Pollutants Emission Characteristics of an Ultra-low Coal-fired Power Unit

Li Bing¹, Song Yongqiang², Zhang Qilong¹, Zhou Can¹ and Duan Haoran¹

1Shandong Branch of Huadian Electric Power Research Institute, Jinan, China
2Huadian Power International Corporation Limited Zouxian Power Plant, Jining, China
E-mail: 13869187893@163.com

Abstract: The concentration of particulate matter (PM), SO₂, NOₓ, SO₃, HCl, HF, and PM2.5 were measured in a 330MW ultra low emission coal-fired power unit. The pollutants emission characteristics and the effect of the conventional pollution control devices on non-conventional pollutants were investigated. The test results show that the concentration of NOₓ, SO₂ and PM are 26.9 mg/m³, 18.1 mg/m³, 2.9 mg/m³ respectively. The coal-fired power plant, equipped with WFGD and WESP could well control SO₂, HCl, HF, and PM2.5 emission from the flue gas. SO₂ removal efficiency of WFGD and WESP are 42.2% and 82.8% respectively. HCl and HF removal efficiency by WFGD are 90.8% and 91.5% respectively. PM2.5 removal efficiency of WESP is 86.9%.

1. Introduction
Coal-fired power plants are a major source of power generation in China so the pollution emission from coal-fired power plants has been paid more and more attention. In 2014, with much attention paid to the pollutant emitted from the coal-fired power plants, Chinese government has put forward the ultra-low emission (ULE) for coal-fired power units. The emissions of dust, sulfur dioxide (SO₂) and nitrogen oxide (NOₓ) are below 10 milligrams per cubic meter, 35 milligrams per cubic meter and 50 milligrams per cubic meter, respectively. Before 2020, coal-fired power plants should be retrofitted to meet ULE standards.

With the successful cases of ultra-low emission from domestic coal-fired power plants in China, the technology route for ULE retrofitting has been formed gradually [1]-[3]. Taking the dust ultra low emission as an example, fine particulate matter (PM) is a very difficult to be captured. Improvements, such as retrofitting the electrostatic precipitator (ESP) and installing a wet electrostatic precipitator (WESP), could help solve this problem. A low-low temperature ESP or a WESP is the primary dust ULE technology route. At the same time, people have paid more attention to the emission of SO₃, PM2.5 and other unconventional pollutants besides dust, SO₂ and NOₓ [4].

This paper has measured the emission concentration of particulate matter, SO₂, NOₓ, SO₃, HCl, HF, and PM2.5 in a 330MW ultra low emission coal-fired power unit, which has been retrofitted to meet ULE standards with low NOₓ burner (LNB) and selective catalytic reduction (SCR) technology to control NOₓ emission, a dry ESP and a WESP to control particulate matter emission and wet limestone-gypsum flue gas desulfurization (WFGD) to control SO₂ emission. The pollutants emission characteristics and the effect of the conventional pollution control devices on non-conventional pollutants were investigated.
2. Experiment

2.1. Unit overview
The field measurements were conducted in a 330MW coal fired power plant. This unit adopted LNB and SCR to control NOx emission. The catalyst was arranged in three layers and the reducing agent was liquid ammonia. WFGD was retrofitted in a single tower with a tray and five spraying layers to control SO2 emission. The design inlet SO2 concentration was 3000 mg/m3 and the design desulphurization efficiency was no less than 98.85%. ESP of horizontal type and four electric fields and one WESP arranged in the top of WFGD were retrofitted to control dust emission.

2.2. Test method

![Diagram of measure point.](image_url)

Figure 1. The diagram of measure point.

In this paper, the pollutants has been measured according to National Standards, such as GB/T 16157-1996 (Determination of particulates and sampling methods of gaseous pollutants emitted from exhaust gas of stationary source), DL/T 414-2012 (Specification for environmental monitoring of thermal power plants) and GB/T 13931-2002 (Methods of performance tests for electrostatic precipitators). The measuring points were arranged as shown in figure 1.

