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Space charge phenomena on low-density poly ethylene film breakdown under heavy water absorption

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ABSTRACT

The effect of dry and heavy water absorption on the electrical breakdown of low-density poly ethylene film was investigated. The temperature rise of the sample was observed by thermograph until the electrical breakdown using direct current ramp voltage. The conduction current of low-density poly ethylene film was also measured, and the result was then correlated with thermograph measurement. Meanwhile, the space charge distribution in a sample was measured by the pulse electro-acoustic method. From the thermograph, the result can be seen that under the heavy water absorption, the sample was more dissipated than the dry condition. Then, the breakdown occurs at the lower value of the voltage application, but the higher conduction current. Furthermore, the pulse electric acoustic show that increases the charge injection to the sample in the heavy water absorption. Increased space charges associated with an increase in the current conduction and the formation of heating, which results in a thermal breakdown.

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1. INTRODUCTION

The polymer is widely used in many areas of industry as an insulating material for medium and high voltage cables. Nowadays, low-density poly ethylene (LPDE) is frequently used for the above purpose due to its excellent electrical and mechanical properties. However, to develop higher performance cables, the improvement of the electrical properties of LPDE is still actively investigated. In the tropical area, both ambient temperature and humidity are very high. It is reported that the highest temperature in Indonesia is as high as 30°C, and the humidity is close to 100%. In such a condition, dew condensation easily takes place, so that the surface of the insulation is covered with water. Besides, the temperature of the insulation surface may increase by several tens of degrees, when it is exposed to the sunbeam. In the real field, the insulating material in the tropical area is often used in high relative humidity and for all years [1-3].

Moreover, in the heavy rainfall areas, this material is often wet for a significant time. The insulation capable of absorbing the water in this condition would lead to an environmental aging factor. On the other side, the technical trends today in which the power apparatuses are being weight-reduced and downsized to reduce power transmission costs, the insulation systems are subjected to higher stresses. Higher stresses play a significant role in the aging and breakdown processes of electrical insulation systems [4-7]. This condition is considered able to affect the breakdown of insulation. In this report, the impact of water absorption on the electrical breakdown of LDPE film using direct current (DC) ramp voltage was studied by observing the temperature rise due to local joule heating and the conduction current until the breakdown takes place. Besides, the conduction current was strongly related to the phenomena of charge in insulation [6-10]. It was measured using pulse electro acoustic (PEA).

2. RESEARCH METHOD

The used sample was a low-density polyethylene. The samples were 20 μm thick for observation of the temperature rise and conduction current and 60 μm thick for measurement of the phenomena of charge in insulation. The effect of heavy water absorption in the sample was compared with the sample under dry conditions [11-13]. For the first condition, the samples were immersed into water for more than two months, while for the second condition, the samples were dried using the silica gel for more than two days.

To measure temperature rise under increasing DC voltage on the configuration of the needle-plane electrode with no distance between the sample surface and the needle tips are adopted [14-16], as shown in Figure 1. The plane electrode was 7 μm thick of polyethylene terephthalate (PET) film, where the one side was gold evaporated. It was connected to the ground, and the other hand was black painted to increase the emissivity. From the black side, the increment of temperature was observed by a thermograph. The ramp voltage with an increased rate of 100 V/s was applied until a breakdown occurs [6]. The conduction current was also measured simultaneously. The PC controlled all measurements.

