Experimental study and Theoretical analysis on the influence for diverse boiler load to SCR denitrification system

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ABSTRACT: This study investigates the performance of SCR catalysts which has been analyzed with a theoretical method from the operation data on the SCR device of a 600MW unit, and then performance experiments have been done under the high load-600MW&the low load-320MW. The results show that compared to the NOX distribution at SCR outlet under the 600MW,the 320MW's has become more uneven with the relative standard deviation υk being quite large; Compared to the results through theoretical analysis, the denitrification efficiency measured at field test on the 320MW is relatively lower than that under 600MW when NH3/NO ratio stays constant, the reason of which mainly lies in the obvious change of flue gas flow field at SCR inlet, distributing in an opposite trend to that under 600MW. Improvement and optimization of rectifying device at denitrification inlet flue is recommended to realize uniform flow field, thus in addition to the improvement of NOX distribution uniformity at denitrification outlet and reduction of ammonia escaping rate, the denitrification efficiency is increased, hopefully providing guidance on the economical operation of SCR denitrification system .
KEYWORD: load; SCR; relative standard deviation of υk; non-uniform flow field; denitration efficiency

1 INTRODUCTION

Nitrogen Oxide (NOx), as one of the major pollutants emissions of coal-fired power plant boile, has serious harm to human health and ecological environment, which has aroused people's attention. As the environmental protection department of NOX controlling emissions increasingly strictly, flue gas denitration technology is widely applied in coal-fired power plant. The selective catalytic reduction (SCR) technology, due to it's a high denitration efficiency and mature technology, is the most widely used in domestic coal-fired power stations with the flue gas denitration technology.

Although the flue flow field characteristics on SCR denitration system took into account in the design phase, denitration entrance of flow field distribution changes as the boiler load is changing with grid needs real-time, whose negative effect on NH_3/NO ratio raises the amount of ammonia escape and the problem of air preheater block-ing. Therefore, the denitration performance experiments have been conducted on the SCR device of a 600MW unit in a power plant under the high load (600 MW) and low load (320 MW), which the experiment content including flue gas velo-city and composition distribution at SCR import and export, and then analysed the result of the experiment combined with the theory method, which could provide a guidance for SCR denitration system.

2 RESEARCH OBJECT AND FIELD EXPERIMENT

2.1 *Research object*

The SCR reactor arranged between the boiler economizer and air preheater in a 600MW unit, 99.6% purity of liquid ammonia as the denitration reductant,was selected for the study.

The denitration device has two reactors and each one was catalyst layout with 2 layers and 1 reserve layer designed. Besides, cellular catalyst adopted as the catalyst, which the main parameters are shown in table 1, and the entrance design values of the flue gas denitration system are shown in table 2.

Table 1. The main parameters of catalyst.

operating temperature	Design temperature	℃	320
	Maximum running temperature	℃	420
	minimum running temper-ature	℃	300
denitration efficiency		%	>80
ammonia escap		(μL/L)	<3
SO_2 / SO_3 conversion ratio		%	<1
pressure loss of catalyst		Pa	<1100
catalyst Chemical life		h	24000
catalyst mechanical life		year	10

Table 2. The design on the parameters of the Inlet flue gain the denitrification system.

parameter	unit	data
concentration of fly ash	g/Nm3	35
NOx	mg/m3	400 in design
SO_2	mg/m3	1500
SO_3	mg/m3	18

2.2 *The experiment method*

For the study of research object, the performance experiments have been carried out respectively under high and low load. And the experiments was conducted only on the side of A reactor denitration unde the working condition of 600 MW and 320 MW due to the two sides of reactor has similar laws, which the specific experiment train of thought is:At fist, the flue gas velocity and composition distribution at SCR import and export was tested, and then analysed the results of the experiment combined with the theory method, which could provide a guidance for SCR denitration system.

3 FIELD EXPERIMENT RESULTS AND ANALYSIS

3.1 *Calculation and analysis of denitrification efficiency*

In the denitrification reactor, the main contractor reaction of Ammonia and NOx under O2 atmos-phere:

