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INVESTIGATION OF THE DIELECTROPHORESIS EFFECT ON THE ELECTRICAL PERFORMANCE OF DIELECTRIC LIQUID

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ABSTRACT

This paper addresses the effect of the contaminant present in the power transformer oil. This transformer oil has been used as liquid insulation as well as heat dissipation in high voltage transformer. Recent, researchers have found that ester oil which vegetable-based oil is capable of outshining the disadvantages of mineral oil such as non-biodegradable and future scarcity as a potential replacement for liquid insulation. However, the performance of ester oil is still arguably, especially in DC energization case. In this present paper, the bridging experiment has been conducted in order to study the ester oil performance with the presence of contaminant under the influenced of DC electric field. This approach will show the effect of polarization and Dielectrophoresis (DEP) that create a conduction path between two different potential paths in the electric field and producing motion in the particles. As an effect of DEP, the contaminant tends to move towards the higher region electric field and may lead to a more serious problem, transformer failures. In total, Cellulose particle with two different conditions i.e. stirred and unstirred was investigated. A complete cellulose bridge is observed between two 13 mm sphere electrodes with 10 mm distance between them. The performance of dielectric properties is analysed by correlating the formation time and breakdown voltage results.

Keywords: mineral oil, ester oil, bridging, cellulose fiber, DEP formatting.

INTRODUCTION

Transformers are one of great importance and basic element in power transmission and distribution system. Majority of the power transformers are oil-filled technology and contain cellulose as an insulator. This liquid insulation provides an insulation in high voltage (HV) system besides as carrier information for diagnostic[1]. Mineral oil has been used as a traditional insulating liquid for power transformers for over a century, i.e. Gemini X are often used in high voltage direct current (HVDC) converter transformer as liquid insulator.

However, in face of increasing awareness of environmental protection recently, i.e. stringent environmental protection regulation, flammability (O class fluid) and future scarcity, applying environmental friendly liquid insulation in transformer have gained popularity [2]-[4]. In respond with this situation, ester oil which is fully biodegradable, less flammable (k class) and less toxic has been regarded as an alternative to mineral oil and interest to use in power transformers has increased[5][6].

Currently, statistical data shown that ester based liquid insulation have been widely used in distribution transformers and nowadays more research has been develop in the aim of used by esters in power transformer [7][8]. Besides that, ester based liquid insulation is available from renewable natural sources compared with mineral oil [9][5].

Meanwhile, their dielectric properties are not yet fully known from the perspective of dc energization. Recently, with the investment and advances in HVDC systems nowadays required a significant studied and detailed information about the dielectric behavior of liquid insulator under dc and ac electric field [10]. Besides that, with the introduction of ester based liquid insulation, it has gathered significant attention from industry manufacturer regarding the performance of ester oil in HVDC system. This HVDC system is suitable to be used for long distance electrical power transmission and getting popularity in European country [10].

Statistical analysis has shown that failure of HVDC converter transformer is 5 -10 times greater compare with the normal HVAC transformers [10]. Moreover, it has been reported that cellulose bridging may occur in contaminated transformer oil in HVDC converter transformer [11]. Paper and pressboard insulation, metallic particle and dust particle during periodic maintenance are the examples of the sources that consume to the contaminated transformer oil.

As an effect of long-term impregnation cellulose in transformer oil, pressboard impurities can be found in a contaminated transformer. Naturally, cellulose particles, iron and copper are existing particles in transformers [12][13]. This particle may create a conduction path between two different paths as an effect of DEP which tends to force the particles into a high field region after a certain period of time [14]. To make it worst, transformer failure may occur due to the formation of conduction path.

This paper focuses on the effect of a contaminant in transformer oil of power transformer. A series of cellulose bridging experiments have been carried out under the influence of a DC electric field. The experimental results are analyzed based on the bridging formation time and breakdown voltage.

EXPERIMENTAL SETUP

A rectangular test cell made from glass with a capacity of 1 litre is used in this experiment. Two sphere electrodes with 13 mm diameter each are placed in the middle of the test cell. A 10 mm gap between electrodes is used throughout the experiment. Figure-1 shows the

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configuration in this research. One of the spherical electrodes is attached to HV supply while the other one is connected to the ground. Digital camera was used throughout the experiment for monitoring and recording purposes. All the process of bridging formation is monitored in control room.

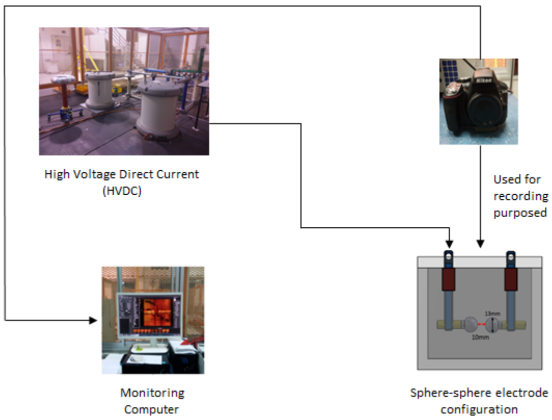

Figure-1. Experimental setup for bridging experiment.

