Optimization design of flue gas temperature for Low-Low Temperature Electrostatic Precipitator

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Abstract. Low temperature corrosion is one of the key issues in application of low-low temperature electrostatic precipitator. The concentration of SO₃ affects the acid dew point temperature of flue gas. The exhaust temperature after the air preheater should be higher than the acid dew point temperature. The residual heat of flue gas is fully utilized by the low-temperature economizer. The efficiency of low-low temperature electrostatic precipitator is improved by the comprehensive effect of the condensation of SO₃ on the surface of the fine particles, the decrease of the specific resistance of the particles and the agglomeration of the fine particles.

1. Introduction
In accordance with the requirements of ultra-low emission standards, the particle emission limit of ultra-low emission needs to reach the emission limit of 10mg/m³, and the emission limit of 5mg/m³ in some areas. The traditional electrostatic precipitator can collect more than 99.9% of the large particles in coal-fired flue gas with limited removal efficiency of submicron-based fine particles. The low-low temperature electrostatic precipitator (LLT-ESP) has some advantages in the aspects of energy conservation and environmental protection [1].

LLT-ESP is different from the traditional electrostatic precipitators. The heat exchange system is installed in front of the electrostatic precipitator. The temperature of the flue gas entering the electrostatic precipitator is reduced below dew point temperature of the flue gas. At this temperature, most of the SO₃ in the flue gas condenses into sulfuric acid mist. Sulfuric acid mist is adsorbed and removed with particles [2, 3].

In this paper, the characteristics of SO₃ generation and conversion in coal-fired power plants were introduced. The dew point temperature of flue gas was calculated. The applicability of low temperature economizer and corrosion protection mechanism were discussed.

2. Introduction of the unit and fuels
A 660 MW ultra-supercritical coal-fired unit is an ultra-low emission unit. The equipment behind the boiler are arranged in order, Selective catalytic reduction denitrification system (SCR)-air preheater (APH)-low temperature economizer (LTE)-low-low temperature electrostatic precipitator(LESP)- Wet flue gas desulfurization (WFGD)- Wet electrostatic precipitator (WESP)-chimney. The flow chart is shown in Figure 1.
The fuels burned are mainly bituminous coal. The industrial analysis and elemental analysis of the coal samples used in the boiler are shown in Table 1.

| Number | Sample 1 | Sample 2 | Sample 3 |
|--------|----------|----------|----------|
| Car (%)| 50.45    | 57.02    | 55.89    |
| Har (%)| 2.48     | 3.27     | 3.10     |
| Oar (%)| 4.35     | 5.68     | 5.96     |
| Nar (%)| 0.66     | 0.74     | 0.63     |
| Sar (%)| 0.65     | 0.7      | 0.92     |
| Aar (%)| 34.41    | 23.09    | 24.70    |
| Mar (%)| 7.0      | 9.5      | 8.8      |
| Mad (%)| 1.7      | 2.13     | 2.58     |
| Vdaf (%)| 30.70  | 32.87    | 32.25    |
| Qnet,ar(kJ/kg)| 18420 | 21470    | 20910    |

3. Results and discussion

3.1. Changes in SO$_3$ concentration in flue gas

The SO$_3$ in the flue gas is mainly derived from the boiler combustion and denitrification system. Combustible sulfur in coal is converted into sulfur dioxide (SO$_2$) during combustion, and 0.5% to 2.0% of SO$_2$ continues to be oxidized to form SO$_3$ at high temperatures. Some substances play catalytic role in the conversion of SO$_2$ to SO$_3$, such as suspended fly ash, ash accumulation on the pipe wall and metal oxides such as V$_2$O$_5$, Fe$_2$O$_3$, SiO$_2$ and Al$_2$O$_3$ contained in the pipe wall.

At present, the most widely used in the SCR denitrification system is a vanadium-titanium catalyst, which also promotes the conversion of SO$_2$ to SO$_3$ during catalytic reduction of NOx. In a unit burning low-sulfur coal, the SO$_3$ concentration in the flue gas is about $10^{-6}$, while the high-sulfur coal can make the value can reach $30 \times 10^{-6}$~$40 \times 10^{-6}$ or even higher.

After the flue gas leaves the SCR denitrification system, SO$_3$ in the flue gas reacts with a fraction escapes NH$_3$ to form ammonium bisulfate (ABS) in the air preheater. The concentration of SO$_3$ in the flue gas is reduced. In the LLT-ESP, SO$_3$ and water vapor in the flue gas generate sulfuric acid mist as the temperature decreases, and the concentration of SO$_3$ in the flue gas is further reduced [4].

3.2. Calculation of the acid dew point temperature

Low temperature corrosion issues must be taken seriously in LLT-ESP applications. The acid dew point temperature of flue gas is the main basis for the design of the inlet flue gas temperature of LLT-ESP. One method for determining the acid dew point temperature of the flue gas is calculated by a thermodynamic method, and the other method is measured by an acid dew point meter[5-7].

