Application research of flue gas depth reduction modification technology in 600MW thermal power unit

Nie Peng-fei¹, Liu Zhi-yuan²,a

¹ Hebei Datang International Wangtan Power Generation Co. Ltd., Tangshan 063611, China
² Hebei Guohua Dingzhou Power Generation Co. Ltd., Dingzhou 073000, China

*496454@qq.com
azhiyuan.liu.m@chnenergy.com.cn

Abstract. According to the policy requirement of No. 156 in 2018, the wet flue gas desulfurization system of a 600 MW unit in a power plant needs to be reformed for deep emission reduction. Based on the technical route of flue gas cooling and condensing, the influencing factors such as exhaust gas temperature and exhaust fan allowance are analyzed, and the design boundary parameters are reasonably selected. The technical characteristics of flue gas condenser and slurry cooler are compared. It is pointed out that slurry cooler has the advantages of no increase in flue gas system resistance, non-stop construction and low energy consumption, and is more suitable for field renovation. Aiming at the water balance problem of desulfurization system after using slurry cooler, this paper combs and analyzes the water balance items, and takes a series of measures: demolishing the first-stage absorber demister, collecting filtrate water and filter cloth washing water for pulping, recovering the slurry circulating pump sealing washing water, etc., which can basically meet the transformation needs. Special-shaped tray is installed in the absorption tower to improve the desulfurization and dust removal performance.

1. Project summary

In hebei power plant of Datang Group, the flue gas volume of Boiler no. 1 and no.2 600MW units is 2199,022nm³/h(standard, dry base, 6%oxygen) when designed, the concentration of SO₂ at the desulfurization inlet is 4,458mg/Nm³, the double-absorption tower limestone-gypsum wet flue gas desulfurization technology is adopted, the concentration of SO₂ at the desulfurization outlet is 35mg/Nm³, and the designed desulfurization efficiency is 99.2%.The flue gas concentration at the desulfurization inlet is designed to be 50mg/Nm³, and the secondary absorption tower is equipped with a tube bundle mist eliminator for efficient dust removal. The flue gas concentration at the desulfurization outlet is 10mg/Nm³, and the dust removal efficiency is designed to be 80%.The first stage absorption tower is equipped with 3 slurry circulation pumps and spraying layer, and the flow rate of each slurry circulation pump is 10140m³/h;Four slurry circulation pumps and spraying layer are set up in the secondary absorption tower, and the flow rate of each slurry circulation pump is 9000m³/h[1-2].

According to the depth emission reduction acceptance standard in Document no. 156, 2018 of Hebei Gas Pilot Office: If the flue gas temperature control adopts cooling and condensation method, the flue gas temperature after condensation in summer (April-October) reaches below 48℃ and the
moisture content of flue gas is below 11.0%; In winter (From November to March of the next year), the condensing flue gas temperature is below 45℃, and the moisture content of flue gas is below 9.5%; On the basis of ultra-low emissions, furthermore, improve the level of flue gas pollution treatment, complete the in-depth treatment of boiler flue gas, dust, sulfur dioxide and nitrogen oxide to reach 5mg/Nm³, 25mg/Nm³ and 35mg/Nm³ respectively. In actual operation, the temperature of the purified flue gas from the plant can reach 50-56℃ in the off-heating period and 47℃-51℃ in the heating period. Apart from nitrogen oxides, dust and sulfur dioxide do not meet the policy requirements. Therefore, it is very necessary to carry out in-depth emission reduction of flue gas. [3]

2. Deep emission reduction transformation scheme

Based on the field investigation and understanding of other power plants, combined with the schemes proposed by various desulfurization companies and design institutes, after technical demonstration, two technical schemes suitable for the deep emission reduction transformation of the power plant are slurry cooler and flue condenser. The cold source adopts seawater and open circulation.

According to the operation data of the past two years, the original flue gas temperature of Unit 1 desulfurization unit fluctuates between 125℃ and 156℃ in the summer of the past two years, and the purified flue gas temperature reaches up to 56℃. The original flue gas temperature of Unit 2 desulfurization unit fluctuates between 120℃ and 150℃ in the past two summers, up to 55.7℃. In order to further reasonably determine the temperature, the average monthly operating temperature of the original purified flue gas of the No. 1 and No. 2 desulfurization system in the past two years was statistically analyzed, as shown in Figure 1 below.

