The Impact of Partial Discharge on the Dielectric Properties of Refined Bleached and Deodorized Palm Oil (RBDPO)

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***Abstract*—Several years ago, insulation oil played an important role in electrical power equipment. Mineral oil extracted from petroleum resources (a non-renewable source) has been widely used as an insulating material in the transformers. Therefore, there is a need to find renewable alternatives to the petroleum-based mineral oil. Refined bleached and deodorized palm oil (RBDPO) is a palm-based oil which has undergone several modifications. In this paper, the dielectric properties of RBDPO and the conventional transformer oil were investigated, followed by an investigation of its partial discharge (PD) impact on the dielectric properties. The breakdown voltage was measured according to the international electrotechnical commission (IEC 6056) standard and the viscosity test was done according to BS EN ISO 3104:1996. The experiments have proved that RBDPO can be used as an insulating oil due to the closeness of its dielectric properties compared to the conventional oil.**

***Index Terms*—Petroleum-Based Mineral Oil; Refined Bleached and Deodorized Palm Oil; Partial Discharge; Dielectric Properties.**

I. INTRODUCTION

Over the years, crude-petroleum-derived mineral oils have been the commonest insulating fluid used in power transformers for cooling and insulation purposes. Meanwhile, there are environmental concerns regarding the effects of mineral oils such as water and soil contamination during spillage which can lead to environmental disaster due to their non-biodegradability. The environmental effects may have serious effects on plants, animal and human lives [1]. A major component studied in power systems is the subsistence of power transformers to oil/paper/ pressboard insulation. Transformer insulator is continuously deteriorated during service due to the applied stress in the form of thermal, mechanical and electrical tensions. These electrical tensions due to insulator deterioration can lead to several types of system failures [2]. The crude petroleum-based mineral oil is commonly used in the transformers due to its exceptional performance compared to other oils [2,3]. However, its poor biodegradability and non-renewability have elicited the attention of finding alternative natural esters from other sources such as sunflower, vegetables, and soya beans [4,5]. Studies have reported the need to purify natural esters to improve their insulation properties [4]. Generally, most vegetable oils have higher breakdown voltages compared to mineral oils. Insulation oils from vegetable sources are commercially available as alternatives to the mineral-based transformer insulating oils. The vegetable-based insulating oils have some advantages to offer, such as being classified as natural esters, having a faster rate of biodegradation, higher flash and fire points, no water hazards and low thermal expansion coefficient. The use of these oils in power transformers presents a strong advantage compared to the mineral oil in current use [6]. Palm and vegetable oils are endowed with a high fatty acid triglyceride and unsaturated fatty acid percentages, coupled with a greater susceptibility to oxidation attack [7].

Experiments on palm oil have demonstrated that RBDPO has similar properties to that of mineral oil, and thus, considering RBDPO as a suitable alternative to the petroleum-based mineral oil.

II. OIL AS INSULATOR

An insulating material is a material with an indefinite electrostatic field. Insulating materials provide a high resistance to the passage of direct current between two conductors. They can be in solid, gaseous, or liquid form and possess good electrical characteristics such as the prevention of arcing and corona. They are mainly used in power transformer applications as dielectric materials for electrical insulation. Additionally, they are also used as coolants in power transformers [8].

The use of oil as dielectrics in power transformers was patented in 1882 by Elihu Thomson. Until now, the crude-based mineral oils have been the commonly used insulation fluid in power transformers. Besides, it is also used as a coolant in power systems such as power capacitors and transformers [6]. Meanwhile, there could be serious environmental and health hazards in case of mineral oil spillage which can lead to serious disasters due to their non-biodegradability [8].

Efforts have been made within the past two decades towards finding alternative natural esters to be used as insulating oils in power transformers. Vegetable oils which have been regarded as the potential alternative to mineral oils are the latest to be implemented for use in electrical applications [9]. The benefits of using vegetable oils as insulating oils include their high biodegradability, fire resistance, low moisture contents, low thermal expansion coefficient, and availability [7]. Transformer filled with vegetable oils have been successfully tested at different voltage levels [8]. Generally, there are two main types of transformer insulating oil as shown in Figure 1 [9].

