Electrostatic charging of water spray by induction

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Abstract. Results of experimental investigation of electric charging of water spray produced by several commercially available single-fluid pressure swirl atomizers, with cylinder induction electrode are presented in this paper. The process of induction charging of water spray is analysed in terms of specific charge and droplet size distribution, for water flow rate, water pressure, induction electrode voltage and inter-electrode distance as process variables. It was found that the specific charge of water droplets increases with increasing voltage applied to the induction electrode, but only to a certain voltage magnitude. The decrease in the specific charge for higher voltages is caused by corona discharge from the induction electrode and the shielding effect of space charge due to electric field produced by the charged droplets. The optimal inter-electrode distance maximizing the specific charge was determined for each of the tested nozzles.

1. Introduction
Charged sprays have electrohydrodynamic properties that are useful for improving many industrial processes. Electric charge accumulated at a liquid droplet allows for droplet trajectory control by the electric field. Charged sprays are, for example, used in agricultural pesticides deposition, spray painting, surface coating or for gas cleaning by electrostatic scrubbers.

The most effective method of charged spray generation are pneumatic or pressure atomization with charging by induction. These methods allow to produce highly charged droplets by relatively high water flow rates, required by various industrial processes. In the process of induction charging, the electric charge is induced on the surface of liquid jet produced by a mechanical atomizer. The electric field required for induction charging is produced by an external electrode placed near the atomizer nozzle outlet, and supplied with high voltage [1]. Droplets are detached from the liquid jet mainly due to mechanical forces of highly accelerated water flow, and convey the electric charge of magnitude equal to the total charge accumulated on the fragment of liquid film from which this droplet is formed.

This paper presents results of experimental investigations of charged spray properties, such as droplets size distribution and droplets specific charge, for various water flow rates, water pressures, induction electrode voltages and inter-electrode distances. In these studies, 6 commercially available single-fluid pressure swirl nozzles have been used for fine spray generation. The electric field was produced by a cylindrical induction electrode supplied with high voltage.

2. Experimental
Six pressure swirl nozzles with axial inflow and full-cone angle of spray plume of 60° have been investigated in the present studies. All the nozzles were produced by Lechler GmbH. The water flow rate of these nozzles ranged between about 3 and 15 dm³/min for a water pressure of 6 bar. The nozzles were supplied with tap water by multistage centrifugal pump Hydro-vacuum OPA-0.08 of flow rate
1-4.5 m³/h controlled by Nordac SK 500e inverter. The water flow rate, pressure and temperature were measured by Endress+Hauser electromagnetic flow meter Promag 50H08, pressure transducer Cerabar M PMC51 and thermometer RTD TR10, respectively.

The measurements of droplet size distribution and spray charge were carried out in two separate steps. Figure 1 presents schematically the experimental setups for droplet size distribution (a) and spray current measurements (b), respectively. Droplet size distribution was measured by optical droplet size analyzer Kamika AWK D. The optical probe was placed 60 cm under the nozzle outlet in two positions: axially with the nozzle, and displaced by 20 cm away from the axial position.

Total spray current flowing to a Faraday cage was measured by picoammeter Keithley 486. The cage of 210 mm diameter was made of two-layer copper mesh, and was suspended on isolating threads. The cage was placed in a PMMA column of 400 mm in diameter and 2000 mm height, with inner walls covered with stainless steel mesh, which was grounded. The distance between the cage inlet and the investigated nozzle positioned above this cage was set in such a way as to allow all the droplets fall into the cage. A cylindrical stainless steel induction electrode of inner diameter of 80 mm and height of 30 mm was used for spray charging. The vertical position of the electrode was changed in order to determine the optimal distance between the upper plane of the induction electrode and the plane tangential to the outlet of the nozzle (δ). The spray current was measured for four inter-electrode distances of -10, 0, 10, 20 mm. High voltage supply (Spellman SL30PN300) of negative polarity was connected to the induction electrode and the nozzle was grounded.

![Figure 1](image.png)

**Figure 1.** Schematic of experimental set-up for droplet size distribution measurement (a), and for the measurement of the spray current (b).

### 3. Results and discussion

Droplet size distribution for all tested nozzles have been measured for two water pressures, 3 and 6 bar, and for two horizontal positions of the optical probe. An example of droplet size distribution is shown in figure 2. The Sauter Mean Diameter (SMD) of the spray, which provides information about the mean ratio of volume to surface area for all droplets is presented in table 1 for all nozzles. The SMD tends to increase with decreasing water pressure and for nozzles of higher flow rates. This effect is particularly visible at the off-axis position of the optical probe. However, the SMD at the axis of the spray do not change significantly for nozzles of smaller flow rates.

