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Technical Note

Effects of Temperature on Electrostatic Precipitators of Fine Particles and SO_3

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ABSTRACT

The fine particles and SO_3 at the outlets of electrostatic precipitators (ESPs) were measured when the temperature of the flue gas decreased to 90°C on a pilot-scale platform with 50,000 m^3 h^{-1} of real flue gas. Based on the test results and scanning electron microscopes (SEMs) of the particulate matter, the mechanism of fine particle change and SO_3 removal was analyzed. The results show that the efficiency of SO_3 removal reaches 73% and the penetration concentration of PM_1 decreases from 0.5 to 0.17 mg m^{-3} when the gas temperature decreases from 120–130°C to 90–95°C in a coal-fired power plant.

Keywords: Coal-fired power plant; Dust emission; Electrostatic precipitator; SO_3; PM.

INTRODUCTION

As air pollution has been a serious problem, the ultra-low emission in China requires that the particles emissions must be less than 10 mg m^{-3} (Saeki *et al*., 2003; Ando *et al*., 2011; Nicol *et al*., 2013; Preston *et al*., 2013; China *et al*., 2015).

The collection efficiency of electrostatic precipitator (ESP) is over 99.9%. However, the difficulty of charging is one of the major limiting factors for particles collection of ESP (Kato *et al*., 1994; Yi *et al*., 2006; Roudier *et al*., 2013; Afshar-Mohajer *et al*., 2014; Xu *et al*., 2015), and the mass concentration at the outlet of ESP was about 50 mg m^{-3} with high penetration efficiency of dust particles in the size range of 0.1–1 µm (Tamaru *et al*., 1998; Misaka *et al*., 2009). Chang *et al.* (2015) had enhanced particles agglomeration by using a pre-charger to increase mean particle size but without reducing the dust resistivity and taken more power.

There are some ESPs operated at different gas temperatures in coal-fired power plants (Xia *et al*., 2011; Li *et al*., 2017), Hitachi Plant Technologies developed a gas treatment system with a low low temperature electrostatic precipitator (LLT-ESP), the moving electrode type ESP with gas temperature of 90°C was described (Misaka *et al*., 2008). In 2016, the industrial standard of LLT-ESP was implemented in China (JB/T 12591-2016), but there is few study focused on its mechanism. Thus, this paper will describe the major performances of LLT-ESP and the changes to ESP at different gas temperatures by tests.

TEST

Testing Apparatus

(1) Pilot-scale Platform

The pilot-scale platform (Fig. 1) was built beside a real coal-fired power plant. The flue gas of the pilot-scale platform was pumped from a 300 MW heat-supply unit in Heibei plant after the economizer, thus ensured that the characters of flue gas in the pilot-scale platform. The flue gas volume is 50,000 m^3 h^{-1} in 350°C while 32,221 m^3 h^{-1} in 90°C.

The main parameters of LLT-ESP in the pilot-scale platform is shown in Table 1, which includes of the main components of coal and ash, the inlet flue gas parameters during the texts. The LLT-ESP pilot-plan is shown in Fig. 2.

(2) Test ESPs in 300–1000 MW Coal-fired Power Plants

The three ESPs were set in Changxing coal-fired plant (Power plant name, the unit capacity is 660 MW), Shangan coal-fired plant (the unit capacity is 660 MW) and Ninghai coal-fired power plant (the unit capacity is 1000 MW) for in-depth study of the performances of LLT-ESP in large units. The main parameters of ESPs and the entrance flue gas parameters are shown in Table 1.

Experiment Devices and Methods

In this paper, to test the dust concentrations, SO_3 concentrations and dust practical resistivity of LLT-ESP,

