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# Use Palm Oil as Alternative with Insulation Oil in High Voltage Equipment

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***Authors' contributions:***

*This work was carried out in collaboration between all authors. Author MMY designed the study, wrote the protocol, and wrote the first draft of the manuscript. Author MAA managed the literature searches, analyses of the study performed the spectroscopy analysis and managed the experimental process. All authors read and approved the final manuscript.*

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## ABSTRACT

Transformers have traditionally used mineral oil for cooling and insulation .The better compound material has to produce with good electrical and chemical characteristics. However, recent evidence has shown the deficiencies with these fluids where they have low properties especially flash and fire point and most importantly low dielectric breakdown voltage. The most serious of these shortcomings is the inability to meet up with the health and environmental laws. Besides, they are not organic and hence not biodegradable. In this paper, natural palm oil and its derivatives have been studied in attempt to find an environmental friendly insulating fluid. Samples such as crude and refined palm oils were electrically and chemically tested and comparisons were made with the mineral oil. Electrical tests such as the breakdown voltage, resistivity and dissipation factor were conducted. Besides that, chemical properties such as pour point, flash point, water content, density, kinematic viscosity, dissolved of gases and moisture content of the compound were also being investigated. Results from the laboratory studies have shown that the natural palm oil has better electrical and chemical characteristics as compared to the existing mineral oil for transformer insulation.

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## 1. INTRODUCTION

Transformer is one of the important part apparatus in the power system. Besides, transformer life management is an essential issue in the modern power operation system. Oil filled transformer technology has been used for more than 100 years [1]. Impurity is the main factor that reduces the insulating performance [2]. The maintenance of the insulation system largely determines the extent of transformer's life. Future transformer will no doubt have increased capacity and size and their design may require the use of new materials [3]. Transformer may operate at higher temperature and in turn demand transformer oils of greater stability.

Transformer oil manufacturers desire to supply the customer with oil that gives good performance in actual field of operations [2]. Transformer oil or insulating oil is usually a highly-refined mineral oil that is stable at high temperature and has excellent electrical insulating properties. The oil helps to cool the transformer. Because it provides part of the electrical insulation between internal live parts, transformer oil must remain stable at high temperatures for an extended period.

Since long time ago, petroleum-based mineral oils have been used as liquid insulating materials [3]. Nowadays, the oils are widely used as insulation for power transformer or other high voltage apparatus. This is because the insulating oils have excellent dielectric properties such as high electric field strength, low dielectric losses and good long term performance [4]. However, due to the environmental consideration; the oils are considered to be replaced with more environmental friendly liquid insulating materials such as vegetables oil, palm oil, and others. Many researchers are now searching new types of insulating materials, which are generally organic types and obtained from the nature [3].

In order to get new insulating oil for the transformer insulation medium, tests have been conducted to ensure the properties of this new material follows the standard requirement. The tests are to be related to the function of the oil which is fulfilling some of the implied needs of the user. When oil is integral part of the transformer; its behavior can be related to its molecular composition and physical properties Gill et al. [2]. There are some components which are influence to its behavior such as air content, moisture, dielectric strength and others external factor [5]. The most fundamental requirements of the transformer oil are the electrical properties and the thermal behavior [2].

## 2. POTENTIAL OF NATURAL PALM OIL AS NEW DIELECTRIC FLUID

Based on the finding for the insulating fluid, the alternative should have the property of cooling the electrical equipment. Along with this line, the plant based oils are selected. Resent research work and industrial research and development have come up with idea that vegetables oils termed as "biodegradable oil" can find industrial applications [6].

Vegetable oils do not contain any sulphur, aromatic hydrocarbons, metals or crude oil residue [7]. The absence of sulphur means a reduction in the formation of acid rain by sulphate emissions which can generate sulphuric acid in our atmosphere [7].

The vegetable oil which is fully qualifying as a dielectric fluid, its chemical composition is crucial. Crude vegetables oils extracted from oil seeds have a dark color and contains solid constituents such as proteins, fibers and liquid (fat and oil) [6]. Both fats and oil are triglyceride esters of fatty acids, but fats contains a relatively high percentage of saturated triglyceride and would freeze to solid below room temperature [6].

Naturally, the palm oil is characterized as stabilized oil due to its chemical compositions. As such it can be used in most food applications without hydrogenation, thus reducing production costs by as much as 30%.

