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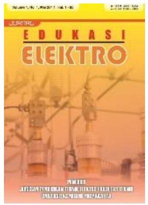

Alternative characteristics analysis of mixture oil transformer using breakdown voltage method

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Abstract— This research shows the effect of oil mixture and temperature on breakdown voltage. Palm oil is combined with diala-b oil in various mix ratios and various temperatures. Test results on the sample, as the concentration of the mixture of diala-b oil increases, the breakdown voltage value also increases. The breakdown voltage values of all oil mixture samples that have gone through the treatment process have met the IEC standard No. 56 of 1991 with results that are classified as above the standard (standard ≥ 30kV/2.5mm). Breakdown voltage values for the composition of 100% diala-b oil, 100% palm oil, and a mixture of 50% diala-b oil: 50% palm oil at 60 °C, 70 °C, 80 °C, 90 °C, and 100 °C is above the standard that is ≥ 30 kV. Water content and acidity affect the breakdown voltage value. Based on the results of breakdown voltage testing that has been done, palm oil can be used as an alternative to transformer oil.

Keywords: breakdown voltage, diala-b oil, palm oil, transformer oil

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1 Introduction

The power transformer is one of the important pieces of equipment in the power system, and its safe operation is closely related to the safe and reliable power supply of the power system. During transformer operation, due to disturbances such as partial discharge, and overheating, various gases will be released in the transformer oil. Monitoring and analysis of gas concentrations can evaluate the operating status of the transformer and find potential faults [1] [2] [3] [4].

In the power transformer used at the substation, there is transformer oil which functions to separate electrically between the primary coil and the secondary coil so that a breakdown voltage does not occur. This transformer oil has a better insulation level when compared to free air. One of the parameters that can indicate whether the insulation level of a material is good or bad is its breakdown voltage.

Mineral oil made from petroleum is a type of oil that has been used as transformer-insulating oil for decades [5]. Petroleum is widely used to date, because of its excellent cooling performance, large dielectric strength, low dielectric loss, and good long-term performance. [6]. Apart from its good properties as insulating oil, mineral oil has a bad impact on the environment because it is not biodegradable. Due to environmental problems and their diminishing sources, eco-friendly resources such as vegetable oil are the best alternatives to replace them.

Vegetable oil has successfully replaced mineral oil as insulation in distribution transformers since the late 1990s [7]. Coconut oil is one of the popular vegetable oils in many tropical countries in the world and its use as a raw material for industrial applications, such as lubricants, metal cutting fluids, and biodiesel has also been researched in recent years [8][9][10][11]. In addition, an alternative to mineral oil is palm oil. Investigations on the electrical, physical, and chemical properties of palm oil show that it is suitable for use as a substitute for mineral oil in high-voltage equipment [12]. Utilities are increasingly open to using vegetable oil in power transformers [13].

Palm oil is extracted from the mesocarp layer. Then it goes through a bleaching and deodorizing process called Refined Bleaching Deodorized Palm Oil (RBDPO). This process will decrease the fat content of palm oil, this is not good because the quality of palm oil depends on the fat content of the oil and the more fat content, the better the dielectric properties of the oil. [6]. Plus the availability of abundant palm oil and coconut oil in Indonesia. Palm oil contains high levels of saturated and unsaturated fats such as lauric acid (48%), myristic acid (8.4%), and palmitic acid (8.4%) [14].

Variations in the dielectric properties of palm oil with changes in temperature, in general, have the same tendency as mineral oils and silicone oils [15]. Another research on testing vegetable oil resulted that vegetable oil can be used for power transformers [16]. Another type of vegetable oil has been tested, namely pure coconut oil. Based on the breakdown voltage test, which is 29.17 kV/2.5 mm. This value does not meet the IEC 156 standard, which is 30 kV/2.5 mm [17]. Oil has the potential to be used as a substitute for mineral oil, therefore in this study, a liquid insulator test of a mixture of palm oil and diala-b oil was carried out with various compositions to determine its characteristics as an alternative to transformer oil.

The use of transformer oil has special requirements that have been regulated by SPLN'50-1982 "Guidelines for Testing Oil-immersed Transformers". and IEC No.56.Thn1991, among others, regarding the requirements and reliability of transformer oil with an oil penetration power of at least 30 kV/2.5 mm.

2 Test Method

2.1 Sample Data

There are two types of oil used, palm oil and diala-B oil. Table 1 show the sample tested consisted of a mixture of palm oil and diala-B oil.

Table 1. Test sample

No.	Sample (%)	
	Diala-B Oil	**Palm oil**
1	100%	0%
2	80%	20%
3	60%	40%
4	50%	50%
5	40%	60%
6	20%	80%
7	0%	100%

In addition, a test was also carried out to determine the effect of the temperature of the liquid insulator on the value of the breakdown voltage test. In the sample shown in Table 2, a heating temperature from 30 °C to 100 °C will be given with an increase every 10 °C. The treatment for mixing the oil was equated by stirring the composite oil for 3 minutes.

