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Influence of the Electrodes Coating with Thin Layers on the Dielectric Strength of Transformer Oils

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***Abstract*- This work is aimed at the influence of electrodes coating with thin layers of polytetrafluoroethylene (Teflon) on the dielectric strength of transformer oils. It's shown that such a deposit on the electrodes enables one to improve significantly the dielectric strength, under ac voltage, of fresh mineral oil as well as oils containing products of decomposition resulting from electrical discharges. The influence of coating is all important as the radius of the sphere electrode is small. On the other hand, in presence of particles (impurities), the electrode coating enables to reduce the local electric field in the vicinity of particle an thence to avoid micro-discharges which can be initiated between the metallic electrodes and these particles.**

I. Introduction

It is well known that the insertion of an insulating barrier in an electrode gap, in the vicinity of the sharpest electrode (i.e., the electrode of the smallest radius of curvature), or the coating of electrodes with a solid dielectric enable one to improve the dielectric strength of insulating oil gaps [1- 3]. The barriers are all the more efficient as the electric field is divergent and the electrode gap is small while the coating of electrodes is all the more efficient as the electric field is uniform. The some results reported in the literature concerning the influence of coating of electrodes were obtained with layers of insulating paints [2] or paper [3].

In previous works [4, 5], we showed that the modification of the surface properties of electrodes, by coating them with thin layers of different materials, can have a deciding effect on the electro-hydrodynamic phenomena and more particularly on the electro-convection; the static electrification phenomenon is also affected. Contrary to thick layers, the thin layers of low breakdown voltage don't have a direct influence on the dielectric strength of oil. However, they can act on the pre-breakdown phenomena and thence on the breakdown of oil. The modification of the electrode/oil interface results in the modification of the double layer of charges [4] which has a key role in the pre-breakdown processes in liquids.

On the other hand, the presence of particles in transformer oils is inevitable and the consequences of such a presence can be dramatic for the dielectric strength of oils. This is due to the micro-discharges which can be initiated close to particles and between the particles and the metallic electrodes resulting of the enhancement of the local electric field in the vicinity of the particles. Thus, it is interesting to know how the coating of electrodes acts on the prebreakdown mechanisms and thence on breakdown of oils.

The present work is devoted to the influence of thin layers of polytetrafluoroethylene (Teflon) of high purity on the dielectric strength of transformer oils. We also analysed the influence of the coating on the local electric field in the vicinity of particles present in oil using the finite element method and Flux2d package [6].

II. Experimental Technique

The experimental set-up consists of a high voltage transformer (220V/110kV, 40 kVA), a capacitive voltage divider and a digital voltmeter, and a transparent test cell containing a sphere – plane electrode arrangement. The test cell is made of metyl-polymetacrylane (170x110x80mm) and both electrodes are made of aluminium of technical purity. The diameter of spheres we used are 5, 10, 15 and 20 mm. The electrode plane is circular and has a diameter of 30 mm; the electrode gap is taken equal to 2 mm. The electrodes are coated with thin layers of polytetrafluoroethylene (Teflon) obtained by magnetron sputtering with a vacuum of 10^{-2} Tr. The magnetron is a WMK-100 type with a maximum power at the target of 7 kW. The thickness of these thin layers varies between 0.5 and 1.0 μm. The tests are carried out on mineral oil the basic characteristics of which are given in Table I. The measurements are achieved on an asymmetric system of voltage (the voltage is applied to the electrode sphere while the electrode plane is grounded). The voltage is progressively increased with a rate of 1 kV/s, from zero up to breakdown.

Preliminary tests show that, thanks to a limitation and an interruption of the breakdown current, one can avoid a significant destruction of oil, electrodes and coating layers. We also observed that on a series of six measurements, the value of breakdown voltage remains approximately constant. For that purpose, the pair of electrodes is changed after each series of 6 consecutive tests. The measurements are achieved alternatively with uncoated and coated electrodes. The time between each test is of 6 minutes for a given series and 15 minutes between the series. The oil is changed each 160 breakdowns; the choice of such a high number of breakdowns has also for objective to analyse the influence of the electrodes coating on the dielectric strength of very contaminated oils by the products of decomposition.