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O \quad (1)$$

$$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O \quad (2)$$

Reaction in the absence of O_2 is:

$$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O \quad (3)$$

$$6NO + 4NH_3 \rightarrow 5N_2 + 6H_2O \quad (4)$$

In the coal-fired boiler SCR reactor, flue gas contains a certain amount of oxygen, NOx is given priority to with NO, therefore in the SCR reaction (1) is the main reaction to NO reduction. In this article the reaction (1) are mainly discussed. Combination law of uz, taking type (5) as the reaction (1) reaction rate equation:

$$-\frac{dC_{NO}}{d\tau} = kC_{NO}^{n} C_{NH3}^{n} C_{O_2}^{m} \quad \text{(where n > 0)} \quad (5)$$

$$k = Ae^{-\frac{E}{RT}} \quad (6)$$

Where C_{NO}、C_{NH3}、C_{O2} as the concentration of NO、NH_3 and O_2 respectively; τ as time constant; n、m as reaction order; k as apparent rate constant of the reaction type (5); E as apparent activation energy of reaction rate for reaction type (5); R as gas constant; T as the reaction temperature. If the concentration of NH_3 and NO at SCR inlet is defined as α, the simplified formula of (1) is (5) that will be obtained when ammonia nitrogen ratio is 1 as the consumption of O_2 in the reaction process can be considered as constant, from which the integral equation (8)of NO concentration in the reactor can be gained similarly.

$$-\frac{dC_{NO}}{d\tau} = kC_{NO}^{n} C_{NH3}^{n} \quad (7)$$

$$\int_{C'_{NO}}^{C_{NO}} \frac{dC_{NO}}{C_{NO}^{2n}} = \int_{o}^{\tau} -k d\tau \quad (8)$$

And the denitrification efficiency formula(9) will be got with the Formula (8) integrated under the α as 1:

$$\eta = 1 - \frac{C_{NO}}{C_{NO,i}} = \begin{cases} 1-e^{-k\tau}, & n=\frac{1}{2} \\ 1-\frac{1}{k\tau C_{NO,i}+1}, & n=1 \\ 1-(2n-1)\sqrt{\frac{1}{(2n-1)C_{NO,i}^{2n-1}k\tau+1}}, & n>0 \text{且} n\neq\frac{1}{2}, n\neq 1 \end{cases} \quad (9)$$

The formula (9) is obtained under the α as1at SCR inlet. Besides, when the α ≠1, the reaction rate in the reactor will be gained as the formula (10) according to formula (7):

$$-\frac{dC_{NO}}{d\tau} = kC_{NO}^{n}\left[\alpha C_{NO,i} - \left(C_{NO,i} - C_{NO}\right)\right]^{n} \quad (10)$$

Considering the accurate reaction order is uneasy to ascertain as the reaction (1) includs more elementary reactions, 1 is used as the reaction order n to undertake a qualitative analysis, and the denitrification efficiency formula(11) will be obtained with the Formula (10) integrated:

$$\eta_{NO} = 1 - \frac{C_{NO}}{C_{NO,i}} = 1 - \frac{\alpha - 1}{e^{k(\alpha-1)C_{NO,i}\tau} - 1} \quad (11)$$

According to the reactor running datas from the unit under 600 MW load including CNO that NO concentration at SCR inlet , ammonia nitrogen ratio α, denitration efficiency Correspondingly, when the α=1 &α=0.84, the denitration efficiency is respectively 90% and 82.1% with the CNO=287 mg/m3, then by type (10) and (12) can be calculated under the condition of the corresponding values of kτ, finally can be calculated by the formula under different alpha denitration efficiency curve as shown in Fig. 1. As you can see, the denitration efficiency is increased with the increase of alpha reactor, that is to say, CNO at the reactor outlet is necessarily decline under the condition of fixed reactor inlet NO concentration.

Flue gas temperature at the reactor inlet is basically consistent when Boiler load is relatively stable at a certain value. Therefore, the reactor reaction rate constant k is the same. According to the type(7), the k value can be calculated, the E could be obtained by drawn the curve from the measure data in the laboratory test, which can the relationship between reaction time and denitration efficiency as is shown in Fig.2.

According to the shown in Fig. 2, different time τ on the denitration effect is different when the unit in a stable working load, but the overall trend is the denitration efficiency increased with the increase of reaction time increase.

