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Post-dispersion electrification of droplets

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ABSTRACT

Electrification of aerosol particles dispersed by a pneumatic atomizer is presented in the paper. For post dispersion electrification of droplets a contact method with external high voltage electrode was proposed. Experiments were carried out using supersonic atomizing head, equipped with a high voltage mesh electrode, placed co-axially and perpendicularly to the droplets stream and closely to the atomizing head. Results of experimental investigations have shown, that the *Q*/*m* ratio values depends on the liquid feed rate according to the power type function. Two steps electrification model with a space charge was proposed for explanation of the observed dependence. Calculations carried out on the basis of proposed model confirmed, that the space charge component of the electric field is significant for the final *Q*/*m* ratio value, and allow to determine *Q*/*m* value with accuracy on the level of 10%. The model suggests bipolar nature of charge carried by droplets leaving the electrification system.

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1. Introduction

Electrification of aerosol droplets have been widely investigated since the half of the 20th century [1]. Electro-aerosol have been applied in agriculture (crop spraying, post-harvesting protection, pollination, disinsection) [2–5], industry (electrostatic painting, thin-film technology, xerographic copying) [6,7], medicine (decontamination, pharmaceutical) [8,9] and other disciplines (cosmetology, fire extinguishing, fuel combustion, air cleaning) [10–13]. Most common methods of electrification of water-based electro-aerosols are induction and conduction (contact) charging [1]. The charging process occurs when the new formed droplets are leaving the capillary placed in electric field. The capillary can be at the earth potential (induction charging) or at high voltage (conduction charging). The difference between induction and conduction charging was described in details [14]. To obtain stream of fine droplets (with diameter 5–15 μm) with high kinetic energy (necessary to place the aerosol stream in a required place – dense crop, other sprayed or decontaminated objects with a dense structure or strictly determined space) a pneumatic dispersion head with de Laval nozzle and supersonic air flow (velocity ≈3 Mach) was applied. For high kinetic energy droplets Coulomb forces start to operate after the stream dispersion in a dense structure of the sprayed object. Previous research of induction electrification process, applied in pneumatic dispersion heads allowed to obtain *Q*/*m* value (where *Q* is a total charge measured on droplets with a total mass *m*) in a range of 0.1–2.3 mC/kg i.e. higher in comparison to the values obtained by Ngomsi [15], but lower in comparison to that obtained by Law [e.g. Ref. [16]. Additionally, the obtained *Q*/*m* values were lower in comparison to that predicted by known limits (Rayleigh's, Paschen's, air electrical strength limits or Maxwell time constant limit) [6,17,18]. Experimental investigations of the induction charging process, applied in dispersion heads with supersonic air flow, seem to confirm appearance of a strong electric-field compensation/shielding effect limiting the value of the *Q*/*m* ratio [19,20]. One of possible method allowing to avoid the effect was application of an electrification process following dispersion of liquid.

The most common method applied for post-dispersion electrification is corona charging. However, the method requires to keep a relatively long charging time for droplets moving in strong electric field through a heavy ionized space. The requirement is difficult for realization in dispersion systems with supersonic gas flow. This is due to too high velocity of the droplets (over 150 m/s), and thus the short transport time of a droplets in an area of corona discharge. Alternatively, a post-dispersion conductive electrification method, with an external high voltage contact electrode, was proposed. The electrode was placed coaxially and perpendicularly to the droplets stream and closely to the atomizing head. During the contact electrification some of aerosol droplets receive the charge, only. The rest of aerosol droplets stream carry the charge introduced due to

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induction electrification. So, the stream of droplets behind the electrifying system contains droplets with a charge of both polarities. Electro – aerosol containing droplets with bipolar electric charge can significantly reduce the effect of corona discharge, which can appear at the sharp edges of the sprayed object [21]. The aim of this study was to limit the influence of the shielding effect and increase the efficiency of electrification with the head with supersonic gas flow. To this end it is proposed electrification after atomization. In this paper presents model of post-atomization electrification of droplets.

