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Electrostatic charging tendency of natural transformer ester - impact of the surface state of solid on electrification currents

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Abstract— This paper deals with the static electrification phenomena of natural ester for the use in power transformers. The spinning disk method was used in the study. The rate of oil flow on the surface of solid material is simulated by the rotational speed of the disk. The dependency of the electrification current of the natural ester versus the flow velocity of the oil and the type of roughness of the surface of the solid material has been investigated; the different roughnesses are obtained by making different scratches' patterns on the rotating disc. As with mineral oils, the static electrification current of natural ester oil increases with the flow rate and/or the surface roughness.

Keywords—flow electrification, natural ester, transformer

I. INTRODUCTION

When a liquid comes into contact with a solid dielectric, as a result of physicochemical reactions at the interphase, the originally electrically neutral system becomes polarized. A so-called double charge layer appears. The phenomenon of space charge formation on the surface of a solid body and in the subsurface layer of a liquid was initially described by Helmholtz. This model was then further developed by Gouy and Chapman, who took into account the fact that the movement of ions in a liquid creates a diffusion layer of finite thickness. Stern's model, which takes into account the existence of both Helmholtz and Gouy-Chapman layers, is based on the two models mentioned above. A schematic representation of the double layer structure according to the models mentioned above can be found in [1].

When there is movement of the oil in relation to the insulation system and structural elements, caused by the transformer cooling system, the ions of the diffusion layer move with the oil flow, generating thence the electrification phenomenon. The development and intensity of this phenomenon are influenced by many factors, such as the type of oil and its flow rate, the type of solid material with which the oil comes into contact and its surface condition. To this must be added other factors which change during the operation of the transformer, in particular the aging of oil and the fluctuations of the water content.

The history of static electrification resulting from the forced flow of oil in power transformers began in the 1970s, when transformer manufacturers and their users began to suspect the phenomenon of static electrification as being at the origin of unexplained failures of power transformers.

The static electrification processes caused by the flow of oil inside power transformers may lead to the initiation of partial discharges and breakdown of the transformer insulation. Failures of power transformers filled with mineral

oil caused by this phenomenon have been known and studied since the mid-twentieth century. Currently, due to the increased requirements for environmental protection, units filled with transformer organic esters occupy a growing share in the production of transformers. Physical phenomena at the solid-liquid interface are obviously dependent on the physicochemical properties of the liquid. Thus, the level of static electrification depends on the kind of insulating oils. Therefore, the use of a new type of insulating oil requires among others the knowledge of its properties with respect to static electrification.

During the expertise of damaged transformers, the presence of traces caused by electrical discharges was revealed. These were traces of electric trees, burned holes or the presence of carbon on the internal elements of solid insulation. Thus, one could assume that the flow electrification process occurring at the interface between oil and solid insulator seems to be responsible for these events [2-4]. These experiments made it possible to design/imagine a hypothetical transformer failure scenario [5]. It includes the electrification processes caused by the flow of oil resulting consequently in:

- generation of space charge
- transferring the space charge in the direction of the forced oil flow
- accumulation of space charge in privileged places of the transformer structure
- deformation of the electric field distribution due to the accumulated space charge
- the possibility of the appearance of a constant component of the electric field
- initiation and development of various forms of partial discharges from places of accumulation of spatial charge
- catastrophic electric breakdown under the action of AC operating voltage.

The problem of static electrification of mineral transformer oils is quite well recognized and documented in literature. Despite this, current articles on this phenomenon can still be found in recognized international journals [6-8]. This proves that not all problems related to the static electrification of mineral oils have been completely solved. In the case of a new class of transformer oils based on organic esters, with a chemical structure different from that of mineral

oils, this issue is still open and requires intensive research [9-11].

The study of the effect of the surface roughness of a dielectric (pressboard, textolite) disk on the electrification of biodegradable transformer oil showed that increasing the surface roughness resulted in higher current values compared to disk with a smoother surface [1]. However, it is problematic in this case to make the pressboard surface roughness with defined patterns. Earlier works on the phenomenon of flow electrification in a system with a rotating disk showed that the electrification currents measured in a system with a conductive disk exhibit very similar behaviour as in the case of disks made of dielectric materials [1,12,13]. In particular, it should be noted that the use of a metal electrode in the spinning disk method allows to demonstrate the differences in the intensity of electrification for fresh and aged oils [14] or for mixtures of different oils [15]. The study of the flow electrification of dielectric liquids, in particular transformer oils, can therefore also be carried out using metal electrodes. It is not without significance here that roughening the electrode surface with a specific pattern is possible for metal electrodes.

