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Original Research Paper

Research on the Application of a Wet Electrostatic Precipitator in Coal-Fired Power Plant for "Gypsum Rain" Prevention and Treatment

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ABSTRACT

Haze pollution involving $PM_{2.5}$ is currently a serious problem in China, and the implementation of tougher measures to further reduce emissions from key air pollution sources such as coal-fired power plants has become an inevitable trend. Wet electrostatic precipitator (WESP) technology is being adopted by an increasing number of power plants because of its ability to remove $PM_{2.5}$ and other fine particulate matter. In this study, key indicators such as filterable particulate matter (FPM), condensable particulate matter (CPM), SO_3, and droplets in the flue gas of Shanghai Changxing Island No.2 Power Plant were measured and analysed. The results indicate that the emission concentrations of total particulate matter (TPM) were 30.31 mg/m^3 and 15.74 mg/m^3, FPM were 20.31 mg/m^3 and 6.09 mg/m^3, $PM_{2.5}$ were 4.06 mg/m^3 and 2.50 mg/m^3, SO_3 were 4.51 mg/m^3 and 3.06 mg/m^3, and droplets were 114 mg/m^3 and 102 mg/m^3 at the stack when the WESP was off and on, respectively. Similarly, CPM accounted for 33% and 61% of TPM, respectively. This study demonstrates that the use of WESP technology has a significant effect on the removal of particulate matter and droplets.

INTRODUCTION

At present, China has around 4467 coal-fired desulfurization units with a total capacity of 750 million kilowatts. This represents over 90% of the total thermal power generation capacity. The sulphur dioxide reduction capability of the coal-fired power plants, accounts for more than 75% of total sulphur dioxide reduction in the country every year. In all desulfurization units, the proportion of wet flue gas desulfurization (FGD) is over 95%. More than 90% of the coal-fired power plants utilize limestone-gypsum wet FGD technology (Li 2012, Wang 2012, Zeng et al. 2008).

The earliest wet FGD systems installed in China were equipped with gas-gas heaters (GGH). However, the components of GGH become significantly corroded and blocked during actual operation, which affects the safe and stable operation of the wet FGD system. Thus, GGH is no longer installed in the recently developed wet FGD systems and most of the installed GGHs have gradually been replaced, leading to "wet stack" emissions (Li 2012, Li & Zhen 2010). The decline of the flue gas temperature to about 50°C results in a phenomenon sometimes referred to as "white plume". The higher the plume concentration, the greater the discoloration and the longer the plume remains in the atmosphere. Under severe conditions, the plume may even reach ground levels. At the same time, small droplets form in the area near the stack, a phenomenon called "gypsum rain". Droplet deposition usually occurs within 800 m downwind of the stack with "wet stack" emissions (Chen 2010, Li 2012). The "white plume" and "gypsum rain" phenomena can be most evident when the unit is running at high load or the meteorological conditions are poor. Since the widespread occurrence of haze in China in recent years, coal-fired power plants have attracted more and more attention as important contributors to atmospheric pollution. Due to the sensitivity of the public to environmental issues, "white plume" and "gypsum rain" have become important problems associated with the running of wet desulfurization systems (Li 2012).

Research results regarding particulate emissions from coal-fired power plants in the country in recent years indicate that the "white plume" discharges not only contain a large amount of condensate water, but also significant quantities of particulate matter; the condensable fraction has not been well addressed in the research studies (Pei 2010). The United States Environmental Protection Agency (US EPA) defines condensable particulate matter as: "a material that is vapour phase at stack conditions, but condenses and/or reacts upon cooling and dilution in the ambient air to form solid or liquid PM immediately after discharge from the stack." Note that all CPM is assumed to be in the $PM_{2.5}$ size fraction. As the CPM is in the vapour phase under stack conditions, the filter mediums used in traditional particulate matter monitoring methods such as Method 5 (U.S. Environmental Protection Agency 1997), Method 17 (U.S. Environmental Protection Agency 1999) and GB/T 16157 (Ministry of Environmental Protection of China 1996) are unable to capture it. CPM is omitted in the stationary source pollutants monitoring and the air pollution management in China.

