Some Aspects of "Long Term" Modelling of Electrostatic Precipitators

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1 Summary / Abstract:

Nowadays modelling of collection efficiency in electrostatic precipitators is commonly examined by using numerical models. Different models exist for simulation of the multi-variable complex system of ESPs, the several determining physical processes [1]. One group of them determines the particle trajectories inside a half channel of a precipitator assuming that they were more or less the same during the operation of the precipitator.
Advanced models take it into consideration, that some phenomena in the ESP build up in a longer time period, so the calculated trajectories must be modified as the function of time, too. One of these basic, typical phenomena is the formation of back corona [2].
Some other phenomena (e.g. changes of environmental parameters and the pollutants stepping into the chamber of electrostatic precipitators) have even longer time constant, so their examination needs much longer period of time. The advanced model described in the paper is able to monitor these "long term" changes explaining some unexpected behaviour of the precipitator.
The complexity of the phenomena has been analysed by the newly improved ESP model of the authors, and "long term" simulations have been presented in several case studies of the paper.

2 Introduction

Numerical models are useful tools for predicting the performance of an electrostatic precipitator. There were numerous models developed by experts to predict the collection efficiency of ESP's. The difficulty by the modelling of ESP's is the large number of processes and phenomenon which have influences on each other. By the modelling some of the effects could be neglected because of the limited computational capacities or minor influence on the modelled phenomena.
In the majority of the models 2D modelling is used. Both of the electric and flow field can be treated as 2D, and the effect of the gravity is neglected, this method provides a simple and good approximation on the processes in the electrostatic precipitators. The use of a 2D model reduces the amount of computation therefore longer sections – a whole ESP channel – and more complex processes can be modelled. 3D models also exists, but because of the high computational needs these are just for short ESP sections (e.g. Chang[4], Adamiak[5]).

3 The modelling of ESP's

In a numerical model it is necessary include the parameters of the precipitated particles, the parameters of the energization and the gas flow. These parameters influence the processes inside of the precipitator. It is essential to know the *electric field* created inside of the ESP channel thus these is relevant for the *particle charging* and the charged particles are transferred in the *flow field*.
The interaction of the flow field and the dust is the diffusion and dispersion of the dust, the interaction between the electric field and the dust is the reason for the charging of the dust particles and the interaction of the flow field and the electric field creates the electro-hydro-

dynamic flow which includes also the ionic wind. The back corona belongs also to the interaction of the dust and the electric field.
All these participants and interactions together determine the dust movement, the precipitation and the reentrainment of the dust, and trough these, the efficiency of the precipitation.

3.1 Long term modelling

In a numerical ESP model the following effects play a role in the efficiency of precipitation:

- electric field modified by space charges (ionic and dust space charge)
- ionization (the generated free charges and the ionic wind)
- particle charging, saturation charge and charging process (diffusion, field and mixed)
- gas flow (turbulent and boundary flow)
- dust collection, dust layer expansion
- dust reentrainment, back corona

To have an accurate model it is necessary to model these phenomenon as accurate as possible and holding the computational needs of the simulation as low as possible. For the long time models it is necessary to generate a model, which calculates the processes in a non stationary manner i.e. it takes the short time (fast) changes and also the long time (slow) changes into account, especially in the case of pulse energization.
“Long term modelling” in ESP equipment containing multiple zones has a great importance. The filters can be modelled by three main zones[3]: the inlet, the middle and the outlet one. In case of the inlet zone particles of higher size are precipitated, and the speed of the accumulation is rather high thus the rapping severity is high.
The middle zone contains more fine particles, forming a layer on the collecting electrode different from the previous one. The rapping cycle (rapping–no rapping–) is longer thus the determination of dust distribution has higher significance.
Change of fuel has influence on both zones, and its effect reaches the third zone as well.
The third zone has low rapping severity. It is on one hand obvious, regarding that the rapping loss can be significant in the third zone. To model the processes in the third (outlet) zone it is important to follow the change of parameters in the whole ESP at least during the rapping period of the 3rd zone.
Also the back corona formation depends highly on the collected dust layer thickness, therefore the back corona occurrence is supposed closer to the inlet earlier, upon faster thickening of the dust layer.
Dust particles are not only collected on the collection electrodes but also there is dust deposition on the corona electrodes. These can have significant influence on the formation of corona discharges. An accurate long term model should handle this effect. One possible way of modelling these effect is to have a slowly growth in the corona electrode radius. Also the rapping of the corona electrodes should be taken into consideration which can also influence the dust emission.