Table 2. Test samples with the effect of temperature

No.	Sample (°C)		
	Diala-B 100%	**Palm 100%**	**Diala-B 50% and Palm Oil 50%**
1	30 °C	30 °C	30 °C
2	40 °C	40 °C	40 °C
3	50 °C	50 °C	50 °C
4	60 °C	60 °C	60 °C
5	70 °C	70 °C	70 °C
6	80 °C	80 °C	80 °C
7	90 °C	90 °C	90 °C
8	100 °C	100 °C	100 °C

2.2 Breakdown Voltage Test

Dielectric strength is a measure of the ability of a material to withstand high stresses without causing dielectric failure. The dielectric strength of liquids depends on the atomic and molecular properties of the liquid itself, the material of the electrodes, temperature, the type of voltage applied, the gas contained in the liquid, and so on which can change the molecular properties of the liquid. In liquid insulation, the dielectric strength is equivalent to the applied voltage [18]. According to Paschen's law, the dielectric strength of liquids ranges from $10^7 V/cm$[19]. The liquid dielectric will fill the volume of the space that must be isolated and will simultaneously dissipate the heat that arises by convection.

Liquid dielectric has a density 1000 times greater than gas dielectric so the dielectric strength is higher than gas dielectric [20]. Another advantage of a pure liquid dielectric is that it can self-repair if a discharge occurs. One of the disadvantages of liquid dielectrics is that they are easily contaminated. Dielectric properties can be observed in all material phases, namely solid, liquid, gas, and plasma. The interaction of molecules in the material at the microscopic level is due to the strong external electric field. The increase in the electric field through the interaction of electric charges in the medium is known as *Coulomb's law*, namely:

$$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{4\pi\varepsilon_0} a_r \quad (1)$$

$$F = QE \quad (2)$$

so that

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2} a_r \quad (3)$$

By Fdenoting the Coulomb interaction force between 2 charges, which are $Q_1$and Q_2which are separated by r meters in a dielectric medium, and $a_r$expressing the unit vector along the direction r. Fcan be expressed as the product of $Q$and Erepresents the intensity of the electric field [21].

The intensity of the electric field is related to a quantity called electric potential V. Electric potential is a switching quantity that is formulated mathematically as follows:

$$E = -\nabla V \quad (4)$$

So that the electric potential equation is obtained.

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r} \quad (5)$$

By Vstating the potential on the distribution of electric charges.

Based on all the theories that discuss the breakdown voltage in liquid materials, a relationship can be drawn between the distance between the electrodes and the maximum dielectric strength. The relationship between the distance between the electrodes and the breakdown voltage in the liquid dielectric can be formulated into a general equation, namely:

$$V_{bd} = Ad^n \quad (6)$$

By V_{bd}stating the magnitude of the breakdown voltage and $d$stating the distance between the electrodes, $A$and na constant which is a logarithmic approach to the relationship between the distance between the electrodes and the breakdown voltage, with a value $n$always <1 [22].

The new insulating oil is expected to have a minimum breakdown voltage value of 30 kV – 50 kV. The value of the breakdown voltage is very dependent on the presence of contaminants in the insulating oil. The presence of contaminants such as water and solid particles will drastically reduce the breakdown voltage value, but a high breakdown voltage value does not necessarily indicate that the oil is free from the presence of contaminants [23]. Therefore, testing the breakdown voltage can be an indication of the presence of contaminants in the insulating oil and the first step in purifying the insulating oil.

The breakdown voltage test was carried out according to the standard test method IEC 60156, using a pair of ball electrodes having a gap of 2.5mm. To get the same particle distribution, the oil is mixed by stirring [16]. The test was carried out at the High Voltage Lab, Department of Electrical Engineering and Information Technology, Universitas Gadjah Mada. The procedure for testing the Dielectric Breakdown Voltage is as follows in Figure 1.

