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Analysis and Countermeasure of NH_4HSO_4 Deposition Area of Air Preheater Heat Transfer Element

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Abstract: According to the area where the air preheater is blocked, from the perspective of the physical properties of NH_4HSO_4, analyzed the reason of NH_4HSO_4 blockage in air preheater heat storage element caused by SCR flue gas denitration in boiler. The deposition of NH_4HSO_4 and low temperature corrosion occur in specific areas of the air preheater, the area is restricted by the gas temperature and the metal wall temperature. When the height of the heat storage piece in the cold section of the air preheater is insufficient, the bonding area of NH_4HSO_4 will span the upper part of the low temperature section and the lower part of the middle temperature section (the two-stage arrangement is the high temperature section), there is the situation that the mid-temperature section cannot be blown through, and the NH_4HSO_4 deposition area expands upward at low load. Through the characteristic temperature of NH_4HSO_4, combined with the flue gas temperature and wall-temperature of heat transfer element of rotary air preheater at different heights, a partitioning judgment method for the deposition process of NH_4HSO_4 in the air preheater was proposed. To solve the clogging problem of air preheater, firstly, the deposition area of NH_4HSO_4 should be concentrated into the cold end heat storage element by raising the height of the heat storage plate in the cold section, so that the soot blower can be blown through and centralized washing is convenient; secondly, the cold wave type with closed channel is selected to improve the soot blowing and washing effect.

Keywords: NH_4HSO_4, Deposition, Partitioning Judgment, Validation

1. Introduction

At present, selective catalytic reduction (SCR) technology is the main technology for flue gas denitrification facilities in coal-fired power plants. After SCR denitrification process is adopted, part of SO_2 in flue gas will be oxidized to SO_3 by denitrification catalyst. When ammonia escape rate exceeds $3x10^{-6}$ (volume concentration), escaping ammonia reacts with SO_3 in flue gas to form ammonium sulfate ($(NH_4)_2SO_4$) and ammonium bisulfate (NH_4HSO_4) [1-3]. These side reaction products will adhere firmly to the surface of the air preheater heat storage element, The heat storage element has strong corrosion and ash accumulation, Especially denitration transformation, not synchronous air preheater transformation power plant, after the denitration unit was put into operation, the problem of plugging of NH_4HSO_4 in air preheater appeared [4-6]. Taking the air preheater of a 300MW unit as an example, the deposition area and deposition characteristics are analyzed and verified by the calculation and analysis of flue gas temperature and metal wall temperature of regenerator at different heights.

2. Power Plant Equipment Condition

2.1. Design Overview

A 330MW unit was put into production in 2008. The boiler is equipped with two 29.5VNT2400 three-compartment rotary air preheaters. The heat storage sheet is arranged in three layers: high temperature segment, medium temperature segment and cold segment, and the cold scetion is non-plated enamel heat storage sheet with 0.8mm wall thickness. In 2013, the denitrification device was transformed, but the regenerative sheet in the cold section was not transformed accordingly.

Table 1. *Specification of air preheater equipment.*

name	unit	high temperature section	medium temperature section	cold section
height	mm	1100	1000	300
waveform	-	HS	HS	HS
area (single side)	m^2	17898	16271	4881
thickness of regenerative sheet	mm	0.5	0.5	0.8
material	-	Q235	Q235	Corten

2.2. Equipment State

2.2.1. Damage Condition of High Temperature Segment Heat Exchange Element

In 2017, the heat exchange element in the high temperature section was inspected. The blow loss and thinning of the heat storage element in the high temperature section were serious, and some components were worn and fractured. The blow loss and thinning of the heat exchange element was about 0.2mm on average, and some parts were worn out, but NH_4HSO_4 was not found in the upper and lower part of the high temperature segment. As shown in the figure 1.