## 3. EXPERIMENTAL WORK

### 3.1 Sample Preparation

In order to investigate the performance of palm oil as a new insulation transformer, there are several samples of palm oil and its derivatives that have been used such as refined palm oil (RPO), crude palm oil (CPO), crude palm oil category 8 (CP8), and crude palm oil category 10 (CP10). Mineral oil are also tested to be as a reference with the palm oil samples and its derivatives.

### 3.2 Experimental Procedure

#### 3.2.1 Breakdown voltage

The breakdown voltage testing had been done in accordance with the BS148 standards. The experimental set up includes the usage of high voltage transformer, measuring capacitors, connectors and accessories and the measuring units. The experiments were conducted at the high voltage laboratory and the test set up is shown in Fig. 1 and Fig. 2 respectively in IVAT center FKE UTM. The ac voltage supply was injected (increased slowly) to the test samples using the high voltage generating and measuring systems.

**Fig. 1. Equipment setup for breakdown voltage test**

**Fig. 2. Measuring unit of breakdown voltage**

*3.2.1.1 Dissipation factor*

Tan Delta or dissipation factor testing is done in accordance with the BS5737 standards. The experimental set up includes the usage of Capacitance and dissipation / power factor test set and high voltage supply and control. The equipment used are the ac *bridge (TETTEX type 2816) and test cell TETTEX type 6835* as shown in Fig. 3. The voltage supply was increased gradually from 2kV until 10kV. Each of the voltage supplied are injected at 10 times per second.

**Fig. 3. Capacitance and dissipation / power factor test set and high voltage supply and control**

*3.2.1.2 Pour point*

The heated sample was cooled gradually in cooling bath as shown in Fig. 4. 50 ml of the sample was poured into a holding cylinder as shown in Fig. 5. The holding cylinder was tilted at regular intervals (every decreasing at 3 ºC) to check the movement of the oil.

**Fig. 4. Seta cloud and pour point refrigerating unit**

**Fig. 5. Holding cylinder**

*3.2.1.3 Flash point*

Flash Point is determined by referring to the standard ASTM D93 by using Pensky-Martens Closed Cup Tester (PMCC) as shown in Fig. 6. ASTM D93 is referenced as an acceptable test method for the classification of flammable liquids. The Pensky-Martens Closed Cup tester is used to determine the flash point of viscous or film forming liquids and liquids with a flash point greater than 93°C (200°F).

**Fig. 6. Pensky-martens closed cup (PMCC) tester**

*3.2.1.4 Density*

Density measurements were conducted using glass hydrometer method by refering to standard ASTM D1298 API Gravity / Density) This method was also being used to determine the relative density (specific gravity), or API gravity of crude petroleum, petroleum products, or mixtures of petroleum and nonpetroleum products normally handled as liquids and having a Reid vapor pressure of 101.325 kPa.

*3.2.1.5 Water content*

The water content of an oil sample can be measured using the Gas Chromatography method as shown in Fig. 7.

**Fig. 7. Gas chromatography**

*3.2.1.6 Kinematic viscosity*

The objective of doing this experiment is to know the flow ability of the oil samples at a temperature of 40ºC and 100ºC. Fig. 8 shows the Baths which are used at 0ºC, 40ºC, and 100ºC. Viscosities of some of the oil samples were also determined using a glass capillary viscometer (Cannon-Fenske, ASTM D 445).

**Fig. 8. Bath, from left at 0ºC, 40ºC, and 100ºC.**

3.2.1.7 *Dissolved of gases*

In order to predict the conditions of oil insulating material to avoid future fault problem the dissolved gas analysis (DGA) was done. The DGA was done by using a Portable Transport X as shown in Fig. 9. Oil samples to be taken into 50 ml glass syringe with 2 way stopcock. Analysis were being performed as soon as possible after sampling.


**Fig. 9. Portable transports X**

## 4. RESULTS AND ANALYSIS

Results of the experimental works are presented and discussed in the followings sections.

## 4.1 Breakdown Voltage

The graph in Fig. 10 shows the results of breakdown voltage for all samples tested. Palm oil samples show the higher value of breakdown voltage as compared to the mineral oil. The CP10 have the highest breakdown voltage level which is 52.73kV followed by CP8 which is 41.92kV. The potential of palm oil in order to be considered as the good dielectric insulation in based on the fatty acids contain in the oil. For CP10 and CP8, the fatty acid is less than the pure palm oil. This is due to the distillation process being conducted to produce CP10 and CP8 reduces the contents of fatty acids in the oil.