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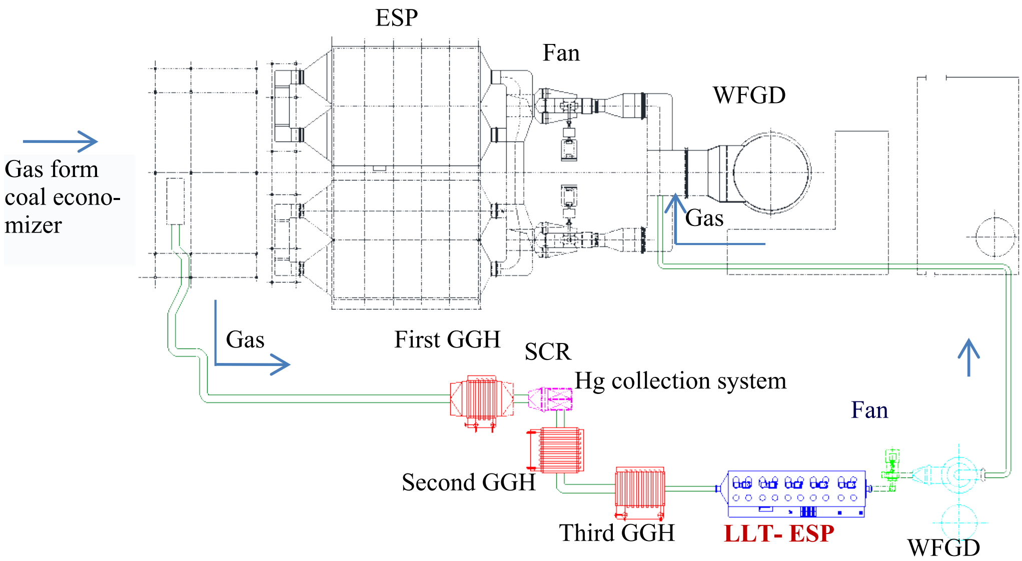


GGH means gas-gas heater, SCR means selective catalytic reduction

Fig. 1. System diagram of pilot-scale platform.

Table 1. Main parameters of LLT-ESPs and flue gas parameters during followed tests.

Item	name	LLT-ESP pilot-plan platform	LLT-ESP in Changxing plant	LLT-ESP in Ninghai plant	LLT-ESP in Shangan plant
Main Parameters of ESPs	Design Dust Collection Efficiency/%	≥ 99.87	≥ 99.782	≥ 99.93	≥ 99.93
	Guaranteed Particle Emission/mg m^{-3}	≤ 20	≤ 20	≤ 15	≤ 20
	Number of ESP per boiler, electric field	1, 4+1	2, 5	2, 4	2, 4+1
	SCA of LLT-ESP/m^2 (m^3 s^{-1})$^{-1}$	124.52	162.1	81.01	85.33+16.33
	power supply	high-frequency	high-frequency	high-frequency + pulsed	high-frequency
Entrance Flue Gas Parameters	Gas Flow Rate/m^3 h^{-1}	32221	2742800	8243956	2091580
	Inlet Dust Loading/g m^{-3}	15.735	11.55	11.735	28.589
	Gas Temperature/°C	90	88.25	90	95
	D/S	605	195	323	261
Main Components of Coal/%	Moisture	16.20	21.1	14.00	8.1
	Received Base Ash	12.80	6.60	7.04	23.81
	The Yankees Coal Ash Dry Without Volatile Matter Content	37.05	8.82	33.19	15.84
	Carbon	56.32	58.00	63.25	62.39
	Hydrogen	3.40	2.99	3.40	2.97
	Oxygen	10.03	10.13	11.18	2.61
	Nitrogen	0.77	0.61	0.64	0.96
Main Ash Characteristics/%	Sulfur	0.49	0.57	0.50	1.32
	SiO_2	41.32	42.98	26.31	55.66
	Al_2O	32.09	27.92	12.66	29.55
	Na_2O	5.14	2.98	0.43	0.45

the following test data got by the equipment and method are shown in Table 2.

The measurement of dust concentration was on the basis of ISO 12141-2002. The sampling points were set at the inlet and outlet of ESP. The PM was sampled by a normal sample tube, a glass fiber cartridge at the inlet of ESP and by a low concentration sample tube, quartz membranes at the outlet of ESP, respectively. Especially, the gas was sampled with a heating sample tube by isokinetic sampling. The fiber cartridges or membranes were weighed before and after by an electronic balance in tens of millions.