EXPERIMENTAL PROCEDURE

Two types of dielectric liquid are used in the experiment for comparison purpose, synthetic ester (Midel 7131) and natural ester (Midel eN). A new experiment started with adding up 1 litre of transformer oil to sufficiently submerge the electrodes under to oil in the test cell. Prior to that, the oil will be replaced with new oil from the drum and test cell is cleaned up using n-hexane solution after each bridging experiment is undertaken. To maintain the similarity of the oil, Karl Fischer titration method was used to monitored moisture content of the oil samples. This method is one of analytical techniques that most frequently used in laboratories around the world to measure water (moisture). Moisture content was monitored between 180-220 ppm for both oils for all the experiments presented.

In order to simulate the presence of cellulose contaminants, a piece of new cellulose pressboard is scraped and the dust obtained from this action is inserted into the oil sample. 500 μm sizes of contaminant and 0.001g concentration level of contaminant will be used for this study. Digital measurement weight scale was used to achieve highest accuracy. The bridging phenomenon of cellulose particles is studied with unstirred condition of the oil prior the experiment. For unstirred condition, cellulose pressboard particle will be placed bottom/under the electrodes to see polarization and gravity effects.

The experiment was conducted by applying HVDC in steps of 5 kV with 1-minute interval for each step until breakdown occurs. However, for the first 3 steps, the voltage was increased to 2 kV, 7 kV and 10 kV. The experiment was repeated five times for validity and reliability in obtaining the results. Breakdown voltage (BDV) with the contaminant, time the particles start attached on the electrode surface and form a complete bridging are measured from this experiment.

RESULTS AND DISCUSSIONS

The bridging process in the dielectric liquid is shown in Figure 2 - 6. The bridging process was classified into 5 stages including the breakdown stage.

STAGE ONE

Initially, after the HVDC is applied to the system, under the influence of DC electric field, particle started to become polarized and move in between the electrodes as shown in Figure-2. Polarization occurred when an externally materials is applied to the electric field. Such a phenomenon may lead to DEP under the influence of non-uniform DC electric field. This phenomenon happens at the voltage level between 0kV - 2kV only. For both oils, the particles start to become polarized 50s after HVDC supply is applied to the system.

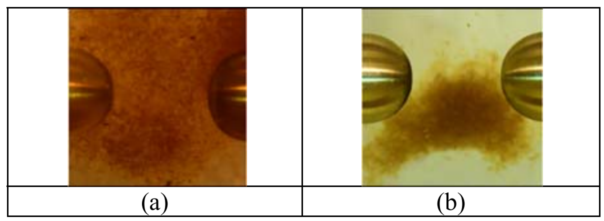

Figure-2. Initial condition of bridging experiment, a) Midel 7131, b) Midel eN.

STAGE TWO

Subsequently, some of the particle move towards the electrodes surface and once they touch it, the particle start to acquires and produce charges as shown in Figure-3. After being charged for several times, the particle tend to pull themselves from electrodes surface and move towards the other electrodes under the influence of DEP force, columb force and the drag force from viscous oil. The movement of the particle during the migration process is slow and light. The particles started to attach on the electrodes surface due to repelling coulomb and attractive charge. This situation occurred when the voltage was further increased from 2kV - 7kV.

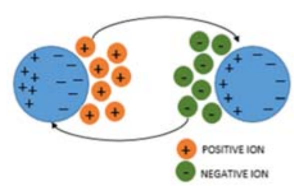

Figure-3. Cellulose particle after polarization process.

STAGE THREE

At this stage, the particles start to align themselves in parallel to electric field lines generated between two electrodes due to DEP force. Figure-4 shows the phenomenon occurs when the particle start aligns themselves in parallel to the electric field. The particles start to travel back and forth between electrodes and attached on the electrodes surface. Consequently, the chain

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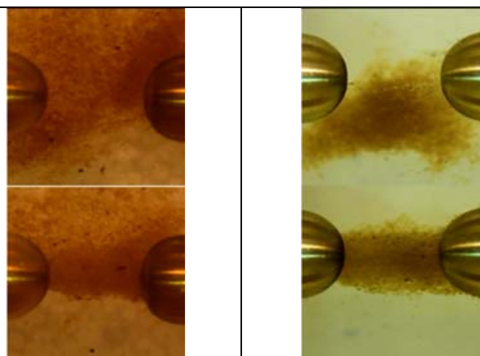
of the cellulose particle is increased towards the mid-point between the electrodes which causes the maximum electric field is distributed further away from the electrode surface, i.e. at the tip of the cellulose particles. Such phenomenon is believed to happen due to the distribution of electric field generated between the electrodes and cellulose particles attached on the electrodes surface. In addition, it also has been reported that cellulose bridge that connected both electrodes allows a very small conduction current (in the order of 10^{-9}) to flow between both electrodes [11].

