The behaviour of water droplets on the silicone rubber surface in an electric field

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Abstract. This paper describes the influence of a water droplet placed on flat samples of silicone rubber for enhancement the local electric field and generate electrical discharges. Studies have shown a significant influence of the droplet geometry on the electric strength of the samples. For non-symmetrical arrangement of the three droplets in the inter-electrode space electrohydrodynamic phenomena was observed: a stable change in the droplets shape placed near the electrodes and stretching and tearing down of the water droplets placed far from the electrodes. Captured photos and films of the water droplets behavior placed on the surface of the samples provided data to perform the simulation of the distribution of electric field and an estimate the value of the electric field, which was followed by the development of electric surface discharges.

1. Introduction

Assuring a proper contamination resistance of insulators used in conditions of increased humidity, industrial and environmental pollution is still an important problem not solved entirely. Using composite insulators equipped with housings made of HTV and LSR silicone rubbers in electricity power transmission and distribution lines and covering porcelain insulators already installed with a sheath made of RTV silicone rubber allows substantial decreasing risk of any contamination flashover and increasing reliability of power delivery to consumers.

However, it results from the literature data regarding composite insulators used in power lines that an important danger for these insulators is not an electric flashover, but aging degradation of their surface properties [1,2,3]. Resistance of composite insulators to dangers resulting from their exploitation is connected with their surface properties: strong hydrophobicity of outer housing surface, ability to self-regeneration of surface properties after their temporary loss due to unfavourable environmental conditions and ability to hydrophobization of polluted layer deposited on the insulator surfaces.

In unfavourable weather conditions, long-lasting rains and fogs cause a gradual decline of hydrophobic properties of insulators. Interactions of water molecules with a surface layer of the housing causes turning of methyl groups and approaching the surface by polar linkages of the Si-O chain [4, 5]. This process is reversible. However, temporary moisturizing insulator outer surfaces may initiate surface electric discharges which are a basic factor degrading polymer insulators. Partial electric discharges between wetting areas of the housing deliver energy necessary to reactions creating aging degradation of composite insulators: loss of hydrophobicity, increasing surface roughness and even erosion of the housing material and its unsealing. Exposing a glass - epoxy bearing rod of a

composite insulator to exploitation dangers creates danger of breaking the insulator. Problem of aging degradation of the housing material concerns particularly composite insulators of the highest voltage which are characterized by very uneven distribution of voltage along the insulator. In this case, local values of the electric field intensity enhanced by water drops may go much beyond intensity of initiating partial discharges.

The way water wetting housing surfaces behaves influences significantly increase of the local electric field by water drops [6, 7]. Electrohydrodynamic phenomena of deformation, coalescence, instability of a water drop shape and its moving along hydrophobic surfaces of samples in the electric field are a topic of numerous theoretical and experimental works [8, 9, 10].

2. Methodology of research

In this article results of research regarding the influence of how a drop behaves in the electric field on electric endurance of examined samples and distribution of the electric field on their surfaces are presented.

On the long-rod insulator, the direction of the electric field intensity vector is close to tangent at the insulator rod and normal at the shed surface. In the research, a model case of the electric field parallel to the insulating surface was made.

Tests were conducted in the spark gap presented on Figure 1 at constant high voltage of reversed polarity increased with constant speed of about 2 kV/s. The samples were plates made of HTV silicone rubber of 62x40x4 mm stuck centrally between brass electrodes of ⌀70 mm. An adjustable pipette was used to distribute water drops of defined volume of 80 µl and conductivity of 200 µS/cm on the sample surface.
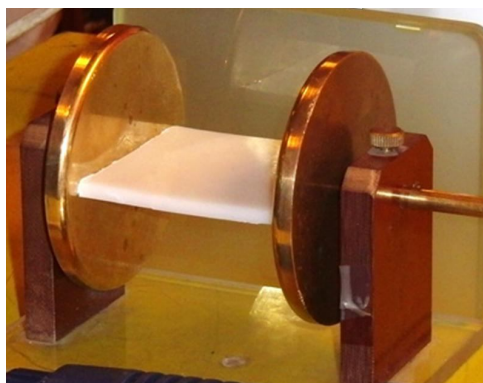

Figure 1. The measuring spark gap with a stuck sample made
of HTV silicone rubber.

