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STUDY REGARDING ELECTROSTATIC SEPARATION OF NANOMETRIC PARTICLES IN GASES USING CORONA DISCHARGE

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Abstract

The nanometric particles (<100 nm) represent a very important issue for human health, because once inhaled, they get into the blood and become dangerous. The electrical purification is done by passing a gas current through a non-uniform electric field between two electrodes, on which a voltage of 10 – 60 kV is applied. The particles separation occurs due to the Corona effect around the thin electrode. The dispersed particles in the gas receive electric charges from the Corona discharge field, and migrate to the opposite electrode, where they deposit.

1. Introduction

One of the actual problems is that of the nanometric dust from the gaseous emissions in metallurgical and cement industries [1]. The nanometric particles (<100 nm) represent a very important issue for human health, because once inhaled, they get into the blood and become dangerous (the macrophage cells cannot recognize and retain them). The idea is to use the electrical purification, passing the dusty gas through an electrofilter [2], [3]: a device consisting in a thin electrode (the discharge electrode), placed coaxial in a cylinder, the opposite electrode. The electrical field generated around the thin electrode is highly nonuniform, most excitation and ionization processes taking place in the close proximity of the wire, in the high-field zone.

As a consequence, a corona discharge appears, only in the nonuniform field zone, within a low area around the thin electrode. The name of corona originates in the fact that the discharge has the appearance of a luminous crown surrounding the thin electrode [4]. The remaining space between the electrodes is dark, because there are no excitation and ionization processes of the gas taking place due to the low intensity of the field (here the field can be

considered constant), therefore the corona discharge can be considered as an incomplete penetration of the gas. At low pressures the discharge occupies a volume that increases as the gas pressure decreases, at high pressures ($p = p_{atm}$) the crown being reduced to a thin film around the thin electrode.

2. Theoretical considerations

By analyzing the volt-ampere characteristic (figure 1), it can be observed that the discharge appears at an initial voltage V_{cor}. Starting from this voltage, the current increases gradually, and at a certain point reach the saturation. If the voltage keeps increasing, a current jump occurs, corresponding to the generation of the first electrical sparks, for higher voltages the discharge turning into electrical arc [4], [6].

The field intensity at which the corona effect appears is called *initial intensity* of the corona effect field, and it depends on the curvature of the surface of the electrode around which the discharge occurs. At the same time the field intensity increases with the discharge current (to be proved later).

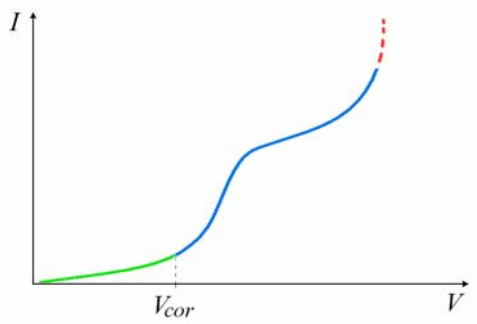

Figure 1: The V-A characteristic of the corona discharge

The intense field around the discharging electrode generates around it multiplications through electron avalanches, even though the potential between the electrodes is inferior to the gas penetration potential ($V_{cor} < V_s$).

When the thin electrode is negatively charged (negative corona discharge), the positive ions generated by the discharge are accelerated towards the wire. As a result of the processes of secondary electron emission at ionic impact, secondary electrons are generated that are also accelerated by the field, but in the opposite direction. In their way they collide with the gas molecules or atoms, causing processes of excitation and ionization through electron avalanches. Moving away from the wire, their energy decreases more and more due to the decrease of field intensity, so that, at some point, they are not able to cause excitations and ionizations anymore, *i.e.*, they have left the discharge zone. Next they will move under the

influence of a weak field, relatively constant, towards the other electrode through a dark zone also called *spatial charge zone*. Their velocities being low, there is the possibility of negative ions to appear as a result of processes of electron attachment to the gas atoms or molecules.

Therefore it can be stated that in the zone outside the corona conduction is unipolar, being provided by a single type of charge carrier (which makes this type of discharge suitable for the purpose stated above). The carriers are generated in the discharge zone, their concentration depending on the potential of the thin electrode, the material it is made of, the nature and pressure of the gas in which the discharge takes place. Another important characteristic of the corona discharge is that, unlike other discharges, the discharge current is not conditioned by the resistance of the external circuit, but by the conductivity of the spatial charge zone [3], [4].

