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Influence of Thin Layer Deposits and Temperature on Static Electrification Phenomena of Transformer Oils

A. Beroual and J. Fleszynski

Abstract— The static electrification phenomenon is studied versus the temperature and the properties of the solid/liquid interface. The investigations are achieved on a test cell with a rotating metallic disk coated on both sides with thin layers issued from three kinds of materials (aluminium, silicon and polytetrafluoroethylene (Teflon)). It is shown that the current characterising the static electrification increases with temperature and rotating velocity. The currents measured with aged oil are higher than that with fresh oil. For a disk coated with pure aluminium, all measured currents are negative with fresh oil and positive with aged oil. For a disk coated with silicon or polytetrafluoroethylene, changes of the currents polarity have been observed.

I. INTRODUCTION

IN order to prevent the defects of large forced-oil-cooled power transformers, intense investigations have been undertaken to understand the processes involving in the static electrification mechanism of materials used in power transformers [1]-[3]. It appears from the reported results that these processes depend upon the properties of oil/solid insulating material interface which constitutes the electric charge double layer seat. The characteristics of this latter depend in their turn on the physicochemical properties of oil (ageing, moisture,...) and the surface state (roughness, porosity,...) of the solid material as well as the external parameters such as the streaming velocity of oil, the temperature and the applied voltage [3], [4]. Therefore, the modification of the surface properties of electrodes can have a deciding effect on the static electrification phenomenon. In presence of an electric field, other important phenomena (charge injection, electroconvection, electrification and mobility of impurities in suspension and discharge initiation) can also be influenced [5] - [8].

This paper is aimed at the study of the evolution of the static electrification phenomenon of oils when the interface properties are modified by thin layers deposited on the solid material and/or the temperature and/or the oil streaming velocity are varied.

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II. EXPERIMENTAL ARRANGEMENT

The experiments are achieved on a typical test cell known as "CIGRE test cell", similar to that we used in a previous work [4]. For the continuity, we remind here the main features. The test cell consists of a rotating disk of 150 mm diameter and 5 mm thickness, covered with thin layers on its both sides or not, immersed in a metallic tank of 170 mm diameter and 80 mm height (Figure 1). The disk is placed at the centre of the tank where it can be rotated thanks to a little electrical motor ; the rotating velocity of the disk is varied between 100 to 600 rpm. The tank as well as the rotating disk are made of aluminium. A heating system allowing to vary the temperature between 20°C and 80°C is used.

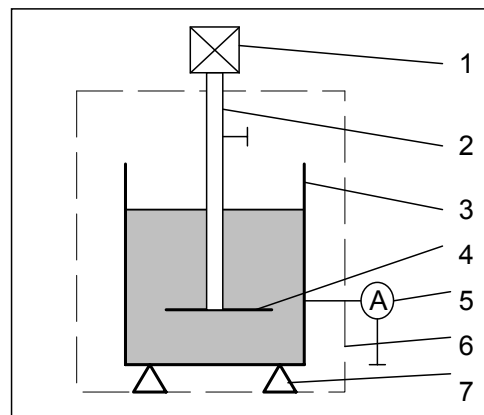


Figure 1: Rotating disk test cell: 1 - variable speed motor, 2 - rotation axis, 3 - measuring vessel, 4 - rotating disk, 5 - electrometer, 6 - electrostatic screen, 7 - Teflon insulators.

Three kinds of materials are used to coat the rotating disk with thin layers : a pure aluminium Al (5N) layer of 2 μm thickness, a silicon Si ("n" type) layer of 2 μm thickness and a polytetrafluoroethylene (Teflon) layer of 0.5 μm thickness. These deposits are 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 tested oil samples are fresh or aged ones taken from a transformer in service. The basic characteristics of these samples are given on table 1.

The static electrification current is measured thanks to an electrometer (Keitley 485) inserted between the tank and the

earth. The test cell and the electrometer are placed in a Faraday cage.

