KIEE International Transactions on EA, Vol. 3-C, No. 3, pp. 81~85, 2003 **81**

Behavior of Water Droplet on the Polymer Surface and Influence of the Charge

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Abstract - This paper describes the results of experiments made to examine the behavior of water droplet on the polymer surface and influence of the charge. In this experiment, water droplet was put on the polymer surface in an applied AC electric field and the investigations of its behavior were done with a high-speed video camera. It can be observed that the droplet elongates and vibrates with being pulled towards the positive electrode in a wave synchronism with the frequency of the power source. The volume and conductivity of water droplet are shown to have a marked effect on the mode of discharge development. These behaviors may be caused by the change of electric field of applied AC voltage and induced charges in/on the water droplet.

Keywords: Polymer, behavior of water droplet, induced charge, flashover voltage, surface potential

1. Introduction

Most power transmission lines with the form of overhead line make use of air insulation. Their mechanical support and electrical insulation are charged with "insulator", and as the "insulator" materials, porcelain and glass have been used widely. But recently the application of polymer to various outdoor electrical equipments is increasing rapidly, because this kind of material has lightweight, high mechanical strength and superior contamination resistant performances etc.

In particular, silicone rubber has superior hydrophobicity to exclude water. If the hydrophobicity of silicone rubber material is temporarily lost with degradation of UV, acid rain, salt fog, atmospheric pollution and so on, it is recovered by the action of low molecular weight component (silicone oil) migrating from underneath the surface of material and surrounding the salt and dust on the surface [1]. So it is known that the lifetime of material can be prolonged.

But just because of its good hydrophobicity, water droplets will be formed on the surface of polymer exposed to rain and moisture and hence the conductive contamination dissolved within the water is discontinuous[2]. The corona discharge usually occurs from water droplets on the polymer surface, which are considered to be one of the ageing mechanisms responsible for the failure of the insulators [3][4]. The corona discharge that can be generated locally due to high electric field can destroy hydrophobicity and cause the degradation of the insulators [5]. So it is necessary to note that how water droplets behave in an applied electric field. The purpose of this study is to clarify the behavior of water droplet on the polymer material and the influence on the discharge characteristics [6][7][8].

In this experiment, water droplets with different conductivities and volumes were singly put on the surface of silicone rubber sample, respectively. In addition, the voltage and current characteristics of corona discharge were investigated in needle and plate electrodes system under the increasing AC voltage. The behavior of the water droplet before and after flashover was observed with a high-speed camera. The correlation between the charge distribution in the vicinity of the droplet on the polymer surface and an applied electric field were also investigated. In the concluding portion, the influences of droplet behavior on the discharge characteristics are discussed.

2. Experimental Procedure

The experimental set-up for investigation of the behavior of water droplet on the polymer surface is shown in Fig 1. It consists of one needle electrode (high voltage side) and one plate electrode (earth side), between which the separation is 20mm, and an increasing AC power frequency (60Hz) voltage was applied. HTV(High Temperature Vul-

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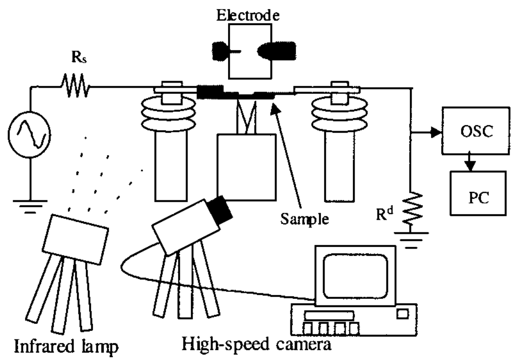
Received April 24, 2003 ; Accepted May 22, 2003

canized) silicone rubber(with 60% $AL(OH)_3$) of size 80× 50× 2mm was used as the test sample. Water droplets with the conductivities of 2.0μS/cm (ion-exchange water) and 20mS/cm (solution simulated as seawater), whose volumes were respectively about 30μl, 50μl and 100μl, were respectively singly deposited on the sample surface in the central region between the electrodes. The behaviors of water droplets in electric field were observed by a high-speed video camera (FastcamNet, Photron) with an imaging rate of 1000 frames per second. An infrared lamp was used to lighten the droplet. The surface potential distribution on and around the droplet was investigated using an electrostatic voltmeter as shown in Fig 2. Distribution of the potential on the polymer sample was investigated intervals of 5mm by moving the XY stage.



