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Full Length Article

Challenge of SO_3 removal by wet electrostatic precipitator under simulated flue gas with high SO_3 concentration

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A R T I C L E I N F O

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A B S T R A C T

Wet electrostatic precipitators (WESP) have been proven to be a promising technology for the removal of sulfuric acid mist from flue gases. Recent studies indicate that WESPs, when mitigating sulfuric acid mist, can be less effective on systems that burn high sulfur content fuel. This paper reports on a pilot-scale WESP used to investigate SO_3 removal with high SO_3 concentration. Both mass concentration of SO_3 and number concentration of sulfuric acid mist were measured. Two key parameters, i.e., electrical characteristics and gas loading, were studied to evaluate their effects on SO_3 removal efficiency under severe corona suppression conditions. Results showed that the maximum corona current was reduced by 83.1% when the WESP inlet SO_3 concentration increased from 0 to $5c_0$, and the corresponding SO_3 removal efficiency decreased from 74.5% to 54.2%. SO_3 removal efficiency can be improved by increasing corona power and reducing gas velocity. A comprehensive method was proposed to enhance SO_3 removal efficiency, with removal efficiencies greater than 90% using proper electrode configurations and lower velocity under a pilot plant condition. In addition, other challenges including new ultra-fine mist generation, material corrosion and insulator failure are summarized.

1. Introduction

Recently, there has been much attention to sulfuric acid mist pollution due to its environmental impact. Once sulfuric acid mist is emitted into atmosphere, problems such as high plume opacity and acid deposition [1–3] can occur. These problems can be more severe for the plants burning a high sulfur content fuel [4]. To reduce sulfuric acid mist pollution, governments of many countries such as the USA, Germany and Singapore have issued emission standards for coal-fired power plants. In China, the local standard of Shanghai requires the emission of sulfuric acid mist $< 5\,mg/m^3$.

Sulfuric acid mist is typically formed from a combination of SO_3 with H_2O [1]. Industrial sources and coal-fired power plants are two primary sources for sulfuric acid mist emission, where SO_3 can be generated during combustion in furnace and oxidation from a selective catalytic reduction (SCR) catalyst. When fuel is burned in boiler furnace, about 1–1.5% of sulfur contained in fuel can be oxidized to gaseous SO_3. Additionally, 1–2% of SO_2 is converted to SO_3 by the catalytic effects when flue gas passes through SCR [5,6]. SO_3 remains gaseous before flue gas entering air pre-heater (APH) [7]. Alkaline injection in the furnace, or at outlets of economizer, SCR, APH or electrostatic precipitator (ESP) can significantly reduce SO_3 emissions [1]. These sorbent injection technologies can achieve very high SO_3 removal efficiency. Although the investment is relatively low, the operational costs are high, which limits their applications [8]. SO_3 can also be partially removed by wet flue gas desulfurization (WFGD). Flue gas is scrubbed to super-saturation condition by WFGD. This super-saturation gas condition leads to homogeneous nucleation and consequently results in sulfuric acid mist formation [9]. The formed sulfuric acid mists are very small sizes (sub-micron) with a high number concentration ($> 10^8/cm^3$) [2,10]. It's too fine to be physically captured by collision. Therefore, SO_3 removal efficiency in WFGD is relatively low (30–70%) [11–13].

WESPs are typically installed downstream of WFGD to remove fine particle and sulfuric acid mists from flue gases [14–16]. It can also be used to prevent aerosol formation during an amine based carbon capture process [17]. Recently, much attention has been paid on the WESP performance for sulfuric acid mist removal because of the increasingly strict emission standards. Anderlohr et al. [18] evaluated a lab-scale WESP for sulfuric acid mist removal and a maximum removal efficiency of 99.97% at an optimum voltage. Chang et al. [19] and Jeong et al. [20] investigated sulfuric acid aerosol removal with pilot-scale WESPs

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Nomenclature

$\bar{c}_{on}$	average concentration with corona discharge, mg/m^3
$\bar{c}_{off}$	average concentration without corona discharge, mg/m^3
η	removal efficiency, %
$c_{on}(r_i)$	fractional concentration with corona discharge, mg/m^3
$c_{off}(r_i)$	fractional concentration without corona discharge, mg/m^3
u/U_{max}	ratio of operation voltage to maximum voltage
j/I_{max}	ratio of operation current to maximum current
j_{max}/I_{max}	ratio of maximum operation current to maximum current
U_0/U_{max}	ratio of corona onset voltage to maximum voltage
c/c_0	ratio of measured concentration to referred concentration
c/c_{max}	ratio of measured concentration to maximum concentration
ρ	total space charge density, C/m^3
ρ_i	ionic space charge density, C/m^3
ρ_p	particle space charge density, C/m^3
J	current density in space, A/m^2
b_i	ion mobility, m^2/V/s
b_p	particle mobility, m^2/V/s
E	electric field strength, V/m
A	collection area, m^2
ω	migration velocity, m/s
Q	gas flow rate, m^3/h
q	particle charge, C
C_m	Cunningham correction factor
μ	viscosity, Pa·s
d_p	particle diameter, m
w/w_{max}	ratio of operation corona power to maximum corona power
j	current density on the collection plates, A/m^2
h	half of the distance between electrode and plate, m
ρ_g	gas density, kg/m^3
v	gas flow velocity, m/s

