Journal of Renewable Energy, Electrical, and Computer Engineering
Volume 4, Number 1, March 2024. 68-74
eISSN 2776-0049
DOI: https://doi.org/10.29103/jreece.v4i1.16253
Research Original Article

Efect of Antioxydants on Viscosity and Breakdown Voltage of Palm Oil Insulation

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Abstract
Insulating oil is a type of insulator that is widely used as insulation in electrical equipment such as transformers. The insulating oil in the transformer functions as insulation in the transformer windings so that flashover does not occur and causes voltage leaks to the outside of the transformer, then the insulating oil also functions as a transformer coolant. Generally, the insulating oil used today is made from mineral oil which cannot be renewed so its availability is limited and may run out in the future. In an effort to reduce the use of mineral oil as a basic ingredient for insulating oil, it is necessary to develop a basic ingredient for making insulating oil, which can use vegetable oils such as crude palm oil (CPO) with the additive butylated hydroxytoulene added. In testing the suitability of crude palm oil with the addition of butylated hydroxytoulene additive as insulating oil, breakdown voltage testing was carried out using Megger OTS80Af and viscosity. Based on the test results, the highest breakdown voltage value was obtained for crude palm oil with the addition of butylated hydroxytoulene of 11.13 kV and a viscosity of 27.12 cSt. From the test results, it can be concluded that crude palm oil with the addition of butylated hydroxytoulene is not suitable for use as transformer insulating oil because it cannot meet the standard SPLN 49-91: 1982, the breakdown voltage of transformer insulating oil is 30 kV/2.5 mm.
Keywords: Palm Oil; Antioxydants; Viscosity; Breakdown Voltage

Introduction
Up to date, mineral oil is still the main liquid insulation for power transformer. This is true, due to the mineral oil has good capability as insulation and coolent of a power transformer. However, the mineral oil has flaws due to its toxity (McShane, 2001), (Martins, 2010) due to polynuclear aromatic hydrocarbons contain in the mineral oil. So, if the power transformer tank damages or leaks, the oil spill might contaminated land area around the transformer.

Thus demand for enviromentally frienly insulation, which is easy and safety to dispossal on ground force reasearchers to developt the substitusion for mineral oil insulation. Vegetable oil (Ester oil) seems to meet the creterion above to substitute the mineral oil as liquid insulation on power transformer.. Ester oil, not only enviromentally friendly and non toxic, as plant base produce has high availability and sustainability.

Research on physical and chemical characteristic of ester oil as a substitue for liquid insulation for power transformer has been carried by many researcher. The results show the esters oil, including palm oil, have high dielectric strenght thus able to fullfil the breakdown voltage level for liquid insulation (Dang et al., 2010). Ester oil also has almost as high as mineral oil permitivity (Li et al., 2012). However, the esters oil have fundamental flaws i.e have high viscocities. High viscosity will reduce the liquid insulation cooling properties due to low circulation.

Alim, M. et.al, 2022 discussed the possibilities of using castor oil for liquid insulation. It is found the castor oil has viscocity as much as 48.70 cSt (McShane, 1999). Palm oil as studied by Roslan, M. H. et.al, 2021 shows viscosity 54.44 cSt (Oommen, 2002). The two vegetable oil has far higher viscocity of permitted for transformer liquid insulation, i.e 40 cSt (Thomas et al., 1995). To reduce the vegetable oil viscosity, one can add diluent such as fenol, butylated hydroxtoulene and butylated hydroxyanisole. In this research discuss the method to reduce the viscocity of the ester oil by adding antioxydants, I.e Butylated Hydroxtoulene and Butylated Hydroxyanisole.

