Influence of the operating parameters of the needle-plate electrostatic precipitator on the size distribution of aerosol particles

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Abstract. The influence of the operating parameters (voltage and aerosol flow rate) of the needle-plate electrostatic precipitator (NP-ESP) on the size distribution of aerosol particles has been studied. The NP-ESP consists of a needle and a plate located in the plastic tube used as aerosol transport duct. Alumina (Al₂O₃) particles were synthesized by a spark discharge and used as a test aerosol with a size range from 25 to 500 nm. It was found that the average particle size decreases with increasing voltage and aerosol flow rate through the NP-ESP. It was also found that the average particle size can be reduced more than in 2 times in comparison with the initial size distribution at a voltage and aerosol flow rate through the NP-ESP are equal to 16 kV and 250 l/min, respectively.

1. Introduction
In recent years, there has been growing interest in the use of nanoparticles in science and technology [1]. Nanoparticles are widely used in electronics, optics, energy and medicine [2–4]. It is known that properties of nanoparticles mainly depend on their size [5]. Usually, many methods of producing particles, such as synthesis by spark discharge, do not significantly change the particle size during the synthesis process [6,7]. In this regard, there is a need to develop special equipment that allows to control the particle size after their production process. In this work, there has been developed the needle-plate electrostatic precipitator (NP-ESP) to separate particles by size. A distinctive feature of the developed equipment is a simple design, consisting of a needle and a plate in a dielectric tube. The influence of the parameters of the NP-ESP, namely, the voltage and the aerosol flow rate, on the particle size distribution is investigated.

2. Experimental
The scheme of the experiment is shown in figure 1a. Aerosol particles (Al₂O₃) were obtained using the multi-spark discharge generator (m-SDG) [8]. Then the aerosol particles were sent to the needle-plate electrostatic precipitator (NP-ESP). The particle size distribution was measured using an aerosol spectrometer (AS) at the outlet of the NP-ESP. Aerosol particles were obtained by the erosion of the electrodes made of Al in air at energy stored in the capacitor and the repetition rate of discharges is equal to 6 J and 1 Hz, respectively. A developed the NP-ESP consisted of a needle and a plate that were located in a dielectric tube with an internal diameter of 45 mm. A steel needle with a radius of curvature of about 40 μm was used as the corona electrode. The needle was located at a distance of 10 mm from the steel plate with a size of 100x30x2 mm. The distance between the needle and plate was chosen experimentally for achieving of the maximum current of a corona discharge. A corona discharge was created between the needle and the plate when a high voltage of 5 to 16 kV was applied.
to the needle. The source of high voltage was the source of VIDN-30 (up to 30 kV and 250 μA), and the corona discharge current was measured with an Agilent U1253B multimeter. The current-voltage characteristic of the NP-ESP is shown in figure 1b. Electrical breakdown of the gas gap length of 10 mm occurred at a voltage between the needle and the plate is more than 16 kV (figure 1b).

![Figure 1 (a, b).](image)

**Figure 1 (a, b).** The scheme of the experiment (m-SDG – multi-spark discharge generator, NP-ESP – needle-plate electrostatic precipitator and AS – aerosol spectrometer) (a). Voltage-current characteristics of the NP-ESP at needle-plate spacing is about 10 mm and negative corona polarity. The inset shows the appearance of the corona discharge (b).

Aerosol nanoparticles adsorbed charge due to collisions with ions or electrons. Then the particles were separated according to their size and charge in the field of corona discharge. The efficiency of separation $E_s$ of aerosol nanoparticles in the NP-ESP was determined from equation (1):

$$E_s = \left(\frac{n_{in} - n_{out}}{n_{in}}\right) \cdot 100\%$$  

where $n_{in}$ and $n_{out}$ – the particle number concentration measured when the NP-ESP was turned off and turned on, respectively.

Commercial aerosol spectrometer TSI SMPS 3936 was used to determine the size and concentration of aerosol particles. The particle size distribution was studied depending on the voltage between the needle and the plate $V_c$, and from the aerosol flow rate $Q_a$ through the NP-ESP.

3. Results and discussions

Figure 2a shows the particle size distributions after passing the aerosol through the NP-ESP at a voltage between the needle and the plate $V_c$ of 0, 8.5, 12.5 and 16.0 kV, respectively. The operating mode of the precipitator at $V_c=0$ kV means that the precipitator was turned off, and therefore the aerosol is the initial aerosol. Figure 2a shows that as $V_c$ increases from 8.5 to 16.0 kV, the average particle size decreases from 117±8 nm to 87±6 nm, respectively. It should be noted that the initial aerosol at $V_c=0$ kV has an average particle size of 158±11 nm. Thus, it can be argued that a change in voltage between the needle and the plate $V_c$ makes it possible to control the size of the particles separated in the NP-ESP. The result can be explained as follows, according to the theory of charging [9], it is known that large particles are charged more efficiently and gain a larger number of charges than small particles.
In this connection, it follows that larger particles in the electric field will have a higher electrical mobility \( Z_p \) in accordance with the equation (2):

\[
Z_p = \frac{n_p e C_c}{3 \pi \eta d_p}
\]

where \( n_p \) – the charge per particle, \( e \) – the elementary unit of charge, \( C_c \) – Cunningham correction factor, \( \eta \) – the viscosity of the gas, \( d_p \) – the particle size.

