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Experimental study on the Specific Electrical Charge of the Droplets of a High Velocity Electrified Jet

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In this paper, we present the results of a set of experiments we have done on high velocity electrified jets with distilled water and at room pressure. After the description of the device we designed for this study, we give the results of all the electrical phenomena we observed and specifically the results of the influence of different parameters such as the potential of the electrode, the velocity of the jet, the diameter of the electrode, etc...

1. INTRODUCTION

When one submits a jet to an electric field, an increase in charge of the distilled water flowing out of the capillary nozzle can be observed. The movement of the charged droplets is rather complicated. Many studies on such an electrical phenomenon using an electrostatic charging electrode have been already made [1-3]. If the electrode is brought to a positive potential, it attracts negative charges near the surface of the jet and repels the positive ones. The droplets produced carry the negative charges situated on the surface of the jet towards the earth (the wall of the vessel receiving the jet), which gives us the possibility to measure an electrical current from which we deduce the specific charge of the jet.

2. EXPERIMENTAL EQUIPMENT

In Fig.1 we can see a diagram of the experimental apparatus used for this study. It is composed of the following three parts :

the injection system
the jet electrification system
the jet reception system.

2.1. Injection system

The main elements of this system are represented in Fig.2. A piston pump (1) pressurizes the liquid. Its characteristics are : 21.1 cm^3/s (maximum flowrate), 138 bars (maximum pressure) and 1500 r.p.m (the maximum rotation speed). The flowrate of the liquid can be changed by making the piston stroke and (or) the rotation speed vary. A filter (mean diameter 100µm), fixed on the suction branch of the pump, prevents dust from being sucked.

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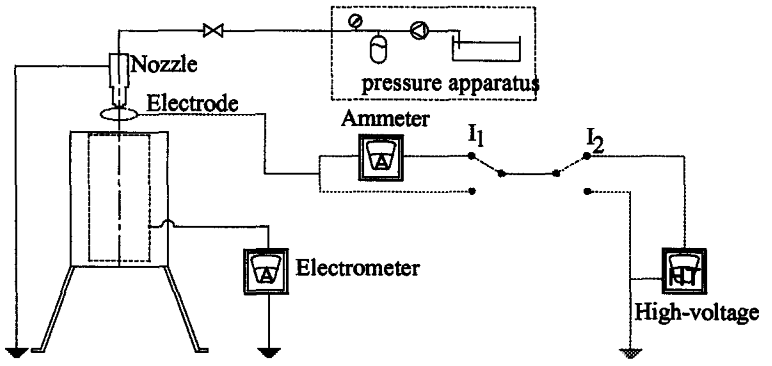
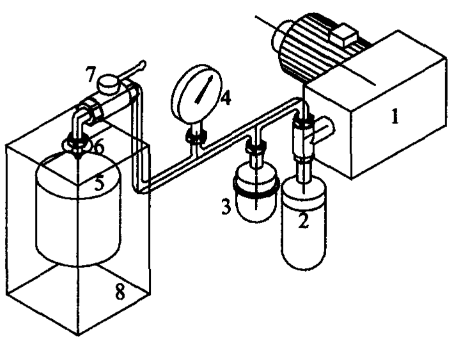


Fig. 1. Experimental apparatus.



1-pump
2-liquid container
3-pressure fluctuation damper
4-manometer
5-reception current system
6-nozzle
7-valve
8-tank.

Fig. 2. Injection system.

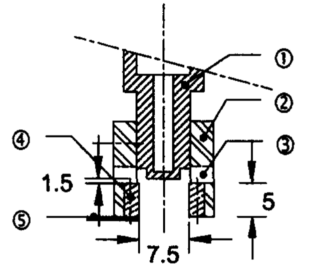
The distilled water comes from a 30-litre insulating plastic container (2). A hydropneumatic accumulator (3) with a nitril membrane damps the pressure fluctuations provoked by the movement of the piston of the pump, from 40 bars.

The nozzle we used is more or less the same as those other authors worked with in their studies of atomisation of jets [4 - 5]. It is made of stainless steel. Its orifice and its inclined inner walls were obtained by electroerosion. For this experiment the diameter of the nozzle is 405μm.

2.2. Jet electrification system

In Fig.1 we represent the electrification system. The high potential difference (from 0 to 3kV) is provided and controlled by a high-voltage dc source. With switch I2 we connect the electrode either to the generator (situation with electric field) or to earth (situation without electric field). With switch I1 we can select the branch of the circuit containing an ammeter (position 1) or the other (position2). In position 1, the ammeter gives information on the electrical "cleanliness" of the system : a large current means that water is stuck between the electrode and the injector and that no experiment can start (the jet would then be charged by conduction mechanisms and not by electrostatic ones). The experiment starts only if there is no detectable current in this branch, I1 is then put in position 2.

