Negative Corona discharge from a Viscous Water Droplet

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***Abstract* -- Negative corona discharge from a water droplet under a dc electric field involves periodic formation of a Taylor cone and ejection of some extent of charge. The periodical motion at the formation of the cone is consistent with resonant vibration of the volume of a tip of the water droplet. To confirm the effect of water viscosity on corona discharge from a water droplet, corona phenomena was investigated by using a grounded tip of capillary electrode to a ring electrode system and by mixing starch sugar with ion exchanged water. A water droplet with a viscosity below 5.7 mPa·s manifests the periodic vibration with corona pulse trains. Water viscosity affects the frequency and the time variation of pulse height in a series of corona pulse trains. This means the motion of the water droplet is strongly influenced by viscosity.**

***Index Terms*-- corona discharge, pulse trains, resonant vibration, Taylor cone, viscosity, water droplet.**

I. INTRODUCTION

Corona discharge from a water droplet under a dc electric field involves not only formation of a Taylor cone but also ejection of a number of fine drops and vibration of the water droplet [1]. Therefore, a current waveform of corona discharge from a vibrating water droplet inevitably has unique feature, quite different from that occurring at a metal electrode. Moreover, since physical properties such as surface tension and viscosity affects the shape of the tip of water droplet, they would influence on corona discharge occurring there.

On the other hand, since disruption of Taylor cone would followed by ejection of some extent of charge quantity, the electric field strength at the tip of the droplet is weaken more or less at the instant of the ejection and the sharp tip of the droplet return to the round one. Since physical property of water acts an important role to disruption or deformation of water droplet, it inevitably would influence corona discharge from a water droplet.

The tip of water droplet could vibrate periodically with a particular time interval. The periodic vibration of water droplet yields a series of corona pulse trains. The occurrence frequency of corona pulse trains strongly depends on the water volume. The inherent vibrating frequency of an isolated droplet depends on the size of droplet[2]. Therefore, vibrating motion a tip of a Taylor cone might deeply relate to resonant frequency of the droplet with a given volume or govern an occurrence frequency of corona discharge.

We have investigated corona discharge from a water droplet located on the insulating sheet under the condition of horizontal or vertical electric field [1,3]. Moreover, corona discharge from a water column formed by eruption of air bubble at the water surface was studied [4].

Physical property such as surface tension, viscosity, would affect the shape of a water droplet, thus, it must influence on the discharge aspect more or less. The purpose of this research is to figure out the effect of viscosity of water on corona discharge from a tip of a water droplet. By using a capillary to a ring electrode system, effect of viscosity of water on corona discharge has been investigated with adjusting the value of viscosity

II. EXPERIMENTAL

A pair of a rod electrode having a capillary and ring electrode was used for measuring the characteristics of corona discharge from a water droplet. Water droplet was formed at the tip of the capillary grounded electrode. Positive dc voltage was applied to the ring electrode and the waveform of corona discharge current was caused.

The viscosity of water naturally depends on temperature and the viscosity varies from 0.4 to 1.8 mPa·s. for temperature from 0 to 80°C. Within these narrow ranges, corona onset voltage was almost constant. To widen the range of viscosity, starch sugar was mixed into ion exchanged water in the experiment. Starch sugar is made of maltose, $C_{12}H_{22}O_{11}$, with a molecule quantity of 342.3 and is completely resolvable into water. Water viscosity at 25 °C

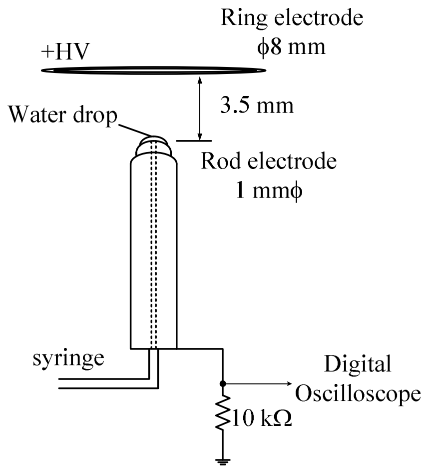


Fig. 1. Arrangement of a ring to capillary electrode system to occur corona discharge from at the tip of water drop.

varies from 0.9 to 5.7 mPa·s by mixing starch sugar up to 40% by weight.