Figure 1. *Wear condition of regenerator in the High Temperature section of air preheater.*

2.2.2. Contamination Situation of Medium Temperature Section Heat Exchanger Element

Because the installation position is in the middle, the heat exchange element in the middle temperature section basically has no blowing damage and light wear, no sticking phenomenon was found in the upper part of the medium temperature section, but the ash accumulation in the lower part of the medium temperature section is very serious, ash blocking area accounts for more than 40% of the total area, there was a pungent smell of ammonia from the burning adhesions. It is proved that the adhesive contains NH_4HSO_4, as shown in the figure 2.

Figure 2. *Plugging condition at the lower part of regenerator in the Middle Temperature section.*

2.2.3. Damage Condition of Cold Section Components

The upper part of the heat exchange element in the cold section and the lower part of the middle temperature section also have serious contamination problem, but, the lower part of the heat exchange element in the cold section shows no obvious signs of ash accumulation and blockage, but shows large area corrosion, wear and peeling, The average height of peeling is 30mm-40mm, the individual heat exchange elements fall off height of 80-100mm, thinning about 0.3mm, and it can be broken off easily by hand, as shown in the figure 3.

Figure 3. *Corrosion and Wear condition of of regenerator in the Low Temperature section.*

2.2.4. The Resul of Check

1) There is no contamination in the upper part, lower part and upper part of the heat exchange element in the high temperature section, and only the wear of the heat exchange element after long-term operation;
2) The contamination area is the lower part of the medium temperature section and the upper part of the cold section, where the signs of adhesion are more serious;
3) No obvious contamination was found in the lower part of the heat exchange element in the cold section, and there was serious corrosion and peeling.

3. Analysis of Sticking and Plugging Process

3.1. Physical Properties and Properties of NH_4HSO_4

The melting point of NH_4HSO_4 is 147°C, and it is generally liquid at 147~207°C [7, 8], in this temperature range, the liquid NH_4HSO_4 will adhere to the air preheater heat exchanger element, the fly ash is wrapped, the NH_4HSO_4 solidified on the heat transfer element causes the air preheater to be blocked, the melting point of $(NH_4)_2SO_4$ is 513°C, which is solid in the operating temperature range of air preheater, and has no influence on the operation of air preheater.

Even if the exhaust temperature is higher than the liquid temperature of NH_4HSO_4, about 207°C, the metal wall temperature of the heat exchange element of the air preheater is still within the temperature range of liquid NH_4HSO_4 (146~207°C), air preheater still has the possibility of clogging [9-11].

3.2. The Relationship Between Temperature and Adhesion Process of NH_4HSO_4

In order to facilitate the analysis, excluding the influence of other factors in flue gas on NH_4HSO_4 gasification and condensation temperature, it is considered that there is an obvious critical state transition point for NH_4HSO_4, that is, it is solid below 147°C and gaseous above 207°C.

Based on the description of the characteristics of NH_4HSO_4 in the previous literature, according to the change of smoke temperature and wall temperature along the height of heat storage sheet, the relationship between smoke temperature (t_g) of air preheater, wall temperature (t_b) of heat storage sheet and sticking process of air preheater can be established.

Table 2. *The Relation between Flue Gas Temperature, Wall- Temperature and NH_4HSO_4 Adhesion.*

conditions	NH_4HSO_4 state	blocking state
t_b>207 and t_g>207	gas	don't happen
t_g>207 and t_b<207	finite condensation	limited deposition
147<t_g, t_b<207	condensing	infinite deposition
147<t_g and t_b>t_{ld}	condensation after contamination	infinite deposition
t_{ld}<t_g, t_b<147	solid	don't stick the corrosion
t_g<t_{ld} or t_b<t_{ld}	condensation	corrosion

