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Identifying the Breakdown Voltages of Vegetable Oils with Silicone Carbide Nanoparticle Additive as Insulating Oil for Transformers

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ABSTRACT

This paper discusses on the breakdown voltage of vegetable oils with nanoparticles added to be used as insulating oil for transformers. Raw samples of Palm Oil (PO) and Coconut Oil (CO) were used in this research. Different percentages of silicone carbide (SiC) nanoparticles was added into the samples of the vegetable oils. The different parameters of the vegetable oil mixtures were investigated through the breakdown voltage tests to analyse the effect of the additive on the dielectric strength of the oils. The performance of insulating oils varies according to the percentage of nanoparticles added through viscosity test and partial discharge (PD) measurement. The initial results for vegetable oils showed that the percentage of additives influenced the value of breakdown voltage of the oils highly. Furthermore, the result shows that PD measured became very low after the addition of silicone carbide nanoparticles.

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1. INTRODUCTION

Power transformers are a major component in transfer and distribution of electric power. Transformer oil or mineral oil is used as liquid insulation in electrical power transformers and also act as heat transfer agent. The research to replace the present transformer oil with vegetable oils that have a great potential in physical, chemical and electrical properties have been done worldwide [1]. Vegetable oils have different properties compared to present mineral oil. Vegetable oils are non-toxic and biodegradable, has higher flash and fire points and low thermal expansion coefficient [2]. A significant number of researchers have done studies to find a replacement for transformer oil, and they have found that the vegetable oils have shown impressive properties as an alternative.

Breakdown voltage test for transformer oil, also known as dielectric strength test which are performed to find the maximum withstand voltage of the oil before breakdown occurs [3]. Viscosity measures the flow resistance of oil on smooth surface which is related to heat transfer ability. Viscosity is always higher for vegetable oils compared to mineral oil, and thus have potential as a substitute to mineral oil [4]. Partial discharge is a physical discharge phenomenon that partially bridges the gap between two electrodes under high voltage. Insulation degradation due to various physical factors such as voids, cracks, ageing and pre-mature failure present within it are always linked to presence of partial discharges [5]. The occurrence of partial discharge (PD) is also an indication of insulation abnormality. In particular condition, due to the high electric stress and the existence of defects, the partial discharges may also take place in liquid insulation [6]. Pulse Sequence Analysis technique (PSA) have been used widely to supervised the deprivation of electrical equipment by analysing the sequence of each PD event [5]. In this study, the technique used to investigate the PD is through PSA process using the high voltage laboratory equipment. The additive SiC possesses high purity, narrow range particle size distribution, and larger specific surface area. Besides that, it exhibits the characteristic like high stability, high thermal conductivity, smaller thermal expansion coefficient and better abrasion resistance. These particles are also resistant to oxidation at high temperatures and have excellent thermal conductivity [7].

The aim of the study is to investigate the breakdown voltage of PO and CO with the present of SiC additives. Hence, the following experiment such as viscosity test and measuring the partial discharge is being conducted for the oils in the laboratory is carried out.

2. METHOD

The samples used in the experiment were natural fluids; palm oil (PO) and coconut oil (CO). The oil samples must be 500ml each to ensure the electrode is completely immersed during the voltage breakdown test. In this study, the additive SiC nanopowder was added at different percentage of 0.1%, 0.2%, 0.3%, 0.4% and 0.5% into each sample of the oil. Thus, there are 10 samples of 500 ml of PO and CO with added SiC. Then, the samples will undergo one hour treatment of magnetic stir at 60 °C at 900 rpm speed. Next, the samples underwent two hours of ultrasonic cleaner treatment at 50°C until each mixture sample was well blended. Figure 1 illustrates the step in the preparation of the oil samples.