The US EPA recommends Method 202 (U.S. Environmental Protection Agency 2010b) to determine CPM. Corio & Sherwel (2000) tested several coal-fired boilers with Methods 202 and 201/201A (U.S. Environmental Protection Agency 2010a). The results showed that, on average, the CPM comprises 76% of the PM_{10} stack emissions and 49% of the TPM emissions, respectively. According to the point of view of "sources-sinks", the TPM emissions from stationary pollution sources should be the sum of filterable particulate matter (FPM) and CPM.

H_2SO_4 generated by sulphur trioxide (SO_3) and water vapour is the major component of CPM, which also produces a visual discoloration of the plume exiting the power plant stack ("blue plume"). According to estimates, 75% to 85% of bituminous coal-fired plants with selective catalytic reduction (SCR) and/or wet FGD systems are likely to produce enough SO_3 vapour and mist to make their emissions opaque. Though much attention has focused on the "blue plume" phenomenon, SO_3 also shows significant negative impact on the plant performance, operations, and maintenance, including:

- The reduction of unit heat rate and increased corrosion of downstream equipment due to an increase in the dew point by SO_3.
- The fouling of air heaters and SCR catalysts due to the reaction of SO_3 with ammonia.
- The competition of SO_3 with mercury for adsorption sites on carbon particles, reducing the effectiveness of mercury emissions control.

SO_3 production within a coal-fired plant is affected by several systems, such as the furnace, the SCR system, the air preheater (APH), the electrostatic precipitator (ESP), and the wet FGD unit (scrubber). Differences in SO_3 production within a plant result from different chemical reactions that form SO_3 during combustion and flue gas conditioning. The production and reduction of SO_3 within a coal-fired plant is presented in Fig. 1. It should be noted here that the term "SO_3" refers to varying proportions of vapour-phase SO_3 and vapour-phase sulphuric acid, and to sulphuric acid aerosol particles downstream of the wet FGD system.

Haze pollution involving $PM_{2.5}$ is currently a serious problem in China, and the implementation of tougher measures to further reduce emissions from key air pollutant sources, such as coal-fired power plants, has become an inevitable trend. The study by Lu et al. (2010) indicated that the application of FGD technology has a significant effect on particulate emission, due to the release of fine particles and part volatile metals in the FGD slurry. This causes an increase in the concentration of TPM in the stack flue gas to about three times that at the FGD inlet. The "wet stack" emissions from power plants may not only lead to "gypsum rain", but also to the discharge of significant amounts of FPM and CPM into the atmosphere. At the same time, the "white plume" will have potential impacts on atmospheric visibility and human health. However, there is a lack of understanding of the emission characteristics of coal-fired power plants in China, especially regarding "gypsum rain", the CPM content of the emissions, and the impact of existing targeted treatment technologies. This is because of insufficient fundamental knowledge and test methods. In this study, the effectiveness of the "gypsum rain" control project at the Shanghai Changxing Island No. 2 Power Plant was evaluated. The measurement of key indicators, such as concentrations of PM, SO_3, and droplets and moisture in flue gas, was carried out in order to test the removal efficiencies of these pollutants by WESP, and to provide reference data for the selection of control processes and the formulation of control policies for "gypsum rain".

UNIT CONDITIONS AND TEST METHODS

Unit conditions: Shanghai Changxing Island No. 2 Power Plant was built in the mid-1990s, with two condensing coal-fired units, each of 12 MW. Both coal-fired units were converted into condensing bleeder units in 2008 to meet the district heating demand. The maximum heating capacity of the power plant is about 60 t/h. Fig. 2 shows the process flow of the flue gas comprehensive treatment renovation project of Unit No. 1. This includes, sequentially, a secondary low temperature heat exchanger, an electrostatic precipitator (ESP), a primary low temperature heat exchanger, a classic wet FGD, a WESP, and a stack.

