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Original Research Paper

An experimental study of ash accumulation in flue gas

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ABSTRACT

Accumulation of small particles is beneficial for dust removal. We have carried out experiments to investigate the influences of flue gas properties, especially temperature, humidity, sulfuric acid, and dust concentrations, on ash particle accumulation. The ash used was collected from an electric precipitator of a coal-fired power station. It is found that ash accumulation is strongly influenced by the flue gas temperature in comparison with the Engineering Acid Dew Temperature (EADT). With decreasing temperature below the EADT, both the sulfuric acid in flue gas and the ash humidity rise, and the collected particles weight and sizes increase. Therefore, the flue gas temperature can be controlled to enhance particle accumulation and improve ash collection efficiency.

1. Introduction

The emission of industrial waste gas and aerosol especially micro/nano particles brings great threats to the health of human beings. Not only may it affect and disable organs of human body, but also interfere with the function of human immune system [1,2]. Dust collectors are thus necessary in power plants. The collection efficiency of a dust collector is closely related to ash size. According to the study of Zhou et al. [3], a traditional dust collector was efficient to particles of diameter larger than 10 μm but inefficient to inhalable small particles of diameter between 0.1 and 10 μm. Ash accumulation is one of the most effective and economical methods for improving dust collection efficiency. Research and technological development on ash accumulation have aroused widespread interests [4].

Ultrasound was utilized to intensify the accumulation of submicron particles by de Sarabia et al. [5]. Others investigated the influence of bipolar charging on the efficiency of fine particles accumulation [6–9]. These studies found that the percentage of fine particles (0.1–1.0 μm) decreased by 17–19% due to particle accumulation. Watanabe [10] studied the electrostatic accumulation. Thonglek and Kiatsiriroat [11] observed the accumulation of submicron particles by a non-thermal plasma electrostatic precipitator and noted that the efficiency increased when the gas velocity was increased from 0.5 to 1 m/s at 45 kVp voltage and 20 kHz frequency. Tiwary and Reethof [12] and Rodriguez-Maroto et al. [13] studied the method of acoustic accumulation. Their results revealed that the accumulation caused a 20% concentration reduction for particles of diameter smaller than 1 μm. The above-mentioned studies considered particle accumulation via adjusting the operation parameters of dust collectors, such as gas velocity, voltage, and current frequency.

Recently some researchers and engineers put forward the method of decreasing the exhaust gas temperature from 120–170 °C to 90–110 °C or an even lower range in order to recover waste heat from exhaust flue gas [14]. Low-temperature dust removal technology can prevent the corona effect of an electrostatic precipitator effectively and reduce the dust emission, because the flue gas velocity declines with decreasing temperature, and the flue gas would stay in the precipitator for a longer time, which is helpful for dust removal [14]. Noda and Makino [15] investigated the influence of operating temperature on the performance of an electrostatic precipitator, and pointed out that the collection efficiency of a low-temperature electrostatic precipitator is related with Na and K contents. Ronsse et al. [16] discovered the effect of particle surface moisture on accumulation growth rate in fluidized beds through population balance modeling. As a matter of fact, flue gas properties vary with temperature. To authors' knowledge, study of the gas temperature effects on a wide range of flue gas properties affecting ash accumulation is not yet available in the literature.

In this treatise, a series experiments were conducted to investigate the influence of flue gas properties such as temperature, SO_3 volume fraction, water vapor content, and dust concentration on

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Nomenclature

A	ash
C_A	dust concentration
EADT	Engineering acid dew temperature (°C)
K	conversion rate
M	molar mass (g/mol)
P_0	local atmospheric pressure (Pa)
Q	calorific value (kJ/kg)
R	volume fraction
S	sulfur
T	temperature (°C)
V_Y	actual flue gas volume (m^3/kg)
Greek symbols	
α	excess air coefficient
α^h	fly ash coefficient
β	coefficient
ρ	density (kg/m^3)
Subscripts	
ld	dew point
sld	acid dew point
ar	as received basis
net	low calorific
Superscripts	
X	converted mass fraction

ash particle accumulation. The collected ash particle size distribution was analyzed. The Engineering Acid Dew Temperature (EADT) for the flue gas was calculated and compared with the actual gas temperature during dust collection. A focus is to lower the gas temperature below the EADT to increase ash accumulation in order to improve ash collection efficiency.

