Effect of Electrical Ageing on Electrical Properties by Mixing of Coconut Oil and Mineral Oil as Dielectric Material

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***Abstract* - Transformers are very important and costly apparatus in power system especially in high voltage. Without them, utility companies would not be able to transmit and distribute electricity generated at remote power stations. Great care to be exercised to see that the transformers are not damaged. Oil is used as an insulator and coolant in transformers and by monitoring its condition the transformer's overall health is determined. Temporary failures due to overvoltage are reinsulated quickly by liquid flow to the affected area. Since years ago, petroleum-based mineral oil has been used to serve the dual purpose of insulation and heat dissipation. However, this petroleum will be come to an end because it is a non-renewable source. Most importantly is the inability of mineral and petroleum oils to comply with environmental regulation laws. Therefore, mixture of RBD coconut oil and mineral oil will be used in this project as alternative liquid insulation. According to previous research, natural vegetable oils have been found to meet the specifications IEC 60296. Their biodegradability makes them safe for use in densely populated areas and close to waterways. This also makes them to be environmentally compliant and avoidance of sanctions from regulatory agencies. Since they are from renewable sources, their production and utilization is simple and cost effective. Overall, this can ensure sustainable development.**

***Index terms* – Power transformer, liquid insulating, mineral oil, RBD Coconut Oil, ageing, viscosity, breakdown voltage, dissipation factor.**

I. INTRODUCTION

Mineral oils are the most common insulating liquids. However, due to the poor biodegradability, transformer mineral oil insulation is now slowly being replaced by other oil especially vegetable oils [1]. A number of considerations enter into the selection of any dielectric liquid. There are several important properties such dielectric strength, conductivity, viscosity, dielectric constant, dissipation factor, flash point and pour point and all of them has to be considered when qualifying certain oil as transformer oil [3]. The quality of the oil is very important. Many new liquids have since been developed which have no adverse environmental hazards due to their biodegradability and environmentally friendly nature. These include silicone oils, synthetic and fluorinated hydrocarbons.

Coconut oil has been used mainly for edible and industrial purposes but it also can be as an alternative to the mineral oils for transformers. Unlike virgin coconut oil, refined coconut oil has no coconut taste or aroma. RBD oil is used for home cooking, commercial food processing, and cosmetic, industrial, and pharmaceutical purposes [2]. Coconut oil has been tested for use as a feedstock for biodiesel to be used as a diesel engine fuel. In this manner, it can be applied to power generators and transport using diesel engines. It also has been tested for use as an engine lubricant and as transformer oil.

II. PRELIMINARY STUDY

Preliminary investigations on coconut oil show that most of its physical properties are within the limits for liquid insulation according to IEC 60296. They include dielectric strength, viscosity, pour point, flash point, and moisture content [1]. Even though the viscosity of coconut oil is higher than the recommended value, it is less than some of the vegetable oils currently used as alternative oil. The pour point of coconut oil has the highest diversity from the recommended level. Table I shows the comparison of properties between Coconut Oil and Standard Oil (IEC60296).

TABLE I. COMPARISON OF PROPERTIES OF OILS [3`1]

Property	**Coconut Oil**	**Standard Oil (IEC60296)**
Dielectric Strength [kV]	60	50
Viscosity [cSt at 40°C]	29	13
Pour point [°C]	23/20	-40
Flash point [°C]	170-225	154
Moisture content [mg/kg]	1.0	1.5
Density [kg/dm3] at 20°C	0.917	0.895

III. METHODOLOGY

A. Samples and Test Procedures

Six different samples of mixture of Refined, Bleached and Deodorized Coconut Oil (RBDCO) with Mineral Oil were taken for the study. The volume for each sample is 700*ml*. Details of the samples are given in Table II Table III. Fig. 1 show the samples of RBDCO and Mineral Oil that used in tests.

Fig 1. Samples of RBDCO and Mineral Oil that used for testing

B. Viscosity

Before start the test, all the oil samples shown in Table II were sent to Geology Laboratory to be tested on the chemical properties of the oil such as viscosity. The equipment used for viscosity test is Viscosity Houillon VH2 as shown in Fig. 2. The temperature is setting at 40°C. The values of viscosity can be obtained by using Viscometer software. It has 3 piknometers which is each of the piknometer has volume of 180µl.