Test methods: The indicators tested, when the boiler was operated at a high load, included: concentrations of primary particulate matter (FPM, $PM_{2.5}$, CPM), SO_3, SO_2, NOx, droplets and moisture in the flue gas at the stack; "gypsum rain" deposition downwind of the stack; and plume formation at the outlet of the stack.

Test to determine concentrations of primary particulate matter in flue gas: Concentrations of FPM, $PM_{2.5}$, and CPM

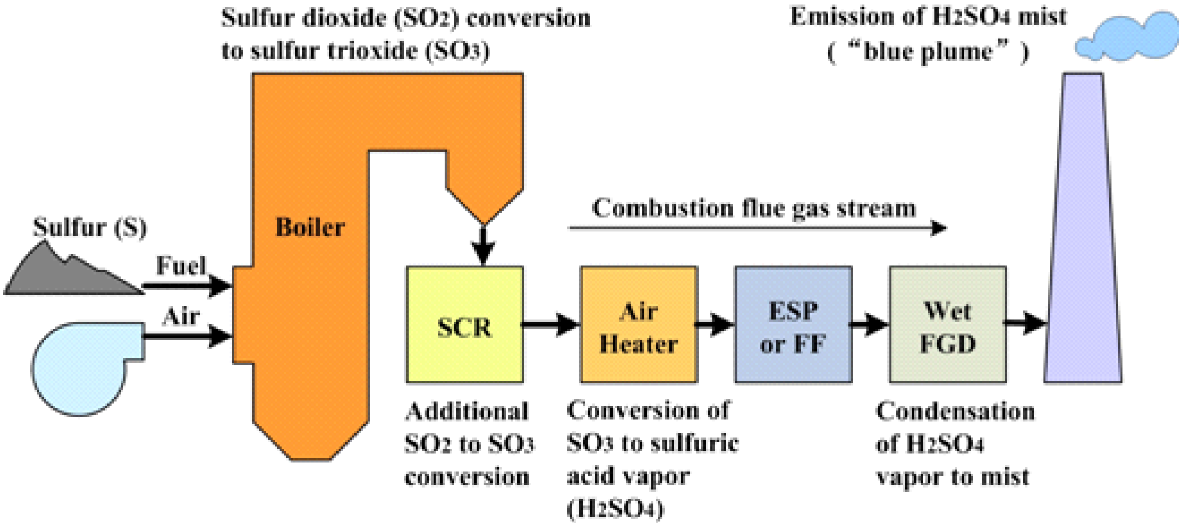

Fig. 1: Formation of SO_3 and H_2SO_4 in a coal-fired power plant (ESP, electrostatic precipitator; FF- fabric filter FGD- flue gas desulfurization system; SCR- selective catalytic reduction system).