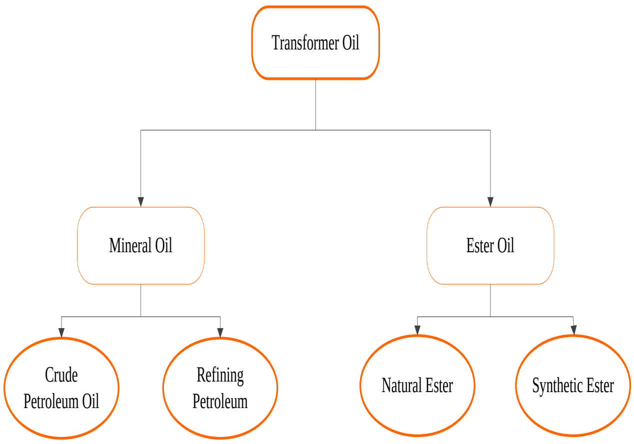


Figure 1: Classification of transformer oil

III. Palm Oil

Palm oil is an edible oil sourced from palm fruits and seeds. It is originally reddish in color due to the abundance of beta-carotene. It has a high saturated fat content and therefore, could be in a semi-solid form at room temperature. It is used for cooking purposes and serve as a main component of margarine and other food processes. The carotenoids content of palm oil is destroyed by boiling for a short period, thereby, bleaching the red color of the oil. The structure of the palm bunch is shown in Figure 2.

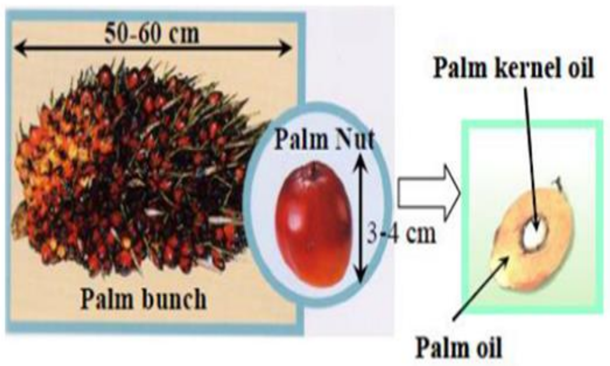


Figure 2: Palm oil bunch structure

Palm kernel oil (PKO) is a tropical oil from palm seeds which is 80 – 85% saturated and low in essential fatty acids. PKO can be heated without seriously altering its basic components. Although PKO is saturated, studies have shown that diets with high tropical oil content can reduce cholesterol levels, though some studies have contrary views. Regarding other saturated oils, PKO, especially refined PKO ought to be avoided or used in moderation in diet [10].

Refining is a process of obtaining edible oils from its crude form by subjecting the crude form to several purification process steps which include degumming, neutralization, bleaching, and deodorization. Bleaching is the removal of color and oxidizing components, residual gums, trace metals and soap by the introduction of special adsorbents such as silica or other bleaching agents. After the bleaching process, the impurities trapped in the adsorbents are filtered out. Deodorized involves the removal of fatty acids, flavor, destabilizing impurities and odor by subjecting the oil to high temperature and vacuum under conditions that encourage the vaporization of the impurities while maintaining the oil in a liquid state [11].

IV. Experiments

The parameters measured in this study were the breakdown voltage, viscosity, the potential of hydrogen (pH) value and PD characteristics. To know the chemical content of the oil samples, the Fourier transform infrared (FTIR) spectroscopy was used. The samples used in the study were aged RBDPO and new mineral oils (transformer oil). Excluding the PD test, all the other tests were conducted on new samples at the sample temperature of 25˚C in all the experiments.

A. Dielectric Properties Test

1) Breakdown Voltage Test

The breakdown voltage was measured according to the IEC 6056 using standard test cells which contains two spherical electrodes made either from brass, bronze or austenitic stainless steel with a space of 2.5mm ± 0.05mm between them in 500mL of oil. The voltage was applied with an increasing rate of 2 kV/s.

2) Viscosity Test

The viscosity test was performed according to the BS EN ISO 3104:1996 standard on the transparent and opaque liquids to determine their kinematic viscosities and calculate their dynamic viscosity. The kinematic viscosity of a liquid is its resistance to flow under gravity [7]. The viscosity test was done with a Brookfield DV-II+ Pro automated viscometer with a CP-61 spindle.