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TABLE I
PROPERTIES OF TESTED OIL

Breakdown voltage	kV	69
Resistivity	Ωm	2.9 10^{10}
Dielectric constant (20°C)		2.2
Dissipation factor (50°C, 50Hz)		0.005
Density (20°C)	g/cm^3	0.885
Flash point	°C	156
Acidity index	mg KOH/g	0.13
water content (25°C)	ppm	17
Surface tension	mN/m	44

III. Experimental Results

The coating of electrodes with thin layers of Teflon enables one to improve the dielectric strength of fresh mineral oil or containing products of decomposition resulting from electrical discharges, under ac voltage (50Hz). Fig. 1-4 give the variations of the breakdown voltage of oil obtained on different successive series of measurements with uncoated and coated electrodes. The influence of coating is all important as the radius of the sphere electrode is small. This is due to the fact that in fresh oil (without impurities), the thin layer deposits of Teflon reduces the injection of charge carriers into the liquid and thence increases the threshold voltages required to initiate pre-breakdown phenomena. This reduction of injected current results in an increase of the electro-convection threshold voltage as shown in a previous work [5]. The coating of electrodes significantly influences the liquid instability limiting the motion and turbulence of flowing.

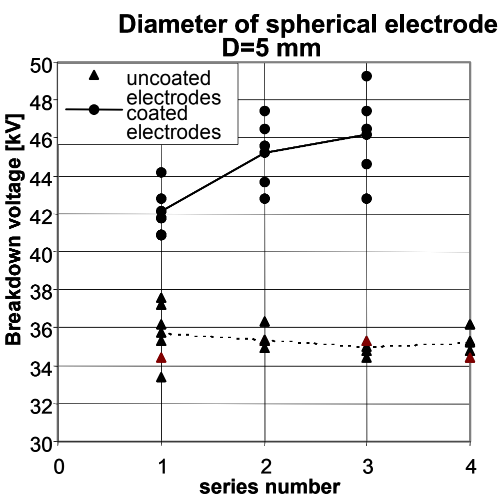

Fig. 1. Breakdown voltage of oil with electrodes uncoated and coated with Teflon. Electrodes gap=2mm; diameter of the sphere electrode =5mm.

At high voltages, the liquid motion is slower, and the laminar character of streaming persists within a wide interval of voltages than in the case of uncoated electrodes [5]. The reduction of the injected current also results in an increase of the threshold voltage of streamer initiation. Indeed, the development of streamers in liquid dielectrics is generally preceded by the generation of a gaseous bubble resulting of local heating of the liquid induced by a current pulse injection [7]. And since the initiation voltage of bubble and then the streamer is increased, the breakdown voltage will be also increased.

The reduction of the current injection can be explained by the fact the work of electronic extraction of Teflon is higher than that of aluminum (i.e., the metal constituting the electrodes). On the other hand, since the dielectric constant of both Teflon and mineral oil are very close, the capacitive effects are negligible.

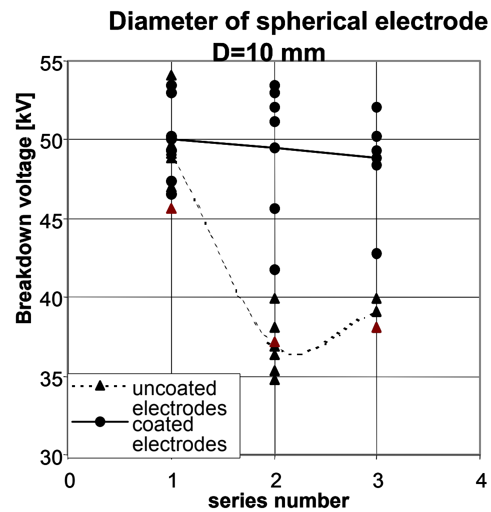

Fig. 2. Breakdown voltage of oil with electrodes uncoated and coated with Teflon. Electrodes gap=2mm; diameter of the sphere electrode =10 mm

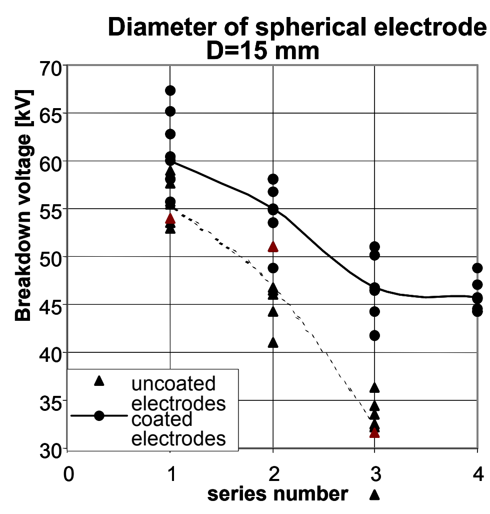

Fig. 3. Breakdown voltage of oil with electrodes uncoated and coated with Teflon. Electrodes gap=2mm; diameter of the sphere electrode =15 mm

The values of breakdown voltage of oil on a series of 6 tests executed with the same pair of electrodes, don't show a large discrepancy between the measurements; the standard deviation doesn't exceed 10%. Therefore, a local deterioration of coating layer doesn't reduce its efficiency.

