen for gas sampling from each of the flues. The sampling results were named according to the position of sampling holes from 1 to 10 (from east to west). The flue gas velocity, NO_x concentration, SO_2 concentration, and SO_3 concentration were measured according to the sampling standards and methods listed above. All sampling were performed three times and averaged. The measuring position during the test is shown in Figure 1.

4.1 Distribution of flue gas velocity and NO_x concentration of SCR inlet and outlet under 100% unit load

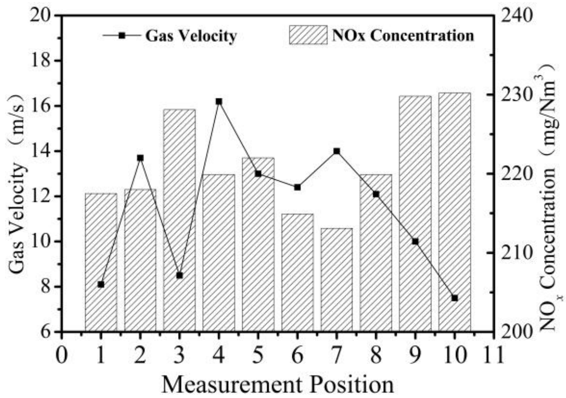

Fig.2. Gas velocity and NO_x concentration of SCR inlet under 100% unit load

Distribution of gas velocity and NO_x concentration of SCR inlet under 100% unit load are listed in Figure 2. Gas velocity ranged from 7.5 to 16.2 m/s. The standard deviation of gas velocity is 2.75 m/s, which is 23.8% of the average gas velocity. The deviation of gas velocity of SCR inlet is quite large, which would lead to the variation of the residence time of flue gas in SCR system and the mixture of ammonia with flue gas. The gas velocity of the middle position of the flue is obviously higher than the edge of flue, which means the gas flow field needed to be optimized to achieve better performance [8,9]. NO_x concentration in flue gas ranged from 213.1 to 230.2 mg/Nm^3, the deviation of which was 5.79 mg/Nm^3, only 2.62% of the average value. The deviation of NO_x concentration was quite low for a long time mixture from the outlet of boiler to SCR inlet.

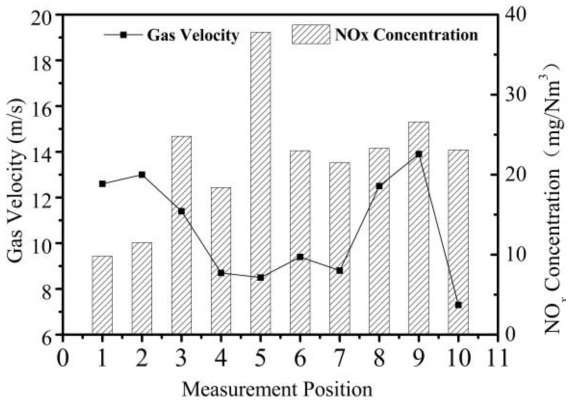

Fig.3. Gas velocity and NO_x concentration of SCR outlet under 100% unit load

Distribution of gas velocity and NO_x concentration of SCR outlet under 100% unit load was listed in Figure 3. Gas velocity ranged from 7.3 to 13.9 m/s. The standard deviation of gas velocity was 2.20 m/s, which was 20.9%

of the average gas velocity. Catalyst layers played as meshes for the rearrangement of gas flow. NO_x concentration at SCR outlet ranged from 9.8 to 37.8 mg/Nm^3, the deviation of which was 7.45 mg/Nm^3, 34.1% of the average value of NO_x concentration at SCR outlet. The great deviation of NO_x concentration resulted from the large gas velocity deviation in the inlet of SCR, which resulted the decrease of residence time of flow gas at middle of the flue, and leads to the increase of high NO_x concentration of the outlet in the middle position of the flue.