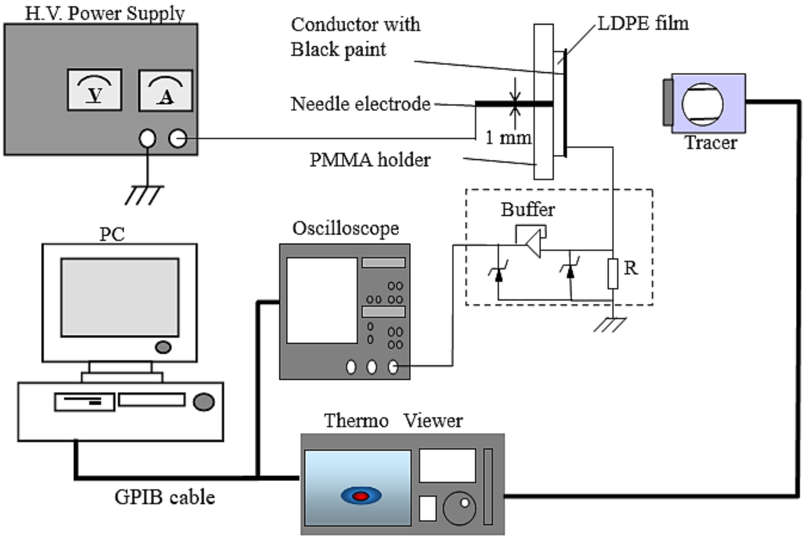


Figure 1. Experimental system for detection of temperature rise and conduction current

The space charge measurement was done by the pulse electro acoustic (PEA) method. Figure 2 shows the improved PEA system for measuring the space charge distribution in a polymeric thin film [16-19]. The measuring of the space charge distribution until breakdown occurs, a semiconducting electrode with 8 mm in diameter was used. In the case of the measurement of the breakdown pressure wave, the sphere-plate electrode was adopted. The pulse voltage of 500 V with a duration of 5 ns was applied to the sample to generate an acoustic signal wave with a frequency of pulse 100 Hz. The pressure was created in the specimen propagate through the lower plate (12 mm) and detect by polyvinylidene fluoride (PVDF) film (9 mm) as a piezoelectric transducer. The polarity of the voltage was defined as that of the applied voltage to the upper electrode. A low-noise band-amplifier amplified the signal from the PEA method and then was recorded by a digitizing oscilloscope with an interval of 1 second. Silicone oil was used as an acoustic coupling agent in order to make good acoustic contact and placed between the sample electrode and the measuring electrode. The configuration was also put in silicone oil to avoid partial discharge. Two kinds of space charges were measured; the first one is the space charge measured after applying a 10 kV dc for 1 minute. The second one is using ramp voltage DC until the breakdown occurred. Space charges of all samples were measured at heavy water absorption and dry condition.