3.2 Modelling of multizone ESP-s

Most of the used electrostatic precipitators have typically more than one zone. In the case of modelling 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 modelled.
There are more possibilities for the modelling of such a precipitator.
If the model handles the whole precipitator with 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.
For the long term modelling one further difficulty is the tracking of the collected dust layers changing properties. If the collected dust properties changes less frequently than the period of rapping, then just two types of dust are in the same time on the collecting electrodes. With these we can use a slightly modified back corona model as shown on Fig. 3–1. The capacitances C_{d1} and C_{d2} can be calculated depending on the relative permittivity of the dust layer and the collected dust layer thickness.

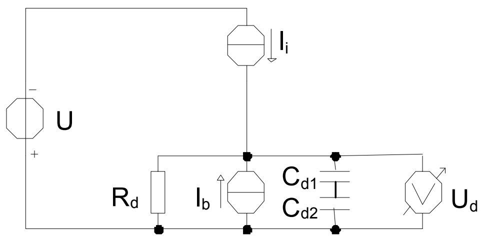

Fig. 3-1: Modified back corona model

If the rapping is infrequent and there is more then one change in the dust parameters, then more layers has to be taken into account, which is more difficult to track.

4 Case studies

In the first case the effect of relative permittivity change can be observed. The dust concentration distribution were calculated for relative permittivity values of 2, 5 and 10 (on Fig. 4-1 the darker regions have lower dust concentrations). The diameter of particles is 5 μm, their specific resistance is 10^{13} Ωm. The dust concentration on the inlet is 12 g/m^3. The corona electrodes are located on the upper side of the presented half-channel cross sections, while the collecting electrode is on the lower edge. The applied voltage on the corona electrodes is 25 kV.
It can be seen that the effect of relative permittivity is significant. On one hand, it increases the saturation charge and therefore improves the collection efficiency. However, it increases the time constant of discharging, thus back corona appears earlier.

In the second case (Fig. 4-2) the calculation were made for different diameters of 10, 5 and 2 μm. For all diameters the value of the relative permittivity was 2. In this case the energization used is different for the 3 sections of the ESP. In the first third the voltage is 32 kV in the second 40 kV and in the last third 45 kV.
In the third case (Fig. 4-3) the applied energization is pulsed with 32 kV pulses. The diameter of the dust particles is again 10, 5 and 2 μm. The permittivity is again the same as in the previous case.
In real situation these parameters are changing together (e.g. by a fuel change), so these phenomenon should be taken into consideration in the same time. The model should be able to handle the permittivity and diameter ranges.
In the second and third case back corona occurred upon the infrequent rapping. The different layer properties makes the calculation of back corona more difficult.
In the case of DC energization the control circuits holds the voltages close to the breackdown voltage. If arcing occurs the voltages are dropped and then raised again. This changes are slow changes which influences the efficiency of the precipitation and should be considered in long time modelling.

5 Conclusions

In long-time modelling it is essential to track the amount of dust collected on the collecting electrode and modelling the effect of rapping. Practical experiences show, that the changes in the dust properties can generate lower efficiency periods for a while. The model should be able to handle dust mixtures with different electric properties and different concentrations. These property changes should be tracked on the collected dust layer also, to get the expected results.

6 Literature

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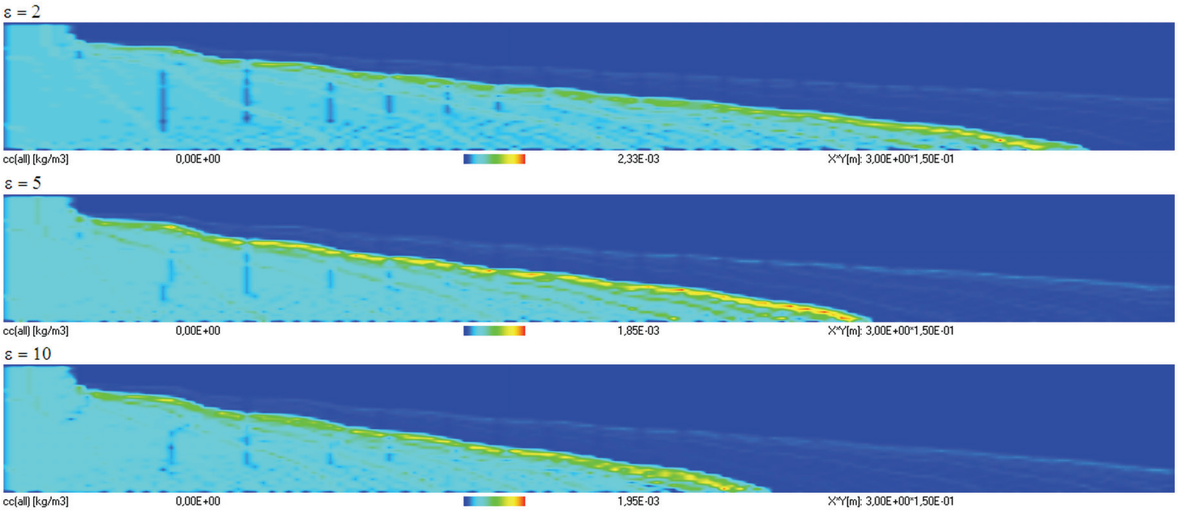

