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Influence of electrodes coating on the initiation and development of electroconvection in transformer oils

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Abstract: This work reports on the influence of electrodes coating with thin layers of different materials, on the initiation and development of the electroconvection. The investigations are achieved with a sphere-plane electrode system of aluminum. The considered oil samples are fresh and aged ones. The thin layers are deposits of polytetrafluoroethylene, Silicon oxide and Silicon nitride, obtained by magnetron sputtering. It shown that the nature of coating materials as well as the geometry and polarity of the electrodes greatly influence the threshold electroconvection voltage (i.e., the voltage required to set the liquid in motion). The effect is more marked when both electrodes are coated; the influence of polarity is more significant with fresh oils than with aged ones. 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.

Introduction

The electroconvection phenomenon is known as one of the most important pre-breakdown phenomena having an influence on the dielectric strength of insulating oils. One of the characteristic parameters of this phenomenon is the so-called "electroconvection threshold voltage", the voltage value required to set the liquid in motion. This threshold voltage depends on the chemical composition and purity of oil as well as on the degree of non-uniformity of the electric field (i.e., the electrode geometry). The strong relation existing between the electroconvection and the ionic injection makes the putting in motion of the liquid enormously dependent on the characteristics of the electrodes surface which in their turn depend on the structure and parameters of the double layer. The modification of properties of the electrode surface by coating the electrodes with thin layers of different materials, can fundamentally influence the value of electroconvection threshold voltage as well as the type of liquid motion (laminar and turbulent) under high electric field [1-3].

This paper deals with the influence of electrodes coating with thin layers of insulating and semi-conducting materials, on the initiation and development of electroconvection threshold voltage in fresh and aged oils.

Experimental Set-up

The experimental setup consists of a high voltage dc supply, a transparent test cell of metyl-polymetacrylane (10x10x20 cm) containing a sphere-plane electrode arrangement and the considered liquid, and an optical system enabling the detection of the liquid motion. Both electrodes are of aluminum. The radius of sphere varies between 5 and *20* mm. The electrode plane is circular and has a diameter of *30* mm; the electrode gap is taken equal to *8 mm*. The coating materials of electrodes are: polytetrafluoroethylene (Teflon-$(CF_2)_n$), Silicon oxide (SiO) and Silicon nitride (Si_3N_4), obtained by magnetron sputtering. The thin layers of deposits we considered are *0.5* µm thickness for Teflon and Silicon oxide, and *0.6* µm thickness for Silicon nitride. The considered oil samples are fresh and aged (taken from transformers in service) ones the basic characteristics of which are given on table 1. The electroconvection threshold voltage is determined using Schlieren method. The measurements are achieved under dc voltage or an increasing voltage of a given rate.

To analyse the influence of the voltage on the electroconvection phenomena, we introduce an inhomogeneity within the electrode gap by changing locally the temperature gradient. For that, we connect one of the electrodes to a radiator. The variation of temperature of oil disturbes locally the homogeneity of the system and leads to a deviation of the beam of light illuminating the electrode gap. A dark spot appears on the screen of a monitor enabling to record the events occuring within the electrode gap. When the voltage applied to the electrodes reaches a threshold value, the liquid sets in motion. This facilitates the observations thanks to the displacement of the dark spot induced by the oil heating.

Experimental Results

The threshold electroconvection voltage depends upon the coating material and the electrodes which are coated. It significantly increases when both electrodes are coated, whatever the material of coating, the polarity and radius of the electrode sphere (Figures 1 and 2). The liquid motion is initiated at voltages lower when the electrode sphere is positive than when it is negative, whatever the considered oil. Similar results are obtained with aged oil whose properties are less good than those of fresh oil. However, the influence of polarity is more significant with fresh oils than with aged ones.

