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Submicron particles emission control by electrostatic agglomeration

Abstract. *Electrostatic precharger/agglomerator based on AC electric field charging principle is presented in this paper. The device is formed by a set of two discharge electrodes separated by a set of two parallel grids placed at both sides of each discharge electrode. The particles are charged by ionic current emitted by the discharge electrodes and flow in transversal alternating electric field generated by the grids. Because of oscillatory motion of the particles, particles of different mobilities can collide and coagulate. Number collection efficiency of PM2.5 particles was higher than 93%.*

Streszczenie. *W artykule przedstawiono elektryzator/aglomerator zbudowany na bazie elektryzatora przemiennonapięciowego. Urządzenie składa się z dwóch zestawów elektrod wyładowczych oddzielonych dwiema równoległymi siatkami umieszczonymi po obu stronach elektrod wyładowczych. Przepływające cząstki są ładowane prądem jonowym emitowanym z elektrod wyładowczych w poprzecznym zmiennym polu elektrycznym. Cząstki poruszające się ruchem oscylacyjnym zderzają się i koagulują. Skuteczność oczyszczania cząstek PM 2.5 jest większa od 93%.* ***Elektryzator/aglomerator zbudowany na bazie elektryzatora przemienno-napięciowego***

Keywords: Electrostatic precipitation, submicron particles, particles agglomeration, PM removal
Słowa kluczowe: Odpylanie elektrostatyczne, cząstki submikronowe, aglomeracja cząstek, usuwanie cząstek

1. Introduction

Well known drawback of electrostatic precipitators is its minimum collection efficiency in the submicron (0.1-1 μm) size range [1, 2]. 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, and phoretic forces and Brownian motion are too weak to cause the submicron 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 [3-8]. For example, the particles first pass through two parallel electrostatic prechargers, in which they are charged to opposite polarities, next they are mixed and coagulated in DC or AC electric field, and after that enter a precipitator in which they are removed from the gas. In another version, the particles are charged in a unipolar electrostatic precharger 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 electrostatic precharger/ agglomerator based on alternating electric field charging principle, 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 precharger/agglomerator followed by an electrostatic 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 gas flow through the channel was forced by a suction fan placed at outlet of the system. The gas 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.

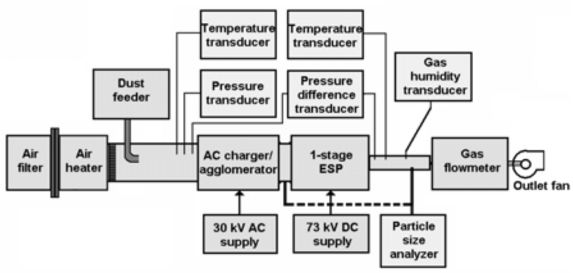


Fig. 1. Schematic of experimental stand of AC precharger/agglomerator and electrostatic precipitator.

Schematic of electrodes configuration in the precharger/agglomerator and electrostatic precipitator sections is presented in Fig. 2, and the side-view photography of experimental precharger/agglomerator electrodes during operation (covered by fly-ash) is shown in Fig. 3. Electrodes of precharger/ agglomerator are photographed through the side window in the wall of the channel.

The one-stage AC precharger/agglomerator is based on an alternating electric field charger [9] 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 precharger/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 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.

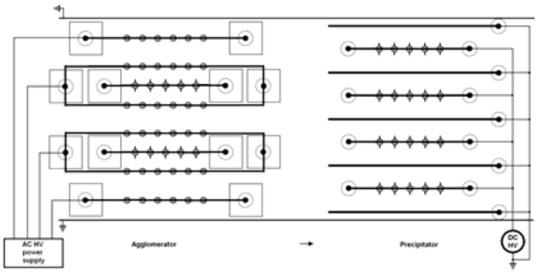


Fig. 2. Schematic of experimental precharger/agglomerator and precipitator (top view).

