The Application and Performance Evaluation of Tube Bundle Demister in Desulfurization Tower System

Liangzhou You* and Yue Zhu
Huadian Electric Power Research Institute CO LTD, Hangzhou, China
Email: liangzhou-you@chder.com

Abstract. In order to realize the ultra-low emission transformation of a 670 mw coal-fired unit, the original demister was transformed into a tube bundle demister. By adjusting the bypass opening of the electrostatic fabric composite precipitator and the operation mode of the spray layer of the desulfurization system. The overall collaborative dust cleaning efficiency of the desulfurization system under different working conditions is tested on site. According to the test results, the tube bundle demisters shows a high collaborative dust cleaning efficiency in the high load condition. However in the low load condition, the collaborative dust cleaning efficiency is significantly reduced, the slurry droplet content is increased, and the spray layer operation mode has a greater impact on the dust cleaning effect.

Keywords. Tube bundle demist; desulfurization series tower system; low-load; application and performance evaluation.

1. Introduction
According to the environmental protection requirements of ultra-low emission of coal-fired power plants during the 13th Five Year Plan period of the Ministry of environmental protection, the dust emission limit at the chimney inlet of coal-fired power plants is 10 mg/m³, while some power generation groups require the dust emission concentration to be 5 mg/m³. In order to meet such strict emission requirements, coal-fired units all over the country have carried out environmental protection transformation, and realized the emission requirements through different transformation lines [1-6]. The tube type dust demist is a kind of desulfurizing cooperated dust cleaning function, which directly realizes the desulfurization and absorption tower outlet smoke concentration below 5 mg/m³.

2. Technical Principle of Tube Bundle Demist
The flue gas after high-efficiency desulfurization and preliminary dedusting is further completed by the centrifugal tube bundle demister, which is composed of separator, booster, guide ring, confluence and tube bundle. Under the action of the primary separator, the flue gas makes the air flow rotate at a high speed, and the droplets form a certain thickness of dynamic liquid film on the wall. The fine particle smoke and slurry droplets carried by the flue gas are continuously captured and absorbed by the liquid film. The continuously rotating and rising flue gas is adjusted by the speed increaser, and then the fine particles and slurry droplets are removed by the secondary separator. At the same time, a thick liquid film is formed on the surface of the speeder and separator blades, which will cause the phenomenon of “water dispersion” under the action of high-speed air flow. A large number of large liquid drops are sent out from the blade surface, and the small slurry droplets passing through the slurry droplets layer are captured. After the large slurry droplets become larger, they are captured and absorbed by the liquid film on the cylinder wall, realizing the removal of small slurry droplets. The
principle of the tube bundle demist is shown in figure 1.

![Image of tube bundle demist principle]

Figure 1. The principle of the tube bundle demist.

3. Project Overview
The supporting precipitator of 670 MW unit in a power plant is “3+1” type electric bag composite precipitator, the desulfurization device adopts the series tower process, and the spray layer is “5+3” configuration. To achieve ultra-low emission of smoke and dust, the original absorption tower demister was reformed, and the original two-stage ridge type + one-stage tube type demister was replaced by tube bundle type demister. The performance guarantee values are shown in table 1 below.

| Item                    | Unit       | Numerical value |
|-------------------------|------------|-----------------|
| Inlet dust concentration| mg/m$^3$   | >30             |
| Outlet dust concentration| mg/m$^3$   | <5              |
| Dust removal rate       | %          | 83.33           |
| Droplet content at outlet| mg/m$^3$   | 25              |

4. Performance Test and Evaluation

4.1. Test Condition
According to the technical agreement for transformation and relevant requirements, the load rates of the test conditions are 100%, 75% and 50% respectively. During the test, the unit operates stably; the load fluctuation of the unit is not more than 5%. The operation of the desulfurization control system and main instruments is normal, the indication is correct, the spray layer of each tower of the desulfurization system operates normally, and the bypass opening of the electric bag composite precipitator is adjustable. The schedule of test conditions is shown in table 2.

| Program                     | unit       | Cond1 | Cond2 | Cond3 | Cond4 | Cond5 | Cond6 | Cond7 | Cond8 | Cond9 | Cond10 |
|-----------------------------|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| Test load rate              | %          | 100   | 100   | 100   | 100   | 75    | 50    | 50    | 50    | 50    | 50     |
| Operation of spray layer    | Layer number | 3+2   | 5+2   | 5+2   | 5+2   | 2+2   | 2+2   | 4+0   | 4+0   | 3+1   | 3+1    |
| desulfurization system      |            |       |       |       |       |       |       |       |       |       |        |
| Bypass opening of electric  | %          | 0     | 0     | 10    | 10    | 0     | 0     | 5     | 0     | 5     |        |
| bag composite precipitator  |            |       |       |       |       |       |       |       |       |       |        |
4.2. Test Items and Methods

