Study on Palm-Oil Based Insulation Oils Conductivity Using PDC Measurement Technique

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***Abstract*—** Biodegradable oil as insulation in transformer currently starts being used as alternative to mineral oil due to its dielectric properties and availability. However, moisture content in these types of insulation oil is the real challenge especially for high voltage application. Malaysian researchers currently try to develop biodegradable insulation oil from palm oil based. This paper present comparative analysis on conductivity behavior of different types of oil which are biodegradable oil (Refined Bleached Deodorized Palm Oil (RBDPO) and Red Palm Oil) and mineral oil (Hyrax Hypetrans and FR3). Polarization and Depolarization Current (PDC) measurement test was conducted on the oil sample compromised with various thickness of insulation pressboard paper (0.2mm, 0.5mm and 1.0mm) was done in lab. In the analysis, the PDC curve was plotted in log scales and the DC conductivity of the oil was calculated. Based on the analysis result the different and variation of the conductivity identify the best palm oil type that have high potential to be commercialized as transformer insulation oil.

***Keywords*—** Biodegradable oil, conductivity, PDC, transformer

I. Introduction

IN electrical equipment especially in high voltage application, insulations are very important. There are many accidents caused by transformer failures are due to poor insulations. Failures of transformers require months to repair, cost millions of dollars to replace, and can leak toxic fluids. Cooling capability ultimately determines the amount of power that can be reliably handled by a transformer. As a result, transformers are designed to maximize heat rejection, and this often means bulky and expensive designs. Therefore, every single research in electrical field is all about insulation and most of researchers nowadays are focusing on how to improve the insulations. Basically, the insulators which are also known as dielectric intended to support or separate electrical conductors without passing current through themselves.

Medium and high voltage transformer usually used liquid insulating material as its behavior of cooling and insulation characteristics. The insulating oil fills up pores in fibrous insulation and the gaps between the coil conductors and the spacing between the windings and the tank, and thus increases the dielectric strength of the insulation [1].

In Malaysia, we are among one of the top popular country that produce palm oil. The sample of palm oil produced includes Crude Palm Oil, Oleic Acid, Refined, Bleached and Deodorized Palm Oil (RBDPO), Red Palm Oil, and Envirotemp FR3. So this is our advantage to produce our own commercial palm-based oil that can be used as insulation oil. Hence, a study should be conducted to investigate the best and suitable palm-based oil.

However, the presence of moisture in liquid continues to be a major cause of problems in transformers and a limitation of their operation. Most of power transformers are using mineral oil as insulation oil because of its excellent dielectric properties. Unfortunately, petroleum-based mineral oil is also has negative effects effect in some circumstances. This type of oil is actually giving a bad effect on the environment. Among the creators of the activists, this type of oil will bring environmental damage to the ecosystem in the event of spills and leaks. In addition, this type of oil is non-renewal sources since it is exist only inside the earth.

II. Polarization and Depolarization Current (PDC)

There are indirect methods available to assess moisture content of paper insulation. Conversely, to date paper ageing and moisture can only be reliably measured by paper samples collected from critical locations (leads, outer winding, etc.) and examining in the laboratory. Solid insulation can only be examined directly by opening a transformer and taking models from the insulation. Apparently, this is not an acceptable method for a non-destructive evaluation of solid insulation. Moisture in oil can be estimated by collecting oil samples from the tank and analyzing by Karl Fischer titration. This has severe inaccuracy in lower part of the equilibrium curves. Hence, there is a great demand in using dielectric diagnostic approaches to relate to insulation properties.

Findings on polarization & depolarization current measurements are to evaluate the quality of the insulation structures of a number of power transformers. They recommend polarization current measurement as the preferred method since the properties of oil and paper can be separately assessed from the experimental results. It also explained that Return Voltage Measurement (RVM) results are convoluted by two constituents and it is difficult to separate the oil and paper impacts. They presented some examples of on-site measurements on power transformers and demonstrated the interpretation of results.

