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Impact of various stresses on the streaming electrification of transformer oil

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ABSTRACT

In this contribution the influence of various stresses and their combined impact on the electrostatic charging tendency of oil is studied. Various physicochemical properties were measured according to ASTM Standards to detect changes in oil quality. A free radical reagent, 2.2 diphenyl-1-picrylhydrazyl (DPPH), was added to oil before and after the application of stresses to determine free radical concentration. The results obtained show that the application of stresses contributes to an increase in the electrification current. These results also demonstrate that electrification current is affected by the quantity of the free radicals.

1. Introduction

The role of insulation is paramount importance, in the sense that it is one of the fundamental conditions for the reliable operation of power equipment. Insulating materials design/selection is one of the most important problem engineers have to face. This is due to wide variety of available insulation (oil, air, vacuum, ceramic, etc…). Moreover, insulating materials span all three forms of matter (solid, liquid and gas), with sometimes a single form involved but often a combination of forms, such as the solid/liquid or the solid/gas forms.

Composite liquid/paper insulation is used in power transformer. Insulating liquid in transformer is mainly of mineral origin, but may be of synthetic and vegetable origin [1]. The most widely used insulation systems for nearly a century are petroleum-based oil, (the so-called transformer oil) combined with solid insulation. The solid insulation materials commonly used as wrapping (e.g., turn insulation, cable wraps) and spacers (e.g., layer insulation) are cellulosic papers and boards made with special care from wood pulps [2]. These papers, pressed boards (the so-called pressboards), and wooden parts show modest dielectric performance due to their porous structure. Their dielectric strength is predominantly conditioned by gaseous ionization within the air inclusions. They are therefore adequately impregnated with transformer oil to eliminate air and increase their resistance to electrical breakdown.

When a liquid comes in contact with a solid wall, the complex liquid–solid polarizes under the effect of a physicochemical phenomenon at the interface; this process leads to the generation of charges within solid/insulating liquid interfaces. The system can be considered in equilibrium when there is no more charge transfer at the interface (no current flowing at the interface): the chemical reaction is stopped or considered stationary, offset by leaks to ground via the interface. Any motion of the liquid affects this dynamic equilibrium condition. The lack or smaller amount of counter charges in the liquid introduces an imbalance for which

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compensation is made by new reactions at the interface generating the streaming/electrification current. The physicochemical processes at the interface generates new charges transfer, compensating the convective transport of the diffuse layer, the generated current is also equal to the currents created by the leak and transient accumulation of charges at the interface, the compact layer remaining integral with the interface [3–5]. It is generally accepted that the transport of charges, present in the diffuse layer is responsible for the electrical double layer (EDL) "rupture" [4].

The streaming current is due to the convection of charge from the layer diffuses into the liquid. It depends on the properties of the double layer: thickness, density of space charge at the interface, and the duration of the double layer.

The thickness of the diffuse layer is generally equated with the Debye length [4].

Streaming/flow electrification in power transformers has been studied for decades, since the charge generation phenomenon was suspected to be responsible for power transformer failures [6].

In the case of the mineral-oil impregnated pressboard and papers, it is observed that the pressboard generally holds a negative charge, while the oils hold a positive charge [4–28]. The oil does not remain charged for a long time because its flow makes it possible for the positive charges to be released, once they contact any metal part connected to the mass (tank). On the other hand, the pressboard retains its negative charges. The charges accumulated at the pressboard–oil interface can lead to high potentials and initiate partial discharges [5].

Many studies reported in the literature made it possible to determine the main factors that influence static electrification [4–28]. Among these factors the purity of oil was recognized as an important one. At the same time, several devices were being developed to study the phenomenon. Different facilities and protocols have been developed for studying the electrostatic charging tendency (ECT) in a spinning disk system [6,7], Couette charger [8,9] or in the Westinghouse protocol [10]. All these measurements analyzed hazards according to the streamed charges, commonly called "streaming current". At the University of Poitiers, an original sensor was developed to measure the quantity of charge that accumulates in well-insulated pressboard [11–15].

Under normal operating conditions, transformer oil is degraded due to various stresses, including electrical, chemical, and thermal ones. The degradation by-products or decay products in the insulating oil are composed of a variety of compounds, such as peroxides, aldehydes, ketones and organic acids. Each one of them is partially adsorbed on the large surface of the paper insulation. This article contains experimental results of the electrostatic charging tendency (ECT) of mineral-based oil submitted to the following stresses: electrical stress, local thermal overheating and a combination of both stresses in a spinning disk system. The results are correlated with the concentration of dissolved decay products (DDP) and free radicals content in the fluid samples. The influence of the type and thickness of papers on the ECT of oil is also investigated.

