WATER DROP TO METAL AND WATER DROP TO WATER DROP CORONA DISCHARGES

D D Hinde[1] and D Birtwhistle[2]

[1]Queensland University of Technology, Australia. dhinde@bigpond.com
[2]Queensland University of Technology, Australia. davidbirtwhistle@tpg.com.au

ABSTRACT

Water drop corona has been identified by many authors as a major cause of deterioration of silicone rubber high voltage insulation but at this stage there have been no thorough studies made of this phenomenon. In this paper fundamental observations are presented of electrical discharges from water drops, movement of drops, and drop coalescence in the presence of 50 Hz alternating electric fields. Measurements are made both with water drops on metal electrodes and with water drops on the surface of silicone rubber insulation. Comparisons are made of current pulses and atomic emission spectra from previous work by the authors on dry point-plane discharges to provide information about the main types of active species which may cause insulator surface degradation. Visual images of wet electrodes show how water drops can play a part in encouraging flashover. The first reproducible visual images of water drop corona at the triple junction of water air and rubber insulation are presented. The current measurements were captured with a digital oscilloscope sampling at 200 MHz. The time constant of the measuring circuitry was approximately 14 nanoseconds.

1. INTRODUCTION

Chemical changes to the surface of silicone rubber (SiR) used for high voltage insulation due to the presence of water have been known since 1994 with work presented by Kim et al [1]. It was accepted that water drop discharges or "water drop corona" were the main cause of these changes. Other workers confirming water drop discharges affect the surface of SiR include Moreno and Gorur [2] and Braunsberger et al [3].

Water is polar and the shape of a water droplet is influenced by an electric field. Roero et al [4] showed that instability of a water drop in a perpendicular electric field is dependant on drop size, surface condition, and electric field strength. Krivda and Birtwhistle [5] have experimented with water droplets on a silicone rubber insulator surface in a parallel alternating electric field. The dynamics of the water drops on a surface in an alternating electric field can produce complex dynamic shapes such as sideways wobbling and other modes of volumetric vibrations. Harmonic and sub-harmonic vibrations of the frequency of the applied voltage were shown to be possible. Roero and Teich [6] show that for each individual drop size a fundamental resonant frequency exists. To provide a better understanding of water drop movements and their ability to affect high voltage insulator performance in wet conditions it was decided to investigate water-drop-to-metal discharges, water-drop-to-water-drop discharges, and to make spectroscopic studies to determine the energy levels of the active species produced by these types of discharges.

2. WATER DROPS ON METAL ELECTRODES

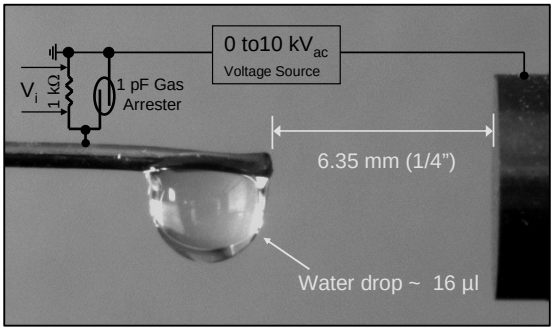

Figure 1 Experimental setup showing AC voltage source, measurement circuitry, water drop, and plane electrode. 31ºC, 30% RH.

The experimental setup is shown in Figure 1. The drop is held by a horizontal steel pin prepared with 1000 grit emery. It has a small upward bend at the end to hold the drop. The motion of drops of various volumes were observed after 50 Hz voltage was applied across the gap. It is found that the results of applying an electric field fall into several categories which are shown in Table 1.

Table 1 Motion of water drops in a 7.2 mm horizontal gap with a 50 Hz applied voltage.

Drop Volume (µL)	Category	Flashover
1	Single pulse with streamer.	No
1.5 to 2.3	Drop disintegrates in gap.	No
3	Drop transferred to opposite electrode.	Yes
6	Drop transferred to opposite electrode.	No
8 to 16	Whole drop falls between the electrodes.	No

Figure 2 shows video images of water drop motion for two conditions with time between frames of about 33 milliseconds. The sequence of images in the left column shows a 2.3 µL water drop initially on the

wire point electrode. In (a) there is no applied voltage. In (b) 9.4 kV_{pk-pk} is applied and current pulses are observed as the water drop vibrates and stretches towards the plane electrode which increases in (c). In (d) streamers are observed as surface tension is overcome and in (e) the drop is disintegrating and conduction current begins to flow between the electrodes. In the right column of Figure 2 a water drop of 7.6 µL is initially hanging on the wire electrode in (a). Application of the voltage causes the drop to wing towards the plane electrode in (b) and (c) and in (d) the drop falls between the electrodes.

