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# CONTRIBUTION ABOUT THE ELECTROHYDRODYNAMIC SPRAYING

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*Sunt prezentate rezultatele originale obtinute de autor despre fenomenul electrohidrodinamic. Sunt prezentate ecuatiile care guverneaza pulverizarea electrohidrodinamica a lichidelor (ecuatiile lui Maxwell, densitatea de current, regimul ohmic, regimul injectiei unipolare si ecuatiile mecanice ale miscarii particulelor). Sunt comparate metodele prin inductie si prin conductie in procesul de incarcare cu sarcini electrice a particulelor de lichid pulverizate.*

*The original aspects achieved by the author about the electrohydrodynamic phenomena are presented. The equations that overrule the phenomena spraying of the liquids are presented (The Maxwell's equations, the current density, the ohmic regime, the unipolar injection regime and the mechanic equations of particle motion). There are compared the induction method and the conduction method in the process of charging with electric charges of the liquid sprayed particle.*

**Keywords:** electrohydrodynamic spraying (EHD).

## 1. Introduction

The electrohydrodynamic spraying is a complex process that converted a bulk of liquid into submicronics or micronics charged drops. The spraying process is conformable to the mechanic laws of free charge on drop sprayed surface. The detail knowledge of the spraying process allowed the development of some performing sprayers, able to produce spraying at variable flow rate of drops with selected dimensions.

The description of the EHD process will be done versus the following parameters: the voltage applied to the nozzle, the charge density of the cloud, the spraying current and the surface charge. These parameters depend by the properties of the liquid as: the conductivity, the surface constraint, the density, the viscosity.

The possibility to use the electric field for disperses the liquids has risen the interest for their applying in different practice domains as: the pesticide

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spraying in agriculture, the painting of the objects, the diesel motors, the printers, the aerosol generate for medicine, etc.

## 2. Phenomena of the liquid EHD spraying

The electrohydrodynamic spraying appears at disruption of a liquid jet which is pumped through a capillary tube, into the fine particles that are electric charged (the Fig. 1).

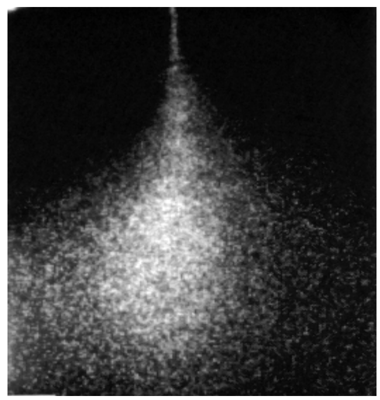

Fig. 1. The spraying cloud

The capillary tube is connected to a tank that contains the liquid for spraying, with adjustable pressure in the tank, so that to form spherical drops at the outlet of the capillary tube. On a ring electrode that is mounted to the end of the capillary tube is applied high voltage. The drops generated in this mode are usually charged till a fraction of Rayleigh limit, having the rays comparable with the nozzle ray (the fig. 2).

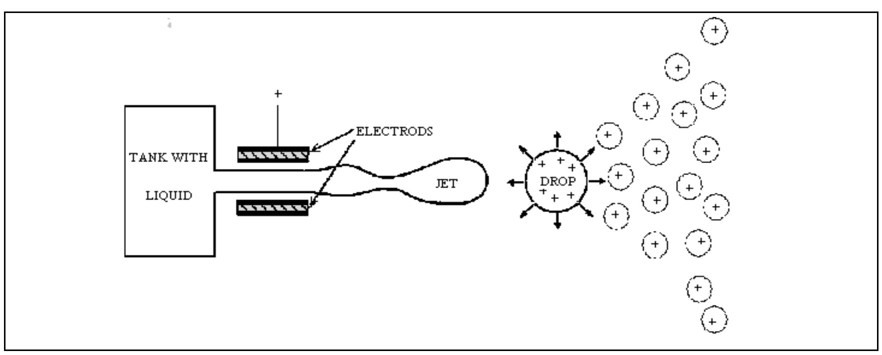


Fig. 2. The design of the sprayer and the disperse mode of the jet

The rising of the voltage carry to successively production of more unipolar charge on drops and smaller and smaller dimension of drops, till the spraying become an extended cloud of spatial charge, that begin to the approach of the capillary tube apex. The EHD spraying system allows obtaining fine particle (1-10μm). The particles are strong charged with electric charged, that allow these to adhere to the stuff surmised to the treatment, because of the Colombian forces.