Fig. 3. Electrodes of experimental precharger/agglomerator (covered by fly-ash)

The precharger/agglomerator and precipitator have been placed in a channel of about 1 m wide and 0.6 m high made of steel. The discharge electrodes of AC precharger/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 precharger/agglomerator section were supplied from two high voltage transformers Arteche UCN-36 (36 kVrms) through the circuit made of diodes and resistors [9]. 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 precharger/agglomerator section were next collected by the electrostatic precipitator section. The precipitator section was supplied from DC HV source APP ModuPowerTM (60 kV, 150 mA).

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

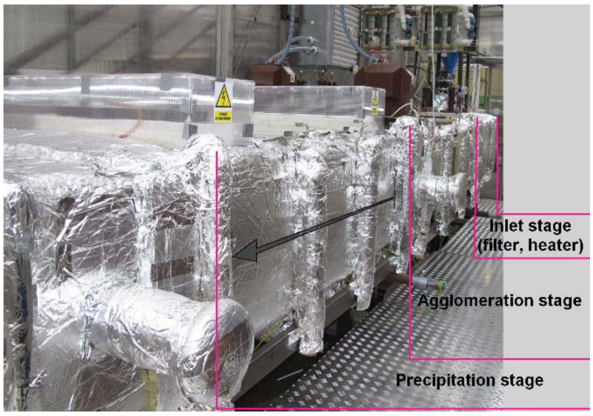


Fig. 4. Photograph of experimental channel. In foreground is the one-stage electrostatic precipitator and at the background, the precharger/agglomerator.

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 obtained 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, aluminum, potassium, iron, magnesium, sodium, oxygen (which forms oxides with those elements).

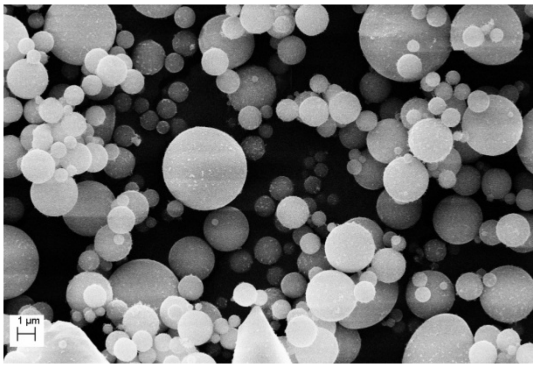


Fig. 5. SEM micrograph of fly ash particles used in the experiments (SEM Zeiss EVO 40).

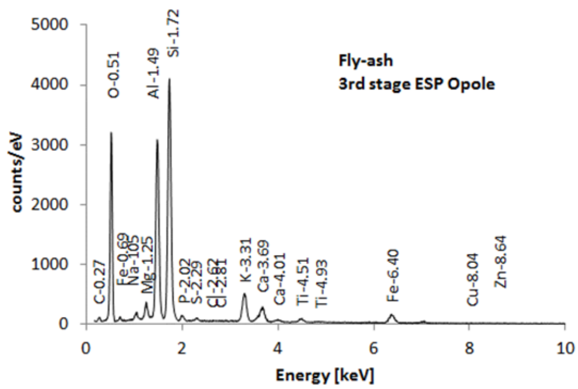


Fig. 6. EDS spectrum of fly ash particles used in the experiments (EDS Bruker Qantax-400).

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.

Table 1. Elemental composition of fly ash particles used in the experiments.

Element	[wt.%]	[at.%]	Error %
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

3. Results

An example of current voltage characteristics of the precharger/agglomerator is shown in Fig. 7. The characteristics present the discharge current from both discharge electrodes (A1 and A2) separately vs. voltage between the electrodes, when gas was loaded with fly ash. The characteristics obey the Townsend law.

