Performance analysis of 600 MW high sulfur coal unit desulfurization unit reform under ultra-low situation

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Abstract: The 600MW high-sulfur coal desulfurizers in a power plant in southwest China adopt the single-tower 5-layer spray limestone wet desulfurization process. However, the change in the quality of coals initiated the need for capacity expansion. A renovation by adding two layers of sprays brought significant improvement to the performances, with the SO2 concentration at the outlet remaining below 400mg/m³. In response to the government's call for ultra-low emission, the plant set up another renovation by constructing a new absorb tower, turning the 7-layer spray to an arrangement of 4+5 dual tower spray so as to lower the concentration of inlet SO2 from 12000mg/m³ to below 35mg/m³ through dual-tower desulfurization. The performance indexes of the two renovations were compared comprehensively, revealing that the gypsum is of poor quality and the content of fog drops at the outlet of desulfurizer is high. The paper also offers suggestions for optimized operation of desulfurizers.

1. Introduction

The phase III project of a power plant in southwest China has two 600MW domestic subcritical coal-fired condensate turbo generators, with a coal sulfur content of 2.39% in the boiler. The flue gas desulfurizer, adopting limestone-gypsum wet desulfurization technology, was constructed simultaneously with the generator set [1]. It was officially put into operation at the end of February, 2007. The system was designed as one furnace with a reverse flow spray air tower system along with pulse suspension and stirring functions. The inlet sulfur dioxide concentration of FGD was wet at 7613 mg/m³ (standard, dry, 6% O₂), whose desulfurization efficiency was greater than 96%. The absorber is equipped with 5 absorber circulating pumps, 2 gypsum slurry pumps and 2 pulsed suspended pumps.

2. Capacity Upgrading of Desulfurizer

Due to the change of the coal market, the sulfur content of the coal purchased by the power plant was on the increase. The existing desulfurization system cannot adapt to the combustion condition of high-sulfur coal nor meet the environmental standards. In 2011, the power plant increased the capacity of the flue gas desulfurizer [2-3], with the sulfur dioxide concentration of the inlet flue gas being increased from the original design value of 7613mg/m³ (standard, dry, 6% O₂) to 12,000 mg/m³ (standard, dry, 6% O₂), and the designed outlet was 400mg/m³ (standard, dry, 6% O₂), whose desulfurization efficiency was greater than 96.2%. The capacity upgrading mainly included:

  ● The sulfur content designed for the improved capacity was 4.24%(St,ar), the concentration of SO2 at the FGD inlet was 12,000 mg/m³ (standard, dry, 6% O₂), the flue gas flow 2116348m³/h (standard, wet, actual O₂), and the SO₂ concentration at the FGD outlet was no more than 400mg/m³ (standard, dry, 6% O₂).
- Add a set of limestone unloading system and pulping system, including a limestone block storehouse, a set of wet grinding system (a capacity of 40t/h, 90% going through 325-mesh screen), a limestone slurry transportation tank and two limestone slurry pumps (one operational and one standby).
  - Make full use of the original absorber to enhance the height and capacity (including the slurry pool). The slurry pool was 4.5m higher while the spray area was lifted by 4.0m. Make use of the original 5 absorber slurry circulation pumps while adding two more pumps and make a best use of the original nozzle and spray pipe; The slurry pool volume of the absorber was enlarged to ensure enough time for slurry retention. Make use of the original three oxidation fans while adding two more fans (four operational and one standby). The original two slurry pulse circulation pumps were retained and the impeller was modified. Keep the inner tank separator and oxidation air tube aeration system without adding absorber agitator on the sides. A new gypsum discharge pump was set up to operate in parallel with the original two gypsum discharge pumps (two operational and one standby). Check all the mist eliminators (roof ridge type) in the absorption tower, replace the damaged parts, and optimize the arrangement of the flushing water system of the mist eliminators.
  - Cancel the original GGH and corresponding ancillary facilities. After the removal of all GGH, the straight flue was installed with the interior being treated with anti-corrosion. The chimney was treated with imported. Penguard block lining system against corrosion.
  - After the removal of GGH, the resistance of the desulfurizer decreased. However, there was an increase of spray in the absorption tower and a decrease of the temperature of the net flue gas entering the chimney as well as changes of the smoke escape force. There was the need to consider these factors affecting the change of the system resistance. Through the calculation of the resistance of the desulfurization smoke air system and the pressure head of the booster fan, the reduced pressure head can make up for the added pressure head without the need to modify booster fan.
  - Replace the original gypsum cyclone station and add a new one. The gypsum slurry was to be completely abandoned, which was transported to the ash field by taking advantage of the first and second phase gypsum slurry abandonment system. And the interface of the gypsum dehydration unit and the site of the gypsum dehydration workshop were reserved.
  - Add 2 new processing water pumps, and replace the original 3 sets of mist remover flushing water pumps.
  - Add one CEMS at the inlet and outlet of the desulfurizer.