To finalize all of it, the polarization & depolarization current (PDC) method is a user friendly method for assessing the integral condition of the oil/paper insulation system of a transformer [2].

A. *Theory of PDC*

The schematic diagram and waveforms of PDC analysis are shown in Figures 1 and 2, respectively. PDC test is completed in two steps. Firstly, the test object (insulating material or equipment) is charged with a step excitation U_c for a long period T_c (10000s). During this period, the polarization (charging) current $i_{pol}(t)$ through the object as the step response is measured. The current is separated into two parts, one of which arising from the activation of polarization process determines the decay segment of current curve, and the other related to the electric conductivity defines the steady segment [3]. Secondly, the voltage U_c is removed and the object is short-circuited for the same period T_c. The formerly activated polarization process now gives rise to the decay depolarization (discharging) current $i_{depol}(t)$ in the opposite direction, where no influence of the conductivity is present. Limited by the practical voltage rising characteristics of dc voltage source, both the polarization and depolarization currents are normally recorded and analyzed from 1s to T_c. And the depolarization current is always flipped vertically and shifted leftwards for the convenience of data analysis, as shown in Fig. 2.

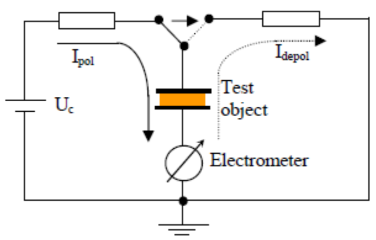

Fig. 1 Schematic Diagram

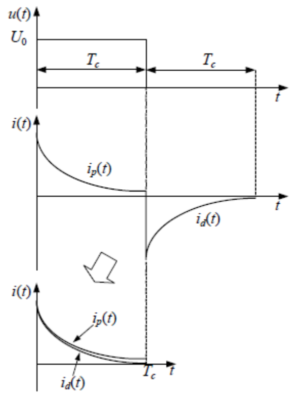

Fig 2 PDC Waveforms

B. Calculation of PDC

During the charging time, the polarization current $I_{pol}(t)$ is measured, arising due to the condition of the insulation material, arising from the activation of the polarization process with different time constants corresponding to different insulation materials and to the conductivity of the object, which has been previously carefully discharged. This polarization (or absorption, or charging) current $I_{pol}(t)$ through the test object can be expressed as :

$$i_{pol}(t) = C_0 U_c \left(\frac{\sigma}{\varepsilon_0} + f(t)\right) \quad (1)$$

Where C_0 is the geometrical capacitance of the test object, U_c is the step voltage (charging voltage=1000V),

σ is the DC conductivity of the dielectric material,

ε_0= 8.854 10^{-12} As/Vm is the vacuum permittivity,

f(t) is the response function of the dielectric material.

The test sample is short-circuited by removing the applied voltage at $t = t_C$, enabling the measurement of the depolarization current (or discharging, or de-sorption) $I_{depol}(t)$ in the opposite direction, without contribution of the conductivity.

According to the superposition principle the sudden reduction of the voltage U_C to zero is regarded as a negative voltage step at time $t = t_c$. Neglecting the second term in (1) we get for $t = (t_0 + T_C)$ [4- 9]:

$$i_{depol}(t) = -C_0 U_c \left(f(t) - f(t + T_c) \right) \quad (2)$$

where T_c is the charging time of the test object. Correspondingly, the condition of oil-paper insulation can be evaluated by PDC measurement. Moreover, PDC measurement can be used for estimation of sample conductivity σ. If the charging/discharging period T_c is sufficiently long so that $f(t+T_c)\approx 0$, equations (1) and (2) can be combined into equation (3) to express the conductivity. And if the values of distance between electrodes d and area of electrodes A are given, the conductivity can also be obtained from equation (4) as an equivalent expression of equation (3). Practically, the conductivity is approximately calculated by replacing t with T_c in equation (3b) [6].

