Study of Breakdown Voltage of Vegetables oil with SiO2 Nanoparticle Additive

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ABSTRACT

This paper investigates the suitability of vegetable oils to replace mineral oil based on its AC breakdown voltage, partial discharge and viscosity. The purpose of the study is to analyze the effect of the nanofluids containing SiO2 nanoparticle in vegetables oils; namely, Coconut oil and Palm oil. A nanofluid is a fluid containing nanoparticles. However, the precise effects on the electrical properties is still uncertain. For decades, transformers use petroleum-based mineral oil because of its good dielectric properties and cooling capability. Coconut oil (CO) and Palm oil (PO) are thought to be suitable alternatives to replace mineral oil as transformer oil as they are sustainable and available in plenty as natural resources. It was obtained in this study that the breakdown voltages of these raw oils have fulfilled the standard specifications of good insulating liquid. However, the addition of SiO2 did not improve the AC breakdown voltage and viscosity of coconut oil and palm oil at different temperatures. However, the addition of SiO2 gave positive results in the values of partial discharges in which the presence of the nanoparticles has greatly reduced the mean volume of partial discharges for both coconut oil and palm oil.

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1. INTRODUCTION

In an electrical power system, transformer is one of the important parts in the system. Transformer is an electrical device, having no moving part, which transfer electrical power from one circuit to another by electromagnetic induction [1]. There are two types of cooling methods of power transformers; dry-type and oil-type cooling methods. Dry-type transformers use air or gas as coolant medium and generally used for indoor application. While, oil-type transformer use oil as coolant medium called transformer oil or insulation oil and usually being used for outdoor application.

Transformer oil is oil that is stable at high temperature and has excellent electrical properties. Hence it is used to be a coolant to extract heat from the core and the windings of the transformer. The insulating oil fills up pores in fibrous insulation and also the gaps between the coil conductors and the spacing between the winding. The important properties of the transformer oil such as dielectric strength, flash point, viscosity, and pour point need to be considered [2].

To assure that a particular oil is acceptable for use in a transformer, the value measured for its relevant characteristics are compared with standard specification or guide developed by a group made up of experts in transformer and transformer materials. The measurement is based on the standard published by International Electrotechnical Commission (IEC). Mostly, the measurements refer to IEC 60296: fluids for electrotechnical applications – unused mineral insulating oils for transformers and switchgear.

For decades, transformer use petroleum based mineral oil because of its good dielectric properties and cooling capability. However, mineral oil is non-biodegradable, and cannot be changed to a harmless natural state by the action of bacteria, and may therefore damage the environment. The usage of insulating oil in the transformer requires a large volume of oil. A typical unit mounted on a pole distribution system rated at 25kVA contains about 20 gallons or 75.7 liters of oil [2]. Almost all country in the world used mineral oil as insulating oil in the transformer. Hence, by substituting the mineral oil with vegetables oil, which is biodegradable and safe to environment, the usage of mineral oil can be decreased.

One of the vegetable oil that can potentially substitute the mineral oil is coconut oil. Coconut oil is a product from coconut tree. The coconut tree (Cocos nucifera) is a member of the family Arecaceae (palm family). Coconut oil is extensively used for edible and industrial purpose. Recent competition with palm oil for land in Malaysia has result in decline of the total area under coconut cultivation. Hence, crude coconut oil is mostly obtained from Indonesia, Philippines and India [3]. The coconut oil is suggested because it is biodegradable and environmental friendly.

Another potential vegetable oil is palm oil. The oil palm tree (Elaeis guineensis) is a native to West Africa and was imported into South East Asia in the mid 19th century [4]. Malaysia is the second largest producer and exporter of palm oil in 2006 [5]. Abundance of palm oil trees in Malaysia nowadays, make palm oil is easily obtained. The alternative to use palm oil is because of its sustainability. To make sure the sustainable development in oil palm plantation and production, Malaysia has been an active member of Roundtable on Sustainable Palm Oil (RSPO).

Many studies have been done to convert coconut oil and palm oil as transformer oil. From the studies, it shows that coconut oil and palm oil has good potential to become liquid insulating material in transformers. Suwarno et. al has discovered that refined coconut oil and refined, bleached and deodorized palm oil may be used as alternative for insulator oil due to its higher breakdown voltage. While, A.A.H. Zaidi et. al has compared the electrical performance of coconut oil, virgin coconut oil and palm oil on the power transformer. Amongst the oils, virgin coconut oil has the most potential properties because it has high breakdown voltage, low moisture content and low viscosity [6]-[9].