Rs : Series resistor PC : Personal computer
Rd : Detecting resistor OSC: Oscilloscope

Fig. 1 Experimental Apparatus

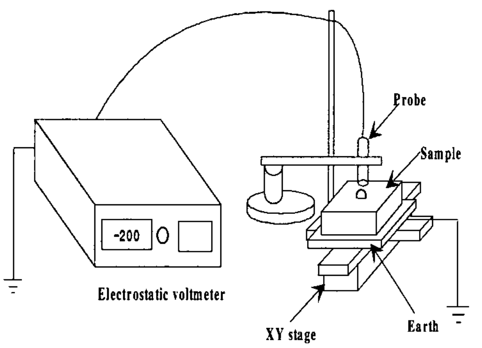


Fig. 2 Surface Potentiometer

3. Experimental Results and Discussions

Fig 3 shows the relation between the volume and conductivity of water droplet and flashover voltage. From the figure, it can be found that the flashover voltage decreased with the volume of water droplet increasing, because water droplet with larger volume more effectively reduced the insulation path between the electrodes and increased the risk of flashover. The conductivity of droplet also is shown to have a marked effect on flashover.

Figs 4 and 5 respectively show the distribution of surface potential in case of ion-exchange water and sea water (the volume is 30μl). From the fig 4(a) and fig5 (a), when the droplet began to weakly vibrate, the positive charge can be found on the surface of droplet. The water droplet began to vibrate at about 7kV in both two cases.

From fig 4(b) and fig 5(b), the central portion of the droplet charged negatively before flashover because of frictional electrification due to the movement of the droplet by the alternating electric field. At this time, the shape of the water droplet is nearly ellipsoid.

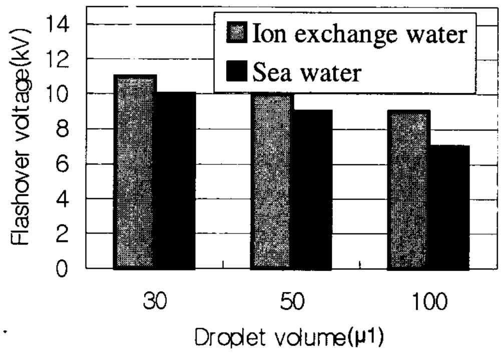
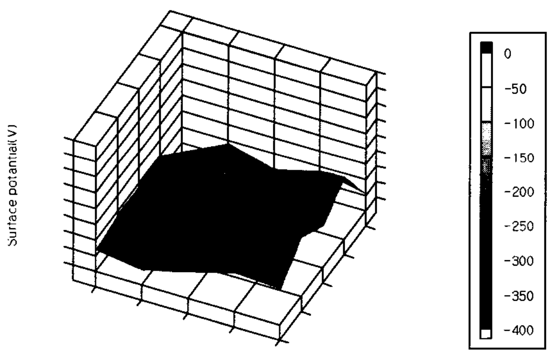
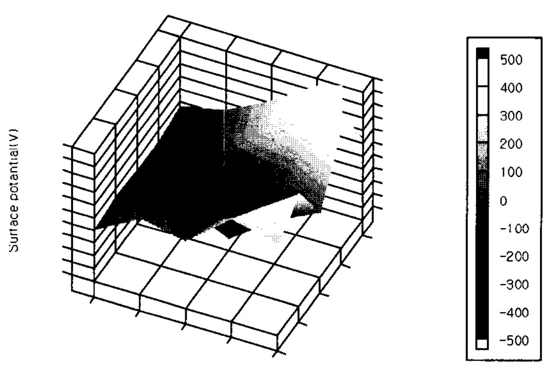