![Figure 1 monthly average operating temperature of original purified flue gas of No.1 and No.2 desulfurization systems in recent two years](image)

It can be seen from Figure 1 that the average purified flue gas temperature of unit 1 in July and August in recent two years is 54℃ and 53.3℃, and that of unit 2 in July and August in recent two years is 53℃ and 53.3℃. In recent two years, the load rate of the whole plant is 75.3% and 72.6% respectively. Through analysis, it is considered that the monthly average temperature of purified flue gas in July is 54℃, so the design temperature of flue gas deep emission reduction is considered as 54℃. The design parameters of flue gas deep emission reduction of the power plant are shown in Table 1.
Table 1. Design parameters of flue gas deep emission reduction of 600MW unit in a power plant

| Serial number | Project                                      | Unit        | Numerical value         |
|---------------|----------------------------------------------|-------------|-------------------------|
| 1             | Flue gas volume (standard dry basis)         | Nm³/h       | 2199022                 |
| 2             | Flue gas volume (standard wet basis)         | Nm³/h       | 2376054                 |
| 3             | Boiler exhaust gas temperature               | ℃           | 140Summer/123.5 winter  |
| 4             | Purified flue gas temperature                | ℃           | 54Summer/50 winter      |
| 5             | Flue gas temperature after cooling           | ℃           | 48Summer/44winter       |
| 6             | Cooling water (sea water) temperature       | ℃           | 28Summer/1winter        |
| 7             | Dust                                         | mg/Nm³      | 5                       |
| 8             | SO₂                                          | mg/Nm³      | 25                      |

2.1. Flue gas cooling technology route
The transformation is to install slurry cooler (one for use and one for standby) on the outlet pipe of slurry circulating pump at the highest and second high level of secondary absorption tower. The slurry is cooled by cooling water (sea water) through slurry heat exchanger, and then the flue gas in the absorption tower is cooled by the cold slurry sprayed to the absorption tower, so as to reduce the temperature and humidity of the purified flue gas at the outlet of the absorption tower. After the flue gas is cooled, the condensate water will return to the slurry pool of the absorption tower. The design parameters of the slurry cooler system of the power plant are shown in Table 2 below.

Table 2. Design parameters of 600MW desulfurization slurry cooler system in a power plant

| Serial number | Project                     | Company          | Winter parameters                  | Summer parameters                  |
|---------------|-----------------------------|------------------|------------------------------------|------------------------------------|
| 1             | Slurry parameters           |                  |                                    |                                    |
| 1.1           | Circulation pump flow       | m³/h             | 9000                               | 9000                               |
| 1.2           | Slurry side pressure drop   | Kpa              | <15                                | <15                                |
| 2             | Cooling water parameters    |                  |                                    |                                    |
| 2.1           | Inlet temperature           | ℃                | 1                                  | 28                                 |
| 2.2           | outlet temperature          | ℃                | 15                                 | 40                                 |
| 2.3           | Flow                        | m³/h             | 4152                               | 5354                               |
| 2.4           | Water side resistance       | Kpa              | 105                                | 105                                |
| 3             | Exchanger type              | /                | Straight channel plate             | Straight channel plate             |
| 4             | Heat transfer element       | /                | 2507 duplex stainless steel        | 2507 duplex stainless steel        |
| 5             | Shell material of heat exchanger | /              | carbon steel                      | carbon steel                      |
| 6             | Slurry reduction drop       | ℃                | 7                                  | 7                                  |
| 7             | Total heat exchange area    | m²               | 2420                               | 2420                               |
The flue gas slurry cooler system of a 2 × 600 MW unit in a power plant (see Figure 2) is mainly composed of slurry cooler, slurry cooling pump, cooling water pipe and valve, etc. Its technical features: ○1 The slurry cooler is installed on the outlet pipe of the slurry circulating pump at the highest and the second high layers, without any modification of the flue gas system and without increasing the flue gas resistance, so it can realize the non-stop construction; ○2 The heat transfer element of the selected heat exchanger is 2205 or 2507 duplex stainless steel, which has the advantages of anti-blocking, corrosion and wear resistance, high heat transfer efficiency and small floor area; ○3 the slurry side resistance drop of slurry cooler is less than 15Kpa, the normal operation of the original slurry system can be ensured; ○4 The condensate water of flue gas directly falls into the absorption tower, which reduces the make-up water for desulfurization.

![Figure 2 system diagram of flue gas desulfurization slurry cooler of a 600MW unit](image)

However, the condensate water in this scheme directly falls back to the slurry tank of the absorption tower and cannot be directly used, so it has a great impact on the water balance of the desulfurization system. The greater the cooling range, the greater the impact on the water balance. Through theoretical calculation and practical experience summary, the condensate water of desulfurization system from 54℃ to 48℃ is about 62t/h[4], and the water balance of desulfurization system is damaged, which is solved by the following four measures: ○1 Remove the ridge type demister of the first stage absorption tower; ○2 Collect the mechanical seal water of slurry circulating pump and recycle it to the process water tank; ○3 the raw filtrate water and filter cloth washing water are mainly recycled in the absorption tower, a new collection tank is added in this reconstruction, which can basically meet the water demand for pulping after recovering filtrate water and filter cloth washing water; ○4 The capacity of desulfurization wastewater system is expanded, and the wastewater discharge is increased when necessary. The water balance table before and after the transformation of desulfurization slurry cooler is shown in Table 3 below. As the moisture carried by the original flue gas does not participate in the desulfurization reaction process, it is omitted[5].

