BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LVII (LXI), Fasc. 6, 2011
Secţia
ELECTROTEHNICĂ. ENERGETICĂ. ELECTRONICĂ

ON THE DUST PARTICLES ELECTRICAL CHARGING MODELS FROM PLATE-TYPE ELECTROSTATIC PRECIPITATORS

BY

GABRIEL-NICOLAE POPA[*] **and S.I. DEACONU**

“Politehnica” University of Timişoara

Received, May 31, 2011
Accepted for publication: July 18, 2011

Abstract. The particles charging models are studied. The dust particles charging are described by two processes. The first process, the field charging relates to the ions produced by the electric field. The diffusion charging is the second process that is produced by the ions random thermal motion. To simulate the charge process was used Matlab environment with real parameters from plate-type electrostatic precipitators of thermal power station S.C. Electrocentrale Deva S.A.

Key words: dust particles; charging model; plate-type electrostatic precipitators.

1. Introduction

The basic concepts of the operation of plate-type electrostatic precipitators (ESPs) are usually known. A dusty gas flow from fields of plate-type electrostatic precipitators must be clean when the dust passes along the duct. Along the middle of the duct are placed discharge wires to which a negative high electric potential is applied. The collecting plates, that form the duct, are connected to positive high electric potential and are earthed. An

---

[*] Corresponding author: *e-mail*: gabriel.popa@fih.upt.ro

electric field and a flow of electric charge are produced between the electrodes (discharge wires and collecting plates). The ionic charge moving in the duct and charge contacts dusts particles and for a period of time, the dust particles become electrically charged. This charge of dust particles interacts with electric field between the electrodes and occurs a force on the particles, perpendicular on the flow direction, which moving the dust particles to the collecting plates. The dust particles form layers on the collecting plates which are removed periodically from the collecting plates, outside of electrostatic precipitators (Lawless & Sparks, 1988; Medlin, 1998).

Knowing the phenomena from electrostatic precipitators is useful for their design and modeling. The dust particle has a limit of charge (at saturation). Electrostatic precipitators are significant devices of the cost in many types of industrial plants were a lot of dust particles are produced, like for coal-fired power stations. Through improving the efficiency of precipitator will reduce the cost of industrial utility (Zhang *et al*., 2010; Parker, 1997).

2. Dust Particles Charging Process

It is considered a spherical particle suspended in gas, in which exist ions generated by the Corona discharge (Lawless & Sparks, 1988; Medlin, 1998; Zhang *et al*., 2010; Parker, 1997). Because the dust particles have the characteristics of a dielectric (due to the surface resistance and volume of very high values), the field lines are passing aside and through the dust particle is deviated. Because a part of the field lines will pass through the dust particle, will pass also a flux of ions towards the particles' surfaces. The ions are considered to move on the field lines. This description is valid as long as the particle's diameter is much larger than the ions' diameter. The free way passed by the ions is given by the relation

$$\lambda_i = \frac{kT}{4\pi\sqrt{2}r_{\text{ion}}^2 p}, \tag{1}$$

where $k = 1.38054 \times 10^{-23}$ J/K is the Boltzmann's constant, r_{ion} , [m] – ion's radius, p, [N/m^2] – fluid's pressure. The radius of an ion is approximated to the value of 2×10^{-10} m, and $\lambda_i \approx 0.1$ μm.

The ions' impact on the particles' surface can determine the adherence to their surface without having transfer of electric charge, or the ions could be neutralized by transferring the charge to the dust particles. Anyway, the ions flux transfers the electric charge to the particles. The particles develop their own field by attaching the ions having electric charge. The particles' electric field distorts the electric field created by the electrons that produce the ions flux, and the component normal to the dust particle's surface becomes null and no ion doesn't attach anymore to the dust particle's surface. Thus, the dust particle is charging electrically up to a certain limit value.