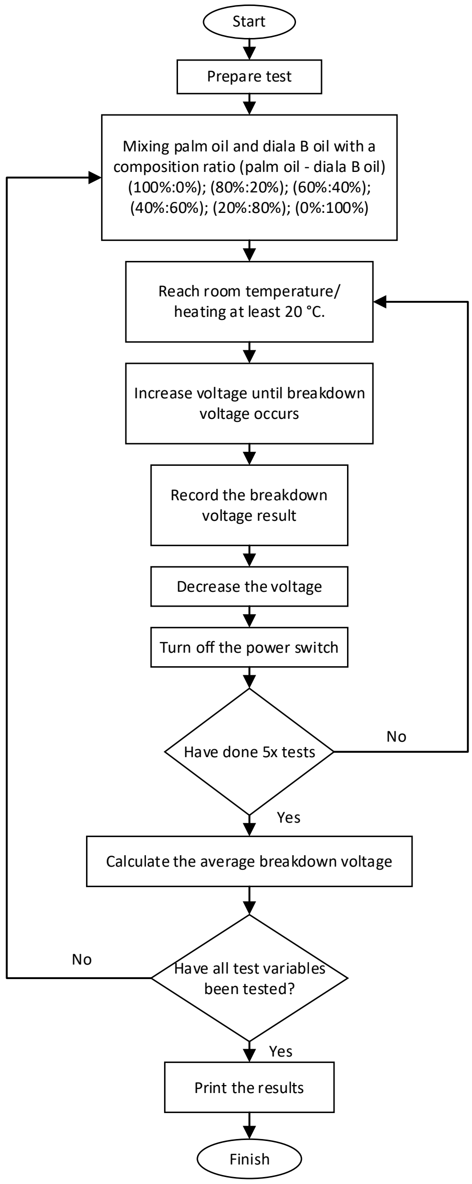

Fig. 1. Dielectric breakdown voltage test flow

The breakdown voltage test scheme is carried out with two test variations, the first without treatment and the second using treatment. The treatment is carried out through a filtering process and preheated to 100ºC. Then during the breakdown voltage test, the oil is allowed to stand until it returns to room temperature of 28ºC.

Furthermore, tests were carried out to determine the effect of liquid insulator temperature on the value of the breakdown voltage test. The one used in this testing phase uses a mixture of palm oil and diala B oil with a composition of 50:50 Test procedure is as follows in Figure 2.

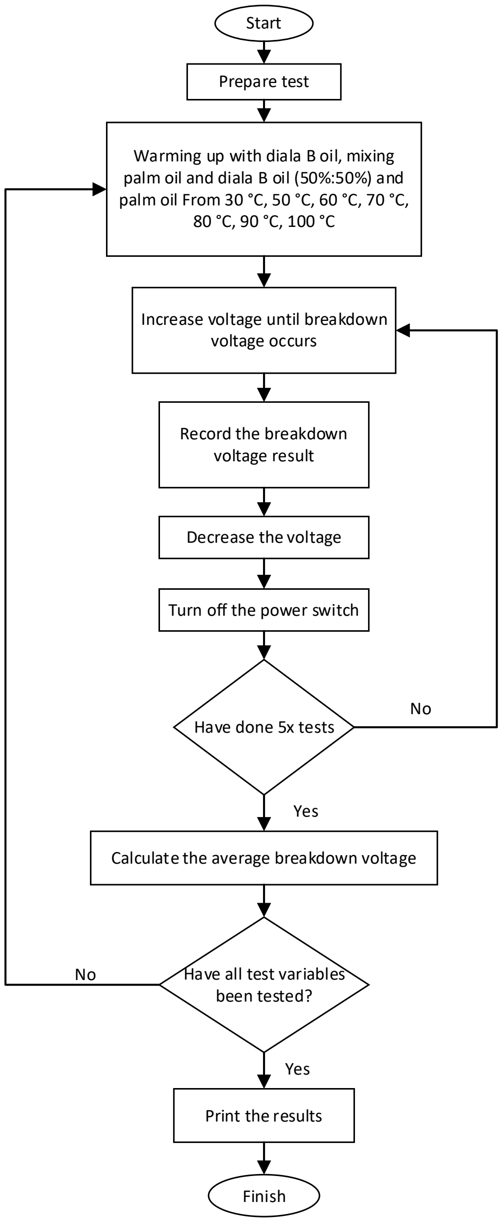

Fig. 2. Dielectric breakdown voltage test flow

3 Results and Discussion

3.1 Breakdown Voltage Test

In this test, the dielectric strength value is obtained from the average breakdown voltage value. Table 3 and Figure 4 show the results of the breakdown voltage test for each test sample before being treated (heated). Based on the test results of the breakdown voltage value all oil samples that have not been treated are less than 30 kV, the highest breakdown voltage value is the composition of 100 % diala-b oil: 0 % palm oil with an average value of 1.9 kV at a ball spacing of 2.5 mm electrode.

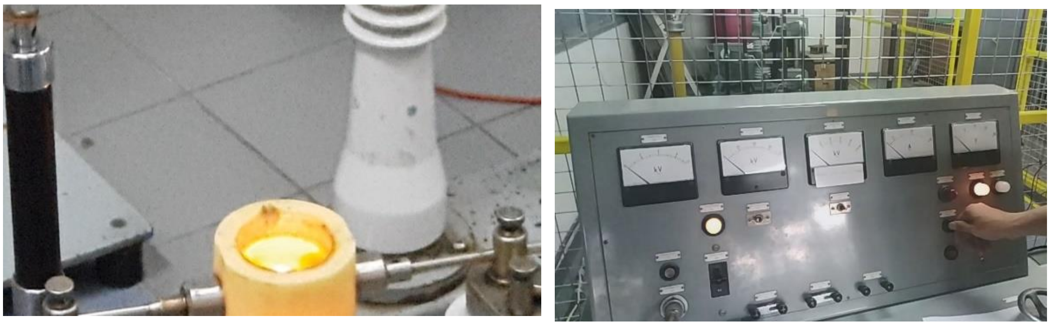

Fig. 3. Equipment and process of voltage breakdown testing

Table 3. The results of the breakdown voltage test before the treatment

No.	Concentration	SAMPLE (kV)					Average (kV)
	Diala B: Palm oil (%)	A	B	C	D	E	
1	100%:0%	19	19	22	17	18	19
2	80%:20%	17.5	16	16	17	18	16,9
3	60%:40%	17	16	16,5	15	15	15,9
4	50%:50%	15	15,5	14,5	14	15	14,8
5	40%:60%	12	12,5	12	13	14	12,7
6	20%:80%	11	13	13	12	12,5	12,3
7	0%:100%	12	11.5	11	10.5	12	11,4