The measurement method of SO_3 was on the basis of GBT 21508-2008 as shown in Fig. 3. The gaseous SO_3 would become mist SO_3 when the flue gas temperature was reduced under acid dew point by the 60–65°C temperature-controlled water bat, and be collected by the snake-like glass tube, depended on the inertial forces. During the test, the constant temperature should not be lower than 60°C to

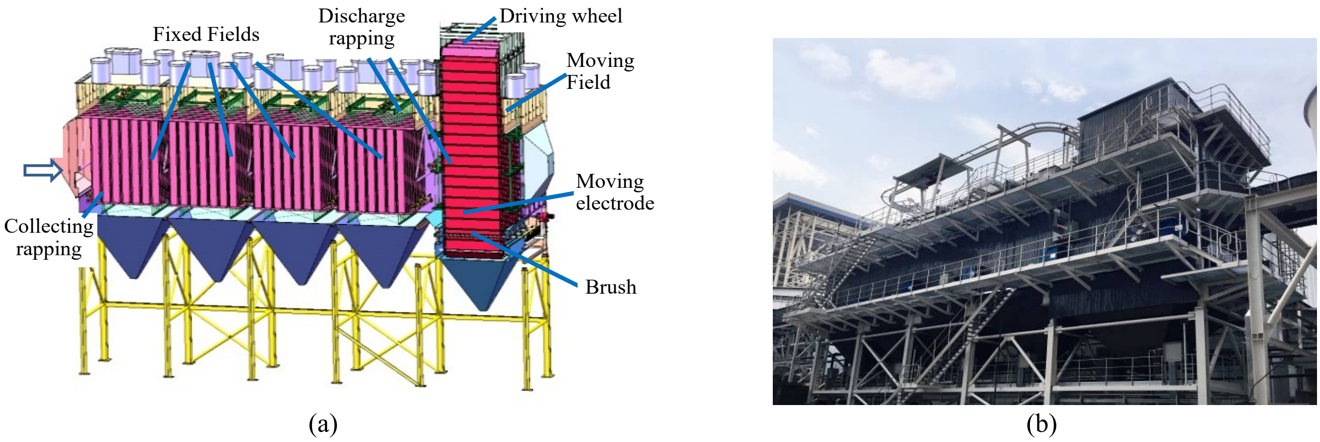


Fig. 2. Sketch of LLT-ESP pilot-plan (a) Schematic diagram and (b) Reality images.

Table 2. The measurement equipment and method (ISO 12141, 2002; GB/T 21508, 2008; GB/T 16913, 2008; JB/T 12591, 2016).

Items	Measurement Equipment	Instrument Types	Reference Standards or Methods
Dust Concentrations	Flue Dust Sampling Instrument, Flue Gas Sampling Gun	*Raoying* 3012H, 1085B, 1085D	GB/T 16157-1996 GB 13931-2002 ISO 12141-2002
SO_3 Concentrations	Ultraviolet Spectrophotometer, Flue Gas Sampling Gun	*Hach* DR5000, ZR-D03A	GBT 21508-2008 DL/T 986-2005
Dust Practical Resistivity	Dust Practical Resistivity Tester	TH2681A	GB/T 16913-2008

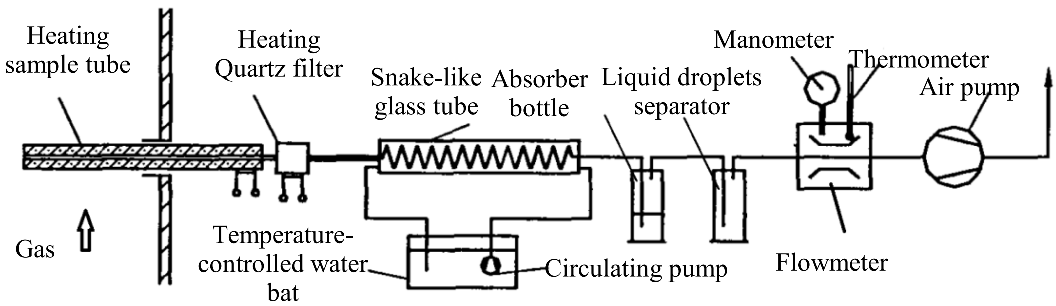


Fig. 3. The measurement method of SO_3.

prevent SO_2 from being condensed. The heating sample tube was set with a quartz filter or a glass fiber to filter the particulate matter and the heating temperature is not lower than 260°C. The content of SO_4^{2-} was tested by titration method with an ultraviolet spectrophotometer.

