

The research of the electric field intensity change in the air gap of the compact electrostatic filter

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Abstract. In the article the parameters of an electrostatic filter were considered, including the level of the electric field intensity and the magnitude of the breakdown voltage. A computer simulation of the electric field between flat parallel electrodes with different potentials was performed. The change pattern of the electric field at the penetration of electrically conductive soot particles is considered. With the help of the "ANSYS" software complex, the pattern of change of the electric field intensity between these electrodes was investigated depending on the concentration of particles between them. A computer model that simulates the creation of a maximal level of electric field intensity in a symmetric electric field with a fixed air gap is proposed. The decrease of the level of the breakdown voltage at these electrodes at the placing between them of elements simulating diesel soot particles with average sizes mentioned in the literature is estimated. According to the simulation results, it was determined that the presence of particles of electrically conductive soot significantly influence on the electric field pattern, due to which a local change in the pattern of the resultant field intensity occurs. With aim of confirming of the obtained data the experimental studies have been carried out for determination of the breakdown voltage between the electrodes which form a symmetric electrostatic field.

The main sources of air, water and soil pollution are various power installations that produce the required type of energy and use for these mainly hydrocarbon-based fuels [1, 2]. The environmental requirements that are strengthened with each passing year condition the need of creation of new designs of electrostatic filters that are characterized by maximum compactness and sufficient cleaning efficiency of smoke flows. A compact electrostatic filter, designed on the basis of the Ufa State Aviation Technical University, is orientated for the using on low-power sources of smoke emissions [3]. One of the main design parameters to which attention should be paid in the process of modeling, developing and constructing of new designs of electrostatic precipitators is the shape and size of the effective air gap formed directly between the corona electrode and the precipitation surface. In addition to throughput, this parameter directly determines the pattern of the electric field and its intensity [4]. For effective capture and precipitation of particles from waste gases, the electric field intensity values at different points in the gap should not differ significantly from each other. According to sources [5, 6], the critical value of the electric field intensity in the air gap in the moment preceding the spark breakdown not exceed 3 kV/mm. At the same time, the heterogeneity of the field



created at the precipitation surface has a positive effect on the process of sedimentation of soot particles contained in the flue gas passing through the filter.

Often, at the analyzing of the electric field at the design stage of an electrostatic precipitator, the influence of soot particles on the operating parameters of the electrostatic precipitator is not taken into account. The presence of particles of electrically conductive soot [7] in the smoke flow passing through the filter leads to a decrease of the breakdown voltage values, an increase of currents and a change of the electric field pattern of the electrostatic filter as a whole. It is obvious that the breakdown of the air gap occurs in places with the highest electric field intensity, which are determined by the configuration of the electrodes in the effective gap, or by the presence in the gap of a significant concentration of electrically conductive particles (soot particles). Therefore, it seems appropriate, along with conducting of experimental studies for determination of possibility of influence of the soot particles concentration in the air gap on the parameters of the electrostatic field created in the filter, to perform in parallel a more detailed research using the "ANSYS" software package.

For determination of the degree of influence of the soot particles contained in the smoke flow on the field pattern in the effective gap of the electrostatic precipitator, in the beginning we will use a computer model that simulates a uniform electrostatic field between flat electrodes with positive and negative potentials. According to [8], the size of soot particles, depending on the conditions of the organization of fuel combustion, can vary from 1 to 1000 nm. For most part of important schemes for organizing the combustion of hydrocarbon fuels, including diesel engines, it has been established that spherical particles having a diameter from 20 to 40 nm form the basis of the structure of soot particles [9, 10 and 11]. Such particles have about 600–2000 atomic mass units, i.e. include about 50–160 carbon atoms [8]. Further coagulation of these particles leads to the formation of agglomerations of a much larger size. The concentration of such particles in the total volume of smoke may be different, depending on the type of fuel, the efficiency of the combustion process and the efficiency of the equipment. For estimation of the degree of influence, we consider several variants with a local and mass content of such particles in the studied volume. As it is shown in figure 1, a group of soot particles that do not have their own charge, but at the same time having electrical conductivity, at the entering in uniform electric field created by two smooth electrodes, begins to act as a conductor.

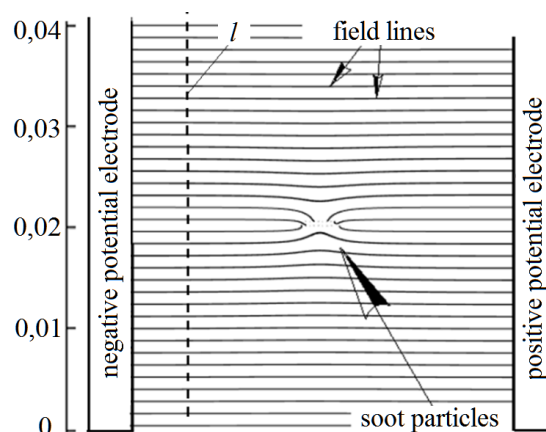


Figure 1. Soot particles in electric field.

