전극 표면에서 전도성 액적의 전하 충전 현상에 관한 연구

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Electrical charging phenomenon of a conducting droplet in dielectric fluid on the electrode surface

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Introduction

When small liquid droplets are dispersed in another immiscible fluid, the electrical charge on that is encompassed by various colloidal and interfacial phenomenon. To measure the electrokinetic properties of oil droplets dispersed in aqueous electrolyte, electrophoresis or common electrophorometer based on capillary electrophoresis technique are used. This method is used by the characteristic of electrical double layer around oil droplet in oil-in-water(o/w) system or water-in-oil(w/o) system. [1] However, when non-insulated electrode is used in water-in-oil(w/o) system, an interesting phenomenon occurs. It is observed that a conducting droplet is back and forth between two electrodes. If we use this phenomenon, it is possible to moving a micro or nano sized droplet in a micro or nano channel without moving bulk fluid. Accordingly, various applications are possible, including lab-on-a-chip based on microfluidics, etc. With such application, in mind, a careful experiment has been performed for electrical charging phenomenon of a conducting droplet on the electrode.

Principle

A conducting droplet in dielectric fluid under the electric field is slowly moved to negative electrode. At the moment a droplet touches the surface of the electrode, it discharges the charges into the electrode and get charged by the electrode. This is the so-called contact charging phenomenon. (Fig.1) Immediately after a droplet arrives at the negative electrode, free charge is charged from electrode to droplet. Then the droplet is repulsed from the electrode due to Coulombic force and is moved to the opposite electrode. A droplet, which approaches the positive electrode, also discharges its free charge and get charges by the electrode. This process repeats itself.

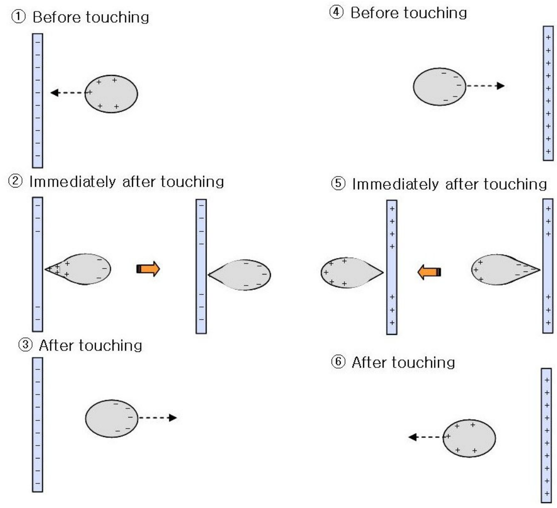

Figure 1. Contact charging process.

In the middle of two electrodes, it is assumed that the drop shape is almost spherical and the drop moves with constant velocity. Then the droplet is governed by the following force balance equation.

$$F_{tot} = F_{coulomb} + F_{drag} = 0$$

$$F_{coulomb} = QE \quad F_{drag} = -4\pi\mu_f a Uc \;,\; c = \frac{3\lambda+2}{2(\lambda+1)} \;,\; \lambda = \frac{\tilde{\mu}}{\mu}$$

where, E is the applied external E-field, Q the total charging, $\tilde{\mu}$ the viscosity of the droplet, μ the bulk viscosity, a the radius of droplet, U the droplet velocity. It is also assumed that the Reynolds number is small enough and the drag force of a droplet is governed by $Hadarmard-Rybczynski$ [2] solution.

Experimental Method

To obtain the velocity of a micro-sized droplet, a rectangular acyl test cell was placed in front of the microscope mounted on high speed camera. After electrodes were aligned in both ends of the cell, two electrodes were connected by DC constant-voltage power supply to apply an external electric field on the droplet. The distance between two electrodes was fixed by 1cm. To omit the thermal effect from light, a cooled light source was used. (Fig.2)

Silicon oil (KF-96) was used due to it the similarity of density with water to neglect the effect of gravity. A de-ionized water($1.2*10^{-4}$S/m, $8.90*10^{-4}$ kg/m·s, 997.75 kg/m^3) was used as a conducting droplet. To observe the effect of various factors, the bulk viscosity was changed as 50, 260, 1000cs, the radius of droplet was changed as 363, 544, 726 μm, the E-field was changed as 2.0E+5, 2.5E+5, 3.0E+5V/m.

Experimental Results and Discussion

(a) The difference between positive electrode and negative electrode

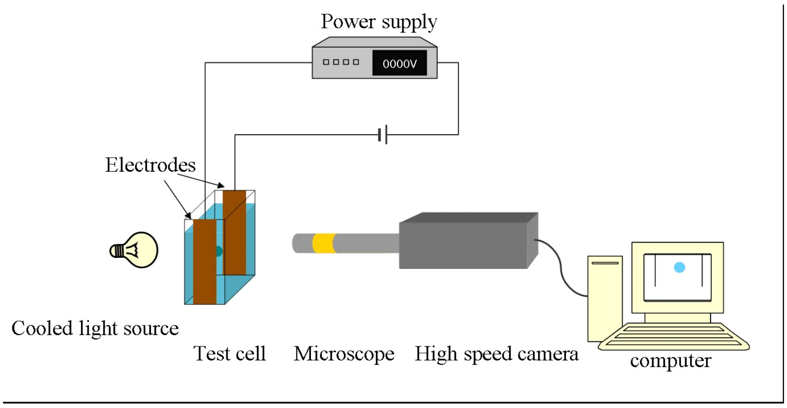

Figure 2. Schematic diagram of test apparatus.

