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Numerical method for determining low intensity electrification areas in the ESP chamber

Abstract*. In this paper the method of numerical analysis of the electric field distribution on ESP chamber have been presented. This method allows us to determinate the best possible distance between the discharge electrodes, providing the potentially highest.efficiency of ESP. This method is based on identifying the areas where the intensity of dust particles electrification is not enough fast, and finding the maximum value of the electric field inside an ESP chamber.*

Streszczenie. *W pracy zaprezentowano metodę cyfrowej analizy rozkładów pola elektrycznego w komorze elektrofiltru. Metoda pozwala na wyznaczenie najkorzystniejszego odstępu między elektrodami ulotowymi, przy którym sprawność elektrofiltru powinna być możliwie największa. Metoda bazuje na wyznaczaniu stref o niewielkiej efektywności elektryzowania cząsteczek pyłu oraz na wyznaczaniu maksymalnych wartości natężenia pola elektrycznego w komorze elektrofiltru. (**Metoda cyfrowego wyznaczania stref o niewielkiej intensywności elektryzowania w komorze elektrofiltru**).*

Keywords: electrostatic precipitation, electric field distribution, intensity of charging.
Słowa kluczowe: elektrofiltr, rozkład pola elektrycznego, szybkość elektryzacji.

Introduction

Electrostatic precipitators are currently the most popular devices used in industry to remove dust particles contained in exhaust and other industrial gases. Its popularity is due to many advantages, such as: very high efficiency of dust removal and working in a wide range of sizes of dust particles and their concentration in the precipitated gases.

The main direction of development of electrostatic precipitators is finding a new geometry of electrodes that will achieve better U-I characteristics of these systems. That will allow for increasing the gas load of a precipitator, while keeping its high efficiency and dimensions unchanged. Another benefit could be the reduction of dimensions of the precipitator with the fixed level of efficiency.

The processes occurring in the ESP chamber are very complex. Therefore in order to calculate the electric field distribution inside it we have to use very complicated mathematical models, that take into account the spatial charge distribution.

A simplified method of calculation that enables one to determine areas where the speed of dust particles electrification in the ESP chamber is not fast has been proposed in this paper. This method does not include the spatial charge distribution. In previous papers [1] it has been proved that the simplification used does not affect the correctness of the results. On the other hand it allows for analyzing much more complex geometry electrode systems.

Theoretical assumptions

The resultant velocity of dust particles in the ESP chamber (w_w) is the sum of vectors (Fig. 1) of dust particles velocity caused by the gas flow (w_g) and the drift velocity caused by the influence of the electric field on an electrified dust particle (w).

The dust particle will be separated from the smoke when the movement time of this particle to the collecting electrode (t) will be shorter than the movement time of the exhaust stream between the inlet and the outlet of the ESP chamber. This condition is fulfilled when

$$t \le \frac{L}{w_g} \tag{1}$$

where: L – distance between inlet and outlet of ESP chamber [m], w_g – gas flow velocity [m s^{-1}].

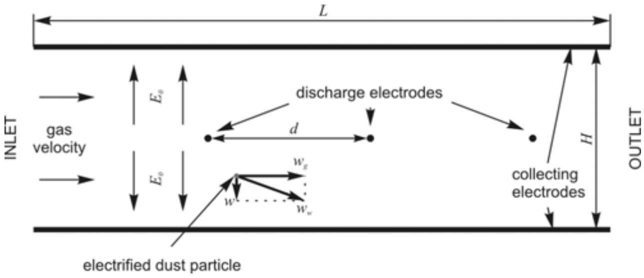

Fig.1. Velocity of electrified dust particle in the electric field and in the gas flow; E_0 – electric field density, w_g – dust particle velocity caused by the gas flow, w – drift velocity, w_w – resultant velocity

At the time t on the surface of a dust particle the electric charge is accumulated. The force of the electric field directs it toward the collecting electrode. Depending on the position at the inlet to the chamber, a particle has to travel towards the collecting electrode the distance of a half or less of the collecting electrodes spacing (H). This means that - before reaching the collecting electrode – a particle must get a drift velocity which meets the condition

$$w \ge \frac{H}{2\,t} \tag{2}$$

where: H – collecting electrodes spacing [m].

Developing the value of drift velocity w [1, 2]

$$w = \frac{2\dfrac{\varepsilon_1\ \varepsilon_2}{\varepsilon_1 + 2\varepsilon_2} R E_0^{\ 2}}{\mu} \tag{3}$$

where: ε_1 – permittivity of dust particles [F m^{-1}], $\varepsilon 2$ – permittivity surrounding of dust particles [F m^{-1}], μ – dynamic viscosity of gas [Pa s], R – radius of the dust particles [m], E_0 – electric field strength [V m^{-1}].

Transforming the formula (3) versus the electric field and by taking into consideration formula (2) the minimal value of the electric field E_{min}, can be obtained, which is necessary to separate a particle from the stream of the flowing gas:

$$E_{\min} = \sqrt{\frac{H\,\mu}{4\,\dfrac{\varepsilon_1\;\varepsilon_2}{\varepsilon_1 + 2\varepsilon_2}\,R\,t}} \qquad (4)$$

Table 1 presents the minimal values of the electric field required in order to separate particles of particular sizes from the exhaust in a typical ESP chamber.