Antioxydants
Additives are substances or ingredients that can be added to other substances with the aim of providing an improving effect on the substance. Vegetable oils such as palm oil have a main weakness, namely very high viscosity or viscosity values, so the addition of additives is expected to improve the viscosity value of palm oil. The effect of adding additives can also be known from the breakdown stress value of palm oil before and after adding additives. The types of additives that can be used to repair oil insulators include:

Phenol
Phenol (Figure 1) is a type of additive with the chemical formula C6H6O. Phenol has chemical properties including a

specific gravity of 1,057 gr/ml, a freezing point of 42o C, a boiling point of 182o C, and a molecular weight of 94.11 gr/mol (Abdullahi et al., 2004). Phenol contains hydrocarbon compounds which function to inhibit oxidation and maintain stability, but if it contains too much it will have a detrimental effect where the dielectric strength value will decrease (Sitinjak et al., 2003). So this research will not use phenol.

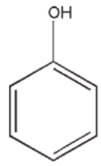

Figure 1. Chemical Phenol Formula Structure

Butylated Hydroxyanisole

Butylated Hydroxyanisole (Figure 2) is a type of additive with the chemical formula C11H16O2. Butylated Hydroxyanisole has chemical properties including a specific gravity of 1,117 gr/ml, a molecular weight of 180.25 gr/mol, a freezing point of 48o C, and a boiling point of 264o C (Kanoh et al., 2008). Butylated Hydroxyanisole is insoluble in water but can dissolve in methanol and ethanol. Butylated Hydroxyanisole works as an antioxidant to maintain a stabilizer for free radicals (Tokunaga et al., 2016), (Nurani & others, 2017), (Sinaga et al., 2021). Butylated Hydroxyanisole is an addictive substance that is widely used in cosmetics, medicines and food. Butylated Hydroxyanisole is often mixed with other addictive substances such as butylated hydroxytoluene, alkyl gallates, and citric acid (Cavallini et al., 2010).

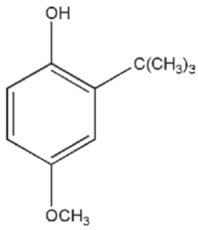

Figure 2. Chemical Structure of Butylated Hydroxyanisole

Butylated Hydroxytoulene

Butylated Hydroxytoulene (Figure 3) is a type of additive with the chemical formula C15H24O. Butylated Hydroxyanisole has chemical properties including a specific gravity of 1,031 gr/ml, a molecular weight of 220.35 gr/mol, a freezing point of 70o C, and a boiling point of 265o C (Sinaga et al., 2014). Butylated Hydroxytoulene does not dissolve easily in water but can dissolve in 95% ethanol solution and dissolves easily in oil. Butylated Hydroxytoulene also contains hydrocarbon compounds so that it can inhibit oxidation and maintain stability so that it can improve oil quality (Susilo et al., 2014). In research conducted by Ade Firmansyah in 2019, it was found that the use of phenol additives in Sunan kemiri oil was able to increase the breakdown voltage to 34.97 kV with the addition of 20% Butylated Hydroxytoulene additive (Hikita et al., 2012), (Cai et al., 2012), (Berchmans & Hirata, 2008).

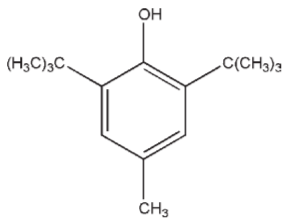

Figure 3. Chemical Structure of Butylated Hydroxytoulene

In this research, the last two additives will be used to improve the viscosity of palm oil. Because these two additives show the ability to improve the viscosity of vegetable oil and increase the breakdown stress of the vegetable oil.

Viscosity of Liquid Insulation

Viscosity is the resistance of fluid flow which is the friction between fluid molecules and each other. A liquid that is easy to flow means the viscosity value is low, whereas if it is difficult to flow it can be said that the viscosity value is high (Peppas et al., 2016). The viscosity value of a fluid depends on its temperature and the presence of aging and oxidation caused by the length of time the fluid has been used. The standard viscosity value of an insulator oil is regulated in SPLN 49-91: 1982 where the viscosity value of an insulator oil is ≤ 40 cSt at a temperature of 20oC. Meanwhile, in IEC 60296, the viscosity value of an insulating oil is ≤ 12 cSt at a temperature of 40oC. In other research conducted by Roslan, M. H. et.al, 2021, it was found that the viscosity value of palm oil was 54.44 cSt (Sitorus et al., 2015).