and concluded that removal efficiencies could be > 95%, but the gas velocity was much lower in his study and the mist size was smaller compared to the conditions of a real WESP. Although some field tests have also proved WESPs to be promising for sulfuric acid mist removal [3,14,21,22], recent results indicate that its performance could deteriorate due to plasma induced SO_2 oxidation, leading to an increasing emission for ultrafine sulfuric acid mist [17,18,23–25]. Moreover, it's very common for sulfur to be highly enriched in oils and coals in many regions. For example, the sulfur content of coals in southern China can amount to more than 4% [26]. Burning a high sulfur content fuel not only produces high SO_3 concentration in flue gases, but also results in the decreasing of SO_3 removal efficiency [4,14]. According to tests in a 660 MW coal-fired power plant, the emission of SO_3 at the stack was more than 20 mg/m^3 when the SO_3 concentration was about 140 mg/m^3 at the outlet of SCR system [27], and severe corona reduction was observed in this full scale WESP. Huang et al. [28] found that the increasing concentration of sulfuric acid mist leads to a shift in the size distribution towards larger sizes, but no further discussion about its effects on removal efficiency was made. Until now, the influence of SO_3 concentration on corona discharge was not systematically investigated, and minimal work has been conducted to reveal the correlation between current reduction and performance deterioration under high SO_3 conditions.

In this study, a pilot-scale, single field WESP experimental system was designed and operated under a simulated flue gas condition. The WESP performance was evaluated by mass concentration of SO_3 and number concentration of sulfuric acid mist, respectively. Corona discharge characteristics of the WESP were analyzed to determine the effects of SO_3 concentration on SO_3 removal efficiency. Influences of applied voltage, corona power and gas loading on SO_3 removal efficiency were investigated, experimentally, under severe corona suppression condition. Based on these results, a comprehensive method was proposed to enhance SO_3 removal efficiency to > 90% under a pilot plant condition. Some other problems emerging during our investigation were summarized and corresponding countermeasures were introduced as well.

2. Experimental setup and methods

2.1. Experimental setup

A schematic diagram of the pilot-scale, single field WESP system is shown in Fig. 1a. It consists of four main sections: (1) a SO_3 generator and a dust feeder (2) a humidifying scrubber (3) a hexagonal tube type WESP (4) and SO_3/sulfuric acid mist and dust measurement. In order to ensure the validation of the obtained results for full size boilers burning high sulfur content fuels, the experimental system was designed by selecting similar parameters with actual operating plants.

Simulated flue gas was generated by a fan drawing in ambient air and then heated from an electric heater before entering the humidifying scrubber. In a power plant application, WESPs typically operate under saturation gas conditions with gas temperatures around 50 °C. To

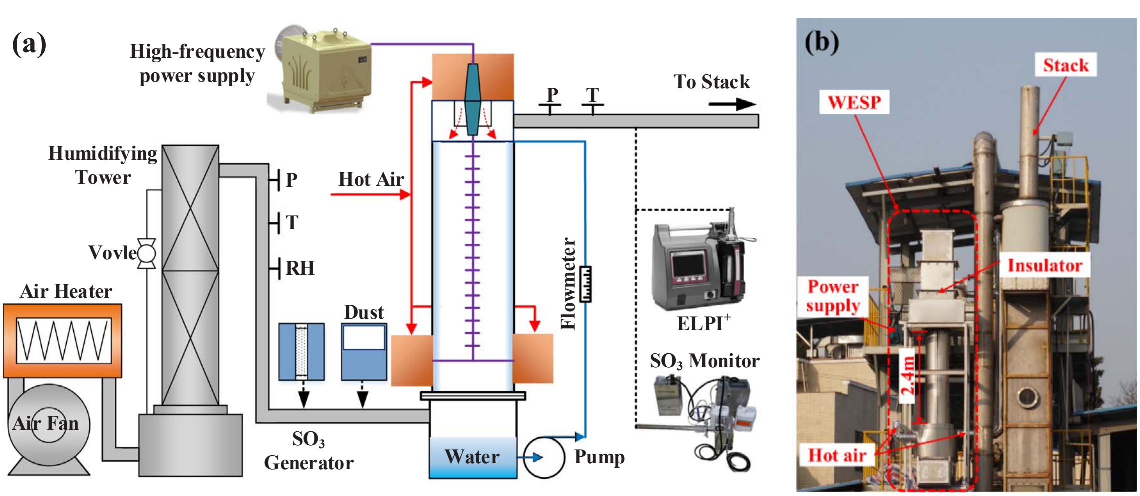

Fig. 1. Experimental system: (a) schematic and (b) photograph.