Fig. 3 Relation between droplet characters and flashover voltage

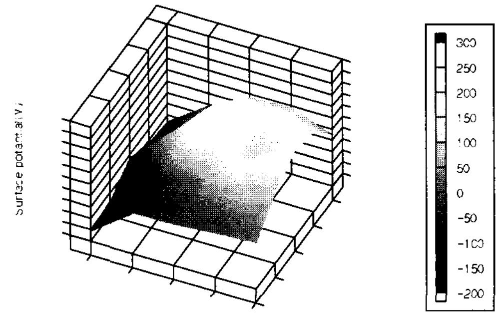


(a) Distribution of surface potential at weak vibration

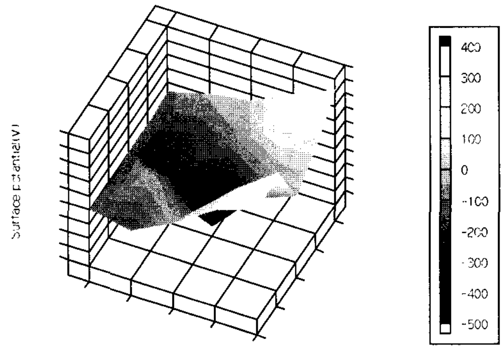


(b) Distribution of surface potential before flashover

Fig. 4 Surface potential distribution in the case of ion-exchange water



(a) Distribution of surface potential at weak vibration



(b) Distribution of surface potential before flashover

Fig. 5 Surface potential distribution in the case of seawater

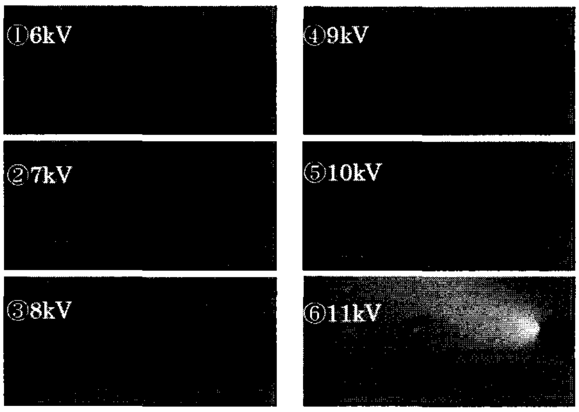


Fig.6 Behavior of water droplet on the polymer surface

Fig 6 shows the behavior of water droplet (ion-exchange water, 30μl) on the polymer surface. When corona discharge occurred at the voltage of about 7 kV and water droplet began charging, it was pulled towards the positive electrode(as shown in fig6-②). Here, high voltage side is regarded as the positive electrode when it is in positive voltage phase, on the contrary, the earth side is regarded as the positive electrode, when the voltage phase of high voltage side changes to negative. With the alternating AC voltage, water droplet moved from left to right in the direction according as the voltage phase. The behavior was observed to move with a wave-like motion and the droplet elongated(as shown in fig 6-② to 6-⑤).In the process some small droplets were separated by corona discharges from the spread tip. At last, flashover happened at the voltage of about 11 kV(as shown in fig 6-⑥). During the experiment, the water droplet deformed and always expanded its tip to the positive side[6][9]. Because as shown in fig 4(b) and fig 5(b), the central portion of the droplet charged negatively due to the frictional electrification from the movement of the droplet when it vibrated strongly. When the surface charge was over a critical value, the droplet released some negative charges from the tip near the positive side. After that the applied voltage was higher, the charges increased again to critical value and were released repetitively. Finally, flashover occurred in the gap between the electrodes.