Fig. 4-1: Concentration distribution for different permittivities

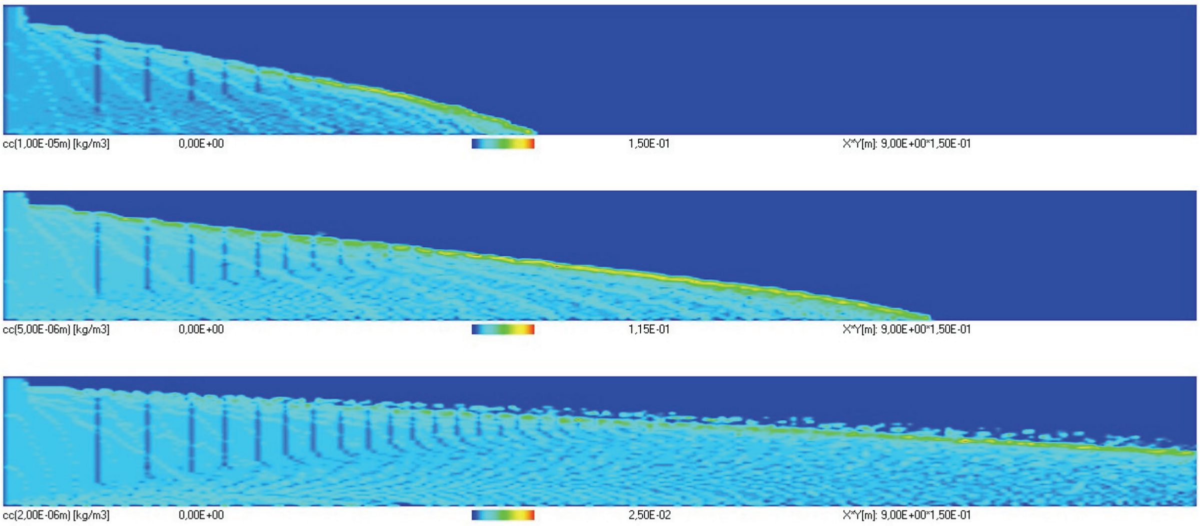

Fig. 4-2: Concentration distribution for different diameters

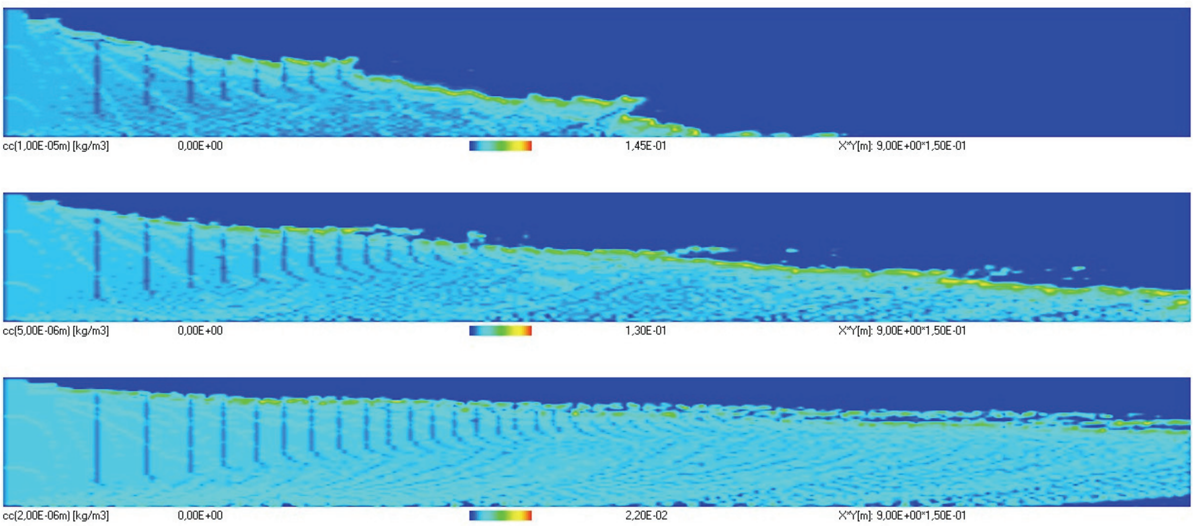

Fig. 4-3: Concentration distribution for different diameters with pulse energization