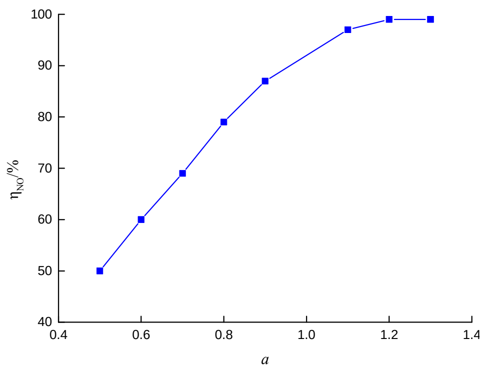

Fig.1 Effect of α on the efficiency of denitrification

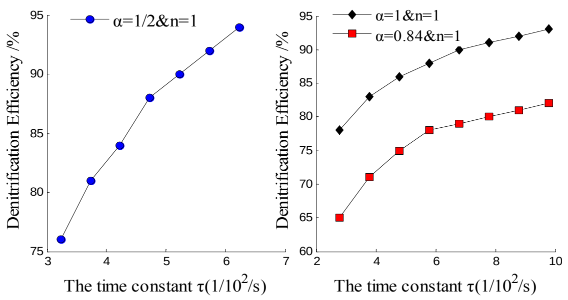

Fig.2 The effect of inlet NO_X concentration distribution of the SCR reactor on denitration efficiency

Similarly according to type(16),the curve of relationship between CNO and denitration efficiency could be obtained with average values of kτ and NO concentrations and ammonia nitrogen ratio α of reactor A under 600MW load, as shown in Fig.3, when the kτ value and ammonia nitrogen ratio α are certain, the higher NO concentration at the reactor inlet is, the higher the denitration efficiency also is . However, both in the pilot experiment and field experiment, the measured denitration efficiency increases with the NO concentration falling, which could be due to the high NO concentration, and NO contact with the surface of the catalyst opportunity is limited, causing part NO molecules could not react with NH3 on the catalyst and escape directly.

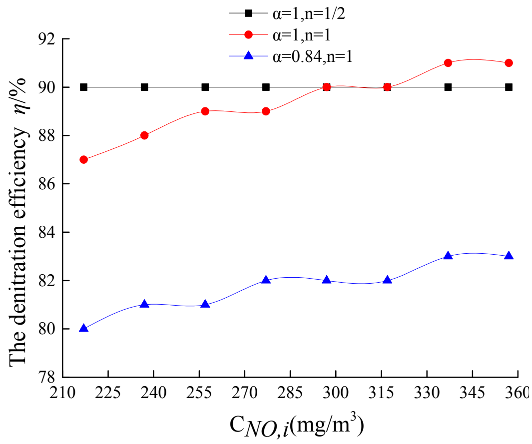

Fig.3 The effect of inlet NO_X concentration distribution of the SCR reactor on denitration efficiency

3.2 *The experiment result and analysis*

The performance experiments on SCR denitration system have been done under the high load-600MW&the low load-320MW, which of the results as shown in fig.4 and fig. 5.

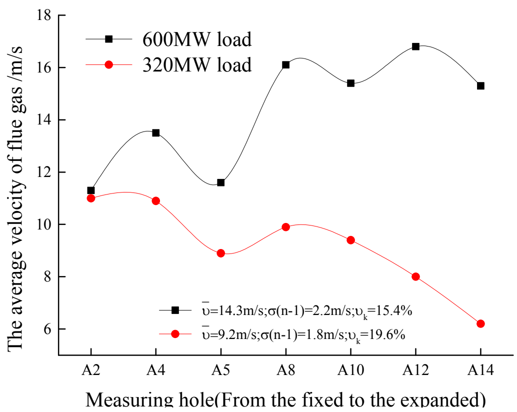

Fig.4 The inlet velocity distribution of SCR reactor

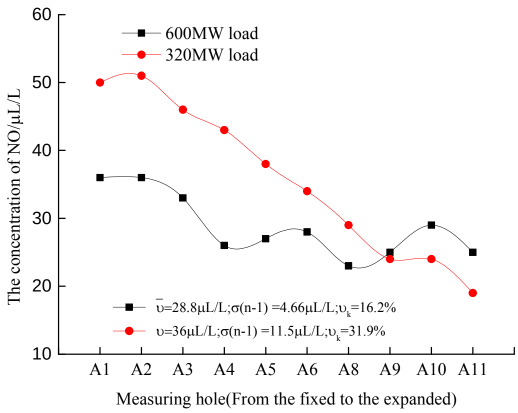

Fig.5 The SCR reactor outlet NO_X concentration distribution under the 320MW load

Fig. 4 shows the entrance velocity distribution at the SCR reactor of A side, it can be seen flue gas velocity distribution under the working condition of

600 MW is relatively uniform in general, other from the measuring point A2, A4, A5 that the flue gas measurement speed slightly low. But under 320 mw load, the relative standard deviation υk of flow field velocity at SCR inlet is 19.6% (over engineering allowed on the speed of the standard deviation coefficient of 15%), which increased by 4.2% compared with under the working condition of 600 MW. That is to say, the boiler working load form 600MW to 320 MW, the uniformity of flow field distribution at inlet becomes poor, and there is an opposite trend on distribution of the flue gas flow between 600MW and 320MW.