| Serial | Water inflow of desulfurization system | Water consumption of desulfurization |
|--------|----------------------------------------|-------------------------------------|
|        | The inlet flue gas temperature of absorption tower is 140 ℃, the outlet flue gas temperature is 54 ℃, and the original flue gas moisture content is 7.1% |                                      |
| Number | Primary Coverage                                      | Before (t/h) | After (t/h) | System                      | Before (t/h) | After (t/h) |
|--------|------------------------------------------------------|--------------|-------------|-----------------------------|--------------|-------------|
| 1      | Flushing water for primary tower demister            | 22           | /           | Evaporation                 | 114          | 52          |
| 2      | Flushing water for demister of secondary tower       | 30           | 30          | Gypsum crystal water + carrying water | 5            | 5           |
| 3      | Water content in limestone slurry                    | 35           | /           | Desulfurization wastewater discharge | 2            | 2           |
| 4      | Oxidizing air cooling water                          | 6            | 6           |                             |              |             |
| 5      | Mechanical seal water of equipment                   | 5            | /           |                             |              |             |
| 6      | Equipment cooling water (closed)                    | /            | /           |                             |              |             |
| 7      | Pipeline flushing water                               | 5            | 5           |                             |              |             |
| 8      | Sealing water for vacuum pump                        | 18           | 18          |                             |              |             |
| 9      | Filter cloth flushing water (from vacuum pump)       | /            | /           |                             |              |             |
| 10     | Filter cake flushing water (from vacuum pump)        | /            | /           |                             |              |             |
| Total  |                                                     | 121          | 59          |                             | 121          | 59          |

After the above measures are taken, the water balance of the desulfurization system after the slurry cooler modification is not affected basically.

2.2. Improvement scheme of desulfurization and dust removal efficiency

In order to improve the desulfurization and dust removal performance of the absorber system synchronously, a scheme of increasing the cooperative desulfurization and dust removal efficiency of flue gas sharing device in the absorber was adopted after optimization. The original system configuration remains unchanged, and a special-shaped tray is installed below the first spray layer of the absorption tower, as shown in Figure 3. Special-shaped tray technology refers to the internal counter-current spray absorber to add a layer of disturbance on the basis of mass transfer, the device pore adopt appropriate Koch curve fractal or sierpinski gasket for you the fractal characteristics of tooth structure, decorate in absorption cross section of the tower, formed in the slurry in the smoke flow of multi-scale, heterogeneous, three-dimensional space chaos, in chaos mixing, gas-liquid mass transfer and heat transfer[6].

The special-shaped tray uses the flue gas in the tower as the disturbance term to tear and blow up the slurry falling from the disturbed mass transfer parts, which increases the residence time of desulfurized slurry and the contact time between liquid and gas, increases the specific surface area of gas-liquid contact, and greatly improves the gas-liquid reaction efficiency and dust trapping capacity of slurry. At the same time, the special-shaped tray can improve the uniformity of the flow field in the absorber, which is helpful to improve the deducting performance of the tube bundle mist.
eliminator. Special-shaped tray is different from the ordinary pallet rectifier, almost no liquid holding layer, so the resistance is only about 300Pa.

Figure 3 special-shaped tray of flue gas desulfurization absorber of a 600MW unit

2.3. Operation effect
The effect is illustrated by taking some operation data of flue gas deep emission reduction transformation as an example, as shown in Table 4.

