



A Study of Palm Oil as an Insulating Medium

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Abstract

A power transformer is the main component in a power system network. The most used insulating material in the transformer is mineral oil because of the high properties and best performance. Insulating oil is very important to protect transformer from any hazard condition. However, the oil can affect the environment, high in cost and unpredictable quantity because it is a natural source. The study of palm oil as insulating medium is suggested as Malaysia is the second largest country that produces palm oil. Palm oil has many benefits and easy to produce without need too much guard after the planting. The aim of this research is to study the characteristic of palm oil that can benefit as transformer oil, compare the differences of palm oil with respect to the mineral oil used in the high power transformer, and test its characteristic. Three experiments conducted are palm oil are breakdown voltage, tan delta, and aging determination. The results show that palm oil has future to be the renewable and biodegradable alternative. As the properties of palm oil used in the transformer has maximum dielectric field strength, low tan delta and can withstand the long aging process.

Keywords: Transformer; Insulation; Breakdown Voltage; Palm Oil; Mineral Oil

1. Introduction

Transformer in the power system mostly type of oil filled [1]–[3]. Nowadays, the demands of the power transformer that can operate in high temperature also increase and the greater stability of the power transformer oil needed[4]. The manufactures of power transformer oil tend to provide the best efficient oil that can supply in long term without worry the source of insulating oil will finish one day[5].

Generally, mineral oil is widely used as the insulator of the transformer due to the outstanding performance of dielectric, viscosity, cooling medium, high availability, oxidation stability, low cost of production and maintenance. [6]. Mineral oil is from the petroleum based oil that from non-renewable source and not only used in power transformer but in other high voltage device. So, the mineral oil based on petroleum oil is required in excessive amount per year. However, due to its hazard, toxic and pollution impact on top of decrement of petroleum-based sources yearly, extensive researched were conducted to substitute or mix the mineral oil with the biodegradable oil such as palm oil, coconut oil, soybean oil, corn oil, olive oil, sesame oil, castor oil, pongamia pinnata oil, rapeseed oil and others. [7]–[10]. This type of vegetable oil has advantageous such as non-toxic, renewable, easy to gain, less flammable, environmental friendly and cheap.

As a consequence, the researchers keep to investigate the suitable vegetables oil to be replaced that friendly environment. Since Malaysia is the world's second-largest producer of the palm oil [11] it become the popular candidate as an alternative for non-biodegradable oil. The composition of palm oil consists of saturated and unsaturated fatty acid is almost balance with high amount

of the antioxidants, β -carotene, and vitamin E [12]. Three different types of palm oil were obtained by extracted from the palm nut which is Crude Palm Oil (CPO), Refined, Bleached and Deodorized Palm Oil (RBDPO) and Palm Kernel Oil (PKO)[13]–[16].

The organic oil like palm oil can be expected to replace as mineral oil because of the increasing in the production per year[17]. Other than that, the important point is the palm oil very beneficial in Malaysia[18]. In transformer application, the palm based oil can predict to use as insulating oil after through the proper investigation[19]. The reviewed in physical, chemical and electrical characteristic of palm based oil will choose the suitable dielectric fluids from all the types of palm based oil[19].

In a power transformer, the 50% failures within five year are reported in the United States[20]. The failures are more around the world due to weak technical abilities in the maintenance of transformer. The high percent of transformer failures is because of the insulation failure. The insulation failure can occur because of the dielectric faults, oil-related faults and workmanship installation of insulate[20]. So, more experiments are needed to improve in dielectric fluid and transformer oil for insulation.

2. Methodology

2.1. Sample Preparation

Samples used in this experiment are mineral oil from Hyrax Oil Sdn. Bhd, Crude Palm Kernel Oil (CPKO) and Palm Oil Stearin (PL52). Hyrax Hypertrans transformers oil is a premium uninhibited mineral insulating oil made from severely hydro-treated wax-free naphthenic oil which is good as a dielectric and coolant. It has

very good low temperature fluidity, high flash point and chemical stability. Meanwhile the CPKO come from the outer side that surround with endocarp and that kernel is white color. Through separation and drying process, the palm kernel oil will produce. This oil also used in commercial cooking and low cost but it can remain stable at high cooking temperature.

Finally, the Palm Oil Stearin is made from refined, bleached and deodorized Palm Kernel Fractions. As palm oil is naturally semi-solid at room temperature 20°C, the liquid portion can be physically separated from the solid portion by fractionation. The liquid fraction is known as palm olein, while the solid fraction as palm stearin. Palm stearin is used in the formulations of trans fat-free margarine, shortening and vegetable ghee.

