Analysis of mechanisms of aerosol particles agglomeration under the electrostatic forces

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ABSTRACT

Agglomeration of aerosol particles occurs when primary particles are combined into larger clusters called agglomerates. The agglomeration process is used in the gas cleaning systems to increase the collection efficiency of harmful dust particles. One of the agglomeration methods is unipolar electrostatic agglomeration, which uses differences in the electrical mobility of particles to cause their collisions.

Between particles charged to the same polarity there is a repulsive electric force resulting from Coulomb interactions between the charges carried by the particles. Research presented in this thesis was aimed to verify whether, despite repulsive Coulomb interactions, it is possible to agglomerate charged aerosol particles of the same polarity.

The thesis: it is possible to agglomerate charged aerosol particles of the same polarity in an alternating electric field.

The research subject in the thesis is the electrostatic unipolar agglomeration in an alternating electric field of fly ash particles formed in the coal combustion process. The agglomeration process was analysed theoretically and the efficiency of the agglomeration process in a single-stage unipolar electrostatic agglomerator installed at Łaziska Górne Power Plant was studied experimentally for various electrical and mechanical parameters (voltage and frequency of power supply and flue gas flow rate).

Two main research problems had to be addressed in the study. Firstly, it was necessary to identify the physical mechanism that can cause the agglomeration of particles charged to the same polarity. Secondly, the efficiency of the unipolar electrostatic agglomeration process had to be evaluated by experimental methods.

The mechanism of unipolar electrostatic agglomeration was investigated through the theoretical analysis. An electric field model was formulated involving the electrode area of a single-stage unipolar electrostatic agglomerator. Subsequently, the motion trajectories of individual aerosol particles were determined taking into account the influence of the alternating electric field. It was found that in the alternating electric field with a trapezoidal voltage

waveform, small particles (<1 μm) move along approximately straight trajectories, while large particles (>1 μm) followed oscillatory trajectories that resembled triangular paths, with the amplitude of their oscillation depending on the particle size. As a result, trajectories of particles of different sizes could intersect, indicating that particles could collide.

Collision trajectories were determined for a small aerosol particle approaching a large collector particle moving along an oscillatory trajectory. The effects of inertial force, electrical force and aerodynamic drag force on the motion of the small aerosol particle were analysed. It was shown that the polarization of particles in the external electric field and the induced charge on the surfaces of approaching charged particles are mechanisms that facilitate the unipolar agglomeration of aerosol particles. In the case of unipolar electrostatic agglomeration, collisions most frequently occur when a large collector particle carrying Pauthenier saturation charge collides with an uncharged or weakly charged smaller aerosol particle.

Experimental studies were conducted on a single-stage unipolar electrostatic agglomerator, which constituted one of the sections of a hybrid filter system at the Łaziska Górne Power Plant. The efficiency of the agglomeration process was evaluated using two methods: analysing the change in the morphology of agglomerates and examining the change in the size distribution of particles.

A quantitative agglomerate detection method originally developed by the author of the thesis was used to investigate changes in agglomerate morphology. The method is based on digital processing of microscopic images of agglomerates samples collected from the agglomerator chamber and enables the identification of the position and size of spherical primary particles, which are subsequently assigned to individual agglomerates. Using this method, the average number of primary particles contained within agglomerates (agglomerate average primary particle count) was determined for particles deposited on microscope stages during the agglomerator operation. The obtained agglomerate average primary particle count was compared with the agglomerate average primary particle count of particles deposited during the operation of the plate electrostatic precipitator. The results show a more than twofold increase in the agglomerate average primary particle count, providing evidence for the occurrence of unipolar electrostatic agglomeration process in the investigated agglomerator.

The influence of the agglomerator's operation on the change in the particle size distribution in the exhaust gas downstream of the agglomerator was analysed based on measurements using a laser particle size analyser. The research results demonstrated a significant decrease in the number concentration of particles within the investigated size range (PM10) during the operation of the unipolar electrostatic agglomerator. As the supply voltage of the agglomerator electrodes increases, a significant decrease in particle concentration is observed in the 0.25-0.6 μm size range. The change in the particle size distribution indicates simultaneous agglomeration and deposition of particles on the agglomerator electrodes.

The fractional collection efficiency of fly ash particles was examined for a single-stage unipolar electrostatic agglomerator operating in combination with a plate electrostatic precipitator. The results show a high collection efficiency for PM10 particles exceeding the values of 97% and 99.9% of the number and mass collection efficiency of the particles, respectively.

Several important practical conclusions arise from the research carried out in the thesis. Unipolar electrostatic agglomeration can be a process for particle agglomeration in many industrial applications, and the single-stage electrostatic agglomerator applied in the gas cleaning systems can improve the collection efficiency of aerosol particles, particularly in the submicron range.

The theoretical model for determining collision trajectories used in the thesis can be a useful tool to identify the optimum operating parameters of a single-stage unipolar electrostatic agglomerator. Furthermore, the developed agglomerate detection method, apart from its application in the gas cleaning technology, can also be used to analyse agglomerates of spherical particles in other applications, such as medicine, metallurgy, and nanotechnology.

The performed measurements and theoretical analysis prove the validity of the thesis: it is possible to agglomerate charged aerosol particles of the same polarity in an alternating electric field.