The measurement mechanism of the acid dew point temperature is complicated by the instruments[8]. When a conductive acid dew point meter or probe is used to directly measure the acid dew point, the sensor is easily contaminated by fly ash in the flue gas, and which makes some error to the measurement results. The concept of engineering acid dew point is proposed as a new criterion for the limit of boiler waste heat utilization at low temperature[9].

The thermodynamic method is used widely for determining the acid dew point[10-11]. At present, various calculation formulas are compared comprehensively. The Muller curve is the basis for
evaluating various methods of acid dew point temperature[12]. Considering the effect of ash and sulfur content on the acid dew point temperature, various more precise acid dew point temperature calculation formulas are proposed. The acid dew point temperature in this paper was calculated according to the following formula[13].

\[ t_d = t_{sl} + \frac{1.1 \beta^{10/\sqrt{x}}}{1.05^\alpha h \times 4182} \]  

(1)

\( T_{sl} \) is the pure water vapor dew point temperature, calculated according to the following formulas.

\[ t_{sl} = -1.2102 + 8.406 \varphi_{H2O} - 0.4749(\varphi_{H2O})^2 + 0.0104(\varphi_{H2O})^3 \]  

(2)

\[ s^x = \frac{s_{ar}}{q_{net,ar}} \times 4182 \]  

(3)

\[ A^x = \frac{A_{ar}}{q_{net,ar}} \times 4182 \]  

(4)

\( \varphi_{H2O} \) is the volume fraction of water vapor in the flue gas, and the values of other parameters are shown in Table 2.

| parameter       | \( \varphi_{H2O}(\%) \) | \( A_{th} \) | \( \alpha \) | \( \beta \) |
|-----------------|--------------------------|-------------|-------------|-------------|
| Value           | 5.02%                    | 0.9         | 1.2         | 121         |

According to the above data, the calculation results of the acid dew point of the three coal samples in Table 1 are 108.34°C, 119.85°C and 120.80°C, respectively. Comparing the above data, it can be seen that as the S content of the fuel samples increases, the acid dew point temperature of the flue gas increases gradually.

3.3. Optimization design to prevent low temperature corrosion

The acid dew point of flue gas is an important factor that restricts deep waste heat recovery technology. Accurate prediction of the value is important for avoiding low temperature corrosion, reducing heat loss of flue gas and improving boiler efficiency.

The lower the boiler exhaust temperature, the higher the boiler efficiency. However, too low exhaust temperature can increase the trend of low temperature corrosion of the air preheater and downstream equipment. The sulfur content in the coal used in the unit is between 0.65% and 1.0%. The exhaust temperature after the air preheater should be designed about 130°C at BMCR, which is higher than the calculated acid dew point of 10-20°C.

The cold-end heat transfer elements of the air preheater are designed as enamel-plated components to control the low temperature corrosion caused by the condensation of the acid dew point and ash blockage. The hot air recirculation or heater system should be designed at the outlet of blower to improve the air inlet temperature under low load and low temperature conditions.

The low temperature economizer is installed for waste heat recovery of low-temperature flue gas. The flue gas temperature is reduced to about 90°C, which is lower than the flue gas acid dew point temperature. The particles concentration in the flue gas entering the low-temperature economizer is high enough to ensure that the condensed SO₃ is adsorbed on the surface of the particles. Therefore, the metal surface of the device could be protected from the corrosion of sulfuric acid mist.

Studies have shown that SO₃ forms a gaseous mixed system of SO₃-H₂O-H₂SO₄ coexisting in LLT-ESP [14, 15]. SO₃ reacts with H₂O to form sulfuric acid mist H₂SO₄, which then reacts with the alkaline substances in the fly ash. The specific resistance of the particles is deceased cause of the condensation of SO₃ on the surface of fine particles. The charging performance of the electrostatic precipitator is improved by the comprehensive effect of the condensation of SO₃ on the surface of the fine particles, the decrease of the specific resistance of the
particles and the agglomeration of the fine particles. The particles removal efficiency is improved remarkably.

4. Conclusions

Low–low temperature electrostatic precipitators have been implemented widely in ultra-low emission plants. Low temperature corrosion is one of the key issues in its application. The concentration of SO$_3$ affects the acid dew point temperature of flue gas. The SO$_3$ is mainly derived from the boiler combustion and SCR denitrification system. The acid dew point temperatures of flue gas were calculated to be 108°C-120°C for different fuels. The exhaust temperature after the air preheater should be set to 130°C on BMCR condition. The residual heat of flue gas is fully utilized by the low-temperature economizer. The inlet temperature of the LLT-ESP should be set to 90°C. The risk of low temperature corrosion could be reduced by the SO$_3$ adsorption on the particles.

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