The fact that the breakdown voltages measured with some coated electrodes, are much lower than the average values, can be attributed to defects in the deposited layers (inhomogeneous and/or discontinuous layer). Fig. 5 gives an example of characteristics of breakdown voltage after changing oil. We observe that after a series of 6 tests, the breakdown voltage increases significantly by about 50% for the next three series.

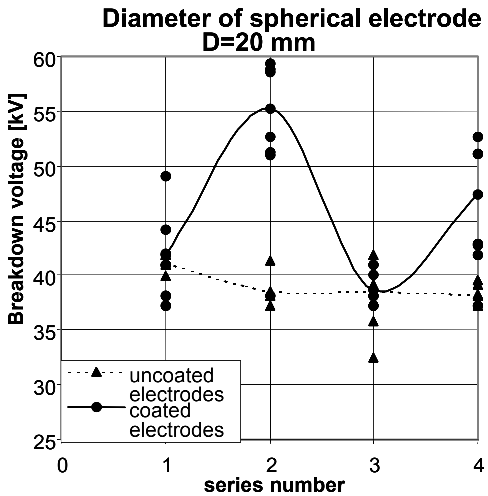

Fig. 4. Breakdown voltage of oil with electrodes uncoated and coated with Teflon. Electrodes gap=2mm; diameter of the sphere electrode =20 mm

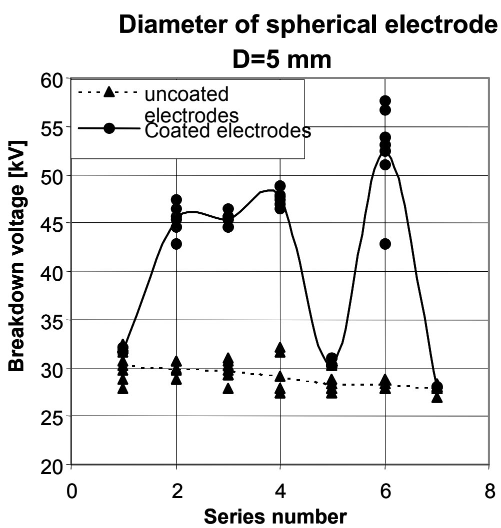

Fig. 5. Breakdown voltage of oil with electrodes uncoated and coated with Teflon. Electrodes gap=2mm; diameter of the sphere electrode =5 mm

In oil containing products of decomposition resulting of dissociation of oil, the thin layer deposits enable one to avoid the concentration of these pollutants in the vicinity of the sharpest electrode (i.e., the sphere of the smallest radius) where the electric field is the highest.

The electrode coating also affects other fundamental mechanisms such as the conductivity, the static electrification, the mobility of impurities in suspension and the discharge initiation. In the next section, we analyze the behavior of impurities and especially the distribution of electric field with coated and uncoated electrodes.

IV. Electric Field In Presence Of Particles

The presence of particles (conducting and/or dielectric) in transformer oils is inevitable. One of the consequences of this presence is the enhancement of the local electric field in the vicinity of the particles resulting in the initiation of micro-discharges often leading to breakdown [8]. In order to appreciate the role of coating on the local electric field in the vicinity of particles, we consider two kinds of impurities – metallic and dielectric – of spherical shape immersed in a transformer oil between two plane electrodes alternatively uncoated and coated with thin layers of Teflon. Note that in practice, particles of different shapes can be present in transformer oils. However, the sphere is the most common shape [9].

Consider uncharged spherical particles of 1 μm radius situated at 0.1 to 4 μm from a plane electrode. The dielectric constants are ε_p=8, ε_T=2,5 and ε_h=2,2 for the dielectric particle, Teflon and transformer oil respectively; the electrode gap d is taken as equal to 100 μm. The thickness of the coating layers (Teflon) are 1, 2 and 3 μm. By using the finite element method and Flux2D package [6] we get the results given in Fig. 6-9.

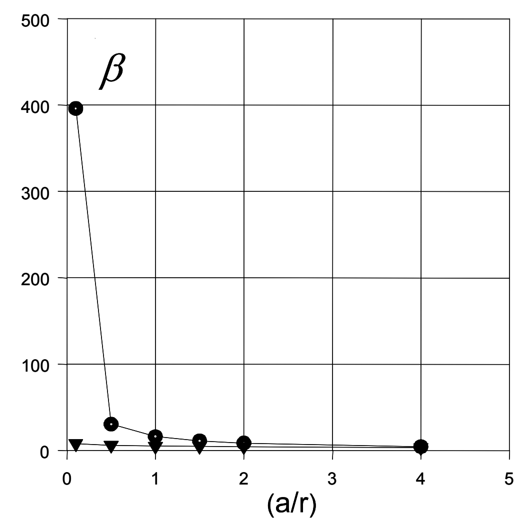

Fig. 6. Coefficient of electrical field enhancement β versus the approach coefficient of a spherical dielectric particle (a/r) towards a plane electrode: (●) uncoated and (▼) coated with a thin layer of Teflon of 3μm.

