Modeling of Back Corona in Pulse Energized “Multizone” Precipitators

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Abstract: Most of the electrostatic precipitators have at least two zones in which different supply parameters, rapping programs can be used. Lot of ESP models are handling the electrostatic precipitator as one block whit the same energization. However, separated operation of zones is useful to improve collection efficiency. In this paper authors represent an improved numerical ESP model that is capable to handle multiple zones with different properties. The represented modeling process is focused on different energization modes and the formation of back corona.

As a case study, application of the model is presented in case of such a situation, when aluminum-oxide dust must be separated from the gas-powder mixture. Determination of electrical and physical properties of the aluminum-oxide dust is involved in the paper as well as results of laboratory measurements predicting the performance of precipitation. Measurement results are compared with calculation results and the performance of the existing industrial electrostatic precipitator for different supply modes to select the best one among them.

Keywords: ESP, modeling, back corona, pulse energization

1 INTRODUCTION

Separation of alumina from the carrying air is a typical task in aluminum smelter plants. Usually the gas to be cleaned is led through a cyclone before it reaches the electrostatic precipitator therefore the mean value of the diameter of particles is about 5 microns. The temperature of the gas is about 250℃–280 ℃, the concentration of the dust at the inlet is approximately 20 g/m^3–30 g/m^3.

Alumina has high specific resistance. According to our measurements made on different samples taken from an existing ESP, its value at the operating temperature is around 5×10^{11}–10^{12} Ωm. This value predicts difficulties in obtaining good collection efficiency, namely appearance of back corona is expected.

Examining the voltage-current characteristics of an existing electrostatic precipitator, this prediction seems to be valid. In Fig. 1, it is possible to compare the V-I curves for the cases when the ESP is empty and loaded. (Figure is valid for one, total zone.)

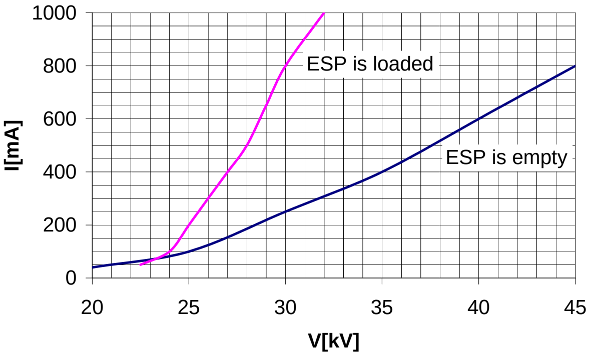

Fig. 1 V-I characteristics for an existing ESP

As it is well-known, the previous distortion of voltage-current characteristics is problematic, because the collection efficiency cannot be increased by increasing the supply voltage; different supply mode, advanced rapping control or other solution (e.g. influencing the specific resistance) is necessary to avoid the harmful effects of back corona, mainly the significant amount of emitted dust.

To model the effect of different solutions, such model is necessary, that is capable to analyze the processes in the electrostatic precipitator in the previously described cases (solutions).

2 THE APPLIED ESP MODEL

To determine the degree of precipitation, a numerical model was developed [1]. This model contains two main modules, one for the determination of the electric field and another one to calculate the flow field.

The first module solves the Laplace-Poisson equation based on the integral equation method. At the determination of the particle charge, the model takes into consideration both of the diffusion and the field charging. Regarding, that the space charge is influenced by the electric field and the electric field is influenced by the space charge, the field computation requires an iteration process.

The inputs of the module are the velocity field and the concentration distribution at a given moment, the geometrical and electrical parameters of the ESP chamber and the dust properties. The output is the drift velocity component of the particles originating from the effect of electric field.

The second module determines the flow field, the dust concentration distribution, and the particle transport.

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 to calculate physical quantities after a given time. Our steady state model 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 was improved to involve the time dependency into the model. To take time dependency into consideration we needed to modify mainly the modules calculating the ion space charge and dust charging.