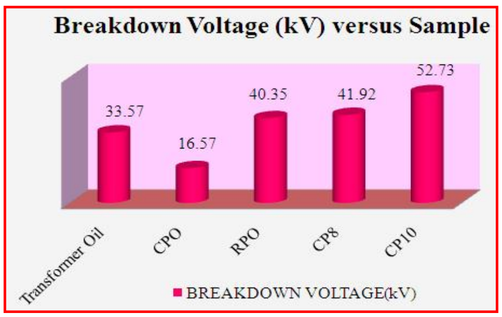


**Fig. 10. Breakdown voltage of oil samples**

### 4.1.1 Dissipation factor

Fig. 11 illustrates the dissipation factor resulting from the experiment conducted. A low value of dissipation factor means that the material is a good insulation. Results show that the mineral oil, CP8 and CP10 have low dissipation factor and is suitable for high voltage insulation purposes. CPO has the highest dissipation factor which is 0.013 followed by RPO which is 0.0125. Both samples of oil derivatives are not suitable to be used as high voltage insulation due to its higher value of dissipation factor which will reduces the oil resistivity.

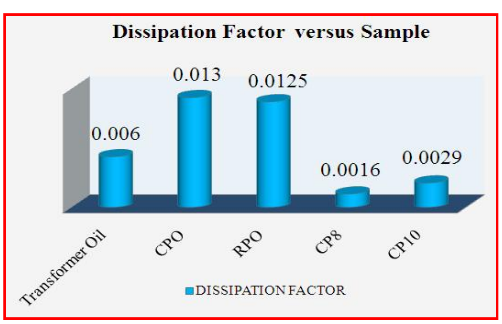


**Fig. 11. Dissipation factor versus oil samples**

#### *4.1.1.1 Pour point*

Fig. 12 shows the oil sample pour point as a function of temperature. All the palm oil samples show the positive value of temperature while the transformer oil is slightly different and show in negative value. When making a comparison to the standard value, the acceptable temperature in negative value with limit till -40ºC. Therefore, all samples of palm oil and its derivatives are pure and have not yet further chemical process to become insulation oil.

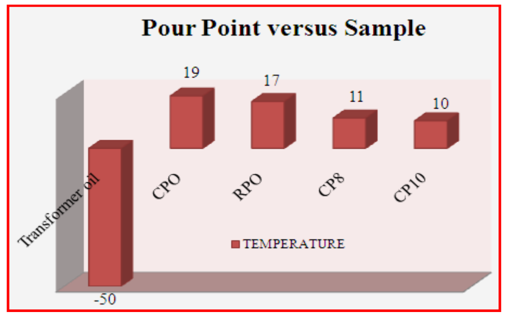


**Fig. 12. Pour Point versus Oil Samples**

#### *4.1.1.2 Flash point*

Fig. 13 show the flash point for oil samples as function of temperature. For the good insulation, oil must fulfill the acceptable value that is at range temperature from 140ºC and less than 285ºC [8]. All samples has high flash point compared to transformer oil. It is possible to be as insulation oil since there have high flash point but some of samples already exceed the limit given for example CP8 and CP10. While the CPO and RPO in the range standard.

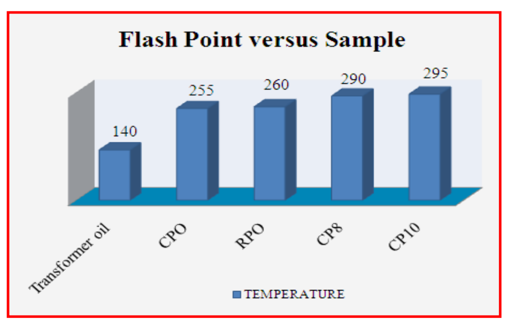


**Fig. 13. Flash point versus oil samples**

#### *4.1.1.2.1 Density*

Density properties will determine the buoyancy and purity of material. To be as 'new transformer oil' the density of oil should be between 0.875 and 0.89 and it will expressed in kg/cm$^3$ unit.CPO and RPO samples show the over limit of it density value. However, the CP8 and CP10 show the good result for transformer oil and fulfill the requirement standard to be new insulation transformer as shows in Fig. 14.