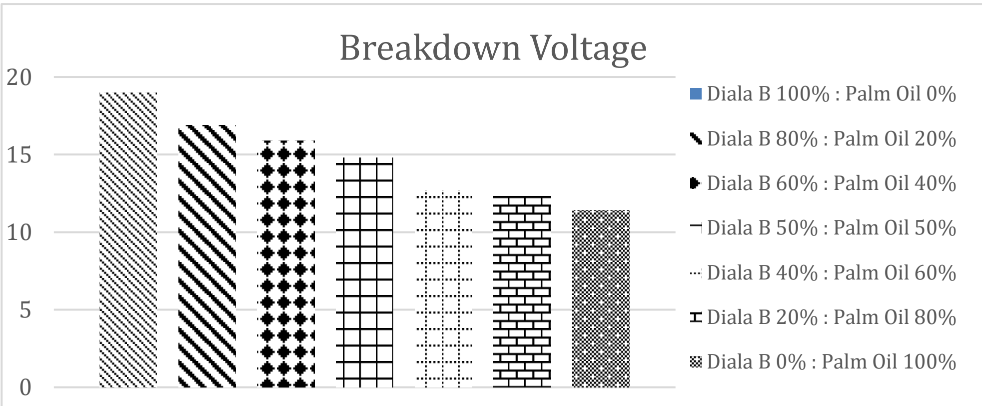

Fig. 4. The breakdown voltage of the oil sample before treatment

Treatment is carried out by boiling /heating method so that the water in the transformer oil evaporates, but contaminants such as dirt or other things still precipitate in the isolation oil because the boiling method is only for heating transformer isolation oil. The increase in the value of the breakdown voltage is due to the reduced liquid content in the oil. As is known, contamination factors and impurities in transformer oil affect the value of the breakdown voltage. Impurities in transformer oil cause unstable conditions in the electric field which can cause failure, so the insulation resistance or dielectric strength will decrease.

Table 4. Results of the breakdown voltage test after treatment

No	Concentration	SAMPLE (kV)					Average (kV)
	Diala B : Oil palm (%)	A	B	C	D	E	
1	100%:0%	34	36	37	36	35	35,6
2	80%:20%	32.5	36	34	35	36	34,7
3	60%:40%	32	29	34	33	32	32
4	50%:50%	32	32,5	30	31	32	31,5
5	40%:60%	30	29	30	32	33	30,8
6	20%:80%	29	25	28	33	32	29,4
7	0%:100%	30	30	26	29	31	29,2

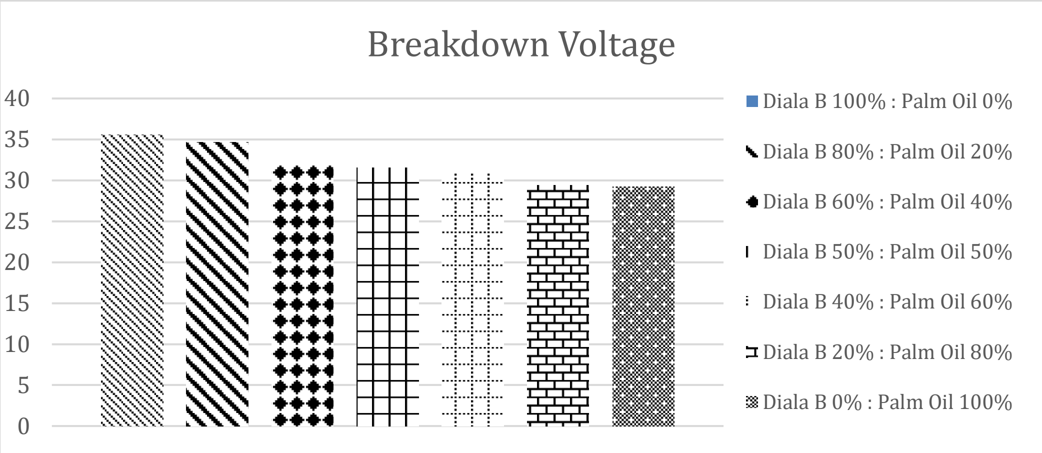

Fig. 5. Mixed breakdown voltage values

After the treatment process was carried out on the transformer oil samples, each test sample according to SPLN'50-1982 and IEC No.56 of 1991 the results that are classified as above the standard (standard ≥ 30kV/2.5mm) can be seen in Table *5* and Figure 5. The concentration mixture that meets the standard according to the average test results is (diala-b 40 %: palm oil 60%), (diala-b 50%: palm oil 50%), (diala-b 60%: palm oil 40%), (diala-b 80%: palm oil 20%), (diala-b 100%: palm oil 0%). The composition of the oil mixture with the highest breakdown voltage value was 100% diala-b oil: 0% palm oil, the test results obtained an average value of 35.6 kV /2.5mm.