Table 1: Basic properties of oil samples

Properties	Fresh oil	Aged oil
Breakdown voltage (kV)	69	62
Volume resistivity at 50°C (Ωcm)	2.9×10^{10}	2.7×10^{9}
Dissipation factor at 50°C , 50Hz	0.005	0.08
Acidity (mg KOH/g)	0.04	0.04
Inflammability point (°C)	156	150
Water content (ppm)	17	24
Interfacial tension (mN/m)	44	29

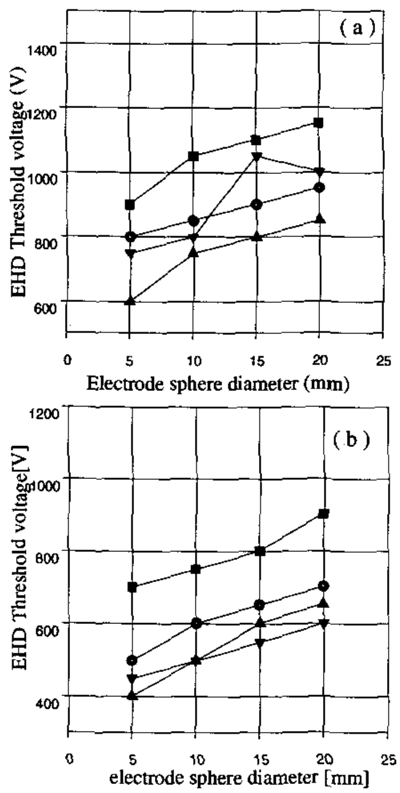

Figure 1: Electro-convection threshold voltage in fresh oil versus the electrode sphere diameter, for different configurations of electrodes coating with Teflon for a negative sphere (a) and a positive sphere (b): (●) uncoated electrodes, (▲) sphere coated with Teflon, (■) both electrodes coated with Teflon, and (▼) electrode plane coated with Teflon.

Influence of the nature of the coating material: Figures 3 and 4 show the influence of the type of thin layer material on the electroconvection threshold voltage in fresh and aged oils, versus the electrode sphere diameter with a sphere of positive polarity.

We observe that with fresh oil and when both electrodes are coated, the Silicon oxide layer is the most efficient as concerns the electroconvection threshold voltage; when only the sphere is coated, the Silicon nitride layer is the most efficient. For aged oil, Teflon layer is the most efficient when both electrodes are coated and that is Silicon nitride layer which is the most efficient if only the electrode sphere is coated.

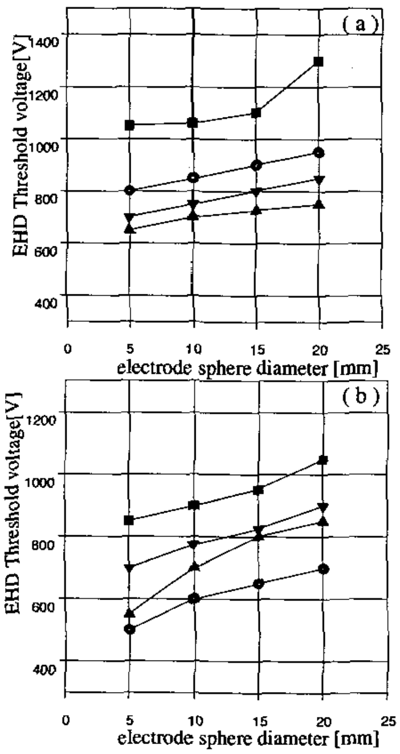

Figure 2: Electro-convection threshold voltage in fresh oil versus the electrode sphere diameter, for different configurations of electrodes coating with Silicon oxide for a negative sphere (a) and a positive sphere (b): (●) uncoated electrodes, (▲) sphere coated with Silicon oxide, (■) both electrodes coated with Silicon oxide, and (▼) electrode plane coated with Silicon oxide.

Influence of the polarity of the voltage: Figure 5 gives the influence of polarity of the electrode sphere on the electroconvection threshold voltage. These diagrams represent arithmetic averages of the experimental results obtained for all the diameters of spheres we used (5, 10, 15 and 20 mm). We observe that the weakest values of the electroconvection threshold voltage are obtained with a positive sphere. And as indicated above, the influence of polarity is more significant with fresh oils than with aged ones.