4.2 Effect of Unit Load on Flue Gas Velocity and Nitrogen Oxide Concentration Distribution

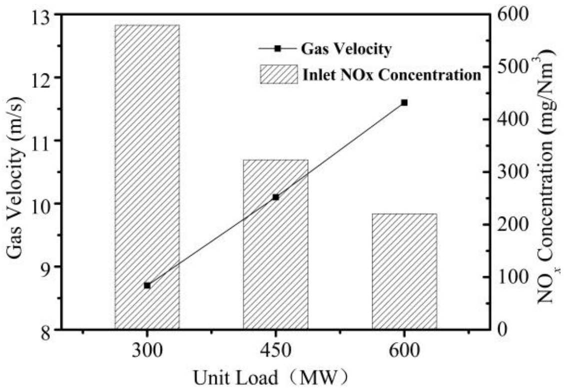

Fig.4. Effect of unit load to gas velocity and NO_x concentration of SCR inlet

Effect of unit load to gas velocity and NO_x concentration of SCR inlet was shown in Figure 4. The unit load of coal-fired power unit needed to adjust its load to fit the load of electricity consumer and the variety of other electricity producer such as solar energy and wind power plant [10]. The effect of unit load to gas velocity and NO_x concentration of SCR was studied and the result was shown in figure 4 and figure 5.

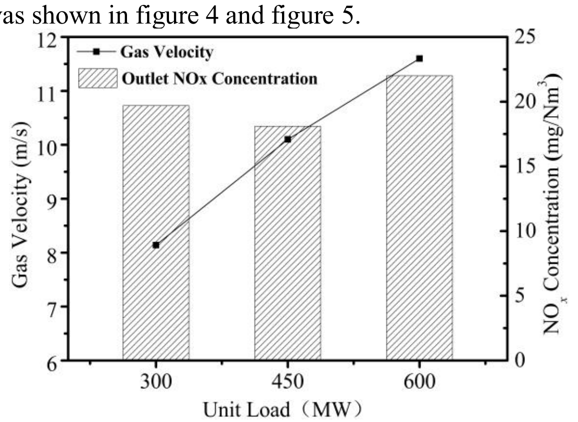

Fig.5. Effect of unit load to gas velocity and NO_x concentration of SCR outlet

Influence of unit load to gas velocity and NO_x concentration at SCR inlet was shown in figure 4. Flue gas velocity increased linearly with the increase of unit load, which agreed ordinary understanding. While the NO_x concentration of SCR inlet achieved 579.2 mg/Nm^3 at 300 MW, compared with 220.3 mg/Nm^3 at 600 MW. The decrease of unit load lead to the deviation of combustion process from rated condition and resulted large amount of NO_x production. The increase of NO_x concentration needed high denitration efficiency to meet requirement of the ultra-low emission standard.

Effect of unit load to gas velocity and NO_x concentration at SCR inlet was shown in figure 5. The change of gas velocity in SCR outlet was the same as which in SCR inlet, while the NO_x concentrations of SCR inlet were 19.7, 18.1 and 22 mg/Nm^3 with the unit load of 300, 450 and 600 MW. The velocity of 300MW and 450 MW was about 70%-75% and 85% compared to which at 600 MW, the decrease of gas velocity increase the residence time of flue gas and avoided the excess of NO_x concentration in SCR outlet.

4.3 Effect of Unit Load on Ammonia slip rate and denitration efficiency

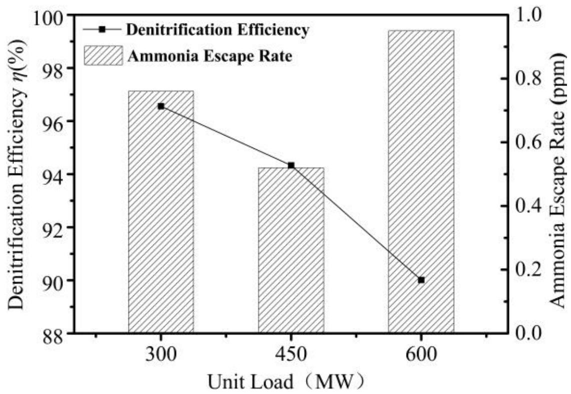

Fig.6. Effect of unit load to denitration efficiency and ammonia escape rate

Effect of unit load to denitration efficiency and escape ammonia concentration were shown in figure 6. Denitration efficiency η was a critical technique issue of SCR system, which was calculated according to equation (1).

$$\eta = 1 - \frac{C_{\mathrm{outlet}}}{C_{\mathrm{inlet}}} \quad (1)$$

While C_{outlet} and C_{intlet} were NO_x concentration of outlet and inlet of SCR. Denitration efficiency decrease with the increase of unit load, 96.56%, 94.33% and 90.01% for 300, 450 and 600 MW. The low unit load result in low gas velocity and increase residence time which favours SCR process, while higher NO_x concentration helps the conversion of NO_x to N_2 for the chemical reactions in SCR were reversible reaction.