By calculating the ion space charge we assume that by a given supply voltage the corona current can be calculated which continuous present in the ESP's half channel. This assumption is fulfilled only when the supply voltage is constant for longer time than the ions traveling time through the half channel of the ESP.

By a microsecond cycle time that the supply voltage changes so fast that a steady constant ionic current could not evolve.

A model was needed which can follow the changes in the supply voltage, and calculates the ion space charge for shorter time steps (Δt) than the period of the supply voltage.

In our new model the donor cell method is used to determine the ion space charge in the ESP half channel [2]. The advantage of this method is the use of an irregular (non equidistant) grid division. So the focus can be on parts of the ESP channel where changes are relevant, and other parts, where physical values not much differ, can be out of focus to fasten the calculation.

The equation $divJ = 0$ is valid for each cell in the grid, so the number of charges entering a cell, equal the number of charges leaving the cell. The current density in a cell is proportional with the ion mobility in the cell (μ), with the charge density in the adjacent cells (ρ_i) with the potential between the adjacent and the current cell $(\varphi_j - \varphi_i)$, and inversely proportional with the distance of the cells $(\Delta_{j,i})$ which is the distance between the midpoints of the cells.

$$J_{j,i} = \rho_j \cdot \mu \cdot \frac{\varphi_j - \varphi_i}{\Delta_{j,i}}$$

(1)

By the charges leaving the cell the charge density of the cell is taken into consideration.

$$J_{k,i} = \rho_i \cdot \mu \cdot \frac{\varphi_i - \varphi_k}{\Delta_{k,i}}$$

(2)

If we complete the equation $divJ = 0$ with the charge loss coming from the recombination of the charge carriers, we get the equation

$$J_{j,i} \cdot L_{j,i} + J_{k,i} \cdot L_{k,i} + J_{l,i} \cdot L_{l,i} + R_i \cdot A_i = 0$$

(3)

Where R_i means the recombination factor for the charge carriers. The solution of the linear equation system gives the ion space charge in the ESP half channel.

To follow the change of ion space charge density in time, it is necessary to modify the donor cell method into a time-dependent form. It means that instead of the balance of currents (or current densities) of the donor cell, the balance of transported charge has to be determined. For this purpose a time step dt is introduced, to obtain a charge amount (as a multiplication of the current and the time step) flowing into and out from the cell. With this procedure, the change of ion charge can be monitored inside the cell as a function of time.

Time step dt is chosen to such a value, which is significantly below the "residence time" of a charge carrier inside a specific donor cell. This requirement can be fulfilled, when the time step is less than the shortest side of the donor cell (ds) divided by the product of ionic mobility (μ) and electric field strength (E):

$$dt << ds / (\mu E) \qquad (4)$$

The previously described method requires the modification of the process of calculation as well as the data structure of the model. A new set of data had to be added to the existing data structure storing the initial ionic charge density

1. Calculation of the electric field with the initial ionic charge density
2. Calculation of currents according to the donor cell method
3. Determination of charge transfer during time interval dt using the initial ion charge density values
4. Calculation of actual ionic charge density
5. Replacing initial ionic charge density by the new one and going back to step 1.

Another module of the model is responsible for the calculation of the formation of back corona. Back corona is a typical problem of electrostatic precipitators, when the dust to be precipitated has a high specific resistance (above $\rho = 10^{12}$ Ω·m). Precipitated dust layer remains charged up for a long time (time constant is determined by $\rho\varepsilon_r$, where ε_r is the relative permittivity of dust particles), thus the particle charge and ionic current result in a continuously increasing electrical field strength at the surface of the collecting electrodes. Above a critical limit a breakdown is formed through the dust layer. Because of the breakdown, discharges appear that inject ions into the ESP channel. These ions have opposite polarity related to the ones produced near the corona electrodes, thus the particle charge is reduced and collection efficiency decreases [3].