2.2. Breakdown Voltage Measurement

Breakdown voltage in transformer oil also known as BDV test. There are two ways to test the breakdown voltage of oil which is in DC breakdown voltage or AC breakdown voltage. In simply definition, the breakdown voltage is when the minimum applied voltage that would cause a given insulator or electrode to break down. The maximum capacity to withstand voltage of insulating oil is the dielectric strength. This testing is measured by observing at what voltage, sparking straits between two electrodes emerged in the oil, separated by specific gap.

There are many factors that affect the dielectric breakdown voltage of insulating medium at commercial power frequencies. Firstly, the affected by the degree of uniformity of the electric field, the area of the electrodes or volume of the liquid under maximum stress, the length of time for which the liquid is under stress, the temperature of the liquid (especially insofar as it affects the relative saturation level of moisture in solution), gassing tendencies of the liquid under the influence of electric stress, concentration of dissolved gases (especially if saturation levels are exceed as a result of sudden cooling or decrease in pressure, which may cause the formation of gas bubbles), incompatibility with materials of construction and velocity of flow. A decrease in dielectric strength of the liquid can have an accentuated effect on the electric creep age strength of solid insulating materials immersed in the liquid.

Each samples of palm oil are tested using breakdown voltage (BDV) test set in accordance with IEC 60156 standards [6] as shown in Fig. 2. The test cell had a volume capacity of 500 ml consisted of VDE electrodes with the gap of 2.5 mm. Using a hot plate as heater, the sample of CPO were directly heated up to 40 °C because of semi-solid condition while the others sample were tested at room temperature. The test set was capable of supplying the voltage up to 200 kV. In this experiment, the BDV set was run automatically by supplying the AC voltage with 50 Hz frequency at rate of 2 kVs-1 until breakdown occurs. The breakdown voltages were taken in 6 times measurement with 2 minutes pause between consecutive breakdowns.

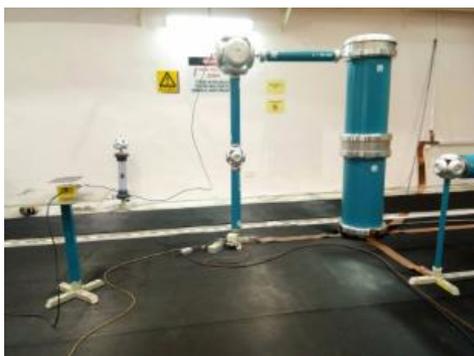


Fig. 2: Breakdown Voltage Testing Equipment

2.3. Tan Delta Measurement

Tan Delta measurement is a dissipation factor measurement. This is a loss-rate of energy of a mode of oscillation in a dissipative system. In a real life, no insulating materials are complete dielectric in nature. Each sample of palm oil is testing by using capacitance and $\tan \delta$ measuring bridge. Normal value for an oil as manufactured is less than 0.005 at 90 °C and 50 Hz to 60 Hz. Each samples of palm oil are tested using BDV test set in accordance with IEC 60247 standards as shown in Fig. 3. The test cell had a volume capacity of 500 ml consisted of VDE electrodes with the gap of 2.5 mm. Using a hot plate as heater, the sample of CPKO and PL52 were directly heated up to 40 °C because of semi-solid condition while the mineral oil sample were tested at room temperature. The tests are in general made in dependence of the test voltage applied; both magnitudes, capacitance and dissipation factor shall be essentially constant with increasing voltage, as insulation systems are linear systems and any. Fig. 4 shows the TG-3 which is a fully automatic capacitance and dissipation factor (power factor) measuring bridge for high precision high voltage insulation diagnostic. This equipment is uncertainty for dissipation factor, measures impedances in all four quadrants. It showed the value of tan delta automatically in the dielectric dissipation factor testing.



Fig. 3: Setting up for Tan Delta measurement.



Fig. 4: Capacitance and Tan Delta Measuring Bridge

2.4. Aging Determination

Aging is the process of becoming older, a process that is genetically determined and environmentally modulated. There are many ways to evaluate the aged of transformer oil, but one of the ways is by conventional tests to assess the degradation in electrical, chemical and physical properties. In this paper, aging can be determined by the color of the oils and the changes of breakdown voltage after aging process. In practically, the properties of transformer oils will changes after a long time in the transformer because of the changes in temperature. Water contents in the transformer oils that affect the oxidation stability for oils after sometimes but the mineral oil already proved can withstand more than natural ester. Natural ester like palm oils with its own chemical properties which is fatty acid definitely is high percentage of changes after aging process.