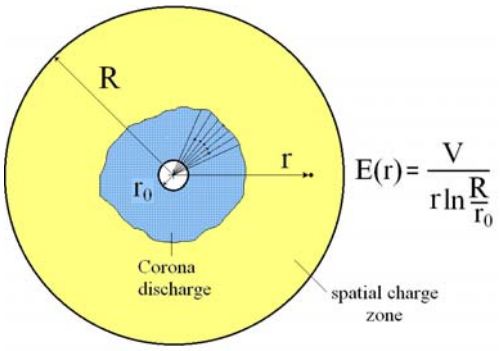

Figure 2: A system of corona electrodes

The evaluation of the particle charge is made for a simplified case: the particles are considered spherical, having a radius a, to the thin wire, having a radius r_0, is applied a negative potential, and the other electrode, coaxial to the wire and having a radius R, is grounded. Pauthenier considers that, excepting the proximity of the discharge electrode, the ionization through electron avalanches is negligible, the phenomenon of electron attachment to the gas atoms or molecules being predominant. The ions thus generated in the spatial charge zone have the mobility [3]:

$$\mu = \frac{u}{E(r)} \tag{1}$$

where:

u – the velocity of ions in the respective zone,

$E(r)$ – the field intensity at the distance r from the wire.

For a point located at the distance r from the negative electrode, the potential satisfies the Poisson equation in cylindrical coordinates [2]:

$$\frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial V}{\partial r}) + \frac{1}{r^2}\frac{\partial}{\partial \theta}(r\frac{\partial V}{\partial \theta}) + \frac{\partial^2 V}{\partial^2 z} = -\frac{\rho}{\varepsilon_0} \tag{2}$$

where ε_0 is the dielectric permittivity of vacuum.

Considering the working conditions:

$$\frac{\partial V}{\partial \theta} = 0 \quad \frac{\partial V}{\partial z} = 0$$

the equation (2) becomes:

$$\frac{d^2 V}{dr^2} + \frac{1}{r}\frac{dV}{dr} = -\frac{\rho}{\varepsilon_0} \tag{3}$$

where ρ represents the charge volume density of the negative ions in the spatial charge zone.

$$\rho = \frac{dq}{dV} = \frac{I\,dt}{2\pi r dr} = \frac{I}{2\pi r E(r)}$$

I represents the intensity of the ionization current per unity of length of the electrodes (the current of the corona discharge).

Substituting ρ in the equation (3) leads to:

$$rE\frac{d^2 V}{dr^2} + E\frac{dV}{dr} = -\frac{I}{2\pi\mu\varepsilon_0} \tag{4}$$

Assuming that in the spatial charge zone the discharge current and the mobility are constant magnitudes, the notation can be made:

$$\frac{I}{2\pi\mu\varepsilon_0} = a = const.$$

The equation (4) will then be written:

$$rE\frac{d^2 V}{dr^2} + E\frac{dV}{dr} = -a \tag{5}$$

Taking into account that:

$$E(r) = -\frac{dV(r)}{dr}$$

the following equation is obtained:

$$rE\frac{dV}{dr} + E^2 = a \tag{6}$$

Since in the present work only the case when $r > r_0$ is considered, *i.e.*,

$$E(r) = const. \quad (\text{because } a = const.)$$

it results:

$$\frac{dE}{dr} = 0$$

Therefore, for the spatial charge zone:

$$E(r) = \sqrt{\frac{I}{2\pi\mu\varepsilon_0}}$$

This is the equation generally used when the calculus of the intensity of the corona discharge current is intended.

Since in the spatial charge zone the field can be considered constant (especially in the proximity of the electrode of radius R where the granules to be charged are located), the discharge current can be considered (as it was assumed) constant.

The expression of the intensity of the electric field E® as a function of the potential V_0 of the discharge electrode is [5]:

$$E(r) = \frac{V_0}{r \ln \frac{R}{r_0}}. \tag{7}$$

For $r >> r_0$ (around the opposite electrode) the discharge current is in the form:

$$I = 2\pi\mu\varepsilon_0 E^2 \cong \frac{2\pi\mu\varepsilon_0}{R^2 \ln^2 \frac{R}{r_0}} \cdot V_0^2 = const \cdot V_0^2 \quad \left[\frac{A}{m}\right]$$

Certainly the mathematical models employed constitute a relatively simplistic representation of the complex processes that occur between the corona electrodes, but the values obtained here are quite close to the real ones for a proper discharge.

The charging of the particles located in the ionized field around the electrode with high curvature radius is studied for two limit cases:

1) conductive particle
2) dielectric particle, having relative permittivity ε_r.

Two types of charges can be distinguished: the charge acquired by the particle, conditioned by the thermal movement of the ions, and the charge determined by the movement of the ions under the influence of the electric field.

The charge acquired by the particle as a result of the thermal movement of the ions is approximately proportional to the radius of the particle, while the charge acquired as a result of the ordered movement of the ions under the influence of the electric field is proportional to the square of the radius of the particle. Therefore, for small particles (radius $a \leq 1\mu m$) the charged is conditioned almost exclusively by the thermal movement of the ions. For large

particles ($a \approx 0.1$mm) the charge acquired from the ions is so large, that the thermal charge can be neglected.

Under these conditions, for the cylindrical field considered the size of the charge that is acquired in time by a dielectric particle is given by the Pauthènier equation [2]:

$$Q(t) = 4\pi\varepsilon_0\left(1 + 2\frac{\varepsilon_r - 1}{\varepsilon_r + 2}\right)Ea^2\frac{t}{t + \frac{4\varepsilon_0}{\mu\rho\upsilon}}, \tag{8}$$

where:

$Q(t)$ – the charge of the spherical particle at the time moment t,

E – the field intensity at the point where the particle is located,

a – the radius of the spherical particle.

