The Application and Performance Evaluation of Condensing Dust Removal and Demisting Device Apply in Desulfurization System

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Abstract. In order to realize the ultra-low emission of flue gas in a 600 MW coal-fired unit, the original demister of desulfurization tower (two-stage ridge demister + one-stage tube demister) was transformed into a Condensing dust removal and demisting device. The Condensing dust removal and demisting device is composed of a three-stage ridge type high-efficiency mist eliminator and a condensing wet film layer. In addition, it is equipped with a cooling station outside the tower composed of a spray cooling water pump and a closed cooling equipment under 100% and 50% working conditions, by adjusting the operation mode of the cooling station and controlling the operation. The slurry droplet emission of the desulfurization system under different working conditions, the overall collaborative dust cleaning efficiency and the SO3 removal rate were tested on site. The test results show that the heat exchange of the cooling station has a great influence on the operation effect of the Condensing dust removal and demisting device, and improving the heat exchange of the cooling station is helpful to improve the removal effect of slurry drop, dust and SO3.

Keywords. Coal fired unit, flue gas desulfurization; condensing dust removal and demisting device; cooling station; collaborative dedusting; performance evaluation of collaborative removal.

1. Introduction
The “limestone gypsum” wet desulfurization process is widely used in the desulfurization system of domestic coal-fired units. The quality of the demister used in this process directly determines the slurry droplet concentration at the outlet of the desulfurization system [1-3], and indirectly determines the dust emission concentration [4-5]. With the increasingly strict environmental protection emission standards, it is very important to improve the removal rate of slurry droplets to reduce the level of dust emission of coal-fired units [6-9]. Relevant research shows that the optimized transformation of the demister can effectively improve the dust removal capacity of the desulfurization system [10-11]. And the emission requirements [12-17] can be achieved through the transformation of desulfurization and collaborative dust removal. Condensing mist eliminator is a new type of mist eliminator with dust removal function. It can directly reduce the dust concentration at the outlet of desulfurization absorption tower to less than 5 mg/m3 through desulfurization and Desulfurization synergistic dedusting.

2. Technical Principle of Condensing Demister
The centrifugal removal technology of condensing wet film is based on the formation principle of “fog” in the atmosphere, that is, the saturated wet flue gas after the spray layer enters the condensing

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wet film layer, the flue gas cools and cools down, and condensing water vapor is precipitated; the water vapor actively takes the fine dust and residual fog droplets as condensation nodules; the fine dust and residual fog droplets grow up; the growing dust and fog droplets collide on the corrugated plate, and are annihilated by the water film, so they are intercepted [18]. The diagram of the condensing mist eliminator is shown in figures 1.

The cooling device has two ways of cooling water, one is closed internal cooling water, which is used to absorb heat and cool flue gas; the other is open external cooling water, which circulates in the cooling equipment, which is used to cool the internal cooling water and transfer the heat in flue gas to the atmosphere in the form of indirect heat exchange. The cooling device is equipped with spray cooling water pump and closed cooling equipment. The layout of the condensing demister system is shown in figure 2.

Figure 1. The diagram of the condensing mist eliminator.

Figure 2. The layout plan of condensing mist eliminator system.

3. General Situation of Engineering Application
The dust precipitator of the 600 MW unit in a power plant is “3+1” type electric bag composite dust precipitator. The desulfurization device adopts “limestone gypsum” wet desulfurization process and “5” spray layer configuration. In order to realize the ultra-low emission of dust, the demister of absorption tower was reformed, and the original two-stage ridge type demister + one-stage tube type
The condensing mist eliminator is composed of a three-stage ridge type high-efficiency mist eliminator and a condensing wet film layer, and an external cooling device is added outside the desulfurization tower. The performance guarantee values of condensing demister are shown in Table 1.

### Table 1. Performance guarantee value of condensing mist eliminator.

| Project                                      | Numerical value |
|----------------------------------------------|-----------------|
| Inlet dust mass concentration (mg·m⁻³)       | ≥ 30            |
| Mass concentration of dust at outlet (mg·m⁻³) | < 5             |
| Dust removal rate/%                          | 83.33           |
| Mass concentration of droplet at outlet (mg·m⁻³) | 25              |

The investment and economic analysis of the desulfurization system demister renovation project is shown in Table 2. In the transformation of the project, in addition to the transformation of the demister, the desulfurization absorption tower body has been optimized. To improve the coverage of the spray layer, select efficient nozzles, further optimize the flue gas flow field in the absorption tower, etc. the investment cost in Table 2 is only for the part of the demister transformation. Compared with other types of mist eliminators, the retrofit cost of condensing precipitator is slightly higher.