3. Renovation of ultra-low emission desulfurizer
In response to energy conservation and emission reduction, the plant renovated the flue gas desulfurizers with ultra-low emission in 2018. The configuration of the desulfurization system was designed according to the received base sulfur content of 4.24%. After modification, the emission concentration of SO₂ at the outlet of the desulfurizer shall be no more than 35mg/m³ (standard state, dry base, 6% O₂), and the desulfurization efficiency shall be no less than 99.71%.

The ultra-low transformation of the desulfurizer adopted a twin tower system, where two absorption towers were set, and the supercharger and induced draft fan were removed to carry out the transformation all in one. After the removal of the original booster fan and the concrete flue at the inlet, a new absorber was constructed as a first-stage tower at the position where the existing booster fan and concrete flue was located. The first-stage tower adopted smoke intake on both sides, and the smoke from the boiler induced draft fan was directly introduced into the new absorber.

The newly built absorption tower served as a first-stage absorption tower, with the diameter of 19m and 17m for the slurry pool and the absorption zone respectively. Four slurry circulation pumps, two slurry discharge pumps and two pulse suspension pumps were installed in the first-stage absorption tower. A layer of alloy tray was installed between the top of the inlet flue of the newly added first-stage absorption tower and the spraying layer on the bottom layer, with a diameter of 17000mm. The alloy tray was made up of 2205 material with a thickness of not less than 4mm. The coverage of all spraying layer of the new absorption tower was designed to be no less than 300%, and the nozzle adopts the efficient hollow cone nozzle. The old oxidation fan was transformed, where the oxidation air in the first
tower was connected to the oxidation fan in the second tower, and an adjusting valve was set in the middle. The limestone cyclone station between the first-stage and the second-stage tower took advantage of the two old gypsum hydrocyclone stations, where the gypsum slurry, transmitted from the gypsum discharge pump, was separated in the limestone cyclone station tower. Then a corresponding branch was set to transport the bottom stream containing a high percentage of solid medium into the secondary tower while the stream of low solid content was sent into the primary tower to control the liquid level, slurry pH and slurry concentration of the secondary absorber for water balance. At the same time, a bypass pipe was set up beside the hydrocyclone for maintenance.

Reconstruction of the existing absorption tower (secondary tower): the existing absorption tower was equipped with seven slurry circulation pumps. In the reconstruction, the two old circulation pumps were transferred to the primary tower while five circulation pumps were reserved, among which the highest lift circulation pump was reserved as the backup of the secondary tower.

According to the renovation plan of the whole factory, a complete gypsum dehydration system was built in another location. Limestone slurry preparation system and water processing system were reserved. The FGD processing system was mainly composed of limestone slurry preparation system, flue gas system, SO₂ absorption system, slurry drainage system, gypsum dehydration system, industrial water system, waste water treatment system, and miscellaneous and instrumental compressed air system.

4. Comparative analysis of performances before and after the renovation
The performance guarantee value and performance test results of the flue gas desulfurizer after the first capacity renovation in 2011 are shown in the following table.

