Submicron particles emission control by electrostatic agglomeration

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Abstract An alternating electric field charger/agglomerator, in which particle charging and their coagulation occurs in one stage, is presented in this paper. The charger/agglomerator is based on an alternating electric field charger formed by a set of two discharge electrodes separated by a set of two parallel grids by each side of the discharge electrodes. The particles are charged by ionic current in alternating electric field that allows the charge imparted to the particles to be higher than for DC chargers. Due to oscillatory motion of the particles between the electrodes, particles of different mobilities can collide and coagulate. Number fractional collection efficiency of PM2.5 particles in semi-industrial scale, two-stage charger/agglomerator with precipitator section was higher than 90%.

Keywords: Electrostatic precipitation, submicron particles, particles agglomeration, PM removal

1. Introduction

Well known drawback of electrostatic precipitators is its minimum collection efficiency in the submicron (0.1-1 µm) size range. Larger particles are easily removed due to high electrostatic forces on electrically charged particles, while smaller than 100 nm are deposited onto the larger ones due to diffusion and electrophoresis forces or Brownian motion. The electric charge on submicron particles is too small for the electric force to overcome gas drag force while phoretic forces and Brownian motion are too weak to cause the particles to coagulate with the larger ones and those particles leave the precipitator to the atmosphere.

In order to avoid difficulties with the removal of submicron fly ash particles from exhaust gases, the agglomeration processes have been proposed and many types of agglomerators have been constructed. In electrostatic agglomerators, charging, coagulation and collection processes are usually separated and accomplished in two or three different stages [1–6]. For example, the particles first pass through two parallel electrostatic chargers, in which they are charged to opposite polarities, next they are mixed and coagulated in DC or AC electric field, and after that enter to a precipitator. In another version, the particles are charged in a unipolar electrostatic charger and enter the coagulation stage between two parallel plates between which alternating electric field is formed, and finally to the precipitation stage, where they are collected.

In this paper, an alternating electric field charger/agglomerator, in which particle charging and their agglomeration is accomplished in one stage is investigated. Fractional collection efficiency of PM2.5 particles in a semi-industrial scale, two-stage agglomerator/precipitator has been measured. The number collection efficiency for PM2.5 particles was higher than 95%.

2. Experimental

The measurements were carried out in experimental stand shown schematically in Figure 1. Air flowing into the channel was filtered by HEPA filters placed at channel inlet. After the filter, an electric air heater was mounted to control the temperature of gas in the range from 20°C to 100°C. The temperature was measured directly after the heater and at the channel outlet by PT100 thermometers. The airflow through the channel was forced by a suction fan placed at outlet of the system. The air flow velocity was measured by vortex flowmeter Prowirl F 200 made by Endress & Hauser. The flow velocity can be changed in the range from 0 to 1 m/s. The particles were injected to the channel after the air heater by a dust feeder with adjustable feed rate from 1 to 2.7 kg/h.

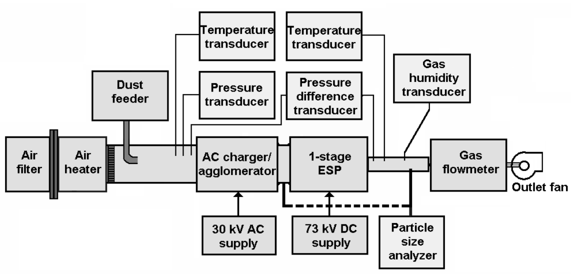

Figure 1. Schematic of experimental stand of agglomerator /precipitator

Schematic of electrodes configuration is presented in Fig. 2 and side-view photography of experimental charger/agglomerator electrodes during operation is shown in Fig. 3. Electrodes of agglomerator covered by fly-ash are shown from the side window in the wall of the channel.

The one-stage AC charger/agglomerator is based on an alternating electric field charger [7] formed by a set of two discharge electrodes separated by a set of two parallel grids by each side of the discharge electrodes. Two additional grids outside this electrode system are used for keeping symmetrical emission of the current by the discharge electrodes to each side. In this type of charger, 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 alternating electric field in the agglomerator forces the charged particles to oscillate, and partially to agglomerate during their motion, but prevents their motion towards the electrodes. Due to the oscillatory motion of the particles between the electrodes only small amount of the particles is precipitated in this stage.