3) pH Value Test

pH is the negative logarithm of hydrogen ion concentration in a given medium. It is a convenient way of expressing small numbers. The pH scale ranges from 0 to 14, 7 indicates a neutral pH. Values less than 7 are considered acidic while values more than 7 are alkaline. This test was conducted using a pH meter.

B. PD Measurement Test

In the electrical network, a high voltage equipment is regarded as an essential element whose failure directly affects the reliability and maintenance cost of the system [11]. When subjected to a high voltage stress, a micro level electrical spark, known as PD, develops in the insulator medium.

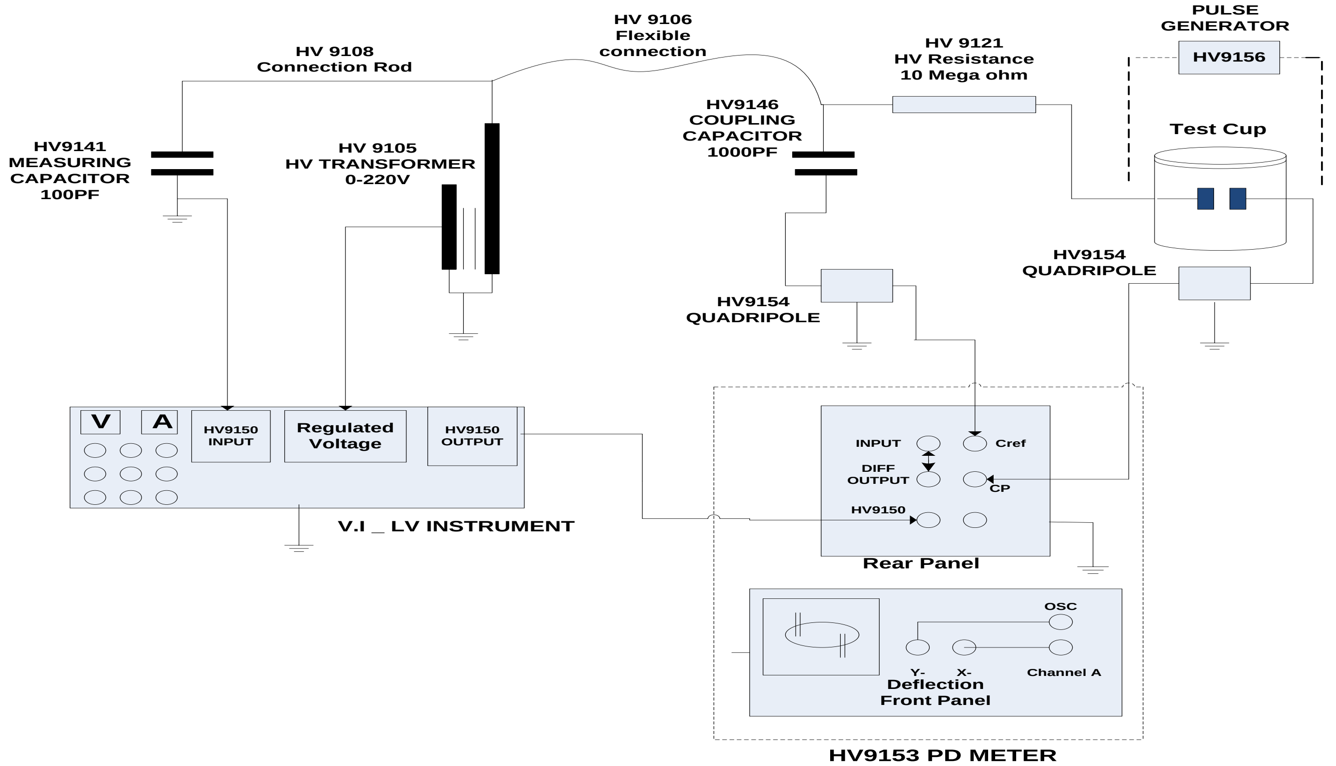


Figure 3: Circuit setup for PD measurement test

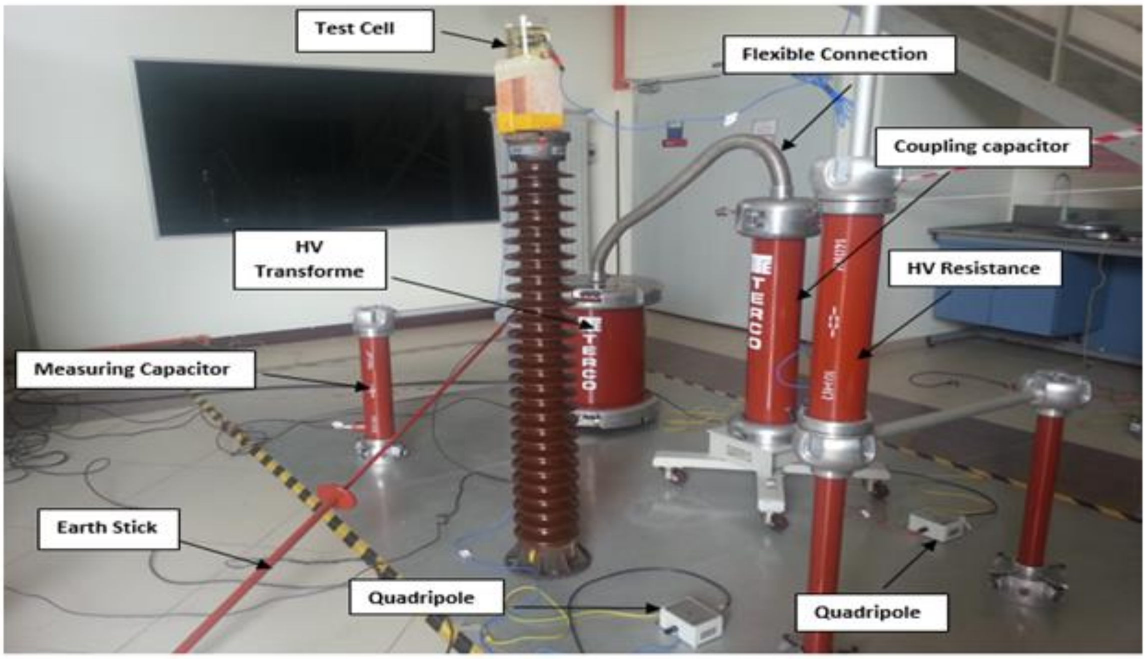


Figure 4: Experimentalsetup for PD measurement test

These micro sparks result in the breakdown of the insulator [11]. All fabricated materials have some air-filled microvoid spaces; these gases are ionized due to the non-uniform electric field and can rupture the void space in the weakest direction. A sudden energy release due to PD effect can generate a number of effects which may include chemical and structural changes in the materials [12]. The circuit setup of PD measurement test, including the circuit parameter values is shown in Figure 3, while Figure 4 shows the experimental setup of PD measurement test, where the experiments were conducted according to the IEC 60270 standard.

C. FTIR Test

This test focused more on the chemical components of the oil. FTIR is used to identify unknown chemical materials in the oil sample. The FTIR machine can determine the amount of the components in the oil sample and can determine the quality or consistency of the sample.

The oil sample before and after the occurrence of PD and breakdown voltage were taken to know the differences or the changes in the chemical components of each oil sample.

V. Results and Discussion

A. *Dielectric Properties of New and Aged RBDPO and Mineral Oil*

Table 1 shows the dielectric properties of the new RBDPO and mineral oil, while Table 2 shows the dielectric properties of the aged RBDPO and mineral oil. Moreover, Figure 5 shows the column chart aging results for both oils.

Table 1
Dielectric Properties of New (Before Using PD Test) RBDPO and Mineral Oil

Parameter	RBDPO	Mineral oil
Breakdown Voltage (KV)	18.91	22.23
Viscosity (mPa-s)	34	18
pH Value	5.14	6.31

Table 2
Dielectric Properties of Aged (After Using PD Test) RBDPO and Mineral Oil

Parameter	RBDPO	Mineral oil
Breakdown Voltage (KV)	10.31	14.69
Viscosity (mPa-s)	53	19.5
pH Value	2.85	5.26