Fig 2. Viscosity Houillon VH2

C. Breakdown Voltage

For breakdown voltage test, all samples were used as shown in Table II. The samples were tested at different temperatures which were 40°C, 50°C and 60°C. In the breakdown voltage test equipment, a voltage of 5kV was injected between two spherical electrodes which is mushroom type separated by a gap of 2.5mm distance and immersed in the oil as shown in Fig. 3.

Fig 3. Test cell filled with test sample

D. Ageing

The procedure of the ageing process is done based on the Breakdown Voltage test. For ageing test, only two samples were selected. Table III shows the samples used for ageing test. The applied voltage for ageing process is maintained at 10kV. Different ageing periods which are 1 hour and 3 hours were selected for both different samples. Both samples were heated at a starting temperature 60°C. After all samples were aged, the applied voltage is increasing to 30kV. After breakdown, the temperature of samples was measured. Breakdown voltage measurement was done. Fig. 4 shows the setup circuit for Breakdown Voltage and Ageing tests.

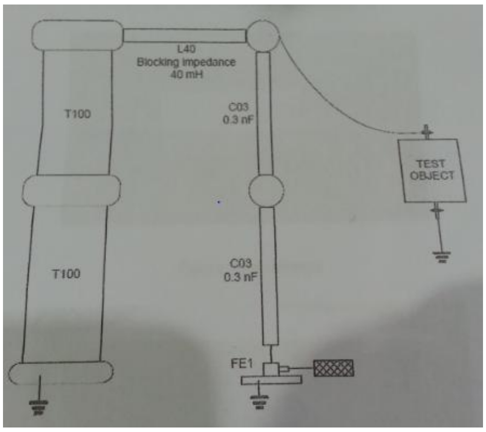

Fig 4. Testing Circuit for Breakdown Voltage and Ageing tests

E. Dielectric dissipation factor (Tan δ)

In dielectric dissipation factor (tan δ) tests, two samples were selected same as the sample used in the ageing test as shown in Table III. The results were obtained by using Capacitance & Tan δ Measuring Bridge as shown in Fig. 5. The applied voltage for both samples was 5kV. The samples were tested at three different temperatures which are 40°C, 50°C and 60°C.

Fig 5. Capacitance & Tan δ Measuring Bridge

TABLE II. SAMPLES USE FOR BREAKDOWN VOLTAGE AND VISCOSITY TEST

Sample No	**Sample**
1	20% RBDCO + 80% Mineral Oil
2	40% RBDCO + 60% Mineral Oil
3	60% RBDCO + 40% Mineral Oil
4	80% RBDCO + 20% Mineral Oil
5	100% RBDCO
6	100% Mineral Oil

TABLE III. SAMPLES USE IN AGEING AND DIELECTRIC DISSIPATION FACTOR (TAN δ) TEST

Sample No	**Sample**
1	20% RBDCO + 80% Mineral Oil
2	80% RBDCO + 20% Mineral Oil

IV. RESULTS AND DISCUSSION

A. Viscosity

Table IV shows the viscosity levels for all tested samples. Fig. 6 shows the variation of viscosity levels for each piknometer.

TABLE IV. VISCOSITY LEVEL MEASUREMENTS

Sample No	**Sample**	**Viscosity (cSt)**		
		Piknometer		
		1	***2***	***3***
1	20% RBDCO + 80% Mineral Oil	13.40	11.04	11.03
2	40% RBDCO + 60% Mineral Oil	15.49	12.61	12.59
3	60% RBDCO + 40% Mineral Oil	21.63	18.18	18.06
4	80% RBDCO + 20% Mineral Oil	26.02	21.81	21.74
5	100% RBDCO	32.48	26.76	26.43
6	100% Mineral Oil	10.75	8.80	8.71

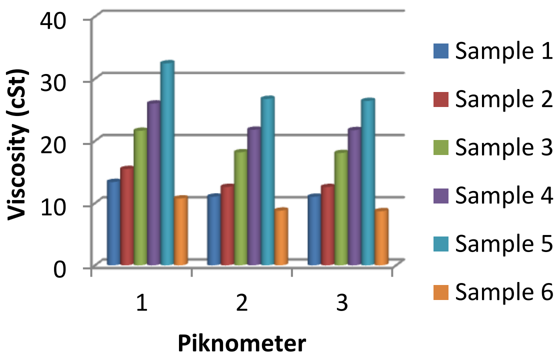

Fig 6. Variation of viscosity levels for each piknometer

According to Table IV, the viscosity measurement was performed in three different piknometer that will give different value for each piknometer. However, the volume for each piknometer is same that is 180 µl.