Table 5. Breakdown voltage 100% diala-b oil composition

No.	Concentration	TEST (kV)					Average (kV)
	Temperature (°C)	1	2	3	4	5	
1	30 °C	23	22	24	22	23	22,8
2	40 °C	24	24	25	28	24	25
3	50 °C	28	26	32	31	31	29,6
4	60 °C	30	34	38	29	31	32,4
5	70 °C	35	34,5	36	34	34	34,7
6	80 °C	35	36	35,5	37	36	35,9
7	90 °C	37	35	36	36.5	34	35,7
8	100 °C	36	34	37	36	35	35,6

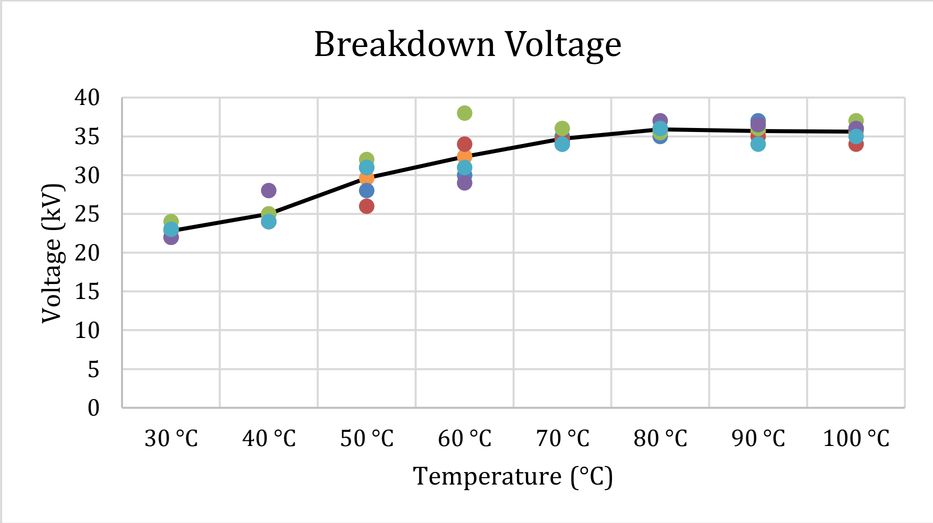

Fig. 6. Breakdown voltage characteristics of 100% diala-b oil composition

From the test results, as the temperature increases, it can be seen that the breakdown voltage value is also increasing. This is because the heating process causes the water content to decrease. For the type of 100% oil diala-b. Starting to reach the IEC standard value of > 30 kV, namely at a temperature of 60 °C with a value of 32.4 kV. From the test results, the breakdown voltage value begins to decrease when the temperature reaches 80°C to 100°C.

After testing on palm oil, experiments were then carried out with a sample of a mixture of 50% diala-b oil and 50% palm oil. Heating starts from room temperature (28°C) to 100°C with increments of 10°C. The results of the experiment can be seen in Table 6 and Figure 7.

Table 6. Breakdown voltage palm oil composition 50% diala-b oil 50%

No.	Concentration	TEST (kV)					Average (kV)
	Temperature (°C)	1	2	3	4	5	
1	30 °C	16	18	17	18	16	17
2	40 °C	24	20	22.5	24	23	22,7
3	50 °C	26	25,5	29	29	26	27,1
4	60 °C	32	31	34	33	32	32,4
5	70 °C	39	35	33	34	39	36
6	80 °C	42	43	41	41,5	40	41,5
7	90 °C	44	45	42	41	41	42,6
8	100 °C	43	41	42	41.5	44	42,3

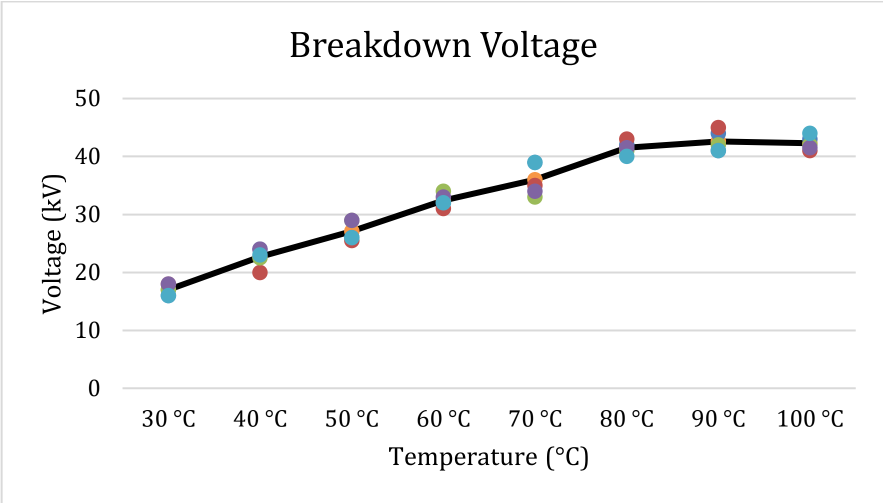

Fig. 7. Graph of breakdown voltage characteristics composition of palm oil 50% diala-b oil 50%

After testing on diala-b oil, an experiment was then carried out with 100% palm oil samples. Heating starts from room temperature (28°C) to 100°C with increments of 10°C. The results of the experiment can be seen in Table *7* and Figure 8.