The precipitation stage is a conventional electrostatic precipitator with discharge electrodes placed in the plane of symmetry between two parallel collection electrodes.

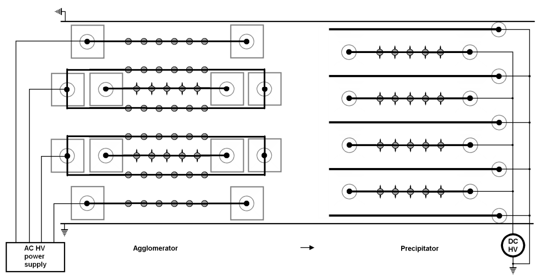

Figure 2. Schematic of experimental charger /agglomerator and precipitator (top view)

Figure 3. Electrodes of experimental agglomerator (covered by fly-ash)

The charger/agglomerator and precipitator have been placed in a channel of about 1 m width and 0.6 m height made of steel. The discharge electrodes of AC charger/agglomerator consisted of 10 rods 350 mm long comprising of 7 stainless steel discharge points at each side of the rod. Each grid was formed by 11 stainless steel rods 350 mm long. 10 mm in diameter spaced at 125 mm from each other. The distance between the plane of grids and between the grids and discharge electrodes was 125 mm. The space between the central grids formed the charging zone. The electrodes in charger/agglomerator section were supplied from two high voltage transformers Arteche UCN-36 (36 kV) through the circuit made of diodes and resistors [7]. In each half-cycle of supply voltage, the ionic current emitted by the discharge electrode maintained at negative potential flows through the nearby grid, which is at ground potential, and through the charging zone between the grids, to the opposite grid at positive potential. The potential of the grids and discharge electrodes change alternately in every half-cycle of supply voltage, and the role of the electrodes also changes. The particles flowing through the charging zone are charged, and leave the charger as charged particles. Because of the oscillatory motion, the particles of different mobilities collide and coagulate, increasing mean size in their size distribution.

The particles leaving the charger/agglomerator section were next collected in the precipitator section. The precipitator section was supplied from DC HV source made by ZWARPOL (60 kV).

A photograph of thermally insulated channel with experimental AC charger/agglomerator section and precipitator is presented on Fig. 4.

Figure 4. Photograph of experimental channel. In foreground is the one-stage electrostatic precipitator and at the background, the charger/agglomerator

The experiments were carried out for fly ash particles collected from 3rd stage of electrostatic precipitator of a coal fired power plant. SEM micrograph of fly-ash particles used in the experiments is shown in Fig. 5 EDS spectrum of fly-ash particles obtain by EDS Bruker Qantax-400 is presented in Fig. 6 and their elemental composition in Fig. 7. Most of the particles were spherical that is characteristic of fly ash from coal fired boilers and their size was smaller than 2.5 μm. Fly-ash particles are composed mainly of silicon, aluminium, potassium, iron, magnesium, sodium, oxygen (which forms oxides with those elements).

The particles volume size distribution is shown in Fig. 9, and particles number size distribution in Fig 10. The mean diameter of the particles was about 1.5 µm and Sauter mean diameter 3.3 µm. The concentration of particles was measured at the outlet of the channel using Aerosol Particle Size Spectrometer LAP 322 (TOPAS) with dilution system 1:100. Samples of dust were collected via isokinetic probe. All measuring signals were recorded by recorder RSG 40 Memograph M made by Endress &Hauser.

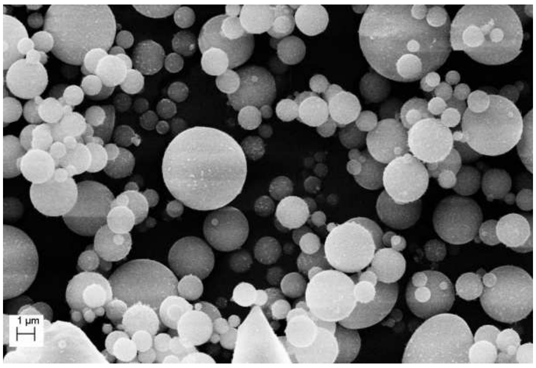

Figure 5. SEM micrograph of fly-ash particles used in the experiments (SEM Zeiss EVO 40)

