Efficient Coordinated Dust Removal Technology and Economic Analysis of Desulfurization System Under Ultra-Low Emission Situation

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Abstract. Base on the ultra-low emission reconstruction project of the 2×600MW unit desulfurization system in the Northwest China. The desulfurization system synergistic dedusting technology route achieves ultra-low emission of soot under the premise of maximizing the use of existing equipment. Through the comparison of the three-stage roof demister, Tube type dedusting and demisting device and condensing type dedusting and demisting device technology, the three-stage roof demister is stable, mature and reliable, and widely used. Under the same transformation conditions, the cost of the three-level roof demister is lower than the other two dust removal and demisting devices.

1. Introduction

According to the relevant requirements of the “Action plan (2014-2020)” issued by National Development and Reform Commission and National Energy Administration (NO 2093 in 2014)[1], dust emission limits of coal-fired power plants is 10mg/m³ (Standard). In order to avoid the emission standard upgrade again, mission concentration required by some generating units of soot to be 5 mg/m³ (standard). The dust concentration of some dust collectors is more than 20 mg/m³ (standard), if consider further improving the dust removal efficiency of the dust collector or constructing a new wet dust collector to achieve ultra-low emissions, it will result in large investment. The desulfurization efficient synergistic dust removal technology route [2-4] is gradually favored, because of it avoids new secondary dust removal equipment, reduces investment and operating costs [5].

This paper is aimed at the ultra-low emission reconstruction project of 2×600MW coal-fired units in Northwest China. Through technical analysis and economic comparison of three synergistic dust removal technologies for desulfurization systems, it provides a reference case of ultra low emission retrofit for similar units.

2. Description of collaborative dedusting technology in desulfurization system

The limestone-gypsum wet desulfurization process is the most widely and mature used flue gas desulfurization technology. Most domestic coal-fired units desulfurization devices use this process [6]. The slurry sprayed from top to bottom in the spray layer of the desulfurization system has a washing effect on the dust in the flue gas, and can remove part of the dust, but cannot be completely removed. The dust that escapes through the absorption tower mainly consists of two parts: one is the fine
particles that the absorption area of the absorption tower fails to capture, and the other is the slurry particles that are not intercepted by the mist eliminator.

The suction tower spray area is generally improved by adding gas-liquid contact devices (such as trays or chokes), which are in full contact with the droplets to improve the mass transfer effect. High-efficiency nozzles are used to improve the spray coverage and reduce the spray slurry particles. The diameter is increased to increase the contact area between the slurry and the dust. The gas collecting ring is arranged to reduce the escape of the flue gas along the tower wall. The flow field design of the absorption tower is further optimized according to the physical model and the digital model result [7].

After the flue gas passes through the spray layer, it continuously flows through the defogging zone to remove the slurry droplets. The main way to improve the efficiency of demisting area is to replace the high-efficiency dedusting and demisting device, it is ensured that the droplets at the absorption tower outlet of the absorption tower are not more than 20 mg/m³ (standard state). At present, the high-efficiency dust and mist removal device is mainly divided into a three-stage roof type demister, a tube bundle type dust removing and demister, and a condensing type dust removing and demister.

The relevant research indicates [8-11] that the solid content of the desulfurization slurry outlet droplet is at a high level. The solid content in the droplets contributes a large amount to the concentration of the dust, which reduces the dust removal efficiency of the desulfurization system. For units with lower inlet dust concentration, the effect of the slurry droplets on the dust concentration is greater. Therefore, the optimized modification of the mist eliminator can effectively improve the dust removal capacity of the desulfurization system.

This paper analyzes the technical and economic analysis of three different high-efficiency dust removal and demisting devices.

3. High-efficient dust removal and demisting device

3.1. Three-stage roof demister
The three-stage roof demister consists of a three-level herringbone demister and six layers of flushing water. The first stage demister is coarse defogging, the second and third stage demisters are fine mist removal, the blade shape is sinusoidal, and the blade type is streamlined 2-channel intermediate barb.

Under the premise of reasonable flow rate of the absorption tower, the appropriate demister area is arranged. The net surface flow rate of the demister is indirectly controlled, thereby obtaining the ideal limit particle size separation effect. And ensuring that the slurry droplets at the exit of the demister is not more than 20 mg/m³ (Standard), which greatly reduces the amount of gypsum carrying. At the same time, the high-efficiency demisters can intercept solid particles in the slurry droplets and reduce the contribution of particulate matter in the slurry droplets to dust.