Besides that, there are also some of the particles that remain to stick on the electrodes surface. This behaviour takes place because of strong DEP force effect which obstructs the particle to acquire enough charge. Due to the distribution of electric field between the electrodes, these types of particle attract other free cellulose particles in the liquid with opposite charges. On top of that, the transfer rate during the movement of the particleis faster compared to the previous stage. This situation occurred when the voltage was further increased from 7kV – 40kV.

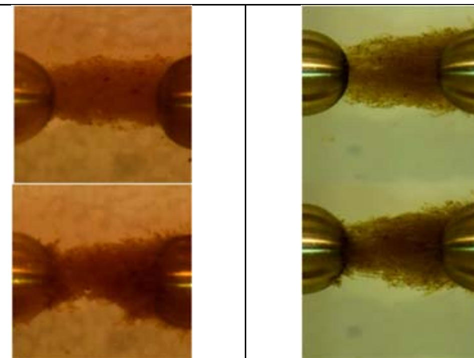


(a) (b)

Figure-4. Formation of conduction path between electrodes, a) Midel 7131, b) Midel eN.

STAGE FOUR

The particle travels at a higher velocity as the voltage closer to the breakdown as shown in Figure-5. It is caused by faster rate of charging and discharging as well repelling and attracting (Coloumb force effect) between the cellulose particles and the electrodes as a result of higher DC electric field within the system. When the voltage is further increased, cellulose particle travel back and forth emerges again but with higher velocity and involving the particle inside the bridge formation until the breakdown occurs. At this stage, the bridge formation narrowed in the middle and broader at the end of the bridge (electrodes surface). While approaching the breakdown voltage, the oil condition is corrugated. This situation occurred when the voltage was further increased from 40kV until breakdown.



(a) (b)

Figure-5. Cellulose bridge condition closer to breakdown voltage, a) Midel 7131, b) Midel eN.

STAGE FIVE

During the occurrence of breakdown, the bubble formationis observed after the breakdown between the electrodes for both oils. Previous studies have shown that this bubble is produced through the conduction current between the electrodes [15]. It is seen from Figure-6 that the cellulose particles burst and scattered into the bottom of the test cell after the occurrence of breakdown as the effect of gravity force is greater compared with DEP force.

(a) (b)

Figure-6. Cellulose particle after breakdown occurrence, a) Midel 7131, b) Midel eN.

Figure 2, 3, 4, 5 and 6 clearly shown the behaviour of cellulose bridging under influence of DC electric field. At the initial stage, the current is small but since the increasing voltage step by step is applied, the particle gets an electric charge and the current increases until it makes a complete bridging between electrodes and breakdown. Previously, these phenomenon has been investigated by several researcher [11], [16], [17] with conductive and dielectric particle and resultant to it, a complete cellulose particle bridging are occurred in both oils under influence of DC electric field.

Table-1 compares the results of bridging experiment between synthetic and natural esters. The table shows that there is no significant different between both oils at the early stage of the experiment. It is observed that the cellulose particles start to move towards the electrode surface after 45s of applying 2 kV of HVDC supply. However, there are significant different as the voltage increases in terms of the time to form a complete thin bridge and the level of breakdown voltage. It shown that the bridging time in synthetic ester is faster than that in the natural ester. This could be due to synthetic ester has a lower viscosity compared to natural ester. As shown in the Table-1, Synthetic ester always have lower performance compared with natural ester in terms of time and dielectric properties.

Table-1. Bridging formation behaviours comparison in Midel Synthetic and eN.

Characteristic	Time particles startattached at electrode surface	Time to complete bridging	BDV without contaminant	BDV with contaminant	Luminous flashover during breakdown
Midel 7131	45s at 2kV	140s at 10kV	740s at 62kV	960s at 75.50kV	No
Midel eN	50s at 2kV	155s at 10kV	780s at 65kV	1020s at 79.22kV	No

CONCLUSIONS

The present work demonstrates the effect of cellulose particles on the breakdown strength of ester-based oils. The following conclusion can be drawn based on findings of this research. Firstly, the formation of complete cellulose bridge is observed for both oils contaminated with cellulose particles tested in this research. It is believed due to dielectrophoresis force which plays a significant role in the formation of Cellulose Bridge under non-uniform electric field.

Secondly, a definite relationship exists between the breakdown voltage of oil and the degree of contaminant. Type, size, concentration level of particle will influence and determine the breakdown voltage of oils. Results indicated that cellulose pressboard has increased the breakdown voltage of the oil and the BdV in Midel eN slightly high compared with Midel 7131. It proved that the higher the viscosity of the oil, the higher the insulation breakdown voltage. Besides that, comparison between this Midel eN and Midel 7131 shown that time taken to form a complete bridge are influenced by viscosity of the oil.

Finally, it can be concluded that both time taken to form a bridge and breakdown voltage are useful tools to provide an information and knowledge regarding the performance of ester oil in high voltage application. Contamination in practice can seriously affect the dielectric performance of the insulation oil.

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