Fig. 1 shows a ring to fine rod electrode system. The rod electrode has a length of 10mm and radius of 1 mm and has three capillary tubes inside. Radius curvature of the tip is almost 0.5 mm. The ring electrode has an inner diameter of 8 mm and a thickness of 0.5 mm. The distance between both electrodes was set at 3.5mm.

A given volume of water droplet was formed at the tip of the rod electrode through the capillary tube where water was fed by syringe pump. To confirm of a volume of water droplet, the water droplet formed at the tip of the rod electrode was checked with a microscope and a height of 0.1mm from the surface of the rod electrode kept constant at 10μL. The temperature of sample water was kept 25°C in all experiment for every condition of viscosity by keeping at constant temperature vessel.

By increasing the positive voltage applied to the ring electrode by 50V/s, corona onset voltage was obtained by measuring corona current with a digital recorder (NEC San-ei, RT3600). The waveform of corona discharge current flowing through a register of 10kΩ was measured with a digital oscilloscope (Tektronix TDSB, 1GHz 5GS/s) . The luminous aspect or motion of a water droplet was taken with a high-speed video camera (Photron, FASTCAM-Ultima II) equipped with an image intensifier at a speed of 9,000 frames/s.

III. RESULT AND DISCUSSION

A. Corona discharge from a water droplet

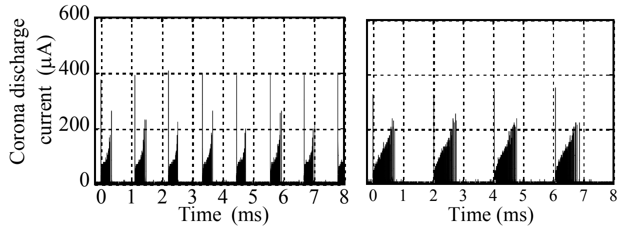
Corona onset voltage from a droplet was 4.2 kV for a viscosity up to 1.9 mPa·s, but it is increased with viscosity. Corona onset voltage is 4.3, 4.5, and 4.9 kV for a viscosity of 5.7, 27, and 246 mPa·s, respectively. As the viscosity of water is increased a, it is hard to form a Taylor cone and Water droplet was elongated keeping round tip.

Fig 2 shows a difference in corona discharge from a water droplet with a viscosity of 0.9 and 5.7 mPa·s. Below the concentration of starch sugar of 40% or viscosity of 5.7 mPa·s, the corona pulse trains occurred periodically Above the value, periodic corona pulse trains hardly appeared and burst pulses occurred irregularly. Occurrence of periodic corona discharge means that a droplet forms and deforms a sharp cone.

The disruption of a Taylor cone appears as occurrence of the first largest pulse in a series of pulse trains. Once a tip of a Taylor cone breaks into a number of fine jets, the cone returns to the round shape at the original or lower position with causing corona discharge. If the electric field exerting to the droplet is strong enough, droplet forms a cone again. These processes could repeat if the viscosity was low enough to form the cone. Therefore, small successive corona pulses follow an initial large pulse corresponding to the motion of the tip of water droplet.