3.2. Tube bundle dust and mist removal device
The upper part of absorption tower is equipped with tube bundle type dust removal and mist removal device, which is composed of speed increaser, separator, guide ring, confluence and internal tube bundle. Under the high-speed gas separator, the liquid droplets are continuously trapped by the high-speed gas flow and the liquid droplets are continuously trapped by the high-speed gas separator. Under the action of high-speed air flow, the phenomenon of "water dispersion" occurs. Large droplets are removed from the blade surface due to centrifugal force, and small droplets form into large droplets, and large droplets are removed by centrifugal force, so as to realize the removal of liquid drops in flue gas. The flue gas concentration at the outlet of the absorption tower is not higher than 5mg / m³, and the droplet content at the outlet is not higher than 20mg / m³.

3.3. Condensing dust removal and demisting device
The main device is divided into two systems in the absorption tower and outside the absorption tower. The high efficiency mist eliminator, the condensing wet film centrifugal separator and the ultrafine
separator are arranged in the absorption tower, and the circulating water cooling system is arranged outside the absorption tower.

The saturated wet flue gas passes through the high-efficiency demister, 80% ~ 90% of the droplets are removed, the residual droplets are small particles, and the flue gas is effectively rectified; the flue gas is further cooled by the condensing separator (the temperature drop of flue gas is no more than 1°C), so a large amount of water vapor is generated. The generated water vapor takes the dust as the condensation nodule, and the residual droplets and dust are wrapped by a large amount of water vapor to form large droplets. When these long droplets pass through the specially designed curved flow channel, great centrifugal force is generated, and the droplets are thrown on the surface of the corrugated plate covered with a layer of water film, so as to intercept the dust and fog drops. The concentration of dust at the outlet of the absorption tower is not higher than 5 mg/m$^3$ (standard), and the slurry droplet content of the outlet is not higher than 20 mg/m$^3$ (standard).

4. Comparison of three high-efficiency dust removal and demisting devices

According to relevant research, the dedusting efficiency of the desulfurization system is generally not high, and has a great relationship with the inlet dust concentration [11]. High inlet dust concentration, high desulfurization and dust removal efficiency. For low concentration and fine particle dust, no matter whether it is single tower or double tower desulfurization system, the desulfurization and dust removal efficiency is low [12].

This paper is aimed at the ultra-low emission reconstruction project of 2×600MW coal-fired unit in Northwest China. Two “1+3” type electric bag composite dust collectors are installed in a single unit. At present, the dust concentration at the outlet of the dust collector is controlled at 20 mg/m$^3$(standard) or less. In order to achieve ultra-low emission, improve the dust removal efficiency of the desulfurization system. Under this premise, technical comparisons were made among three high-efficiency dust removal and demisting devices. The main design parameters of the reconstruction project are shown in Table 1 Comparison of three high-efficiency dust removal and demisting devices are shown in Table 2.

### Table 1. design parameters

| No | Item Name                                      | Unit | Parameter  |
|----|-----------------------------------------------|------|------------|
| 1  | FGD inlet Flue gas components                 |      |            |
| 1.1| Flue gas volume (standard, wet basis, actual O$_2$)  | m$^3$/h | 2413878    |
| 1.2| FGD process design Flue gas temperature       | °C   | 140        |
| 2  | FGD outlet Flue gas components                |      |            |
| 2.1| H$_2$O (standard, wet basis, actual O$_2$)     | Vol% | 9.52       |
| 2.2| N$_2$ (standard, dry, actual O$_2$)            | Vol% | 72.34      |
| 2.3| CO$_2$ (standard, dry, actual O$_2$)           | Vol% | 12.5       |
| 2.4| SO$_2$ (standard, dry, actual O$_2$)           | Vol% | 0.15       |
| 2.5| O$_2$ (standard, dry, actual O$_2$)            | Vol% | 5.49       |
| 3  | Concentration of pollutants at the entrance of FGD (standard state, dry basis, 6% O$_2$) |      |            |
| 3.1| SO$_2$ (standard state)                        | mg/m$^3$ | 4200     |
| 3.2| dust concentration (standard state)            | mg/m$^3$ | 20        |