We observe that the electrode coating reduces significantly the electric field enhancement coefficient β (β is the ratio of the local electric field at the particle to the average electric field E_a=U/d, U being the applied voltage and d the electrode gap). For a particle very close to the electrode, β is reduced by a factor 400 for dielectric particle and 500 for a metallic one. And β also decreases when the thickness of Teflon layer increases. This example shows the positive role of the electrode coating in the improvement of the dielectric strength of oils.

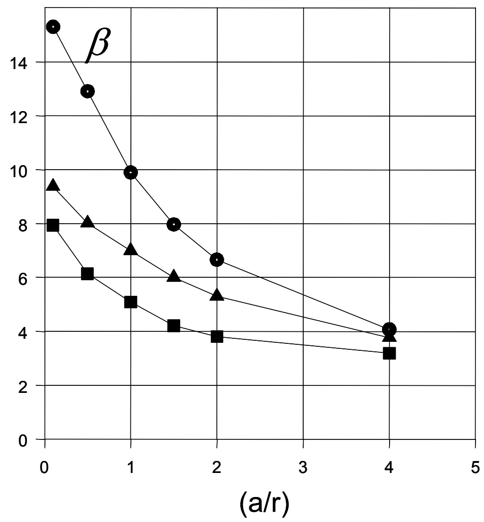

Fig. 7. Coefficient of electrical field enhancement β versus the approach coefficient of a spherical dielectric particle (a/r) towards a coated plane electrode with different thickness of Teflon layer: (●) 1 μm; (▲) 2 μm and (■) 3μm.

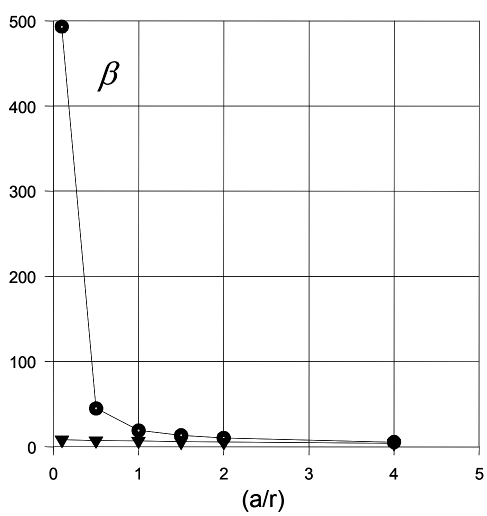

Fig. 8. Coefficient of electrical field enhancement β versus the approach coefficient of a spherical metallic particle (a/r) towards a plane electrode: (●) uncoated and (▼) coated with a thin layer of Teflon of 3μm.

V. CONCLUSION

This work shows that by coating electrodes with thin layers of Teflon one can improve the dielectric strength, under ac voltage (50Hz), of fresh mineral oil or containing products of decomposition resulting from electrical discharges. This effect is all the more marked as the radius of the sphere electrode is small. On the other hand, in presence of particles, the electrode coating enormously reduces the enhancement of the local electric field in the vicinity of particle enabling to avoid the initiation of micro-discharges and then to improve the dielectric strength of oil.

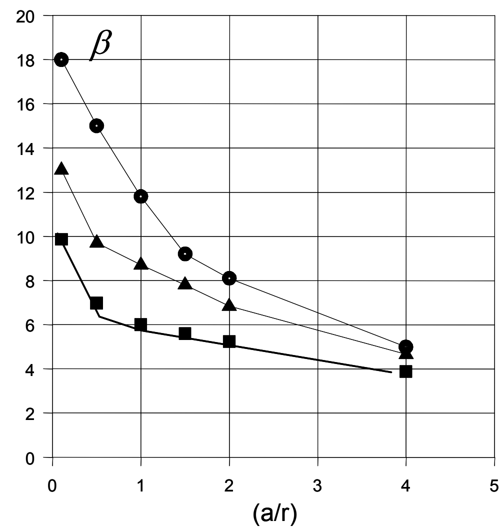

Fig. 9. Coefficient of electrical field enhancement β versus the approach coefficient of a spherical metallic particle (a/r) towards a coated plane electrode with different thickness of Teflon layer: (●) 1 μm; (▲) 2 μm and (■) 3μm.

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