The samples of mineral oil, CPKO and PL52 had been put into the Temperature (and Humidity) chamber platinumous J series. It runs

automatically after setting up by the user. All of the oils that want to be age had been puts into this equipment. The temperature in the chamber was set for 100°C with 100 hours. The chamber will automatically off after 100°C. Aging determination is based on changes in the breakdown voltage after the oil is heat for 100 hours. The method after the oils are ready to test is similar to the breakdown voltage before.

Fig. 6 shows the palm oil is natural ester that contains saturated fat or unsaturated fat. The highest contains of saturated fat will make oils changes due the surrounding temperature. The oils became semi-solid after some period of time in the laboratory. The testing must be run in the liquid condition for this oil. So, the oils will be hot in the hotplate. The starting temperature can be increase until 100°C. Then, the oils will be stirred up until became fluidity. Lastly, leave the oils again until the temperature reach 40°C before run the testing.



Fig. 5: Temperature (and Humidity) Chamber Platinox J series Equipment



Fig. 6: CPKO had been heated on the hot plate

3. Result and Discussion

There are 12 properties that the oils have to be passed before it can be used as an insulation material. Three mains of the property is breakdown voltage where the oil has been tested in terms of electrical stress by injecting with high voltage, Tan Delta measurement happen when an insulating medium is placed between the live part and grounded part of an electrical circuit, and the breakdown voltage after an aging process. This project focuses on three testing which had been tested at UiTM Shah Alam (High Voltage Lab).

3.1 Breakdown Voltage

Table 1: Breakdown Voltage of Different Types of Palm Oil

Type of palm oil	Breakdown voltage (kV)	
	Before Aging	After Aging
Mineral Oil	32	11.1
CPKO	39.8	40
PL52	19.3	40

Table 1 illustrates the mean value of breakdown voltage before and after aging with environment humidity has been negligible. It is seen that the best result of breakdown voltage is CPKO. Both

voltage value is more than 30 kV which is similar to previous research [21], [22]. Meanwhile, result for mineral oil has been decreased when applied aging process. Two samples of palm oil that are best performance before the aging had been choosing to test which is CPKO and PL52. For PL52 result after aging is much more better as the water content in the sample reduced through aging process. CPKO and PL52 will become semi solid when the surrounding temperature is less than 27°C. Both oils need heating process before testing. Each sample had been tested using BDV test set in accordance with IEC 60156 standards.

Breakdown voltage for both vegetable oils are increasing after aging process. The ability for withstand the high voltage is increased than before. The oil after an aging process is more viscosity than before an aging. The amount of water content also decreased as stated by M.M Arifin [22]. From investigation, the mineral oil is losing its ability to withstand the high voltage after an aging process.

3.2 Tan delta

Table 2: Tan Delta for Different Types of Oil

Type of oil	Tan Delta
CPKO	0.0207
PL52	0.0222
Mineral Oil	0.025

Each samples of palm oil are tested using BDV test set in accordance with IEC 60247 standards. Each sample has been testing for two times to achieve the accurate value. Table 2 shows the value of Tan Delta for all oil that had been testing. From the observation all sample are meet the standard for tan delta testing (the standard value for tan delta testing is less than 0.05).

4. Conclusion

The study of palm oil as an insulating medium has been investigated. From the experimental result, it is reveals that CPKO has the highest breakdown voltage as well as the most potential of transformer liquid. The breakdown voltage after an aging shows the improvement value. It is good as an insulating medium. While the Tan Delta value for all of palm oil are close to mineral oil. Further investigations are required to be implemented for replacement of palm oil as a transformer liquid.

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References

- [1] M. S. Mohamad, H. Zainuddin, S. A. Ghani, and I. S. Chairul, "AC breakdown voltage and viscosity of palm fatty acid ester (PFAE) oil-based nanofluids," *J. Electr. Eng. Technol.*, vol. 12, no. 6, pp. 2333–2341, 2017.
- [2] N. Pamuk, "Investigation of the usage of palm oils with the aim of insulation in high voltage power system equipments," *Teh. Vjesn. - Tech. Gaz.*, vol. 22, no. 5, pp. 1287–1296, 2015.
- [3] N. Azis, J. Jasni, M. Z. A. Ab Kadir, and M. N. Mohtar, "Suitability of palm based oil as dielectric insulating fluid in transformers," *J. Electr. Eng. Technol.*, vol. 9, no. 2, pp. 662–669, 2014.
- [4] A. A. Abdelmalik, "Chemically modified palm kernel oil ester: A possible sustainable alternative insulating fluid," *Sustain. Mater. Technol.*, vol. 1, pp. 42–51, 2014.
- [5] N. Zimmerman, R. Bass, and D. Ph, "Consideration of Ester-Based Oils as Replacements for Transformer Mineral Oil," 2014.