A part of lines of the electric field are closed on the surface of these particles. The electric field intensity (figure 2a) along the electrodes in this case varies locally (sector E) according to the location of the group of given electrically conductive particles. An increase of the groups of such particles leads to a multiple change in the static values of the intensity of the created electric field (Figure 2b), that subsequently can increase the electric field intensity to critical values in some areas of the effective air gap and it leads to the emergence of electron avalanches and electrical breakdown [5].

The value of breakdown voltage in this case will be significantly reduced, which is caused exclusively by the currents flowing in the gap in this area.

At the analyzing of the pattern of a uniform electric field, a local group of fourteen particles with a size of 4 nm, located at a distance of 3×10^{-5} from each other were placed in given field. Measurement of the intensity of the modeled electric field was produced along the electrode (along the line l).

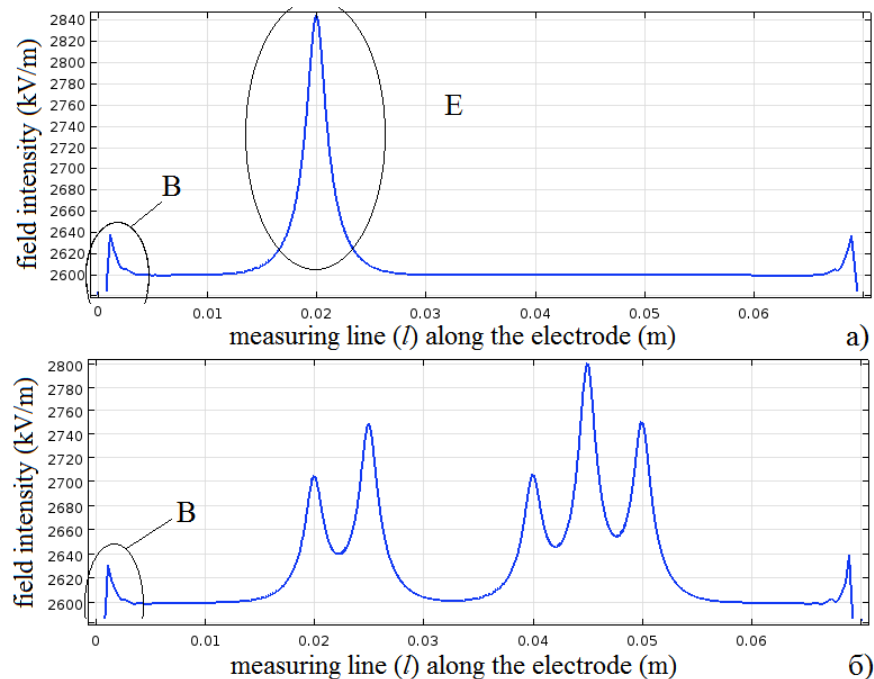


Figure 2. Characteristics of electric field intensity.

The decrease of the electric field intensity at the edges, according to the schedule, is caused by the presence of sectors of dissipation of the electric field observed at the ends of the gap between the flat electrodes [12]. The sharp increase of electric field intensity in sector B of the graph is due to the presence of acute edges on the ends of the electrodes, where corona areas are created.

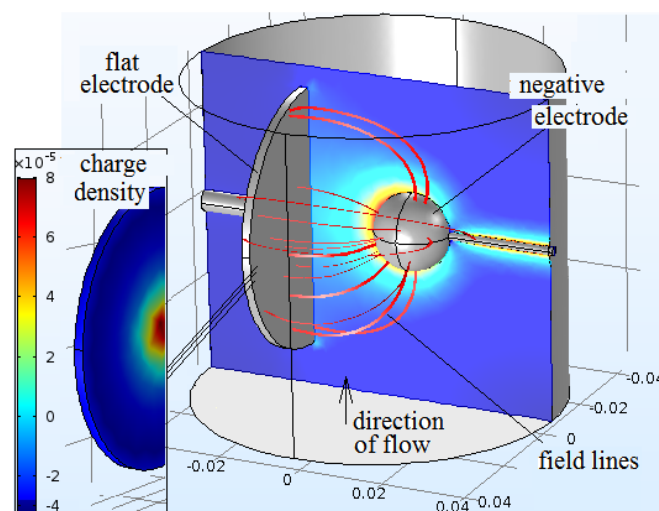


Figure 3. The pattern of the electric field distribution of the computer simulation.

For determination of the decrease level of breakdown voltage in the presence of soot particles in flue flow, we will use another model in which the positive electrode is a smooth disk, which has no sharp edges and is located along the direction of the flue flow, and the negative electrode is made in the form of a ball of much smaller dimensions and located relatively to the center of the positive electrode at a distance δ from it (Figure 3). Given configuration of electrodes allows to create a field symmetric relatively to the negative electrode, excluding areas of third-party corona discharge, which is confirmed by the picture of the density of charge distribution over the surface of a given disk (Figure 3).