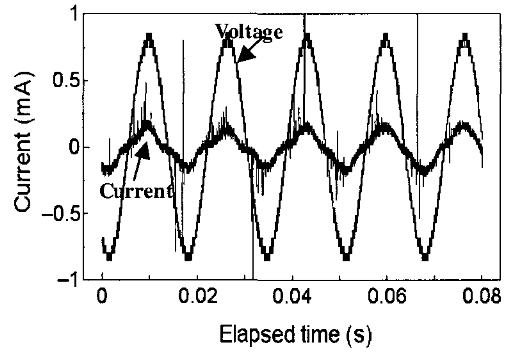
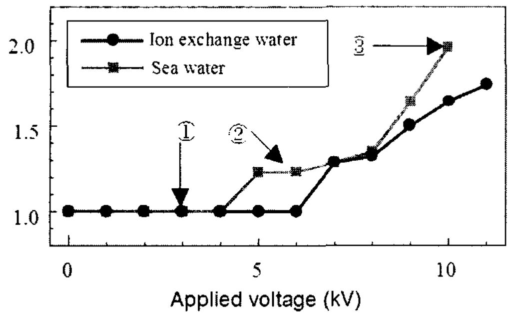


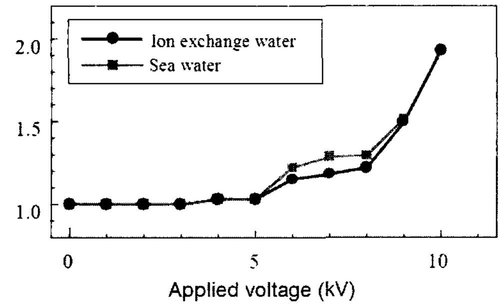
Fig. 7 Voltage and current waveforms during vibration of water droplet

Fig 7 shows voltage and current waveforms during the vibration of water droplet in case of seawater with the volume of 30μl. From the measurement using a high-speed camera, it had been observed that the discharge started at the tip of the water droplet [10]. In this figure, the large corona current can be found, because the tip of the droplet became sharp with the change of the shape and a high electric field was built up at the tip.

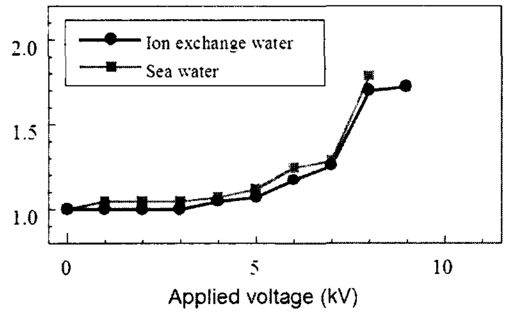
The change of deformation factor of all kinds of water droplets are shown in fig 8 (The definition of deformation factor is shown in the addendum) and the shapes of the droplets marked ①,②,③ in fig 8(a) are shown in fig 8(d). From the figure, the deformation factor is larger in case of sea water than in case of ion exchange water at the same voltage after the vibration begins. Because the conductivity of sea water is higher than that of ion-exchange water, the potential on the polymeric surface covered by droplet is lower, i.e., the electric field at the tip of droplet is higher in case of sea water than in case of ion-exchange water. It also can be found that the water droplet began to vibrate at lower voltage with the increase of droplet volume. It can be considered that the volume and conductivity of water droplet are shown to have a marked effect on the mode of discharge development and increase the risk of flash-over between the electrodes, as shown in fig 3.



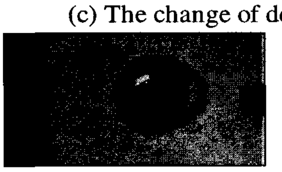
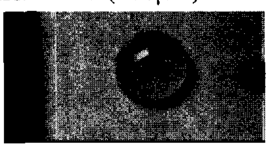
(a) The change of deformation factor(30μ 1)



(b) The change of deformation factor(50μ 1)



(c) The change of deformation factor(100μ 1)

(1) The shape of droplet marked ① (2) The shape of droplet marked ②

(3) The shape of droplet marked ③

(d) The shape of droplet marked ①, ②, ③ im (a)

Fig. 8 The change of deformation factor with the increase of AC voltage

4. Conclusion

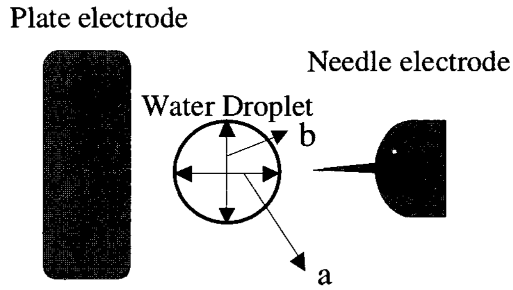
The charging phenomena of water droplets on the surface of polymer with hydrophobicity and its influence on the discharge characteristics were studied. The main results are summarized as follows:

(1) The onset voltage of vibration and flashover voltage decrease with the volume and conductivity of water droplet increasing. The volume and conductivity of water droplet are shown to have a marked effect on the mode of discharge development.