4.1. Load applicability

The load of the random group fluctuates, and the amount of flue gas at the inlet of the desulfurization system changes greatly, causing the flow velocity in the tower to change. According to the operation
principle of three kinds of dust removal and demisting devices, three-stage roof demister has a certain critical flow rate, and the flow rate is too high or too low, which will affect the demisting efficiency [13]. Usually, the design flow rate of the demister is adjusted to avoid the change of flow rate as much as possible. The impact can be achieved at full load; The tube bundle dedusting and demisting device uses the centrifugal force of the flue gas to remove the dust and slurry droplets in the flue gas. The flow velocity of the low load is reduced, the centrifugal force is reduced, and the dedusting and demisting effect is obviously reduced. Some project companies have tried to arrange the electric regulating device at the inlet of the tube bundle dedusting and demisting device. Close some of the flue gas passage through the electric regulator to improve the flow rate of the flue gas during low load, but this method greatly improves the system resistance and is not worth the loss. The condensing dust removal and demisting device is developed based on the roof type demister. The condensing device is installed between the two-layer roof demister, and the load adaptability is compared with the conventional three-stage roof demister. Consistent, but if the flow rate is too fast, the water particles deposited in the flue gas will further carry the slurry droplets to escape.

4.2. Reconstruction quantity
Make a Comparison of reconstruction quantity of three kinds of high efficiency dedusting and demister. The main work of the roof type demister is concentrated in smooth optimization. The reformatio of the tube bundle type dust removal and demist device is relatively simple, use the tube bundle type condensation dedusting and demisting device instead of original demister. And adjust the arrangement position of the demister flushing water. The condensing dust removing and demisting device also removes the condensing dust removing and demisting device of the original demister, and the spray layer of the desulfurization system needs to be optimized, and a new set outside the tower is needed. The external cooling device is equipped with two channels of cooling water, and is equipped with a circulating pump, a spray pump and a cooling fan. The system is complicated. In contrast, if the demister is modified separately, the condensing dust removal and demisting device has the largest amount of engineering work, the tube bundle type is relatively low, and the roof type is the lowest.

4.3. Scope of application
Achieve the dust concentration emission lower than 5 mg/m³ (standard), the three dust removal and demisting devices have different application scopes. Three-stage roof demister is stricter on the inlet dust concentration, and the applicable dust concentration is not more than 20 mg/m³ (standard, dry basis, 6% O₂). Tube bundle dust removal and demisting device has a relatively large concentration of dust at the inlet, which can meet the single-tower inlet dust concentration of not more than 35 mg/m³(standard state), and the double-tower inlet dust concentration is not more than 50 mg/m³ (standard State). But the running stability under low load conditions is not satisfactory. With the decrease of flue gas flow rate, the particle Brownian motion effect is greater than the inertial motion, the particle trajectory is unstable, easy to pass through [14]. If the full load section is required to achieve ultra-low emission, the flue gas concentration at the inlet shall be further controlled. The condensation dedusting and demisting device can meet the inlet dust concentration below 30 mg/m³ (standard), but its application cases are less. There is not enough performance to prove its long-term stable operation reliability.
**Table 2.** Comparison of three kinds of dust removal and defogging device

| No. | Contents                  | High-efficiency three-stage roof demister | Tube bundle dust removal and demisting device | Condensing dust removal and demisting device |
|-----|---------------------------|-------------------------------------------|---------------------------------------------|---------------------------------------------|
| 1   | Technology maturity       | mature                                    | mature                                      | mature                                      |
| 2   | Coal species adaptability | Wide range                                | Wide range                                  | Wide range                                  |
| 3   | Load adaptability         | Full load                                 | Medium and high load effect                  | Full load                                   |
| 4   | absorption tower outlet droplets (mg/m³) | ≤20                                       | ≤20                                         | ≤20                                         |
| 5   | Resistance (Pa)           | 200-350                                   | 500-800                                     | 350                                         |
| 6   | water consumption         | High                                      | Low                                         | High                                        |
| 7   | Market share              | High                                      | Higher                                      | Lower                                       |
| 8   | Project cost              | Higher                                    | High                                        | High                                        |
| 9   | Arrangement of the tower  | In the tower                              | In the tower                                | In the tower + Outside the tower            |
| 10  | Renovation period         | 60d                                       | 45d                                         | 60d                                         |
| 11  | Inspection and maintenance| less                                       | less                                        | More                                        |
| 12  | application performance   | Many                                      | Many                                        | Rarely                                      |

5. Analysis of economic indicators of reconstruction

The economic indicators for the ultra-low emission reconstruction project of the 2×600MW unit desulfurization system of a power plant are shown in Table 3. For the desulfurization system of this project, a secondary absorption tower is needed, and the original absorption tower is not used as a primary absorption tower for transformation. Therefore, the difference in investment costs of the three transformation routes is mainly reflected in the demister and supporting transformation. As can be seen from Table 3.

