Study on the technology of SCR flue gas temperature adjustment during low load in coal-fired boilers

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Abstract. With more and more power plants participating in the low load peaking operation of the power grid, the problem that flue gas temperature at the inlet of the SCR reactor is close to or cannot meet the minimum allowable requirements of the catalyst has become the general focus. This paper summed up advantages and disadvantages of system modification methods that are used to improve the inlet smoke temperature of SCR reactor. It discussed the methods to improve the inlet smoke temperature of SCR reactor through combustion adjustment at low load operation, and proved the adjustment effect of these methods by experiment. Research shows that, methods to improve inlet smoke temperature of the SCR reactor focused on system transformation, but the cost was high. This paper increased the rate of SCR usage by the combustion adjustment. That not only eliminated the time cost, investment cost and maintenance cost of the system transformation, but also made it not difficult to control the system and had less impact on the efficiency of the boiler. The results of this paper provide theoretical basis and technical support for the adjustment direction of similar units.

1. Overview
In recent years, along with the increasingly serious environmental pollution problems, the environmental protection situation facing our country is more and more serious, the coal-fired power plant air pollutants emission standards (GB13223-2011) regulation of NOx emission standard is 100 mg/Nm³[1], some coastal areas of emission standards are more strict. At present, the low temperature catalyst and the wide temperature catalyst are still in the research stage, and most of the plants choose the more mature selectective catalyst reducation to meet the emission standards. SCR catalysts for the entrance of the smoke temperature requirements in general is 310 ℃ to 420 ℃. When the flue gas temperature is low, the ammonia escape rate is increased due to the decrease of catalyst activity, and the ammonium bisulfate produced in the flue gas is a great risk to the air preheater. And ammonium bisulfate is also deposited on the catalyst, further reducing the activity of the catalyst. In severe cases, it even causes irreversible deactivation of the catalyst[2].

As the depth of the power plant in power grid, more and more units are operating at 30% to 50% low load, economizer outlet smoke temperature (smoke denitratioin inlet temperature) have been unable to meet the requirements of catalyst for minimum ammonia injection temperature. How to improve the inlet smoke temperature of the denitration reactor at low load is mainly the modification of denitration system and the combustion adjustment in operation. In recent years, relevant researches of the former have been more and more[3], and many power plants have successfully carried out systematic transformation, and the advantages and disadvantages of different transformation methods are obvious, while the research and demonstration of the latter are very few. This paper introduces the advantages and disadvantages of various systems retrofit, and focuses on how to improve the
temperature of denitration inlet flue gas through combustion adjustment to improve the denitration rate.

2. Introduction of system transformation and analysis of advantages and disadvantages

Through the system modification to improve the denitration inlet smoke temperature mainly divided into two parts: the work quality side reformation and the flue gas side reconstruction. The side of the working medium is by changing the economizer arrangement or improving economizer inlet water temperature to reduce the heat absorption of economizer, thus improving the economizer outlet flue gas temperature, the specific measures include: economizer water side bypass, economizer classification reform, hot water recirculation and set #0 high-pressure heater[4]. The modification of the flue gas side is by increasing the flue gas bypass. the control part of the high temperature flue gas does not flow through the economizer directly into the denitration inlet flue to improve the smoke temperature.

2.1. Water side bypass of economizer

Add the connection line, make the water side of the economizer water side to be short, adjust part of the water supply not pass the economizer directly into the down pipe, and then mix with the water supply of the economizer. Reduce the water supply flow in the economizer and reduce the heat transfer of the economizer to improve the export smoke temperature of the economizer. After the renovation of pingwei power plant in anhui province, denitration entrance smoke temperature increased 10℃[5]. Although economizer water side of the transformation cost is small, simple structure, the temperature increase effect is poorer. The economizer flow and outlet temperature must be strictly controlled, preventing economizer vaporization, which brings to the boiler safe operation risk.