### 3. The equations that govern the EHD spraying phenomena

For solving the equations that govern the EHD spraying phenomena is used the electrohydrodynamic, that study the moving of the liquids surmised to electric fields. The electric field forces exert upon the free charges or the polarization charges, are transmitted by collisions to the neutral molecules. The liquid will be moved, changing the charge distribution that will modify the electric field.

The charge distribution of the drops depends on the limit of charging that is well defined for the liquid drops. The charging of the drops is limited by the maxim surface electric field (Es), the ionic emission limit ~$10^9$ V/m for negative charge and ~$10^{10}$ V/m for positive charge. The larger drops can be charged to the Rayleigh limit, at that the disruptive forces owing to the trapped charge, balance the surface constraint that maintain the drop. Augmenting with the charge on a drop at the Rayleigh limit will cause disruption.

**a) MAXWELL's equations and electroquasistatic limit**

In the electrohydrodynamic the electric field is prevailing field, so it will be encountered the electroquasistatic regime E>cB that is treated with the Galilean electromagnetic theory. In the electrohydrodynamic the Maxwell's equations are drawn as:

$$div\vec{D} = q, \quad rot\vec{E} = 0, \quad \frac{\partial q}{\partial t} + div\vec{J} = 0 \tag{1}$$

**b) The current density law**

According with the electric current density law, the dielectric liquids are classified in two grand categories: the liquids that keeps the Ohm's law that are named ohmic liquids and the liquids that don't keeps the Ohm's law that are named no-ohmic liquids.

For the low electric field most liquids present an ohmic component. But for the high field the injection phenomena are the principals' sources of ions and the Ohm's law don't keeps. In the unipolar injection regime (there is injected only a kind of ions into a liquid that is fully insulator, σ=0), the current density law will be:

$$\vec{J} = qk\vec{E} - \vec{D}\nabla q + q \cdot \vec{v} \tag{2}$$

The first term represent the total contribution owned to the drift of ions that are moving along the liquid with a speed $k\vec{E}$, with k- the ionic mobility. The second terms justify the molecular diffusion, with $\vec{D}$ - the diffusion coefficient of the charge. The third term is due to the convection of the charge density through the field of the speeds.

The diffusion will be insignificant comparative with the drift if the potential difference is of the order 0,025V. It usually happens in the thin layers, either to the edge layers or to the internal layers.

**c) The electrostatic charging of the particles**

When the particles pass through an ionized zone, some ions are laid down on the surface and this becomes charged.

Depending on the kind of the ions, the mean free way of the ions varies between $10^{-1}$ to $10^{-2}$ µm. Consequently, for the greater ions than $10^{-1}$ µm, it is applied only the usual continuum theory, at one atmosphere pressure. For the smaller particles than $10^{-3}$ µm, the behaviors of the greater ions must be analyzed by the free molecular moving.

In the simple case of a drop it can be described its migration from the electrified meniscus to a grounded counter electrode, using the Lagrange equation for a single drop arises from a jet of the liquid:

$$\frac{\pi}{6}\cdot d_i^3\cdot\rho_d\cdot\frac{d\vec{v}_i}{dt}=C_D\cdot\frac{\pi}{8}\cdot\rho_g\cdot d_i^2\cdot\vec{v}_i^2\cdot\vec{e}_i+q_i\cdot\vec{E}_{ext.}-\frac{1}{2}E^2\nabla\varepsilon+\frac{1}{2}\nabla\left(E^2\rho\frac{\partial\varepsilon}{\partial\rho}\right) \quad (3)$$

The terms represent:

- the first term from the right hand of the equation (1) represents the friction force with the environmental gas;
- the second term from the right hand of the equation (1) represents the electric force on the drop owed to the external electric field $\vec{E}_{ext}$ between the spraying nozzle and the coating grounded surface;
- the third term from the right hand of the equation (1) represents the electric force produced by the spatial charges;
- the fourth term from the right hand of the equation (1) represents the force produced by the no homogeneity of the electric field (the electrostriction term).