For a spherical particle of radius r_p and constant dielectric ε_r the charging rate with electric charge is calculated with relation (Ammer & Woschitz, 2006; Fjeld *ei al.*, 1990; Jaworek *et al.*, 1998; Castle *et al.*, 1988)

$$\begin{cases} \dfrac{\mathrm{d}q_p}{\mathrm{d}t} = \dfrac{\rho_i k_i q_{\mathrm{sat}}}{4\varepsilon_0}\left(1-\dfrac{q_p}{q_{\mathrm{sat}}}\right)^2, \ q_p < q_{\mathrm{sat}}, \\ \dfrac{\mathrm{d}q_p}{\mathrm{d}t} = 0, \ q_p \geq q_{\mathrm{sat}}, \end{cases} \tag{2}$$

where

$$q_{\mathrm{sat}} = \frac{12\pi\varepsilon_0\varepsilon_r E r_p^2}{\varepsilon_r + 2}. \tag{3}$$

In these relations ρ_i, [C/m^3], is the ions' charging density, k_i, [m^2/(V·s)] – the ions' mobility, q_{sat}, [C] – the saturation electric charge, q_p, [C] – the dust particle's electric charge, ε_0, [F/m] – the void's electric permittivity, $\varepsilon_0 = 1/4\pi \times \times 9 \times 10^9$ F/m, and ε_r – the environment's relative permittivity.

Were adopted the following simplifications:

a) the dust particles are spherical;

b) the space between particles is much higher than the particles' diameter;

c) the ions concentration and the electric field are invariant in the particles' neighborhood.

The saturation electric charging is the limit charging obtained by the particle by charging the electric field and depends on the local intensity of the electric field E, [V/m], and the particle of radius r_p, [m]. In general, the electric charge is obtained by integrating the relation (2) as function of time

$$q_p(t) = q_{\mathrm{sat}}\frac{t}{t+\tau}, \tag{4}$$

$$\tau = \frac{4\varepsilon_0}{\rho_i k_i} = \frac{4\varepsilon_0 E}{j}, \tag{5}$$

where: τ, [s], is the time constant of the charging and represents the time necessary to reach at 50% from the saturation charging, E – electric field strength, j – current density. The magnitude order is of few hundredths of seconds for particles of small dimensions ($r_p \approx 1$ μm), and from practical viewpoint these particles can be considered that are charging instantaneously at saturation. The particles' charging at saturation is directly proportional with the (local) intensity of the electric field, E, and the square of the particle's radius, r_p, according to the relation (3). If $t \to \infty$, then $q_p \to q_{\text{sat}}$; for perfectly conductive environment $\varepsilon_r \to \infty$, and for vacuum $\varepsilon_r \to 1$. So, it can be written that

$$q_{\text{satvacuum}} \approx \frac{q_{\text{satconductor}}}{3}. \tag{6}$$

Charging by diffusion is similar with the electrostatic charging, the charging rate increasing with the particles' surface (Lawless & Sparks, 1988; Zhang *et al.*, 2010; Ammer & Woschitz, 2006; Fjeld *ei al.*, 1990). Making the assumption that the ions' density is much smaller than the gas molecules' density, the charging by diffusion depends mainly by the thermal energy of the ions during the exposure time. Charging by diffusion was determined by means of the relation

$$\frac{\mathrm{d}q_p}{\mathrm{d}t} = \pi r_p^2 v_{\text{med}} \rho_i \mathrm{e}^{-q_p e/(4\pi\varepsilon_0 r_p kT)}, \tag{7}$$

where: v_{med}, [m/s], is the ions' medium speed, ρ_i, [C/m^3] – the ions' charging density, $e = 1.6 \times 10^{-19}$ C – the electric charge of one electron, k – Boltzmann's constant, and T, [K] – environment's temperature.

The medium speed of an ion is given by

$$v_{\text{med}} = \sqrt{\frac{3kT}{m_{\text{ion}}}}, \tag{8}$$

in which m_{ion}, [kg], is the ion's mass.

By integrating the relation (7) for a constant charge density (ρ_I = ct.) it results

$$q(t) = q^* \ln\left(1 + \frac{t}{\tau_{\text{diff}}}\right), \tag{9}$$

where

$$q^* = \frac{4\pi\varepsilon_0 r_p kT}{e}, \text{ [s]}, \tag{10}$$

is a constant charge, and

$$\tau_{\text{diff}} = \frac{4\varepsilon_0 kT}{r_p v_{\text{med}} \rho_i e}, \text{ [s]}, \tag{11}$$

represents a time constant at charging by diffusion.

Eq. (7) has no limit at $t \to \infty$. Charging depends on the particle's radius,

r_p, and environment's temperature, T, being independent on the intensity, E, of the exterior electric field.