2.2. Grading and upgrading of economizer

A part of the economizer heating surface is arranged to the flue after denitrification device, and the water supply first absorbs some heat from the flue gas after denitration, and then enters the economizer before denitration to heat up. To improve the inlet water temperature of the economizer before denitration and to reduce the heat transfer surface of the flue gas economizer before denitration, so as to improve the export smoke temperature. Economizer grading reformation has obvious advantages, first guodian zhejiang beilun power plant successfully after transforming denitration entrance smoke temperature increased 18℃ to 25℃[6], and does not affect the efficiency of the boiler. Reconstruction of the high cost and long cycle[7], reconstruction after the completion of the denitration entrance shall not adjust the smoke temperature. Under the full load smoke temperature which is higher than the SCR reactor temperature allowable limit risk, from another Angle it also limits the space of temperature rise.

2.3. Hot water recycling

The recirculation line is extended from the descending tube, which is brought to the water supply after being pressurized by the circulating pump, so as to improve the inlet water temperature of the economizer, reduce the heat transfer between the economizer and flue gas, and improve the flue gas temperature of the denitration inlet. Using hot water recirculation technology of power plant in shajiao C, denitration entrance smoke temperature raised 20℃[8]. It is necessary to invest in a circulating water pump. When adjusting, it is necessary to pay attention to the lag of temperature control. If the control is not good, the risk of vaporization of the economizer can be increased.

2.4. Set #0 high pressure heater

Add a steam turbine extraction pipe to heat the water supply, and improve the inlet water temperature of the economizer to improve the export smoke temperature. One power plant 2 x 1000 MW ultra-supercritical coal-fired units in "regenerative extraction to improve the inlet water temperature"
after transforming[9, denitration input rate on low load increases significantly, but the retrofit scheme requires a certain space, and the high cost, difficult to adjust, also has certain influence to the efficiency.

2.5. Increase bypass of flue gas
Add a by-pass from the economizer to the economizer outlet flue, and then enter the denitration device after mixing with the flue gas flowing through the economizer to reduce the flue gas flow through the economizer, to improve the temperature of denitration inlet. The 300MW unit in zou county adopts the gas bypass reform plan[10], which improves the denitration rate of the low load. The improvement temperature rise adjustment range is larger and the system is simple. However, when the high load runs, the flue gas temperature of the economizer inlet is high, and the baffle is prone to deformation and even leakage, which affects the efficiency of the boiler. In addition, the high temperature and low temperature flue gas will bring irreversible damage to the SCR catalyst.

Table 1. Advantages and disadvantages of different system improvement schemes [11]

| Improvement scheme          | Flue gas temperature | Improvement cost | Advantage                                      | Disadvantage                                           |
|----------------------------|----------------------|------------------|------------------------------------------------|--------------------------------------------------------|
| Water side bypass of economizer | Low                  | Low              | Low cost, simple                               | The effect of temperature rise is poor, and the boiler efficiency is affected. |
| Grading and upgrading of economizer | High                 | High             | Effect is better, does not affect boiler efficiency | Complex system, high cost, the make temperature can’t control. |
| Hot water recycling        | Middle               | Middle           | The temperature rise effect is better, control difficulty is general. | Invest in a circulating pump, impact on boiler efficiency. |
| Set #0 high pressure heater | Middle               | Middle           | The temperature rise effect is better          | The control is difficulty, the reconstruction cost is high, has influence to boiler efficiency. |
| Increase bypass of flue gas | High                 | Middle           | The temperature rise effect is better, system is simple | Difficult to transform the space and operation, uneven wind temperature mixing, effect on the boiler efficiency |

3. Operation adjustment of low load operation
As more and more thermal power unit to participate in power grid, the peak load regulating operation has also gradually reduced the minimum load, some units in the 30% to 50% load running, the denitration entrance flue gas temperature down to 290 ℃ to 310 ℃, slightly below the denitration input value. In particular, because of the high degree of cleanliness of the new unit, the heat transfer efficiency is high, and the temperature of the furnace outlet is low.

The advantages and disadvantages of retrofit scheme is analyzed, it can be seen that no matter what kind of system are unable to make up for the shortcomings, the high cost with good effect, poor effect with low cost, and not successful transformation will affect the unit economy, even bring safe hidden trouble. If we can through the way of combustion adjustment during low load operation to increase the
SCR reactor inlet flue gas temperature to denitration allows lower limit value, will save a lot of late reformation investment and maintenance cost, decrease the difficulty of the control system to avoid the negative effects of system transformation, the economy and the influence of the boiler efficiency is also small.