4.2.1. Dust Test. At the inlet of the first stage absorption tower, the second stage absorption tower and the chimney, the automatic isokinetic sampling instrument of dust shall be used for sampling point by point according to the grid method. During the sampling process, record the volume, temperature, pressure and atmospheric pressure of the flue gas, the empty weight of the flue gas sampling membrane gun head and the actual weight after sampling, and then calculate the flue gas concentration according to the weight difference. Before and after the measurement, all the filter heads were dried at 105 °C for 2 hours. According to the principle of constant speed sampling, select the way of filtering in the flue, take a certain volume of gas containing particles from the flue, through the filter membrane with known weight in the sampling head, the particles in the gas are captured by the filter membrane, and calculate the emission concentration of particles according to the weight difference of the filter membrane before and after sampling, as well as the particles deposited in the upstream of the filter membrane and the volume of gas production. The schematic diagram of soot sampling device is shown in figure 2.

![Figure 2](image2.png)

Figure 2. Sampling equipment of the slurry droplet. Description: 1-droplet catcher; 2-sampling gun; 3-wet flowmeter; 4-pressure gauge; 5-thermometer; 6-air extraction pump.

4.2.2. Droplet Test. The flue gas sampled at the same speed passes through the primary and secondary absorption devices to make the droplets in the flue gas adhere to the inner wall of the absorption device. The quality difference of the absorption device before and after the test is the weight of the collected droplets. It is corrected by the concentration of Mg²⁺ ions in the solution of fog drop and absorption tower. The device for droplet application is shown in figure 3.

![Figure 3](image3.png)

Figure 3. The sampling equipment of dust. Description: 1-sampling nozzle; 2-membrane bracket; 3-s pitot tube; 4-temperature probe; 5-temperature measurement; 6-total pressure measurement; 7-dynamic pressure measurement; 8-support pipe (in flue device); 9-cooling and drying system; 10-extraction unit and gas metering device; 11-shut-off valve; 12-regulating valve; 13-pump; 14-flowmeter; 15-gas volume flowmeter; 16-temperature measurement; 17-barometer.

4.2.3. Dust Removal Efficiency. The dedusting efficiency is calculated according to the following formula:

\[ \eta = \left( \frac{C_{\text{in}} - C_{\text{out}}}{C_{\text{out}}} \right) \]

where: \( \eta \) - dust removal efficiency, \%; \( C_{\text{in}} \) - dust concentration of flue gas at the inlet (standard state, dry basis, 6% O₂), mg/m³; \( C_{\text{out}} \) - dust concentration of flue gas at the outlet (standard state, dry basis, 6% O₂), mg/m³.
4.2.4. Test Result. In view of the low dust concentration at the outlet of the electric bag composite precipitator, in order to further verify the overall dust washing capacity of the desulfurization system string tower process, the bypass of the electric bag composite precipitator will be opened, the operation layers of the spray layer of the desulfurization absorption tower will be adjusted, and the smoke and dust concentration at the inlet and outlet of the first and second absorption towers will be tested. The test results are shown in table 3.

Table 3. The result of test.

| Item                  | Measuremen t Position | Unit | Cond 1 | Cond 2 | Cond 3 | Cond 4 | Cond 5 | Cond 6 | Cond 7 | Cond 8 | Cond 9 | Cond 10 | Cond 11 |
|-----------------------|-----------------------|------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Test load             |                       | MW   | 661    | 664    | 649    | 666    | 501    | 340    | 342    | 359    | 343    | 355    |
| Spray layer           | Layer number          |      | 3+2    | 5+2    | 5+2    | 5+2    | 2+2    | 2+2    | 4+0    | 4+0    | 3+1    | 3+1    |
| Opening of dust remover bypass | %       |      | 0      | 0      | 10     | 5      | 10     | 0      | 0      | 5      | 0      | 5      |
| Flow rate of absorption tower | m/s  |      | 4.0    | 3.9    | 3.9    | 3.9    | 3.2    | 2.4    | 2.4    | 2.4    | 2.4    | 2.4    |
| Dust concentration    |                       | mg/m³| 18.6   | 16.8   | 105.7  | 59.8   | 82.8   | 15.6   | 14.5   | 15.2   | 65.1   | 14.2   | 55.3   |
| Primary absorber inlet |                      |      | 13.4   | 11.5   | 50.4   | 30.7   | 39.0   | 10.9   | 10.3   | 10.1   | 34.2   | 9.6    | 29.6   |
| Secondary absorber inlet |                  |      | 3.3    | 2.2    | 9.6    | 5.3    | 6.5    | 2.6    | 3.8    | 6.1    | 8.5    | 4.5    | 6.2    |
| Chimney entrance      |                       | mg/m³| 30.8   | 32.1   | 32.1   | 33.2   | 31.2   | 33.5   | 40.9   | 38.1   | 36.8   | 38.5   | 38.0   |
| Chimney entrance      |                       |      |        |        |        |        |        |        |        |        |        |        |        |
| Droplet content       | Dust cleaning efficiency of primary tower | %      | 27.96  | 31.64  | 52.35  | 48.59  | 52.91  | 30.35  | 28.97  | 33.57  | 47.52  | 32.56  | 46.3   |
| Dust cleaning efficiency of secondary tower | %       |      | 75.21  | 80.86  | 80.89  | 82.69  | 83.22  | 75.76  | 63.44  | 39.47  | 75.10  | 53.17  | 79.0   |
| Dust removal efficiency of desulfurization system | %     |      | 82.14  | 86.92  | 90.89  | 91.10  | 92.10  | 83.12  | 74.03  | 59.79  | 86.93  | 68.42  | 88.7   |

Note: The above smoke concentration is standard state, dry basis, 6% O₂.