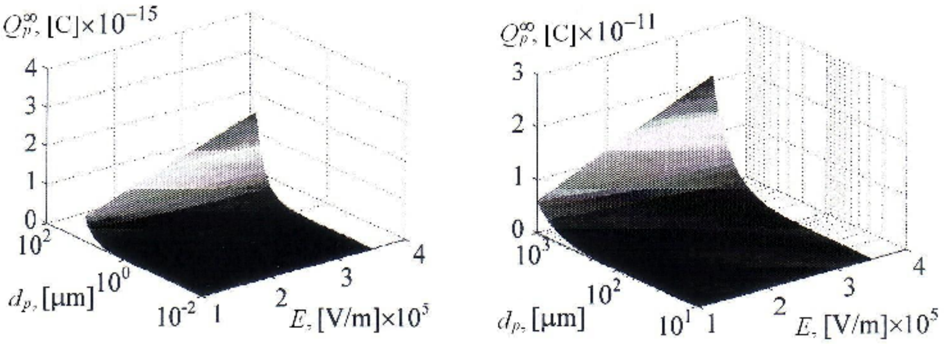
The Cochet's charging model is presented further (Lawless & Sparks, 1988; Medlin, 1998). After an infinite time is considered that the particle's saturation charge is given by

$$Q_p^\infty = \left[\left(1+\frac{\lambda_i}{r_p}\right)^2 + \frac{2}{1+\dfrac{\lambda_i}{r_p}} \cdot \frac{\varepsilon_r - 1}{\varepsilon_r + 2} \right] 4\pi\varepsilon_0 r_p^2 E, \tag{12}$$

where: λ_i, [m], is the molecules' free way, r_p, [m] – the particles' radius, ε_r – the molecules' relative permittivity, ε_0, [F/m] – the void's absolute permittivity, and E, [V/m] – the electric field's intensity.

3. Simulations of the Electrostatic Charging Process

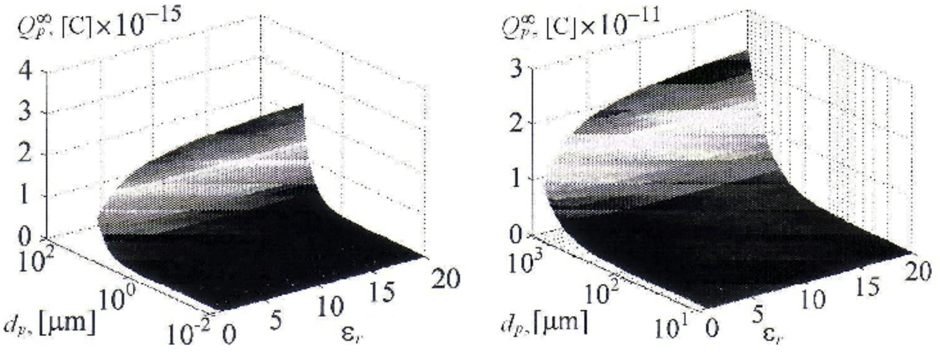
Based on the Cochet's charging model (12) and by means of the MatLab program were drawn-up graphics (Figs. 1,…,3) of the particle's charge at saturation depending on different parameters (d_p, [μm], E, [V/m], j, [A/m^2], ε_r, t, [s]).



a *b*

Fig. 1 – Particles' charge at saturation *vs.* the electric field's intensity, when $\varepsilon_r = 5$ and the dust particles' diameter is: *a* – $d_p \in [0.01\ldots10]$ μm; *b* – $d_p \in [10\ldots1{,}000]$ μm.

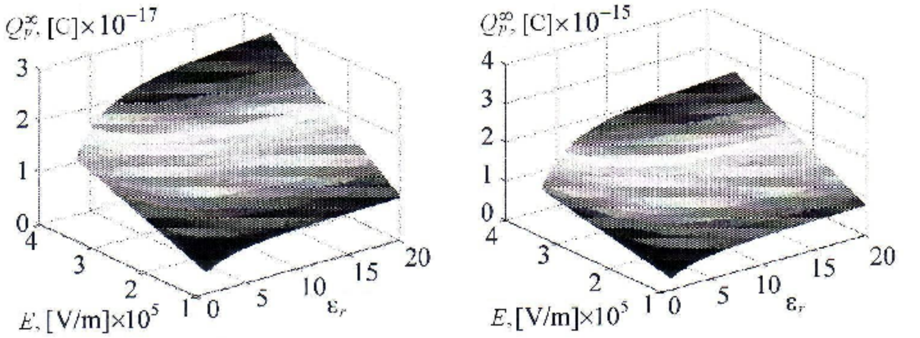
For drawing-up the graphics from Figs. 1,…,5, were used domains within the parameters are framing in (d_p, [μm], E, [V/m], j, [A/m^2]) determined at the ESPs from S.C. Electrocentrale, Deva S.A. (ICPET, 2006, 2008). The domain in which can be modified the relative permittivity ε_r of the dust particles was taken from literature (Medlin, 1998; Parker, 1997; Ammer & Woschitz, 2006).



a *b*

Fig. 2 – Particles' charge at saturation *vs.* the environment's relative permittivity, when E = 3 kV/cm and the dust particles' diameter is: a – $d_p \in$ [0.01…10] μm; b – $d_p \in$ [10…1,000] μm.

