Operation Performance and Economic Efficiency Analysis of Power Plant Boilers Ultra-low Emission Facilities

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Abstract. In this paper, four units of a power plant are taken as the research object, and the air pollutant emission performance standards, equipment installed economic efficiency, operational economic efficiency and energy saving potential of four units using different technical methods for ultra-low emission transformation are analyzed. Take unit 4 as an example, the ultra-low emission operation cost is discussed. The results show that the operation performance, stability and reliability of some units of low-temperature economizer need to be improved; the K values of different ultra-low emission technology methods were between 7.6~12kW/MW. The installation of a low temperature economizer allows the wet desulfurization facility to have a greater water saving capacity.

1. Introduction
Coal, accounted for 64% China's total energy consumption in 2015, is a basic energy source in China in the next long period of time [1]. From the perspective of safety and economic efficiency, coal has the irreplaceable advantage compared with other energy sources. Using coal for thermal power generation and industrial boiler combustion is a major part of China's coal consumption. The pollution generated during coal combustion is the key issue in coal utilization, which is an important source of emissions affecting environmental quality, and ultra-low emission of coal-fired pollutants will play a positive role in reducing the total amount of pollutants discharged, improving the ecological environment and boosting the efficiency of coal clean utilization [2-4].

With the upgrading of boiler air pollutant control technology, especially the promotion of ultra-low emission technology, the technical selection of pollutant control and its economic analysis of construction and operation are still insufficient. Economic analysis of boiler air pollutant control technology is of great significance to the selection and evaluation of environmental protection process routes [5-6].

Based on the research on the operating parameters and energy consumption data of coal-fired power station boilers, this paper compares and analyzes the performance indicators and energy consumption data of different transformation technology methods, studies the economic efficiency of different process routes and the potential of energy saving and consumption reduction, and provide reference for the selection of process routes and improve the economics of system operation.
2. Operational evaluation of ultra-low emission environmental protection facilities

2.1 Performance compliance analysis

2.1.1 Analysis of the standard of dry electric dust removal

![Fig. 1 Dust emission indicators of electrostatic precipitators in each unit](image1)

Figure 1 shows the dust concentration at the outlet of the electrostatic precipitator (desulfurization tower inlet) under different load conditions. After the high-frequency power supply is modified, the outlet concentration of the electrostatic precipitators of each unit is stable to reach the standard of < 20mg/Nm$^3$. The average concentration of smoke and dust at the outlet of the four units of electrostatic precipitators was 17.1/11.5/13.3/12.1mg/m$^3$, as shown in Figure 2.

![Fig. 2 The average value of the outlet smoke and dust concentration of the electrostatic precipitator after the ultra-low emission reform](image2)

Figure 3 shows the inlet flue temperature of the desulfurization tower under different loads after the low-temperature economizer is put into operation. After the economizer is put into operation, the flue temperature drops to 100 °C ~ 130 °C, and the system temperature of the 1# unit, 2# and 3# is about 100 °C, and unit 4 # system temperature is between 90 °C to 130 °C, which have the effect of reducing the temperature of the smoke. 1# unit, 2# system temperature is relatively stable, 3# unit, 4# system temperature fluctuation is large. Especially 4# unit, which performance stability needs to be improved.
2.1.2 \( \text{SO}_2 \) emission standard analysis

Figure 4 shows the \( \text{SO}_2 \) concentration at the inlet and outlet of four units. It can be seen from the figure that the \( \text{SO}_2 \) concentration at the outlet of the desulfurization tower is stable to reach the emission standard of 35mg/Nm\(^3\). The above four technical routes can stably reach the technical requirements of ultra-low emission.

2.2 Analysis of Installed economic efficiency

2.2.1 Comparison of installed capacity of desulfurization systems with different process routes
Taking the 1# unit as an example, the power consumption of the desulfurization system is analyzed (without the pulping part), and the installed capacity of the desulfurization system is as shown in
Figure 5. From the figure, in the system installation, the circulating pump, the oxidation fan, the vacuum pump and the slurry disturbance pump. The power ratio is about 89%, which is the most important part of the energy consumption of the desulfurization system, and is also the main starting point for system economic analysis and energy saving.

![Fig. 5 Desulfurization system equipment installed capacity ratio](image)

The desulfurization tower transformation plans of the first stage two units (1#, 2#) and the second stage two units (3#, 4#) are the same. The main equipment installation of the desulfurization system is shown in Figure 6. Comparing these two desulfurization system transformation plans, the installed capacity of the first stage (350MW) system is about 11% higher than that of the second stage, but the installed capacity of the first stage ultra-low emission technology route is about 35% higher than the second stage.