1) When the flue gas temperature and the wall temperature of the heat storage sheet are both greater than 207°C, no liquid NH_4HSO_4 is generated and no NH_4HSO_4 deposition occurs in the regenerative sheet;
2) When the flue gas temperature is greater than 207°C and the wall temperature of heat storage sheet is less than 207°C, $NH4_HSO_4$ will condense on the surface of heat storage sheet, and adhere to form ash pollution. Ash pollution acts as thermal resistance, so the surface temperature of ash pollution is higher than the wall temperature of heat storage sheet. When the ash thickness reaches a certain value, the ash surface temperature will reach 207°C, and the flue gas temperature and ash surface temperature both exceed 207°C, NH_4HSO_4 in the flue gas will no longer condense, so the ash surface thickness will not further increase, which can be called the limited deposition zone.
3) When the flue gas temperature and the wall temperature of the heat storage sheet are between 147°C and 207°C, the fly ash contains liquid NH_4HSO_4 and becomes sticky, and the wall temperature of the heat storage sheet does not have the conditions for the transition of NH_4HSO_4. NH_4HSO_4 constantly adheres to the heat storage sheet and eventually causes the blockage of the air preheater. Therefore, it is called continuous or infinite deposit area.
4) When the flue gas temperature is greater than 147°C and the wall temperature is less than 147°C, Because the wall temperature of the heat storage sheet is lower than the freezing point of NH_4HSO_4, if the heat storage sheet is absolutely clean and free of dirt on the surface, it will theoretically not bond to NH_4HSO_4, but, after running for a period of time, ash accumulates on the surface of the heat storage sheet, which affects the surface temperature of ash pollution higher than 147°C. In this way, liquid NH_4HSO_4 will still be continuously bonded to the external surface of ash pollution. Therefore, this area still belongs to continuous bonding area or infinite deposition area.
5) NH_4HSO_4 deposition does not occur when the flue gas temperature and the heat storage sheet wall temperature are between the acid dew point of flue gas and 147°C.
6) When the wall temperature of the heat storage sheet is lower than the acid dew point, H_2SO_4 vapor condenses on the metal wall, resulting in corrosion of the metal wall.

As the flue gas temperature and the wall temperature of the heat storage sheet decrease along the height of the air preheater, When the structure of the heat storage sheet, flue gas parameters and air parameters are determined, namely, the flue gas temperature at each height of air preheater and the wall temperature of the heat storage sheet are functions of the height of the heat storage sheet.

The air preheater can be divided into clean zone, limited deposition zone, continuous deposition zone, non-deposition zone and corrosion deposition zone from top to bottom.

4. Theoretical Calculation Analysis Verification

4.1. Calculation Method

To analyze the deposition area in air preheater operation, it is necessary to calculate the smoke temperature at the inlet and outlet of air preheater in the high temperature section, medium temperature section and cold section, and the wall temperature of the heat storage sheet. At the same time, the acid dew point of common coal was calculated to determine the temperature of H_2SO_4 corrosion.

Literature [12-14] gives the calculation formula of average wall temperature of metal in air preheater.

$$t_b = \left(x_g h_g \theta'' + x_k h_k t'\right) / \left(x_g h_g + x_k h_k\right) \quad (1)$$

t_b is the average metal wall temperature at the bottom of the outlet of the hot/cold section of the air preheater; x_g and x_k are flue gas and air share respectively, θ'' and t' are the outlet smoke temperature and inlet air temperature of the hot section/cold section of the air preheater respectively, h_g and h_k are the average convective heat transfer coefficients of flue gas passage and air passage in hot section and cold section of air preheater respectively.

The thermodynamic calculation method of air preheater is given in references [15], established the calculation model of three-stage air preheater, calculated the smoke temperature, the convective heat transfer coefficient on the flue gas side and air side.

The acid dew point of flue gas is calculated according to the empirical formula given in the literature [5]:

$$t_b^a = t_d + 125S_{zs}^{\frac{1}{3}}/(1.05\alpha_{fh}A_{zs}) \quad (2)$$

t_b^a is the acid dew point of flue gas; t_d is the water dew point calculated according to the water vapor partial pressure in flue gas; S_{zs} and A_{ZS} are the converted sulphur and converted ash respectively; α_{fh} is the fly ash coefficient.