Table 1. Basic characteristics of oil samples.

| Oil characteristics | fresh oil | Aged oil |
|--|----------------------|-----------------|
| Breakdown voltage (kV) | 69 | 36 |
| Volume resistivity at 50° C (Ωm) | $2,9 \times 10^{10}$ | 1×10^9 |
| Dissipation factor at 50° C, 50 Hz | 0,005 | 0,05 |
| Density (g/cm^3) | 0,885 | 0,885 |
| Acidity index (mg KOH/g) | 0,04 | 0,2 |
| Flash point ($^{\circ}\text{C}$) | 156 | 145 |
| Water content (ppm) | 17 | 45 |
| Interfacial tension (mN/m) | 44 | 19 |

III. RESULTS AND DISCUSSION

In fresh oil at ambient (20°C) or 80°C , the amplitude of the electrification current increases with the rotating velocity of the disk whatever the type of deposit (Figures 2 and 3). This increase is moderate with an uncoated disk or coated with silicon. However, the current measured with uncoated disk or coated with Teflon or silicon are positive whereas it's negative with a pure aluminium layer. The current is the highest with Teflon deposits. This is due to the fact that Teflon is an insulating material and the double layer at oil/Teflon interface accumulate more charges. At 80°C , the deposit of silicon doesn't influence the current ; the currents are very close to that measured with the uncoated disk.

With aged oil at 20°C , the current increases with the rotating velocity in the cases of Teflon and aluminium deposits (Figure 4). For a deposit of silicon, we observe that the current decreases and changes its polarity to become negative over 340 rpm. At 80°C , the currents in aged oil are higher than that measured at 20°C . For deposits of Teflon and silicon, one observes a weak decrease of the current when the rotating velocity increases (Figure 5). With a deposit of aluminium, the current is positive and it increases with the rotating velocity of the disk.

We also observe that for given temperature and rotating velocity of the disk, the current are higher with aged oil than with fresh oil. This is likely due to the fact that the conductivity and thence the dissipation factor are higher for aged oil than with the fresh one. This confirms the results we reported elsewhere [3]. On the other hand, a high acidity index of oil, as it's the case of aged oil, contributes to the increase of the current ; this parameter is in relation with the dissipation factor.

For a given rotating velocity of an uncoated disk, the current increases with temperature for both fresh and aged oil samples (Figures 6 and 7). However, this increase is more important in the case of aged oil.

When increasing the temperature, we observe that with a disk coated with pure aluminium, all measured currents are negative with the fresh oil (Figure 8) whereas they are all positive with the aged oil (Figure 9). In both fresh and aged oils, the amplitude of the current increases with temperature. And in fresh oil, the amplitude of the current increases significantly with the rotating velocity over 60°C .

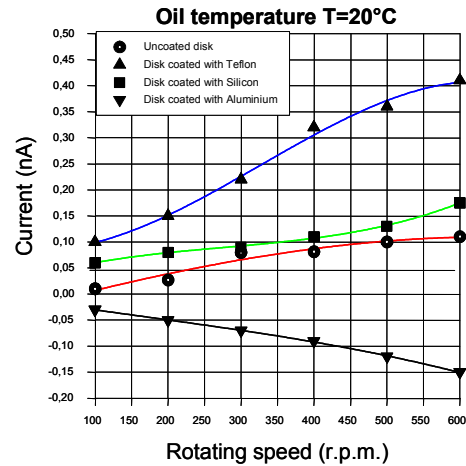


Figure 2: Influence of the type of deposit and the rotating velocity of the disk on the current in fresh oil at 20°C .

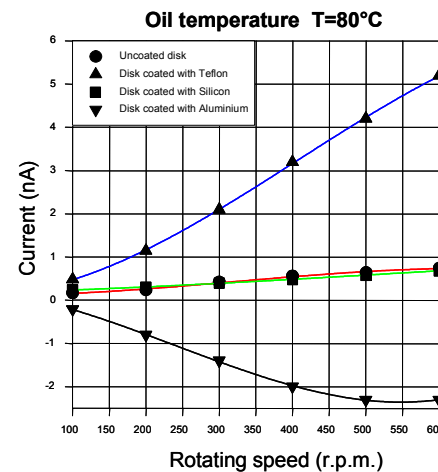


Figure 3: Influence of the type of deposit and the rotating velocity of the disk on the current in fresh oil at 80°C .

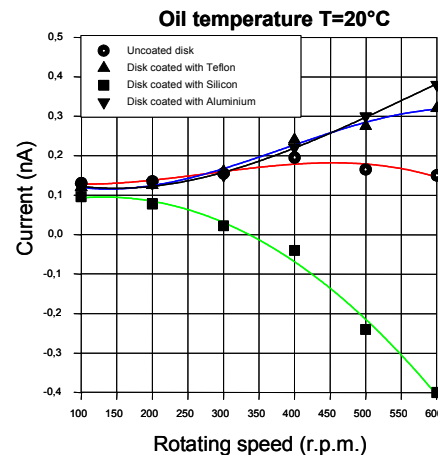


Figure 4: Influence of the type of deposit and the rotating velocity of the disk on the current in aged oil at 20°C .