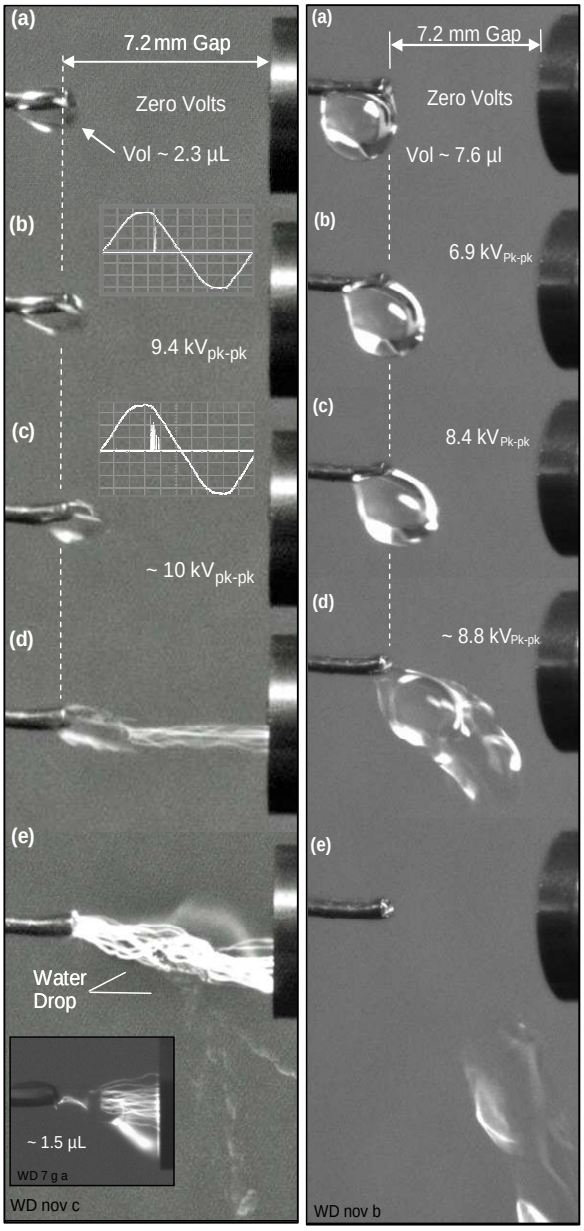

Figure 2 Water drops under the influence of a 50 Hz electric field taken at 30 frames per second. (a) 2.3 µL drop (insert 1.5 µL) and (b) 7.6 µL drop. Drops are salt water (1%wt).

Figure 3 shows how drops can be transferred from one electrode to another without causing full conduction within the gap. In this sequence of images the water drop stretches towards the plane electrode in (a) and in (b) the drop can be seen about half way between the electrodes with discharges on both sides of the drop. The drop has fully transferred in (c) and (d).

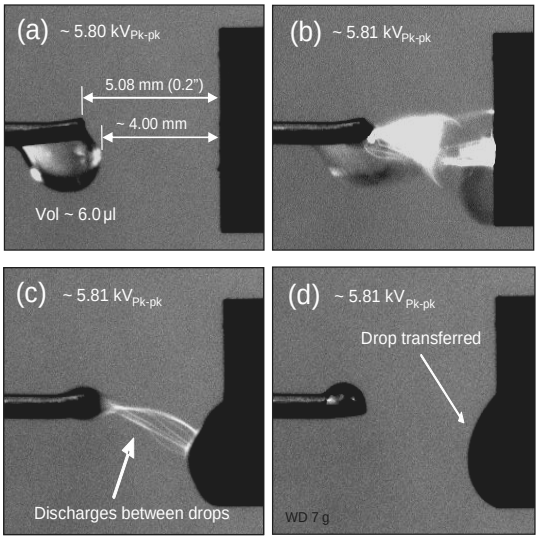

Figure 3 Sequence of images showing stages of a 6.0 µL water drop transferring to the opposite electrode without causing full conduction across the gap.