In contrast, there are very few papers investigate the vegetable oils with nanoparticle additive. In current years, some researchers have added nanoparticle additive with mineral oil to investigate the effect on the oils parameters [10], [11]. Nanoparticle is a particle between 1 and 100 nanometers (nm) in size. Nanofluids are potentially used in many applications in heat transfer, including microelectronics, fuel cells, pharmaceutical processes, hybrid-powered engines and others. Nanofluids are good in thermal conductivity and the convective heat transfer coefficient compared to the base fluids [12]. There are also conducted studies on the vegetable insulation oil dispersing with Fe_3O_4 nanoparticle [13], [14].

There are many type of nanoparticles. One of the nanoparticle is silicon dioxide or namely silica with chemical formula SiO_2. H. Jin et al. have done a research on the AC breakdown voltage and viscosity of mineral oil based SiO_2 nanofluids [15]. The results give improvement on the AC breakdown voltage of mineral oil. The breakdown voltage increases with particle concentration. Instead of using mineral oil as in the above paper, the usage of vegetable oil is suggested.

This study was conducted to investigate the effect of SiO_2 nanoparticle on the vegetables oil. The breakdown voltage tests and viscosity tests on coconut oil and palm oil with and without additive were performed at two different temperatures. Besides, partial discharge measurement of the samples will be recorded. All tests will be performed at 30^oC and 40^oC to be compared with the IEC Standard. At the end of the study, the relationship between AC breakdown voltage and viscosity will be obtained. The effect of SiO_2 nanoparticle on the AC breakdown voltage, viscosity and partial discharge of coconut oil and palm oil will be discussed.

2. RESEARCH METHOD

This section explains the experiment setup for breakdown voltage test using standard mushroom electrode arrangement. The apparatus required for measurement of liquid breakdown, description of equipment used for breakdown test and experimental procedure for conducting the liquid breakdown voltage are discussed.

2.1. Test Samples

The samples used in this study are based on coconut oil (CO) and palm oil (PO) obtained from readily available cooking oils in the market. The SiO_2 nanoparticle was purchased from sigma-aldrich. The particle size is less than 50nm with density 1.087g/ml at 25^oC. For each type of oils, the SiO_2 nanoparticles will be added at different volume percentage of 0.1%, 02%, 0.3%, 0.4% and 0.5%. Firstly, the SiO_2 nanoparticles were weighed based on formula in Equation (1). Table 1 show the weight of SiO_2 based on the volume percentage.

$$W(nm) = \frac{\rho(nm) \times V(oil) \times PVF(nm)}{100} \quad (1)$$

Where;
W(nm) = Weight of nanoparticles (g)
ρ(nm) = Density of nanoparticle (g/cm^3)
V(oil) = Volume of oil (ml)
PVF(nm) = Volume percentage of nanoparticles (%)

Table 1. Weight of SiO_2 Based on the Volume Percentage

PVF_{nm} (%)	V_{oil}(ml)	ρ_{nm}(g/cm)	W_{nm}(g)
0.1	500	1.087	0.5435
0.2	500	1.087	1.0870
0.3	500	1.087	1.6305
0.4	500	1.087	2.1740
0.5	500	1.087	2.7175

The mixtures were stirred with magnetic stir at 60oC. Then each mixture sample was put into ultrasonic cleaner treatment (Figure 1) at 60oC for 180 to 300 minutes until each mixture sample became homogeneous and no sedimentation could be observed inside the nanofluids.

Figure 1. Ultrasonic cleaner treatment

2.2. AC Breakdown Voltage Test

The AC Breakdown Voltage gives the value of electrical potential at which the oil will stop the function of insulating and will eventually collapse. A higher value of breakdown voltage is required to ensure the safety of transformer. Hence in this study, AC breakdown voltage of coconut oil and palm oil were to be determined. The test was conducted according to IEC 60156 test method standard, which use a pair of spherical electrode with a gap of 2.5mm. The oil samples should immersed the spherical electrode before the test was conducted as shown in Figure 2. For each sample, a 6 kV of AC voltage was applied during the starting of the test, with a voltage rise rate of 1 kV over 10 seconds interval.

Figure 2. Spherical electrode with 2.5mm gap immersed with vegetable oil

The AC breakdown voltage test was repeated 3 times for each sample. The test sample was allowed to rest for one minute after the previous breakdown test to allow breakdown by-products to clear the gap.

Each sample will be tested at two different temperatures which were 30°C and 40°C. For each sample, the test was started at 40°C and the sample was allowed to cool down to 30°C before a series of tests was perform at the lowered temperature.

2.3. Measuring Partial Discharge

Partial discharge (PD) measurement is one of the most important non-destructing methods for the detection of insulation defects in electrical power equipment. The PD measurement was done according to the IEC Standard 60270 that describes the PD measuring circuit, the measuring instruments, the calibration and the measuring procedures [16]. The most important PD quantity is the apparent charge of PD pulse. It is that charge which, if injected within a very short time between the terminals of the test object, would appear on the PD detector.