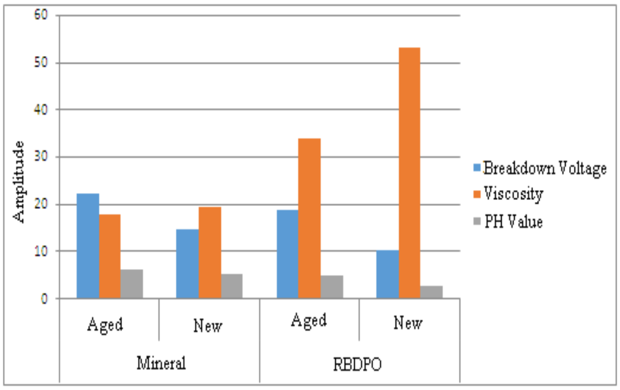


Figure 5: Column chart of aging results for mineral oil and RBDPO

Table 1 and Table 2 show the breakdown voltage, viscosity and pH values for both the new and aged oils. The breakdown strength of RBDPO was slightly lower than that of mineral oil. In general, the breakdown voltage for both oils were decreased as shown in the column chart. The viscosity of RBDPO remained significantly higher than that of the mineral oil due to the degradation process after partial discharge test. This means that the oils were losing their dielectric insulation properties which made the rate of heat transfer to be low. The pH value of RBDPO was decreased by aging more than the pH value of mineral oil, meaning that the acidity of RBDPO was higher than that of the mineral oil after aging.

B. *PD Characteristics of RBDPO and Mineral Oil*

Figure 6 shows the PD trend of the new RBDPO and Figure 7 shows the PD trend of the new mineral oil.

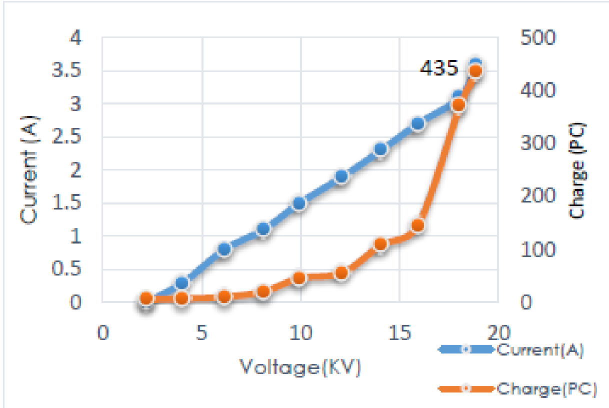


Figure 6: PD measurement for new RBDPO.

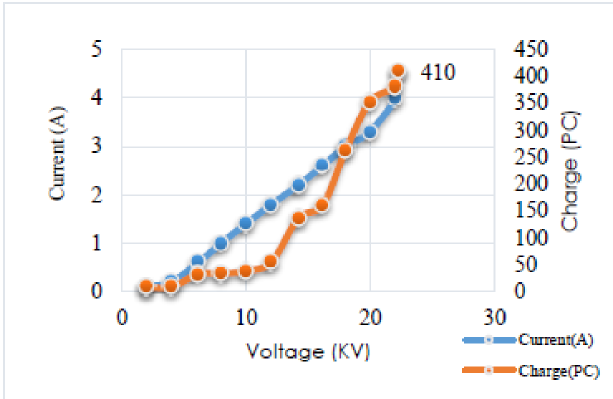


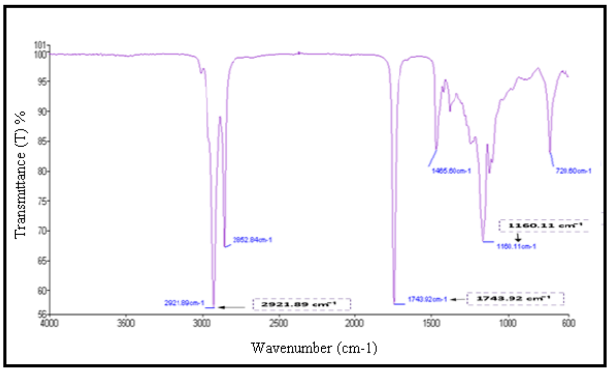
Figure 7: PD measurement for new mineral oil.

Both figures show the PD trends in pico coulomb (PC). The PD of RBDPO was higher than that of the mineral oil. The PD rate of ester oils is higher than the mineral oil because ester oils have a higher dissipation factor (tanδ) compared to mineral oils.