Dust Removal Efficiency with Different Diameters

The result of the tests done on the LLT-ESP pilot-plan is shown in Fig. 4. It showed that the dust concentration via gas temperature and diameter. The sizes of dust particles between GGH and LLT-ESP were growing from 130 to 90°C and the particles ratio of ≤ 1 µm, ≤ 2.5 µm, ≤ 10 µm decreased by 65%, 50% and 35% respectively. In general, the dusts whose size was in a range of 0.1–1 µm were difficult to remove (Zhao *et al*., 2018). When the temperature reduced, the penetration concentrations of PM_1 decreased from 0.5 to 0.17 mg m^{-3}. As the penetration concentration of PM_1 decreases about 65% when the temperature of flue gas decreases to 90°C according to the tests, about 60% of PM_1 has grown up to big particle which was easy to collect by ESP.

As the same trend, the tests of LLT-ESP in Changxing plant (600 MW) showed that the penetration efficiency of PM_1 decreased 65% as the gas temperature decreased from 120 to 90°C as shown in Fig. 5. And the total particles concentration (TPS) were less than 11.5 mg m^{-3} at the outlet of LLT-ESP, contrasted with 19 mg m^{-3} at the outlet of normal ESP, accorded by the test of Shangan plant.

The LLT-ESP which reduced the gas temperature to near 95°C made a good effect on the performance of ESP and effectively solved the problem of low removal efficiency of fine particles. Moreover, the WFGD would show an

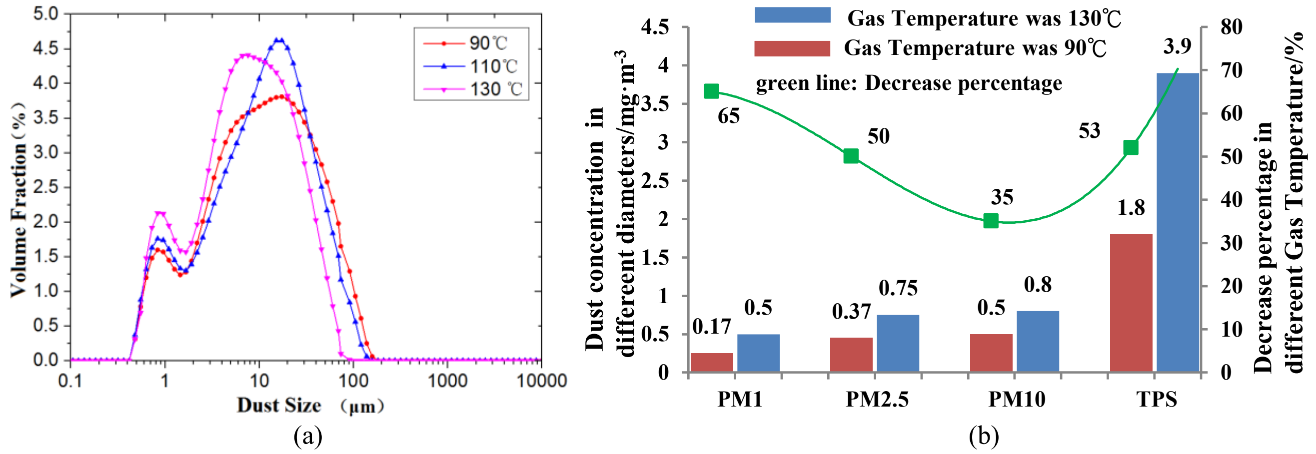


Fig. 4. Dust concentration via gas temperature and diameter (a) Sizes distribution of PM at the inlet of ESP and (b) dust removing efficiency of different diameters.