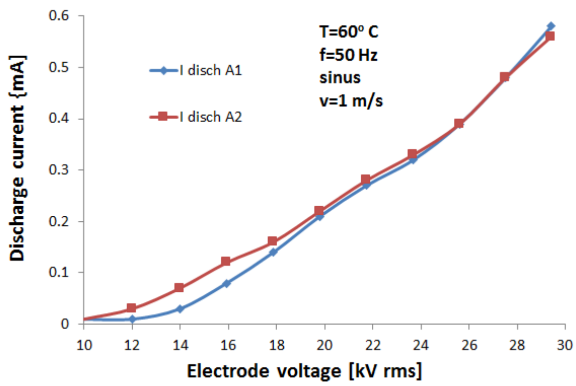
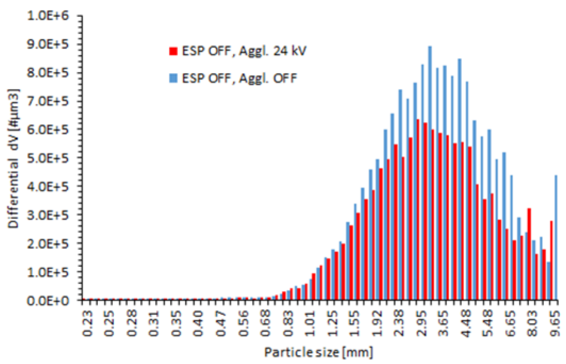


Fig. 7. Current-voltage characteristics of AC Precharger / agglomerator with dust loading of 1.5 kg/h.

volume and number size distributions of particles at the outlet of precharger/agglomerator and one-stage electrostatic precipitator, for AC voltage switched ON (24 kV) and OFF, are shown in Figs. 8a) and 8b), respectively. Electrostatic precipitator was OFF during these measurements.

a)



b)

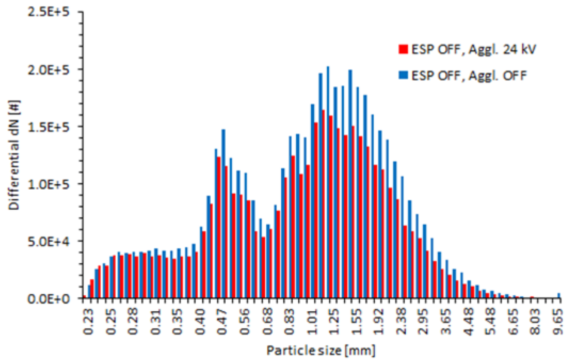
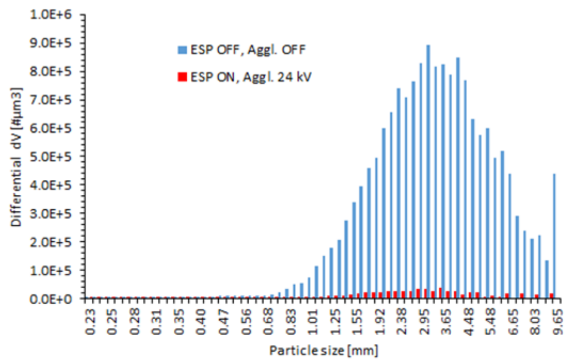


Fig. 8. Particle a) volume and b) number size distribution of fly-ash particles after AC precharger/agglomerator for AC voltage ON (24 kV_{rms}) and OFF. ESP is OFF. Gas velocity 0.5 m/s, temperature 100°C.

a)



b)

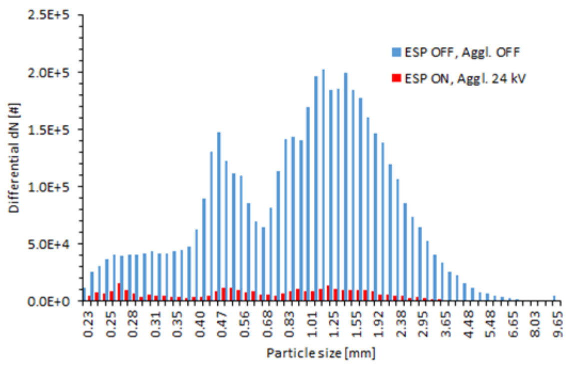


Fig.9. Particle a) volume , b) number size distribution of fly-ash particles at the outlet of AC precharger/agglomerator for AC voltage ON (24 kV_{rms}) and OFF. Gas velocity 0.5 m/s, temperature 100°C.