Table 1. The minimum strength of electric field necessary to separate dust particles in the ESP chamber for the different radius R and relative permittivity ε_{1r} of dust particle; w_g = 1,5 m s^{-1}, L = 15 m, H = 0,4 m, μ = 1,8·10^{-5} Pa·s

R [μm]	E_{min} [kV cm^{-1}]	
	ε_{r1} = 2	ε_{r1} = 5
0,05	9,02	7,54
1	2,02	1,69
5	0,90	0,75
10	0,64	0,53

Therefore the value of the electric field in each part of an ESP chamber is a parameter deciding on the dynamics of the processes aiming at separating the dust particles from the stream of the cleaned gas.

Results

The article presents the samples of calculations for two types of discharge electrodes shown on Fig. 2.

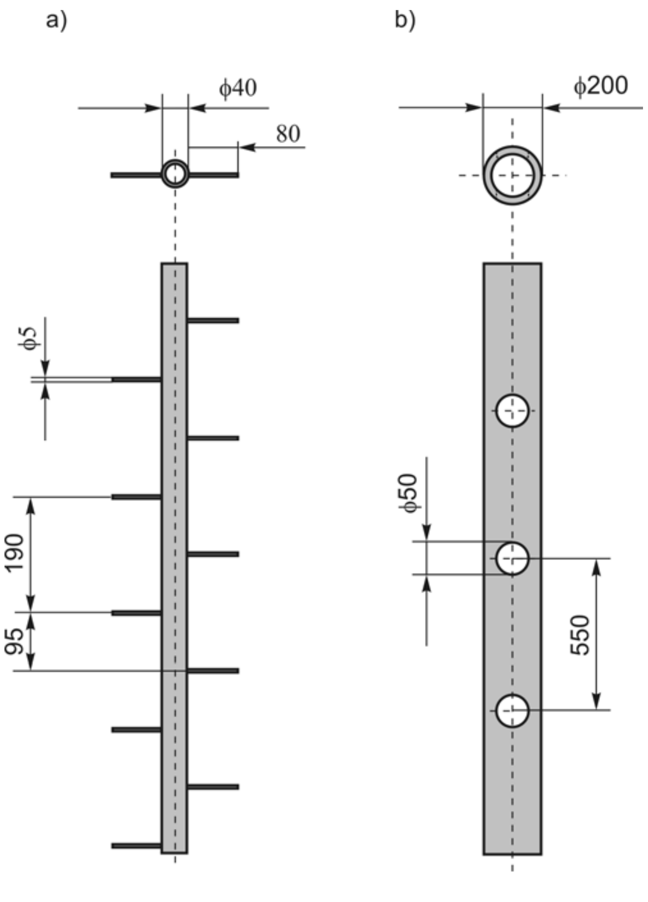

Fig.2. Shape of discharge electrodes used in an ESP chamber model: a) multiblade electrode [3], b) tube electrode

In the simulations the constant voltage with negative polarization and value of 140 kV has been appiled to the discharge electrodes. The scale of the ESP (H) was 0.4 m. The full set of discharge electrodes and collecting electrodes has been placed on a conductive, earthed case.

In order to simplify the calculations in the presented systems the influence of other conductive elements located in the ESP chamber, e.g. the electrodes' fitting system or the rappers' mechanism have not been taken into account. Those elements disturb the distribution of the electric field only on marginal fragments of the electrodes and from the point of view of the whole device do not have significant influence on the efficiency of filtering. What is more it has been assumed that the interior of the model ESP chamber is filled with air.

The presented simulations have been performed using the COMSOL Multiphysics program for field calculations. This package is based on the Finite Element Method.

Figure 3 presents the diagrams of electric fields obtained in the 3D model using multiblade discharge electrodes, with the distance of 80 cm between the electrodes.

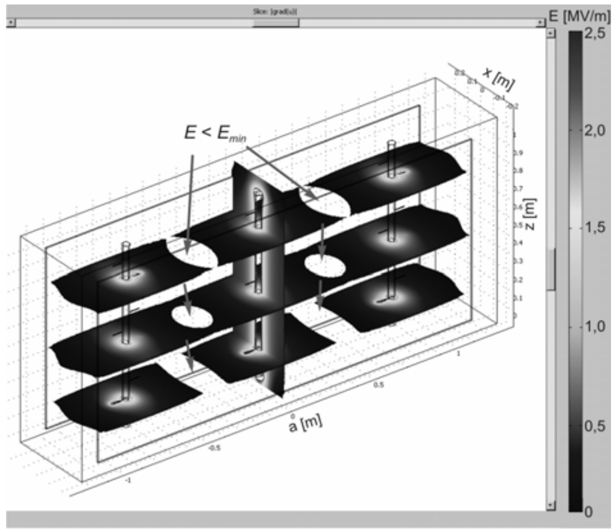

Fig.3. View of electric field with mark areas where the strength of its is below the minimum value that is needed to precipitate a dust particle; U = 140 kV, t = 10 s, H = 0,4 m, d = 80 cm, R = 5 μm, μ = 1,8·10^{-5} Pa·s