(2) The charged water droplet on the polymer surface oscillates with the alternating electric field and elongates in the direction of both electrodes. At last, the pointed tips trigger flashover

(3) In the condition of an applied AC voltage, the droplet movement corresponds to the voltage polarity at corona inception. When the surface charge is over a critical value, the droplet releases some negative charges from the tip and the charges on the droplet surface repeatedly decrease and increase temporarily. After that the applied voltage is higher, the charges increase again to critical value and are released repetitively. Finally, flashover occurs in the gap between the electrodes.

Addendum



The value of the deformation factor is a/b

References

[1] R. Hackam: "Outdoor HV Composite Polymeric Insulator", *IEEE Trans on DEI*, Vol.6, No.5, pp.557-585.

[2] I.J.S.Lopes et al., "A Study of Partial Discharges from Water Droplets on a Silicone Rubber Insulating Surface" *IEEE Trans. DEI*, Vol.8, pp.262-268 (2001).

[3] R.S. Gorur, E.A. Cherney and J.T. Burnham, "Outdoor Insulator",Gorur Ltd,Arizona,USA,1999.

[4] A.J. Philips, D.J. Childs and H.M. Schneider, "Water drop corona effects on full-scale 500kV non-ceramic insulators", *IEEE Transactions on Power Delivery*, Vol.14, pp.258-265, 1999.

[5] B.N.Pinnangudi, R.S.Gorur and A.J.Kroese, "Energy quantification of corona discharge on polymer insulators", 2002 *Annual Report Conference on Electrical*

Insulation and Dielectric Phenomena.

[6] M. Otsubo, N. Arise, T. Hashiguchi, Y. Okraku-Yirenkyi, C. Honda, O. Takenouchi, K. Tsurugida, T. Yamashita: "Charge Characteristics of Water Droplet and Its Influence on the Discharge Characteristics", *Proc. of 13th Int. Conf. on Gas Discharge & Their Applications*, Vol.2, pp.912-915, 2000.

[7] A.Krivda and D.Birtwhistle, "Breakdown between water drops on wet polymer surface", *IEEE-CEIDP*, pp.572-580, 2001

[8] S.Keim and D.Koenig, "The dynamic behaviour of water drops in an ac field", *IEEE-CEIDP*, pp.613-616, 2001.

[9] Y. Mizuno, M. Nagata, K. Naito, K. Kondo, S. Ito and Y.Koshino, "Water droplet Behavior and Discharge Activity on Silicone Rubber Energized by AC Voltage" *IEEE-CEIDP*, pp624-627, 2001.

[10] N. Arise, H.Nishioka, Y.Okraku-Yirenkyi, M. Otsubo, C. Honda: "Behavior of Waterdroplet on Polymer Material and the Influence on Discharge Characteristics", *IEEE-CEIDP*,pp.455-458,1999.

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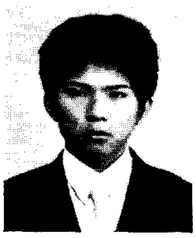

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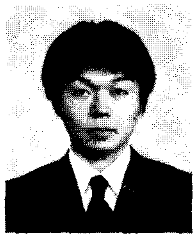

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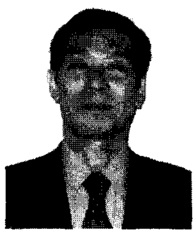

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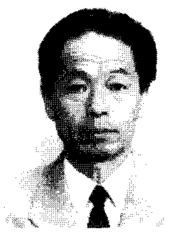

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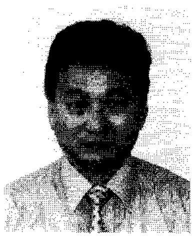

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