Thermal energy and radiation in the area endangered by electric flashover cause temporary degradation of surface properties of silicone rubber. Time for regeneration of surface properties of the samples between succesive tests was 24 hours.

Because of dynamics of observed electrohydrodynamic phenomena, recording of changes in water drop shapes was done using a digital FH100 camera at filming speed of 240 frames per second. Chosen pictures were used to simulate the normalized electric field (for potential 1 V) on the sample surface in the COMSOL MULTIPHYSICS programme.

3. Results of the research

Analysis of behaviour of many water drops located on the solid dielectric surface is very complicated because of mutual corelations between observed electrohydrodynamic phenomena, the electric field distribution and incomplete electric discharges among drops. Taking the above into account, the research was made for chosen variants of distributing three water drops in the interelectrode area.

On Figure 2, chosen pictures of changes in water drop shapes are presented while they are distributed symmetrically in the central part of the interelectrode area. On Figures 2b,c,d,e, are stable changes in shapes of successive water drops situated farther and farther from the high voltage electrode can be seen.
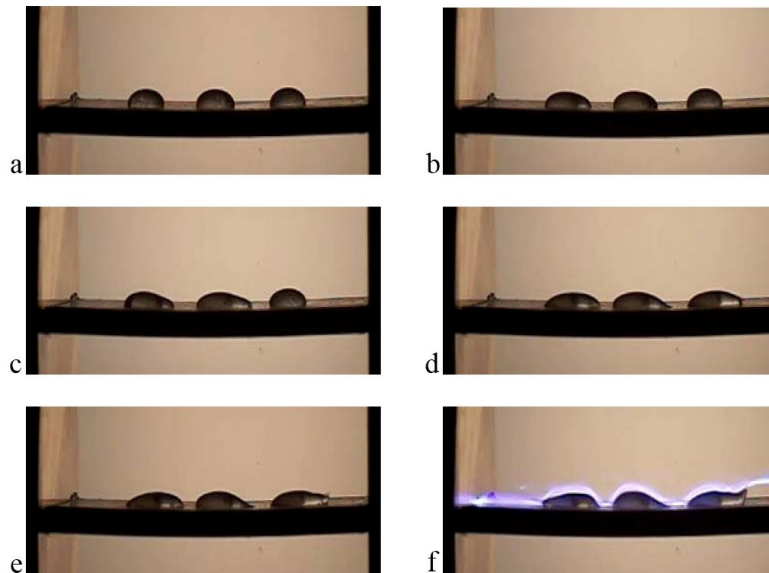

Figure 2. Behaviour of three water drops situated symmetrically in the central part of the interelectrode area: the flashover voltage is 35 kV.
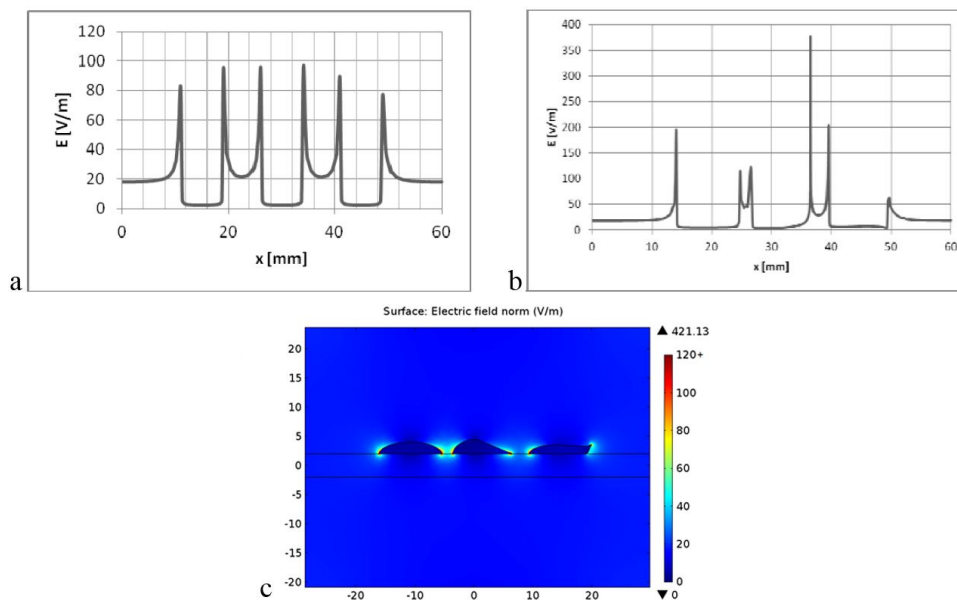