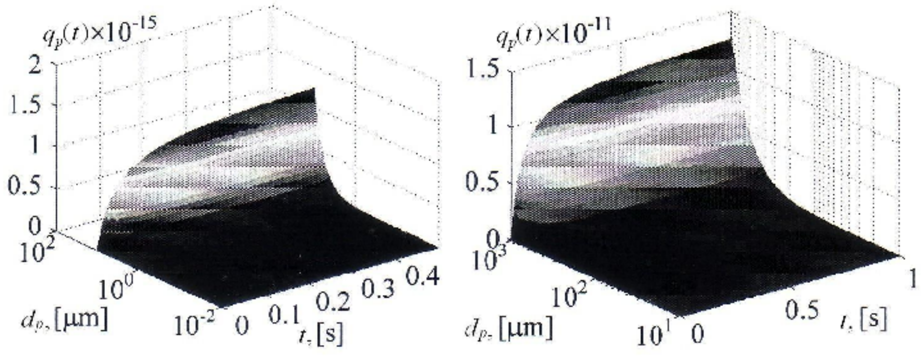
The particles' electric charging in time is described by eq. (4) using the time constant, τ, [s], for the charging process. If is considered that the electric field's intensity is constant, then the particles' electric charging is independent on the particles' dimensions. By MatLab program were drawn-up two graphics (Figs. 4 and 5) of the particles' electric charge variation in time.



a *b*

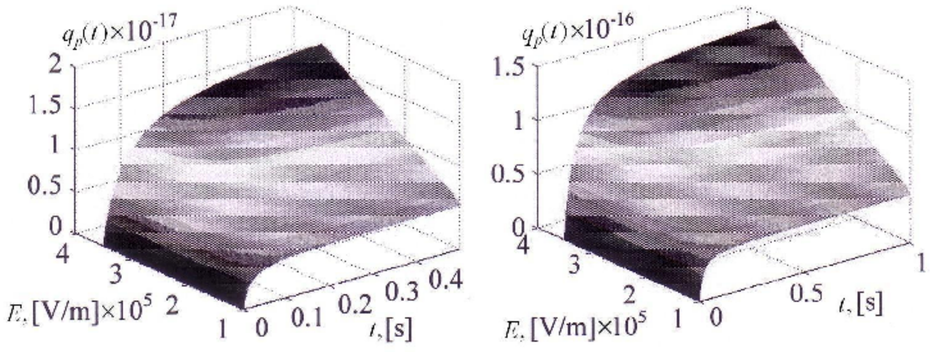
Fig. 3 – Particles' charge at saturation *vs.* the environment's relative permittivity and the electric field's intensity, when: a – d_p = 1 μm; b – d_p = 10 μm.

The dust particles' saturation charge increases with the square of the dust particles' diameter, and increases linearly by the electric field's intensity and increases non-linearly with ε_r. The dust particles resulted further burning has diameters from the order of μm up to tenths and hundredths of μm. The electric charge is higher and higher as time passes for a dust particle of a certain diameter and for a certain intensity of the electric field.



a *b*

Fig. 4 – Modification of the electric charge in time *vs.* $\varepsilon_r = 5$, $E = 3$ kV/cm, $j = 0.24$ mA/m^2, and the particles' diameter are: *a* – $d_p \in [0.01\ldots10]$ μm; *b* – $d_p \in [10\ldots1{,}000]$ μm.



a *b*

Fig. 5 – Modification of the electric charge *vs.* time depending on the electric field's intensity, when $\varepsilon_r = 5$, and $j = 0.24$ mA/m^2: *a* – $d_p = 1$ μm; *b* – $d_p = 10$ μm.

Collecting of dust particles below 10 μm is still a problem. Some researches (Medlin, 1998; Ammer & Woschitz, 2006; Lackowski, 2001) shown that charging of dust particles in a zone with alternate electric field and collecting of particles in another zone with continuous electric field (bipolar charging of dust particles), represents a solution for improving the collection of these particles. The dust particles with diameters smaller than 10 μm appear further the coal burning, which is fine crushed.