2.3. Test condition
During the test, the unit load was at 100% BMCR and remained stable, no more than 5% or minus 5% BMCR. The coal quality remained stable and the results of coal analysis during the test are shown in Table 1.

| Moisture | Ash | Volatile matter | Fixed carbon | Total sulfur | Calorific value |
|----------|-----|-----------------|--------------|--------------|-----------------|
| Mad (%)  | Aad (%) | Vad (%) | Fad (%) | Sad (%) | Qnet,ad(MJ·kg⁻¹) |
| 1.7      | 25.84 | 38.92          | 44.26        | 1.05         | 20.67           |

3. Results and Discussion

3.1. Emission characteristics of NOx, SO2 and dsut

![Table 2. NOx, SO2 and dust emission characteristics.](image_url)

| Unit | NOx | SO2 | Dust |
|------|-----|-----|------|
| Concentration (mg·m⁻³) | Performance (g·(kW·h)⁻¹) | Concentration (mg·m⁻³) | Performance (g·(kW·h)⁻¹) | Concentration (mg·m⁻³) | Performance (g·(kW·h)⁻¹) |
The emission concentration of NOx, SO\(_2\) and dust at the chimney inlet are shown in table 2. The NOx concentration is 314.9 mg/m\(^3\) at the SCR inlet and that at the chimney inlet is 26.9 mg/m\(^3\). The SO\(_2\) concentration is 2500.3 mg/m\(^3\) at the WFGD inlet and that at the chimney inlet is 18.1 mg/m\(^3\). The dust concentration is 33.2 g/m\(^3\) at the ESP inlet and that at the chimney inlet is 2.9 mg/m\(^3\). The emission concentration of NOx, SO\(_2\) and dust has met ULE standards respectively. The emission performance of NOx, SO\(_2\), and dust is 0.079 g/ (kW·h), 0.053g/ (kW·h) and 0.009 g/ (kW·h), respectively.

3.2. Emission characteristics of non-conventional pollutant

3.2.1. SO\(_3\). Sulfur trioxide (SO\(_3\)) is formed in the furnace and convective pass of coal-fired boilers, and the rate of formation depends strongly on coal properties, boiler design and operation conditions. The parameters that influence the amount of SO\(_3\) formation in the boiler are fuel sulfur content, ash content and composition, excess air level, convective pass surface area, and tube metal surface temperature distribution[5, 6]. For boilers equipped with SCR reactors to control NOx emission, additional amounts of SO\(_3\) are formed in the SCR reactors, with rate of formation depending on parameters such SCR design and reactor temperature. However, there are undesirable impacts of SO\(_3\), including corrosion and fouling of air preheater, corrosion of flue duct and formation of acid mist in the stack plume[7].

The collaborative control of SO\(_3\) by WFGD and WESP is shown in figure 2. The results show that SO\(_3\) can be simultaneous removed by WFGD and WESP. The SO\(_3\) concentration is 32.2 mg/m\(^3\) and 18.6 mg/m\(^3\) at the WFGD inlet and outlet, respectively. The SO\(_3\) removal efficiency by WFGD is 42.2%. Once formed in the boiler, the SO\(_3\) reacts with H\(_2\)O vapor to form H\(_2\)SO\(_4\) vapor in the cold end of the air preheater. When the H\(_2\)SO\(_4\) vapor-containing flue gas passes through a WFGD system, it is rapidly cooled below the acid dew point. Because the rate of this cooling is greater than the rate of adsorption of H\(_2\)SO\(_4\) vapor in the scrubber liquid, that results in H\(_2\)SO\(_4\) mist with sub-micron droplets. In a WFGD system, the mass transfer between the scrubbing liquid and H\(_2\)SO\(_4\) mist is lower, which occurs through inertial impaction, gravitational settling, Brownian diffusion, and other effects. In general, larger H\(_2\)SO\(_4\) mist droplets can be removed by WFGD, but a significant portion of sub-micron mist droplets are not removed and emitted from WFGD, so, ~30% of H\(_2\)SO\(_4\) may be removed by WFGD.

![Figure 2. The collaborative control of SO\(_3\) by WFGD and WESP.](image)

For sub-micron H\(_2\)SO\(_4\) mist droplets with diameters less than 0.05 μm, Brownian diffusion is known to
be the primary component of mass transfer. In a WFGD scrubber, the mass transfer depends on the relative velocity between the $\text{H}_2\text{SO}_4$ mist droplets and the scrubbing liquid. In the WFGD system of this 330MW unit, a tray was retrofitted. The uniformity of flue gas distribution is improved and the mass transfer is enhanced, and then the $\text{SO}_3$ removal efficiency is improved, reached 42.2%.