It is shown that the droplet velocity repulsed from the positive electrode is different from that for the negative electrode. (Fig.3) It is due to the different charging process from anode and cathode. The exact reason is not known. Probably it is due to the mobility difference of the positive and negative charges.

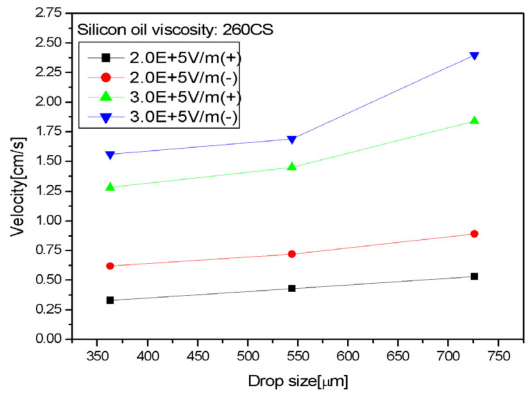

Figure 3. The velocity difference of the droplet ((+): repulsed from the positive electrode and (-): repulsed from the negative electrode)

(b) The effect of the droplet size and applied E-field

The amount of charge increase with the size of the droplet and the strength of the applied E-field. (Fig.4) The extent of the effect of external E-field is highly dependent on the bulk viscosity. When the viscosity is low, the effect of external E-field seems insignificant. Yet with higher viscosity, the effect of E-field becomes more significant. Especially, when the droplet is large, the variation of the charge according to the electric field becomes larger. It is shown that the viscosity of bulk fluid is a very important factor in the electrical charging process of droplet.

(c) The effect of bulk viscosity

As mentioned above, the viscosity of the external fluid plays an important role for determination of the total charge. In the case of viscosity lower than 260cs, the total charge acquired from the electrode increases with the viscosity. However, when the viscosity is higher than 260cs, the amount of charge does not increase with the viscosity. The detailed mechanism should be studied.

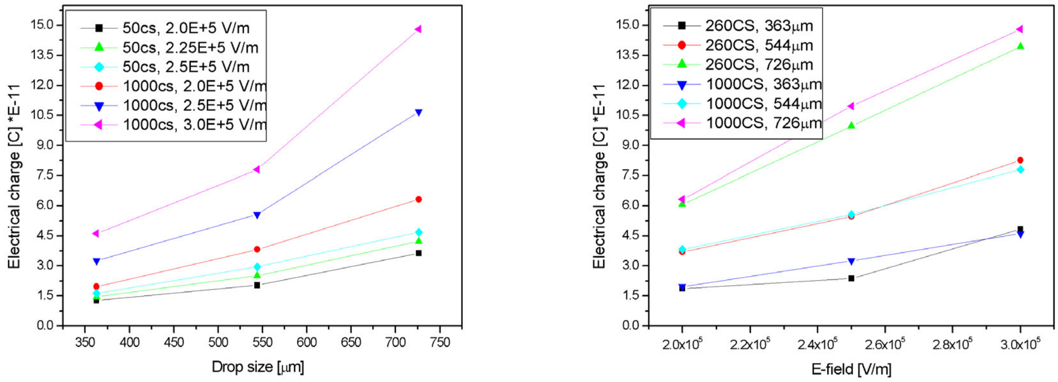

Figure 4. The effects of drop size and applied E-field.

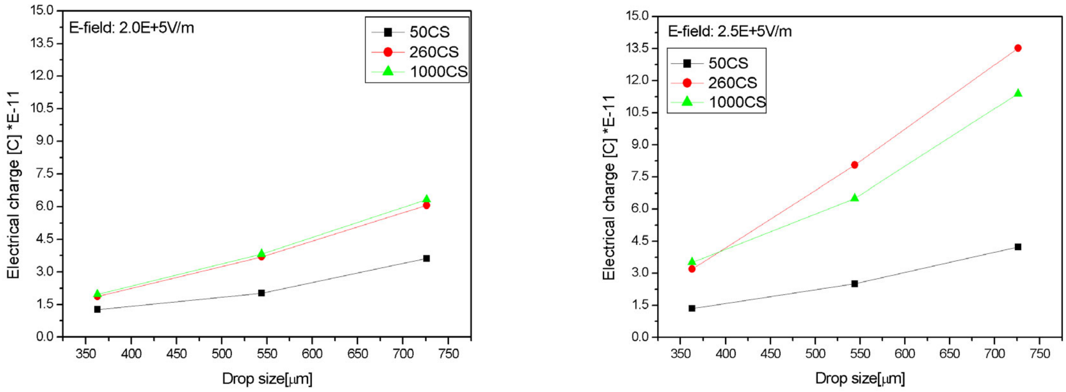

Figure 5. The effect of bulk viscosity.

Concluding remarks

In this study, electrical charging phenomenon of a conducting droplet in dielectric fluid on the electrode surface has been studied. To find the effects of key factors, the droplet size, the bulk viscosity and the external E-field were varied in experiments. It is shown that the more electrical charging occurs with larger drop size and higher electric field. The effect of the bulk viscosity is more complicated. In the case of not so high viscosity, the amount of charge increases with the bulk viscosity. However, in the very high viscosity case, the trend may be reversed. The observed results indicate that the charging phenomenon may be more complicated than expected and requires careful studies.

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