### Table 2. Economical index of reconstruction of condensing mist eliminator.

| Project                                      | Cost          | Remarks                                                                 |
|----------------------------------------------|---------------|-------------------------------------------------------------------------|
| Mist eliminator reconstruction cost (Ten thousand yuan) | 850           | Including three-stage high-efficiency demister, condensation wet film and cooling station |
| Depreciation cost (Ten thousand yuan)        | 56            |                                                                         |
| Repair cost (Ten thousand yuan)              | 17            |                                                                         |
| Annual electricity cost (increment) (Ten thousand yuan) | 30            |                                                                         |
| Loan interest (Ten thousand yuan)            | 20            |                                                                         |
| Production cost + financial expense (Ten thousand yuan) | 122           |                                                                         |
| Increase the online electricity charge (excluding tax) (yuan/(MW·h)⁻¹) | 0.27          |                                                                         |

Note: The utilization hours of the unit are calculated as 4000 H; the depreciation life of the asset is considered as 15, the residual value rate is 5%, and the straight-line depreciation method of equal amount is used; the maintenance and deposit rate is 2%; the electricity price is calculated as 0.265 yuan/kwh; the above expenses are the investment expenses of a single unit.

### 4. Performance Test and Evaluation

#### 4.1. Test Condition

According to the technical agreement and relevant requirements of the transformation, the load rates of the test conditions are 100% and 50% respectively. During the test, the unit operates stably, the load fluctuation of the unit is not more than 5%, the desulfurization control system and main instruments operate normally, the indication is correct, and the spray layer of each tower of the desulfurization system operates normally.

#### 4.2. Test Items and Methods

**4.2.1. Dust Test.** At the inlet and outlet of the absorption tower, use the dust isokinetic sampling
instrument to sample according to the grid method. During the sampling process, record the sampling volume, temperature, static pressure and atmospheric pressure, and the weight of the filter membrane before and after the smoke sampling. Calculate the mass concentration of the smoke in the smoke according to the mass difference after weighing twice. Before and after the measurement, the filter heads were dried at 105 °C for 2 hours. The soot sampling device is shown in figure 3.

**Figure 3.** The diagram of sampling equipment of dust. Description: 1-sampling nozzle; 2-membrane bracket; 3-static 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.

The filter membrane bracket (see figure 4) is composed of a net bracket and a sealing ring supporting the filter membrane. The selected materials shall ensure that different flue gas conditions (temperature, humidity, pH, etc.) will not affect the measurement results.

**Figure 4.** The diagram of component of filterable membrane. Description: 1-sampling nozzle; 2-front elbow; 3-filter membrane; 4-mesh support; 5-sealing ring.

Dust removal efficiency. The deducting efficiency is calculated according to the following equation (1):

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

where: \( \eta \)-dust removal efficiency, %; \( C_{in} \)-dust concentration of flue gas at the inlet (standard state, dry basis, 6% O2), mg/m³; \( C_{out} \)-dust concentration of flue gas at the outlet (standard state, dry basis, 6% O2), mg/m³.

4.2.2. Slurry Droplet Sampling. Through the absorption device, the mist in the flue gas is absorbed on the inner wall of the droplet catcher by centrifugal force. The quality difference of the droplet catcher before and after sampling is the quality of the droplet. The mass concentration of the droplets was corrected by the ratio of the concentration of Mg\(^{2+}\) ions in the droplets and the slurry of the absorption tower. The droplet sampling device is shown in figure 5.
4.2.3. SO$_3$ Sampling and Calculation. The sampling device condenses SO$_3$ in the sampling gas with glass tube with water bath (figure 6). After sampling, wash the glass tube with deionized water to obtain the solution containing SO$_4^{2-}$, and calculate the SO$_3$ concentration in the flue gas according to the SO$_4^{2-}$ content in the solution.

\[
\eta_{SO_3} = \frac{C_{SO_3, \text{in}} - C_{SO_3, \text{out}}}{C_{SO_3, \text{in}}} \quad (2)
\]

where: \(\eta_{SO_3}\) is the removal efficiency of SO$_3$, \%; \(C_{SO_3, \text{in}}\) is the mass concentration of SO$_3$ in the inlet flue gas (standard state, dry basis, 6% O$_2$), mg/m$^3$; \(C_{SO_3, \text{out}}\) is the mass concentration of SO$_3$ in the outlet flue gas (standard state, dry basis, 6% O$_2$), mg/m$^3$.

4.3. Test Result
Adjust the closed circulating pump, spray water pump and cooling fan in the cooling station outside the condensing demister tower, and test the flue gas concentration at the inlet and outlet of the absorption tower, the SO$_3$ removal rate and the mass concentration of fog drop emission. The test results are shown in table 3. It should be noted that due to the low dust concentration at the outlet of the electrostatic fabric composite precipitator, it fails to reach the design value, which limits the test.

5. Test Data Analysis

5.1. Dust
Under 100% and 50% load, the dust washing efficiency of the condensing demister at different inlet smoke concentration of the desulfurization system is shown in figures 7 and 8.