Without the situation of the ammonia injection changed, velocity distribution must have effect on α value and even denitration effect of different parts of reactor, which also influence the distribution of NO_X concentration at the reactor outlet.

Fig.5 shows the NO_X concentration distribution at SCR reactor outlet under above loads, where the reactor NO_X concentrations were 59.0 mg/m^3 and 73.8 mg/m^3, which still can satisfy the NO_X emission standards in our country, but the NO_X distribution at outlet is uneven, compared with fig.4 and Fig.5, it can be seen that NOx distribution homogeneity at denitration reactor outlet with the load change is different, which the relative standard deviation υk is 31.9(600MW) and 16.2% respectively. Compared to the unit under 600 MW Load, the denitration outlet NO_X relative standard deviation υk is bigger under 320 MW load, increased by 96.9%, which could not meet the requirement of relative standard deviation υk≦20%, showing the distribution of flow field at SCR inlet under 320 MW load changed a lot then the 600 MW, resulting the opposite trend between two loads

As shown in Fig.5,Fom the average velocity of flue gas at reactor outlet, it can be seen that flue gas flow at SCR inlet under 600 MW load is 1.5 times more than 320 MW load, so the reaction time τ under 320 mw load is 1.5 times more than 600 MW load. According to the related boiler efficiency of SCR catalyst temperature curve, the denitration efficiency under 320 MW (310 ℃ as corresponding temperature at SCR inlet) is 96% under the 600 MW (355℃ as corresponding temp-erature),

Which can be thought that value k of the reaction (6) under 320 MW is 96% under the 600 MW, so reaction (14) of kτ value is 1.4 times than that of 600 MW. Considering the ammonia nitrogen raitio α=0.8 samely, and 300 MWload inlet NO_X concen-tration is higher than 600 MW, which could be concluded that the denitration efficiency η under low load should be higher.

However, according to the results of the field experiment, the denitrification efficiency is 78.3% under 320MW with the maximum ammonia escaping.Compared to the results through theoretical analysis, the η measured at field test on the 320MW is relatively lower than that under 600MW when NH_3/NO ratio stays constant, of which mainly lies in the obvious change of flue gas flow field at SCR inlet, distributing in an opposite trend to that under 600MW. Improvement and optimization of rectifying device at denitrification inlet flue is recommended to realize uniform flow field, thus in addition to the improvement of NO_X distribution uniformity at denitrification outlet and reduction of ammonia escaping rate, the denitrification efficiency is increased, hopefully achieving the SCR denitrification system with a style in economic operation.

As restricted by power plant operation, this paper only studies operation of the boiler under two kinds of load (high load (600 MW) and low load (320 MW)), Due to the large difference range for working load between 600MW and 300MW, considering the denitration performance experiment would be carried out in the midst of a load, which to further study the influence of boiler load change on the denitration system research.

4 CONCLUSIONS AND RECOMMENDATIONS

This paper studies boiler working load have effect on SCR denitration system through the denitration performance experiment under different loads based on the SCR device in 600 MW unit at one power plant , the main conclusions and recommendations are as follows:

(1) Compared to the NO_X distribution at SCR outlet under the 600MW, the 300MW's has become more uneven with the relative standard deviation υk being quite large.

(2) According to the integral equation of the reaction rate of NO concentration in A reactor , When the values of kτ and ammonia nitrogen ratio α are definite value, the higher the NO concentration at reactor inlet is, the higher the denitration efficiency is. However, both in the pilot experiment and field experiment, the measured denitration efficiency increases with the NO concentration falling, which could be due to the high NO concentration, and NO contact with the surface of the catalyst opportunity is limited, causing part NO molecules could not react with NH_3 on the catalyst and escape directly.

(3) Compared to the results through theoretical analysis, the denitrification efficiency measured at field test on the 320MW is relatively lower than that under 600MW when NH3/NO ratio stays constant, the reason of which mainly lies in the obvious change of flue gas flow field at SCR inlet, distributing in an opposite trend to that under 600MW.

(4) Improvement and optimization of rectifying device at denitrification inlet flue is recommended to realize uniform flow field, thus in addition to the improvement of NO_X distribution uniformity at denitrification outlet and reduction of ammonia escaping

rate, the denitrification efficiency is increased, hopefully providing guidance on the economical operation of SCR denitrification system.

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