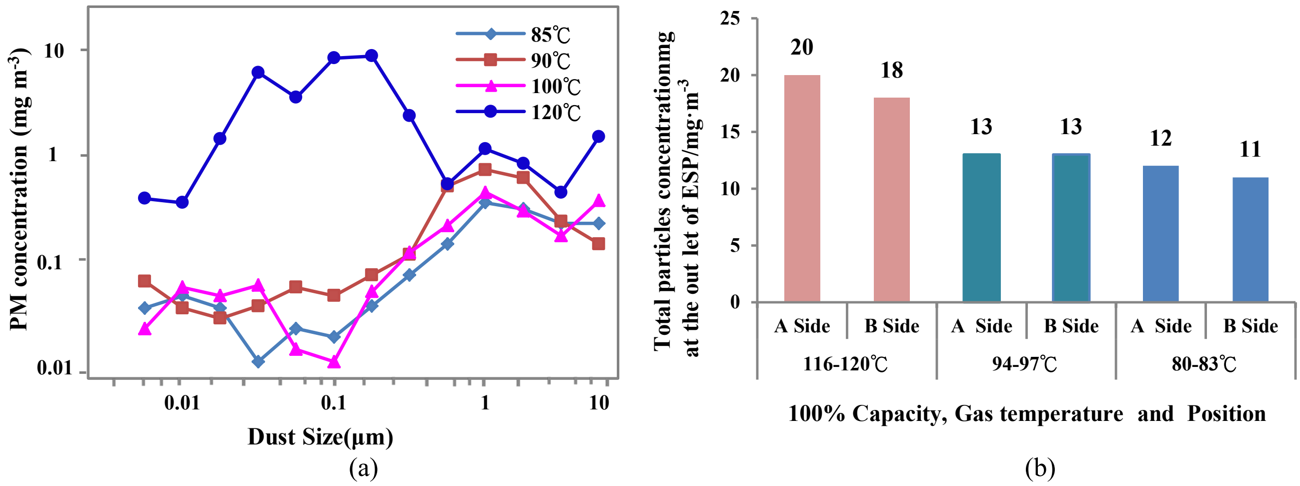


Fig. 5. Particulate removal performance vs. gas temperature (a) Changxing plant (600 MW) and (b) Shangan plant (300 MW).

apparent increase of dust removal efficiency as the particles diameters increased at the inlet of WFGD when took a LLT-ESP (Ondov *et al*., 1979).

SO_3 Removal Efficiency

The tests done on the LLT-ESP pilot-plan showed that the removal efficiency of SO_3 was 22.84%, 96.15% and 96.61% when the gas temperature was 120°C, 90°C and 80°C, respectively. Furthermore, the tests done on the LLT-ESP in Changxing plant showed that the removal efficiency of SO_3 achieved 73% by GGH and LLT-ESP, and the SO_3 concentration was less than 6 mg m^{-3}, as shown in Fig. 6, while the penetration concentration of PM decreased from 28 to 18 mg m^{-3}. SO_3 removal efficiency is increased with LLT-ESP.

Mechanism Analysis of Fine Particles Change and SO_3 Removal

To analyze the mechanism of fine particles change and SO_3 removal, membranes was set at the inlet of ESP in the pilot-scale platform, and particulate matter was observed by scanning electron microscope (SEM) as shown in Fig. 7.

Contrast of 120°C, the particulate matters in the gas temperature of 90°C got together, and the fine particulate adhered to coarse particulate.

As the flue gas before ESP includes relatively much PM than SO_3, the gas SO_3 condensed into SO_3 mist and was condensed on PM when the flue gas temperature was reduced below acid dew point. According the analysis of those SEM images, the rule of condensation, adsorption, the model of fine particles change and SO_3 removal was put forward as shown in Fig. 8, which supports the test results of dust particles grow when the flue gas decreases to 90°C in Fig. 4. At the same time, the SO_3 would be collected together with PM and solved the high penetration rate of SO_3 of normal ESP in 120–130°C.

CONCLUSIONS

When the gas temperature in a coal-fired power plant decreased from 120–130°C to 90–95°C, the particulate matter aggregated and adhered to coarse particles, and the