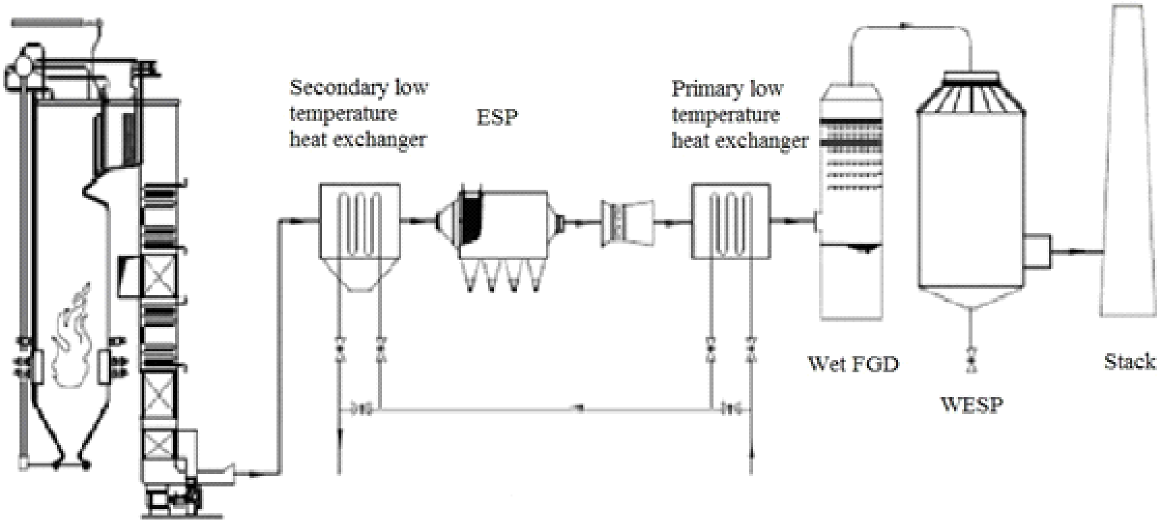

Fig. 2: Process flow of the flue gas comprehensive treatment renovation project.

were measured using Method 201A (U.S. Environmental Protection Agency 2010a) and Method 202 (U.S. Environmental Protection Agency 2010b).

Test to determine SO_3 concentration in flue gas: The SO_3 concentration was measured using NCASI Method 8A (National Council of the Paper Industry for Air and Stream Improvement, Inc 1997).

Test to determine droplets concentration and moisture content in flue gas: The concentration of droplets was measured using the China National Standard GB/T 21508 (General Administration of Quality Supervision, Inspection and Quarantine of China 2008). Moisture content was measured using the dry-wet bulb method.

Test on "gypsum rain" deposition downwind of the stack: "Gypsum rain" deposition means the total liquid deposition including gypsum slurry droplets and condensate water. Several sampling sites were selected downwind of the stack and a sample collector was located at each site. In order to maintain the comparability of the data under different WESP operating conditions, "gypsum rain" deposition measurements

Fig. 3: Sampling sites of “gypsum rain” deposition measurement.

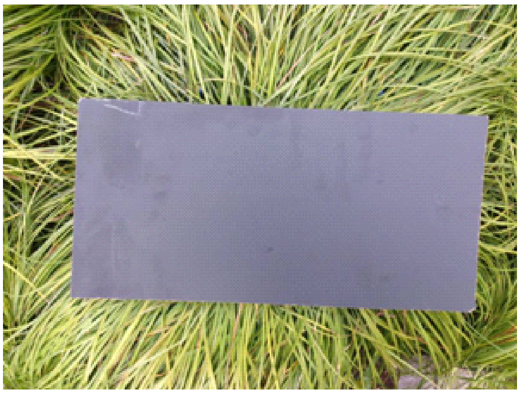

Fig 4: The sample collector for “gypsum rain” measurement.

Fig. 5: The plume under different WESP operating conditions.

were done under similar meteorological conditions. Pictures of plume at the stack outlet were also taken during the “gypsum rain” deposition measurement.

The mass of “gypsum rain” deposited was defined as the weight gain of “gypsum rain” on the sample collector during the sampling period.

The number of “gypsum rain” deposits equalled the number of “gypsum rain” spots on the sample collector that appeared during the sampling period.

Test on concentrations of other pollutants in flue gas: The concentrations of other pollutants, such as SO_2 and NOx, were measured using a flue gas analyser (Testo 350, Testo AG).

RESULTS AND DISCUSSION

The test results for different WESP operating conditions are given in Table 1.

The results indicated that the concentration of FPM was 6.09 mg/m^3 at the stack when the WESP was on, implying that the WESP has a significant effect on dust removal.

The concentrations of $PM_{2.5}$ were 4.06 mg/m^3 and 2.50 mg/m^3 at the stack when WESP was off and on, respectively. Literature show that $PM_{2.5}$ generally accounts for 40% to 50% of FPM after desulfurization (Pei 2010, Corio & Sherwell 2000). The percentages in this study were 20.0% and 41.1% when WESP was off and on, respectively, which are generally in agreement with literature data.

The concentrations of CPM at stack were 10.0 mg/m^3 and 9.65 mg/m^3 and the corresponding CPM/FPM ratios were 0.49 and 1.58 when WESP was off and on, respectively, indicating that while WESP can greatly reduce the dust concentration, it only has a minor effect on CPM reduction.