Experiment

a. Mixing Crude Palm Oil with Butylated Hydroxytoulene

Palm oil is mixed with the additive butylated hydroxytoulene, where before mixing the palm oil with the additive butylated hydroxytoulene, the butylated hydroxytoluene is weighed according to the specified ratio. Butylated Hydroxtoulene is weighed in a ratio of 1 gr, 2 gr, 3 gr, 4 gr, 5 gr, 6 gr, 7 gr, 8 gr, 9 gr, and 10 gr. Two samples were made for each mixing composition, so that for crude palm oil samples without mixing there was only 1 sample, so the total samples to be tested were 21 samples. The palm oil sample is first heated to a temperature of 100 oC to remove moisture. The temperature of the palm oil sample was then lowered to 70 oC. Next, butylated hydroxytoluene is mixed with the palm oil sample and stirred consistently so that it can be mixed using a magnetic stirrer at a speed of 800 rpm for 20 minutes (ALIFIAH & others, 2019).

b. Breakdown Voltage Testing on Crude Palm Oil with the addition of Butylated Hydroxytoulene

Breakdown voltage testing is carried out on palm oil to obtain the breakdown voltage value of the palm oil to be tested. Testing the breakdown voltage will use a tool, namely the Megger OTS80Af Oil Tester. Breakdown voltage testing will use hemispherical electrodes with a diameter of 12.5 mm and the distance between the half-spherical electrodes is 2.5 mm. The standard breakdown voltage value of transformer oil insulation is regulated based on SPLN 49-91: 1982 where the breakdown voltage value is > 30 kV/2.5mm. The test is carried out by placing the oil to be tested in the test container until all the electrodes are submerged in oil. The test equipment will receive a voltage supply of 220/380 V which will then increase gradually until it reaches the kV voltage value. When the test oil is no longer able to withstand the voltage, a spark will appear on the electrode, then the breakdown voltage value is obtained.

c. Viscosity Testing of Crude Palm Oil with the addition of Butylated Hydroxytoulene

Kinematic viscosity testing was carried out on palm oil to determine the viscosity level of palm oil with the addition of butylated hydroxytoulene additives. This test was carried out to determine the effect of adding the additive butylated hydroxytoulene on the viscosity value of the palm oil to be tested. The standard viscosity value based on SPLN 49-91: 1982 has a maximum value of 40 cSt at a temperature of 20oC and based on the IEC standard IEC 60296 the viscosity value of an insulating oil is ≤ 12 cSt at a temperature of 40oC. The test was carried out using the viscosity measurement method using an Ostwald viscometer. The measurement method using an Ostwald viscometer is to measure the time it takes for oil to get from limit a to reach limit b. This process will be repeated 3 times and then the average time for the 3 trials will be calculated. The results of these calculations will then be used to calculate the viscosity value of the palm oil sample. The Ostwald viscometer will be filled with a palm oil sample that has been heated to a temperature of 40°C.

Results and Discussion

a. Kinematic Viscosity Testing

Kinematic viscosity testing will be carried out using the viscosity measurement method using an Ostwald viscometer. Viscosity measurements will be carried out by measuring the length of time it takes for oil to flow from limit a to reach limit b on an Ostwald viscometer. This process will be repeated 3 times and then the average time for the 3 trials will be calculated. The results of these calculations will then be used to calculate the viscosity value of the palm oil sample. The Ostwald viscometer will be filled with a palm oil sample that has been heated to a temperature of 40°C.