3.1. Adjustment of the flue gas baffle
The common supercritical type of boiler furnace and rear shaft flue. Low temperature superheater and economizer arrangement in the behind of the flue, low temperature reheater arrangement in front of the flue, arrange in the shaft flue outlet baffle, by adjusting the baffle opening to control the gas flows through the smoke of economizer. Because the heat capacity of the water in the economizer is large and the heat exchange is large, it can effectively reduce the absorption heat of the economizer by adjusting the flue gas baffle of the reheater, and effectively improve the smoke temperature of the denitration inlet.

In this paper, a 350MW supercritical dc furnace was selected for the experiment, and the control load was 175MW, and the combustion stability of the boiler was maintained, and the parameters were stable and coordinated. Change the opening of the baffle, and stabilize 20 to 30 minutes in each working condition to record the average temperature of denitration inlet.

Table 2. effect of adjusting baffle on the flue gas temperature of denitration inlet

| Opening of the superheater baffle | Opening of the reheater baffle | The unit load MW | Fuel quantity t/h | Water temperature ℃ | Main steam temperature ℃ | Main steam pressure MPa | Denitration inlet gas temperature ℃ |
|------------------------------------|--------------------------------|------------------|------------------|----------------------|--------------------------|-------------------------|------------------------------------|
| 30%                                | 100%                           | 175              | 79.6             | 240                  | 555                      | 13.9                    | 334                                |
| 45%                                | 100%                           | 175              | 80.1             | 241                  | 558                      | 14.1                    | 328                                |
| 65%                                | 100%                           | 175              | 80.8             | 241                  | 557                      | 14.2                    | 324                                |
| 100%                               | 100%                           | 175              | 78.9             | 241                  | 558                      | 13.9                    | 320                                |
| 100%                               | 75%                            | 175              | 80.5             | 240                  | 560                      | 13.8                    | 315                                |

As can be seen from table 2, when the experimental unit is operating at 50% load (175MW), it can influence the flue gas temperature by adjusting the baffle. During the process, the water flow and the water temperature of the upper water remain unchanged, and the water side of the economizer is stable. Adjust the flue gas baffle, increase the gas flows through the flue gas of economizer, under the condition of other parameters constant, denitration entrance flue gas temperature fell by nearly 20 ℃. Therefore, under the premise of ensuring the normal operation of the unit, the regulation of flue gas regulating baffle is an effective control method to improve the flue gas temperature of denitration inlet.

3.2. Adjustment of air volume and air distribution
Oxygen during low load operation generally more ample, found by the theoretical calculation in the oxygen combustion conditions[12], when the flame center at constant, increase the total air volume will increase furnace outlet smoke temperature, whereas lower secondary air volume can reduce furnace outlet smoke temperature. However, the effect is weaker, and the lower the load is, the smaller the effect on the temperature, and the smoke temperature is almost constant when the load is low. In addition, the air distribution of the secondary wind, especially the opening of the over fire air, will also affect the height of the flame center, thus affecting the smoke temperature of the furnace outlet. If the total air volume is certain, open the over fire air baffle, the lower air volume will be reduced, and the upper air volume will increase. When the over fire air baffle is closed, the wind is moving down.

Because the change of parameters under low load will affect the combustion, the disturbance amplitude of the adjusted variable in the experiment is also limited. The change of total air volume and air distribution can influence the temperature of denitration inlet to a certain extent. The test results also demonstrate its directivity, but the temperature change is small.

3.3. Improve steam quality
Superheater and reheater are important components of boiler heating surface, and the heat exchange is
larger. Under certain load, the improvement of steam quality has a positive effect on improving the flue gas temperature of denitration inlet. Drum boiler can be appropriately increase the drum pressure and saturation temperature to increase into the superheater steam temperature, the direct current furnace can control the temperature of the intermediate point through the control of the water coal ratio to improve the steam temperature of the superheater. Under the premise of not exceeding the temperature, reduce the use of water reducing water, improve the main steam quality, and also raise the cold reheat retemperature, and reduce the heat transfer of superheater and reheater from all angles. In addition, the main steam pressure will be increased under the constant load, and the fuel quantity will also increase, which will have a certain effect on the increase of the flue gas temperature of denitration inlet.

