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ELECTRICAL CHARACTERISTICS IN ELECTROSTATIC PRECIPITATOR WITH SHAPED COLLECTING ELECTRODES

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ABSTRACT
In this paper are presented the results of numerical calculation of electrical characteristics in an electrostatic precipitator with so called sigma collecting electrodes. Calculations are performed by using finite volume numerical method. The significant features of this method are simple and accurate numerical technique, less memory space, and fast convergence. The presented results show that proposed method can be useful in the design aspects of the wire-plate electrostatic precipitator, as for instance the simulating and comparing the voltage-current characteristics of different wire-plate precipitator configurations before optimizing the geometrical parameters.
Keywords: Electrostatic precipitator, Shaped collecting electrodes, Numerical calculation, Finite volume method.

1. INTRODUCTION

An electrostatic precipitator (ESP) is an air pollution control device that removes particles from a gas-particles flow with electric forces. The need to provide effective removal of both particles and gaseous pollutants introduces new factors in the determination of the best technology for industrial air pollution control and also has complicated the design of electrostatic precipitators. The geometry of the discharge and collecting electrodes is an important factor for efficient electrostatic precipitator operation. The well design of the discharge and collecting electrodes brings about the reduction of the operating power and precipitator dimension as well as the improvement of collection efficiency. The various types of discharge and collecting electrodes have been developed so far, in order to achieve high space charge densities. In this work we assumed wire discharge electrodes to simplify problem and as a collecting electrodes sigma plates.

During the last ten years, beside the experiments, there has been carried out an intensive development of mathematical modeling of the process in electrostatic precipitators as well as their numerical solving by computers. Complex geometry of a real electrostatic precipitator makes the problem to be always three dimensional. However, a 2D model of the problem can give useful information on the solution, although sometimes only qualitative. Few studies about the particle dynamics in the ESP composed of specific shaped plates have been attempted. As Park and Kim cites [1], Leonard at al. (1982) reported that the introduction of a baffle in a parallel flat plate ESP causes decreases of precipitation performance while, Vincent and MacLennan (1980) and Stenhouse and Barnes (1990) claim that strengtheners increase the collection efficiency of ESP. Recently, Rajanikanth and Sarma used combination of finite difference method and R-functions for modeling the dust free electrical characteristics in ESP.

2. MATHEMATICAL MODEL

Electrical characteristics can be described by reduced set of Maxwell's equations. The equations governing the electric field under steady-state conditions (in the absence of magnetic effects) for an electrostatic precipitator are:

$$\int_S \mathbf{D} \cdot \mathrm{d}\mathbf{s} = \int_V \rho \,\mathrm{d}V \tag{1}$$

$$\int_S \mathbf{J} \cdot \mathrm{d}\mathbf{s} = 0\,, \tag{2}$$

Equations (1) and (2) refer to the system of the volume V with surface area S , where $\mathbf{s}$ is the surface vector, ρ is the space charge density C/m^3, $\mathbf{D}$ is the electric flux C/m^2, $\mathbf{J}$ is the current density A/m^2. The vectors $\mathbf{D}$ and $\mathbf{J}$ are defined as:

$$\mathbf{D} = \varepsilon_o \,\mathbf{E} \tag{3}$$

$$\mathbf{J} = \rho K\mathbf{E} - D\mathrm{grad}\rho \tag{4}$$

where $\varepsilon_o = 8.854 \cdot 10^{-12}$ (F/m) is the permittivity of the free space, K (m^2/Vs) is the ion mobility and $\mathbf{E}$ (V/m) is the vector of electric field. For electrostatic case $\mathbf{E} = -\mathrm{grad}\phi$, where ϕ is the scalar potential of electric field $\mathbf{E}$. In equation (4), some influence of ion diffusion is assumed where D (m^2/s) is the coefficient diffusivity. In order to complete the mathematical model, it is also necessary to define the boundary conditions and to specify the physical characteristcs of continuum. The field on the wire is equal to the corona onset gradient given by Peek's law [2] and the mobility of the charge carrier's (ions) is uniform.

Since the equations (1) and (2) are mutually coupled, i.e. the electric field is strongly affected by the space charges, and vice versa, they must be selfconsistently determined by appropriate numerical method. In the next paragraph a brief description of the numerical method is given.

3. NUMERICAL METHOD

The method uses vectors and tensors expressed through their Cartesian components. Unstructured mesh with polyhedral control volumes has an ability to deal with geometrically complex solution regions. Such approach do not requires a regular mesh of control volumes, so the mesh can be refined to follow complicated boundaries or in places where unknowns varying more rapidly. All dependent variables are stored at the cell center. The surface and volume integrals are approximated by the midpoint rule of second order. Central differencing scheme is used for diffusive terms. For convection upwind difference, the scheme (first order) is combined with central difference scheme (second order) are used during discretisation process. Due to non-linearity the solution of the system of algebraic equations has to be sought by iterative methods. The segregated approach is used to solve the resulting set of coupled non-linear algebraic equations, for each dependent variable which leads to the set of decoupled linearised algebraic equations for each dependent variable. More details about the discretisation and algorithm can be find in [3, 4]. In addition, an algorithm of adjusting values of electric space-charge ρ at discharge electrode surface was used [5].