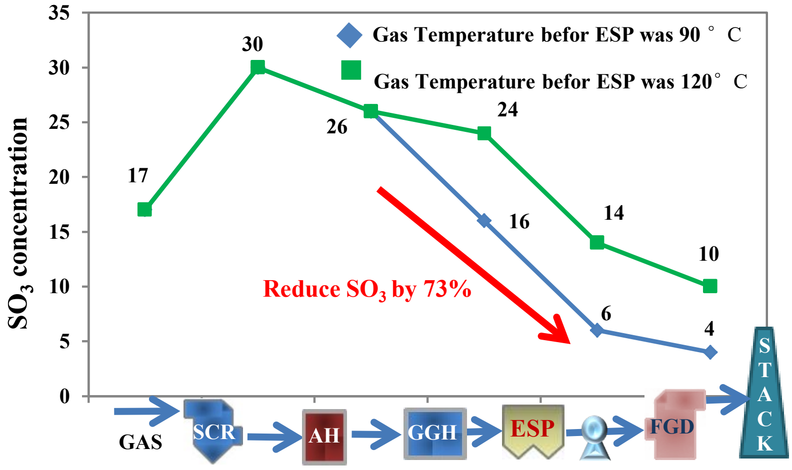
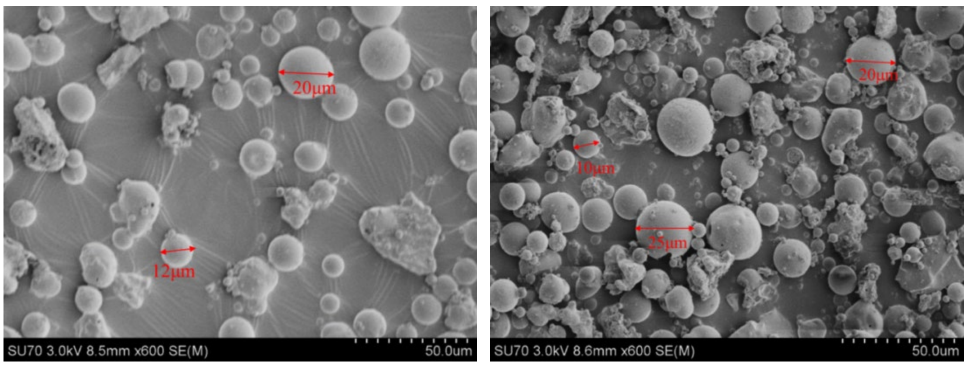
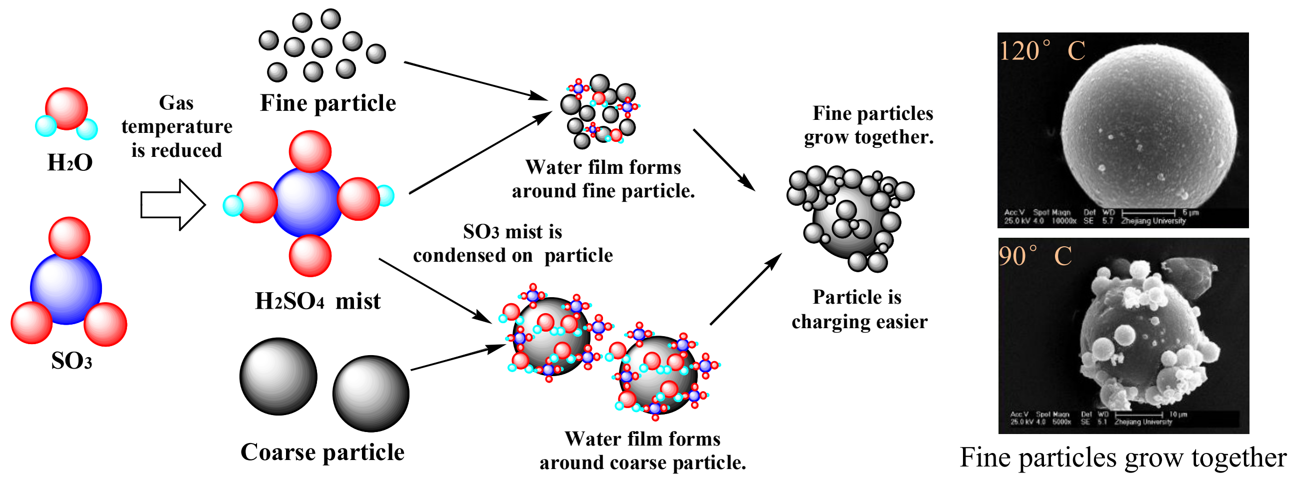


Fig. 6. SO_3 removal performance vs. gas temperature.



(a) (b)

Fig. 7. Contrast of particulate matter with flue gas temperature of 90°C and 120°C (a) Particles morphology in 90°C and (b) Particles morphology in 120°C.



(a) (b)

Fig. 8. Model of fine particles change and SO_3 removal (a) Model and (b) SEM images with gas temperature of 90°C and 120°C.

gaseous SO_3 condensed into SO_3 mist and on the PM. The problem of charging fine dust particles was negated by reducing the flue gas temperature below the acid dew point, as most of the PM_1 developed into large particles, which were easily collected by the ESP. More than 70% of the SO_3 was removed with the PM, and the penetration concentration of the PM_1 decreased from 0.5 to 0.17 mg m^{-3}.

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