The water-drop-to-metal discharges are characterised by current bursts consisting of a large initial pulse followed by a rapid series of pulses that successively increase in both magnitude and time interval. Figure 4 show these pulses that relate to Figure 2 (c) (left image). These are in the same form reported by Sugimoto et al [7] using DC applied voltage.

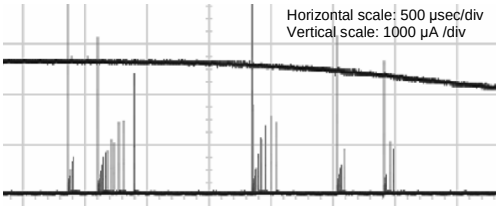

Figure 4 Typical bursts of current pulses from a discharging water drop to a metal plane electrode.

Figure 5 shows a single burst in detail and shows a general trend of the pulse peaks.

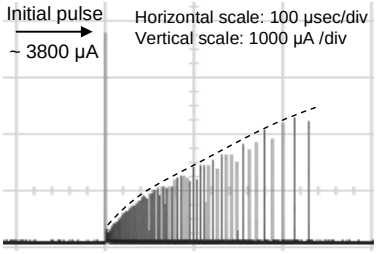

Figure 5 Detail of a typical burst of discharge current pulses for a water drop to a metal plane electrode.

All bursts of current pulses for all drop sizes investigated were found to appear after the voltage peak in the second quadrant of the 50 Hz voltage cycle while the drop is negatively charged and the plane positively charged.

3. WATER DROPS IN A RADIAL $\bar{E}$ FIELD

Figure 6 shows the apparatus used to study the movement and corona discharge pulses of rain water drops on a surface of SiR. The water drops were approximately 2 mm diameter when hand placed from a wire onto the SiR.

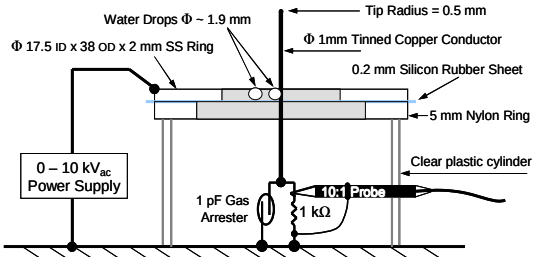

Figure 6 Drawing of apparatus showing electrical circuitry.

One drop is placed against the centre conductor and the other placed to create a gap of approximately 2 mm between the drops. The voltage is raised until discharge current pulses are detected and then held steady (~ 4 kV_{pk}). Figure 7 shows the discharges with 0.125 seconds of camera exposure time. Discharges between drops are not always observed in the same frame as the discharges that are indicated with arrows.

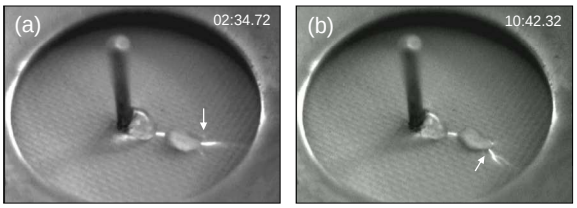

Figure 7 Water drop discharges (a) Negatively charged water drop discharge (b) Positively charged water drop discharge.

Figure 8 shows consecutive frames as two drops coalesce in a two drop experiment with wetted outer conductor. Figure 9 shows the current measured during the exchange of charge during coalescence. In a similar experiment the drops did not coalesce and provided several minutes of discharge recordings before extinguishing (Fig. 10).

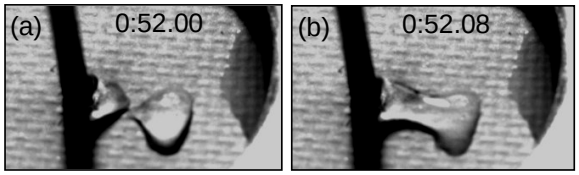

Figure 8 Water drop coalescence (a) Discharges occurring between water drops. (b) Drops coalesced.