In order to determine the level of electric charge of charged spray, the most useful parameter is the specific charge, which indicates the ratio of charge on a single droplet to the mass of this droplet. The mean value of specific charge may be estimated from the ratio of total spray current to the mass flow rate of water dispersed by the spraying nozzle [2–5]:

\[
\frac{l}{m} = \frac{\sum_{i=1}^{N} 4\pi \sigma_q (i) r_i^2}{\sum_{i=1}^{N} \pi \rho r_i^3} = \frac{4\pi \sigma_q N r_s^2}{\pi^2 \rho N r_s^3} = \frac{Q(r_s)}{m_d(r_s)}
\]  

(1)
where \( \sigma_q(i) \) is the surface charge density on the \( i \)-th droplet of radius \( r_i \), \( r_s \) is the Sauter mean radius, \( \rho \) is the water density, \( N \) is the total number of droplets in the spray, \( Q(r_s) \) is the charge of droplet of Sauter mean radius, and \( m_d(r_s) \) is the mass of this droplet.

Table 1. Sauter Mean Diameter (SMD) of droplets dispersed by various spray nozzles, for two water pressures and at two positions of the optical probe.

| Nozzle model | Water flow rate [dm³/min] | Sauter Mean Diameter [μm] |
|--------------|--------------------------|--------------------------|
|              | Measuring probe position | axial | axial | 20 cm off axis | 20 cm off axis |
|              | Water pressure [bar]     | 3    | 6    | 3    | 6    | 3    | 6    |
| 490,524      |                          | 2.20 | 2.88 | 287  | 295  | 350  | 310  |
| 490,604      |                          | 3.56 | 4.74 | 297  | 297  | 357  | 316  |
| 490,644      |                          | 4.51 | 6.11 | 231  | 220  | 275  | 254  |
| 490,724      |                          | 6.97 | 9.43 | 321  | 303  | 363  | 320  |
| 490,764      |                          | 9.06 | 11.96| 347  | 300  | 316  | 305  |
| 490,804      |                          | 10.98| 14.61| 374  | 350  | 362  | 332  |

Figure 2. Normalized number and volume size distributions of droplets for the nozzle 490.524.

Figure 3. Specific charge of spray generated by the nozzle 490.524 for various distances \( \delta \).

Figure 3 presents experimental results of specific charge dependence on the voltage applied to induction electrode. For low voltages, the specific charge increased nearly proportionally to the voltage, but over a specific voltage magnitude it departed from the linearity. This effect was observed also for other type of nozzles [3,4,6,7]. The current reduction was caused by the oppositely charged droplets falling from the induction electrode, which were formed from the mist deposited on this electrode during the spraying. Additionally, with the voltage increasing, small liquid jets directed towards the spraying nozzle were produced. These droplets, of opposite charge, may reduce the charge of main stream of droplets after their collision and coalescence. Another phenomenon, which can be responsible for spray current reduction is the space charge of generated spray, which reduces the electric field on the surface of liquid film.

Figure 3 also compares the effect of various inter-electrode distances (\( \delta \)) on specific charge for the 490.524 nozzle. For each of the tested nozzles, the optimal distance in terms of the specific charge maximization, has been selected. The specific charge vs. induction electrode voltage characteristics for the optimal position of induction electrode have been compared in figure 4. The highest maximum specific charge (136.6 \( \mu \)C/kg at inter-electrode distance of 0 mm and water pressure 3 bar) was obtained for the nozzle of the lowest water flow rate. The optimal charging conditions for each of the tested nozzles have been summarized in table 2.

Figure 5 compares the maximum specific charge and SMD vs. water flow rate for 6 tested nozzles. Results presented in paper [7] obtained for 5 similar swirl nozzles, but of lower flow rate (1-3 dm³/min) have been added to this figure in order to generalize the conclusions. This analysis shows that the specific charge is significantly higher for nozzles of lower flow rates, but SMD slightly decreases.
4. Conclusions

Properties of charged spray generated by commercial single-fluid pressure swirl nozzles with induction charging have been tested. Experimental results showed that the specific charge of droplets increases nearly proportionally with increasing induction electrode voltage up to a certain magnitude. For higher voltages, the specific charge attains the maximum and next decreases, due to the shielding of electric field in the vicinity of the liquid jet at the nozzle outlet by the space charge of charged spray and ionic current, and additionally due to corona discharge from the induction electrode. The maximal specific charge of spray varied from 25 to 140 μC/kg, and was higher for nozzles of lower flow rates.

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