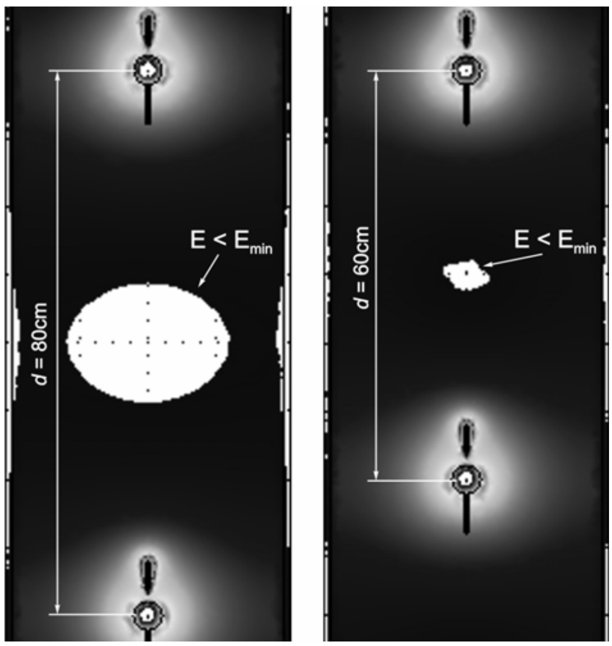

Fig.4. View of slice of electric field with mark areas where the strength of its is below the minimum value that is needed to precipitate a dust particle for different distances between adjacent multiblade discharge electrodes (d); U = 140 kV, t = 10 s, H = 0,4 m, R = 5 μm, μ = 1,8·10^{-5} Pa·s

It is obvious that a beneficial solution is to minimise the unused areas in the device. However, it should be kept in mind that putting the discharge electrodes closer can lead to lowering the non-uniform of the electric field distribution and as a result it can lower the maximum corona discharge intensity close to the blades (Fig.4) [4].

The maximum values of the electric field obtained from the simulation results with different distances between adjacent discharge electrodes of multiblade construction and with the collecting electrodes spacing of 0.4 m have been presented in table 2.

Analogical results for tube electrodes have been shown on Figure 5 and in table 3.

Table 2. The maximum value of electric field in ESP chamber for different distances between adjacent multiblade discharge electrodes

d [cm]	E_{max} [kV cm^{-1}]
20	82
40	130
60	155
80	150

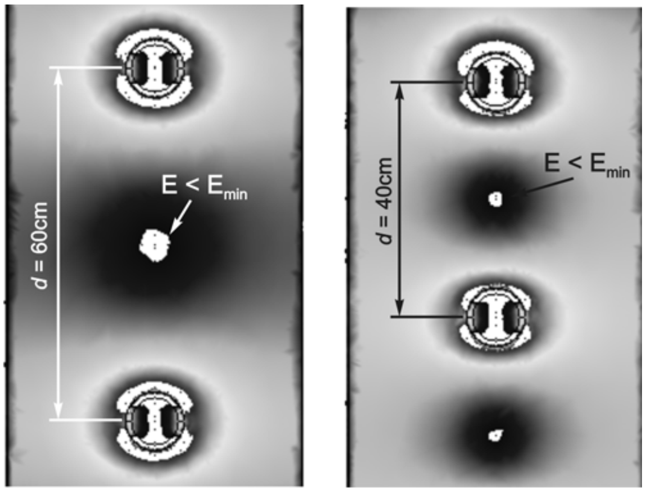

Fig.5. View of slice of electric field with mark areas where the strength of its is below the minimum value that is needed to precipitate a dust particle for different distances between adjacent tube discharge electrodes (d); U = 140 kV, t = 10 s, H = 0,4 m, R = 5 μm, μ = 1,8·10^{-5} Pa·s

Table 3. The maximum value of electric field in ESP chamber for different distances between adjacent tube discharge electrodes

d [cm]	E_{max} [kV cm^{-1}]
20	98
35	120
40	150
60	150

As it is visible in the results there exists an optimal distance between the adjacent blade electrodes. With this distance the maximum values of the electric field obtained in this system as well as the dimensions of the areas of the electric field values below the minimal value are the highest. Too sparse fitting of the discharge electrodes will result in the creation of areas of low precipitation efficiency (Fig. 4 and 5) and fitting them too close can cause the lowering of non-uniform of the electric field in the ESP chamber (table 2 and 3) and therefore will increase the initial value of the discharge occurrence and will decrease the intensity of ionization processes

Conclusions

The presented results show that the distribution of the electric field specified using the Laplace's formula can be a valuable tool, helpful in designing the new shapes of discharge electrodes as well as the systems of electrodes inside the ESP chamber. The application of the described simplifications, the most important of which being the exclusion of the influence of the space charge, from the point of view of the whole ESP had no negative influence on the obtained results of the simulation, which has been confirmed by the performed measurements in the actual ESP chamber [4].

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