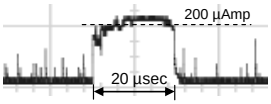

Figure 9 The measured current pulse that occurred when the two water drops in Figure 8 coalesced.

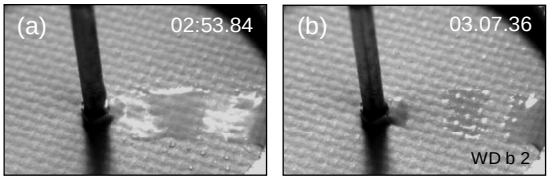

Figure 10 (a) Final stages of discharges between water drops (b) Water drops evaporate and discharging ceases.

Comparing Figures 11(a) and 11(b) shows the discharge onset voltage (V1) does not change with increasing voltage, however, the onset voltages (V2 to V3) show the opposite polarity onset voltage increases with applied voltage.

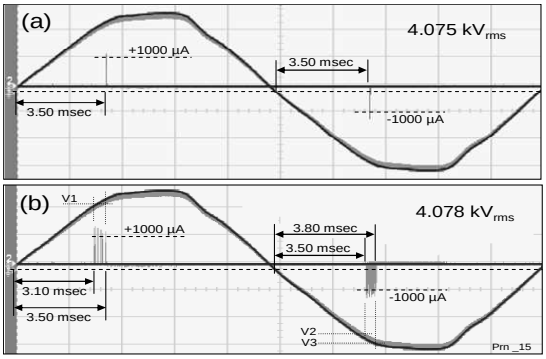

Figure 11 Water drop to water drop discharge current pulses. (a) At onset. (b) Envelope as voltage is increased.

The current pulses are singular in nature and slightly different at the peak and at the tail when compared to metal electrode discharge current pulses (Fig.12).

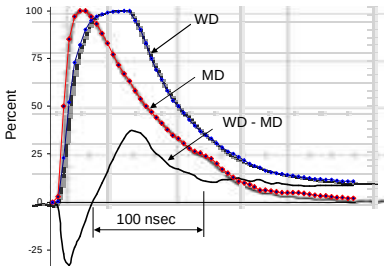

Figure 12 A normalised comparison between a water drop to water drop discharge current pulse (WD) and a metal point to metal plane discharge current pulse (MD).

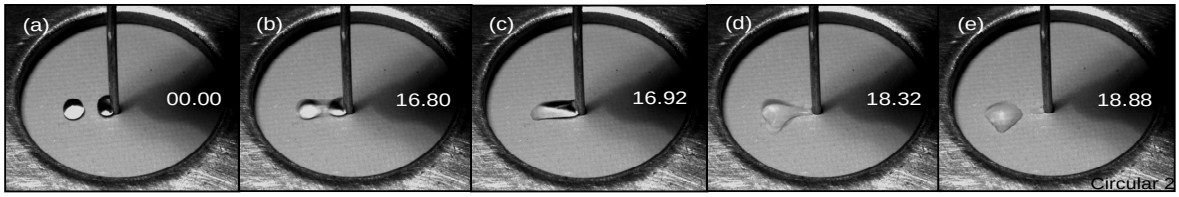

Figure 13 Behavior of water drops in a steady AC electric field on the surface of SiR (a) A water drop against the central conductor and an isolated water drop with zero applied voltage. (b) Increasing the applied voltage to approximately 2 kV_{pk} causes discharges to occur between the water drops. (c) Two drops coalesce to form one drop. (d) Coulomb forces act to draw the drop toward the outer electrode. (e) Radial movement of the drop ceases when the circuit breaks from the centre electrode. Time stamp = xx.xx seconds. Ambient: 16.3 ºC , 40% RH .

4. SPECTROSOPIC STUDIES

Atomic emission spectra were obtained from an Ocean Optics HR 4000 fibre optic spectrometer set for 100 milliseconds integration time between scans. The position of the optical fibre is shown in Figure 14.