The period between large pulses is consistent with that of formation of a cone. The period was 1.1, 1.5, and 2 ms for a viscosity of 0.9, 2 and 5.7 mPa·s, respectively. The inverse of the period is obtained as the vibrational frequency of a water droplet. The frequency for the droplet with a viscosity of 0.9, 2 and 5.7 mPa·s is 900, 650, and 490Hz, respectively

The period became longer as viscosity was increased. A water droplet with larger viscosity takes a long time to form or return to the original shape. Occurrence of corona pulse



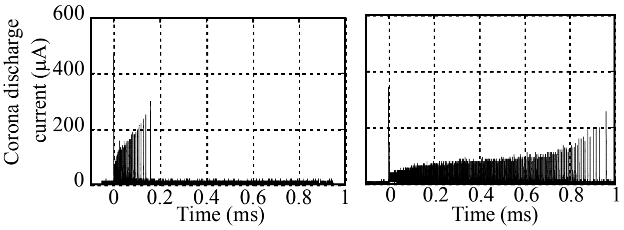
(a) 0.9 mPa·s (b) 5.7 mPa·s,

Fig. 2. Time variation of pulse groups in corona discharge occurring from the tip of a water droplet with various viscosity

trains with a regular period shown in Fig.2 indicates that corona discharge from a droplet occurs synchronized with change of the droplet shape or with a resonant vibration of the water droplet. This means that a water droplet with a smaller viscosity forms a smaller cone.

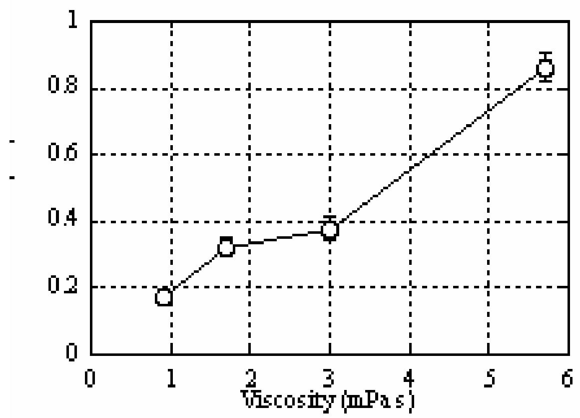
A single series of corona pulse trains in the pulse groups is enlarged in Fig. 3. In case of a water droplet with larger viscosity, corona discharge occurs for a long period continuously. On the other hand, corona discharge from a droplet with smaller viscosity has a shorter duration. This fact indicates formation of a Taylor cone or vibration of water droplet with small viscosity occurs relatively quickly. Regardless of viscosity, the last corona pulse in the pulse trains has the highest corona pulse except the first one. The largest pulse occurs at the relatively lower electric field at the tip of the cone, because the tip is descending toward the round shape.

Fig. 4 shows the duration time of a series of corona pulse trains during formation of a cone for a viscous water droplet. As expected from the pulse trains in Fig. 2 and 3, the time duration of a single series of corona pulse trains kept longer for a droplet with larger viscosity.



(a) 0.9 mPa·s (b) 5.7 mPa·s

Fig. 3. A series of pulse trains in corona discharge occurring from the tip



of a water droplet during resonant vibration

Fig. 4. Duration time of corona pulse group in corona discharge occurring from a viscous water droplet

The time variation of each pulse height in the corona pulse trains is shown in Fig. 5. The figure shows the mean value for 80 sets of corona pulse trains. The deviation from the mean value is relatively narrow. This means that corona pulse trains would occurs at high reproducibility. After the pulse height increased quickly within 50μs, it continues to increase with time until corona pulse ceased. The larger viscosity, the height of corona discharge became lower. The difference in the height might result from the size or radius curvature of a Taylor cone.

The total charge quantity ejected during a period in a series of corona pulse trains was obtained by a time integration of the waveform of the corona pulse trains. Fig. 6 shows the mean value of charge quantity in 80 series of the corona pulse trains. The charge quantity ejected during a period from the formation of a Taylor cone to return to the original round shape is increased as the viscosity increased. This tendency would result from the duration time of corona pulse trains during a single vibration.