Ammonia escape cause air preheater blockage and ash deposition on heat exchanger downstream. Ammonia escape rate should be kept at low-level during the performance of SCR system, the Ammonia escape rates were 0.76, 0.52 and 0.95 ppm at 300, 450 and 600 MW, the highest ammonia escape rate was found at 600 MW for the high velocity lead low residence time for SCR, while some ammonia (reducing agent in SCR) were not fully react with NO_x.

4.4 Effect of load change on SO_2/SO_3 conversion rate

The production of SO_3 was one of the side reactions during SCR process. SO_3 resulted in the production of NH_3HSO_4 with escaped ammonia, and resulted blockage of air preheater, ash deposition and corrosion of downstream heat exchanger [11]. The SO_2/SO_3 conversion rate is an important evaluation index in SCR performance. The SO_2/SO_3 conversion rates δ was calculated according to equation (2).

$$\delta = \frac{C_{\text{outlet}}^{SO_3} - C_{\text{inlet}}^{SO_3}}{C_{\text{inlet}}^{SO_2}} \tag{2}$$

While $C_{\text{outlet}}^{SO_3}$ and $C_{\text{inlet}}^{SO_3}$ were SO_3 concentration of outlet and inlet of SCR, $C_{\text{inlet}}^{SO_2}$ was the SO_2 concentration of inlet of SCR. δ denotes conversion rate of SO_2 to SO_3 during SCR process.

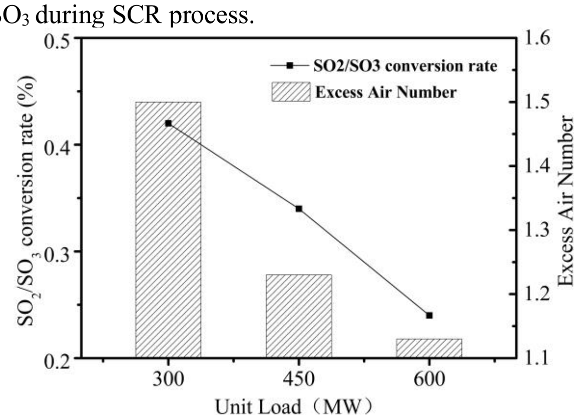

Fig.7. Influence of unit load and excess air number to SO_2/SO_3 conversion rate

The SO_2/SO_3 conversion rates of different load unit were shown in figure 7, which were with great consistency of excess air number. SO_2/SO_3 conversion rate was decrease with the increase of unit load for the lower of oxygen content in the flue gas. Oxygen services as the oxide agent in SO_2/SO_3 conversion process, while the SO_2/SO_3 conversion rate achieved the highest value 0.42 with excess air number 1.5 at 300 MW.

5 CONCLUSION

Main technique issue of the retrofit for the coal-fired unit to meet ultra-low emission standard were achieved according to the performance test. The main technique issues of the retrofit was listed below:

(1) NO_x concentrations of outlet SCR were 10.45, 10.45 and 22.99 mg/Nm^3 at 300, 450 and 600MW, which lower than design emission requirement (40 mg/Nm^3).

(2) Denitration efficiencies of SCR were 95. 56%, 94. 33% and 90. 01% at 300, 450 and 600 MW, higher than the design requirement (90%).

(3) Ammonia escape rates were 0. 76, 0. 52 and 0. 95 ppm at 300, 450 and 600 MW, less than the design requirement (1 ppm).

(4) The SO_2/SO_3 conversion rate were 0. 42%, 0. 34%and 0. 21% at 300, 450 and 600 MW, less than the design requirement (1%)

However, the test of the gas velocity distribution of the unit show that the gas flow field needed to be adjusted to get a more uniform gas velocity distribution, in order to achieve better SCR performance.

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