Table 7. Breakdown voltage palm oil composition 100%

No.	**Concentration**	**TEST (kV)**					**Average (kV)**
	Temperature (°C)	**1**	**2**	**3**	**4**	**5**	
1	30 °C	14	15	14	17	16	15,2
2	40 °C	16	15	19	18	18.5	17,3
3	50 °C	25	24	29	25	28	26,2
4	60 °C	31	27	32	33	33,5	31,3
5	70 °C	38	45	42	43	41	41,8
6	80 °C	45	47	42	41	46	44,2
7	90 °C	43	49	50	42	48	46,4
8	100 °C	49	50	49	50	50	49,6

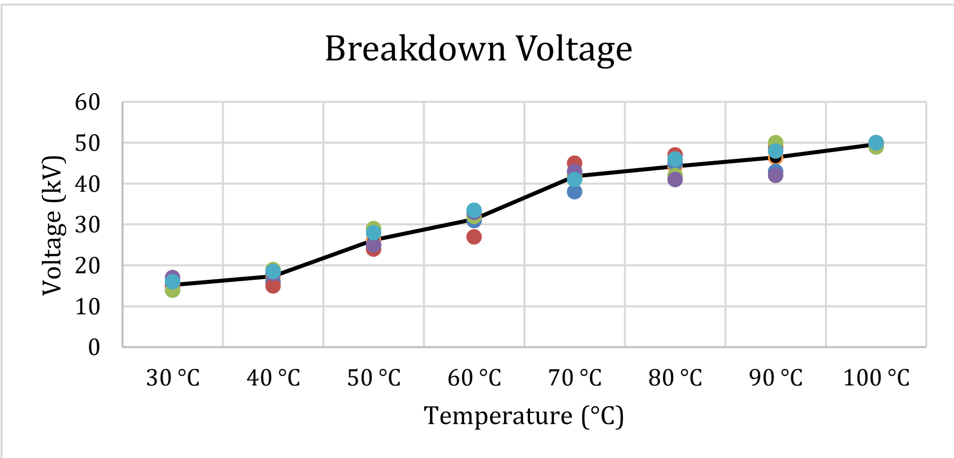

Fig. 8. Breakdown voltage characteristics of 100% palm oil composition

From Table 8 and Figure 9, it can be seen that the value of the breakdown voltage tends to increase with increasing temperature. Test results for IEC standard palm oil > 30 kV can be fulfilled when the oil temperature is more than 60 °C.

Table 8. breakdown voltage 3 types of oil (kV)

No.	Temperature (°C)	SAMPLE (kV)			Standard IEC 156 (kV)
		Diala B 100%	**Palm 100%**	**Diala B 50 % : Palm Oil 50%**	
1	30 °C	22,8	15,2	17	≥ 30
2	40 °C	25	17,3	22,7	≥ 30
3	50 °C	29,6	26,2	27,1	≥ 30
4	60 °C	32.4	31.3	32.4	≥ 30
5	70 °C	34.7	41.8	36	≥ 30
6	80 °C	35.9	44.2	41.5	≥ 30
7	90 °C	35.7	46.4	42.6	≥ 30
8	100 °C	35.6	49.6	42.3	≥ 30