As it seen from the graph (Figure 4), which characterizes the distribution of electric field intensity along a flat disk in the direction of smoke flow, the maximum level of electric field intensity is created in the center of the disk in a place with a minimum distance between the electrodes δ_{\min} , which also causes increased charge density on the disk surface. It can be argued that the breakdown of the air gap at the increasing voltage from the source and reaching the critical value of the field intensity will occur directly at this place. According to computer simulation data, at the minimum gap of 6 mm, the maximum level of the electric field intensity in the researched model of 3000 kV/m is created at the voltage on the electrodes of 18 kV (characteristic 1, Figure 4).

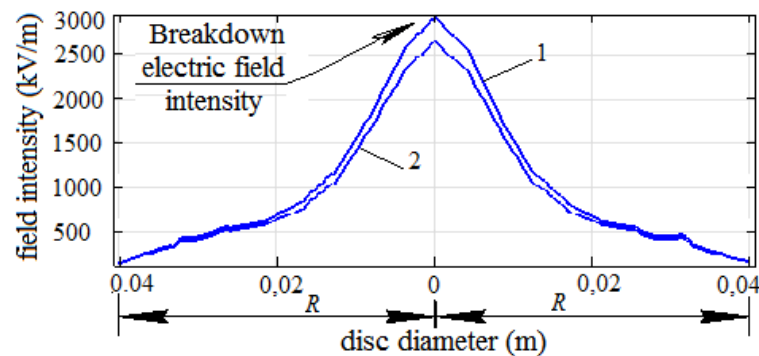


Figure 4. Characteristics of electric field intensity without particles in the air gap.

The placing of a particle having electrical conductivity, but not having its own charge, with a diameter of about 9 microns, simulating the agglomeration of soot particles between the electrodes of the researched model, reduces the level of breakdown voltage to values of 15.5 kV (Figure 5). In the case of the absence of particles between the electrodes at the voltage on the electrodes of 15.5 kV, the level of maximum electric field intensity is approximately 2600 kV/m (characteristic 2, Figure 4).

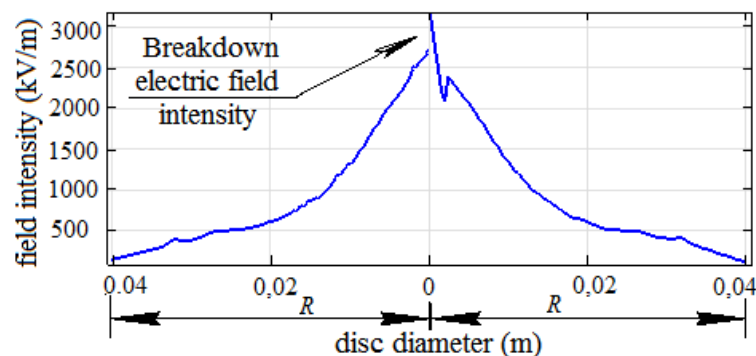


Figure 5. Characteristics of electric field intensity at the presence of particles in the air gap.

Experimental confirmation of the values of the level of breakdown voltage was made on a similar experimental installation. In this case, the voltage on both electrodes was supplied from a high voltage source IVN-20. The obtained experimental data were collected in the table. Smoke was created at the burning of diesel fuel. For the reliability of the obtained data, the experiment was repeated several times, with different concentrations of soot particles (determined by Bacharach smoke number).

As the experiment showed, the maximum decrease of the breakdown voltage values during the passage of smoke between the electrodes reached 14.5%, in compare with the breakdown voltage of the this air gap without smoke. The obtained data is characterized by a sharp decrease of the resistance between the electrodes of the experimental installation, which is caused by the presence of particles of electrically conductive soot in the passing smoke flow. The soot particles precipitated during the experiment have sizes from 10 nm to 50 nm, the determination of average values of which was carried out according to the method of average numerical diameter [13]. Soot particle sizes were measured on a transmission electron microscope JEM-2000EX.

If we consider medium- and high-capacity boiler rooms, the size of the soot particles at the exit of the chimney in these cases can reach significantly larger sizes than those obtained in the experiment, including $25\text{-}70 \times 10^{-6}$ [14], without taking into account the agglomerations created by them. Accordingly, the resultant action of larger particles in an electric field will be significantly larger.

Thus, knowing the concentration and size of soot particles and their agglomerations in the smoke flow, controlled by soot meter "Testo 308", it is possible to effectively regulate the magnitude of the voltage applied to the precipitator electrodes, thereby maintaining efficiency of its working, preventing the emergence of the critical value of the electric field intensity leading to the occurrence of spark breakdown. Assuming that the smoke flow has a homogeneous concentration of particles and moves at a constant speed, according to the obtained experimental data, it is possible to prevent breakdown in the experimental installation by reducing the field intensity to 2,56 kV/mm.

Estimation of the level of breakdown voltage decrease relatively to the specific design of the electrostatic precipitator should be carried out individually, taking into account the design features of the considered electrostatic precipitator, its operation parameters and characteristics of boilers and fuel.

The obtained results allow us to more accurately estimate the parameters of the electrostatic filter working, depending on the modes of its operation and can be used both at the constructing of new designs of electrostatic filters and for effective control of used filters.

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