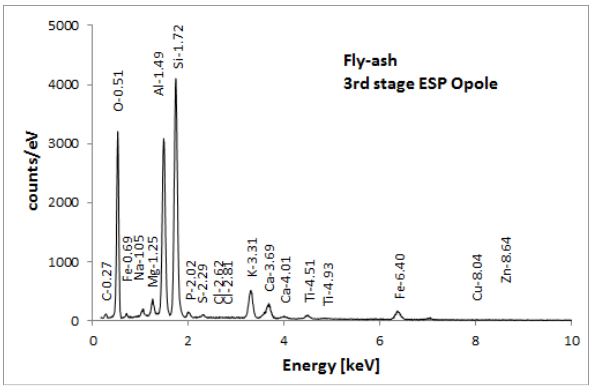

Figure 6. EDS spectrum of fly-ash particles used in the experiments (EDS Bruker Qantax-400)

Element	[norm. wt.%]	norm. at.%	Error in %
Oxygen	48.19	61.02	5.88
Silicon	20.02	14.44	0.88
Aluminium	15.88	11.92	0.79
Potassium	3.66	1.90	0.14
Iron	3.09	1.12	0.12
Carbon	3.04	5.13	0.84
Magnesium	1.69	1.41	0.13
Sodium	1.17	1.03	0.11
Calcium	1.15	0.58	0.06
Phosphorus	0.66	0.43	0.06
Titanium	0.57	0.24	0.05
Fluorine	0.52	0.55	0.21
Sulfur	0.32	0.20	0.04
Copper	0.03	0.01	0.01

Figure 7. Elemental composition of fly-ash particles used in the experiments

3. Results

An example of current voltage characteristics of the charger/agglomerator is shown in Fig. 8. The characteristic present the discharge current from both discharge electrodes (A1 and A2) vs. voltage between the electrodes. The characteristics obey the Townsend law.

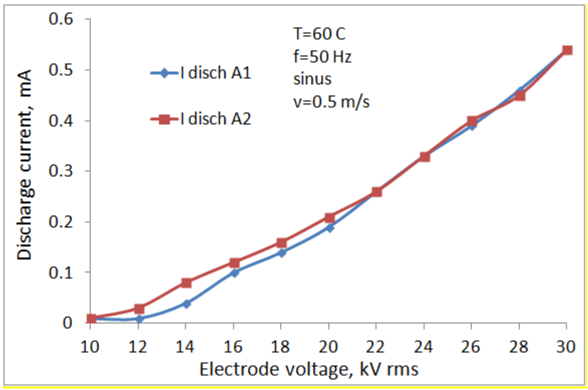

Figure 8. Current-voltage characteristics of AC Charger/Agglomerator with dust loading of 1.5 kg/h

Volume and number size distributions of particles at the outlet of AC charger/agglomerator and one-stage electrostatic precipitator for AC and DC voltages switched OFF and ON are shown in Figs. 9 and Fig. 10, respectively.

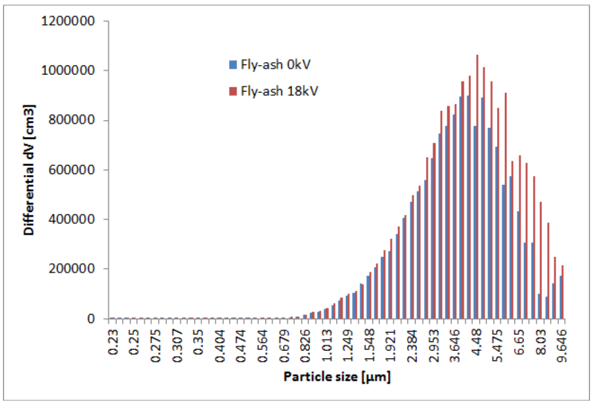

Figure 9. Particle volume size distribution of fly-ash particles after AC charger/agglomerator for AC voltage ON (18 kV) and OFF (0 kV)

The number concentration of particles for switched-OFF voltages varied between 10000 and 14000 #/cm^3. When AC voltages were ON, the total concentration of particles decreased below 8000 #/cm^3. The maximum size of particles in volume particle size distribution for the voltage OFF was about 3.7 µm and it increased to about 4.5 µm during AC charger/agglomerator operation.

