Post-dispersion electrification of droplets in a system with pneumatic atomization

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Abstract. The process of electrifying aerosol particles dispersed by a pneumatic sprayer with supersonic air flow is presented. To avoid the electric-field shielding effect, confirmed by investigations of induction charging of aerosol droplets with application of a concentric induction electrode placed in the region of liquid dispersion, the droplet electrification process following the dispersion of liquid was proposed. The supersonic atomizing head was equipped with an external high voltage contact electrode placed concentrically and perpendicularly to the droplets stream and closely to the atomizing head. Experiments were conducted in air, at ambient conditions ($T=18\pm2 \, ^\circ \text{C}$, $\text{RH}= 55\pm3\%$), for standard air feeding rate (0.5 m$^3$/min, 0.4 MPa) and regulated dispersed liquid rate (0.1 – 0.55 l/min). Results of the applied electrification process, characterized by a $(Q/m)$ factor measured as a function of liquid feed rate, have shown that the $(Q/m)$ values achieved for post-dispersion electrification are comparable to the values obtained for typical induction electrification with application of a concentric electrode.

1. Introduction
Investigations of the induction charging process in relation to electrostatic spraying were undertaken in the early 1960's [1,2]. Induction or conduction (contact) charging of aerosol droplets were usually realized with the application of a concentric charging electrode placed in the region of liquid dispersion. The electrode was usually placed at the tip of the liquid feeding capillary and the charging process occurred during the removal of a particular droplet from the continuous liquid stream (being at the earth or high voltage potential). It was generally assumed that the charge-to-mass $(Q/m)$ parameter could be treated as a droplet electrification effectiveness measure.

Previous research of the electrification process for aerosol droplets carried out on various types of pneumatic spraying heads with de Laval nozzles has shown that using the induction method obtained $(Q/m)$ parameter of 0.1 - 2.3 mC/kg. It was found that the $(Q/m)$ value was closely related with both the geometry of the electrostatic system of the atomizing head as well as the media feeding conditions (air pressure and liquid feed rate). The mentioned values for the $(Q/m)$ parameter were obtained for the electric field intensity (existing in the electrification region – capillary tip) being close to the electric strength of air. The $(Q/m)$ values obtained in the case of pneumatic heads with supersonic gas flow were much lower in comparison to the values predicted by generally known limits (Rayleigh’s, Paschen’s, air electrical strength limits or Maxwell time constant limit) [3]. Experimental investigations of the induction charging process of aerosol droplets of pneumatically atomized liquid with using a concentric induction electrode (placed in the region of liquid dispersion at the tip of liquid
feeding capillary) seemed to confirm the appearance of a strong electric-field shielding (field compensation) effect [4] limiting the value of the \( (Q/m) \) parameter. To avoid the shielding effect the droplet electrification process following the dispersion of liquid was proposed. The corona discharge method is usually applied in the case of post-dispersion electrification of particles of different nature. The corona discharge method requires a relatively long time (or relatively large space with strong electric field) for efficient electrification of particles. Alternatively the post-dispersion conductive electrification method was proposed to avoid the shielding effect in case of pneumatic liquid dispersion.

2. Atomizing head and electrification system

The post-dispersion electrification of droplets was conducted using typical supersonic atomizing nozzle head (Telesto®, EFEN 110,5) producing droplets within the diameter range 10-15 μm. The head was equipped with an external high voltage contact electrode in the form of a metal ring of 70 mm diameter. The electrode cross-section was filled with a metal mesh (3 x 3 mm, \( \phi = 0.3 \) mm wire diameter) in order to increase contact probability with aerosol droplets. The electrode was placed concentrically and perpendicularly to the droplet stream along its axis. The distance separating the atomizing head and conduction electrode was adjustable in a range of 20 – 100 mm and kept in position by two insulating rods. Experiments were conducted in air at ambient conditions (\( T=18\pm2 \) °C, \( RH=55\pm3\% \)), for a standard air feeding rate (0.5 m³/min, 400 kPa) and a regulated dispersed liquid rate (0.1 – 0.55 l/min). In all the experiments tap water with electric conductivity 0.40\pm 5 mS/cm was used.

3. Measurement circuit

The efficiency of the aerosol electrification process was characterized by determining the \( (Q/m) \) parameter value using the measuring system shown in figure 1.