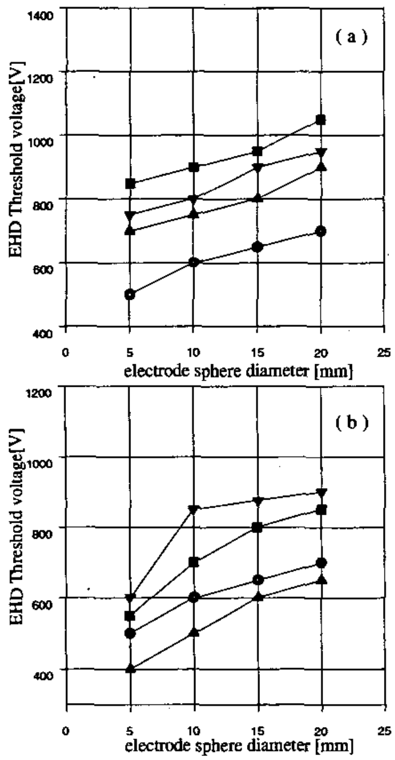

Figure 3: Electro-convection threshold voltage in fresh oil versus the electrode sphere diameter, for different coating materials when both electrodes are coated (a) and when only the sphere is coated (b): (●) uncoated electrodes, (▲) coating with Teflon, (■) coating with Silicon oxyde, and (▼) coating with Silicon nitride; the electrode sphere being positive.

Development of electroconvection: To appreciate the influence of thin layers on the development of electroconvection, we measured the transient time t_r necessary for a trickel of oil to pass from one electrode to the other, for different voltages; t_r enables to calculate the electrohydrodynamic mobility. Thus, our tests consist in increasing the voltage at the electrodes and to observe the evolution of the liquid motion and its character, for different coating materials. We remark that for high voltages, the thin layers we used influence not only the electroconvection threshold voltage, but also the development and the type of motion of the liquid. For coated electrodes, the liquid motion is slower, and the laminar character of flowing persists in a wide interval of voltages than in the case of uncoated electrodes (Figure 6). Figure 6a presents the case when the liquid motion is blocked by the presence of a thin layer deposited on the electrodes. The liquid motion starts at U=900 V (Figure 6b) and it is very well developed for U=1500 V (Figure 6c). For uncoated electrodes, the electroconvection starts at U~700 V.

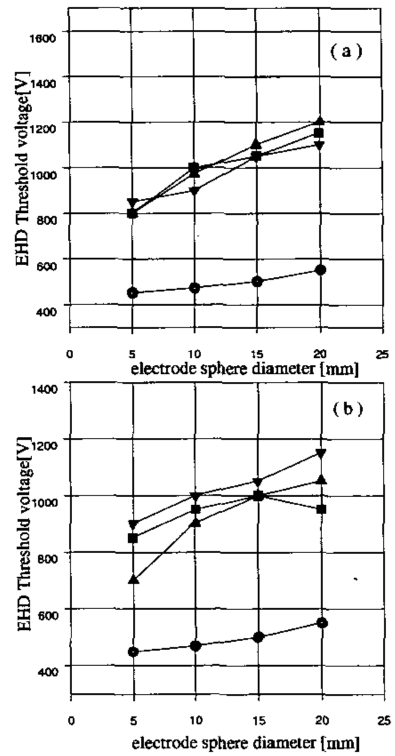

Figure 4: Electro-convection threshold voltage in aged oil versus the electrode sphere diameter, for different coating materials when both electrodes are coated (a) and when only the sphere is coated (b): (●) uncoated electrodes, (▲) coating with Teflon, (■) coating with Silicon oxide, and (▼) coating with Silicon nitride; the electrode sphere being positive.