Table 1. Viscosity testing of crude palm oil with the addition of butylated hydroxytoulene

No.	Sample (ml)	*Butylated Hydroxytoulene* (gram)	Viscosity (cSt)		
			Sampel 1	Sampel 2	Rata - rata
1.	500	0	29,71	-	29,71
2.	500	1	30,28	27,57	28,92
3.	500	2	30,46	24,67	27,56
4.	500	3	29,50	25,48	27,49
5.	500	4	28,66	23,97	26,31
6.	500	5	27,26	26,34	26,8
7.	500	6	27,05	25,83	26,44
8.	500	7	27,42	26,82	27,12
9.	500	8	26,90	25,73	26,31
10.	500	9	26,95	25,31	26,13
11.	500	10	26,80	23,78	25,29

Table 1 shows the viscosity test results data on sample 1 and sample 2 of crude palm oil with the addition of butylated hydroxytoulene. The viscosity value of crude palm oil without the addition of butylated hydroxytoulene is 29.71 cSt. In the crude palm oil sample which added butylated hydroxytoulene, the highest average viscosity value was obtained in the composition of mixing the crude palm oil sample with 1 gr of butylated hydroxytoulene, namely 28.92 cSt, while the lowest average viscosity value was in the composition of mixing the crude palm oil sample with 10 grams of butylated hydroxytoulene is 25.29 cSt.

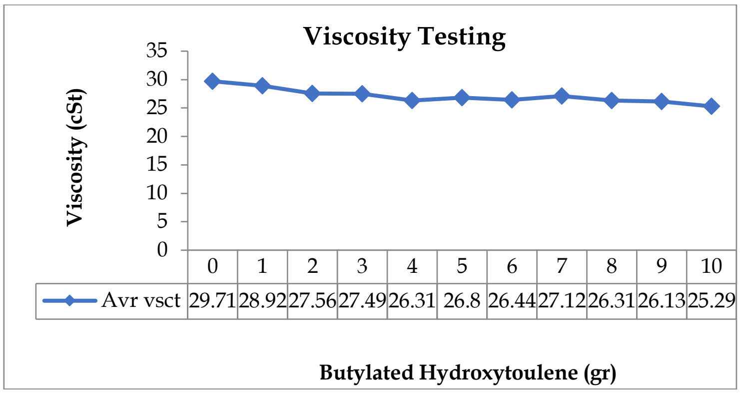

Figure 1. Graph of the average viscosity of crude palm oil with the addition of butylated hydroxytoulene

Figure 1 is a graph showing a comparison of the effect of adding the additive butylated hydroxytoulene on viscosity values. From the graph it can be seen that the addition of the additive butylated hydroxytoulene has an improving effect on the viscosity of the crude palm oil sample. The addition of a greater concentration of butylated hydroxytoulene additive has the effect of decreasing the viscosity value of the crude palm oil sample so that it can be concluded that the greater the concentration of butylated hydroxytoulene additive added to the sample, the lower the viscosity value of crude palm oil becomes.

b. Breakdown Voltage Testing

Testing the breakdown voltage will use a tool, namely the Megger OTS80Af Oil Tester. Breakdown voltage testing will use hemispherical electrodes with a diameter of 12.5 mm and the distance between the half-spherical electrodes is 2.5 mm. The breakdown voltage test will be carried out 6 times on each sample and then the average value of the breakdown voltage test will be calculated.

Table 2. Breakdown voltage test on crude palm oil with the addition of butylated hydroxytoulene sample 1

No	*Butylated Hydroxytoulene* (gr)	Breakdown Voltages 1st to 6th (kV)						Breakdown Voltage (kV)
		1	2	3	4	5	6	
1	1	11,4	11,1	11,0	10,0	7,8	10,2	10,25
2	2	9,1	10,0	11,3	11,1	9,7	8,9	10,01
3	3	9,2	11,2	9,1	8,3	7,9	8,2	8,98
4	4	10,4	10,8	10,6	11,5	9,9	10,2	10,56
5	5	8,7	10,0	11,5	9,7	8,8	9,0	9,61
6	6	9,4	10,4	11,4	10,1	11,4	11,3	10,66
7	7	11,2	10,6	10,9	11,4	10,9	11,8	11,13
8	8	11,0	9,6	10,7	11,9	11,7	9,6	10,75
9	9	9,7	10,3	10,1	9,0	9,3	10,6	9,83
10	10	9,3	9,4	11,1	11,8	10,6	11,1	10,55