The electrode (4 in Fig.3) is a 3mm thick annulus made of stainless steel. It is fixed inside a teflon body (2 in Fig.3) which insulates it from the injector and allows the electrification of the spray. Holes inside the teflon body (3 in Fig.3) have been made in order to avoid the formation of a "bridge" of water between the injector and the electrode. A nylon screw maintains the electrode-teflon system on the injector and enables us to choose the distance between the high-voltage electrode and the nozzle.



1-stainless steel nozzle
2-teflon body
3-holes inside the teflon
4-high-voltage electrode
5-electrode contact.

Fig. 3. Electrode

2.3. Reception aerosol system

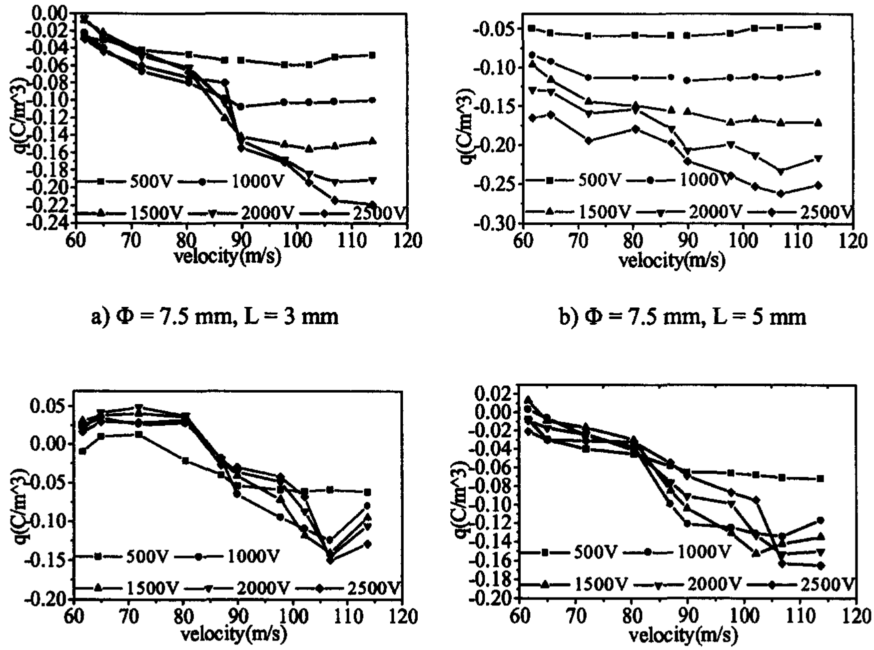
This system is composed of a tank and the current measuring system. The tank (8 Fig.2) is made of plexiglas. The main function of this tank is to prevent the jet from spreading out into the room. The current measuring system is composed of an internal cylinder suspended from the top of an external coaxial one by nylon threads. The internal cylinder is therefore electrically insulated from the external one. It is linked to a Keithley electrometer. The external cylinder is connected to earth and thus behaves as a Faraday cage for the internal one.

In the inner cylinder, the electrically charged droplets discharge at the contact of the wall made of stainless steel and the current created is then measured by the Keithley electrometer. The value of this current is the same as that in the conductor which connects the injector to earth, but it is of opposite sign. The current in the high-voltage circuit is negligeable in comparison with the other two.

3. MEASUREMENTS AND RESULTS

The volumetric flow rate D is calculated by measuring the volume of the liquid collected in the vessel during a certain time. If "i" is the value of the current given by the Keithley electrometer, the specific charge $q(C / m^3)$ is then given by : $q = \frac{i}{D}$. In our experiment we did not work with potentials higher than 2.5 kV because we noticed that above this value we had numerous electric discharges between the electrode and the nozzle

3.1. Influence of the potential and the velocity



a) $\Phi = 7.5$ mm, L = 3 mm

b) $\Phi = 7.5$ mm, L = 5 mm

c) $\Phi = 5$ mm, L = 3 mm

d) $\Phi = 5$ mm, L = 5 mm

Fig. 1 : Influence of the potential and the velocity

Fig 1 shows the relation between the specific electrical charge and the velocity of the jet for various positive potentials with distilled water ($\rho \cong 2594\ \Omega m$). Although different values of the electrode internal diameter Φ and the distance L between the injector and the electrode are considered, in all cases [a), b), c) and d)] we notice that when the velocity of the jet increases, the absolute value of the charge density of the jet increases too, except in c) where the behaviour of the jet is not clear. We also notice that for a fixed velocity, and in a more pronounced way for the higher velocities, the magnitude of charge density increases with the applied potential. Those two remarks require an explanation. In both cases the velocity of the ions,of mobility μ, plays an important part. It is composed of the drift velocity $V_e = \mu$ E where E is the electric field strengh and of the velocity of the liquid V_l, (we neglect diffusion). In the region of the electrode (where the field is high) the two velocities of the negative charges are pointed towards the bottom of the tank whereas only one velocity (V_l) of the positive charges is pointed to the tank, the other (V_e) being pointed to the injector.