- [6] A. Narayani, M. W. Iruthayarajan, and M. Bakruthen, "A statistical study on the AC breakdown voltage of corn oil and mineral oil for liquid insulation," in Proceedings of the 3rd IEEE International Conference on Advances in Electrical and Electronics, Information, Communication and Bio-Informatics, AEEICB 2017, 2017, pp. 320–323.
- [7] C. Kocatepe, E. Taslak, C. F. Kumru, and O. Arkan, "An investigation on vegetable oils as potential insulating liquid," *Int. J. Electr. Comput. Energ. Electron. Commun. Eng.*, vol. 9, no. 8, pp. 739–742, 2015.
- [8] A. Beroual, U. Khaled, P. S. M. Noah, and H. Sitorus, "Comparative study of breakdown voltage of mineral, synthetic and natural oils and based mineral oil mixtures under AC and DC voltages," *Energies*, vol. 10, no. 4, 2017.
- [9] N. A. Zakaria, Y. Z. Arief, M. F. M. Taib, Z. Adzis, M. H. Ahmad, N. A. Muhamad, M. Abu Bakar Sidik, N. K. Mohd, L. W. Huei, and Y. S. Kian, "Experimental investigation on palm-based oil as alternative for biodegradable power transformer oil application in Malaysia," *J. Telecommun. Electron. Comput. Eng.*, vol. 8, no. 12, 2016.
- [10] M. S. A. Kamal, N. Bashir, M. H. Ahmad, and Z. Bamalli, "Dielectric properties and oxidation stability assessment of vegetable-based oils as insulation for power transformers," *J. Optoelectron. Adv. Mater.*, vol. 17, no. 9–10, 2015.
- [11] N. Abdullah and F. Sulaim, "The Oil Palm Wastes in Malaysia," in *Biomass Now - Sustainable Growth and Use*, 2013.
- [12] M. Koushki, M. Nahidi, and F. Cheraghali, "Physico-chemical properties, fatty acid profile and nutrition in palm oil," *J. Paramed. Sci. Summer*, vol. 6, no. 3, pp. 2008–4978, 2015.
- [13] S. S. Sinan, S. N. Shawaludin, J. Jasni, N. Azis, M. Z. A. A. Kadir, and M. N. Mohtar, "Investigation on the AC breakdown voltage of RBDPO Olein," in 2014 IEEE Innovative Smart Grid Technologies - Asia, ISGT ASIA 2014, 2014, pp. 760–763.
- [14] A. A. Abdelmalik, J. C. Fothergill, S. J. Dodd, A. P. Abbott, and R. C. Harris, "Effect of side chains on the dielectric properties of alkyl esters derived from palm kernel oil," in Proceedings - IEEE International Conference on Dielectric Liquids, 2011.
- [15] A. A. Abdelmalik, J. C. Fothergill, and S. J. Dodd, "Electrical properties of ester dielectric fluids from palm kernel oil," in Annual Report - Conference on Electrical Insulation and Dielectric Phenomena, CEIDP, 2011, pp. 415–418.
- [16] A. A. Abdelmalik, J. C. Fothergill, and S. J. Dodd, "Electrical conduction and dielectric breakdown characteristics of alkyl ester dielectric fluids obtained from palm kernel oil," *IEEE Trans. Dielectr. Electr. Insul.*, vol. 19, no. 5, pp. 1623–1632, 2012.
- [17] N. Zhou et al., "Sime Darby palm oil facts and figures," *J. Microbiol. Methods*, vol. 1, no. 1, pp. 1–11, 2013.
- [18] D. Sheil, a Casson, E. Meijaard, M. Van Noordwijk, J. Gaskell, J. Sunderland-Groves, K. Wertz, and M. Kanninen, *The impacts and opportunities of oil palm in Southeast Asia*. 2009.
- [19] D. Fluids, "R2000," pp. 1–8.
- [20] D. S. Derick Njombog Tante, Shafiq Yousef Al Liddawi, "PROPERTIES OF TRANSFORMER OIL THAT AFFECT EFFICIENCY . Contact :," no. January, p. 41, 2014.
- [21] S. S. Kumar, M. W. Iruthayarajan, and M. Bakruthen, "Analysis of vegetable liquid insulating medium for applications in high voltage transformers," in 2014 International Conference on Science Engineering and Management Research, ICSEMR 2014, 2014.
- [22] M. M. Ariffin, M. T. Ishak, M. H. A. Hamid, N. I. A. Katim, A. Ishak, and N. Azis, "Ageing effect of vegetable oils impregnated paper in transformer application," in International Conference on High Voltage Engineering and Power Systems, ICHVEPS 2017 - Proceeding, 2017.