According to the Fig. 6, it is clearly show that sample 5 which is pure RBDCO is more viscous compared to sample 6 which is pure Mineral Oil. Samples that have more amount of RBDCO have high value of viscosity while samples that have more amount of Mineral Oil have low value of viscosity. In other words, the viscosity levels increased in the samples that have more amount of RBDCO than Mineral Oil. However, for a good oil insulator, it is important to have a low viscosity level to facilitate convection [3].

From Table IV, sample 1 is less viscous compared to other mixtures sample. The sample meets the standard requirement of viscosity for transformer oil. It is important to have a low viscosity to make cooling process in transformer become faster. In order to reduce the viscosity levels, the oil must be heated at the higher temperature from the standard rate of temperature which is 40**°C**.

B. Breakdown Voltage

Table V shows the results of breakdown voltage measurements for all tested samples. A graphic presentation of the breakdown voltage between all samples along the temperature is described in Fig. 7.

TABLE V. BREAKDOWN VOLTAGE RESULTS

Sample No	Sample	Temperature (°C)		
		40	***50***	***60***
1	20% RBDCO + 80% Mineral Oil	32.6	39.53	38.96
2	40% RBDCO + 60% Mineral Oil	33.13	29.88	27.15
3	60% RBDCO + 40% Mineral Oil	29.09	30.9	31.56
4	80% RBDCO + 20% Mineral Oil	34.88	33.9	35.1
5	100% RBDCO	34.58	32.45	35.5
6	100% Mineral Oil	26.13	23.75	22.15

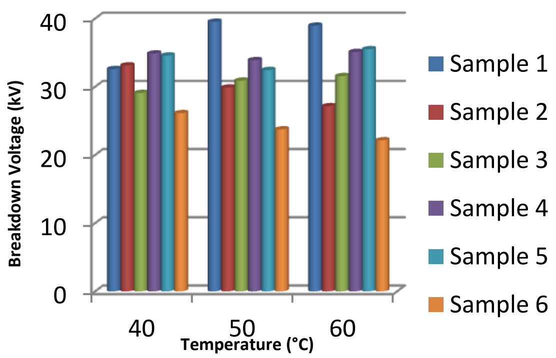

Fig 7. Variation of breakdown voltage with respect to temperature

According to Table V, breakdown voltage measurement was performed for three times for each sample at different temperatures which are 40°C, 50°C and 60°C. The results listed in Table V are the mean values of the breakdown voltage.

From the Fig. 7, by comparing between sample 5 and sample 6, the RBDCO has higher value of the breakdown voltage than Mineral Oil at all different temperatures. This shows that the RBDCO has the higher dielectric strength and can be a better liquid insulating material. In general, the breakdown voltage for coconut oil was comparatively higher than mineral oil. Sample 1 has the highest dielectric strength among other mixture samples. It clearly shows that even though the sample is mixed with small amount of RBDCO, the higher the value of breakdown voltage that will obtained compared to sample 6 that not mixed with RBDCO. However, the breakdown voltage can increases up to 40kV only, because it is the maximum applicable voltage by the apparatus. Water content is one of the factors that affect the dielectric strength in the sample [3]. At a high temperature, water content is low and hence increases the breakdown voltage.

C. Ageing

Table IV shows the breakdown voltage measurements of the samples during ageing. Fig. 8 shows the variation of breakdown voltage levels during ageing.

TABLE VI. BREAKDOWN VOLTAGE RESULTS DURING AGEING

APPLIED VOLTAGE (kV)	AGEING TIME (HOUR)	BREAKDOWN VOLTAGE (kV)	
		20% RBDCO + 80% Mineral Oil	**80% RBDCO + 20% Mineral Oil**
		Sample 1	***Sample 2***
10	0	38.96	35.05
	1	26.30	20.21
	3	37.64	33.02

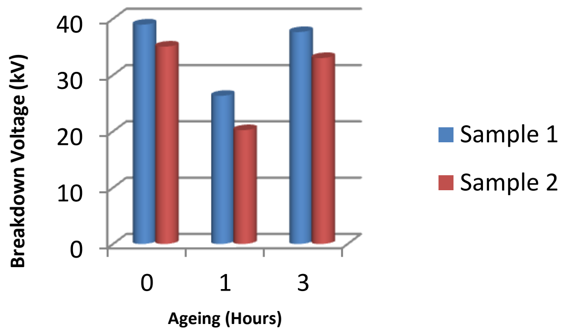

Fig 8. Variation of breakdown voltage with respect of ageing time

Breakdown Voltage measurement was performed in such a way that two samples were used for each ageing stage and three breakdown tests were conducted on each sample. Thus, there were six breakdown voltages obtained for each sample.