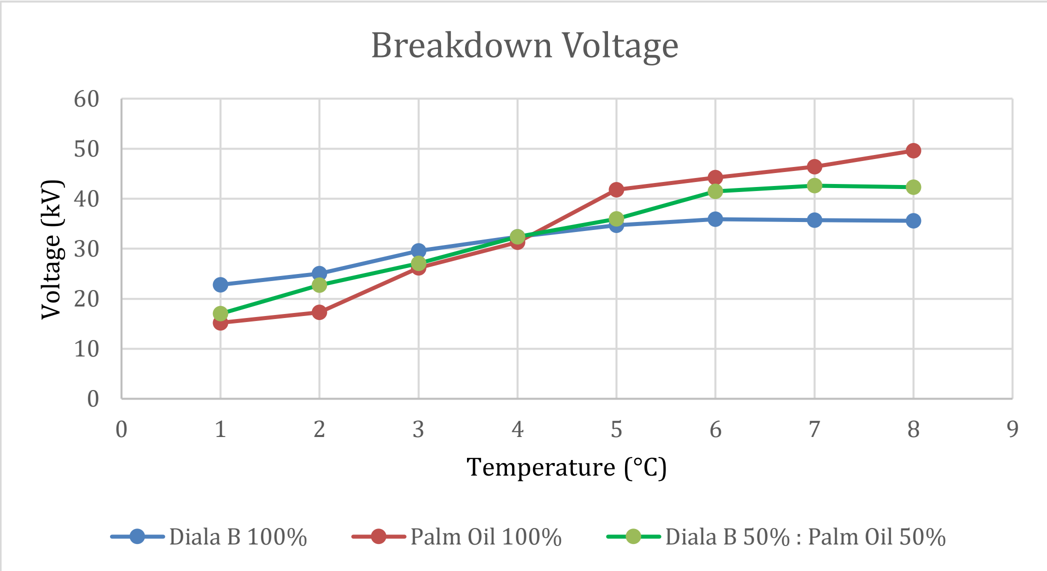

Fig. 9. Graph of breakdown voltage characteristics of 3 types of oil

Seen from the three samples tested to have the same characteristics. As the temperature increases, the breakdown voltage value also increases. The increase in the breakdown voltage value is due to the reduced liquid contained in the transformer oil because it has undergone heating so that the water evaporates and the water content contained in the oil decreases. Based on the measurement results, Diala B oil has the highest value at 80 °C, which is 35.9 kV. As for palm oil, the highest measurement results were at 100 °C of 49.6 kV. In each test sample carried out at temperatures above 60 °C, according to SPLN'50-1982 and IEC No.56 of 1991 obtained results that were classified as above the standard ≥ 30 kV/2.5mm.

3.2 Moisture content test

Water and moisture in transformer oil can thicken the oil due to oxidation. Transformer performance becomes less than optimal, due to oil viscosity and high water content. The content of water and moisture in the oil affects the dielectric strength of the oil. The low level of the water content affects the high dielectric strength and vice versa. Table 8 is the result of testing the water content in oil samples.

Table 9. Test results for water content in oil (ml)

No.	Mixed Composition (%)	Water content (mL)	
	Diala B : Oil palm		
1	100% : 0%	0.16mL	0.080%
2	80% : 20%	0.20mL	0.100%
3	60% : 40%	0.24mL	0.120%
4	50% : 50%	0.26mL	0.130%
5	40% : 60%	0.28mL	0.140%
6	20% : 80%	0.32mL	0.160%
7	0% : 100%	0.36mL	0.180%

The level of acidity contained in transformer oil affects the quality of the oil within a certain time. The high level of acidity causes corrosion of the metal contained in the transformer. Corroded metal materials cause contaminants in transformer oil content. Metal contaminants in transformer oil reduce the dielectric ability of the oil. Table 9 below presents the acidity level values for each oil mixture composition.

Table 10. Test results for acidity levels (ph) in oil

No.	Mixed Composition (%)	Acidity (PH)
	Diala B : Oil palm	
1	100% : 0%	5,32
2	80% : 20%	5,37
3	60% : 40%	5,42
4	50% : 50%	5.45
5	40% : 60%	5,47
6	20% : 80%	5,52
7	0% : 100%	5.58

The viscosity or thickness of the oil affects the smooth circulation of oil in the transformer. The occurrence of circulation in the oil serves to cool the temperature of the transformer. If the temperature is hot, the oil will circulate quickly and well, if the temperature is cold the oil will circulate slowly. The following samples test the viscosity value of palm oil with a temperature treatment of 30°C and 40°C presented in Table 10. Table 11 shows that the viscosity value of palm oil at 30 °C is above the standard, which is 59.19 cst. The measurement results for diala-b oil and mixtures are still standardized at 30 °C and 40 °C.

Table 11. Viscosity test results (cSt)

Temperature	Oil testing (cSt)			IEC 3104 standard (cSt)
	Palm (cSt)	Diala-B (cSt)	Mixture (cSt)	
30°C	59,19	13,41	28.78	≤ 40
40°C	38,72	10.01	19.65	≤ 40

4 Conclusion

From the test results, it was found that the breakdown voltage of the sample before going through the treatment process was very low, namely between 11.4 – 19 kV/2.5 mm due to external contamination such as dirt and water deposits contained in the sample. After the treatment process, good breakdown voltage test results were obtained, namely between 30-35 kV/2.5 mm. The results of the breakdown voltage test on the treatment samples were higher as the mixture concentration of diala-b oil increased.

Breakdown voltage testing at 30°C, 40°C, 50°C is below IEC standard 156 while at 60°C, 70°C, 80°C, 90°C, 100°C is above standard ≥ 30 kV. In testing the water content, the results that did not meet the standard were palm oil at temperatures ≤ 50 °C. Meanwhile, the sample Dia B and the mixture at all temperatures met the standard with a value of ≤ 30 ml. The value of acid content in the samples of palm oil, diala-b oil, and mixtures (50% : 50%) was neutral in the range of neutrality values from 5.5 to 6.5.

Viscosity values for samples of palm oil, diala-b oil, and mixtures (50%; 50%) obtained results according to IEC 3104 standards (≤40 cSt) at 40 °C, and palm oil samples at 30 °C did not meet the standard with a value of 59,19 cSt. Breakdown voltage testing that has been done palm oil can be used as an alternative to transformer oil.

5 References

[1] J. Dai, H. Song, G. Sheng, and X. Jiang, “Dissolved gas analysis of insulating oil for power transformer fault diagnosis with deep belief network,” *IEEE Trans. Dielectr. Electr. Insul.*, vol. 24, no. 5, pp. 2828–2835, 2017.