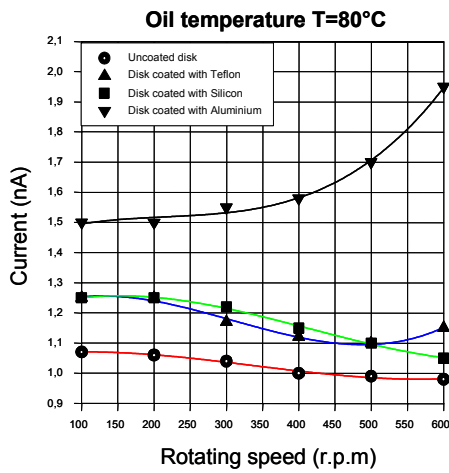


Figure 5: Influence of the type of deposit and the rotating velocity of the disk on the current in aged oil at 80°C.

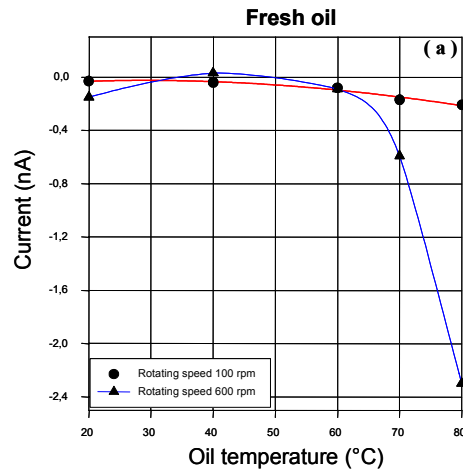


Figure 8: Influence of temperature on the current for a disk coated with pure aluminium in a fresh oil, for two rotating velocities (100 and 600 rpm).

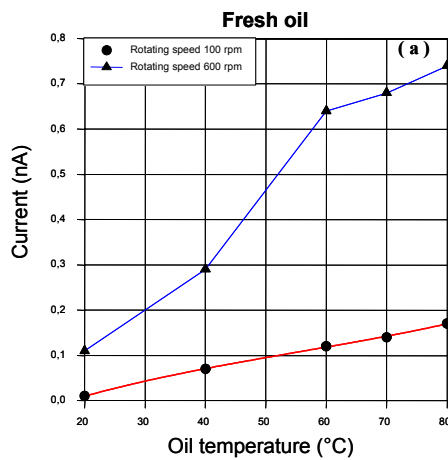


Figure 6: Influence of temperature on the current for an uncoated disk in a fresh oil, for two rotating velocities (100 and 600 rpm).

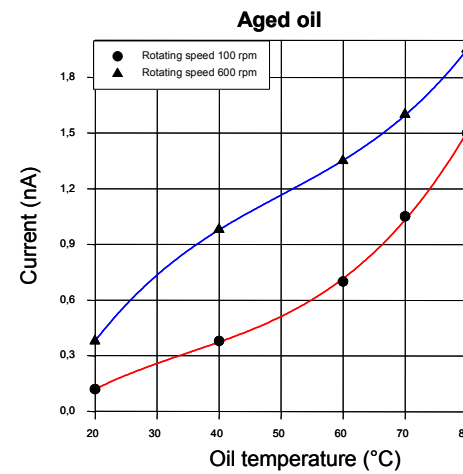


Figure 9: Influence of temperature on the current for a disk coated with pure aluminium in a aged oil, for two rotating velocities (100 and 600 rpm).

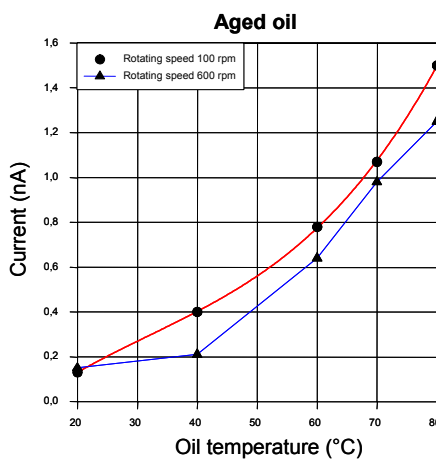


Figure 7: Influence of temperature on the current for an uncoated disk in a aged oil, for two rotating velocities (100 and 600 rpm).