The results of each ageing time listed in Table VI are the mean value of the six measurements values.

According to Fig. 8, it is clearly shows that the breakdown voltage of sample 1 was higher than the breakdown voltage of sample 2. At the beginning of the ageing period, the breakdown voltage decreased at 1 hour, and then increased at 3 hours of ageing time but the value was still lower than the breakdown voltage at the beginning of test. It shows that the breakdown voltage increase along with the ageing time. In theory, the moisture content in the samples affects the dielectric strength. Absorption of moisture will reduce the dielectric strength. This is because it increases the water content in the samples. The moisture content of RBDCO is low compared to Mineral Oil. The environment surrounding may affect the results obtained. This is due the cold atmosphere in the laboratory that will increase the moisture content in the samples.

D. Dielectric dissipation factor (Tan δ)

Table VII show the tan δ result for both mixtures of sample along the temperature. Graphical presentation of the dielectric dissipation factor (tan δ) for both samples along the temperature are illustrated in Fig. 9.

TABLE VII. DIELECTRIC DISSIPATION FACTOR (TAN δ) MEASUREMENTS

Temperature (°C)	**Tan δ**	
	20% RBDCO + 80% Mineral Oil	**80% RBDCO + 20% Mineral Oil**
	Sample 1	***Sample 2***
40	0.6478	0.6327
50	0.6614	0.6377
60	0.6080	0.7010

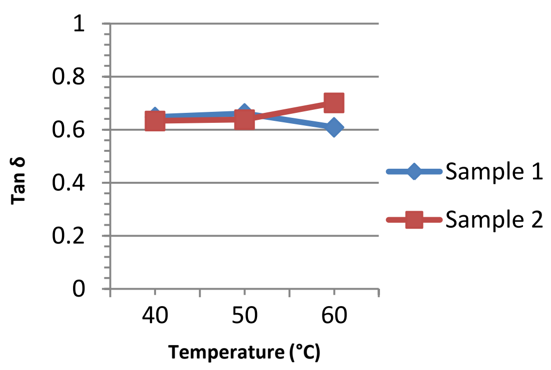

Fig 9. Variation of Tan δ with respect of temperature

According to Table VII, the results were obtained by using Capacitance & Tan δ Measuring Bridge. The applied voltage for both samples was 5kV. The samples were tested at three different temperatures which are 40°C, 50°C and 60°C.

From the Fig. 9, it is clearly visible that the tan δ values for both samples had similar and have higher values than required by the standard. The values of tan δ for both samples increased slightly between 40°C to 50°C, but when the sample heated at 60°C, the value of tan δ for sample 1 decreased while the value of tan δ for sample 2 continue increased.

Usually the viscosity of the oil could be a cause for the enhancement of the value tan δ. Good insulator should have the dissipation factor below 0.005 [5]. Low value of dielectric dissipation factor needed to ensure that the dielectric losses are small. Since the value of tan δ for sample 1 is lower that sample 2 at 60°C, the sample has the possibility for insulating material.

V. CONCLUSIONS

As far as dielectric properties are concerned, Refined, Bleached and Deodorized Coconut Oil shows as a better liquid insulation compared to Mineral Oil. Due to the poor biodegradability and future scarcity of mineral oil, this paper proposes mixture of RBDCO with Mineral Oil can be a good alternative liquid insulation to be used in power transformer. Even though the sample only contains a small amount of RBDCO mixed with Mineral Oil, but it gives the big impact results especially for breakdown voltage results. Its breakdown strength was considerably high compared to the sample that not mixed with RBDCO. Further tests need to be done more in future. Considered all the facts, mixture of Refined, Bleached and Deodorized Coconut Oil with Mineral Oil shows its suitability as an alternative for transformer oil, despite limitations found in some of their physical properties. Furthermore, by comparing the cost for both products, RBDCO is cheaper compared to Mineral Oil and it also easily available.

VI. RECOMMENDATIONS

In order to maintain the usage of mixture of RBDCO with Mineral Oil as a liquid insulation, further studies are recommended to improve some of the physical properties such as viscosity. To reduce the absorption of moisture in the sample, a covered test cell will be use in test. Furthermore, more samples of mixture will be tested for a longer ageing period to get better results of dielectric strength. In addition, different types of coconut oil will be tested in the mixtures to compare their dielectric strength such as virgin and copra.

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