The maximum charge which the particle can acquire is given by the expression:

$$Q = Q(t)_{t\to\infty} = 4\pi\varepsilon_0\left(1 + 2\frac{\varepsilon_r - 1}{\varepsilon_r + 2}\right)Ea^2 \tag{9}$$

For a metallic particle ($\varepsilon_r \to \infty$) it is obtained:

$$Q = 12\pi\varepsilon_0 Ea^2$$

Knowing the electric field and the charge of the particles it is possible to determine the forces that act on them in a corona electrofilter.

Electrofilters

Electrofilters [1] are apparatuses used for the reduction of air pollution through the removal of polluting particles by passing the gas through an electric field. The reduction of polluting gas emission and dust emission introduced new parameters related to environmental pollution.

The electrofilters are used both for suspension trapping from powder and industrial gases and for the retrieval of some useful materials (Cu, Pb, cement powder).

The mechanism through which the ions that *provide* the electrical charging of particles are formed is the corona discharge.

The most important processes that take place in electrofilters are:

- the electric charging of the particles;
- the motion law of the particles in suspension;
- the processes at the collecting electrode.

For the separation of particles from a biphasic medium using an electrofilter the following operations are necessary:

- electrical charging the particles in the biphasic medium
- migration of dust particles to the deposition electrodes
- separation of particles on the deposition electrodes
- removal of material from the deposition electrodes, for the purpose of its removal out of the electrofilter

The electric charging takes place by attaching of ions to the particles in suspension. In an electric field with cylindrical symmetry the number of ions that are trapped by a conducting particles of radius a, is given by the relation [6]:

$$n = 4\pi\varepsilon_0 \frac{3E_0 a^2}{e}. \tag{10}$$

At the same time the particle total charge is:

$$q = n \cdot e$$

In the case of dielectric particles, polarization charges interfere with the charge of the particles.

The motion law for the gas particles is [3]:

$$m\frac{d\mathbf{v}}{dt} = q\mathbf{E}_d - 6\pi\eta r\mathbf{v} \tag{11}$$

where: E_d is the electrical stray field;

η is the viscosity coefficient;

υ is the speed of the particle.

The dipole electric forces are reduced and practically have no influence on the motion.

Integrating the last equation, on obtain:

$$\upsilon = \frac{qE_d}{6\pi\eta a}\left[1 - \exp\left(1 - \frac{6\pi\eta a}{m}\right)\right]. \tag{12}$$

For nanoparticles found in the industrial deviling ($a < 1$ μm and $\eta = 1.8 \cdot 10^{-4}$ poise) the exponential can be neglected, and obtain:

$$\upsilon = \frac{2\varepsilon_0 \cdot E_0 \cdot E_d}{\eta} a \tag{13}$$

For determining the speed of the gas in the active zone of the filter one can use [2]:

$$\upsilon = \frac{H}{360 \cdot S}$$

where: S is the active surface (m^2) of the electrofilter.

H is the volume of gas per time unity, which passes through the electrofilter.

The precipitation efficiency is:

$$\delta = 1 - \exp\left(-\frac{Sv}{H}\right). \tag{14}$$

The electric potential at which the discharge is initialized is called breaking potential or breaking threshold and depends on the geometry of the electrode, on the distance between the electrodes, and the nature of the gas. The increase in the electric field up to where sparks appear between the electrodes has a positive influence onto the efficiency. In figure 3 a scheme of the electrofilter is presented:

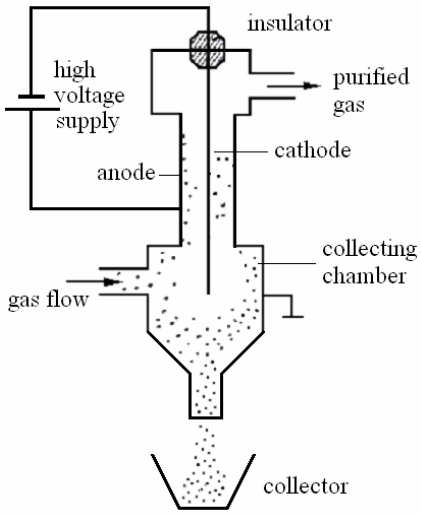

Figure 3: The scheme of the electrofilter

Each electrofilter consists of the following main parts:

- the collecting chamber, through which the gas stream to be purified passes
- the electrical equipment that supplies this chamber with high-voltage direct current

Inside the chamber there are the deposition and the emission electrodes. The deposition electrodes are placed vertically at a constant distance between them and are high-surface area smooth or profiled plates on which the dust deposits. The emission electrodes, also named corona electrodes, are attached to mobile frames placed on the axis between the deposition electrodes. High voltage is applied on the emission electrodes from the transformer-redresser power source.

The dust particles in the raw gases become electrically charged and move towards the deposition electrode of opposite charge.

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