Conclusion

It appears from the experimental observations and measurements that the electroconvection threshold voltage is increased when the electrodes are coated with thin layers. The effectivness of these thin layers (i.e., the increase of the electroconvection threshold voltage) depends on the type of coating material as well as the electrodes configuration, the polarity of the voltage and the properties of oils. The effect is more marked when both electrodes are coated. The liquid motion is initiated at voltages lower with a positive sphere than with a negative one, whatever the considered oil.

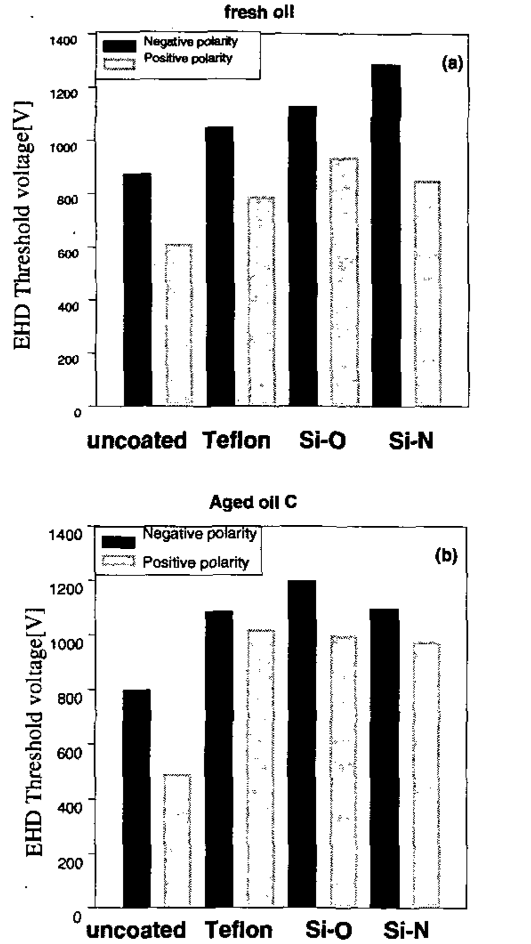

Figure 5: Electro-convection threshold voltage for electrodes uncoated and coated with Teflon, Silicon oxide and Silicon nitride, for both *polarities of the electrode sphere: (a) fresh oil, (b) aged oil.*

On the other hand, the influence of polarity is more significant with fresh oils than with aged ones.At high voltages, the coating of electrodes significantly influences the liquid instability limiting the motion and turbulence of flowings. With coated electrodes, 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.

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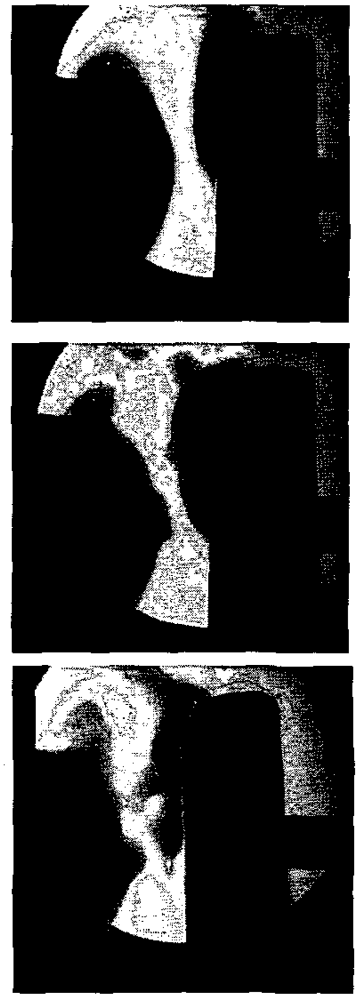

Figure 6: Development of the electroconvection phenomena in fresh mineral oil, in a sphere - plane electrodes coated with Teflon, 2 s after applying the voltage: (a) 700 V, (b) 900 V, (c) 1500 V. The electrode sphere being positive.

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