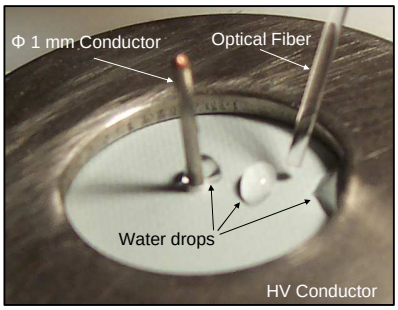

Figure 14 Photograph showing three water drops and the UV transparent optical fibre to the HR4000 Spectrometer.

In a darkened room the applied voltage was smoothly increased until discharges were detected. Figure 15 shows the results overlaid with spectra obtained from a previous point- plane experiment at 30.3 ºC and 43% RH.

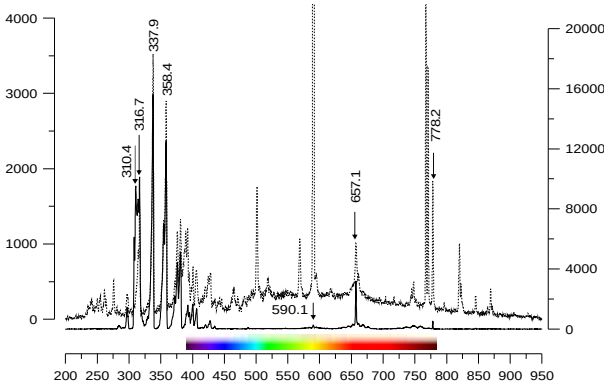

Figure 15 Atomic emission spectra over the range 200 nm to 950 nm for a water drop to water drop discharge and for a metal point to metal plane spark discharge (dotted) is overlaid for comparison. The vertical units are counts (1 count = 100 Photons).

The spectra were compared and found to be significantly different in the range 305 nm to 340 nm. The spectra were then normalized to provide Figure 16. There is a notable

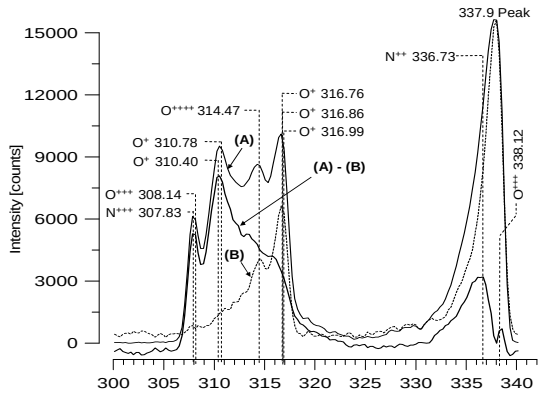

Figure 16 A comparison between atomic emission spectra normalised to the 337.9 nm peak shows the differences in UV emitted radiation ((A) – (B)) between water drop to water drop discharges (A) and metal point-plane discharges (B).

increase in the ratio of intensity in the range 314 nm to 317 nm and a significant increase from 310 nm to 311 nm. The new lines that appear between 307 nm and 309 nm relate uniquely to the water drop discharges. The difference in the 337.9 peak appears to be from doubly ionized nitrogen at 336.73 nm.

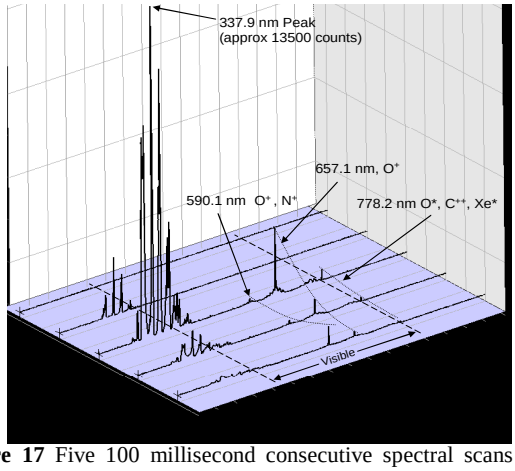

Figure 17 Five 100 millisecond consecutive spectral scans showing late radiative emission at 590.1 nm.

CONCLUSIONS

Discharges between water drops are different from water-to-metal discharges. Pulse magnitudes increase with time for the water-to-metal discharges but are almost constant for the water drop to water drop discharges. Current flows between water drops on a surface as they coalesce. Discharges between water drops produce highly active O^{+++} and possibly N^{+++} ions which may accelerate the degradation process of SiR.

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