Table 1. Guarantee value and main performance test results of capacity enhancement and renovation project of flue gas desulfurization unit.

| Number | Project                              | Company Design Value | Test Result (100% Load Rate) |
|--------|--------------------------------------|----------------------|------------------------------|
| 1      | Flue Gas Volume                      |                      |                              |
|        | Standard, dry, actual O₂             | m³/h                 | 2116348                      | 2179620                      |
| 2      | Original Flue Gas Temperature        | °C                   | 125.9                        | 136                          |
|        | SO₂ (standard, dry, 6% O₂)           | mg/m³                | 12000                        | 10231                        |
|        | Dust (standard, dry, 6% O₂)          | mg/m³                | 133                          |                              |
| 3      | Net Flue Gas                         | °C                   | 51                           |                              |
|        | SO₂ (standard, dry, 6% O₂)           | mg/m³                | ≤400                         | 348                          |
|        | Dust (standard, dry, 6% O₂)          | mg/m³                | ≤50                          | 35                           |
| 4      | Desulfurization Efficiency           | %                    | ≥96.7                        | 97.1                         |
| 5      | Gypsum Quality                       |                      |                              |
|        | Moisture Content                     | wt%                  | ≤10                          | 11.8                         |
|        | CaSO₄·2H₂O Content                   | wt%                  | ≥90                          | 90.4                         |
|        | CaSO₃·1/2H₂O Content                 | wt%                  | ≤1                           | 0.431                        |
|        | CaCO₃ Content                        | wt%                  | ≤3                           | 5.18                         |
|        | Cl⁻                                 | wt%                  | ≤0.01                        | 0.081                        |
| 6      | Limestone Consumption                | t/h                  | ≤43.5                        | 41.1                         |
| 7      | Water Consumption                    | t/h                  | ≤242                         | 214                          |
| 8      | FGD Electricity Consumption          | kW                   | ≤13910                       | 13111                        |
| 9      | Total FGD Pressure Loss              | Pa                   | 2760                         |                              |
| 10     | Droplet Content                      | mg/m³                | ≤75                          | 78.10                        |

It can be seen from the table that the main performance indexes such as desulfurization efficiency, SO₂ concentration, outlet smoke concentration, limestone consumption, water consumption and power
consumption basically satisfy the standards. However, a small number of guaranteed value indicators such as gypsum ingredients and demister export droplet content does not meet the standards, indicating that in actual operation, the desulfurization system, especially the gypsum, was not in a good condition, and the demister wasn't given a full play, indicating the need for further improvement. The performance guarantee value and performance test results of the desulfurizer after ultra-low emission renovation in 2018 are shown in the following table.

Table 2. Guarantee value and main performance test results of ultra-low modification project of flue gas desulfurization unit.

| Number | Project                  | Company | Design Value (100% Load Rate) |
|--------|--------------------------|---------|-------------------------------|
| 1      | Flue Gas Volume          |         |                               |
|        | Standard, dry, actual O₂ |         | m³/h                          |
| 2      | Original Flue Gas        |         |                               |
|        | Temperature              | °C      | 132                           |
|        | SO₂ (standard, dry, 6%O₂) |         | mg/m³                        |
|        | Dust (standard, dry, 6%O₂) |         | mg/m³                        |
| 3      | Net Flue Gas             |         |                               |
|        | Temperature              | °C      | 52                            |
|        | SO₂ (standard, dry, 6%O₂) |         | mg/m³                        |
|        | Dust (standard, dry, 6%O₂) |         | mg/m³                        |
| 4      | Desulfurization Efficiency |     |                               |
|        | Gypsum Quality           |         |                               |
|        | Moisture Content         | wt%     | ≤10                           |
|        | CaSO₄·2H₂O Content       | wt%     | ≥90                           |
|        | CaSO₃·1/2H₂O Content     | wt%     | ≤1                            |
|        | CaCO₃ Content            | wt%     | ≥3                            |
|        | Cl⁻                     | wt%     | ≤0.01                         |
| 5      | Limestone Consumption    | t/h     | ≤46.3                         |
| 6      | Water Consumption        | t/h     | ≤242                          |
| 7      | FGD Electricity Consumption |   | kW                            |
| 8      | Total FGD Pressure Loss  | Pa      | ≤5200                         |
| 9      | Droplet Content          | mg/m³   | ≤75                           |