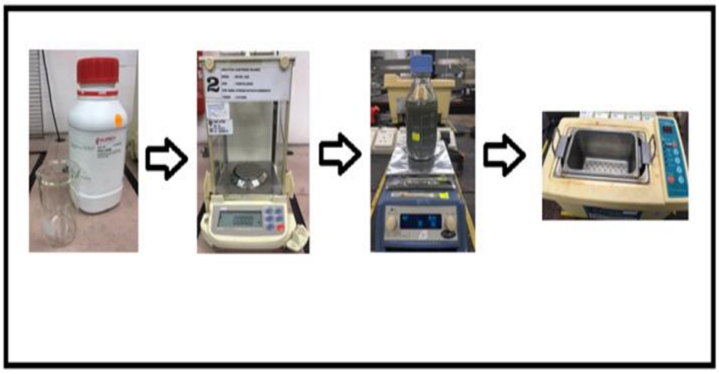

Figure 1. Steps in preparation of oil samples

The breakdown voltage test was executed on each oil sample to measure the electrical breakdown strength of the oils. The oil tester used a mushroom type of electrodes with separation of 2.5mm as shown in Figure 2. The oil sample was put into a test cell with the dimension of 10 cm in length, 9.2 cm in width and 10 cm in height. AC voltage of 6 kV was applied across the electrodes whilst conducting this experiment. During the test, the applied voltage with a rise rate of 1kV every 15sec for the breakdown test was carried out until the breakdown occurred. The test circuit is shown in Figure 3.

For each of the samples provided, the breakdown voltage test was carried out at a constant room temperature of 27°C. Before the breakdown voltage test takes place, the presence of bubbles content in the samples must be removed. The other oils with additives SiC are also being measured to investigate the breakdown voltage at each percentage. The breakdown voltage of the liquid insulation test follows IEC 60156 Standard.

Viscosity can be divided into categories, which are dynamic viscosity and kinematic viscosity. The experimental setup is done for dynamic viscosity but through a formula, it can calculate the kinematic viscosity as shown below. Each oil sample was maintained at a 27°C temperature in the measurement and done under controlled condition as per IEC 296 standard. However, the oil samples are placed into the Hamilton Beach mixer for five minutes in order to blend the oil with the additives well before conducting the test. The circulating cup of Viscometer Model 35 needs 350ml of oil samples and operate under five minutes duration with 600 rpm constant speed.

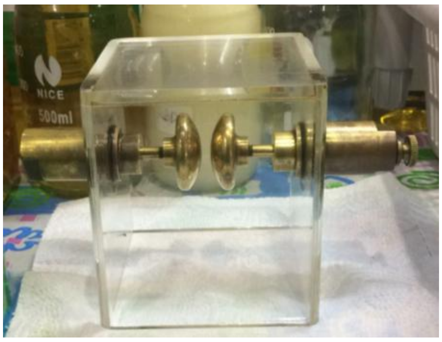

Figure 2. Test cell apparatus with electrodes

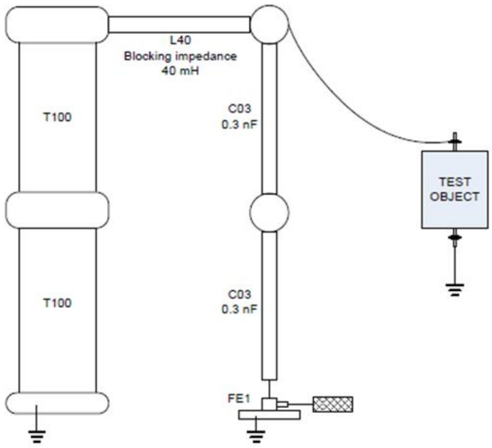

Figure 3. Schematic drawing of test setup

$$\textit{Kinematic Viscosity (centistoke)} = \frac{DynamicVis\cos ity(centipoise)}{Density(g/mL)}$$

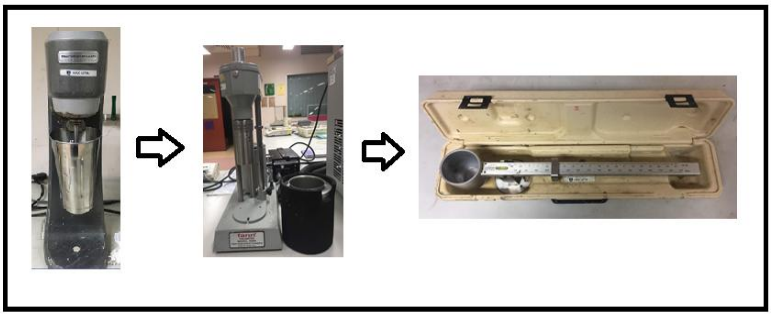

Fig. 4: The measurement apparatus for dynamic viscosity test.