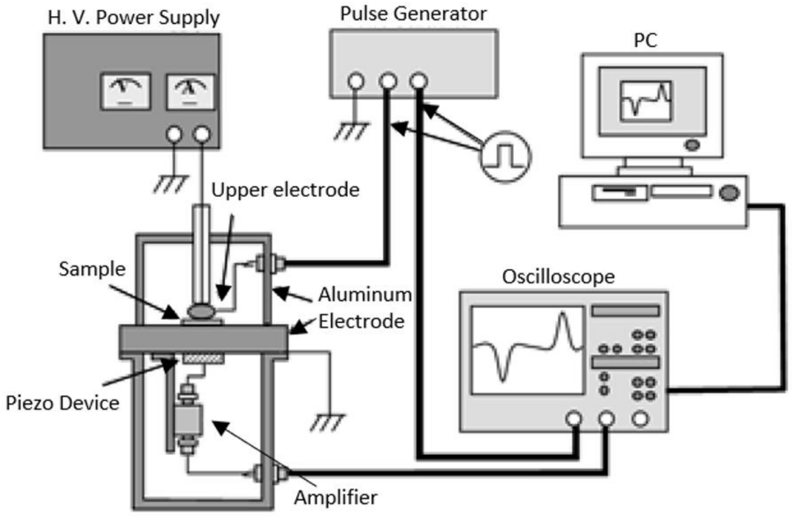
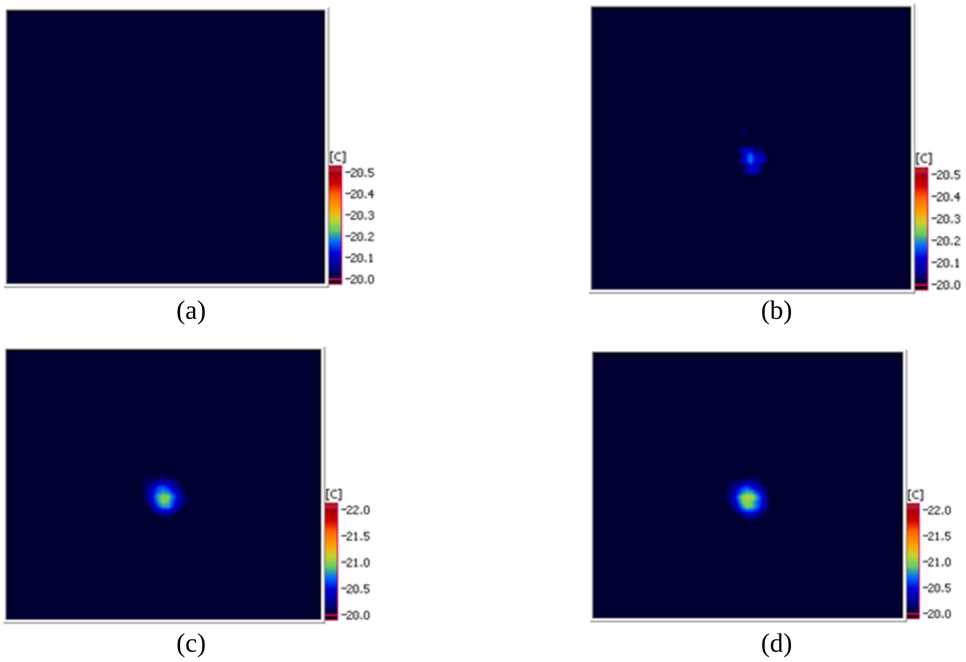


Figure 2. Measurement system for the space charge distribution

3. RESULTS AND ANALYSIS

The rise of temperature change of polyethylene due to the increment of DC voltage for dry condition cases was observed by thermograph, as shown in Figure 3. The increment of voltage application was correlated with the thermal image from the thermograph. The ambient temperature was 20°C. During the increment of voltage application, a local temperature rise was not significant for the voltage lower than 9.8 kV as shown in Fugure 3 (a). As soon as the voltage reached the value of 9.8 kV, the local higher temperature point has appeared as shown in Figure 3 (b). At this voltage, the temperature rise was about 0.1°C, and above this point, the temperature rises significantly increase as shown in Figures 3 (c) and (d).

Moreover, at the voltage around 11.6 and 11.7 kV, the temperature rise increased to about 1 and 1.1°C. The breakdown then occurred at this highest temperature point. However, no indication can be seen from the temperature rise to detect whether the breakdown had occurred or not.



(a) (b)

(c) (d)

Figure 3. The thermal image at the dry condition as a function of applied voltage just before the breakdown; (a) at 0 Kv, (b) at 9.8 kV, (c) at 11.6 kV, and (d) at 11.7 kV

Figure 4 shows the conduction current function of voltage increment. The result was measured simultaneously with the observation of the temperature surface. From 0 V until 8.3 kV, the conduction current increased from 0 to 0.08 μA, and the increment of current in this range was linearly increased as a function of voltage application, and a linear relationship between conduction current and the applied voltage is Ohmic. However, the increment of voltage application from 8.3 kV until the point just before breakdown (around 11.7 kV), the conduction current increased significantly as a function of voltage application from 0.08 to 0.2 μA, and the increment of current conduction is singled out above which the transition between low slope to the high slope characteristic occur or likewise conduction current, which changes instantaneously as the linear voltage increases is defined as the threshold point [8, 9, 20-22]. Under the initiation threshold point, the result can also be seen that the conduction current in this region was quite low; therefore, the increment of temperature could not be observed by a thermograph. Above the initiation threshold point, the conduction current increased remarkably as function voltage application, in this range, the electric power was dissipated, and this is enough to initiate the increase in the temperature of the sample. Then the temperature continues to increase under increasing the voltage application until the breakdown occurred. At one second before the breakdown point, it was challenging to observe the current conduction change because it rose very abruptly.

