EFFICIENCY OF THE PRECIPITATION OF FINE PARTICLES INFLUENCED BY THE ESP SUPPLY MODE

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Abstract

Behaviour of fine particles is still a "hot topic", especially, because of the regulations connecting to PM 2.5. To determine the performance of ESP for fractions 2.5 μm and below is extremely important, because these particles are more dangerous for the human health than larger pollutants.

The present examinations represent further development of our previous ESP model [1,2,3] especially by taking into consideration the change of the supply mode (different types of the time function of the supply voltage and supply current) of the electrostatic precipitators. As a case study, two different supply modes are compared, continuous DC case and supply by impulse voltage.

1. Introduction

It is well-known, that impulse mode supply of electrostatic precipitators results not only energy saving, but the efficiency of the process is also increasing. [4] Experiments were made by various type of impulses and results have been justified the expectations connecting this supply mode.

Knowing these facts, it can be understood, that the modelling of impulse mode became a very important question. Regarding, that a lot of ESP models have modular structure, appropriate combination of modules can make the model suitable to operate in the time domain describing time-dependent processes, like impulse mode supply of electrostatic precipitators. [5]

In our new model such kind of combination has been working out taking the difference between the time constant of the processes into consideration. The basis of this new model was our previous one calculating the electric field, flow field and particle trajectories in case of constant DC supply voltage. It was constructed to find steady state of the precipitation process.

As in the previous publications, we have analysed wire to plate test arrangement. Although in the practice rods with spikes are most effective, wire-plat geometry was suitable to recognise the trends from the computed result.

2. Steady state models

Lot of models like our previous one try to find steady state solution. For this purpose the determination of the electric field and the flow field is produced according to an iteration process. For the very first calculation, flow field is supposed to be even and the velocity components of the gas are parallel to the collecting electrodes.

The electric field intensity $\boldsymbol{E}$ can be calculated according to (1-4), where ρ_{ion} and ρ_{dust} are the space charge density of ions and dust, μ represents the mobility of ions, ε is practically ε_0, the dielectric constant of the vacuum, $\boldsymbol{j}$ is the current density and φ represents the electric potential.

$$div\boldsymbol{E} = (\rho_{ion}+\rho_{dust})/\varepsilon \quad (1)$$

$$\boldsymbol{j}=\rho_{ion}\,\mu\,\boldsymbol{E} + \rho_{dust}\,\boldsymbol{v}_{dust} \quad (2)$$

$$div\boldsymbol{j} = 0 \quad (3)$$

$$\boldsymbol{E} = -grad\varphi \quad (4)$$

Usually the second part of the right hand side in (2) is neglected, because the mobility of ions is higher than the mobility of dust particles. Thus substituting (2) into (3):

$div(\mu\rho_{ion}(x,y)\mathbf{E}(x,y)) = 0$ so $\rho_{ion} div\mathbf{E} + \mathbf{E} grad\rho_{ion} = 0$ and because of $div\mathbf{D} = \rho$,

$$\rho_{ion}(\rho_{ion}+\rho_{dust})/\varepsilon + \mathbf{E} grad\rho_{ion} = 0 \quad (5)$$

One possible numerical solution of (5) can be produced by (6), which applies the notation of Fig. 1. This figure represents a half channel of the electrostatic precipitator with corona electrodes KE. The half channels are divided into subregions with regular mesh. E_{0x} and E_{0y} are representing the field strength component parallel to and perpendicular to the collecting electrodes.

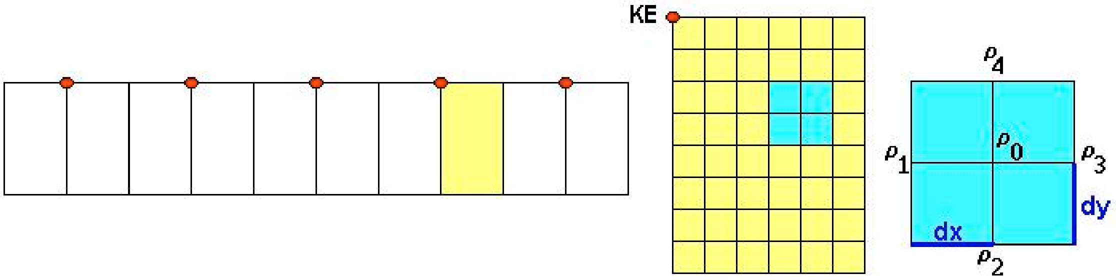

Fig. 1.