Table 3. Breakdown voltage test on crude palm oil with the addition of butylated hydroxytoulene sample 2

No	*Butylated Hydroxytoulene* (gr)	Breaakdown Voltage 1st to 6th cycles test (kV)						Breakdown voltage (kV)
		1	2	3	4	5	6	
1	1	9,6	9,0	8,6	8,8	8,5	6,7	8,53
2	2	8,3	9,2	8,6	8,4	9,9	9,0	8,9
3	3	10,5	10,1	10,3	9,6	8,9	7,6	9,5
4	4	9,3	9,9	9,8	9,2	9,4	9,8	9,56
5	5	8,3	8,6	9,6	9,1	8,3	10,2	9,01
6	6	9,5	9,4	9,9	10,3	9,3	11,1	9,91
7	7	9,5	9,4	8,5	9,0	10,7	9,3	9,4
8	8	10,4	9,8	10,6	7,3	7,2	8,7	9
9	9	10,0	9,4	9,2	10,3	10,5	9,5	9,81
10	10	10,2	10,0	7,9	7,8	8,3	8,5	8,78

Table 4 shows the test results data and the average value of breakdown voltage in sample 1 and sample 2 of crude palm oil with the addition of butylated hydroxytoulene. In the crude palm oil sample which added butylated hydroxytoulene, the lowest average breakdown voltage value was obtained, namely in the composition of mixing the crude palm oil sample with 3 grams of butylated hydroxytoulene, namely 9.24 kV, while the highest average breakdown voltage value was in the crude sample mixing composition. palm oil with 6 grams of butylated hydroxytoulene, which is 10.285 kV.

Table 4. Average breakdown voltage values (for sample 1 and sample 2

No	*Butylated Hydroxytoulene* (gr)	Average breakdown voltage (kV)		
		1st sample	2nd sample	Total
1	1	10,25	8,53	9,39
2	2	10,01	8,9	9,455
3	3	8,98	9,5	9,24
4	4	10,56	9,56	10,06
5	5	9,61	9,01	9,31
6	6	10,66	9,91	10,285
7	7	11,13	9,4	10,265
8	8	10,75	9	9,875
9	9	9,83	9,81	9,82
10	10	10,55	8,78	9,665

Table 4 shows the test results data and the average value of breakdown voltage in sample 1 and sample 2 of crude palm oil with the addition of butylated hydroxytoulene. In the crude palm oil sample which added butylated hydroxytoulene, the lowest average breakdown voltage value was obtained, namely in the composition of mixing the crude palm oil sample with 3 grams of butylated hydroxytoulene, namely 9.24 kV, while the highest average breakdown voltage value was in the crude sample mixing composition. palm oil with 6 grams of butylated hydroxytoulene, which is 10.285 kV.

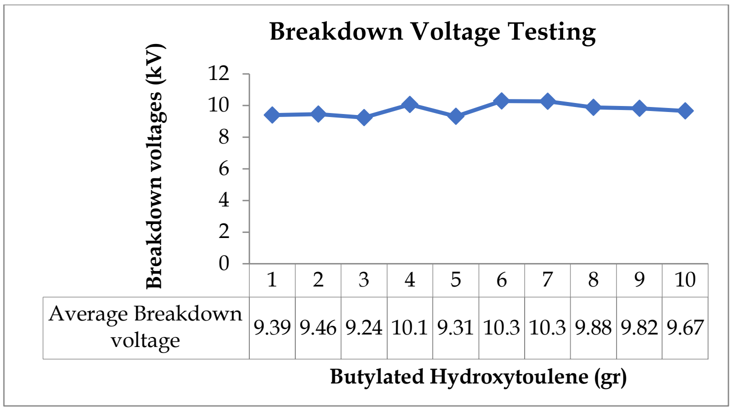

Figure 2. Graph of average breakdown voltage of crude palm oil with the addition of butylated hydroxytoulene