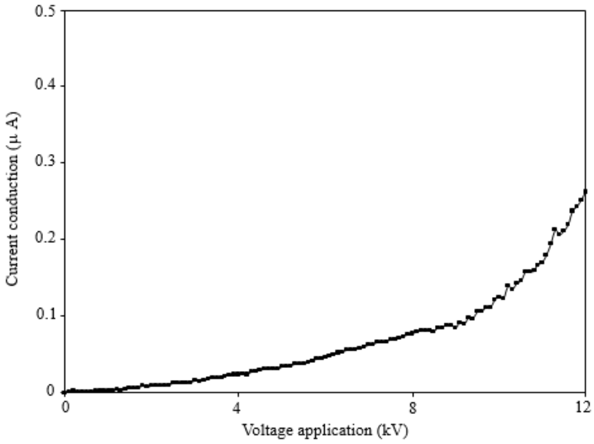
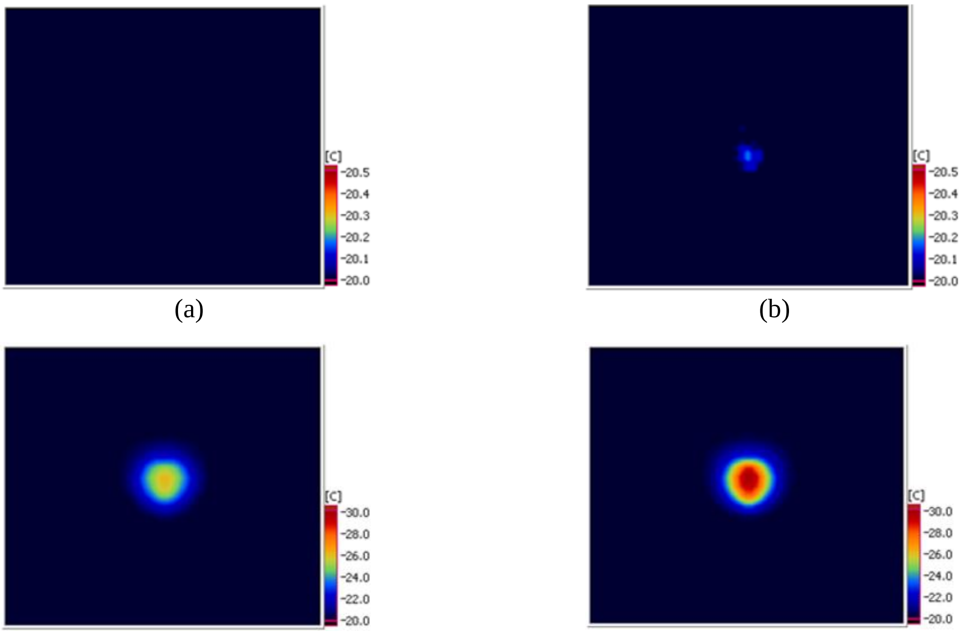


Figure 4. Conduction current function of voltage application at dry condition

In the case of heavy water absorption, the temperature rise of the samples due to increasing of the voltage application was observed by thermograph, as shown in Figure 5. The ambient temperature was almost similar to the previous cases. By increasing the voltage application, the temperature rises around 0.1^{o}C was detected at the voltage 5 kV, and then the temperature rise increases significantly as shown in Figures 3 (c) and (d) to the 26^{o}C and 29^{o}C for the voltage 8.9 and 9 kV respectively. At this point (9 kV), then the breakdown occurred. In the same way, the temperature rise in this step was also increased significantly as the function of voltage application but had a difference in temperature rise value just before breakdown. The heavy water absorption has a higher temperature rise than dry conditions.