**Table 3 Economic index of project**

| project                     | unit  | High-efficiency three-stage roof demister | Tube bundle dust removal and demisting device | Condensing dust removal and demisting device |
|-----------------------------|-------|-------------------------------------------|---------------------------------------------|---------------------------------------------|
| Engineering static investment demister transformation | 10000yuan | 9553                                      | 10812                                      | 10386                                      |
| Depreciation                | 10000yuan | 621                                       | 703                                        | 675                                        |
| Repair fee                  | 10000yuan | 191                                       | 216                                        | 208                                        |
| Annual electricity cost      | 10000yuan | 616                                       | 822                                        | 672                                        |
| (increment)                 | 10000yuan | 213                                       | 241                                        | 231                                        |
| Loan interest               | 10000yuan | 1640                                      | 1981                                       | 1786                                       |
| Production cost + financial expenses | 10000yuan | 3.27                                      | 3.95                                       | 3.56                                       |
| Increase on-grid electricity bill (excluding tax) | yuan/MWh | 3.27                                      | 3.95                                       | 3.56                                       |

6. Reconstruction effect

There are many reconstruction cases of three-stage ridge demister, relatively few of tube bundle and
condensing demister. Some of them are shown in Table 4. It can be seen from table 4 that three kinds of high-efficiency dedusting and demister can achieve better dedusting effect in the application of different types and capacity units. This paper only discusses the application of High-efficient dust removal and demisting device in China, but not in foreign countries.

Table 4 The dedusting effect at different units based on the dust concentration at the chimney inlet (standard, dry basis, 6% O₂)

| Unit number | Unit capacity/MW | reconstruction technology route                                   | before reconstruction | after reconstruction |
|-------------|------------------|-------------------------------------------------------------------|-----------------------|---------------------|
| A           | 200              | Tube bundle dust removal and defogging device                     | 23                    | 4.2                 |
| B           | 330              | High-efficiency three-stage roof demister                         | 90                    | 8                   |
| C           | 330              | Condensing dust removal and defogging device                      | /                     | 3.7                 |
| D           | 600              | Tube bundle dust removal and defogging device                     | 10                    | 3.9                 |
| E           | 670              | Tube bundle dust removal and defogging device                     | 18                    | 4.5                 |
| F           | 660              | High-efficiency three-stage roof demister                         | 40                    | 3.6                 |
| H           | 600              | Condensing dust removal and defogging device                      | /                     | 2.2                 |
| I           | 1000             | High-efficiency three-stage roof demister                         | 32                    | 4.2                 |
| J           | 1000             | High-efficiency three-stage roof demister                         | 14                    | 4.3                 |

7. Conclusion
According to the technical and economic comparison of the High-efficient dust removal and demisting device, they all can meet the requirements of power plant dust emission concentration, but each of them has advantages and disadvantages.

(1) Three-stage roof demister technology route has many application performances in China. Although there are certain requirements for the inlet dust concentration, most of the electrostatic precipitator or electric bag dust collectors can meet the requirements of the dust concentration.

(2) The technical route of the tube bundle type dust removal and demisting device mainly relies on the inertial force to achieve ultra-low emission of dust. It has certain application performance and wide application range. However, when the unit operating load is low, the inlet dust concentration needs to be further controlled.

(3) The technical route system of the condensation dedusting and demisting device is more complicated, and the operation control has certain difficulty, and the relative transformation engineering quantity is relatively high. And the related production performance is less, there is not enough performance to prove the reliability of its long-term stable operation.

(4) Through desulfurization system synergistic dedusting technology to achieve ultra-low emission of dust has been in-depth research, new technology applications are also emerging. According to different needs of different engineering projects and characteristics of different technical routes, appropriate transformation schemes should be selected to achieve the best effect.

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