$$\frac{\rho_{0ion}(\rho_{0ion}+\rho_{0dust})}{\varepsilon}+\frac{E_{0x}(\rho_{0ion}-\rho_{1ion})}{dx}+\frac{E_{0y}(\rho_{0ion}-\rho_{4ion})}{dy}=0 \quad (6)$$

Of course this calculation requires a starting value at the corona electrode, originating from the corona models. Even nowadays, equations (7) and (8) are very popular to determine the corona current for 1m length of wire, where r_0 is the radius of zero potential in axially symmetrical fields and a modified value according to [6] for wire-plate geometry, r_{KE} is the radius of the corona electrode, and E_{kr} represents the critical electric field at which the discharge starts.

$$U_{kr} = E_{kr} r_{KE} \ln\frac{r_0}{r_{KE}} \quad (7)$$

$$I = \frac{8\pi\varepsilon_0\mu_i}{r_{KE}\ln\frac{r_0}{r_{KE}}}U(U-U_{kr}) \quad (8)$$

For the determination of the saturation charge Q_t in the presence of electric field strength E (9) is commonly used, where r_p represents the radius of particle and ε_{pr} means its relative permittivity. For the time function of the charging process of particles (10) is well-known, in which formula ρ_{ion} is the ionic space charge density and μ_{ion} represents the mobility of ions.

$$Q_t = \frac{12\pi r_p^2 E\varepsilon_0\varepsilon_{pr}}{\varepsilon_{pr}+2} \quad (9)$$

$$Q(t) = Q_t\frac{t}{t+\tau}, \quad \text{where} \quad \tau = \frac{4\varepsilon_0}{\rho_{ion}\mu_{ion}} \quad (10)$$

Chang [7] has pointed out, that the validity of the previous formulas are limited, in case of certain flow field conditions and rotational ellipsoid particles the saturation charge will differ from the previous values.

To obtain the steady state distribution of field strength and space charge an iteration process is necessary, namely the calculation of a new field intensity distribution in the presence of space charge and the calculation of the effect of modified field strength on the space charge, etc.

According to the experience, the stability of his iteration is very good, steady state values can be achieved after some cycles.

The gas flow within the ESP channel can be described by means of continuity equation and momentum conservation law. The continuity equation for incompressible medium is:

$$\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} = 0 \tag{11}$$

Regarding the assumptions mentioned above by neglecting the electrostatic forces acting on the gas phase and the interaction with the dust-phase a simple boundary layer equation can be applied for determining the 2D velocity field:

$$v_x \frac{\partial v_x}{\partial x} + v_y \frac{\partial v_x}{\partial y} = V\frac{dV}{dx} + \frac{\partial}{\partial y}\left(\nu_t \frac{\partial v_x}{\partial y} \right). \tag{12}$$

Turbulent viscosity ν_t is evaluated on the bases of the mixing length model.

Disregarding the streamwise diffusion of the dust-phase the concentration *c* can be computed with the help of a parabolic type transport equation:

$$v_x \frac{\partial c}{\partial x} + v_y \frac{\partial c}{\partial y} = \frac{\partial}{\partial y}\left(\frac{\nu_t}{Sc_t} \frac{\partial c}{\partial y} \right) - \frac{\partial}{\partial y}\left(c \cdot \overline{Wth}_y \right) \tag{13}$$

where in the last term $\overline{Wth}_y$ refers to the theoretical migration velocity of the particle due to the electric field strength, it can be derived from the equation of motion for the dust particle and can be expressed as:

$$\overline{Wth}_y = \frac{Q_p^\infty \overline{E}_y}{3\pi\mu d_p} Cu \tag{14}$$

where Q_p^∞ is the saturation charge of spherical dust particle with a diameter d_p. The Cochet's charging equation is used in this study. *Cu* is the Cunningham correction factor, μ the fluid viscosity, Sc_t the turbulent Schmidt-number and E_y the y component of the electric field strength.