[2] C. Xiang, Z. Huang, J. Li, Q. Zhou, and W. Yao, “Graphic approaches for faults diagnosis for Camellia insulating liquid filled transformers based on dissolved gas analysis,” *IEEE Trans. Dielectr. Electr. Insul.*, vol. 25, no. 5, pp. 1897–1903, 2018.

[3] A. Hoballah, D.-E. A. Mansour, and I. B. M. Taha, “Hybrid grey wolf optimizer for transformer fault diagnosis using dissolved gases considering uncertainty in measurements,” *Ieee Access*, vol. 8, pp. 139176–139187, 2020.

[4] X. F. Wang, Z. D. Wang, Q. Liu, and P. Dyer, “Dissolved gas analysis of thermal faults in transformer liquids simulated using immersed heating method,” *IEEE Trans. Dielectr. Electr. Insul.*, vol. 25, no. 5, pp. 1749–1757, 2018.

[5] S. Vishal and P. Vikas, “Transformer’s history and its insulating oil,” in *5th National Conf., INDIA-Com, Computing For Nation Development*, 2011.

[6] S. Aditama, “Dielectric properties of palm oils as liquid insulating materials: effects of fat content,” in *Proceedings of 2005 International Symposium on Electrical Insulating Materials, 2005. (ISEIM 2005).*, 2005, pp. 91-94 Vol. 1.

[7] C. P. McShane, G. A. Gauger, and J. Luksich, “Fire resistant natural ester dielectric fluid and novel insulation system for its use,” in *1999 IEEE Transmission and Distribution Conference (Cat. No. 99CH36333)*, 1999, pp. 890–894 vol.2.

[8] Suhartono, Suharto, and A. E. Ahyati, “The properties of vegetable cooking oil as a fuel and its utilization in a modified pressurized cooking stove,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 105, no. 1, 2018.

[9] S. Kahwaji and M. A. White, “Edible oils as practical phase change materials for thermal energy storage,” *Appl. Sci.*, vol. 9, no. 8, 2019.

[10] M. A. Kalam, M. Husnawan, and H. H. Masjuki, “Exhaust emission and combustion evaluation of coconut oil-powered indirect injection diesel engine,” *Renew. Energy*, vol. 28, no. 15, pp. 2405–2415, 2003.

[11] N. H. Jayadas and K. P. Nair, “Coconut oil as base oil for industrial lubricants-evaluation and modification of thermal, oxidative and low temperature properties,” *Tribol. Int.*, vol. 39, no. 9, pp. 873–878, 2006.

[12] A. Rajab and Et.all, “Study on properties of palm oleum as a candidate of palm based-transformer insulating liquid,” *Proc. Int. Semin. Dr. Students Clean. Energy Syst. Kitakyushu, Japan*.

[13] D. Martin, I. Khan, J. Dai, and Z. D. Wang, “An overview of the suitability of vegetable oil dielectrics for use in large power transformers,” in *TJ/H2b Euro TechCon Conf., Chester, UK*, 2006, pp. 1–20.

[14] “No Titl.” [Online]. Available: http://www.oilpalmindia.com/whats-is-palm-oil.php.

[15] A. Rajab, A. Sulaeman, and S. Sudirham, “A Comparison of Dielectric Properties of Palm Oil with Mineral and Synthetic Types Insulating Liquid under Temperature Variation,” vol. 43, no. 3, pp. 191–208, 2011.

[16] S. Tenbohlen and M. Koch, “Aging Performance and Moisture Solubility of Vegetable Oils for Power Transformers,” *IEEE Trans. Power Deliv.*, vol. 25, no. 2, pp. 825–830, Apr. 2010.

[17] P. Ir, I. Garniwa, and E. Triswantoro, “Analisis Tegangan Tembus Pada Minyak Transformator Lama Dan Baru Menggunakan Tiga Jenis Elektroda,” no. 021, 2014.

[18] L. T. Bonggas, *Dasar Teknik Pengujian Tegangan Tinggi*. Jakarta: Gramedia Pustaka Utama, 2003.

[19] M. I. Malik, N.H., Al-Arainy, A.A, Qureshi, *Electrical Insulation in Power Systems*. New York: Marcel Dekker Inc., 1998.

[20] V. idu, M.S., and Karamaju, *High Voltage Engineering*. New Delhi: McGraw-Hill, 1995.

[21] S. Neelakanta, P, *Handbook of Electromagnetic Materials: Monolithicand Composite Versions and Their Applications*. Boca Raton, Florida: CRC Press LLc, 1995.

[22] S. Abduh, *Teori kegagalan isolasi*. Jakarta: Universitas Trisakti, 2003.

[23] Y. P. Sinuhaji, “Analisis Keadaan Minyak Isolasi Transformator Daya 150 kV Menggunakan Metode Dissolved Gas Analysis (DGA) Dan Fuzzy Logic Pada Gardu Induk Wilayah Sidoarjo.,” Universitas Jember, 2012.

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