Breakdown Strength of Biodegradable Dielectric Liquid: *The effect of temperature and viscosity*

Rudi Kurnianto & M. Taufan
Dept. of Electrical Engineering
Tanjungpura University
Pontianak, Indonesia
rudikuru@gmail.com

Zainuddin Nawawi
Dept. of Electrical Engineering
Sriwijaya University
Palembang, Indonesia
nawawi_z@yahoo.com

M. Nagao and N. Hozumi
Dept. of Electrical & Electronic Engg.
Toyohashi University of Technology
Toyohashi, Japan
nagao@eee.tut.ac.jp

***Abstract*—The investigation of temperature effect connected with viscosity changes on the breakdown strength of virgin coconut oil (VCO) has been studied by AC voltage and sphere gap electrode system of 2.5 mm distance. The results showed that temperature affected the viscosity and breakdown strength of VCO. The viscosity was inversely proportional to temperature and breakdown strength. The increase of temperature was followed by the increase of breakdown strength. It is considered that the increase of temperature would decrease the fat content in VCO. The same reason could also be used to explain the increase of temperature would decrease the viscosity. However, in a part of experiment, in the range of temperature 55°C and 60°C, we still have no basic reason to conclude, due to the limitation of our data. Thus, this investigation opens the chance for further research and discussion concerning the effect of temperature on the breakdown strength of VCO.**

***Keywords*—VCO, biodegradable, dielectric, breakdown strength, temperature, viscosity, AC voltage, sphere gap electrode.**

I. Introduction

Insulation in power electric equipment, especially in high voltage equipment is one of the most important parts and expensive. Therefore, the use of insulation must be economic yet still has capability as insulators. A kind of insulator has been used in an electric power system is liquid (oil insulation). It is widely used in power plant and transmission switch yards. The equipment used synthetic oil usually transformer, switchgear, capacitor, and cable. There are many researches about mineral oil especially for transformer [1-5]. However, due to high cost of synthetic oil and it is not environment friendly, it was necessary to find other alternatives of oil insulations (biodegradable dielectric liquid) to replace synthetic oil. An effort to find alternative insulation oil that has advantages properties of course could be done by investigating the characteristics of potentially biodegradable dielectric liquid to be new insulating material. The source of biodegradable dielectric liquid could be from coconut. Coconut is one of the food materials that very often being consumed. The availability of coconut oil in Indonesia is very huge. Coconut plants enormously growth in a tropical area, thus it is also called tropical oil. The area of coconut plantation in Indonesia is about 3.712 million ha producing 12.915 billion coconuts per year [6]. The price of coconut is relatively inexpensive compares to synthetic oil and also friendly to environment. These would be the reason to investigate coconut oil as an alternative to substitute synthetic oil. The fruit of coconut is shown as in Figure 1 [6].

Fig. 1. Coconut fruit

The composition of coconut fruit is shown in Table I [6].

TABLE I. The Composition of Coconut Fruit

Old coconut fruit	Weight (%)
Coconut fiber	35
Coconut shell	12
Kernel	28
Coconut water	25

Many products could be made from coconut, such as copra, food material nata de coco, VCO could be made from the fruit. VCO is produced very simple by mechanical treatment and just need minimum heat, without any chemical additives. VCO is pure and colorless, not easy to get rancid, and can endure for

two years. The main component of VCO is saturated fat acid about 90% and unsaturated fat acid just 10%, as shown in Table II [6].

TABLE II. COMPOSITION OF FAT ACID VCO

Fat Acid		Chemical formula	Quantity (%)	Boiling point °C	Melting point °C
a. Saturated fat acid	Caporat acid	$C_5H_{11}COOH$	0,4 - 0,6	60	-4
	Caprilate acid	$C_7H_{17}COOH$	5,0 - 10,0	80	16
	Caprate acid	$C_9H_{19}COOH$	4,5 - 8,0	135	31
	Laurat acid	$C_{11}H_{23}COOH$	43,0 - 53,0	225	44
	Miristat acid	$C_{13}H_{27}COOH$	16,0 - 21,0	-	54
	Palmitat acid	$C_{15}H_{35}COOH$	7,5 - 10,0	390	63
	Stearat acid	$C_{17}H_{35}COOH$	2,0 - 4,0	361	72
b. Unsaturated fat acid	Oleat acid	$C_{17}H_{33}COOH$	5,0 - 10,0	229	16
	Linoleat acid	$C_{17}H_{31}COOH$	1,0 -2,5	237	-5

The researchers studied this material is still few, thus it is not enough to conclude that VCO could replace synthetic oil that has been applied until nowadays. In addition, our region is hot all along the year due to being lied by equator line (even in rainy season the temperature is still hot enough), thus the equipments which used liquid dielectric to supply electric energy should be fitted to the characteristics of this area, to get high reliability. That is why it is necessary to investigate the effect of many factors on the field strength characteristics such as temperature and viscosity.