![Figure 1. Sketch of the measurement set-up for spray electrification.](image)

The measuring system included air and liquid media conditioning stations (equipped with a metering circuitry) supplying the atomizing head which was equipped with a conduction electrode. The conduction electrode was supplied from a dc stabilized high voltage power supply (Glassman EW40/50 type) and could be regulated in the range 0 ±50(40) kV of both polarities. The cloud of electrified particles was collected on the surface of the collecting electrode system containing three metal electrodes (1.30 m × 1.30 m) equipped with droplet velocity damping screens (metal mesh screens 1.00 m × 1.00 m kept at the collecting electrode potential). The collection electrode system
was isolated from the earth and its leakage current $I_c$ was measured by an analogue pico-ammeter, PA100. The value of the charge to mass ratio $(Q/m)$ parameter was determined from the relation

$$\frac{Q}{m} = \frac{I_c t_c}{\gamma V_c}$$

where $I_c$ = the steady state current value determined for the collected clouds of electrified droplets, $\gamma$ = mass density of the dispersed liquid, $V_c$ = the volume of liquid collected on the collector electrodes within the time $t_c$.

4. Results and discussion

The performance of the conduction electrode system was determined by plotting the conduction electrode charging current vs. applied voltage and $(Q/m)$ vs. applied voltage characteristics as shown in figures 2 and 3 respectively, for a fixed head-to-conduction electrode separation of 75 mm.

![Figure 2](image1.png) **Figure 2** Dependence of the conduction electrode charging current on the electrode supply voltage.

![Figure 3](image2.png) **Figure 3** Dependence of the $(Q/m)$ parameter on the electrode supply voltage.

Results show that a saturation of the $(Q/m)$ parameter is closely related with the observed sudden increase of the charging electrode supply current. The corona discharges appearing for applied voltages above ca. 30 kV are probably responsible for both of the observed effects. The influence of the head-to-conduction electrode separation distance on the $(Q/m)$ parameter is shown in figure 4. The results were obtained for an average electric field intensity $E = 400 \pm 5$ kV/m = constant.

![Figure 4](image3.png) **Figure 4** Dependence of the $(Q/m)$ parameter on the atomizing head-to-conduction electrode separation distance $(E=\text{const}=400 \pm 5$ kV/m).
The \( (Q/m) \) parameter dependence (figure 4), may be explained assuming dependence of the droplet-mesh contact probability on the head-to-charging electrode separation distance. The distance increase leads to a decrease in the droplet numerical density in the electrode region as well as to an average contact surface increase (of the mesh of conduction electrode) determined per one droplet. A simplified model [5] assuming proportionality of the droplet – electrode contact probability to the average contact surface (per one droplet) and constant droplets diameter (not affected by liquid feed rate) leads to the expression

\[
(Q / m) = \frac{C E x^2}{\gamma W_w}
\]  

(2)

where \( C = \) constant, \( E = \) electric field intensity in the electrifying system, \( x = \) atomizing head-to-conduction electrode separation distance, \( \gamma \) and \( W_w = \) liquid mass density and feed rate, respectively.

The results shown in figures 3 and 4 support the validity of relation (2) from the point of view of the expected dependences on field intensity \( E \) and the distance \( x \). The expression (2) suggests additionally a hyperbolic dependence of the \( (Q/m) \) parameter on the liquid feed rate. Results of appropriate investigations shown in figure 5 confirm a power-type dependence of the \( (Q/m) \) parameter value on the liquid feed rate \( W_w \) but the curve slope \( n = -1.44 \) was found to be higher than the expected one \( (n = -1.0) \). The observed discrepancy is probably due to an influence of the liquid feed rate on the droplet diameter. Decreasing the liquid feed rate usually leads to a decrease in droplet diameter and an increase in the \( (Q/m) \) parameter.

![Figure 5. Dependence of the \( (Q/m) \) parameter on the liquid feed rate. Measurements conditions: temperature \( T=18\pm2 \) °C, relative humidity \( RH=55\pm3\% \), \( E=400\pm5 \) kV/m, dispersed liquid – tap water conductivity \( 0.40 \) mS/cm.](image)

The obtained results have shown that conduction electrification using an external mesh electrode allows the \( (Q/m) \) parameter to reach values similar to those obtained for induction electrification (with an internal, ring electrode) [4].

References

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