Figure 6 shows the conduction current function of the voltage increment for heavy water absorption cases. From 0 V until 4 kV, the conduction current in this series increases linearly from 0 to 0.25 μA as a function of the voltage application. Then, from 4 kV until the point just before breakdown (9 kV), the conduction current increases from 0.25 to 6.37 μA. Similarly, the current conduction in this sequence was also increased significantly as the function of voltage application but have a difference of initiation threshold point value. The heavy water absorption has a lower threshold point than dry conditions.

After the heat appeared on the insulation at a certain point of the voltage in both sample conditions, then the increase of the temperature was dominantly caused by increasing of the voltage application. Figure 7 shows the vertical line of the temperature sample, which passed through the hottest point of the sample. The cases of heavy water absorption have a more significant temperature rise until the breakdown occurred than the cases of dry conditions. From these results, it was obtained a good correlation between the temperature rise of the sample and the current that flow through the film. Generally, it can be noted that the heavy water absorption of the LDPE film brings a higher conduction current through the sample. It is resulting from the significant temperature rise and the lower breakdown strength in terms of the thermal breakdown process.



(a) (b)

(c) (d)

Figure 5. The thermal image at heavy water absorption condition as a function of applied voltage just before the breakdown; (a) at 0 Kv, (b) at 5 kV, (c) at 8.9 kV, and (d) at 9 kV

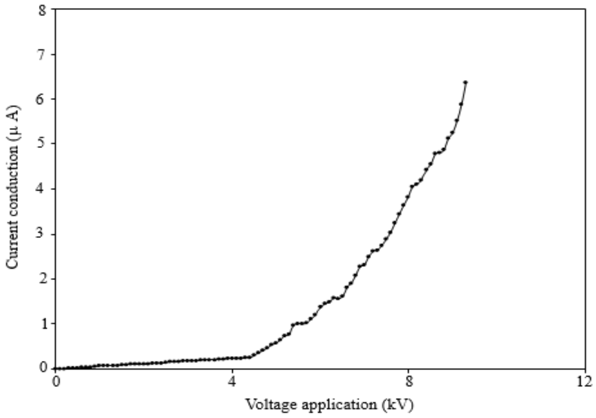
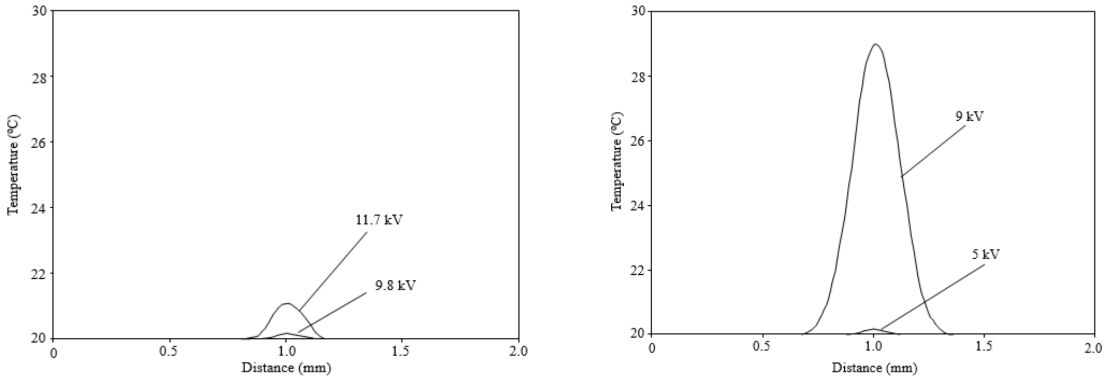


Figure 6. Conduction current function of voltage application at heavy absorption condition