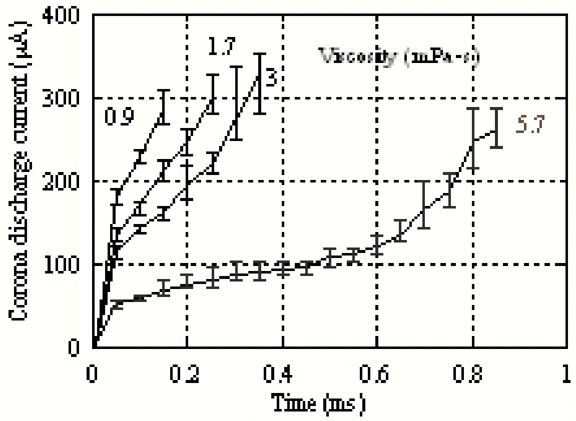


Fig. 5. Time variation of mean peak value of corona pulse group in a single deformation

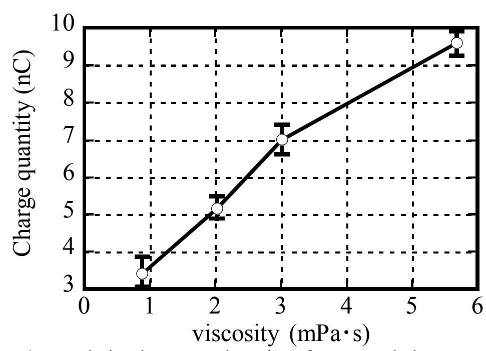


Fig. 6 . Relation between viscosity of water and charge quantity of corona pulse train

B. Vibration and corona discharge

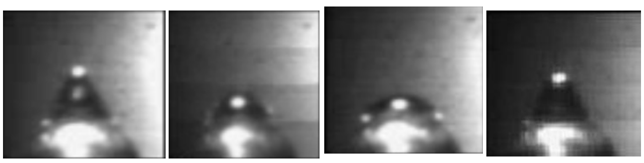
Fig. 7 shows the change in a shape of a droplet during regular motion taken by a high-speed video camera with a speed of 4,500 frames/s. Although it is hard to clearly recognize the difference of a shape of a cone tip in the figures, the period during the highest peaks varies with viscosity of a water droplet. The upward and downward motion of the tip of a droplet verifies the difference in the corona pulse trains shown in Fig. 2.

Fig 8 shows the time variation of the height of the tip of a cone tip but also the time interval of peak. As a result, vibrating frequency or corona discharge as shown in Fig.2 has a dependency of viscosity. The difference in vibrating water droplet measured from the surface of the rod electrode. Viscosity of water certainly affects not only the height of the motion could result from the speed of movement of deformation of a droplet.

Fig. 9 shows the upward and downward speed of the tip of a water droplet. The upward speed for the droplet with small viscosity is much higher than that with larger one. The downward speed for a much viscous droplet is also small. As a whole, the viscous cone keeps for a long period compared with a less viscous cone.

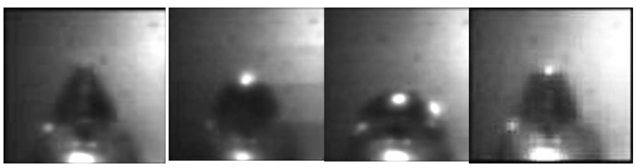
0 ms 0.42 ms 0.84 ms 1.26 ms

(a) 0.9 mPa·



0 ms 0.42 ms 0.84 ms 1.68 ms

(b) 1.7 mPa·s



0 ms 0.42 ms 1.264 ms 2.12 ms

(c) 5.7 mPa·

Fig. 7. Behavior of a viscous water droplet during corona discharge

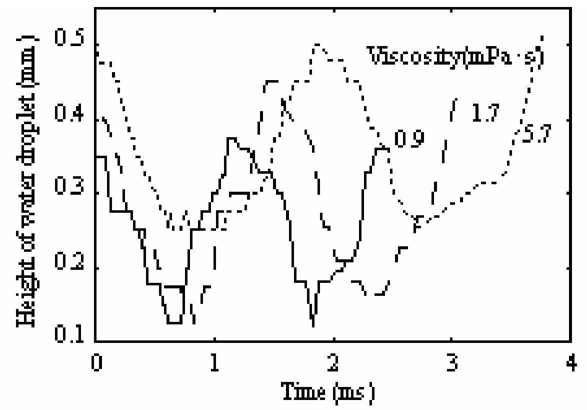


Fig. 8. Time variation of the height of a viscous water droplet during resonant vibration.