Modeling of back corona can be separated into two parts. First one is the determination of the time function of electrical field E_m at the dust layer - collecting electrode interface, second one is the determination of back corona current and its effect on the particle charging. For the determination of E_m, the following assumptions are considered to be valid

—Thickness of dust layer is examined in different sections along the collecting plate, it is considered to be constant in a given section.

—Speed of increase of dust layer thickness is considered to be constant for an analyzed section, it is denoted by h.

—Density of corona current is considered to be constant along a given section.

Based on these assumptions it is possible to express the time function of electrical field strength at the surface of the dust-collecting plate interface:

$$E_m = E_s(ht) + [J\rho + E_s(ht)](1 - e^{-\frac{t}{T}}) \qquad (5)$$

Where $J = J_{dust} + J_{ion}$, and $T = \rho\varepsilon_r$. According to equation (12), it is obvious, that after a given time denoted by t_{kr} E_m will reach the breakdown limit (E_{bkr}).

After the breakdown charge carriers are injected into the ESP channel by the back corona. The value of this current can be determined for example by the simplified model published in [4].

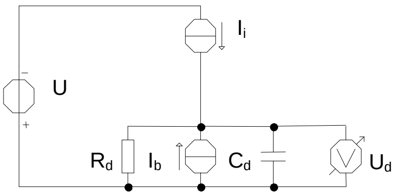

Fig. 2 Simplified model of back corona

Fig. 2 shows the schematic diagram of the model. I_i represents the normal corona current, I_b denotes the back corona current, while R_d and C_d symbolizes the resistance and the capacitance of the dust layer respectively. Using this notation, I_b can be calculated as follows:

$$I_b = K_1\left(\frac{U_d}{h} - E_{bkr}\right)^2$$

(6)

Back corona current decreases the charge of particles. Introducing

$$\gamma_J = \sqrt{\frac{J_+}{J_-}},$$

(7)

the charge of particles Q_t' changes according to the following equation

$$Q_t' = Q_t \frac{1-\gamma_J}{1+\gamma_J}$$

(8)

Where Q_t is the particle charge without back corona.

This process of computation can be inserted into the numerical ESP model. $E_s(ht)$ can be determined according to the electrical field computation module of the model, while precipitated dust amount determines the value of h. Taking into consideration the modified particle charge it is possible to calculate the collection efficiency in case of back corona.

3 PROBLEMS BY THE MODELING OF “MULTI-ZONE” ESP-S

Most of the used electrostatic precipitators have typically more than one zone. In the case of modeling such a multi zone precipitator, the model has to deal with larger number of corona electrode. Also the multiple energization of the zones has to be modeled.

There are more possibilities for the modeling of such a precipitator.

If the model handles the whole precipitator whit the multiple zones as one unit, it has to deal with a complex flow field in and between the zones, a large number corona electrodes and changing energization options. If the model would use the same fine grid extended for the multiple zone unit, the electric field calculation time increases dramatically. To get the calculation time to an acceptable level, the grid should be changed to a coarser grid. This change influences (decreases) the accuracy of the calculation.

Another possibility is, if the model calculates the zones separately. In this case the calculation time is just the calculation time multiplied by the number of zones, which is much faster than the previous solution. In this solution the handling of the changes in the particle transport between the zones is difficult. To calculate the boundaries in steady state is possible, but in non steady state the boundary conditions are not enough for the calculations. If the model is calculating a pulse energized ESP, the parameters on the boundaries are changing in each calculation step, therefore it is not possible to calculate the boundary conditions.

4 CASE STUDY

To demonstrate the operation of the previously described model a wire-plate electrostatic precipitator containing three zones was selected. In this ESP the distance between the wires and the collecting plate is 150 mm, the length of one zone is 3 m, number of corona electrodes in one zone is 9.