The above equation is three-dimensional integrated. The model was experimental validate in the literature [5, 6] by comparing the numeric solutions of the equations of the transport and the spatial distributions of the drops Below are presented the experimental set-ups for the induction and conduction process.

**I. Direct charging (the injector to the voltage and the mesh to the ground (the negative charging))-the conduction charging**

The set-up is shown in Fig. 3:

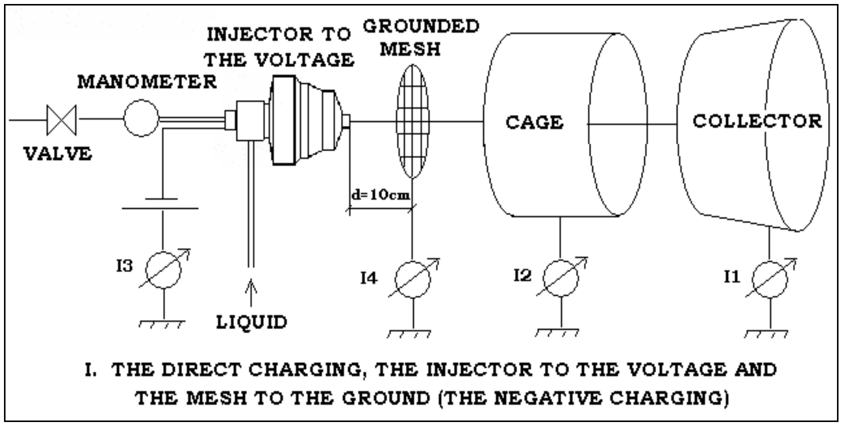


Fig. 3.

With this set-up (the distance nozzle-mesh d=10cm, the pressure p=2,5atm, the diametre of the nozzle Φ=0,3mm, the volume v=2,5ml, the voltage on the electrod U=20kV) were obtained the graphics from Fig. 4:

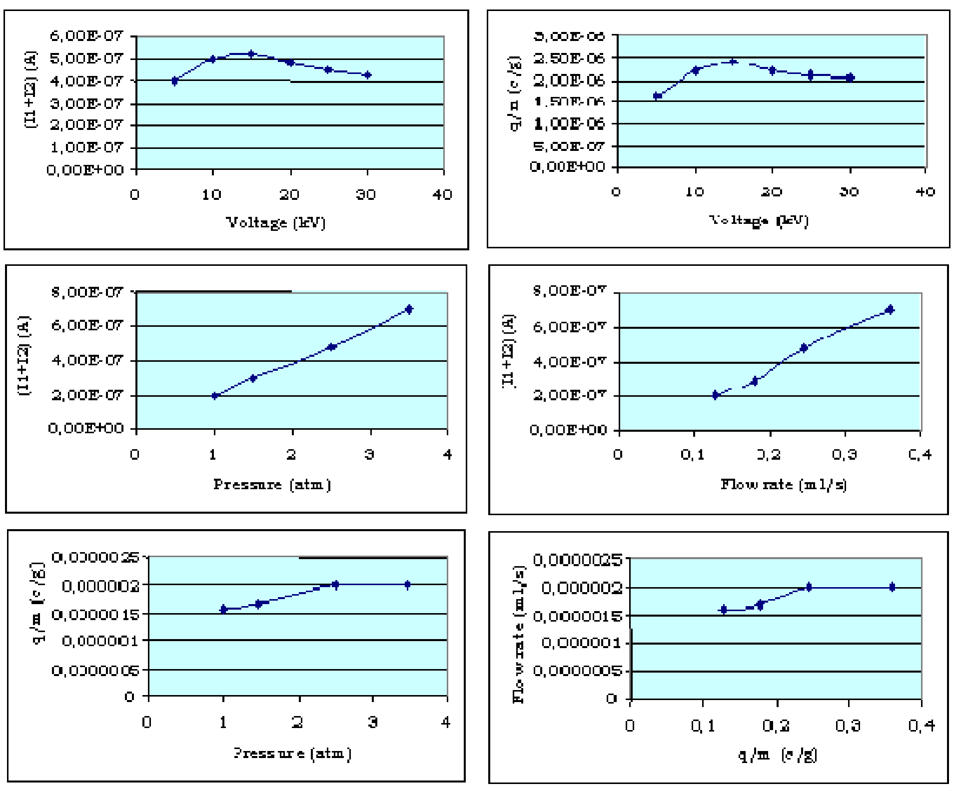


Fig. 4.