Discharges (PD) measurement has been widely applied to diagnose the condition of the electrical insulation in operating apparatus such as switchgear, transformers, cables, as well as motor and generator stator windings [8]. The method used to evaluate the PD measurement is through the technique PSA that records the initial PD value when injecting the voltage and when the breakdown voltage occurred. Figure 5 below represent the circuit used in this experiment to measure the PD value, following the precondition of IEC 60270 standard. The ICM Compact will display the PD pulse of the samples and recorded in the personal computer (PC). After the data were recorded, the average values were analysed.

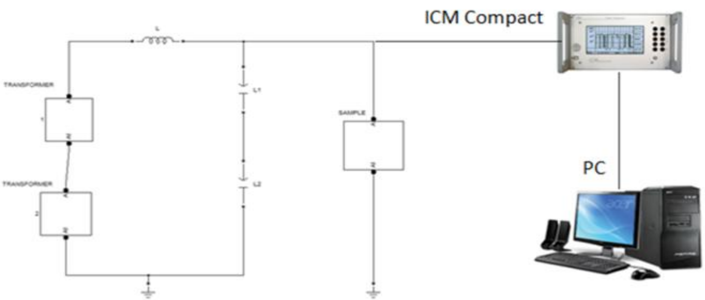

Figure 5. Schematic diagram of partial discharge measurement circuit

3. RESULTS AND DISCUSSION

The amount of SiC nanopowder in gram (g) to be added to the oil samples is based on the given formula below, where the amount of additive to be added in percentage, 0.1%, 0.2%, 0.3%, 0.4% and 0.5% , is converted to gram (g).

$$W\,(nm) = \frac{\rho(nm)xV(oil)xPVF\,(nm)}{100}$$

Table 1. Conversion of SiC percentage to weight (g)

PVF (nm) %	V oil (ml)	ρ (nm) (g/cm)	W (nm) (g)
0.10	500	4.23	2.115
0.20	500	4.23	4.230
0.30	500	4.23	6.345
0.40	500	4.23	8.460
0.50	500	4.23	10.575

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One of the important parameters observed in the experiment is the breakdown voltage of the samples. Firstly, the breakdown voltages of the raw sample of PO and CO were obtained. The highest value of breakdown voltage of the raw sample PO is 33.28 kV. According to Figure 6 below, the breakdown voltage of sample with 0.1% SiC added was 19.73 kV. The values of breakdown voltage for 0.2% and 0.3% of added SiC were 21.21 kV and 19.24 kV respectively. However, the breakdown voltage of at 0.4% was highest at 22.12 kV. It can be seen that the breakdown voltages with SiC additive were lower than that of raw PO sample. It also shows that the best doping of Silicon Carbide for PO is at 0.4%.

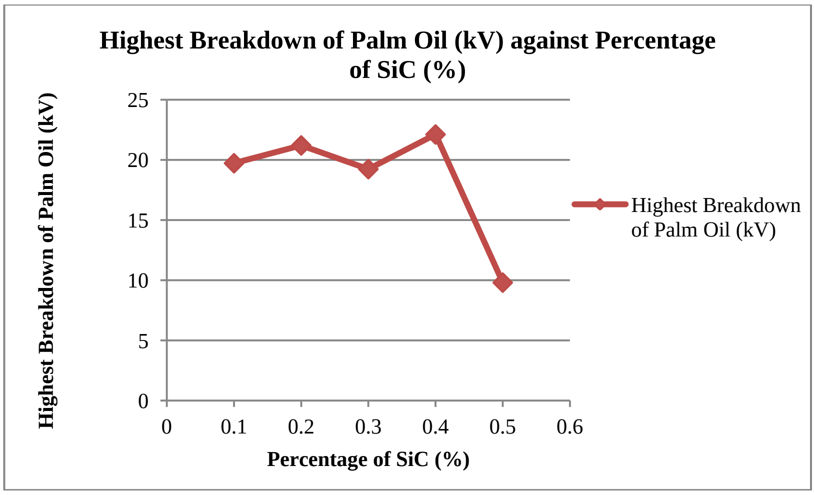

Figure 6. Graph of Breakdown Voltages of PO at Different Percentages of SiC doping

Figure 7 shows the graph of breakdown voltages for CO with different percentages of doping with SiC. It can be seen that at 0.3% of SiC, the breakdown voltage reached the highest value which was 28.04 kV. For the raw CO sample, the highest breakdown voltage was 36.98 kV. It can be concluded that the breakdown voltages of CO with SiC nanopowder added were lower than that of raw PO sample. It also shows that the best doping of Silicon Carbide for CO is at 0.3%.