As a result, in the electric field of the corona discharge, larger particles will precipitate more efficiently, while the smaller particles will leave the NP-ESP without deposition on the plate. This explanation is confirmed by the graph in figure 2b, which shows the dependence of the separation efficiency \( E_s \) on the particle size for different values of \( V_c \). Figure 2b shows that large particles with a size of more than 200-300 nm are precipitate more effective, the separation efficiency of which exceeds 80%. However, the low efficiency of separation is observed for particles with sizes smaller than 200-300 nm because of their low charging efficiency. As a result, at the outlet from the NP-ESP an aerosol with a smaller average size is obtained than at the inlet to the NP-ESP.

**Figure 2 (a, b).** The influence of the voltage between the needle and the plate \( V_c \) on the particle size distribution (a). The dependence of the separation efficiency \( E_s \) on the particle size for various voltages between needle and plate \( V_c \) (b). Aerosol flow rate \( Q_a \) is equal 33 l/min.

Figure 3 shows the particle size distribution depending on the aerosol flow rate \( Q_a \) through the NP-ESP. In figure 3, it is seen that when the aerosol flow rate \( Q_a \) are equal to 33 and 250 l/min, the average particle size in the initial aerosol are 156±11 nm and 95±7 nm, respectively. The decrease in
the average size with the increase in aerosol flow rate is associated with a decrease in the particle concentration as a result of their dilution with a stream of pure gas.

Figure 3 also shows that an additional reduction in the average particle size is achieved when the NP-ESP is turned on at $V_c=16.0$ kV. So, for example, with the aerosol flow rate $Q_a$ of 33 and 250 l/min, the use of a precipitator at $V_c=16.0$ kV reduces the average particle size to 86±6 nm and to 70±5 nm, respectively. It can also be seen from the data in figure 3 that when the aerosol flow rate through the precipitator is low, $Q_a=33$ l/min, more efficient charge of particles is achieved, and as a result, the average particle size changes by a larger number than with the aerosol flow rate $Q_a=250$ l/min. Thus, the use of a precipitator can significantly change the average particle size at low aerosol flow rates. For example, it has been found that the average particle size can be reduced by more than 2 times (from 156±11 to 70±5 nm) compared to the initial size of the aerosol (figure 3a) at the $V_c=16.0$ kV and $Q_a=250$ l/min (figure 3b), respectively.

4. Conclusion
Based on the results of the experiments, it is established that the use of the developed NP-ESP makes it possible to reduce the average particles size of aerosol by more than 2 times in comparison with the initial aerosol. It is established that the NP-ESP performs the functions of an electrofilter-separator, precipitating large particles more than 200-300 nm from the aerosol stream. It is determined that the separation efficiency of the particles increases with increasing their size and increasing the voltage between the needle and the plate. The developed precipitator is a promising device for controlling the size of the synthesized particles, which is relevant for a number of applications in electronics, optics and medicine.

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References
[1] Wang C, Friedlander S K and Mädler L 2005 Nanoparticle aerosol science and technology: an overview China Particuology 3 243–54
[2] Kruis F E, Fissan H and Peled A 1998 Synthesis of nanoparticles in the gas phase for electronic, optical and magnetic applications—a review J. Aerosol Sci. 29 511–35
[3] Raimondi F, Scherer G G, Kötz R and Wokaun A 2005 Nanoparticles in Energy Technology: Examples from Electrochemistry and Catalysis Angew. Chem. Int. Ed. 44 2190–209
[4] Murthy S K 2007 Nanoparticles in modern medicine: State of the art and future challenges Int. J. Nanomedicine 2 129–41
[5] Grassian V H 2008 When Size Really Matters: Size-Dependent Properties and Surface Chemistry of Metal and Metal Oxide Nanoparticles in Gas and Liquid Phase Environments J. Phys. Chem. C 112 18303–13
[6] Efimov A, Sukharev V, Ivanov V and Lizunova A 2015 The influence of parameters of spark discharge generator on dimensional characteristics of synthesized TiO2 nanoparticles Orient. J. Chem. 31
[7] Efimov A, Lizunova A, Sukharev V and Ivanov V 2016 Synthesis and Characterization of TiO2, Cu2O and Al2O3 Aerosol Nanoparticles Produced by the Multi-Spark Discharge Generator Korean J. Mater. Res. 26 123–9
[8] Efimov A A, Ivanov V V, Bagazeev A V, Beketov I V, Volkov I A and Shcherbinin S V 2013 Generation of aerosol nanoparticles by the multi-spark discharge generator Tech. Phys. Lett. 39 1053–6
[9] Hinds W C 1999 Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles (New York: Wiley-Interscience)