$$\sigma \approx \frac{\varepsilon_0}{C_0 U_c}\left(i_{pol}(t) - i_{depol}(t)\right) \quad (3)$$

$$\sigma \approx \frac{d}{A U_c}\left(i_{pol}(t) - i_{depol}(t)\right) \quad (4)$$

III. Experimental Setup

This experiment was done by using test cell shown in Fig. 3 that being analyzed and verified by using COMSOL™ software. The samples were varied in 2 categories which are solid insulation (Kraft-paper) and liquid insulation (oil). The conductivity of paper being analyzed depends on its thickness with different type of oil. There were 3 different thickness of Kraft-paper 0.2mm, 0.5mm and 1.0mm that being cut in circular shape with diameter of 100mm which follow the diameter of copper electrode in the test cell. Red Palm Oil, Mineral Oil and Envirotemp (FR3) are the samples for liquid insulation.

Fig. 4 shows the test arrangement used during the PDC measurements system with a stabilized dc power source up to 1000V that controlled by a digital electrometer for the small current measurements and a High Voltage Switching Relay in order to operate the test setup by a computer [9]. The main components of the data acquisition system are a National Instrument DAQ plug-in board, installed in a PC, and the LabVIEW™ application software. The user-friendly interface developed under LabVIEW™, enables the operator to choose the voltage and time for charging and discharging. Once the operator sets the system into operation the measurement system becomes fully automated. Both currents (polarization and depolarization) are stored for analysis in the computer. Table I shows the designation of samples.

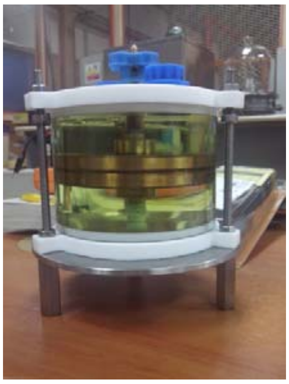

Fig. 3 Test cell

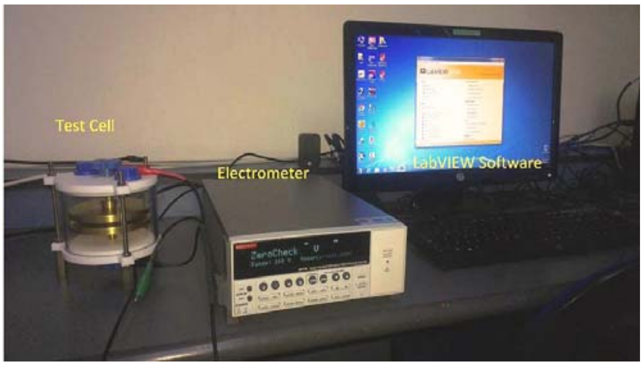

Fig. 4 PDC setup

TABLE I
SAMPLES DESIGNATION

Test Sample		Designation
Kraft Paper	0.2mm	P1
	0.5mm	P2
	1.0mm	P3
Oil	Red Palm Oil	A1
	Mineral Oil	B1
	FR3 Envirotemp	C1

IV. Results and Discussions

The results for polarization and depolarization currents measured for samples P1, P2 and P3 without oil are shown in Fig. 4 and Fig. 5. Sample P3 is the thickest sample and has lower polarization and depolarization current values than other. It is shows that the sample has high resistive value.