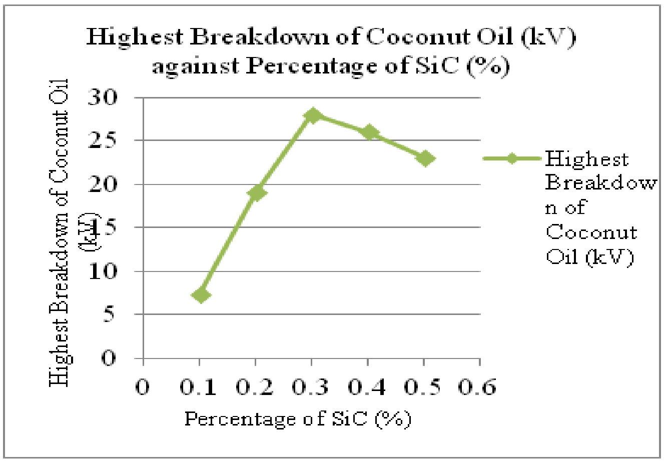

Figure 7. Graph of Breakdown Voltages of CO at Different Percentages of SiC doping

Based on the observations, the results were compared to the standard breakdown voltage of Mineral Oil (MO) which is 6.10 kV. In practical operation, the power transformer will generate heat while the insulating oil serves as the cooling medium. Thus, it is better to have an insulating medium with higher value of breakdown point to withstand any condition because the electro-insulating oils in terms of breakdown voltage and electrical breakdown strength values were affected by the weather exposure [8].

The results of the viscosity tests were observed. It was found out that the viscosity of these oil samples has increased when the additive of SiC was added into the raw sample of PO and CO. The results are shown graphically below. The measurement of AC breakdown voltage can be affected by the increasing of the viscosity of the oil [9].

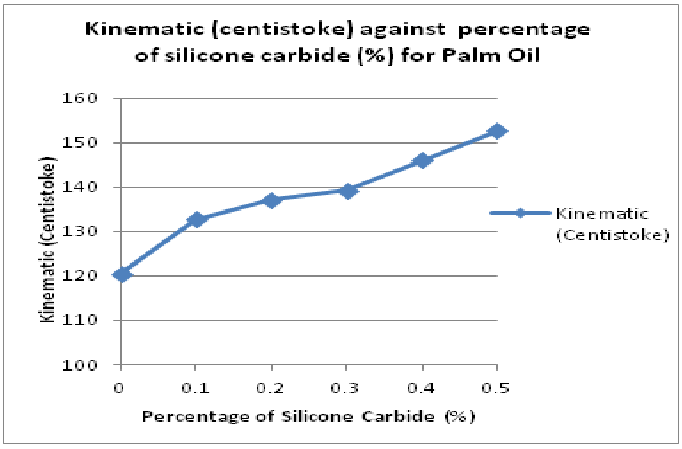

Figure 8. Viscosity of PO versus Percentage of SiC doping

Figure 8 shows that the kinematic viscosity of PO increases as the percentage of SiC added was increased in the oil samples. Figure 9 shows that the values of kinematic viscosity of the CO continues to increase as the percentage of SiC doping was increased, although there was aslight drop in the viscosity at 0.3 % doping. The results can be compared to the kinematic viscosity mineral oil (MO) which is 12.4 mPa.s/cP.