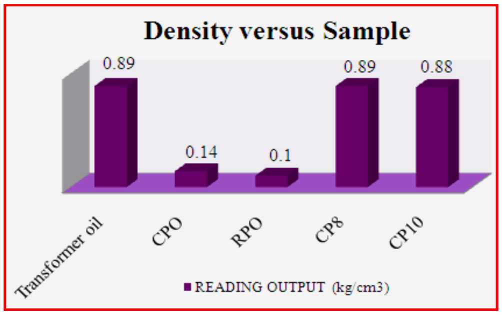


**Fig. 14. Density versus Oil Samples**

*4.1.1.2.2 Water content*

Water content for oil samples indicates in part per million (ppm). Water content can be varies from time to time. Since water content is under monitoring part, it can be measured by using Portable Transport X to test DGA and water content together. Fig. 15 indicates that CPO has the highest of water content with 80 ppm but in contrast CP10 show only 23 ppm.

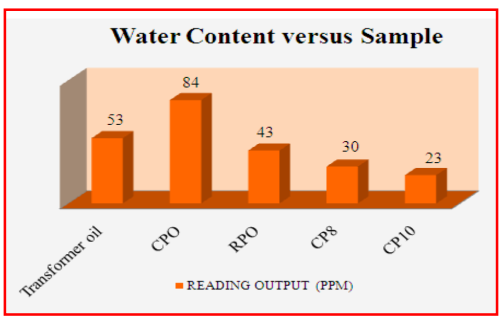


**Fig. 15. Water content versus oil samples**

*4.1.1.2.3 Kinematic viscosity*

Fig. 16 shows the effect of temperature on the viscosities of palm oil and its derivatives with compare to transformer oil at 40°C and 100°C. The high value of kinematic viscosity is not suitable to be use as insulation because the resistance of oil to flow is high So, it cannot transfer heat properly. At 40°C the kinematic viscosities of CPO is the greatest value, followed by RPO, then transformer oil, and the less value of CP8 and CP10, respectively. At 100°C, these viscosities are diminishing to the lower value below than 12 cSt, respectively. Oil samples of CP8 and CP10 suitable use as new insulation transformer. Besides, it can be seen that viscosity decreases linearly with increasing temperature. CP8 and CP10 are always similar value for both temperatures 40°C and 100°C.

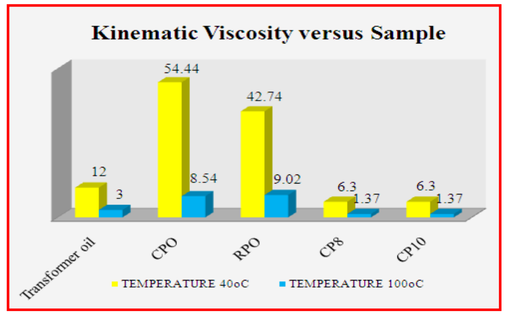


**Fig. 16. Kinematic viscosity versus oil samples**

*4.1.1.2.4 Dissolved of gases*

Table 1 shows the pure gases content in the oil samples. Based on the experiment conducted, all the samples are below the standard warning of the gases content to be insulation transformer.

| Type of Gases | Symbol | CPO | RPO | CP 8 | CP 10 | Transformer oil | Standard warning limit |
|---|---|---|---|---|---|---|---|
| Hydrogen | $H_2$ | 8 | <5 | <5 | <5 | <5 | <700 |
| Carbon Dioxide | $CO_2$ | 17220 | 485 | 498 | 525 | 456 | <4000 |
| Carbon Monoxide | CO | 8 | 2 | 4 | 2 | <1 | <350 |
| Ethylene | $C_2H_4$ | 3 | 2 | 4 | 8 | 3 | <100 |
| Ethane | $C_2H_6$ | 19 | 2 | 1 | 5 | <1 | <100 |
| Methane | $CH_4$ | 3 | 1 | 1 | 3 | 2 | <400 |
| Acetylene | $C_2H_2$ | <1 | <1 | <1 | <1 | <1 | <5 |
| TDCG | - | 41 | 12 | 14 | 20 | 10 | 1900 |

**Table 1. Dissolved of gases in oil samples**

## 5. CONCLUSION

We had investigated the electrical and chemical properties of natural palm oil and it derivatives to be proposed as new insulation transformer. The results showed that CP8 and CP10 could be considered as insulating materials in the future. Besides, both of this samples show good properties compared to existing mineral oils. Further investigations are needed concerning long term properties and the ability to be friendly to our environment.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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