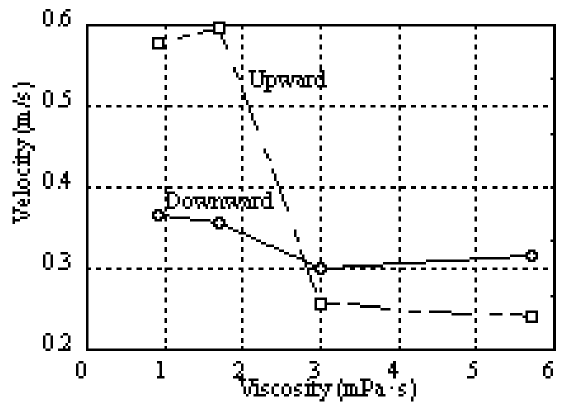
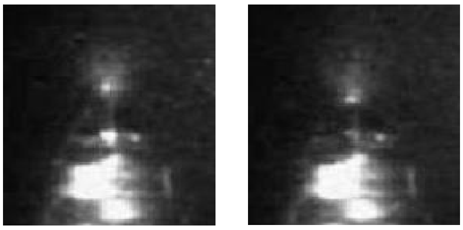


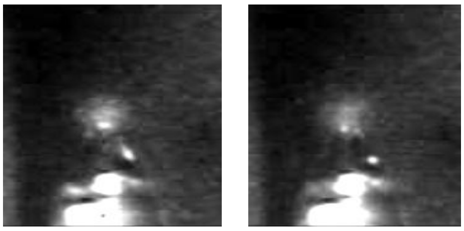
Fig. 9. Upward and downward velocity of thetipof a viscous water droplet during resonant vibration.

Fig. 10 shows the luminous aspects of corona discharge from a water droplet. Corona discharge occurs not only at the maximum height of a water droplet during the descent of the height. The viscosity of 0.9, 2, and 5.7 mPa·s, the corona luminous bright area can be seen until 0.3, 0.4 and 1 ms. Appearance of luminosity is consistent with the occurrence of corona pulse. A tip of viscous water forms a relatively round cone. Thus, less viscous water forms a cone before the cone elongates and corona discharge occurs at the relatively lower position. The cone of the water droplet might return to the original shape by the act of electro-hydrodynamics rather than by the act of resonant vibration. In case of a viscous droplet, droplet elongates to form longer and rounder cone. Corona discharge occurs at the higher position because of lack of sharp cone. As a result, the volume of the vibrating tip would be larger and the resonant frequency for vibration would be lower. This would result in the slower speed of upward and downward motion.



0~0.1 ms 0.2~0.3 ms

(a) 1.7 mPa·s



0~0.1 ms 0.6~0.7 ms

(b) 5.7 mPa·s

Fig. 10. Luminous aspect of corona discharge occurring from the tip of a water droplet.

IV. CONCLUSION

Negative corona discharge from a viscous water droplet has been investigated by using water mixed with sugar starch. Corona onset voltage from a viscous water droplet was increased with viscosity due to the difficulty of forming sharp cone. The shape of the tip of Taylor cone influences the characteristics of corona discharge. With increase of viscosity, corona pulse trains have the lower peak and the longer duration in corona discharge.

It is necessary to confirm deeply the relationship between the resonant vibration and viscosity of droplet.

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