4.2. The Calculation Results

The metal wall temperature of each part of air preheater is analyzed under two load rates of 50% and 75%. The calculation results are shown in Table 3.

Table 3. *Flue Gas Temperature and wall-Temperature.*

Temperature location	75%THA		50%THA	
	flue gas	wall temperature	flue gas	wall temperature
high temperature inlet	371	365	337	333
high temperature outlet	317	300	295	281
medium temperature outlet	195	158	184	151
low temperature outlet	129	86	119	81

Table 4. *Calculation results of acid dew point.*

name	symbol	unit	the numerical
applied base sulfur	$S_{t,ar}$	%	0.45
applied base moisture	M_{ar}	%	32.82
applied base ash	A_{ar}	%	16.52
water dew point in flue gas	t_d	°C	53.6
dew point of pure water of flue gas	A_{ZS}	—	5.144
converted sulphur of flue gas	S_{ZS}	—	0.1401
acid dew point of flue gas	t_{DP}	°C	106.1

Table 5. *The height of Heat storage element to critical flue gas temperature and wall temperature.*

	unit	base point	H1	H2	H3	H4
height of heat storage element	m	0	0.077	0.25	0.36	0.55
flue gas temperature	°C	129	147	186	207	239
wall temperature of heat storage element	°C	86	106	147	171	207

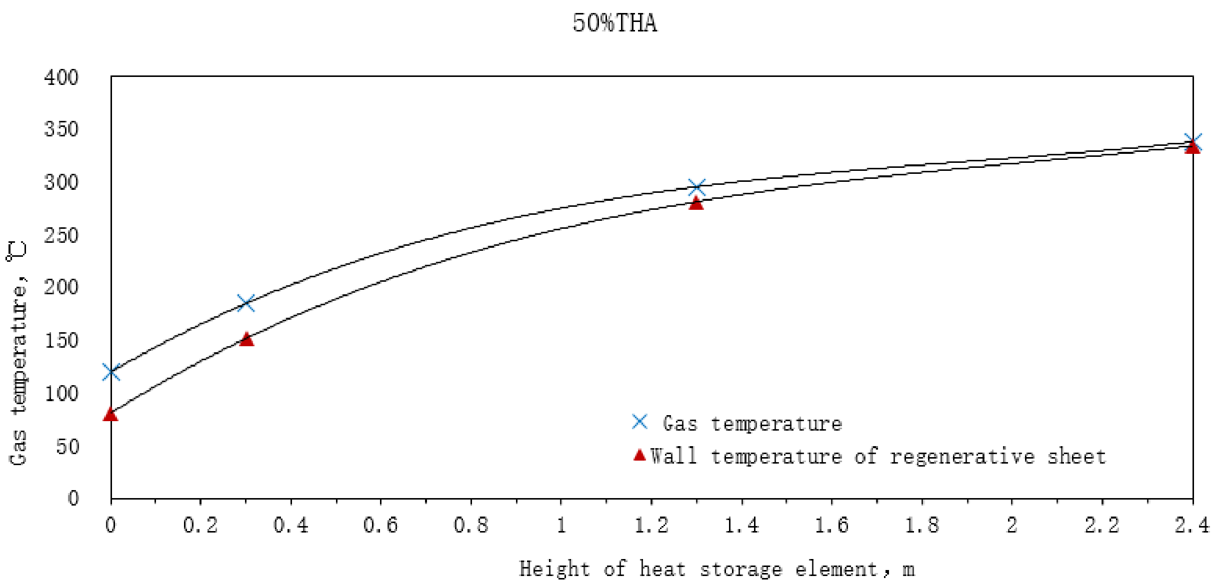

Figure 4. *Flue Gas temperature and Wall-Temperature of the heat storage element at different Heights in 50%THA condition.*