2. Experimental procedure

The investigations were performed using a spinning disk system designed in our laboratory, in which the disk is covered on both sides with cellulose or aramid paper [20–25]. This system has been adopted by CIGRE (Conférence des Grands Réseaux Électrique, Paris, France) for international comparative measurements of both insulating liquid and solid transformer materials (CIGRE Paper [16,17]) and is used relatively often in streaming electrification studies [6,7,18–27].

A disk having a diameter of 40 mm and a thickness of 5 mm was used in these investigations. The spinning disk system and the electrometer were placed in a Faraday cage (Fig. 1). The rotating disk was driven by a proportional-integral (PI) based speed controlled DC motor. The rotating velocity of the disk was varied between 100 and 600 rpm. The container as well as the rotating disk was made of aluminum. The temperature of oil was set and controlled within the range of 20 ± 0.1 °C using a heating system. The electrification currents and the rotation speed measured using an encoder, were simultaneously recorded via a data acquisition Excelinx system developed by Keitley. The data were stored as Excel files to allow further analyses using other software applications. The static electrification current (leakage current) created by the charge concentration gradient was measured with a programmable electrometer (Keitley 6514) inserted between the tank and the ground.

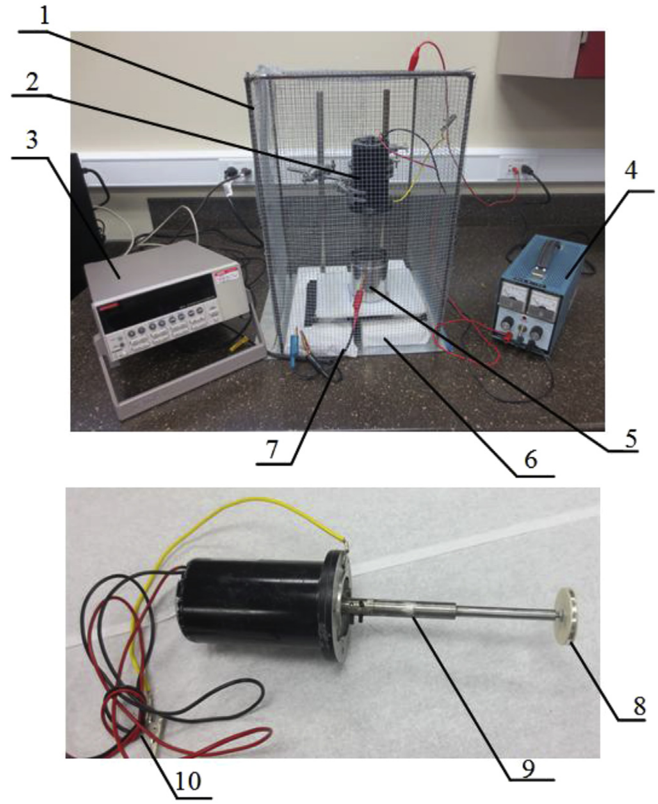

Fig. 1. Diagram of the system with a spinning disk for studying the electrification of insulating liquids: (1) Faraday cage; (2) DC motor; (3) Electrometer; (4) DC power supply; (5) measuring container containing oil; (6) insulator; (7) coaxial cable; (8) disk (9) rotating mandrel (10) connecting wire.

Due to centrifugal force, the charges created by the rotating motion of the disk in oil are drained toward the tank wall, where they are collected. The streaming current was measured as leakage current (in pA), from the container to the ground using an electrometer inserted between the tank and the ground.

The electrometer, based on the National Semiconductor LMC6001 BiFET op-amp, had an input resistance of 10^{15} Ω and an input bias current no greater than 25 fA. The 1000 MΩ feedback resistor made it possible to take measurements as low as ±5nA. The 500 kΩ input resistor limited the input current to safe levels in cases of significant electrostatic potential on the electrometer input. Two different papers were used to cover the rotating disk: (i) cellulose having a thickness of 1 mm and 3 mm, and (ii) a 1 mm thick Aramid Paper. These paper samples were vacuum dried in an oven at 100 °C for 48 h, and then impregnated with dehydrated, degasified naphthenic type based inhibited oil.