The number concentration of particles varied between 10000 and 14000 #/cm3 for switched-OFF voltages. When AC voltage at precharger/agglomerator was ON, the total concentration of particles decreased below 8000 #/cm3. 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 precharger/agglomerator operation.

The volume size distribution of fly-ash particles at the outlet of electrostatic precipitator with AC precharger/agglomerator switched ON (AC voltage 24 kVrms) and switched OFF is shown in Figs. 9a) and 9b), respectively. The mean diameter of particles for all voltages OFF was about 1.26 μm and it decreased to about 0.9μm during precharger/agglomerator operation.

Fractional penetration of particles through the AC precharger/agglomerator with electrostatic precipitator OFF has been determined in experimentally (Fig. 10). 70-80% of the particles is passing the precharger/agglomerator supplied with 24 kVrms, for gas velocity of 0.5 m/s. 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.

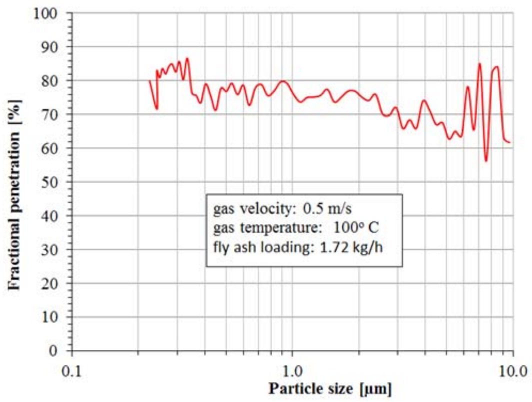
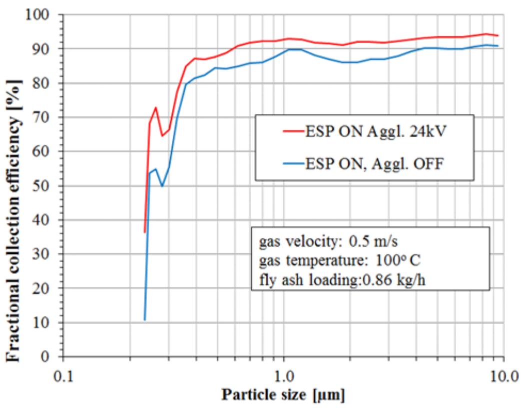


Fig. 10. Fractional penetration of particles through the AC precharger/agglomerator supplied with 24 kV_{rms} for gas velocity 0.5 m/s.

a)



b)

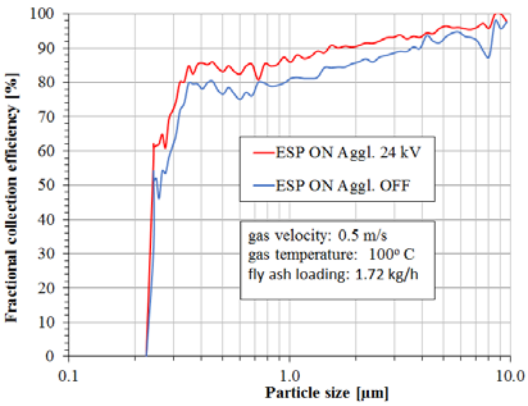


Fig. 11. Fractional collection efficiency of electrostatic precharger/agglomerator and electrostatic precipitator for gas velocity 0.5 m/s.

Fractional collection efficiency of particles through the AC precharger/agglomerator and one-stage electrostatic precipitator has been determined experimentally. In Fig. 11a) and 11b) are shown examples of fractional collection efficiency of the precipitator system for gas velocity 0.5 m/s, and for fly ash loading of 0.86 kg/h and 1.72 kg/h, respectively, when electrostatic precharger/ agglomerator is switched ON and OFF. More than 70% of the particles of the size below 1 µm (PM1) is precipitated in this system and up to 95% of the particles of size between 1µm to 10 µm.

Fig. 12 shows an increase in fractional collection efficiency of the system when electrostatic precharger/agglomerator was ON related to the case when only electrostatic precipitator was in operation, for gas temperature of 100°C. For the particles of size smaller than 0.3 µm, the fractional collection efficiency increases by about 25%, after switching ON the precharger/agglomerator system.