Figure 2 is a graph showing a comparison of the effect of adding the additive butylated hydroxytoulene on the breakdown voltage value of crude palm oil. From the graph it can be seen that the addition of the additive butylated hydroxytoulene to the crude palm oil sample has a changing effect on the breakdown voltage value. The average breakdown voltage value obtained from the test results shows a fluctuating trend but does not experience a significant increase or decrease in the breakdown voltage value. The insignificant change in the average value of breakdown voltage can be caused by the addition of a small concentration of butylated hydroxytoulene additive between samples. The graph shows that the breakdown voltage value experiences a fluctuating trend but the value tends to increase. So the addition of a greater concentration of butylated hydroxytoulene additive has a changing effect where the greater the concentration of butylated hydroxytoulene additive added to the sample, the higher the breakdown voltage value of crude palm oil tends to be.

c. Comparison between Viscosity and Breakdown Voltage

Figure 3 shows a comparison graph between the breakdown voltage and viscosity values of crude palm oil with the addition of butylated hydroxytoluene additives with additive concentrations of 1g respectively; 2 g; 3 g; 4 g; 5 gr; 6 g; 7 g; 8 g; 9 g; and 10 gr. From the results data graph, you can see the comparison of the viscosity value to the breakdown voltage value to find out what effect viscosity has on the oil breakdown voltage value. Viscosity does not really affect the breakdown voltage value of the crude palm oil sample with the addition of butylated hydroxytoluene where the change in viscosity value to the change in breakdown voltage value does not experience a significant change in comparison value. The breakdown voltage testing process for each sample is carried out using procedures and parameters that have been adjusted to standards where the sample temperature when tested is 40oC with an electrode distance of 2.5 mm.

Table 5. Comparison of viscosity and breakdown voltage of crude palm oil with the addition of antyoxidants

No	*Butylated Hydroxytoulene* (gram)	Viscosity (cSt)	Breakdown Voltages (kV)
1	1	28,92	9,39
2	2	27,56	9,455
3	3	27,49	9,24
4	4	26,31	10,06
5	5	26,8	9,31
6	6	26,44	10,285
7	7	27,12	10,265
8	8	26,31	9,875
9	9	26,13	9,82
10	10	25,29	9,665

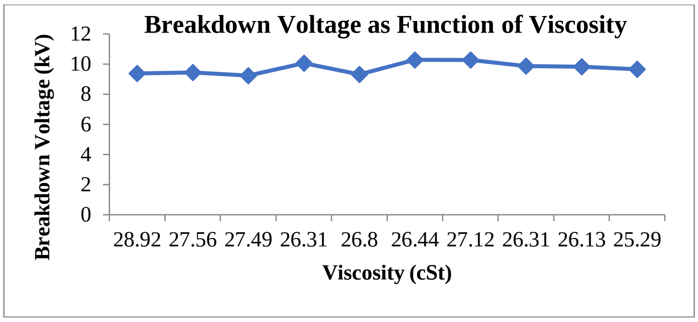

Figure 3. Comparison graph between viscosity and breakdown voltage in crude palm oil with the addition of butylated hydroxytoulene

Conclusion

Viscosity testing on crude palm oil showed that the lowest average viscosity value was produced by crude palm oil samples with the addition of 10 grams of butylated hydroxytoulene, namely 25.29 cSt. Based on the standard viscosity value of insulating oil, namely <12 cSt at a temperature of 40 oC, it can be concluded that the viscosity of the sample tested does not meet the standard value. Meanwhile, in the breakdown voltage test after the addition process using the additive butylated hydroxytoulene, the breakdown voltage value was not suitable for use as transformer insulation. The highest average value of breakdown voltage produced is 10.285 kV, which does not meet existing standards referring to SPLN 49-91:1982 standards where the standard value of breakdown voltage for insulating oil is ≥ 30 kV/2.5mm.

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