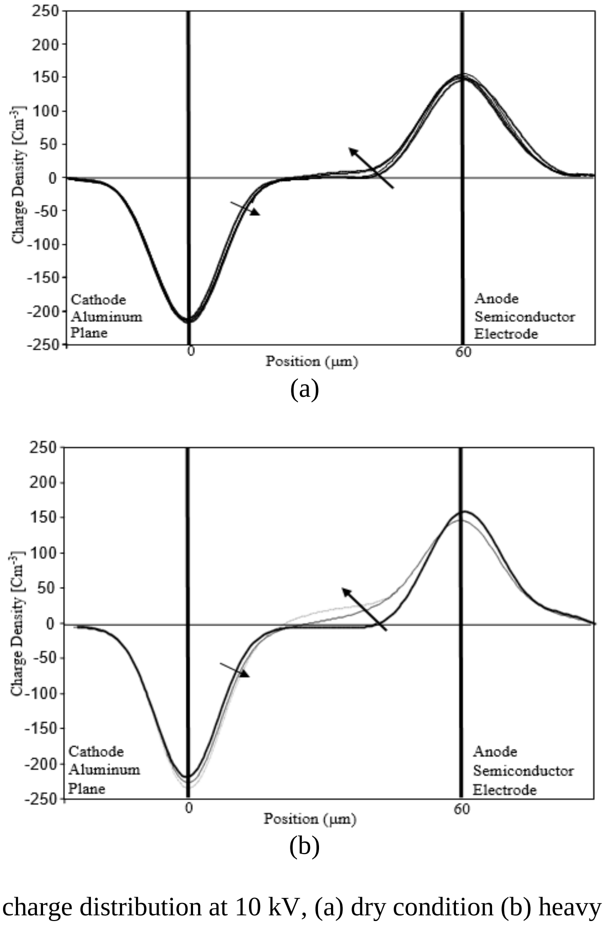


(a) (b)

Figure 7. One line of temperature sample pass through the hottest point at the sample, (a) dry condition, (b) heavy water absorption

The correlation between the increments of temperature surface as a function of the voltage application and the conduction current has already been discussed. In general, words can be described that a higher temperature rise was mostly caused by a higher conduction current in insulation [23-26]. Temperature rise due to the current is also related to the movement of charge inside the insulation. Therefore, it is necessary to investigate the phenomena of the current due to the effect of the charge inside the insulation. The direct way to look at the formation space-charge into insulation is resorting to technique able to display space charge concentration along with the insulation thickness. Among these techniques, the PEA method is considered here. One of the advantages of direct observation of space charge concentration if available of electric field profiles in insulation, which can give information on the phenomena breakdown caused by heavy water absorption.

Figure 8 shows the profile of space charge distribution in specimens under a DC voltage of 10 kV in different cases. The curve space charge density function of the vertical distance from the anode is obtained from the PEA method. The distance between two vertical solid lines is the depth of the sample referring to the distance of anode to cathode. The voltage was applied so that the semiconducting electrode was positive. Because of a space charge is formed more quickly in the case of positive polarity. Both cases, positive carriers are injected from a semiconductive electrode into the LDPE film. The amount of positive space charge increased with time. In the case of the dry condition, the positive space charge increased the first 30 seconds after the application of DC voltage, and then it tends to saturate as shown in Figure 8 (a). At the heavy water absorption case, the amount of the positive charge increased with time in the first 10 sec, and then it has a tendency to saturated. In accumulation, the amount of positive space charge has higher than dry conditions as shown in Figure 8 (b). In our opinion, by having heavy water absorption at the film LDPE the migration of positive space charge is much faster than in dry condition; besides, the amount of positive space charge in Heavy water absorption is much more significant than in dry condition.