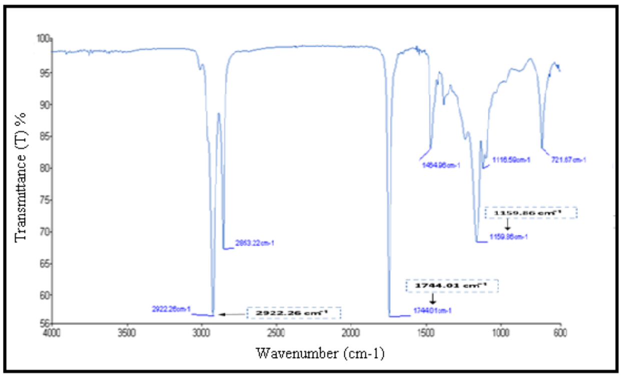
C. *FTIR Spectroscopy*

Figure 8 shows the FTIR of (a) new RBDPO, (b) aged RBDPO, (c) new mineral oil and (d) aged mineral oil at room temperature. The new RBDPO contained 2921.89 cm^{-1} of –OH which are hydroxide components, 1743.92 cm^{-1} of C=O, which are carbonyl group components, and 1160.11 cm^{-1} of a methyl vinyl ether compound, which is an organic compound. After the PD test, the aged RBDPO was found to contain 2922.26 cm^{-1} of –OH components, and 1744.01 cm^{-1} of C=O.

The C=O bond shows a low increment of 0.0052% between the new and aged RBDPO.



(a)



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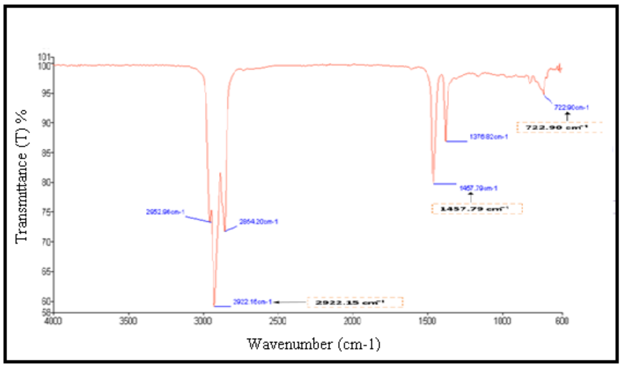
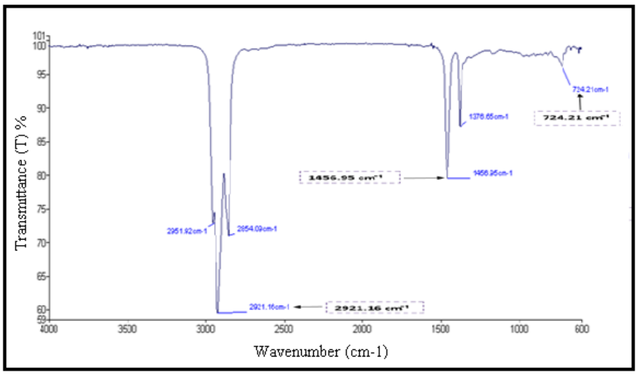


(c)



(d)

Figure 9: The FTIR of (a) New RBDPO, (b) Aged RBDPO, (c) New Mineral Oil and (d) Aged Mineral Oil.

The new mineral oil contained 2922.15 cm^{-1} of hydroxide component, 1457.79 $cm^{-1}$of CH2 component, which are methylene components, and 722.90 cm^{-1} of alkene components, which is a carbon-to-carbon double bond, while the aged mineral oil contained 2921.16 cm^{-1} of hydroxide components, 1456.95 cm^{-1} of CH2 component, which are methylene components, and 724.21 cm^{-1} of alkene components.

VI. Conclusion

This study has been carried out with the main objective to investigate the PD effects on the dielectric properties of RBDPO compared to mineral oil. The experimental results revealed that the RBDPO results were similar to those of mineral oil. We can, therefore, conclude that RBDPO can be a good alternative to the conventional mineral oil as a power transformer insulating oil. It will contribute to the strengthening of the Malaysian economy as one of the highest global producers of palm oil.

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