Figure 3. Distribution of the normalized electric field in the tests for water drops situated symmetrically in the central part of the interelectrode area: a) droplets not deformed, b, c) a moment before the flashover

Distribution simulations of the normalized field made for drops which are not deformed in a electric field (Fig. 3a) and a moment before the flashover (Fig. 3b) indicate more than threefold increase of the local electric field values caused by stretching and shape changes of the drops. At relatively small drop conductivity of 200µS/cm, the way of flashover goes through the drop surface (Fig. 2f) and joins the strong electric field areas as shown on Figure 3c.

For Figure 4a presenting configuration of water drop distribution during increase of the test voltage, initially strong stretching of the water drop situated in the middle of interelectrode area in the direction of the earthed electrode was captured (Fig. 3b). Such a drop deformation caused almost twofold increase of the electric field value at its rim (Fig. 5). While the test voltage was increasing further, the drop came back to the original shape (Fig. 4d) and oscillated in the electric field (Fig. 4f, g). The cause of vibrations could be the electric charge of the middle drop because of partial discharges to the drops at the electrodes.
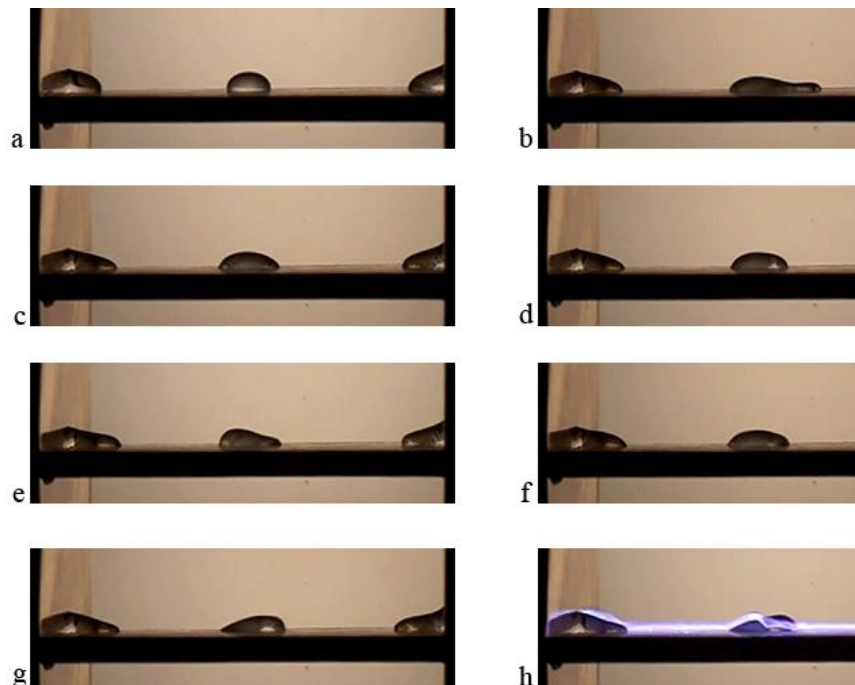

Figure 4. Behaviour of three water drops situated symmetrically in the central part of the interelectrode area: the flashover voltage is 36 kV.
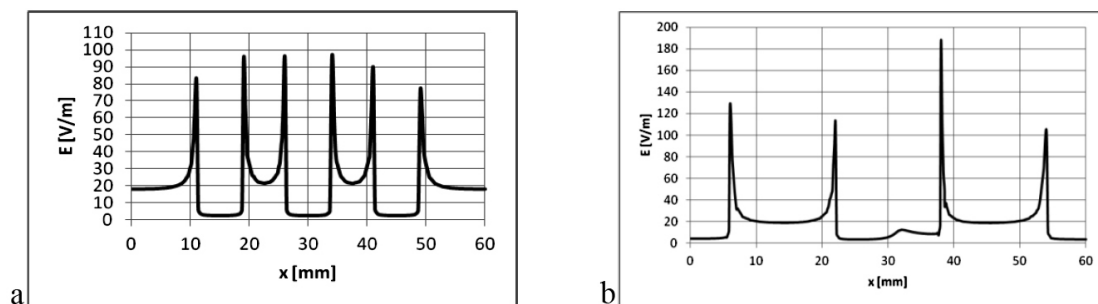