4. Conclusions

The dust particles' electrostatic charging is better achieved in conditions of increasing the electric field's intensity and in case when the dust particles are less conductive of electricity (a higher ε_r). A higher intensity of the electric field can be achieved in conditions of a neater mechanical construction of the discharge wires and the collecting plates (keeping the parallelism and the distance between electrodes). Utilization of some supply sources to ensure a voltage level as higher possible is another important condition. The dust particles with smaller diameters are charging electrostatically much harder. Further the coal's crushing in case of thermal power plants and the burning process is important to obtain dust particles of diameters as large possible or to obtain agglomeration of dust particles of smaller diameters (to be with a higher equivalent diameter).

Acknowledgments. This paper was supported by the project "Development and Support of Multidisciplinary Postdoctoral Programmes in Major Technical Areas of National Strategy of Research – Development – Innovation" 4D-POSTDOC, contract no. POSDRU/89/1.5/S/52603, project co-funded by the European Social Fund through Sectoral Operational Programme Human Resources Development 2007-2013.

REFERENCES

Ammer M., Woschitz R., *Properties, Charging Processes and Depositions of Particles in Electrostatic Filtration Systems*. The Xth Internat. Conf. on Electrost. Precip. (ICESP), Cairns, Queensland, Australia, July, 2006, *9B2*.

Castle G.S., Inculeț I.I., Lundquist S., Cumming J.B., *Measurement of the Particle Space Charge in the Outlet of an Electrostatic Precipitator Using an Electric Field Mill*. IEEE Trans. on Ind. Appl., **24**, *4*, 702-707 (1988).

Fjeld R.A., Wu D., McFarland A.R., *Evaluation of Continuum Regime Theories for Bipolar Charging of Particles in the 0.3-13 μm Diameter Size Range*. IEEE . on Ind. Appl., **26**, *3*, 523-528 (1990).

Jaworek A., Krupa A., Adamiak K., *Submicron Charged Dust Particle Interception by Charged Drops*. IEEE Trans. on Ind. Appl., **34**, *5*, 985-991 (1998).

Lackowski M., *Unipolar Charging of Aerosol Particles in Alternating Electric Field*. J. of Electrost., *51-52*, 225-231 (2001).

Lawless P.A., Sparks L.E., *Modeling Particulate Charging in ESPs*. IEEE Trans. on Ind. Appl., **24**, *5*, 922-927 (1988).

Medlin A.L., *Electrohydrodynamic Modelling of Fine Particle Collection in Electrostatic Precipitators*. Ph.D.Diss., School of Phys., Univ. of New South Wales, Australia, 1998.

Parker K.R. *et al.*, *Applied Electrostatic Precipitation*. Chapman a. Hall, Londra, U.K., 1997.

Zhang Z.S., Liu Q., Xiao Z.L., Zhang B., Yang Z.Y., Liu Z.Q., Li Q., *The Influence of High Voltage and Coal Dust Particle Size Distribution on Dust Collecting Efficiency*. 2nd Internat. Conf. on Ind. a. Inform. Syst., U.S.A, 2010., 148-151.

* * * *Measuring for Establishing the Collection Efficiency at Electrical Undusting*

Installation, Energetic Group, no.1 from Thermoelectric Power Plant Mintia-Deva (in Romanian). 2181-CPPM, S.C. ICPET S.A., Bucharest, Romania, 1996.

* * * *Operations Optimization of ESPs from Group no.1, with Four Fields* (in Romanian). 7815-1, S.C. ICPET S.A., Bucharest, Romania, 1998.

* * * *Operations Optimization of ESPs from Group no.4, with Three Fields* (in Romanian). 7815-2, S.C. ICPET S.A., Bucharest, Romania, 1998.

ASUPRA MODELELOR DE ÎNCĂRCARE ELECTROSTATICĂ ALE PARTICULELOR DE PRAF DE LA ELECTROFILTRELE USCATE CU PLĂCI

(Rezumat)

Se studiază procesul de încărcare electrostatică a particulelor de praf rezultate în urma arderii combustibilului. Încărcarea electrică se realizează prin două procese distincte. Primul proces se referă la încărcarea electrostatică prin ionii produşi de câmpul electric. Încărcarea prin difuzie reprezintă al doilea proces care este datorat agitaţiei termice. Pentru simularea procesului de încărcare s-a utilizat procedeul Matlab cu parametrii reali de la electrofiltrele uscate cu plăci de la termocentrala S.C. Electrocentrale Deva S.A.