Relative permittivity and specific mass of the alumina was selected to 1.76 and 4000 kg/m^3 respectively. Dust load was supposed to have 3 fractions, 2, 5 and 10 microns, the resultant concentration at the inlet was 10 g/m^3

The first analysis was made for that case when no back corona appears and the supply voltage can be increased to 45 kV. Fig. 3 shows the dust concentration distribution for the fractions. The upper part shows the 10 micron fraction in a half-channel of the ESP, then 5 micron fraction follows, finally, at the bottom 2 micron particles are shown. It can be observed that larger particles reach the colleting plate quickly and collection efficiency is good even in case of the finest fraction.

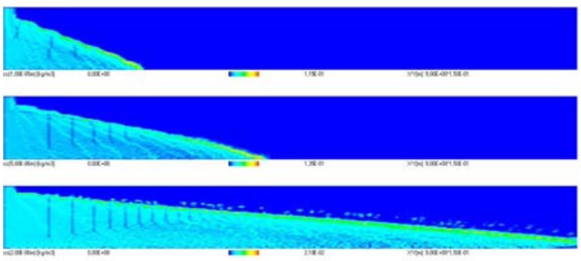

Fig 3 Dust concentration distribution at a supply voltage of 45 kV, no back corona

Fig. 4 shows the same distribution in case of back corona, when DC supply voltage drops down dramatically. It can be observed, that particle amount leaving the precipitator increases significantly.

Fig. 5 show how the collection efficiency for the different fractions changes as a function of the lengthwise position. The change of the overall efficiency can also be observed. It can be seen, that significant amount of dust leaves the ESP due to the back corona.

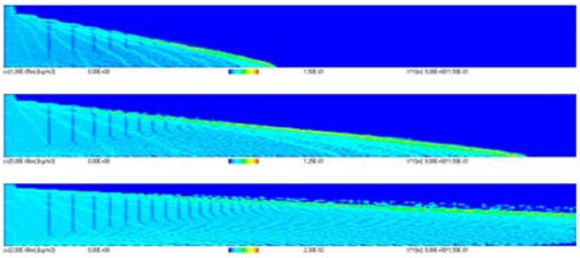

Fig. 4 Dust concentration distribution when back corona exists

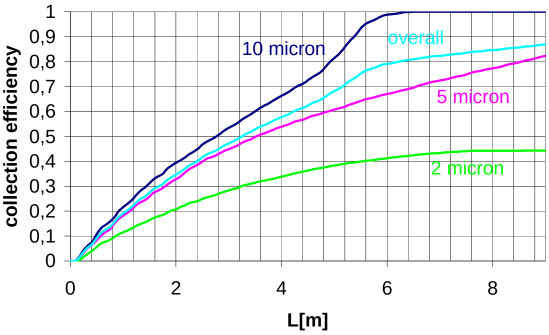

Fig. 5 Collection efficiency without pulse energisation

Application of pulse energization with a t_{on}/T ration of 60 % and t_{on} = 2 ms, collection efficiency becomes better as it can be seen in Fig. 6.

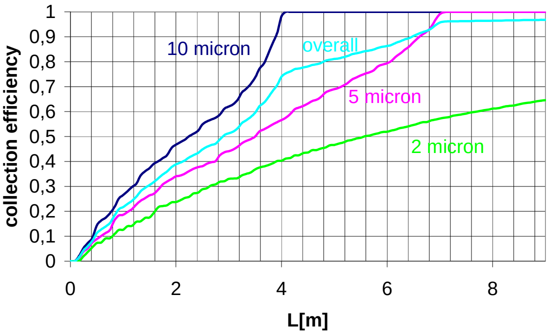

Fig. 6 collection efficiency without pulse energisation

4 CONCLUSIONS

Application of advanced models that are able to handle “multizone” precipitators are very useful tools to help in the selection of operational parameters of electrostatic precipitators (supply mode, rapping control, etc.) It was demonstrated how these models can be applied for the solution of an existing industrial problem.

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