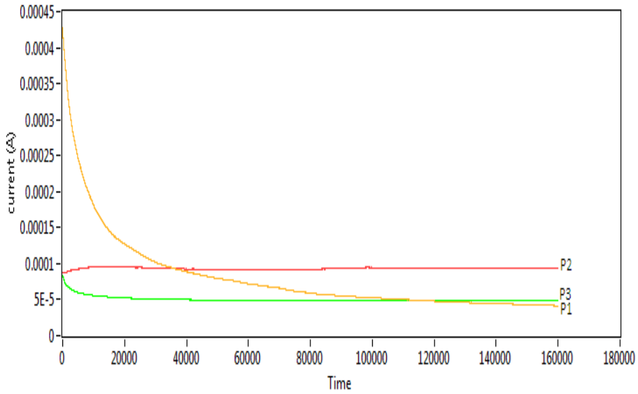

Fig. 5 Polarization current values for sample P1, P2 and P3

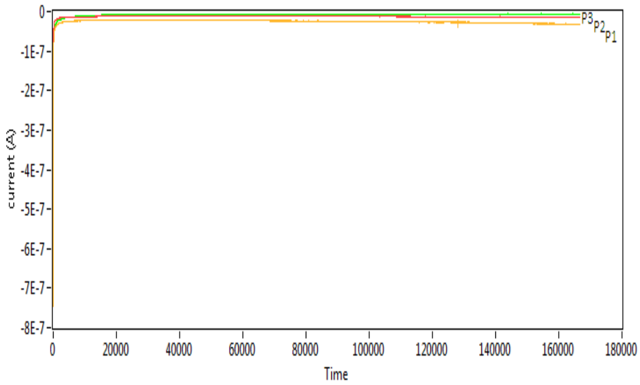

Fig 6. Depolarization current values for sample P1, P2 and P3

Fig. 7 shown is the polarization currents measured for sample P3 that immersed in 3 different types of oil. The results show that sample P3 immersed in B1 has higher value of polarization currents followed by C1 and A1. It is found that sample A1 which is Red Palm Oil has lower polarization current. Conductivity analysis of oil is shown in Fig. 8. Based on the plotted graph, sample A1 again shows the lowest conductivity.

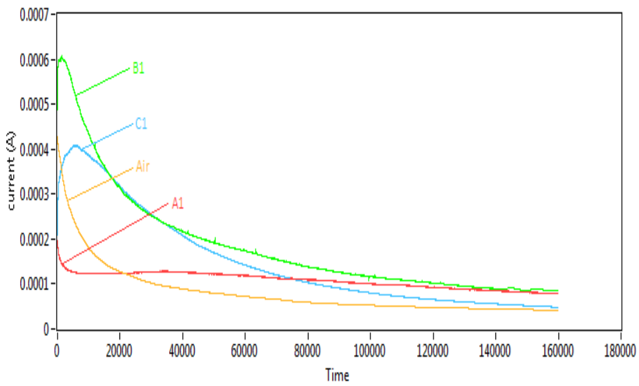

Fig. 7 Polarization current values for sample P1, P2 and P3

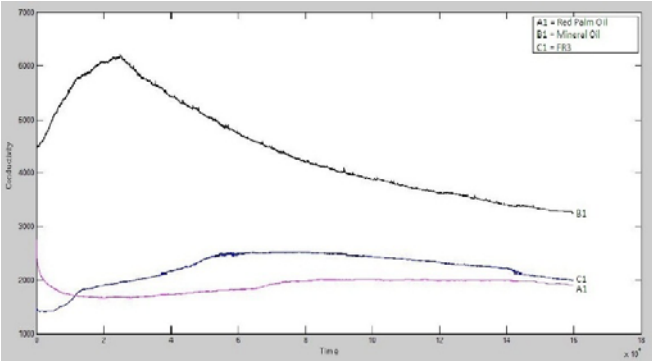

Fig. 8 Conductivity of oil

V. CONCLUSIONS

In this work, the conductivities of biodegradable and mineral transformer insulation oils were studied. Polarization current values are found to be the most important and useful parameters to assess the insulation materials. Paper conductivity can be calculated from the final polarization current values. The higher the value of paper conductivity, the higher the moisture contents in the insulation. It was clear that the polarization and depolarization current could separately assess the condition of the sample of paper and oil. In conclusion, this experiment shows that palm oil has very low conductivity compared to mineral oil. This characteristic is very helpful in electrical applications. Therefore further study on how to adapt palm oil into power transformer need to be done.

ACKNOWLEDGMENT

The authors gratefully acknowledge the Malaysia Ministry of Higher Education, Universiti Teknologi Malaysia for financial support (Vot 05J82, 04H67, 4L014, and 4L607)., TNB Research Sdn Bhd for equipment support and verification.

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