Table 4. Operation parameters of a 600MW unit after deep emission reduction

| Running time | Load | Untreated flue gas/ concentration | Flue gas after treatment/ concentration | Desulfurization efficiency (%) | Dust removal efficiency (%) |
|--------------|------|----------------------------------|----------------------------------------|--------------------------------|---------------------------|
|              | MW   | SO2 (mg/Nm³) | dust (mg/Nm³) | before cooling (°C) | SO2 (mg/Nm³) | dust (mg/Nm³) | after cooling (°C) |                             |                          |
| 2019.10.18 18:45 | 605  | 1843     | 88          | 51.8             | 14.25     | 7.2         | 44.5            | 99.35                  | 91.82  |
| 2019.10.18 19:17 | 609  | 1820     | 85.7        | 51.8             | 10.41     | 7.4         | 44.6            | 99.43                  | 91.37  |
| 2019.10.20 13:10 | 300  | 2567     | 36.5        | 50.6             | 15.8      | 4.5         | 41.2            | 99.39                  | 87.67  |
| 2019.10.20 18:26 | 553  | 2766     | 53.5        | 51.9             | 10.7      | 4.2         | 44.7            | 99.61                  | 92.15  |
| 2019.10.21 16:24 | 554  | 2722     | 47.3        | 50.7             | 15.9      | 3.1         | 43.3            | 99.41                  | 93.45  |
| 2019.10.21 10:00 | 300  | 2731     | 48.4        | 50.5             | 17.2      | 4.3         | 40.5            | 99.37                  | 91.12  |
| 2020.06.12 12:15 | 551  | 2469     | 88.6        | 53.6             | 12.9      | 6.5         | 46.6            | 99.47                  | 92.66  |
| 2020.06.12 13:35 | 574  | 2290     | 78.9        | 53.9             | 15.2      | 4.6         | 47.1            | 99.33                  | 94.17  |
| 2020.06.12 15:36 | 573  | 2098     | 84.7        | 54.1             | 13.9      | 7.7         | 47.3            | 99.34                  | 90.91  |
| 2020.07.09 20:11 | 560  | 3650     | 34          | 55.9             | 25.4      | 2.8         | 48              | 99.31                  | 91.76  |

After this transformation, all the environmental protection parameters can meet the requirements of emission reduction. It can be seen from the above table that after the slurry cooler is put into use, the flue gas cooling effect is better with the cooling range above 6°C. The desulfurization and dust removal performance of the absorber have been improved to a certain extent after the flue gas is processed by spray layer, special-shaped tray and tube tube type mist eliminator inside the absorber. Among them, the desulfurization efficiency is increased by about 0.2% and the dust removal efficiency is increased by more than 10%. Observation by start-stop grout cooler showed that the main flue gas pollutants did
not fluctuate significantly except the temperature parameters of the purified flue gas. It was inferred that grout cooler had no obvious promoting effect on the flue gas, sulfur dioxide and other pollutants. In terms of energy consumption, the outlet pressure of slurry circulation pump after installing slurry cooler increases by 15Kpa, and the flue gas resistance of special-shaped tray increases by 300pa; these two items are equivalent to about 300kW of energy consumption. After using the special-shaped tray, although the power consumption of the induced draft fan increases, at least 1 slurry circulation pump can be stopped for desulfurization performance improvement. Considering the power saving of 800kW, the power consumption of desulfurization can still be reduced by 500kW. If the grout cooler is put into operation and superposition the power consumption of 1000kW slurry cooling pump, the power consumption of the plant will increase by 500kW.

3. Conclusion
The technical route selection of flue gas deep emission reduction transformation plays an important role in the effect of the whole project. In accordance with the environmental protection requirements of a 600 MW unit of Datang Group, starting from the actual situation of the plant, the technical scheme of deep flue gas emission reduction transformation is studied and demonstrated, and the technical schemes suitable for the plant are introduced and compared. After the slurry cooler is selected for application in the power plant, the water balance of the system is maintained by optimizing the desulfurization process water system; the special-shaped tray is used to improve the desulfurization and dust removal performance of the absorption tower; finally, all parameters of flue gas meet the requirements of flue gas deep emission reduction.

Other power plants should fully consider the cold source, climate, induced draft fan output, transformation period, shutdown transition, project investment and other factors when selecting the transformation scheme of flue gas deep emission reduction, and select the technical route suitable for the power plant, so as to realize the win-win situation of environmental protection and social benefits.

References
[1] NIE Peng-fei, ZHANG Hong-yu. Causes Resulting in Stack rainout of Wet Flue Gas Desulphurization for the Thermal Power Plant Without GGH and its Countermeasures, 2012, 38(2): 4-8.
[2] Wang Zongmin. Discussion on Eliminating of "Wet Plume" in Coal-Fired Power Plants [J]. SHANGHAI ENERGY CONSERVATION, 2018, (5): 328-331.
[3] YE Yi-ke, HUI Run-tang, YANG Ai-yong, et al. Technical research of wet plume control in coal-fired power plant [J]. Electric Power Technology and Environmental Protection, 2017, 33(4): 32-35.
[4] NIE Peng-fei, Wang Yang, Chen Qi-fu. Case Study on Reconstruction of Wet FGD Bypass Damper Plugging for 600-MW Thermal Units [J]. ELECTRIC POWER, 2013, 46(3): 100-103.
[5] Wu Yong-jie, Dai Yong-yang, Dong Ling-hong, et al. The research of managing wet stack rain in the Huaneng Yang Liuqing power plant 2 ×300 MW unit. Energy Environmental Protection, 2014, 28(5): 16-19.
[6] Yao Zeng-quan. The rise and condensation of a moist plume. International Electric Power for China, 2003, 7(1): 42-45.