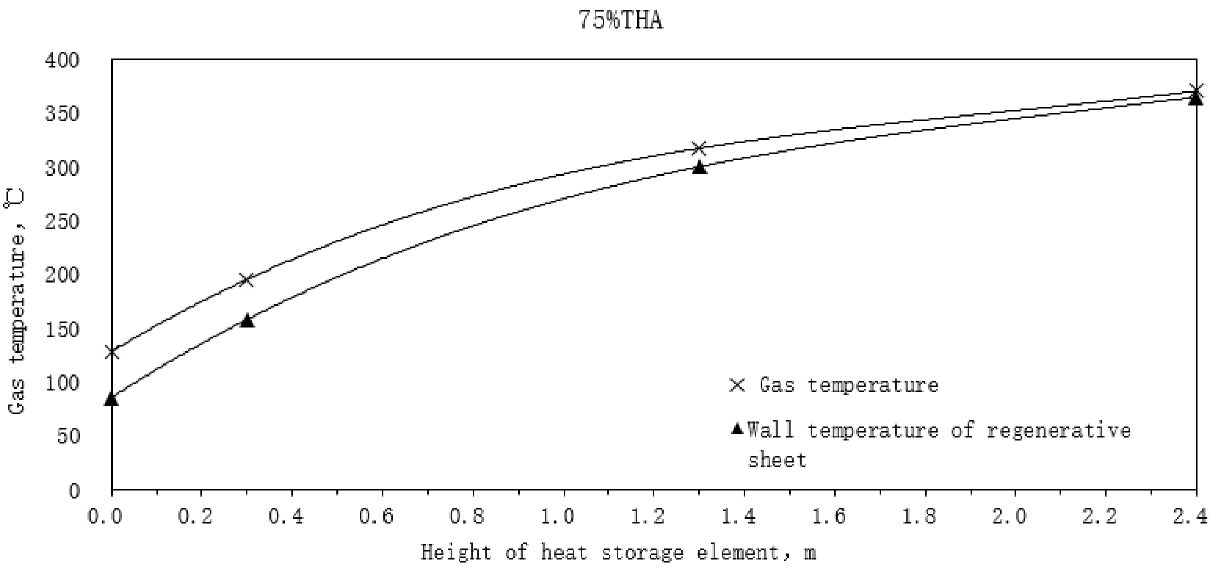

Figure 5. *Flue Gas temperature and Wall-Temperature of the heat storage element at different Heights in 75%THA condition.*

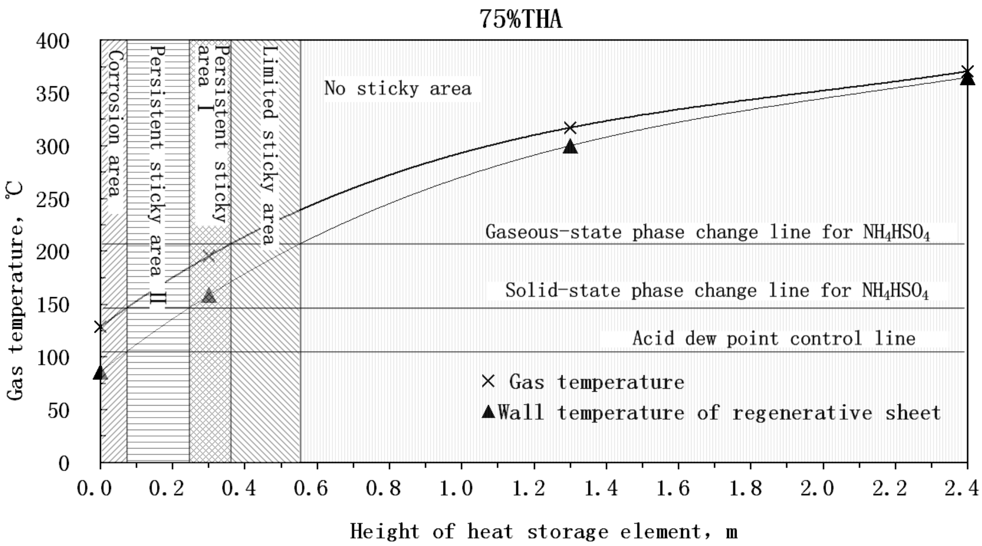

Figure 6. *Distribution of deposition area at height direction in 75%THA condition.*