A 350MW supercritical direct current furnace was selected for the experiment, and the control load was 175MW. Change the vapor pressure, stabilize 20 to 30 minutes, and record the average temperature of the denitration inlet. The results are shown in table 3.

Table 3. Influence of steam quality on the flue gas temperature of denitration inlet

| The unit load MW | Fuel quantity t/h | Water temperature ℃ | Intermediate point temperature ℃ | Main steam temperature ℃ | Main steam pressure MPa | Cold reheat temperature ℃ | Denitration inlet gas temperature ℃ |
|-----------------|------------------|----------------------|----------------------------------|--------------------------|-------------------------|---------------------------|----------------------------------|
| 175             | 79.7             | 241                  | 336                              | 545                      | 13.1                    | 323                       | 318                              |
| 175             | 80.1             | 240                  | 344                              | 565                      | 13.2                    | 335                       | 322                              |
| 175             | 82.2             | 240                  | 349                              | 564                      | 14.9                    | 333                       | 324                              |

When the load and fuel quantity of the unit are constant, the main steam pressure is changed, the temperature of the middle point is raised, the temperature of the main steam is increased by 20℃, the inlet temperature of the reheater is increased and the inlet temperature of denitration can be increased by 4℃, and the main steam temperature is unchanged, the main steam pressure is increased by 1.8MPa, and the unit is stable under the coordinated mode, the final inlet temperature of the denitration increased by 2℃. It can be seen that increasing steam parameters and reducing the use of cooling water can reduce the heat transfer of the reheater when the stable load is constant. At the same time, the increase of pressure can also increase a small amount of fuel, and finally improve the flue gas temperature of the denitration entrance.

3.4. Increase the temperature of the water
The heat transfer of the coal economizer in the rear shaft is larger. When the unit is running at low load, it is necessary to ensure that the heater is fully invested to increase the temperature of the water to reduce the heat transfer to the economizer, thus increasing the temperature of the flue gas at the entrance of the SCR reactor. The #0 high pressure heater, economizer grading transformation and hot water recycling are also starting from this idea.

3.5. Adjustment of the running mode of coal mill
During the process from high load to low load, the total fuel consumption needs to be gradually reduced. Due to the limitation of the minimum output of the coal mill, it is necessary to stop the coal mill. When selecting the order of the coal mill, it is considered that the running of the upper coal mill is higher than that of the lower coal mill, and it has a positive effect on improving the flue gas temperature of the denitration entrance. Therefore, in keeping the low load operation of the 2 to 3 coal coal mill, the middle layer coal mill or the upper coal mill should be kept in consideration, and the stability of the combustion is closely concerned in the process of coal mill.

3.6. Control of furnace flame center
Through combustion adjustment, the flame center of the furnace can be increased effectively, and the flue gas temperature at the outlet of the furnace can be effectively increased, thus increasing the inlet flue gas temperature of the denitration. In view of different furnace type and design, the means of
controlling the center of the flame are more: (1) the amount of fuel is moved up, the coal quantity of the coal coal mill is raised, or the different combination mode of the coal mill is selected; (2) properly increase the negative pressure of the furnace; (3) to reduce the outlet temperature of the coal mill to delay the combustion of the pulverized coal in the furnace; (4) appropriately increase The fineness of pulverized coal causes the delayed combustion of pulverized coal to delay combustion in the furnace; (5) increase the ratio of air to coal and improve the wind speed of the powder pipe; (6) to ensure the stability of the combustion, open the hole of the blast furnace bottom, the cold wind in the bottom of the furnace will raise the center of the flame; (7) increase the total air volume, adjust the mode of air distribution, and reduce the burning air volume; (8) The combustion trajectory of the pulverized coal furnace can be changed by changing the burner angle or adjusting the burner with the air to improve the flame center; (9) adjusting the quality of the coal entering into the furnace, the change of the coal quality will change the combustion trajectory in the furnace.

In order to adjust the height of the flame center, we should pay attention to the combustion stability and the change law of the steam temperature in the furnace. The different effects of each adjustment method with the design of the boiler should be different, and the suitable adjustment mode should be selected according to the actual conditions.

