Dust particles precipitation in AC/DC electrostatic precipitator

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Abstract. Submicron and nanoparticles removal from flue or exhaust gases remain still a challenge for engineers. The most effective device used for gas cleaning in power plants or industry is electrostatic precipitator, but its collection efficiency steeply decreases for particles smaller than 1 micron. In this paper, fractional collection efficiency of two-stage electrostatic precipitator comprising of alternating electric field charger and DC supplied parallel-plate collection stage has been investigated. The total number collection efficiency for PM2.5 particles was higher than 95\% and mass collection efficiency >99\%. Fractional collection efficiency for particles between 300 nm and 1 \textmu m was >95\%.

1. Introduction

The efficiency of removal of dust particles smaller than a few micrometers in diameter by conventional electrostatic precipitators decreases with decreasing particle size. The electric charge on such particles is too small for the electric force to overcome air drag force that causes the particles to leave the precipitator. In order to avoid difficulties with the removal of submicron fly ash particles from exhaust gases, the charging and collection processes can be separated and accomplished in two different stages. Two types of such devices can be distinguished: electrostatic scrubber and two-stage electrostatic precipitator. In electrostatic scrubbers [1], the charged particles are deposited onto oppositely charged water droplets. In two-stage electrostatic precipitators [2-7], the particles pass through the charging stage, where they are charged by ionic current, and next, enter the precipitation stage, which is usually formed by two parallel plates at opposite potential, where they are collected. Additional advantage of such device is that it is free of back discharge due to lack of ionic current in the precipitation stage.

Two-stage electrostatic precipitator was first investigated by White [2] and applied by Masuda et al. [3,4], which used the boxer charger [5] to charging and control the emission of high-resistivity dust. Later, nozzle charger equipped with corona electrodes, corona-triode charger, quadrupole precharger, and alternating electric field charger were used as the charging stage by various authors [6-8].

In this paper, fractional collection efficiency in PM2.5 range of laboratory scale, two-stage AC/DC electrostatic precipitator, with alternating electric field charger (AC stage) and DC supplied precipitation stage, is investigated. In alternating electric field charger [9,10], the particles are charged by ionic current in alternating electric field, and the charge imparted to the particles can be higher than for DC chargers. The precipitation stage has no discharge electrode, and the precipitation occurs due only to electrostatic field between the electrodes that reduces power consumption by precipitator.
2. Experimental

The measurements were carried out in experimental stand shown schematically in Figure 1. The charger consisted of two discharge electrodes comprising of 104 stainless steel pins 0.6 mm in diameter and 5 mm long, mounted to brass sheet. Between the discharge electrodes, two parallel grids 140 mm high and 160 mm long, made of 9 stainless steel rods, 2 mm in diameter spaced 20 mm from each other were placed. The distance between the grids was 50 mm, and between each grid and the tip of pins - 45 mm. The space between the grids formed the charging zone. The electrodes were supplied from two high voltage transformers through the circuit made of diodes and resistors [7]. The ionic current emitted by discharge electrode at negative potential flow through the nearby grid, which was at ground potential, and through the charging zone between the grids, to the opposite grid at positive potential. The role of discharge electrodes and potential of the grids changed alternately in every half-cycle of supply voltage. The particles flowing through the charging zone are charged, and leave the charger as charged particles. The alternating electric field existing within the charging zone causes charged particles to oscillate, and partially to agglomerate during their motion, but prevents them from migrating to the charger electrodes. Two parallel-plates electrodes were used in the collection stage. The electrodes, 140 mm high and 340 mm long, were made of brass sheet. The distance between them was 80 mm. One of these plates was connected to high voltage power supply (SPELMANN HV model SL600W/30kV/P), and the other was grounded. The alternating electric field charger and collection electrodes were placed in a channel of square cross section of 160x160 mm, made of PMMA. A flow straightener was mounted at the inlet of the channel to eliminate air vortices. The airflow through the channel was forced by a suction fan placed at its outlet. The experiments were carried out for MgO test particles of mass mean diameter of about 2.8 μm. The particles were dissolved in methanol forming a colloidal suspension and stirred for at least 1 hour. The solution was sprayed by Aerosol Generator ATM 226 (TOPAS) and injected to the channel at its inlet. The concentration of particles was measured at the outlet of the channel using Aerosol Particle Size Spectrometer LAP 322 (TOPAS). The air flow velocity in the channel was measured by hot wire anemometer TSI model 8455.

![Figure 1. Schematic of experimental set-up of two-stage electrostatic precipitator with alternating electric field charger.](image)

3. Results

Size distributions of particles at the outlet of AC/DC precipitator for AC and DC voltages switched OFF and ON are shown in Figure 2. The number concentration of particles for switched-off voltages varied between 8000 and 10000 #/cm$^3$. When both AC and DC voltages were ON, the total concentration decreased below 500 #/cm$^3$. The maximum in particle number size distribution for voltages OFF was about 350 nm and it decreased to about 250 nm during precipitator operation. The volume mean diameter decreased from 2.82 μm to 1.44 μm.
Figure 2. Number size distribution of particles leaving AC/DC precipitator for AC and DC voltages switched OFF and ON.

Fractional collection efficiency of two stage AC/DC electrostatic precipitator was determined from the measurements of size distribution of particles, from the ratio of particles concentration in each class when the voltages were switched ON \( n_{on} \) to that when the voltages were switched OFF \( n_{off} \).

\[ \eta = 1 - \frac{n_{on}}{n_{off}} \]  

(1)
The fractional collection efficiency of AC/DC electrostatic precipitator is higher than 95% for particles larger than 1 µm, and drops below 90% for particles smaller than 300 nm. These results are higher than for conventional electrostatic precipitators. The measurements have been carried out for two gas velocities: 0.35 and 0.5 m/s, for AC voltages of 12 kV and 15 kV, and DC voltage between plate electrodes in precipitation stage of 20 kV. The total number collection efficiency was higher than 95% and mass collection efficiency >99 wt.% for AC voltage of 12 kV at the charger electrodes and 20 kV-DC in the collection stage. For 15 kV the collection efficiency was slightly lower (93% and 98 wt.%, respectively), due probably to particle re-entrainment from the collection electrodes because of high electric field between them [7].

4. Conclusions
Fractional collection efficiency of two-stage electrostatic precipitator has been determined experimentally. Alternating electric field charger was used as a particles charging and agglomerating unit in two-stage electrostatic precipitator, which allows effective charging of particles to high electric charge. Parallel-plate collection electrodes, free of corona discharge have been used for the removal of charged particles leaving the particle charger. In this system, the number collection efficiency for particles larger than 1 µm was higher than 95%, but it dropped below 90% for particles smaller than 300 nm. Mass collection efficiency of this system was >99% for PM2.5 particles.

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