4.3. Analysis of Calculation Results

1) The height between 1.3m and 2.4m is the hot section, and the inlet and outlet smoke temperature and the metal wall temperature of the heat storage sheet are far higher than 207°C. No NH_4HSO_4 deposition occurs on the the high temperature section and the upper part of the middle temperature section, which conforms to the judgment logic in Table 2.
2) The interface between the medium temperature section and cold section is located at 0.3m height of the heat storage sheet. On this interface, the smoke temperature is 196°C and the metal wall temperature is 158°C in 75%THA condition, both lower than 207°C, serious deposition of NH_4HSO_4 occurred, which consistent with the infinite deposition judgment logic in Table 2. At this flue gas temperature and metal wall temperature, deposition is continuous and the deposition problem becomes more serious with the increase of operation time.
3) The 0m height of the regenerator sheet is the outlet of the air preheater, the metal wall temperature is lower than the acid dew point, and no evidence of NH_4HSO_4 deposition is found, tut there is serious metal corrosion. It is consistent with the judgment logic of H_2SO_4 of the heat storage sheet at the lower part of the cold section. Corrosion in the lower part of the heat storage sheet in the cold section in relevant literature also verifies the applicability of judgment logic in Table 2 [16].
4) Theoretically calculate that the deposition area of NH_4HSO_4 is between 0.077m and 0.55m, it spans the lower part of middle temperature and the upper part of low temperature. It is consistent with the actual inspection results.
5) In 75%THA condition, the flue gas temperature at 0.077m is 147°C, and the metal wall temperature is equal to the acid dew point. It shows that the range of

flue gas temperature and metal wall temperature between acid dew point and 147°C is small, that is, the theoretical range of non-deposition and non-corrosion area in the low temperature section is very small.

6) The calculation results show that the smoke temperature and metal wall temperature at each height of the heat storage sheet decrease with the decrease of the load, so, the deposition area of heat storage sheet develops to the height direction with the decrease of load.

5. Conclusion

1) NH_4HSO_4 deposition and low temperature corrosion occur in a specific area of air preheater, and the area is restricted by the temperature of flue gas and the temperature of metal wall.
2) The characteristics of NH_4HSO_4 generation and deposition are different in the process of smoke temperature and metal wall temperature decreasing gradually along the flue gas flow.
3) When the height of cold section is insufficient, the bonding area of NH_4HSO_4 will span the upper part of the low temperature section and the lower part of the middle temperature section (the two-stage arrangement is the high temperature section), and the ash blowing in the middle temperature section is not permeable.
4) Under low load, NH_4HSO_4 deposition area extends upward.

6. Thinking and Countermeasures

Due to the inevitable problem of NH_4HSO_4 sticking to the air preheater heat storage plate caused by ammonia escape, we need to recognize the deposition process and law through a lot of calculation and analysis, so as to obtain more countermeasures. In this case, the deposition area of NH_4HSO_4 was concentrated into the heat storage element at the cold end by raising the height of the heat storage plate in the cold section, so that the soot blower could be blown through and centralized flushing was convenient, which was one of the effective measures to relieve the air preheater sticking. Secondly, it is another important measure to choose cold wave type with closed channel to improve the effect of blowing ash and washing. It is noteworthy that, with the aggravation of the pollution degree of the cold section, the overall temperature of the metal wall decreases, which also causes the upward expansion of the NH_4HSO_4 sticking area, therefore, it is the main means to ensure the stable operation of air preheater to improve the frequency of soot blowing and to carry out water washing and dry burning regularly.