In this study, High Volt partial discharge detector, type ICM Compact (Figure 3) available in the High Voltage Laboratory, Uitm Shah Alam, was used. The PD measurement was taken concurrently during the AC breakdown voltage tests until the breakdown occurred.

Figure 3. High Volt partial discharge detector, type ICM Compact

2.4. Viscosity Test

Viscosity is one of the important parameters to be determined for transformer oil. Viscosity influences the breakdown voltage and the thermal properties of the oil. Hence, it is importance to investigate the effect of SiO_2 nanoparticle in the vegetable oils. For this viscosity test, in Figure 4, a Fann Viscometer 35SA model was used with a water bath to ensure the oil temperature remains constant at 40°C. The test was conducted according to IEC 296 standard.

Figure 4. Fann Viscometer 35SA with water bath

3. RESULTS AND ANALYSIS

3.1. Ac Breakdown Voltage Test

The AC breakdown voltage test for transformer oil was performed to find out the maximum withstand voltage of the oil samples. The mean breakdown voltage value was obtained from the repeated test from the breakdown voltage test conducted. Figure 5 show the results of breakdown voltage tests of coconut oil and palm oil at 30°C and 40°C without any additive. As can be noticed, coconut oil at 30°C shows the highest breakdown voltage of 36.65 kV. Palm oil at 40°C has the lowest breakdown voltage compared to other samples. The value of breakdown voltage for the raw oils were greater than 30 kV at 30°C and 40°C, which fulfills the IEC 60296 standard for transformer oil.

However, when the vegetable oils were added with SiO_2 nanoparticles, the breakdown voltage (BDV) of coconut oil and palm oil at 30°C and 40°C had reduced to below 30 kV which did not fulfill the IEC 60296 Standard. On Figure 6 and 7, the results of BDV of the coconut oil and palm oil with varied percentage of additive were shown. The highest value of BDV recorded by palm oil sample was at 0.1 % of SiO_2 at 30°C, and the value was 25.46 kV. Coconut oil gave the lowest value at 0.3 % of SiO_2 at 40°C which was 9.3 kV.

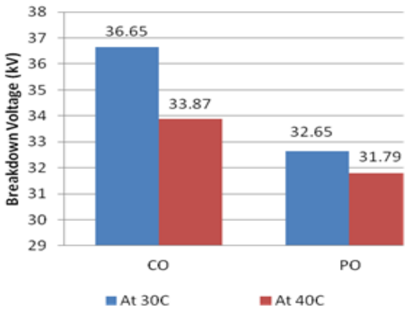

Figure 5. breakdown voltage of raw coconut oil and palm oil

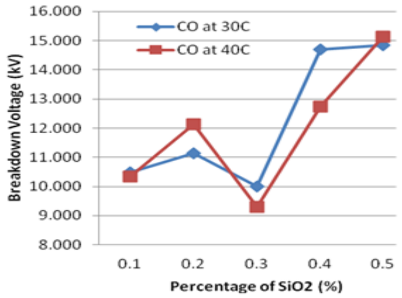

Figure 6. Breakdown voltage of coconut oil

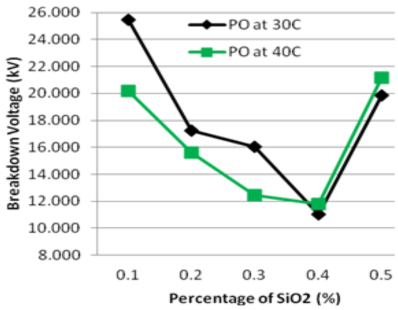

Figure 7. Breakdown voltage of Palm

From the results obtained, clearly it can be observed that the addition of SiO_2 nanoparticle did not improve the breakdown voltage. Both the oils had lowered breakdown voltages, dipping to a minimum at 0.3% of additive volume for coconut oil, and dipping to a minimum at 0.4% of additive volume for palm oil. This observation was similar to the result obtained by H. Jin et al, which stated that addition of SiO_2 did not provide improvement in the breakdown voltage of mineral oil.

3.2. Partial Discharge

Partial discharges (PD) is the localized breakdown or ionization that produces ions and electrons. PD is caused by discontinuities or imperfections in the insulation system. Thus, PD testing gives an indication of deterioration of the insulation and is an indicator of incipient faults. In this study, the amounts of Partial Discharges (PD) were determined. Table 2 showed the mean PD of the palm oil and coconut oil samples with and without additives. The unit of measuring the partial discharge is pico-Coulombs (pC). It can be seen that, the addition of the SiO_2 nanoparticles in the coconut oil and palm oil samples had contributed to the decreasing of PD in the oils.