4. CALCULATIONS

The physical model is shown in Figure 1 (left). Geometry and input data for calculation were selected from project parameters of electrostatic precipitators except that real discharge electrodes are replaced by cylindrical wires. The main dimensions of model are: distance between discharge electrodes is c = 495 mm, between plates $2b$ = 400 mm and the radius of discharge electrodes is a = 1.5 mm. The geometry details of sigma collecting electrode are given in Fig.1 (right). The problem is assumed to be two dimensional, since for clean and smooth wires there is no variation of voltage or corona current along the length of the corona wires and collecting electrodes. Due to symmetry only one half of the section can be used (hatched area in Fig.1). Symmetry boundaries are proposed wherever electrode surfaces are not a part of the domain boundary. The domain for calculation is divided to 25212 control volumes (CV) and a part of numerical mesh is shown in Figure 2.

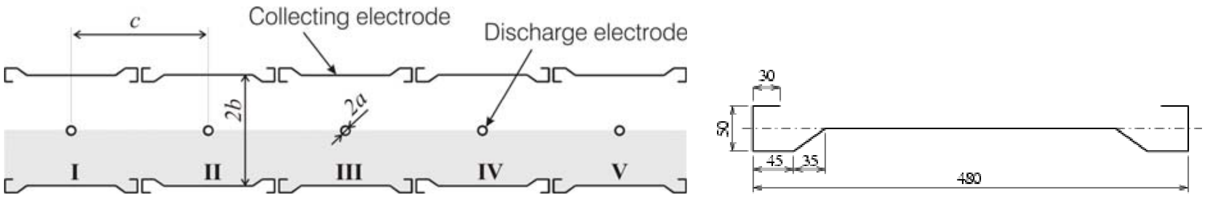

Figure 1. Configuration of electrostatic precipitator electrodes with denoted calculation domain (left) and geometry of sigma electrode (right)

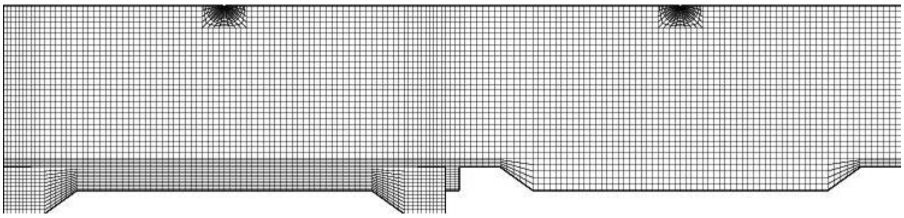

Figure 2. Part of the numerical mesh

The calculations of the equations mathematical model are carried out for the applied voltage of 65 kV. The ion mobility is $K = 2\cdot 10^{-4}$ m^2/Vs and coefficient of the diffusivity $D = 2\cdot 10^{-2}$ m^2/s. Figure 3 shows contours of electric potential field ϕ chosen so that they illustrated (emphasized) local distribution near the walls of the sigma plates. The equipotential lines are clustered near the edge of the cavity and wall surface normal to the corona wire, so we expect that the electric field intensities are much stronger compared with those on the other wall surface. The electrical field strength in the space between electrodes is an important parameter because it determines the distribution corona current and the sparking conditions.

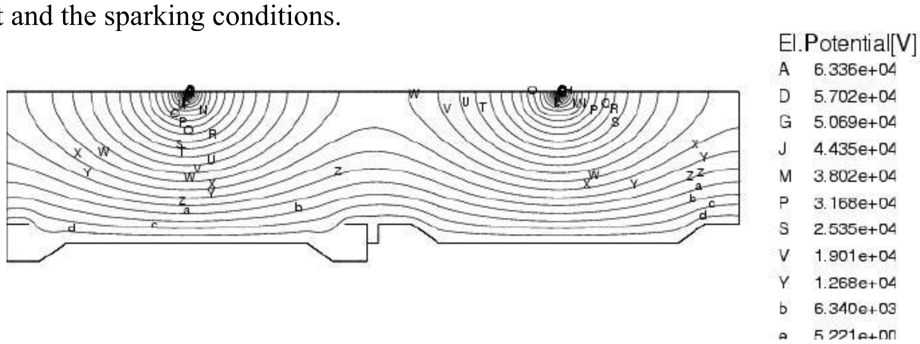

Figure 3. Contours of electric potential ϕ

Figure 4 shows contours of electric space charge density distribution in the same part of solution domain. The most high values of the space charge density appear at the discharge electrode surface in amount of 14.39 $\mu C/m^3$. We see a radial reduction in ρ moving further away from the wire and a concentration of charge along the line from the wire to the plate where it is expected more dense electric current. Also, we see that the contour levels are very similar above both sigma plates.