Fractional penetration of particles through the AC charger/agglomerator precipitator has been determined in experimentally. 60-70% of the particles is passing the charger/agglomerator with 20 kVAC for gas velocity 0.8 m/s and next is precipitated by the electrostatic precipitator (Fig. 11). The alternating electric field in the agglomerator forces the charged particles to oscillate, and partially to agglomerate during their motion, but prevents their precipitation onto the electrodes. Due to the oscillatory motion of the particles between the electrodes only small amount of the particles is precipitated in this stage.

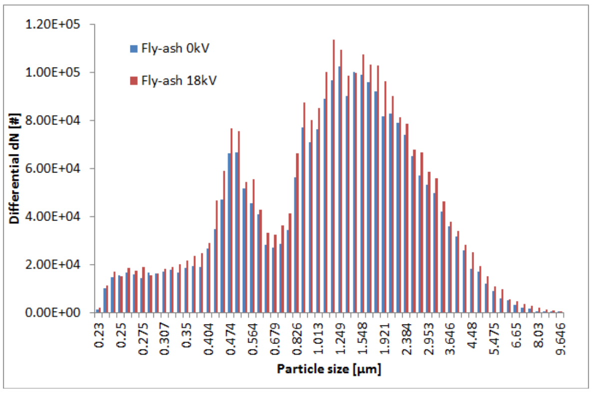

Figure 10. Particle number size distribution of fly-ash particles after AC charger/agglomerator for AC voltage ON (18 kV) and OFF (0 kV)

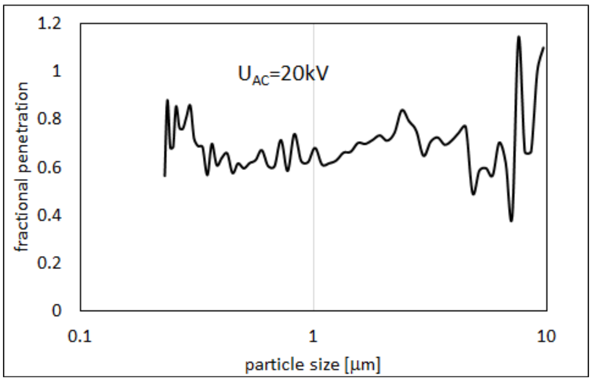

Figure 11. Fractional penetration of particles through the AC charger/agglomerator supplied with 20 kVAC for air velocity 0.8 m/s

Fractional collection efficiency of particles through the AC charger/agglomerator and one-stage electrostatic precipitator has been determined experimentally. In Fig. 12 an example of fractional collection efficiency of AC DC precipitator system for air velocity 0.5 m/s is presented. 70% of the particles of size below 1µm is precipitated in AC/DC ESP and up to 95% of the particles of size between 1 µm to 10 µm.

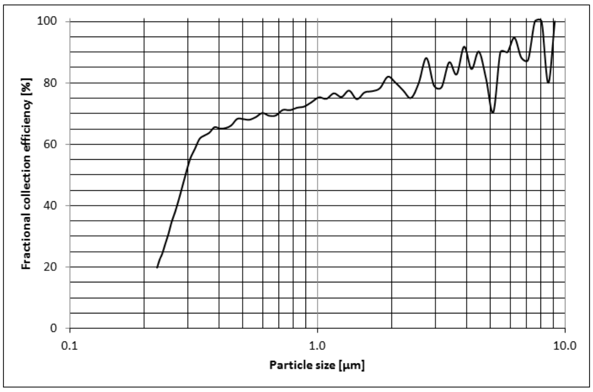

Figure 12. Fractional collection efficiency of agglomerator/precipitator for air velocity 0.5 m/s

4. Conclusions

Alternating electric field charger/agglomerator was used for control of PM2.5 fly ash particles emission. In this type of charger/agglomerator, charging and agglomerating of particles is accomplished in one unit. This device can operate as a charging stage in two-stage electrostatic precipitator. This configuration allows effective charging of particles to high electric charge their partial agglomeration in the alternating electric field and removal from the gas in a precipitator stage. In this system, the number collection efficiency for PM2.5 particles was higher than 90%, but for PM1 it gradually decreased below 90%. Mass collection efficiency of this system for PM2.5 particles was > 95%.

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