![Fig. 6 Main equipment installed capacity of different process routes](image)

2.2.2 Comparison of installed capacity of different process wet dust collectors
The power consumption of the wet electrostatic precipitator is mainly the power consumption of the power supply. Its energy consumption accounts for more than 92% of the energy consumption of the wet dust removal system. Compared with the three units of wet electrostatic precipitators (as 3# unit is not equipped with wet electricity), the system power consumption is shown in Figure 7. As can be seen from the figure, the installed capacity of the 1# unit power supply is the smallest, the 2# unit has the installed capacity nearly double that of the 1# unit, and the 4# unit is between the two.
2.2.3 Comparison of desulfurization and wet dust collector total installed capacity

The total installed capacity of the integrated desulfurization and wet electrostatic precipitator system, the total installed capacity of the four units is shown in Figure 8. As can be seen from the figure, since the 3# unit is not equipped with a wet electrostatic precipitator, its installed capacity is significantly lower than other units. Among the three units of wet electricity installed, the installed capacity of the 2# unit is the highest due to the high installed capacity of the wet electric power. Among these three units, the total installed capacity of the 4# unit is the lowest. The main reason is that 4# unit has one less spray layer than 1# unit, which makes the total installed capacity decrease obviously.

Since the power generation capacity of the first and second stages is slightly different, the first stage is 350MW and the second stage is 315MW. Therefore, the unit installation K value can be used as the measurement index. The calculation formula is as follows:

\[ K = \frac{Environmental\ protection\ installed\ capacity}{Power\ generation\ capacity} \]

\[ (Desulfurization + Wet\ dust\ collector) \]

Fig. 7 Power supply capacity of different units of wet electrostatic precipitator
(1#, 2# are 350MW, 3#, 4# are 315MW)

Fig. 8 Total installed capacity of main equipment of different units (kW)
The K value of the unit installed in different units is shown in Figure 9. The K value of the unit installed in 4 units of ultra-low emission system is between 7.6~12kW/MW, of which the unit installed capacity in 2# unit is the largest, about 12kW/MW. Since 3 # unit does not install wet electricity system, its unit installed is smallest, about 7.5kW / MW.

2.3 Analysis of operational economic efficiency and energy saving potential of ultra-low emission facilities

The operation of the desulfurization facility is the final indicator for measuring the energy consumption of the facility. By analyzing the operational parameters of the facility, the economics of the technical route of the environmental protection facility is investigated. The operation of the desulfurization system is mainly related to the flue gas flow rate and the SO2 content in the flue gas, that is, the imported SO2 flow rate M:

\[ M \text{ (kg / h)} = \text{smoke volume (Nm}^3 / \text{h}) \times \text{SO}_2 \text{ concentration (kg / Nm}^3) \]

2.3.1 Analysis of circulating pump operation economy and energy saving potential

The operating power of the first stage (1#, 2#) and the second stage (3#, 4#) circulating pumps are analyzed. The actual operation of the first stage is shown in Figure 10 (taking 1# as an example). The inlet SO2 mass flow M mainly between 300kg / h to 1300kg / h. In most working conditions, the M value is between 500kg/h to 1200kg/h, three circulating pumps are turned on, and two or four circulating pumps are turned on under a few working conditions.

![Fig.10 1# unit circulating pump power under different working conditions](image)

The second stage (taking 3# as an example) shows the actual operating conditions as shown in Figure 11. The inlet SO2 mass flow M is mainly between 200kg/h and 1100kg/h. Under most working conditions, the M value is between 300kg/h and 1000kg/h, two circulating pumps are turned on, and
three circulating pumps are turned on under a few working conditions.

It can be clearly seen from Figure 10 and Figure 11 that there is no obvious SO$_2$ flow limit for the switching of the circulating pump. Taking 3# unit as an example, under the same inlet SO$_2$ mass flow rate M, there are a lot of operating condition points with 2 pumps and 3 pumps working, and the number is a huge amount. The same problem exists in the 1# unit. That is to say, the running of the circulating pump still has room for optimization. Under the condition that the 2 (or 3) pumps working can reach the standard, the new circulating pump should be no more put into operation, thus having the potential of energy saving.

In order to compare the energy consumption characteristics under different technical routes, the energy consumption of the two units under the same M value is analyzed, as shown in Figure 12:

According to the different inlet SO$_2$ mass flow in Figure 12, the main points of the circulating pump energy consumption of each unit are summarized: from the operational point of view, the two process routes have advantages in certain intervals in different SO$_2$ flows. When the SO$_2$ flow rate is low (or higher), the 1# technical route with 4 circulating pumps is more advantageous because the
adjustment is more flexible. When the M value is between 550mg/m$^3$ to 850mg/m$^3$, the technical route of the 3# unit has relative advantages.