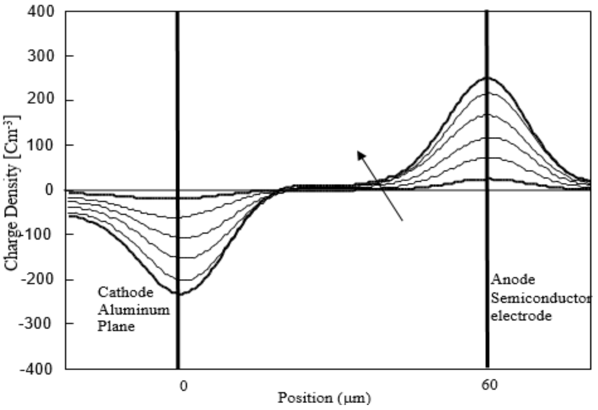
(a)

(b)

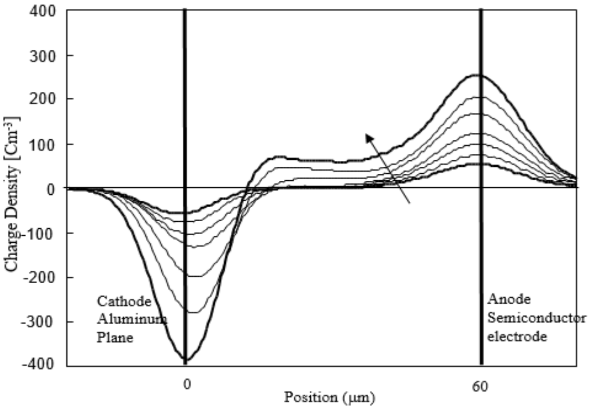
Figure 8. Space charge distribution at 10 kV, (a) dry condition (b) heavy water absorption

In the measurement space charge distribution up to breakdown, same as before, the voltage was applied so that the semiconducting electrode was positive polarity. In the dry sample shown in Figure 9 (a), with the increase of the applied voltage, shows that a positive space charge is formed inside the specimen as the applied voltage was increased, and only a small amount of charge entry to sample until the breakdown occurred (at the voltage about 32 kV). The initiation charge enters the insulation at 25 kV, and the amount of charge is small. On the other hand as shown in Figure 9 (b), in the heavy water absorption, increasing applied voltage illustrates that a positive charge is appearances inside the sample, which has a significant amount of positive charge, and the initiation of charge appears at 8 kV.

The result notified that the presence of water in the sample promotes the injection of charge from the electrode, probably by modifying the barrier at the interface of the electrode. On the other hand, the positive charge accumulation takes place in the heavy water absorption samples with a lot of water absorption. The presence of water in insulation promotes the charge injection from the electrode into the insulation. Based on the correlation between the space charge formation and the current through the insulation, it can be noted that the increase of charge injection into the insulation due to water absorption increases the conduction current and induce the easy occurrence of thermal breakdown.



(a)



(b)

Figure 9. Space charge distribution up just before breakdown; (a) dry condition, (b) heavy water absorption

4. CONCLUSION

The electrical breakdown phenomenon in the LDPE film's influence of Dry and heavy water absorption was discussed, and some results are described. Voltage breakdown on the ramp voltage decreased under heavy water absorption. This is caused by the significant increase of conduction current and results in a temperature rise at the point rising higher than in dry conditions. Based on the correlation between the space charge formation and the current through the insulation, it can be noted that the increase of charge injection into the insulation due to water absorption would increase the conduction current and induce the natural occurrence of thermal breakdown.

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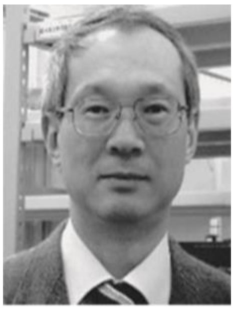

Naohiro Hozumi received his B.S. and M.S. degrees from Waseda University, Japan, in 1981 and 1983, respectively. From 1983 to 1999, he had joined the Central Research Institute of Electric Power Industry, Japan. He was an associate professor from 1999 to 2006 at the Toyohashi University of technology and a professor from 2006 to 2011 at the Aichi Institute of Technology, Japan, respectively. Since 2011, he has been a professor at the Toyohashi University of Technology. His research interests are insulating materials and diagnosis for high voltage equipment and measurement and signal processing for the medical device.

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