Let us now explain the influence of the potential. It is clear that for a fixed velocity (V_l), when the potential increases, the charges present in the liquid are better separated. The negative ones are better attracted by the electrode and the positive ones better repelled towards the injector. Hence, for the same flowrate we have a greater charge density.

If now the potential is fixed, the velocity varying, the positive and negative ions are equally attracted or repelled by the field whatever the velocity (V_e does not vary). Nevertheless the most important fact here is the change of the constitution of the jet when the velocity varies. Experiments we did in our laboratory (granulometry with a Phase Doppler Particle Analyser (P. D. P. A) [6]) show that for a fixed distance from the injector the jet is more disintegrated as the velocity increases. This helps the separation of the charges and leads to a greater charge density.

3.2 Influence of Φ and L

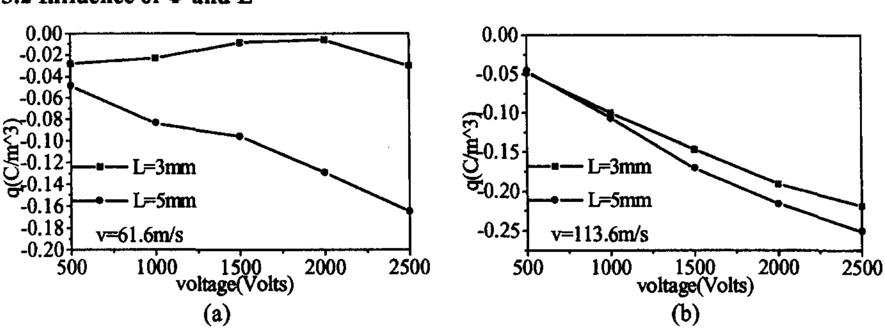


Fig 2 : Infuence of L, ϕ = 7.5 mm

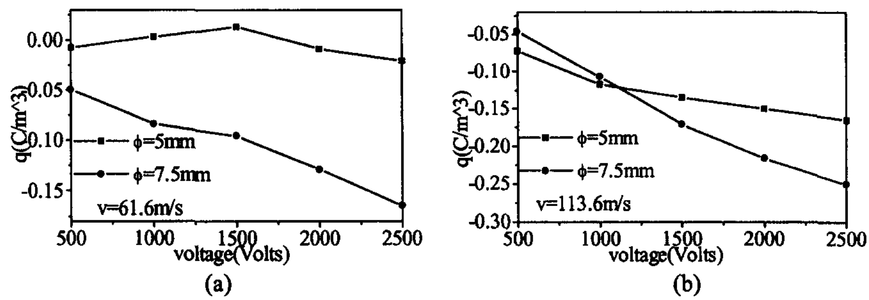


Fig 3 : Influence of Φ, L = 5 mm

Fig.2 shows the influence of L the length between the electrode and the injector at flow speeds of 61.6 and 113.6 m/s. Globally we can see once again that the magnitude of charge density increases with the potential, as we mentionned above, except for the small velocity where one more time we have a different behaviour especially for L = 3 mm. We also notice that the smallest charge densities correspond to the smallest value of L and there is a great difference for the small velocity (Fig.2 a)) and almost no difference for the high one (Fig.2 b)). Again the explanation lies in the internal composition of the jet. For a fixed velocity, the jet is more disintegrated far from the injector than close to it. The action of the field (separation of the charges) will be more efficient in the first case than in the second one. If we compare Fig.2

a) and Fig.2 b) we see that for a fixed potential the values in Fig.2 b) are greater than those in Fig.2 a), which confirm what we said before, if we remember that the higher the velocity the better the disintegration of the jet.

Fig.3 seems to prove that as the field increases the charge density diminishes, which would not fit with our analysis. In order to explain this, we have to report that during the experiment we noticed that a lot of droplets went directly to the electrode, and they were a lot more numerous with $\Phi = 5$ mm than with $\Phi = 7.5$ mm. Therefore we had a net loss of charges at the receptor and it is probable that the increase of field due to the diminution of the electrode diameter does not compensate the increase of loss due to the proximity of the electrode. We think that this is the reason why we have this kind of evolution on Fig.3 and we believe that more experiments with more electrode diameters and more distances from the injector are necessary in order to better understand this point.

4. CONCLUSIONS

Basically, the purpose of that work was to bring simple ideas out of a set of experiments, making the more possible parameters vary. We now know the main results concerning the charge of an electrified jet considered as a whole. We need more experiments especially on the size of the droplets to be able to conclude not only on the jet in its intirety but also on the mean charge density of the droplets and on the spatial distribution of the charge in the spray. However we know that :

-1) The charge density of the jet increases when the velocity of the jet increases.

-2) The charge density of the jet increases when the potential of the electrode increases.

-3) The charge density of the jet is sensitive to the position of the electrode. A jet is more charged if the electrode is in the region where the jet is dispersed within a region close to the injector.

-4) Discharges on the electrode can perturb the results.

Other experiments are being done and these will give more information on the mechanisms of the electrification of the jet.

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