References

[1] MA Shuang-chen, JIN Xin, SUN Yun xue, et al. The formation mechanism of ammonium bisulfate in SCR flue gas denitrification process and control thereof [J]. Thermal Power Generation, 2010, 39 (8): 12-17.

[2] LONG Yuan-sheng, WU Kai, HUANG Guo-hui. Zonal generation analysis of ammonium bisulfate in coal-fired units and air preheater prevents adhesion blockage [J]. Jiangxi electric power, 2018, 8: 60-63.

[3] Shi Y J, Shu H, Zhang Y H, et al. Formation and decomposition of NH_4HSO_4 during selective catalytic reduction of NO with NH_3 over V_2O_5-WO_3/TiO_2 catalysts [J]. Fuel Processing Technology, 2016, 150 (141-7).

[4] HUI Run-tang, WEI Fei, WANG Bao-de, YANG Ai-yong. Analysis and Prevention of SCR DeNOx-Caused Air Preheater Clogging [J]. Electric Power, 2014, 47 (10): 110-112.

[5] WANG Xing, LIU Guo-zuo, ZHANG Zhi-qiang, et al. Comprehensive control technique of ABS blockage of air preheater in a 600 MW unit [J]. Thermal Power Generation, 2021, 2 (50): 132-137.

[6] WANG Le-le, ZHOU Jian, YAO You-gong, et al. Evaluation on effects of SCR ammonia injection system modulation for flue gas system [J]. Electric Power, 2015, 48 (4): 16-22.

[7] WANG Xin, CHEN Chen, LI Fu-bao. Countermeasure analysis of air preheater clogging in SCR denitration process [J]. Jilin electric power, 2012, 40 (6): 43-45.

[8] WANG Hai-gang. Proposals for controlling air heater pluggage of SCR denitration units [J]. Environmental Engineering, 2016, 34 (2): 96-10.

[9] LIANG Jun-jie, ZHANG Zhan-feng, ZHOU Jian, et al. Analysis on whole process operation data of SCR flue gas denitration system [J]. Thermal Power Generation, 2018, 47 (12): 93-99.

[10] SONG Yu-bao, LIU Xin-hui, HE Chuan, et al. Study on the ammonium bisulfate deactivated SCR catalyst at low load operation [J]. Electric Power, 2019, 52 (1): 144-150.

[11] CAI Pei, ZHAO Yang. Study on optimization scheme of SO_3 removal to prevent preheater clogging [J]. Electric Power Technology and Environmental Protection, 2016, 32 (3): 42-43.

[12] YAN Wei-ping, HUANG Jing-li, LI Jun, et al. Calculation of minimum wall temperature and inlet air temperature ofregenerative air heater [J]. Thermal Power Generation, 2007, 36 (4): 47-49, 28.

[13] LIANG Hai-wen, QIU Feng-xiang, YAO Xue-zhong, et al. Numerical calculation of inner temperature fields of rotary air preheaters [J]. East China Electric Power, 2009, 9 (37): 1614-1618.

[14] LIU Fa-zhi, HE Jian-le, YANG Guo-hua. Retrofit of Heat Storage Elements in Air Preheater Based on Ammonium Bisulfate Blockage [J]. Modern Manufacturing Technology and Equipment. 2021. 8: 175-178.

[15] ZHOU Qiang-tai, et al. Principles of Boilers (3rd Ed.) [M]. Beijing: China Electric Power Press, 2013: 315.

[16] HUA NG Guo-qiang, HE Shuang-jiang, LIU Jun-lai, et al. Analysis and treatment of air preheater blockage in 600MW unit [J]. Hebei Electric Power Technology, 2013. 32 (1): 41-42, 46.