II. EXPERIMENTALS

The breakdown voltage test is done by 2.5 mm sphere gap system in a chamber of 200 mL VCO. The applied voltage is then being increased until a breakdown occurs (the increasing rate is 2 kV/s). The test is done under room temperature of 30°C and varied temperature from 35°C up to 80°C with interval 5°C. In case of the test under varied temperatures, the VCO is being heated by heater until a certain value of temperature, and then the applied voltage is increased until a breakdown to occur. The chamber is attributed by heater and thermostat. The experiment is done five times for each temperature. The breakdown test circuit and sphere gap system is shown in Figure 2.

The winding ratio constant (a) was 0.0044. The breakdown voltage (V in kV) was calculated from the reading of the voltmeter (V_v) by equation below [7].

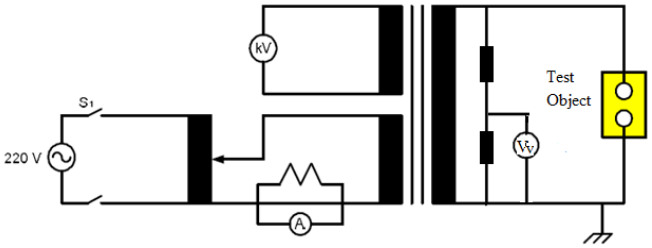
$$\boldsymbol{V} = \left(\frac{V_v/a}{1000}\right) \quad (1)$$

The breakdown field strength (E) is calculated by [7].

$$E = \frac{V}{s} \quad (2)$$

Where s is a distance of sphere gap = 0.25 cm.

The viscosity of VCO is tested by viscotester VT-03F with 200 mL of volume under room temperature of 30°C and varied temperature from 35°C up to 80°C with interval 5°C. The experiment is also done five times for each temperature. The viscotester is attributed by hotplate to test temperature effect.



(a) Breakdown test circuit

(b) The test object and sphere gap system

Fig. 2. Breakdown test circuit and test object with sphere gap system

The viscotester VT-03F and hotplate used in the experiment is shown in Figure 3.

Fig. 3. Viscotester VT-03 F and hotplate

III. Results And Discussion

A. The Effect of Temperature on Breakdown Field Strength of VCO

From the calculation of an experimental result, the breakdown field strength of VCO under room temperature of 30°C and under varied temperatures is shown in Table III.

TABLE III. The Breakdown field Strength of VCO Under varied temperatures

Temperature (°C)	Breakdown strength (kV/cm)
30	34
35	38.55
40	42.55
45	49.27
50	64.0
55	131.82
60	149.1
65	128.73
70	133.64
75	152.73
80	162.73

This table could be converting into graph as shown in Figure 4 below.

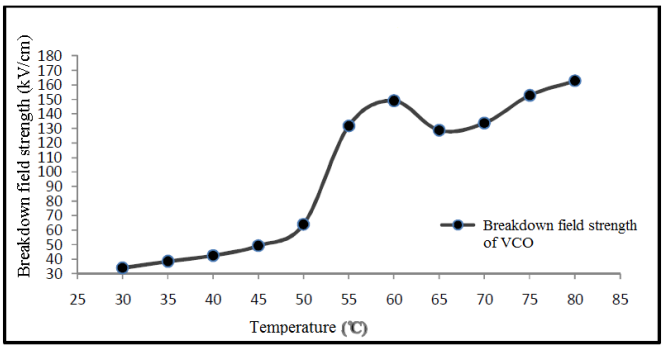


Fig. 4. Characteristic of breakdown field strength of VCO under varied temperatures

From the Figure 4, it is shown that the breakdown field strength of VCO increased with the increase of temperature (from 30°C up to 80°C). According to Suwarno et al. [8-9], the increase of temperature on the palm oil was followed by the reduction of fat contents. Therefore in this result, it is considered that the increase of temperature would reduce the content of fat in VCO. The graph showed linear relationship from the temperature 30°C up to 50°C and 65°C up to 80°C, However, when the temperature reached 55°C, the increase of breakdown field strength is high enough i.e. 131.8 kV/cm and 149.1 kV/cm, the increase were about two- or three-fold than before.