3.7. Early soot blowing before low load
In the normal operation of coal-fired boilers, ash deposition and slagging on the surface of heating surfaces are difficult to avoid, which will seriously affect the normal operation of boilers. Normal soot blowing is essential, but it is necessary to adjust the time and frequency of soot blowing reasonably according to the actual situation, especially the high cleanliness of the heating surface of the new set, which can control the soot blowing frequency according to the heat exchange of the steam water system. On the other hand, according to the scheduling load planning curve, the furnace ash blowing work is completed as early as possible at large load, and the large area soot blowing is strictly prohibited during the load reduction or low load operation. A small amount of floating ash on the surface of the heating surface can reduce the heat transfer in the furnace, and increase the outlet temperature of the furnace and the inlet temperature of the denitration.

The 350MW supercritical unit in a factory is running at full load, short blowing (a total of 30) blowing ash, the furnace outlet smoke temperature decreased nearly 20 degrees, denitration inlet smoke temperature decreased 3-4 degrees, and the subsequent 1-5 hours of smoke temperature slowly rebounded. It can be seen that soot blowing has obvious and rapid effect on flue gas temperature. Reasonable arrangement of soot blowing time and frequency is helpful to improve the input rate of denitration under low load.

There are many factors that affect the unit operation at low load. Different furnace types, combustion modes, air distribution design and running time determine the different adjustment modes. The input rate of denitration increased by means of combustion adjustment, which is superior to system improvement in terms of economy and practicability. The research and experimental results of this paper provide the adjustment direction, and the effect is different because of the actual conditions of the unit. It provides technical support for adjusting the flue gas temperature of the denitration inlet in the low load operation of the coal-fired power plant.

4. conclusion
The state will be more and more strict with the emission index of power plants, and the intensity of assessment will also gradually increase. At present, there are imperfect areas of denitration technology, and the temperature of a lot of power plants is close to or slightly lower than the allowable value when the peak load operation of many power plants is low. Therefore, it is more feasible and economical to improve the denitration input rate by combustion adjustment.

This paper expounds several more mature denitrification techniques and points out the advantages and disadvantages of each kind, and focuses on how to improve the flue gas temperature of the denitration entrance at low load operation by the method of combustion adjustment, and the
experimental verification is carried out on the adjustment method, the direction and effect of adjustment are summarized, which provides reference and reference for the full load SCR denitrification of coal-fired power plants.

References
[1] GB13223-2011 air pollutant emission standard [S] for thermal power plants
[2] Research on Operation Strategy of Li Hua Min, Baiyuan, SCR System under Low Load Conditions, Electric Power Science and Environmental Protection, 2014.10 (30-5): 36-37
[3] Xie Qianyang, Technical Method for Increasing the Flue Gas Temperature at the Inlet of SCR Reactor, China Electric Power, 2015.04 (48-4): 36-43
[4] Chen Yue, based on the study of denitrification of supercritical unit with refrigerant side modification, applied energy technology, 2017 (06): 24-26
[5] Zhao Weijun, Zhao Peichao, full load denitrification technology, East China Science and technology, 2015 (10): 494-494
[6] Xu Zhao, Xu Liang, Hu Jie, Xu Zhongxiong, Practice of Improving the Smoke Temperature at the SCR Entrance of the Economizer of the First Thermal Power Unit in China, Boiler Manufacturing, 2014.11 (6): 42-56
[7] Guan Xiangfeng, Jiao Yulong, Wu Xiaoming, 2 *670MW thermal power unit denitrification transformation analysis and application, 2017.1 (39-1): 68-72
[8] Yangqing, Shajiao C Power Plant SCR Denitrification Wide Load Condition Reform Technical Scheme and Application, Technology and Technology, 2016 (09): 88-89
[9] Jiang Bo, Chen Shangdong, Research and Reform of Low Load Denitrification for 1000MW Ultra-Supercritical Unit, Science and Technology Economic Guide, 2016 (16): 92-95
[10] Research and Application of Operation Technology for Denitrification System of 300MW Unit at Low Load in Gaopeili, Zouxian, 2015 (24): 32
[11] Jiang Nina, Wu Qirong, Zhao Weijun, Qu Xiaofan, Low-load Denitrification Research, Energy and Environment, 2014 (04): 76-78
[12] Wang Chunchang, Correlation Study between Air Volume and Furnace Exit Flue Gas Temperature, Thermal Power Generation, 2007 (7): 37-42