According to the test results, after ultra-low emission renovation, the SO₂ concentration of the net flue gas has reached the national standard, but the concentration of the flue gas is still below standard, and the desulfurization fog drop value is still high, bearing the risk of gypsum rain [4]. The wet electric dust remover is installed for the desulfurizer to ensure that the dust reaches the standard and that the demister have a better cleaning effect. The test results show that the water consumption, power consumption, absorption tower resistance loss all meet the standard. However, the cast is still of poor quality with a high moisture content, indicating an unsatisfied desulfurization effect. The FGD slurry is still of poor quality with the CaSO₃·1/2H₂O content remaining high, showing an unsatisfied slurry oxidation effect. If high sulfur coal combustion runs in a long-term condition, the quality of FGD slurry will deteriorate further, making it more likely for net flue gas in the desulfurization system to go out of standard, thus dampening gypsum sales.

Table 3. Comparison of modification of flue gas desulfurization unit.

| Contrast | Initial Stage | Capacity Upgrading | Ultralow Upgrading |
|----------|---------------|--------------------|--------------------|
| Absorption Tower Types | Single tower | Single tower | Twin Towers |
| Slurry Circulating Pump Number | 5           | 7             | 4+5              |
From Table 3, we could see that the desulfurizer, after two technical renovations, has been able to control the SO$_2$ emissions within the range of national ultra-low emissions standard when calculated in net flue gas concentration. Coal desulfurizers with a SO$_2$ concentration of 12000 mg/m$^3$ (standard, dry, 6% O$_2$) are still rare in China. And the above design of the inlet flue gas parameters is not common, neither[5]. Thus, the plant's ultra-low emission renovation of desulfurizers is of great significance for other desulfurizers in high sulfur coal regions.

5. Suggestions for future optimization

A comparison of the two renovations show that both renovations satisfy the requirement of guarantee values. However, the gypsum indexes are poorer mainly because in overloaded desulfurizers, the flue gas flow is greater along with higher inlet SO$_2$ concentration. In order to guarantee high desulfurization efficiency, the pH value of the absorber slurry in the desulfurizer is set at a high level between 5.5 and 5.9. Under the pH value, CaSO$_3$·1/2H$_2$O content is higher in gypsum, directly increasing the consumption of limestone as well as the operating costs, a sign not conducive to gypsum dehydration. At the same time, under this pH value, SO$_3^{2-}$ has a weaker oxidation effect, resulting in increasing content of CaSO$_4$·1/2H$_2$O in the slurry. As CaSO$_4$·1/2H$_2$O has a large viscosity, it is not conducive to gypsum dehydration. It is suggested that the pH value should be optimized and adjusted on the premise of meeting the discharge requirements, with a focus on the density of gypsum slurry as well as operation management to reduce the consumption of limestone and improve the quality of gypsum slurry, thus stabilizing the economical operation of desulfurizers.

The results of the two tests showed a small difference in the value of fog drops, and the defogging effects of the demisters were similar. Because of the high SO$_2$ concentration in the flue gas, the designed liquid-gas ratio was very high, with a relatively large amount of slurry spraying, worsening the loads of the demister. Moreover, because of the high content of CaSO$_3$·1/2H$_2$O in the slurry, the viscosity was relatively large, and it was easy to stick to the surface of the demister. Therefore, it is necessary to flush and maintain the demisters in a timely manner to avoid fouling and blocking caused by delays in flushing, which could affect the stable operation of the device under heavy loads and cause the loss of power.

Currently, there are a total of nine slurry circulating pumps of “4 + 5” arrangements. The plant is in the southwest, rich in hydropower resources and low in boiler load all the year round. In this situation, it is suggested to actively explore the combination of the slurry circulating pumps to balance the distribution of primary and secondary towers to improve desulfurization efficiency, reduce energy consumption and guarantee stable operation of desulfurizers in a long-term condition.

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