B. The Effect of Temperature on Viscosity of VCO

To know the viscosity of VCO, the viscometer is used. The results of viscosity measured under room temperature of 30°C and varied temperature of 35 up to 80°C is shown in Table IV.

TABLE IV. Viscosity under varied temperatures

Temperature (°C)	Viscosity (mPa.s)
30	35
35	26
40	23
45	19
50	14
55	13
60	11
65	10
70	8
75	7
80	7

This table could be converting into graph as shown in Figure 5 below.

It is shown that, the higher temperature is set in VCO, the lower viscosity would be. The lowest value of viscosity was at 75 and 80°C i.e. 7 mPa.s, while the highest (26 mPa.s) was under room temperature of 30°C. Under room temperature, VCO is considered has high density of fat [8-9]. However, after being heated the particles density of fat would be decreased results in low viscosity.

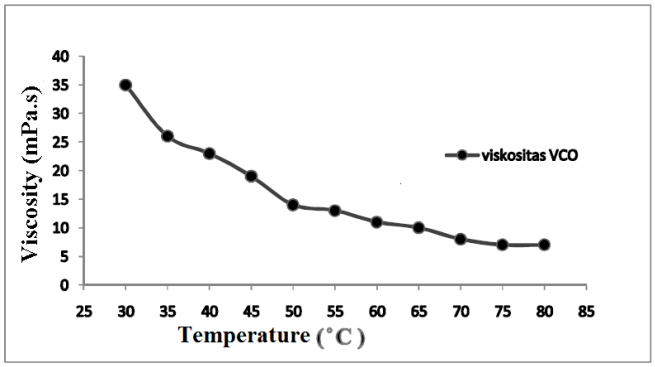


Fig. 5. Characteristic of viscosity of VCO under varied temperatures

C. The Effect of Viscosity on Breakdown Field Strength of VCO

From the results of Figure 4 and Figure 5, the effect of viscosity on the breakdown filed strength could be made as Figure 6 below.

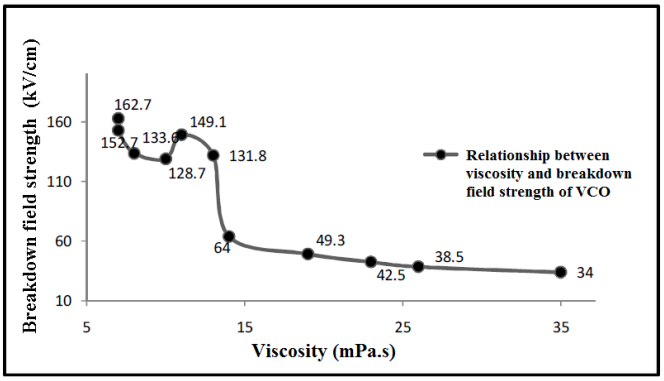


Fig. 6. Relationship between viscosity and breakdown field strength of VCO

From this figure, in general the characteristic of breakdown field strength was inversely proportional to the viscosity of VCO. It means that the lower viscosity, the higher breakdown filed strength would be. This paper applied the change of the temperature parameters to see the breakdown field strength which is connected to their viscosity. It is considered that, as the temperature is increased, the fat contents in VCO would be decrease. The decrease of fat content in VCO would result in higher breakdown field strength and lower viscosity. However, since the limitation of our data, the result in range of viscosity (11-13) mPa.s with the breakdown field strength of 149.1 kV/cm and 131.82 kV/cm still could not be explained. Thus, this research is open for discussion and necessary to be continued.

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IV. Conclusion

The breakdown field strength of VCO is measured using 2.5 mm sphere gap system under 50 Hz AC voltages. In addition the viscosity is also measured using viscotester. Both tests are measured under temperature changes. The main results are concluded below.

The increase breakdown field strength was proportional to the increase of temperatures. On the other hand, the higher temperature is set in VCO, the lower viscosity would be. Thus, the breakdown field strength was inversely proportional to the viscosity of VCO. It is considered that, as the temperature is increased, the fat contents in VCO would be decrease. The decrease of fat content in VCO would result in higher breakdown field strength and lower viscosity.

Acknowledgment

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