This paper deals with the static electrification phenomena of natural ester through the electrification current using a rotating disk method. The electrification current is especially investigated versus the flow velocity of the oil and the type of roughness to the surface of the solid material; the different roughness are obtained by making different scratches' patterns on the rotating disc.

II. MEASURING SYSTEM

The experiments were performed using the rotating disk method. This method involves immersing a rotating electrode in a conductive vessel filled with transformer oil. The rotation of the electrode disk with respect to the oil causes the charge of the bilayer to break and flow to the walls of the vessel. The measuring vessel is grounded through a pico-ammeter and the current flow is recorded in the external circuit. The schematic diagram and photo of the circuit are given in Figures 1 and 2, respectively.

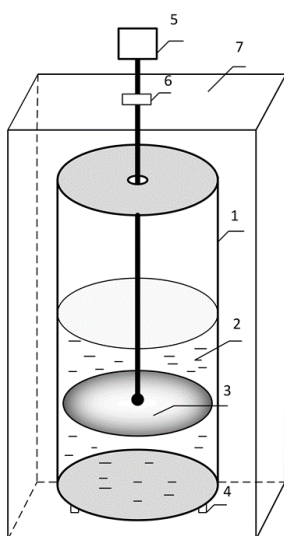


Fig. 1. Scheme of the system for measuring static electrification of oils with the spinning disk method: (1) measuring vessel, (2) oil, (3) target, (4) Teflon supports, (5) motor, (6) Teflon coupling / electrical separator, and (7) Faraday's cage.

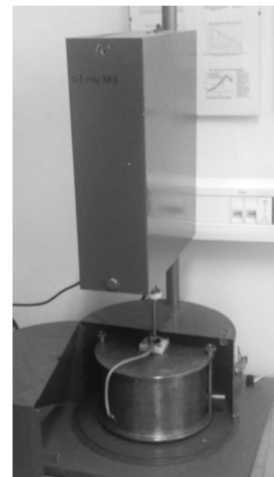


Fig. 2. Photo of test cell

The disc rotational speed was regulated by changing the voltage supplying the motor. The rotational speed was measured with a DMT 21 tachometer from POLMATIK with an accuracy of $\pm 0.2\%$, using an optical converter. The measurement of the current generated by the rotating disk was carried out using a KEITHLEY type 485 pico-ammeter with an accuracy of $\pm 0.2\%$.

Measurements were made for target electrodes made of copper. Shields with a smooth and rough surface were used. The smooth reference electrode (electrode A) was cut out of the rolled sheet, not subjected to additional treatment. Rough electrodes have undergone additional surface treatment by:

- Electrode B - applying scratches by rotary polishing with 600 grit sandpaper;
- electrode C - applying scratches by longitudinal polishing with 600 grit sandpaper;
- electrode D - applying scratches by radial polishing with 600 grit sandpaper.

Fig. 3 shows the diagram of the surface treatment of electrodes.

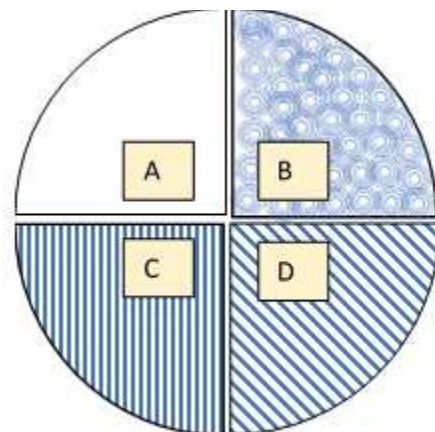


Fig. 3. Diagram of the surface treatment of the electrodes

Before the tests, each disc was cleaned in order to remove any contamination from the surface. Five electrification current characteristics were made as a function of rotational speed ω at intervals of at least 20 minutes. From the data obtained in this way, mean values were calculated and the characteristics presented in the figures were plotted.