**II. Direct charging through the no insulated electrode to the voltage and the injector to the ground (the positive charging) - the conduction charging**

The set-up of the EHD spraying plant is shown in Fig. 5:

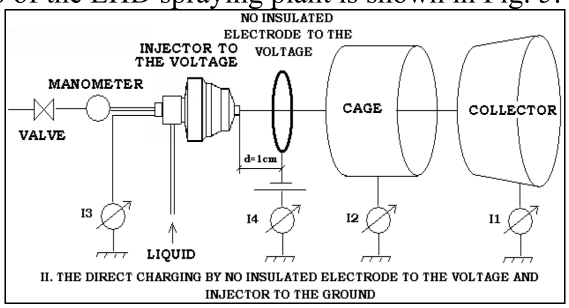


Fig. 5.

With this set-up (the distance nozzle-mesh d=10cm, the pressure p=2,5atm, the diametre of the nozzle Φ=0,3mm, the volume v=2,5ml, the voltage on the electrod U=20kV) were obtained the graphics on Fig. 6:

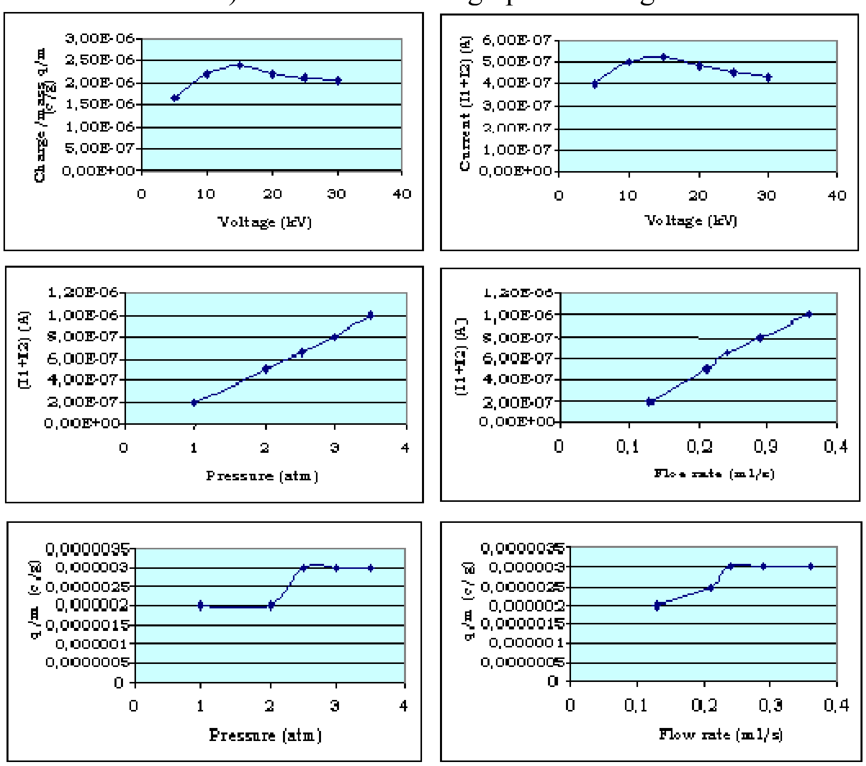


Fig. 6.

**III. Charging by induction, the insulated electrode to the voltage and the injector to the ground (the negative charging)**

The set-up for EHD spraying is shown in the Fig. 7:

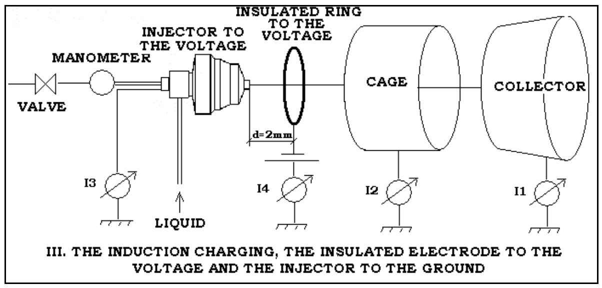


Fig. 7.