2. Description of experiments and methods

2.1. Experimental system

The experimental system used for ash collection is shown in Fig. 1. The major part is a small wind tunnel of about 8 m long with a cross section of 300 × 280 mm^2. The air duct is insulated outside to minimize heat dissipation. During experiments, the air generated from the forced fan remains constant, i.e., 383 m^3/h at 15 °C. Thus, the air mass flow rate is 0.137 kg/s. The air flows through the baffles, electric heating system, spraying system, feeding system, cooling system, accumulation section, and dust samples collector in turn. The baffles are used to adjust the air velocity in the accumulation section during pre-experiments. Once a formal experiment starts, the baffles opening remains constant.

The heating system is to heat up the air from the fan. It is composed of a 380 V three-phase power supply, a solid-stay relay, an intelligent temperature controller, 6 electric heating pipes, and a thermocouple. The temperature controller receives the signal from the thermocouple. When the air temperature at the measuring point is higher/lower than 130 °C, the controller will actuate the relay to power off/on the power supply of the heating pipes to keep the air temperature constant (130 °C).

The spraying system sprays atomized water and sulfuric acid into the heated air to adjust the air component precisely. It is composed of an anti-corrosion flow meter, a low-pressure superfine atomizing nozzle, a speed regulator, a micro high-pressure pump, and a tank. The prepared dilute sulfuric acid is sprayed into the air with average drop diameter about 20–40 μm. The flux of sulfuric acid is adjusted by the speed regulator, which can control the rotating speed of the pump. The thermocouple in the heating system locating in the downstream of the spraying system monitors the temperature and ensures that the sprayed water and sulfuric acid turn into vapor at the temperature of 130 °C. The air volume flow rate after the spray system is 535.9 m^3/h after temperature correction. Thus, the duct air velocity is about 1.77 m/s.

The feeding system feeds ash into the air. It is composed of an ash bunker, a screw feeder, a frequency converter, and an electromotor. The ash used in the present experiments was collected from an electric precipitator of a coal-fired power station in China. Now the air in the duct is changed into flue gas with the additions of water vapor, ash, and sulfuric acid vapor after flowing through the heating system, the spraying system, and the feeding system.

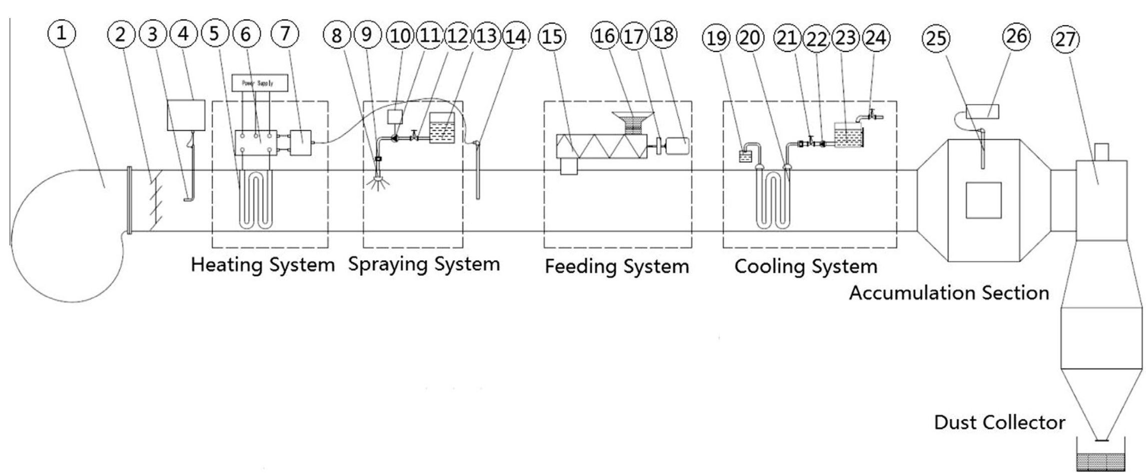

Fig. 1. Schematic diagram of the experimental system. 1-forced fan; 2-baffles; 3-pitot tube; 4-micromanometer; 5-electric heating pipes; 6-solid state relay; 7-intelligent temperature controller; 8-atomizing nozzle; 9 anti-corrosion flowmeter; 10-speed regulator; 11-mirco high-pressure pump; 12-valve; 13-sulfric acid tank; 14-thermocouple; 15-screw feeder; 16-ash bunker; 17-frenquency converter; 18-electromoter; 19-drainage; 20-heat exchanger; 21-valve; 22-circulating water pump; 23-water tank; 24-make up water valve; 25 thermocouple; 26-digital temperature indicator; 27-cyclone separator.