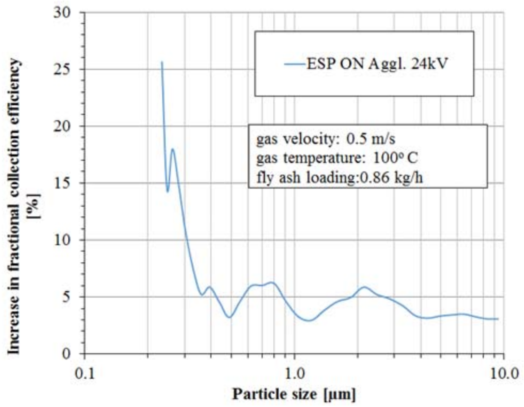


Fig. 12. Increase of fractional collection efficiency in electrostatic precharger/agglomerator and electrostatic precipitator system after switching ON the precharger/agglomerator. Agglomerator voltage 24kV_{rms}. Gas velocity 0.5 m/s. Gas temperature 100°C.

An effect of magnitude of supply voltage of precharger/agglomerator on the collection efficiency for PM1 and PM 2.5 particles is shown in Fig.13. The collection efficiency for PM 2.5 particles is above 93% and for PM1 about 90%.

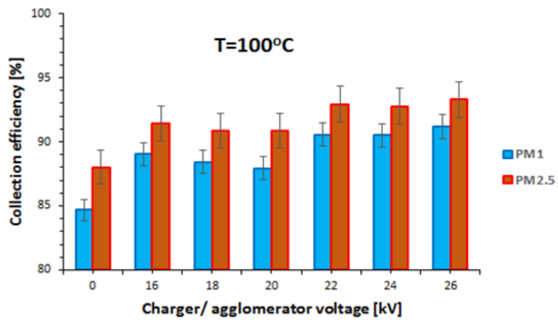


Fig. 13. The effect of supply voltage on the collection efficiency for PM1 and PM 2.5 particles. Gas velocity 0.5 m/s, temperature 100°C

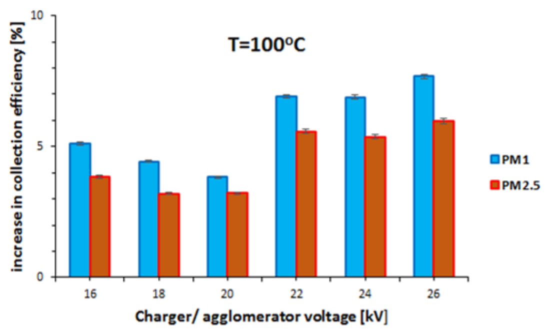


Fig. 14 The effect of supply voltage on an increase of the collection efficiency for particles PM1 and PM2.5. Gas velocity 0.5 m/s, temperature 100°C.

An effect of supply voltage of precharger/agglomerator on an increase of collection efficiency for PM1 and PM 2.5 particles (difference between aglomerator is OFF and ON) is shown in Fig.14. The electrostatic precharger/agglomerator causes and increase in the collection efficiency for PM1 particles from 5% to 10%.

4. Conclusions

Alternating electric field precharger/agglomerator was used in order to increasing the collection efficiency of PM2.5 fly ash particles by electrostatic precipitator. In this type of precharger/agglomerator, charging and agglomeration of particles is accomplished in one unit. This device can operate as a charging stage in two-stage electrostatic precipitator for increasing the PM2.5 fractional collection efficiency. This type of precharger/agglomerator allows effective charging of particles to high electric charge magnitude with simultaneous their partial agglomeration in the alternating electric field. Such particles are removed with higher efficiency from the gas than in a conventional electrostatic precipitator. In the system tested, the number collection efficiency for PM2.5 particles was higher than 93%, but for PM1 it gradually decreased below 90%. Mass collection efficiency of this system for PM2.5 particles was >95%. The stage of precharger/agglomerator allows to increase the collection efficiency from 5% to 10% for particle PM1.

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