Knowing the flow field in the ESP channel, the concentration distribution of the suspended particles in the flow can be calculated. Equations (12)-(14) can be solved numerically by application of a straight forward method, so obtaining a layer by layer solution for v_x, v_y and *c* marching along the axis x (see e.g. [2]). This computational model also allows an iterative method for determination of the additional space charge due to the charged dust particles.

Since the suspended dust particles in gas are regarded as a continuum, its flow can be characterized with stream function Ψ. Equation (5) can be written in the following alternative form:

$$div\, \vec{j}_{tot} = 0 \tag{15}$$

where $\vec{j}_{tot}$ is the total flux vector of the dust phase:

$$\vec{j}_{tot} = \vec{j}_C + \vec{j}_D + \vec{j}_E \tag{16}$$

where $\vec{j}_C$ means the convective, $\vec{j}_D$ the diffusive and $\vec{j}_E$ the „electrostatic" flux vector-components of $\vec{j}_{tot}$ total flux vector. On the bases of equation (5) can be written:

$$\vec{j}_{tot} = c \cdot \underline{v} - \left(\frac{\nu_t}{Sc_t} \right) \cdot grad c + c \cdot \overline{Wth}_y \tag{17}$$

Based on equation (18) we can define the stream function Ψ as:

$$\vec{j}_{tot}\Big|_x = \frac{\partial \Psi}{\partial y}\,, \quad \vec{j}_{tot}\Big|_y = -\frac{\partial \Psi}{\partial x} \tag{18}$$

Knowing the distribution of dust concentration *c* and v(x,y) velocity field, the flux vector-components and thereby the stream function $\Psi=\Psi(x,y)$ distribution can be calculated using the interpolation method the streamlines of the dust-phase, $\Psi=$ constant, can be determined.

3. Supply mode in the modelling

To examine the effect of the supply mode, time dependency of the processes has to be involved into the model. Usually it is made by creating a time loop tore-calculate physical quantities after a given time. Our steady state model that is based on the calculation process presented in the previous chapter is not suitable to calculate the effect of impulse mode supply, because it is constructed to make an iteration to obtain steady state condition, considering continuous gas flow, voltage, ionic current and incoming dust amount.

Therefore the ESP model had to be improved to involve the time dependency into the model. One possible solution is to consider the calculated gas flow constant during the calculation process and determine the electrical quantities (field distribution, space charge), particle migration and collection at given moments. Similar solution can be found in [5].

In case of our model a regular mesh was defined for the half channel, as it was in the steady state version, but now the quantities calculated in the gridpoints of the mesh are connected to a time moment. The moment of the next calculation period (in other words, the value of the time step) was determined according to the following assumptions.

- The time during ions run through the half channel is much less than the chosen time step.
- Time step is smaller than the duration of high voltage impulse
- Time step is smaller than vx/dx, where vx is the speed of gas at the inlet and dx is the lengthwise dimension of the channel.

The applied voltage had 20 kV peak, the duration of "ON" state was 30 ms the total time of period was 50 ms.

4. Results of calculation

Fig. 2 and 3 represents the result of calculation. In case of Fig. 2 the voltage is on, the corona current charge up the particles, so they reach a certain level of charge creating space charge in the half channel.

In. Fig. 3 the voltage is off, the ionic space charge is zero, but the space charge caused by the charged particles is a given value. That is the reason, that the theoretical drift velocity of dust is significant, resulting precipitation of dust.