Figure 5. Distribution of the normalized electric field in tests for water drops situated symmetrically in the central part of the interelectrode area: a) which are not deformed, b) while the middle drop was stretched as presented on Fig. 4c.

In the research made for a system of three drops situated not symmetrically in the interelectrode area, the electric sample endurance was dependent on polarity of the electrode near which the drops were situated. Figure 6 presented electrostatic distribution of the normalized electric field for water drops not deformed in the electric field dependent on geometrical configuration.
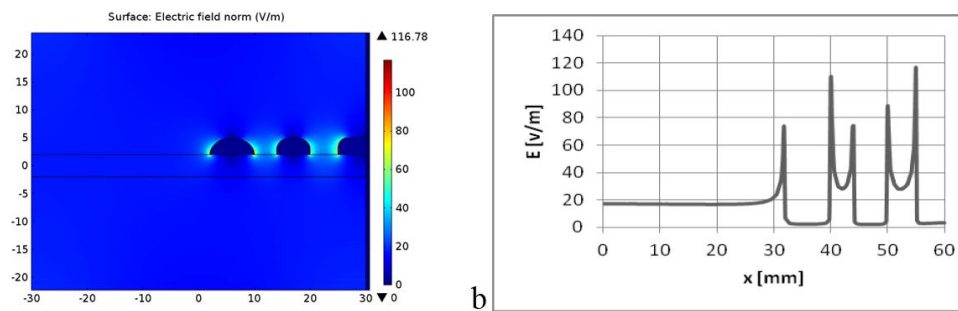

Figure 6. Distribution of the normalized electric field in tests for water drops situated in the half of the interelectrode area; the drops are not deformed in the electric field.

The flashover voltage value measured at the constant voltage for drop distribution near the high voltage electrode was 26 kV. Figure 7 presents chosen recordings of drop behaviours while increasing test voltage values and the electric flashover between the electrodes at the voltage of 26 kV (Fig. 7f).

Stretching of drops was observed before the flashover. The drop moved most to the interelectrode area was deformed most. Its sudden stretching in the direction of the earthed electrode was recorded before the flashover.
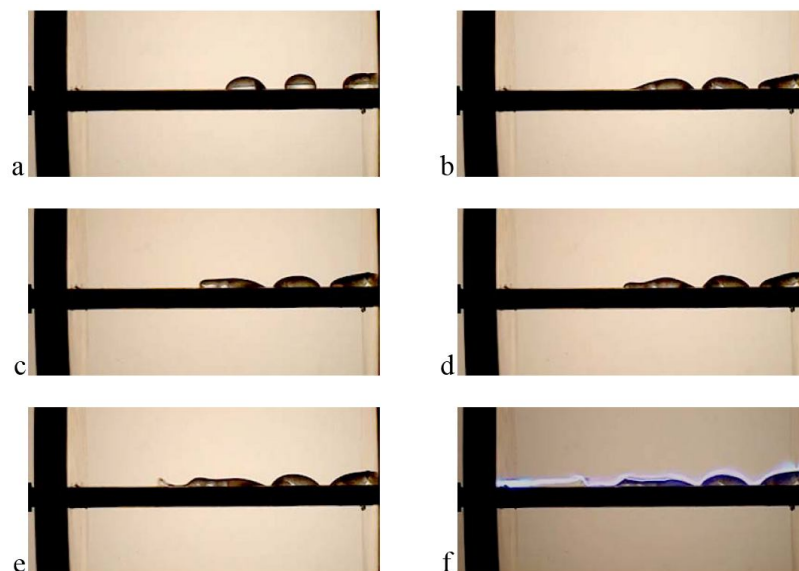

Figure 7. Behaviour of three water drops situated near the high voltage electrode: the flashover voltage is 26 kV.

