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Electrostatic agglomeration of fly ash particles for hybrid gas cleaning devices.

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Abstract. The paper presents experimental results of the investigation of agglomeration of PM2.5 fly ash particles with larger particles in an electrostatic agglomerator. SEM micrographs of the obtained agglomerates shown that a single particle of the size of 10-20 μ m can collect more than 20-50 PM2.5 particles in this type of agglomerator. The experiments were carried out in a semi-industrial scale channel of a cross section of about 600 mm height and 1100 mm width. The agglomerator can be used as a particle precharger in a hybrid system or as the first stage in a two-stage electrostatic precipitator, in order to increase their total collection efficiency.

1. Introduction

Conventional gas-cleaning devices, such as cyclones, scrubbers, electrostatic precipitators or bag filters, can remove particulate matter from flue gases with high mass collection efficiency, but their performances in submicron size range are insufficient regarding more stringent environmental protection regulations. Submicron and nanoparticles are of particular interest because the concentration of heavy metals in those particles is higher than in larger ones. One of the possible solutions to the challenge of increasing the collection efficiency for these particles are hybrid systems, which combine various gas cleaning methods in a single device, for example, electrically energized fibrous filters or hybrid electrostatic precipitators [1]. Another solution, which can further improve performances of those devices is the process of agglomeration of fine particles to larger agglomerates [2]. These agglomerates can be removed by the same device with higher collection efficiency than the primary fine particles.

The purpose of this paper is to investigate the process of agglomeration of PM2.5 fly ash particles with larger particles present in the same fly ash, in a new type of electrostatic agglomerator. In this type of unipolar kinematic agglomerator, the processes of particle charging and agglomeration occur simultaneously in the same single device. The unipolar agglomeration means that all particles are charged to the same polarity, in opposite to a bipolar agglomeration process, by which Coulomb attraction forces between oppositely charged particles is employed. The kinematic agglomeration means that two particles flowing in the gaseous phase are promoted to collide due to differences in their mobility. In the developed agglomerator, charged particles flowing between two electrodes, which produce an alternating electric field, oscillate perpendicular to the gas flow direction, and are charged by ion current generated by other two discharge electrodes. Following the Pauthenier and Arendt-Kallmann equations, larger particles (>5 μ m) are highly charged, (to pC), while small particles (<1 μ m) to a couple of elementary charges only. For this reason, larger particles oscillate with large amplitude perpendicular to the gas flow and collect the submicron and nanoparticles during their motion [3].

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2. Experimental

A scheme of experimental set-up is shown in figure 1. The stand comprised of rectangular channel made of construction steel with a width of 112 cm, height of 62 cm and total length of 6.4 m. The agglomerator was located in the middle of the length of this channel. The agglomerator consisted of two discharge electrodes and six grids arranged in the manner shown in figure 1. The grids adjacent to the channel walls were used to maintain symmetric electric field distribution by both sides of each discharge electrode. Each discharge electrode was assembled from 5 stainless steel rods distributed with a pitch of 250 mm, equipped with 4 spikes at both sides of the rod, parallel to the gas flow. The diameter of rods was 10 mm and their height 350 mm. The diameter of spikes was 3 mm and cone angle of about 45°. Each grid comprised of 11 stainless steel rods, 10 mm in diameter, 350 mm high, 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 length of the agglomerator electrodes was about 1.25 meters. The AC voltage of frequency of 50 Hz applied to the agglomerator electrodes was changed in the range from 10 kV to 28 kV. The detailed description-of the agglomerator construction was presented in reference [4].

The inlet air was sucked to the channel through a HEPA filter and the air temperature was controlled by a heater of a power of 44 kW, in the range between 80 and 100° C. Fly ash was dispersed with mass flow rate of 1.72 kg/h to the flowing air by a feeder. The gas velocity in the channel was set to 0.8 m/s. The gas flow rate was measured with Prowirl F 200 (Endress & Hauser) mounted at the channel outlet before a suction fan. The temperature at the inlet and the outlet of the system was measured with PT100 thermometer (Endress & Hauser). The pressure in the channel was measured with pressure transducer Cerabar T PMC131 (Endress & Hauser). The particle concentration and size distribution were measured by laser aerosol particle sizer LAP 322 (TOPAS) in the range from 0.24 to 10 μ m, in 64 size classes. The particles were sampled by the sizer with a flow rate of 3 l/min by an isokinetic probe located in the center of the channel cross section, 2 meters behind the agglomerator.



Figure 1. Scheme of experimental setup.