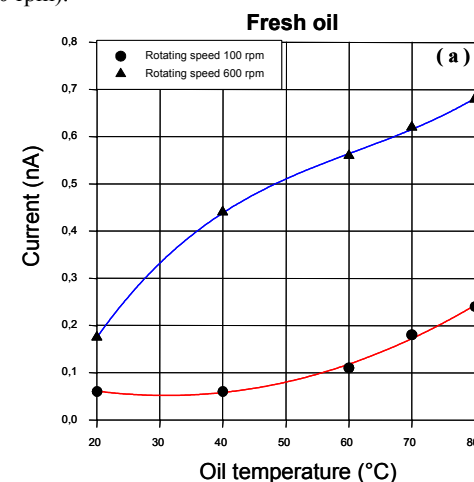


Figure 10: Influence of temperature on the current for a disk coated with silicon in fresh oil, for two rotating velocities (100 and 600 rpm).

With a disk coated with silicon in both fresh and aged oils, the currents increase with the rotating velocity and temperature (Figures 10 and 11). On the other hand, the current is higher at 100 rpm than at 600 rpm. For a deposit of Teflon and a fresh oil, the currents increase with the temperature and velocity. However and contrary to the case of silicon deposit, the current amplitudes are higher with the fresh oil than with the aged oil (Figures 12 and 13).

Note that the increase of temperature leads to an increase of the conductivity and thence to that of the dissipation factor ; it results an increase of the current as indicated above.

Depending on the oil/solid material interface, the velocity, temperature and oil ageing, the sign of the current values can change. The temperature contributes to the ageing process resulting in the oxidation of oil. The different species resulting from this oxidation lead to the generation of charges and then to the increase of the electrification current.

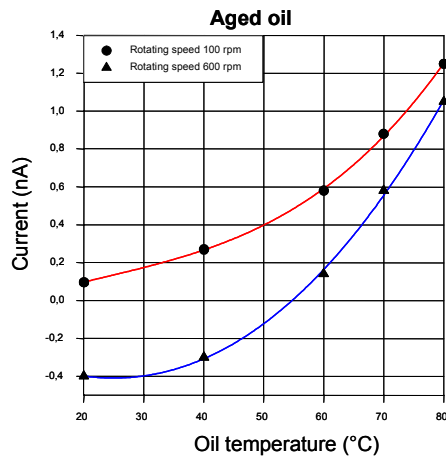


Figure 11 : Influence of temperature on the current for a disk coated with silicon in aged oil, for two rotating velocities (100 and 600 rpm).

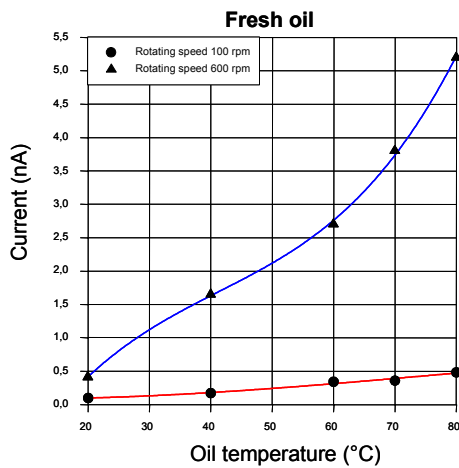


Figure 12: Influence of temperature on the current for a disk coated with Teflon in fresh oil, for two rotating velocities (100 and 600 rpm).

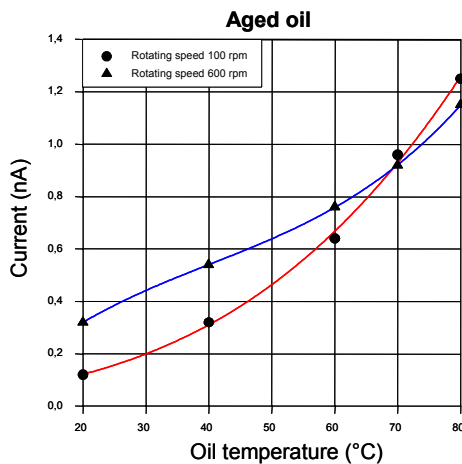


Figure 13 : Influence of temperature on the current for a disk coated with Teflon in aged oil, for two rotating velocities (100 and 600 rpm).

IV. CONCLUSION

This work shows that the static electrification phenomena is influenced by the type of oil/solid interface, the rotating velocity, temperature and ageing. Generally, the static electrification current increases with the rotating velocity, temperature and ageing. Note that the sign of the current when thin deposits of pure aluminium (5N) are in contact with a fresh oil is negative while it's positive with aged oil.

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