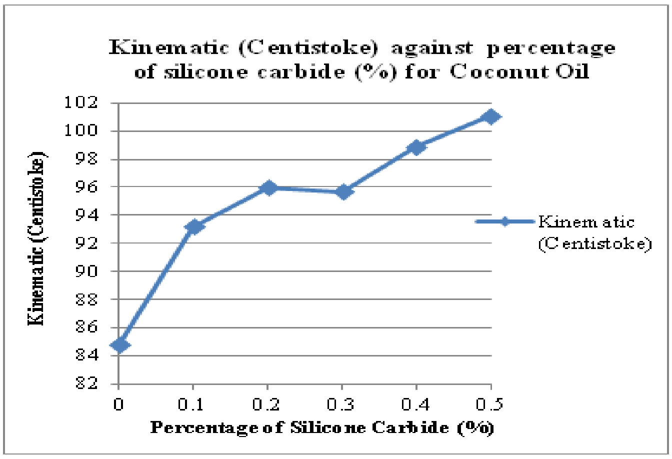

Figure 9. Viscosity of CO versus Percentage of SiC doping

The results of the partial discharge (PD) measurements are shown in Figure 10 below. After the voltage was injected into the circuit, the ICM compact will produce a pulse for each second. Then, the average value was calculated. The measurement of the pulses were taken at the beginning when the initial voltage was injected, before the breakdown occurred and lastly when the oil reached the breakdown point. As illustrated in Figure 10, the average values of PD in both raw samples of CO and PO were the highest at 118.1 pico-Coulomb (pC) and 161.9 pC respectively. The average PD value of 0.1% SiC doping of CO at 3.59 pC was the lowest. The average PD value increased to 43.77 pC at 0.3% SiC doping of CO, which was the highest value of PD for doped samples. The results showed clear evidence that adding Silicon Carbide as additive to vegetable oils like CO or PO has reduced immensely the values of partial discharges in the oils, contributing to the improved insulating attribute of the oils to be used as transformer insulating oil.

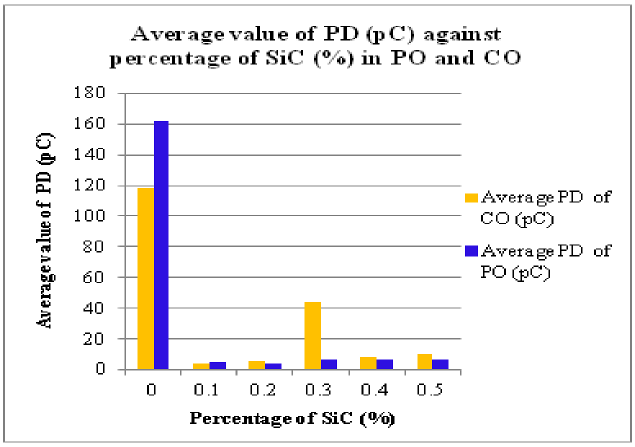

Figure 10. The average value of PD on sample of oils contain different percentages of SiC doping

4. CONCLUSION

The main objective of this research is to measure the insulating properties of local vegetable oils, namely PO and CO as substitutes to mineral oil to be used as transformer oil. It was found that the breakdown voltage of raw PO and CO is 33.28 kV and 36.98 kV respectively. Meanwhile, the breakdown voltage of MO is lower than those vegetable oils, which is 6.10 kV. When different percentages of SiC nano particles were added into each oil sample, the breakdown voltages have drop low, but still higher than the breakdown voltage of MO. The breakdown voltage of PO at 0.4% doping was highest at 22.12 kV. This shows that the best doping of Silicon Carbide for PO is at 0.4%. It can be seen that for CO at 0.3% of SiC doping, the breakdown voltage reached the highest value which was 28.04 kV. This shows that the best doping of Silicon Carbide for CO is at 0.3%. Thus, in terms of the breakdown voltage alone, it does look like the vegetable oils do have the potential to substitute the transformer oil, even better. However, the viscosity of the vegetable oils increases as the percentage of the SiC doping was increased.

The results of the partial discharge (PD) measurements showed a very promising property of the vegetable oils as an insulating medium. Presence of partial discharges can contribute to the final breakdown of the insulating medium, the higher the values of partial discharges, the higher will be the risk of breakdown. Adding Silicon Carbide nanoparticles to the oils has reduced the partial discharges in the oils very significantly, giving a very promising attribute to the vegetable oils as insulating medium for transformers. Hopefully, this research will contribute to society which is in line with NKEA (National Key Economy Area) in the production of vegetable oil in Malaysia.

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