3. Results

Fly ash used in these experiments was collected from a second field of an electrostatic precipitator in a hard coal fired power plant in Poland. Before measurements, the fly ash was dried in an oven at a temperature of about 150°C for 1.5 h. The morphology of fly ash particles collected at the agglomerator outlet was investigated with scanning electron microscope EVO-40 (Zeiss).

Time-averaged current-voltage characteristic of electrostatic agglomerator is shown in Figure 2. The corona onset voltage for electrostatic agglomerator was about 9 kV.

The charge of particles may be estimated using the rate of charging equations determined by Arendt and Kallmann, and Pauthenier, for diffusion and field charging, respectively [5]:

$$\frac{d}{dt}Q_p\left[1 + \frac{\pi\epsilon_0 \langle v_i \rangle d_p^2}{4b_i Q_p}\right] = \frac{\pi}{4}en_i \langle v_i \rangle d_p^2 exp\left(-\frac{eQ_p}{2\pi\epsilon_0 d_p^2 kT}\right),\tag{1}$$

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$$\frac{d}{dt}Q_p = \frac{3}{4}\pi n_i e b_i E d_p^2 \frac{\varepsilon_r}{\varepsilon_r + 2} \left[1 - \frac{Q_p(\varepsilon_r + 2)}{3\pi \varepsilon_0 \varepsilon_r E d_p^2} \right]^2, \tag{2}$$

where Q_p is the charge on the particle, *t* is the time, ε_0 is vacuum permittivity, $\langle v_i \rangle$ mean kinetic energy of gaseous ions, d_p is the diameter of the spherical particle, b_i is the gaseous ions mobility, *e* is the elementary charge, n_i is the concentration of gaseous ions in the charging zone, *k* is the Boltzmann's constant, *T* is the absolute gas temperature, *E* is the electric field, and ε_r is the dielectric constant of the particle.

The particle charge determined for the existing experimental conditions, as the sum of charges resulting from equations (1) and (2) vs. voltage applied to the electrodes is shown in figure 3. The charge of a particle of size of 1 μ m changed from about 1.7x10⁻⁵ pC (i.e. about 100*e*) for 10 kV to 2.7x10⁻⁵ pC for 28 kV. For particle of a size of 10 μ m the theoretical particle charge was more than one order of magnitude higher than for a particle of 1 μ m (of the order of magnitude of 10⁴*e*).

The amplitude of oscillations of a particle determined from the equations of motion [2] vs. voltage is shown in figure 4. The amplitude of oscillations of a 10 μ m particle was in the range from about 0.5 mm for 10 kV to 3.7 mm for 28 kV. The amplitude for 1 μ m particle was about 30 and 40 times smaller.

The effect of agglomeration process can be evidenced by microscopic analysis. The samples of particles collected on a microscopic stage at the outlet of the channel for switched OFF voltage and for two voltages applied to the agglomerator, 20 kV and 24 kV, are shown in Figures 5a-5c. Without a voltage applied to the agglomerator, mainly single particles left the agglomerator. After switching ON the voltage, large particle had collected several to 20-50 smaller particles of a size <2 μ m attached to its surface. The size of large particles collecting the smaller ones was about 5-20 μ m. The agglomeration efficiency increased with increasing voltage applied to the agglomerator.



Figure 2. Current-voltage characteristics of electrostatic agglomerator for gas temperature of 80° C.



Figure 3. Theoretical charge of a particle of a size of 1 μ m and 10 μ m.



Figure 4. Amplitude of oscillations of particles of a size of 1 μ m and 10 μ m.

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Figure 5. SEM micrographs of fly ash particles collected at the outlet of agglomerator for a) supply voltage OFF, b) agglomerator supply voltage of 20 kV and c) supply voltage of 24 kV.

4. Conclusions

Experimental results of the agglomeration process of fly ash particles were presented. The experiments were carried out in a unipolar kinematic agglomerator developed by the authors of this paper. It was determined that the amplitude of oscillation of large particles (>10 μ m) was about 1-3 mm, depending on the applied voltage, while of small particles (<1 μ m) the amplitude was smaller than 100 μ m. The large particles were therefore able to collect those small particles at their surface during their oscillatory motion. The SEM micrographs of the obtained agglomerates have shown that in this type of agglomerator a single particle of a size of 10-20 μ m can collect more than 20-50 submicron particles.

This type of electrostatic agglomerator can be used as particle precharger in a hybrid filter or as the first stage in a two-stage electrostatic precipitator, in order to increase the total collection efficiency of such devices.

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