With this set-up (the distance nozzle-mesh d=2mm, the pressure p=2,5atm, the diameter of the nozzle Φ=0,3mm, the volume v=2,5ml, the voltage on the electrode U=3kV) were obtained the graphics from Fig. 8:

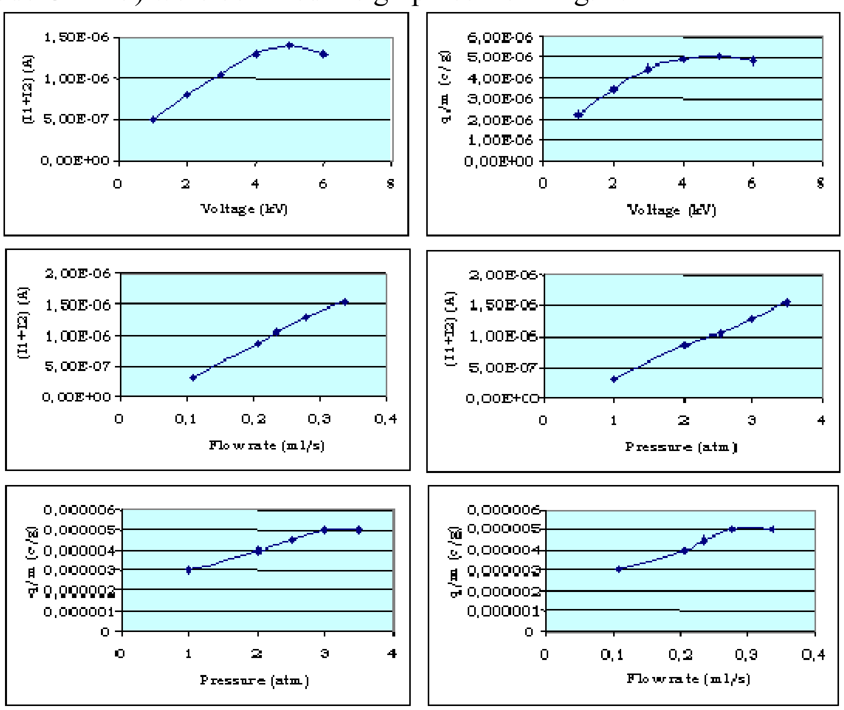


Fig. 8.

The three original charging methods of the drops were used for comparing the induction method and the conduction method.

## 4. Conclusion

At charging by conduction, the DC electric supply is made by contact with the spraying liquid, while at charging by induction the DC electric supply is connected to an adjacent electrode for induction in the point of the disruption of the drops.

In case of the conduction charging, the mechanic energy is used for disperse the liquid into the drops and the current that leak to the power supply and assures a part of the electric energy for charging and accelerate the drops. Both the mechanic energy and the electric energy drive the charged drops to the target. The electric energy depends of the nozzle current and the power supply voltage.

In case of the induction charging, there isn't consumption of the electric energy. The mechanic energy is both used for disperse the liquid into the drops and to drive the charged drops beyond the induction electrode. A part of this mechanic energy is so converted into electric energy contained by the spatial charge cloud. Practically only the current that leak through the power supply is composed by the leak current and the current owed to the laying down of the drops on the induction electrode.

Consequently the charging by conduction and induction differ by: the charging mechanism, the electric field distribution, the moisture of electrodes, the conversion of energy and the effects of spatial charge [1-6]. The comparison of the two conduction sets ups shows that the second set up is more profitable because the high voltage are lower and the specific charge q/m are higher. In the induction set up can be seen the total ionization of the surrounding environment. The characteristics q/m terms of pressure p and q/m terms of flow rate Q give a limit for specific charge over the 3 kV voltages respective over 0,3 ml/s. In this situation the current generated by the power supply is zero and the energy necessary for the charge transport to the target is delivered by the air flow. The total current is zero because the ring electrode is isolated.

Conclusively the third set up for induction is the most profitable to use in the spraying EHD plant because:

1. the injector is connected to the ground and is not dangerous for the operators;
2. there is no consume of energy from the power supply for development the electric field, so it can be used power supply of small electric power;
3. the maxim values obtained on the characteristics for the third set up with induction are higher than the same characteristics for the others set ups for conduction.

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