Table 2. Mean Partial Discharge of Coconut oil and Palm oil

Percentage of SiO2 (%)	Partial Discharge (pC) Coconut Oil		Palm Oil	
	At 30^{o}C	At 40^{o}C	At 30^{o}C	At 40^{o}C
0 (no additive)	384.38	650.88	120.00	189.6
0.1	9.16	8.62	8.08	8.19
0.2	7.78	6.99	6.99	7.63
0.3	7.61	6.94	7.03	7.17
0.4	8.45	8.37	7.07	6.94
0.5	8.37	7.76	8.03	9.46

The PD of raw coconut oil at 40oC was the highest which was 650.88 pC, and at 30oC, the mean PD was 384.38 pC. For raw palm oil, the mean PD was 189.6 pC at 40OC and 120 pC at 30OC. This shows that the partial discharge activities in vegetables oil increases as the temperature increases. In contrast, with coconut oil and palm oil added with SiO2 nanoparticles, the mean PD for both oils were between 6 to 10 pC. As the temperature increased, the mean partial discharges of coconut oil added with SiO2 nanoparticles had slightly decreased. While, the mean PD of palm oil had increased slightly as the temperature was increased.

3.3. Viscosity Test

Viscosity is one of the important parameters in choosing suitable transformer oil. The lower viscosity has better cooling performance. While, increase in temperature will reduce viscosity. As showed in Figure 8, the viscosity of the palm oil and coconut oil at 40^{o}C was lower than 30^{o}C. However, at 30^{o}C, viscosities of palm oil and coconut oil with additive had increased slightly compared to raw palm oil and coconut oil values. The coconut oil with additive increased from 61cSt to 76cSt. While, for palm oil, it increased from 97cSt to 108cSt.

In this study, it was obtained that coconut oil has lower viscosity compared to the palm oil. This indicates a good result since the low viscosity acts as a good insulation and cooling liquid. However, IEC60296 standard has state that the standard for the viscosity of transformer oil was 13cSt at 40oC. This makes the vegetable oils not suitable because of the higher viscosity values. The addition of SiO_2 nanoparticle did not give any improvement to the viscosity of the oils.

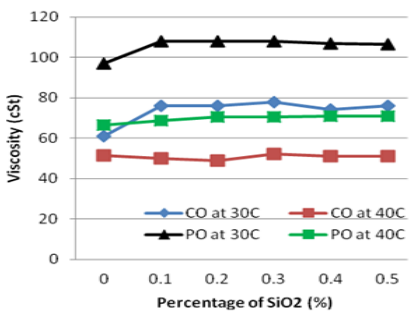

Figure 9: Viscosity of Coconut oil and Palm oil

4. CONCLUSION

The main objective of this study is to determine the AC breakdown voltage, partial discharge and viscosity of the vegetable oils with and without SiO_2 additive, and observe if any of the oils can be suitable to be an alternative to the mineral oil used as transformer oil. Hence, experiments were conducted to two different vegetables oil; namely, coconut oil and palm oil to obtain the AC breakdown voltage, partial discharge and viscosity of the oils at two different temperatures; 30^{o}C and 40^{o}C with addition of silicon dioxide (SiO2). The volume fractions of the SiO_2 additive were varied for each type of the oils which were 0.1%, 0.2%, 0.3%, 0.4% and 0.5%.

As a conclusion, the breakdown voltage of the oils with addition of SiO_2 were lower than raw oils. For raw oils, it was obtained that the breakdown voltage of coconut oil was higher than palm oil at both temperature; 30^{o}C and 40^{o}C. The breakdown voltages of raw oil fulfill the IEC 60296 Standards while the oil with additives did not.

This study also demonstrated that the addition of SiO_2 nanoparticle into the oils did not improve the viscosity of both oils. The graphs of viscosity of the oils with additives at both temperatures of 30^{o}C and

40^oC were almost linear. It was obtained that as the viscosity of vegetables oil with SiO_2 nanoparticle at 40^oC increased, the AC breakdown voltage of the oil were decreased.

It can be concluded that silicon dioxide SiO_2 is not a suitable additive for improvement of the breakdown voltage, as well as the viscosity of the oils.

However, for the partial discharge, the addition of SiO_2 did give positive results in which it has greatly reduced the mean partial discharges of both coconut and palm oil. The highest mean partial discharge of the palm oil was at palm oil added with 0.5% SiO_2 which was 9.46 pC. For coconut oil, the highest mean partial discharge was 9.16 pC, when the additive added was 0.1% SiO_2. It can be concluded that SiO_2 naoparticles added to the oils can greatly diminish the production of partial discharges in vegetable oils, namely coconut oil and palm oil.

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