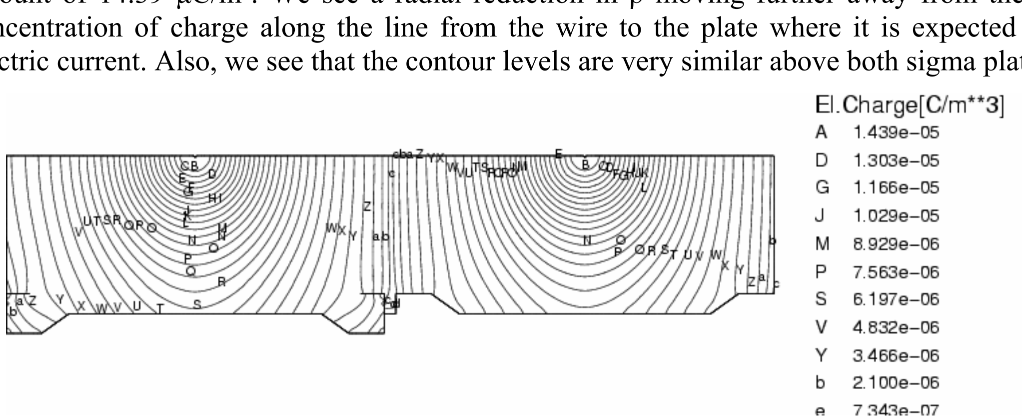

Figure 4. Electric space-charge density ρ contours

In Figure 5 are shown contours of electric field intensity. Because the field is so strong close to the discharge electrode that the interesting features in the vicinity of the sigma electrodes are lost if the entire range of the fields is displayed. For that reason, we set the range of the color to exclude strongest part of the electric field, i.e. only up to 2.5 kV/cm . The maximal calculated value of electric field is on the discharge electrode surface in amount of 54.19 kV/cm. The interesting regions are the protruding corners of the sigma plates. The reason for that is that electrostatic field in general amplified by structures protruding into the field, but not by cavities.

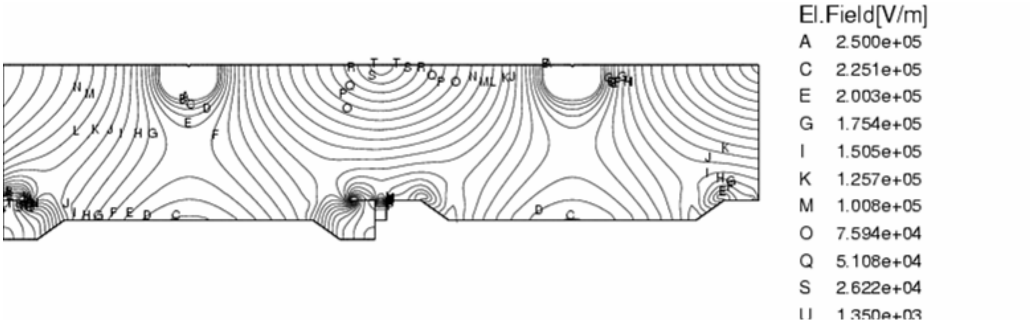

Figure 5. Contours of electric field intensity

In Figure 6 are presented contours of electric current density in the same part of the domain. The maximal value of electric current density is on discharge electrode surface in amount of $1.56 \cdot 10^{-2}$ A/m^2. The peaks of current density exist at the cavity edge and the wall surface normal to the wire as shown in figure 6. Similar as in the case electric field, interesting peaks of electric current arise on convex parts of sigma plate.

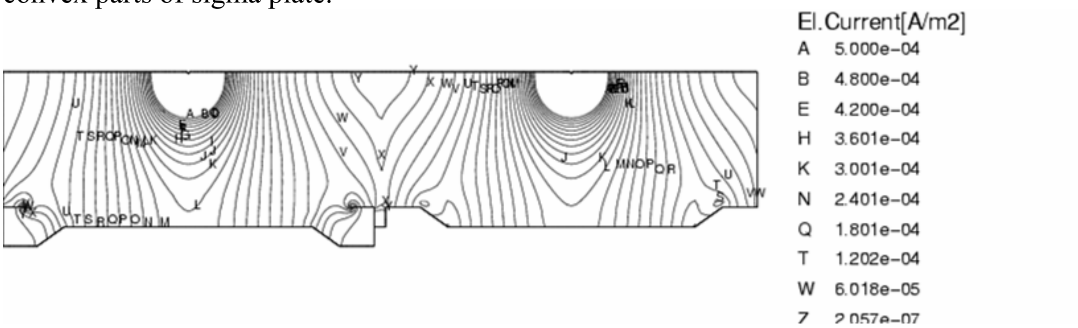

Figure 6. Contours of electric current density

5. CONCLUSION

An approach based on finite volume method has been proposed for the prediction electrical characteristics in a wire/plate electrostatic precipitator. The possibility of using unstructured mesh with polyhedral control volumes enables that any shape of the collecting plates can be modeled with ease. Future investigation would include fluid flow and particles movement into a mathematical model and their interactions with electrostatic fields.

6. REFERENCES

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