The concentration of SO_3 in flue gas fell from 4.51 mg/m^3 to 3.06 mg/m^3 with the operation of WESP. At the same time, the concentration of droplets decreased from 114 mg/m^3 to 102 mg/m^3.

The sampling sites are shown in Fig. 3, and the results of “gypsum rain” deposition measurement in Table 2. “Gypsum rain” was not formed during the sampling period and no spots were found on the sample collector (Fig. 4).

Pictures of the plumes formed under different operating conditions for WESP are shown in Fig. 5. Due to the humidification through the circulating water streams, the flue gas temperature decreased from 48.3°C to 46.7°C inside the WESP, which increased the amount of condensate water in flue gas and the size of the “white plume”. During a stable WESP operation, the pH value of the circulating water de-

Table 1: Results for different WESP operating conditions.

Item	Unit	WESP off	WESP on
FPM	mg/m^3	20.31	6.09
$PM_{2.5}$	mg/m^3	4.06	2.50
CPM	mg/m^3	10.0	9.65
CPM/FPM ratio	-	0.49	1.58
CPM/$PM_{2.5}$ ratio	-	2.46	3.86
TPM	mg/m^3	30.31	15.74
FPM/TPM ratio	-	0.67	0.39
CPM/TPM ratio	-	0.33	0.61
SO_3	mg/m^3	4.51	3.06
Droplets	mg/m^3	114	102
Moisture	%	11.9	9.5
Mass of “gypsum rain” deposition$^{(1)}$	mg/(m^2·d)	ND$^{(2)}$	ND
pH value of WESP recycling water	-	7.00	2.74
Flue gas temperature	°C	48.3	46.7

Notes: (1) “Gypsum rain” deposition means the total liquid deposition including gypsum slurry droplets and condensate water.
(2) “ND” means not detected.

Table 2: Results of “gypsum rain” deposition measurement.

Item	Sampling site 1$^{(1)}$	Sampling site 2$^{(2)}$	Sampling site 3$^{(2)}$
Distance from stack	500 m	76 m	150 m
Direction with reference to stack	N by W 23°	S by E 15°	S by E 15°
“Gypsum rain” deposition	ND$^{(3)}$	ND	ND

Notes: (1) Southeast wind at sampling site 1; (2) Northerly wind at sampling site 2 and 3; (3) “ND” means not detected.

creased from 7 to 2.74, indicating that WESP has a considerable effect on the removal of acidic pollutants such as SO_3 and SO_2. The flue gas was further purified due to the removal of particulate matter and other pollutants with WESP, which caused the plume colour to change from light brown to white.

CONCLUSIONS

The results indicated that the CPM/FPM ratios are 0.49 and 1.58, the CPM/$PM_{2.5}$ ratios are 2.46 and 3.86, and CPM accounted for 33% and 61% of TPM at the stack when the WESP is off and on, respectively. This means that the previous test results for particulate matter emissions from stationary sources (as filterable particulate matter) cannot represent the real situation and the emissions have been underestimated so far. CPM accounts for a high proportion of total $PM_{2.5}$ emissions and its harmfulness cannot be ignored. Therefore, the effective removal of particulate matter (especially CPM) from the flue gases of coal-fired power plants should be the focus of research regarding prevention of air pollution in China.

The removal efficiencies of the WESP at the Shanghai Changxing Island No.2 Power Plant for CPM, $PM_{2.5}$, FPM and TPM were 3.5%, 38.4%, 70.0% and 48.1%, respectively. The smaller the size of the particulate matter, the lower its removal efficiency by WESP. The removal efficiency of SO_3 (mainly sulphuric acid mist) was 32.2%, which lowered the discoloration of the plume. The removal efficiency of droplets was 10.5%, which helped to alleviate or avoid the “gypsum rain” phenomenon. As one of the control processes utilized in the “gypsum rain” control project, the WESP installed between the wet FGD and the stack was shown to reduce the emission concentrations of particulate matter and droplets effectively. These results would be useful for the further practice of pollutant discharge reduction from coal-fired power plants.

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