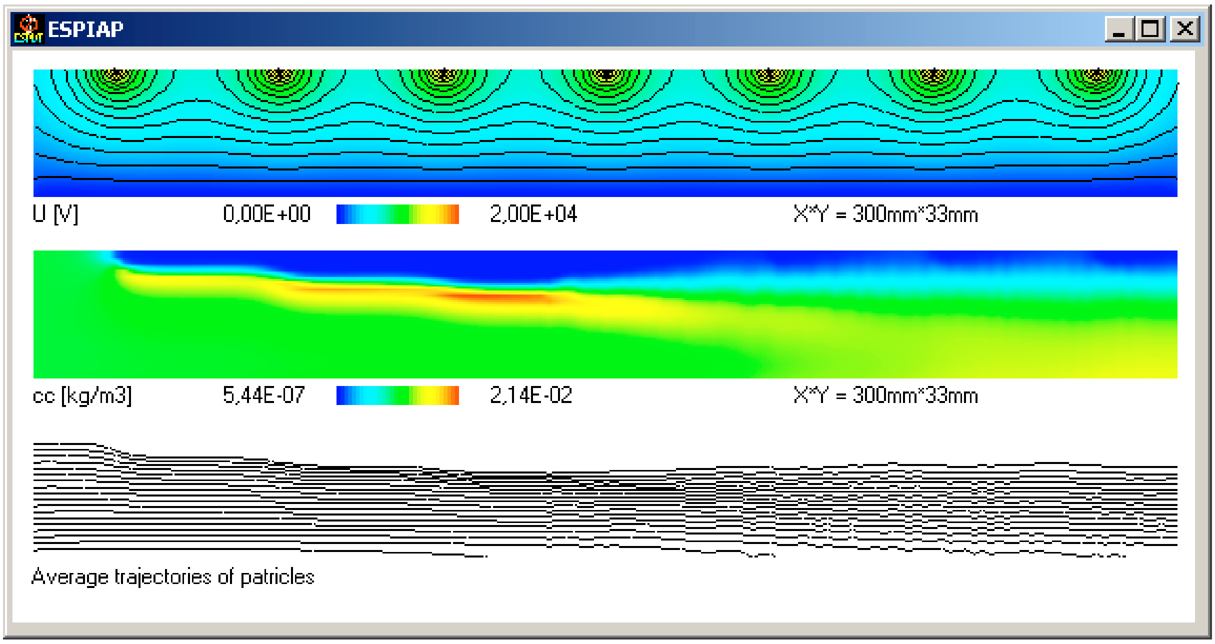

Fig. 2.

Based on the model the possibility is given to make further analysis for various impulse forms. The applicability of the model in case of short time impulses (microsec. range) requires further analysis.

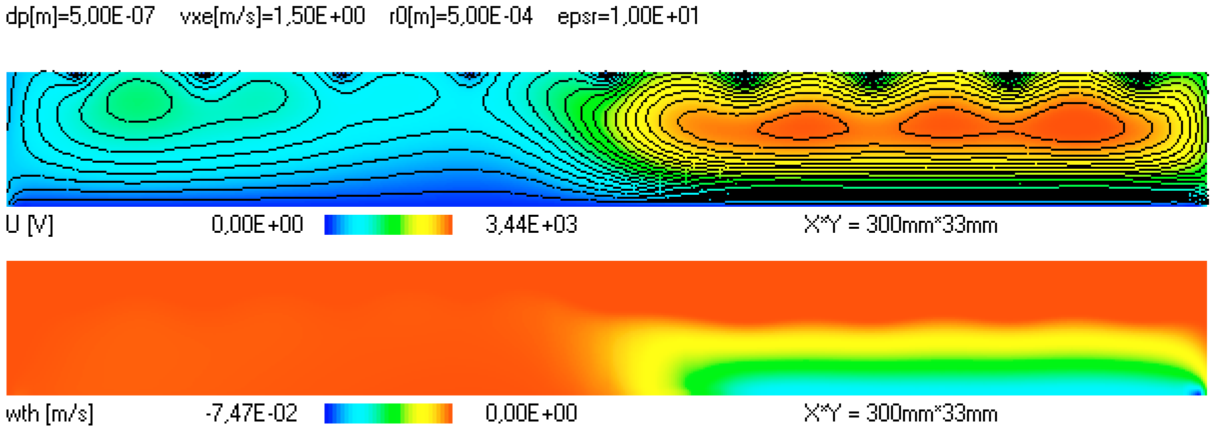

Fig. 3.

5. Conclusions

By our new, further developed model significance of space charge in the precipitation process can be pointed out in case of the impulse voltage supply mode. The model makes the examination of different supply modes possible. Comparison of the efficiency of precipitation in case of different supply modes is a topic for further investigations.

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