2.3.2 Analysis of energy saving potential of oxidation fan

The concentration of imported SO$_2$ in the first and second stage desulfurization systems is 2000mg/Nm$^3$ and 1650 mg/Nm$^3$ respectively, while the maximum SO$_2$ concentration in actual operation is 1300mg/Nm$^3$ and 1100mg/Nm$^3$, respectively, which is only 65% and 67% of the design value. As the oxidation fan of the desulfurization system installed in the machine, which is second only to the circulating pump, it is currently operated at constant speed, that is, it maintains constant speed and constant power operation under all working conditions. Therefore, under the condition of ensuring sufficient oxidation, the oxidation fan has a huge potential for energy saving and consumption reducing.

2.4 Analysis of low temperature economizer for reducing desulfurization tower water consumption

In the process of wet desulfurization, a large amount of water is evaporated, which is an important part of the water consumption of coal-fired power plants. The low-temperature economizers installed in the units studied in this project will reduce the temperature of flue gas before desulfurization from 150 °C to 110 °C. In actual operation, the temperature of the desulfurization inlet flue gas is about 100 °C, which is beneficial to the improvement of the efficiency of the downstream electrostatic precipitator, reduce the flue gas temperature, the flue gas volume of the desulfurization tower and the flue gas temperature, which is beneficial to the improvement of the desulfurization efficiency and the reduction of the water evaporation, taking the 1# unit as an example (under full load), the evaporation water volume of the desulfurization tower at different inlet temperatures of the flue gas is shown in Figure 13.

![Fig. 13 Evaporation water volume of desulfurization system under different flue gas inlet temperature conditions under full load](image)

After installing the low-temperature economizer in front of the electrostatic precipitator, the evaporation water volume of the full-load desulfurization tower is reduced from 75m$^3$/h to 40m$^3$/h, which is reduced by about 40%. Therefore, the use of front-end cooling method is an excellent water-saving measure.

3. Analysis of operating expenses of ultra-low emission facilities

Taking the 4# unit as an example, the installed capacity of the 4# unit ultra-low emission facility is about 3000kW (desulfurization + wet dust removal), and the newly installed capacity is about 1000kW (wet dust removal + fan power increase caused by new system resistance), annual operation time 4200h (China Electricity Council: the average utilization hours of firepower equipment in 2016). The
electricity price is calculated according to the on-grid price, and the operating cost is increased at full load.

\[ 1000\text{kw/h} \times 4200\text{h} \times 0.045\text{ yuan/degree} = 189000\text{ yuan} \]

Which operating costs only increase less.

The power generation capacity in 2016 is shown in Figure 14. The average power is 224MW. According to the Notice on Relevant Issues Concerning the Implementation of the Support Policy for Ultra-Low Emission Electricity Price of Coal-Fired Power Plants, the price raise of the purchase of on-grid electricity is 0.01 yuan/kWh, and the annual operation time is 4200h. Annual subsidy fee

\[ 224000\text{ degrees/h} \times 4200\text{h} \times 0.01\text{ yuan/kWh} = 9408,000\text{ yuan} \]

The subsidy fee can better subsidize the construction cost of ultra-low emission facilities.

4. Conclusion

Based on the research on ultra-low emission retrofit technology and on-site investigation, the actual operating parameters and economics of the ultra-low emission reform project of coal-fired power plants were analyzed. The main conclusions are as follows:

1. After installing the low-temperature economizer and electrostatic precipitator in front of the electrostatic precipitator, the original flue gas temperature is significantly reduced, and the electrostatic precipitator can stably reach the design index of 20mg/m^3. Performance, stability and reliability of some units operate at low temperature economizer still need to be improved.

2. The process route adopted in the survey can stably reach the SO2 ultra-low emission standard with an export concentration of 35mg/m^3, and the current technical level can stably meet the existing standard requirements.

3. The total installed capacity of different ultra-low emission technology methods has a large difference. The unit installed K value of different units is between 7.6~12 kW/MW. Among them, the total installed economics without wet circuit line is the best. Dust removal technology can ensure that the dust is up to standard, try not to install a wet electrostatic precipitator.

4. In the operation of ultra-low emission facilities, the economical operation of the system has a large optimization space; the operation time of the circulating pump still has optimization space, and the system energy consumption has great potential for saving; the first and second stages of desulfurization are extremely low. The emission of the two process routes has their own advantages in
different inlet SO$_2$ concentration ranges at different SO$_2$ flow rates.

(5) Since the actual operating parameters of the facility are much lower than the design parameters, the oxidizing fan operating at constant speed still has a large energy saving potential.

(6) The installation of the low temperature economizer enables the wet desulfurization facility to have a large water saving capacity.

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