Figure 8 presents electrohydrodynamic phenomena recorder for drops situated near the earthed electrode. The electric flashover happened at the voltage of 22 kV. Stable stretching of the water drops was observed before the flashover.

Charts presenting distribution of the normalized electric field for samples with water drops situated in the half of the interelectrode area are shown on Figure 9. Maximum increase of the local electric field value caused by drop deformation before the flashover did not depend on the electrode polarity at which water drops were situated and was similar to values shown on Figure 6b for drops which were not deformed.
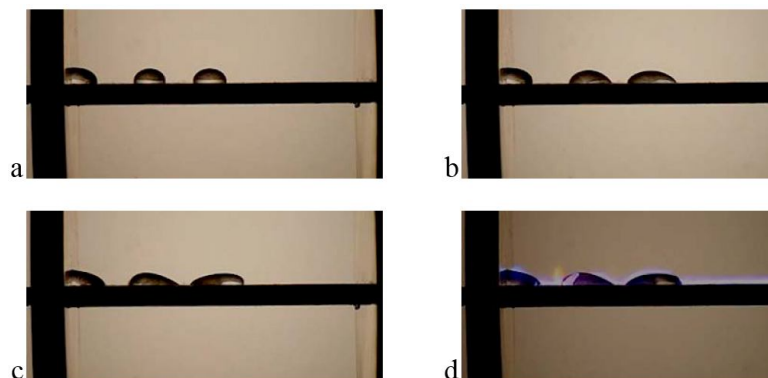

Figure 8. Behaviour of water drops situated near the earthed electrode: the flashover voltage is 22 kV
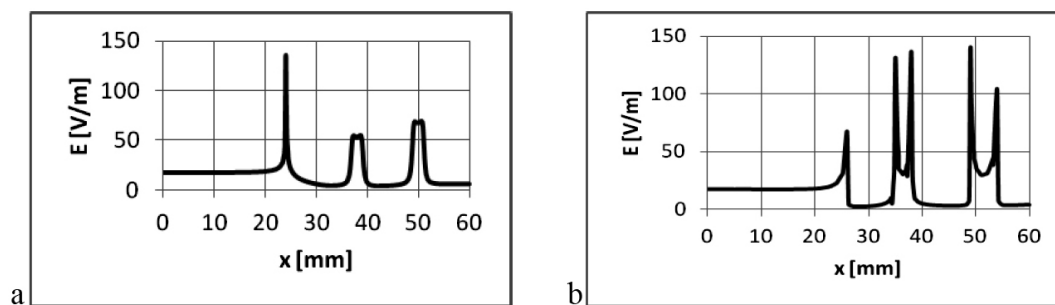

Figure 9. Distribution of the normalized electric field before the flashover for samples with water drops situated in the half of the interelectrode area: a) at the high voltage electrode, b) at the earthed electrode

Electric endurance of samples with water drops situated near the high voltage electrode was approximately 15% lower than samples with water drops situated near the earthed electrode.

4. Summary

At symmetrical distribution of water drops on the sample surfaces, deformations of water drops shapes have a strong influence on distribution of the electric field on sample surfaces. Maximum values of the local electric field at water rims before the flashover are two- or threefold higher than for drops which are not deformed. There is no important influence observed of contact of drops with the electrodes on increasing the electric field and the flashover voltage on the samples.

Concentration of water drops near one of electrodes influenced decrease of the sample electric endurance by about 30% in comparison with samples moisturized symmetrically.

At asymmetrical distribution of water drops on the sample surfaces, observed electrohydrodynamic phenomena cause a small increase of the maximum electric field intensity value by about 20%. Polarity of the electrode at which drops were situated has influence on the flashover voltage on the

samples. In the research made, electric endurance of samples with water drops situated near the high voltage electrode (DC-) was approximately 15% lower than the samples with water drops situated near the earthed electrode.

The research proved that geometrical configuration of water drop distribution on the hydrophobic sample surfaces in the constant electric field has a substantial influence on electrohydrodynamic phenomena, distribution of the electric field and electric endurance of the samples.

5. References

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