III. EXPERIMENTAL RESULTS

Figures 4 to 6 show the evolution of the electrification current for the three types of surface treatment.

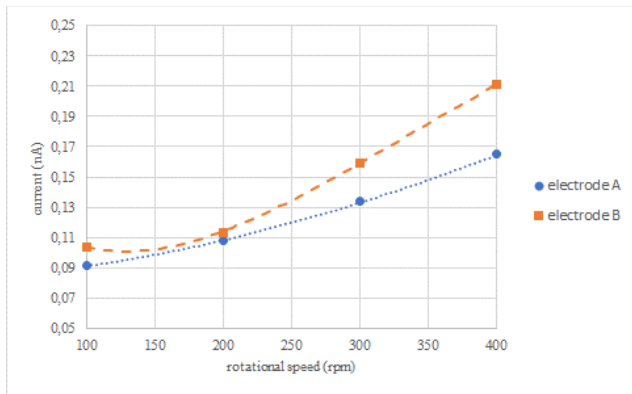


Fig. 4. Electrification current for a smooth electrode (A) and for electrode (B) with additional surface treatment by applying scratches by rotary polishing.

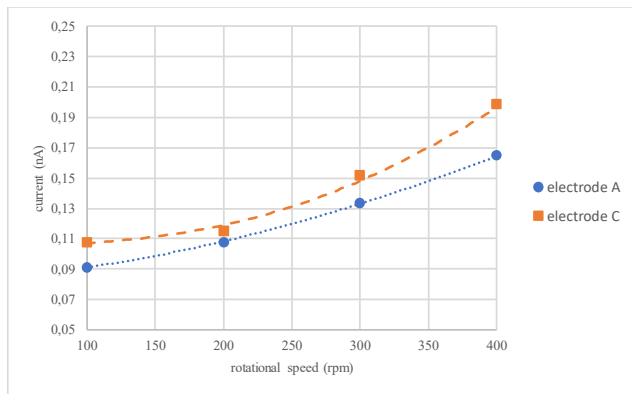


Fig. 5. Electrification current for a smooth electrode (A) and for electrode (C) with additional treatment by applying scratches by longitudinal polishing.

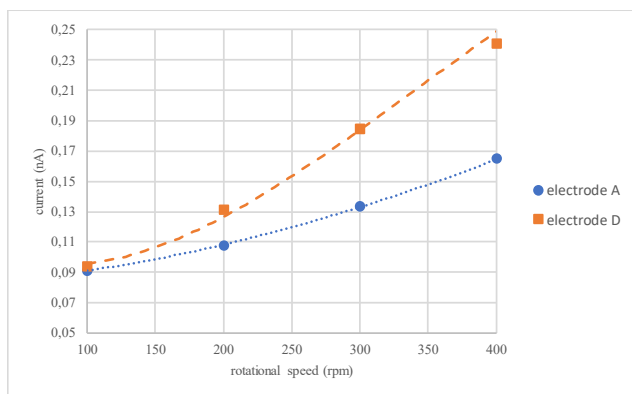


Fig. 6. Electrification current for a smooth electrode (A) and for electrode (B) with additional surface treatment by applying scratches by radial polishing. In the cases of rotary and longitudinal polishing the increase

The general trend observed from these figures is that increasing the disc roughness results in an increase in the electrification current. In the cases of rotary and longitudinal polishing, the increase is much less than in the case of radial polishing. This difference is all the more important as the

rotational speed of the disc increases. These results confirm those reported elsewhere [1, 12].

As for mineral oils, the electrification current in transformer organic esters increases with the increase of the rotational speed of the disc. However, the obtained current values are higher than those in mineral oils [16].

IV. CONCLUSION

The disk surface roughness has a similar effect on the static electrification of biodegradable transformer oil as it does on mineral oils. Increasing the surface roughness of the discs results in higher currents compared to disks with a smoother surface. The increase in electrification current in tests performed with electrodes with modified surface roughness may be related both to the increase in the specific surface of the electrode (disk) and the appearance of "thresholds" that may support the detachment of the diffusion layer charges from the surface of the solid material.

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