WESP has been developed to control a wider variety of particulate pollutants and exhaust gas conditions compared to dry ESP, especially for particles that are sticky, corrosive, or have high resistivity. The problem of acid plume in coal-fired power plant can be solved by installing a wet ESP after a FGD system. The $\text{SO}_3$ concentration is 3.2 mg/m$^3$ at the WESP outlet and the $\text{SO}_3$ removal efficiency by WESP is 82.8%. The wet environment in the WESP lowers particle resistivity and allows high power input levels to enhance the removal of sub-micron mist, so the sub-micron $\text{H}_2\text{SO}_4$ mist is collected by electrostatic forces in a WESP [6].

3.2.2. $\text{HCl}$ and $\text{HF}$. The collaborative control of $\text{HCl}$ and $\text{HF}$ by WFGD are shown in figure 3. Chlorine and fluorine are among the most volatile elements according to trace elements partitioning behavior during coal combustion. The release rate of chlorine and fluorine from coal during combustion in boiler is above 96.6% [8]. Chlorine and fluorine in coal are released as hydrogen chloride and hydrogen fluoride during coal combustion, respectively [9]. The removal rate of hydrogen chloride and hydrogen fluoride by WFGD are 90.8% and 91.5% respectively, because hydrogen chloride and hydrogen fluoride are water-soluble and chemical reaction occurs with the scrubbing liquid in WFGD system, and then chloride and fluorine are most transferred into desulfurization gypsum and desulfurization wastewater.

![Figure 3](image_url)

**Figure 3.** The collaborative control of $\text{HCl}$ and $\text{HF}$ by WFGD.

3.2.3. $\text{PM2.5}$. The ESP is the primary PM control devices in Chinese coal-fired power plants. ESP can effectively capture large particles, but they can do little for fine particles such as PM2.5 or lower. Dry ESPs use electrostatic forces, but charging of fine particles smaller than 1 μm is inefficient, and the collection efficiency sharply drops with decreasing particle size. The fine particles need to be effectively captured due to stronger corona power generated than in traditional ESP. The limits on charging mechanisms for fine particulates are exaggerated in dry ESP due to lower corona power levels caused by the resistivity of the ash layer that accumulates on the collecting surfaces. The re-entrainment of fine particles from the last field collection electrode can also be observed, which also lower the dust collection efficiency.

The flue gas condition after WFGD is that the moisture content in flue gas is high and the temperature of flue gas is close to the dew point temperature. Compared with a dry ESP, WESP is particularly suitable in the flue gas condition after WFGD. WESP may provide much higher average corona power levels compared to dry ESP, because they are constantly being cleaned of resistive ash by flowing...
water to prevent ‘‘back corona’’. This effect enhances collection of sub-micron particles through more effective particle charging. At the same time, the periodic or continuous scrubbing water flow, used to wash the collection electrode surfaces, is found to prevent particle re-entrainment caused by rapping, which occurs in dry ESPs.

The collaborative control of PM by WESP is shown in figure 4. The proportion of PM2.5 to PM at inlet and outlet of WESP are 67.7% and 75.9%, respectively. The proportion of PM2.5 increases as flue gas passes through a WESP system. The removal efficiency of PM and PM2.5 by WESP are 88.4% and 86.9% respectively. The wet environment in the WESP lowers particle resistivity and allows high power input levels to enhance the removal of micron-diameter particulate matter by electrostatic forces in a WESP.

4. Conclusion

The pollutants emission characteristics and the effect of the conventional pollution control devices on non-conventional pollutants in a 330MW coal-fired power unit were investigated. The test results show that the concentrations of NOx, SO2 and dust have met ULE standards. The coal-fired power unit equipped with WFGD and WESP could well control SO3, HCl, HF, and PM2.5 emission from the flue gas. SO3 removal efficiency of WFGD and WESP are 42.2% and 82.8% respectively. HCl and HF removal efficiency of WFGD are 90.8% and 91.5% respectively. PM2.5 removal efficiency of WESP is 86.9%.

![Figure 4. The collaborative control of PM and PM2.5 by WESP.](image)

5. References

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