It can be seen from figures 7 and 8 that in different load sections, the heat exchange output of the cooling station has a significant impact on the dust cleaning efficiency of the absorption tower. The larger the heat exchange is, the more water vapor is released from the flue gas, and the more significant the dust removal effect is. However, if only the internal cooling water pump is operated, the
heat exchanged by the internal cooling water cannot be transferred to the atmosphere and cannot play a role in cooling the flue gas. This mode is no different from the operation of the condensing demister.

Table 3. The result of test of dust, SO\(_3\) and slurry droplet.

| Item                              | 100% Load cond 1 | 100% Load cond 2 | 100% Load cond 3 | 100% Load cond 4 | 50% Load cond 1 | 50% Load cond 2 | 50% Load cond 3 | 50% Load cond 4 |
|-----------------------------------|------------------|------------------|------------------|------------------|----------------|----------------|----------------|----------------|
| Whether the internal cooling water is put into operation | Yes              | Yes              | Yes              | NO               | Yes            | Yes            | Yes            | NO             |
| Whether external cold water is put into operation | Yes              | Yes              | NO               | NO               | Yes            | Yes            | NO             | NO             |
| Whether the cooling fan is put into operation | Yes              | NO               | NO               | NO               | Yes            | NO             | NO             | NO             |
| Flue gas flow rate (m\(^3\)·h\(^{-1}\)) | 2091788          | 2122848          | 2017655          | 2021135          | 1368748        | 1299687        | 1272755        | 1284107        |
| Dust mass concentration (mg·m\(^{-3}\)) | Absorber inlet 21.5 | 19.7            | 18.4             | 18.7             | 16.1           | 13.9           | 14.3           | 15.5           |
|                                      | Absorber outlet  | 1.8             | 2.2              | 3.5              | 3.6            | 2.2            | 2.4            | 4.3            | 4.2            |
| Flue gas temperature at the outlet of absorption tower (°C) | 50               | 53               | 52               | 52               | 51             | 51             | 52             | 51             |
| SO\(_3\) mass concentration (mg·m\(^{-3}\)) | Absorber inlet 29.72 | 20.03          | 28.88            | 21.00            | 23.88          | 31.43          | 27.73          | 27.95          |
|                                      | Absorber outlet  | 15.02            | 12.77            | 19.06            | 16.13          | 13.75          | 18.59          | 18.08          | 18.14          |
| Mass concentration of droplets at the outlet of absorption tower (mg·m\(^{-3}\)) | 14.51          | 17.72            | 19.62            | 18.97            | 17.97          | 18.46          | 23.93          | 22.61          |
| Dust removal efficiency (%) | 91.75            | 88.84            | 81.08            | 80.63            | 86.57          | 82.79          | 69.71          | 73.15          |
| SO\(_3\) removal efficiency (%)  | 49.46            | 36.23            | 34.01            | 23.19            | 42.42          | 40.85          | 34.81          | 35.10          |

Note: Data in table 3 have been converted to standard state, dry basis and 6% O\(_2\) state.
Figure 7. Cleaning efficiency of desulfurization system in 100%-load conditions.

Figure 8. Cleaning efficiency of desulfurization system in 50% conditions.

5.2. Slurry Droplet

It can be seen from Figure 9 that with the increase of cooling station output, the condensing mist eliminator can effectively reduce the fog drop concentration at the outlet, and the load of the random group of slurry droplet concentration decreases with an upward trend. Based on the high-efficiency three-stage ridge demister, the condensing wet film is added to the condensing demister, while the ridge demister has a certain critical velocity, which will affect the demisting efficiency if the velocity is too high or too low [19].

Figure 9. The distribution of slurry droplet concentration in different conditions.

5.3. $SO_3$

Relevant research shows that the removal efficiency of $SO_3$ in flue gas by single tower WFGD is about 30%-40% (Figure 10). $SO_3$ adheres to the surface of fine particles and is removed with the removal of fine particles [20]. As the removal effect of fine particles decreases, the removal efficiency of $SO_3$ decreases. The results show that the condensing demister has a certain effect on the removal of $SO_3$ in the form of aerosols which cannot be removed by the desulfurization system, but the removal
efficiency is limited.

![Graph](image_url)

**Figure 10.** The removal rate of SO\(_3\) under different conditions.

6. Conclusion
The experimental results show that the desulfurization system equipped with condensing demister has a high capacity of collaborative removal of various pollutants on the premise of ensuring heat exchange. The higher the concentration of smoke at the inlet, the higher the efficiency of dust washing; with the reduction of unit load and heat exchange, the concentration of droplet emission is on the rise. In order to ensure high efficiency of dedusting and demisting, the heat exchange station outside the tower used together with the condensing demister must keep high output operation. At present, the application of condensing mist eliminator in desulfurization system is less, and the principle of saturated flue gas re cooling has some novelty, but its effect still needs to be further studied. The results of this paper can provide a reference for the ultra-low emission transformation of coal-fired units.

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