2. Model of electrification

Droplets leaving nozzle of the dispersion head like in Fig. 3 were subjected to a 2-step electrification process. All droplets were subjected to induction electrification during the atomization of liquids due to the electric field occurring in nozzle - grid electrode space. Intensity of the local field (at the nozzle), inducing electric charge on aerosol particles, depending on grid electrode (HV) potential and the distance between nozzle and the electrode. Flow of droplets stream through the HV (grid) electrode for a constant liquid feed rate m [kg/min], allow some part of them, (determined by a factor η) to come into contact with the electrode and change both, the value and sign of charge. The mass of droplets subjected to contact electrification m_{con} in a unit time can be determined from the equation:

$$m_{con} = \eta \cdot m \tag{1}$$

The mass of remaining part of droplets, passing through the grid electrode without changing the electric charge, m_{ind}, was:

$$m_{ind} = (1-\eta)m \tag{2}$$

Finally, cloud of aerosol droplets downstream the grid (HV) electrode contains droplets with bipolar electric charge. Value of the total specific charge carried by droplets is determined by a weighted sum of charges introduced on them during induction and contact electrification and can be determined from the equation:

$$\frac{Q}{m} = \left(\left(\frac{Q}{m}\right)_{con}\right)\cdot\eta + \left(\left(\frac{Q}{m}\right)_{ind}\right)\cdot(1-\eta) \tag{3}$$

where $(Q/m)_{\mathrm{con}}$ and $(Q/m)_{\mathrm{ind}}$ are the values of Q/m ratio achieved by droplets subjected to contact and induction electrification, respectively.

Charge acquired by droplets subjected to contact electrification is determined by local field intensity in the vicinity of wires of the grid HV electrode. The maximum value of the normal component of electric field E_{max} can be determined from the relation:

$$E_{\mathrm{max}} = E_s + E_o \tag{4}$$

where E_s – field component, normal to the surface of grid electrode, originating from its potential, E_o - component of field created by space charge of droplets, previously electrified by the induction method. The value of E_s component (of field created in a space between dispersion head and grid electrode – see Fig. 1), in the plane of grid electrode can be approximately determined from the following relation [22]:

$$E_s = \frac{2r_k U_p}{l^2} \tag{5}$$

where: l – distance between the electrode and the head (capillary), r_k – radius of the capillary, U_p – electrode supply voltage.

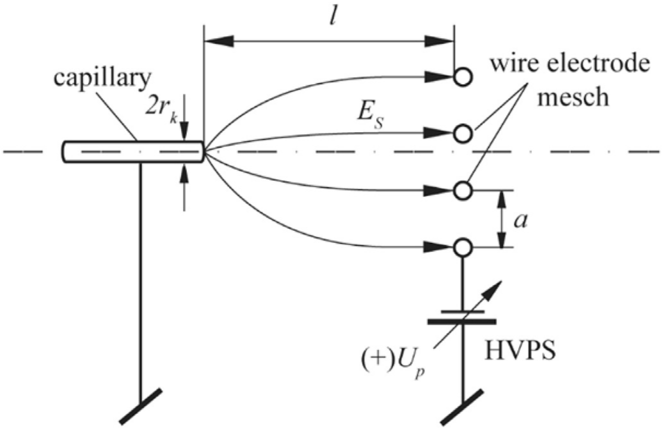

Fig. 1. Illustration of E_s component of the electric field in the plane of a grid (mesh) electrode.

The E_o component of the electric field created by a space charge located in the direct vicinity to wires of the grid electrode was determined using a model shown in Fig. 2. Calculations of the E_o component were carried out using the following assumptions:

1. only the space charge of uniform density q_v and collected in a sphere with a diameter a, (filling the mesh "window" of the HV electrode) is considered;
2. the field created by space charge is the same as a field created by a point charge placed in the sphere center;
3. all electrical field lines created by the charge inside the sphere are collected on the inner surface of the mesh "window" (with diameter equal to that of the sphere – a, and the width determined by the mesh wire diameter) – see Fig. 2;
4. aerosol droplets practically do not change the dielectric constant of air (in a stream), i.e. for this space relative electrical permittivity $\varepsilon_r = 1$.

The total value of a charge Q collected within the sphere spread on the mesh "window" (Fig. 2) can be determined using relation:

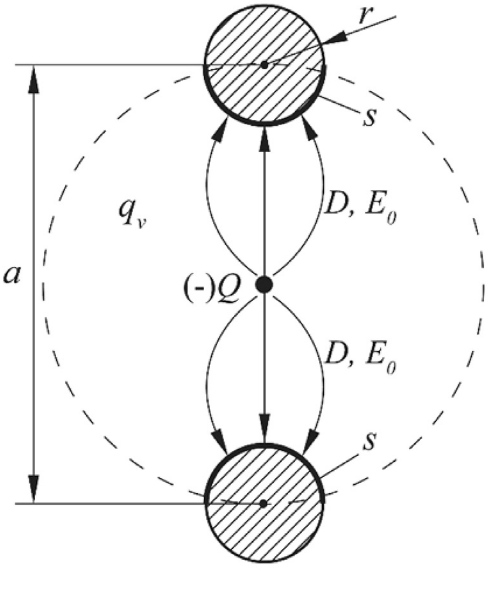

Fig. 2. Mesh of the HV electrode. The effect of space charge on the value of local field E_o.

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