5. Test Data Analysis

5.1. Dust
Under the full load condition, the operation condition of desulfurization system is spray layer “5 + 2” operation. Considering that the precipitator is an electric bag composite precipitator, adjust the bypass opening of the bag area of the precipitator to improve the flue dust concentration at the inlet of the desulfurization system. The distribution of flue dust and the cleaning efficiency of the desulfurization system are shown in figures 4 and 5. It can be seen that the higher the dust concentration at the inlet, the
higher the dust cleaning efficiency of the desulfurization system, especially the dust cleaning efficiency of the single tower of the secondary tower (equipped with tube bundle precipitator) is much higher than that of the first tower. According to the test results, for this project, when the flue gas concentration at the inlet is greater than 59 mg/m³, the effect of desulfurization system collaborative dust washing cannot reach the limit value of flue gas concentration at the inlet of chimney less than 5 mg/m³.

Under the condition of 50% load, when the flue gas concentration at the inlet of the desulfurization system is equivalent (14.2-15.2 mg/m³), the operation mode of the spray layer of the desulfurization system has a great impact on the dust cleaning efficiency of the desulfurization system, as shown in figures 6 and 7, four spray layers are also operated, and the dust cleaning effect of the second absorption tower increases with the number of spray layers of the second absorption tower. When the spray layer of the secondary tower exits completely, the limit value of smoke emission concentration at the inlet of the chimney less than 5 mg/m³ cannot be reached.

Figure 4. The distribution of dust in high-load conditions.

Figure 5. The cleaning efficiency of desulfurization system in high-load conditions.

Figure 6. The cleaning efficiency of desulfurization system in low-load conditions.
5.2. Droplet Content
As shown in Figure 8, as the load decreases, the flue gas flow rate in the tower decreases and the outlet droplet increases. Especially under the condition of low load, the droplet content increases greatly.

6. Conclusion
Through field test and data analysis, the following conclusions are drawn:

(1) The desulfurization system equipped with tube bundle precipitator has a high collaborative dust washing capacity under high load conditions. The higher the inlet dust concentration is, the higher the dust washing efficiency is. However, in order to realize the stable emission of dust concentration, the inlet dust concentration must be controlled below a certain concentration.

(2) Under the condition of low load, the efficiency of desulfuration and collaborative dust cleaning is obviously reduced. Even if the number of spray layers in operation of desulfuration system of cascade tower process is constant, the operation mode of spray layer also has a great influence on the overall dust cleaning efficiency of desulfuration system.

(3) It can be seen from the concentration of the droplets at the outlet of the desulfurization system that the concentration of the droplets increases with the decrease of the unit load.

(4) It can be seen from the comprehensive analysis that the tube bundle precipitator can remove the
fine smoke and dust together under the action of centrifugal force. As the operation load of the unit decreases, the flue gas flow rate decreases, and the centrifugal force effect decreases, resulting in the reduction of the overall collaborative dust washing capacity of the desulfurization system, which is also confirmed in the test.

Acknowledgments
The work is supported by Science and Technology Program of China Huadian Corporation Ltd. (No. CHDKJ17-01-55).

References
[1] Zhou H, Zhao L, Chen C and Li M 2015 Research on the technical route and industrial application of near-zero emission of coal-fired power plants supplied with Shenhua Coal Electric Power 48 (5) 89-92.
[2] Hu H 2014 Research of the domestic 600MW supercritical coal-fired units ultra in low emission of flue gas Electric Power Environmental Protection 30 (5) 8-11.
[3] Chen M, Hu Y and Gui B 2015 Synergistic control technology for ultra-low PM emission from coal-fired power plants and its application Electric Power 48 (9) 146-151.
[4] Chen Yang, Shao L and Tang Z 2015 Study on ultra-low emission reform scheme of 1000 MW coal fired unit Environmental Engineering 33 1026-1029.
[5] Mo H, Zhu F and Yi Y 2013 Application of WESP in coal-fired power plants and its effect on emission reduction of PM2.5 Electric Power 36 (11) 62-65.
[6] Zhang H, Zhou Y and Long H 2015 Study on application conditions of wet electrostatic precipitators in coal-fired power plants Electric Power 48 (8) 62-65.