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Investigation on the Electrical Properties of Palm Oil Under Different Concentration of Recycle Organic Material (Pepper Seed) Doping in Transformer Application

(Penyiasatan Mengenai Sifat Elektrik Kelapa Sawit Di bawah Kepekatan Bahan Organik Kitar Semula Berbeza (Benih Lada) Doping Dalam Aplikasi Transformer)

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ABSTRACT

Many researchers nowadays are looking to find another alternative to replace the use of mineral oil as an insulation fluid used in transformer due to the amount of minerals oil that are depleted. One of the alternatives is by using palm oil as an insulation fluid. However, something must be done to improve the breakdown voltage of palm oil if it wants to replace the use of mineral oil as an insulation fluid. One of approved methods to improve the dielectric strength of palm oil is by inserting another particle inside the oil. In this study, an investigation will be carried out to observe the effect of recycling organic material (black pepper) doping on Refined Bleached Deodorized Palm Oil (RBDPO) for AC breakdown voltage application will be carried out. It is concluded that, 2.5 mm gap between two electrodes produce the highest breakdown voltage compared with 1.5 mm and 2.0 mm. Other than that, the smallest size of black pepper which is 150 mm shows having the highest breakdown voltage compared to 300 mm and 600 mm. A test with different concentration of pepper seed with 0.01%, 0.05%, 0.1%, 0.15%, 0.2%, 0.4%, and 0.5% were conducted and shows that the breakdown voltage starts to increase as the concentration increases from 0.01% until 0.15% and start decreasing from 0.02% until 0.5%. Black pepper doping inside the palm oil does increase the performance of palm oil up to 13% from 49.66 kV to 57.4 kV.

Keywords: Alternative resources of transformer oil; breakdown voltage; palm oil

ABSTRAK

Banyak penyelidik pada masa ini ingin mencari alternatif lain untuk menggantikan penggunaan minyak mineral sebagai cecair penebat yang digunakan dalam transformer kerana jumlah minyak mineral habis. Salah satu alternatifnya adalah dengan menggunakan minyak sawit sebagai cecair penebat. Walau bagaimanapun, sesuatu mesti dilakukan untuk meningkatkan voltan pemecahan minyak sawit jika ingin menggantikan penggunaan minyak mineral sebagai cecair penebat. Salah satu persetujuan untuk meningkatkan kekuatan dielektrik minyak sawit adalah dengan memasukkan zarah lain di dalam minyak. Dalam kajian ini, penyelidikan akan dilakukan untuk mengetahui kesan penggunaan bahan organik kitar semula (lada hitam) terhadap minyak kelapa sawit yang Dihilangkan Bleached Refined untuk aplikasi voltan kerosakan AC akan dilakukan. Kesimpulannya, jurang 2.5 mm antara dua elektrod menghasilkan voltan kerosakan tertinggi berbanding dengan 1.5 mm dan 2.0 mm. Selain itu, saiz lada hitam terkecil iaitu 150 mm menunjukkan voltan kerosakan tertinggi berbanding 300 mm dan 600 mm. Ujian dengan kepekatan biji lada yang berbeza dengan 0.01%, 0.05%, 0.1%, 0.15%, 0.2%, 0.4%, dan 0.5% telah dilakukan dan menunjukkan bahawa voltan pemecahan mula

meningkat ketika kepekatan meningkat dari 0.01% hingga 0.15 % dan mula menurun dari 0.02% hingga 0.5%. Doping lada hitam di dalam minyak sawit meningkatkan prestasi minyak sawit hingga 13% dari 49.66 kV menjadi 57.4 kV.

Kata kunci: Sumber alternatif minyak pengubah; Voltan kerosakan; minyak sawit

INTRODUCTION

A transformer is a device that changes AC electric from one voltage level through the action of magnetic field to another level. Transformers have a capability of changing current level and voltage level easily. They are used to step-up or step-down generator voltage for power transfer to distribution or power utilization. As transformer ages, its internal condition will degrade, which will increase the risk of failure. Failure is usually triggered by severe conditions such as loss of winding clamping, overheating, system fault or other incidents. Table 1 below shows the typical causes of transformer failure. When the transformer is aged, its insulation strength can degrade to the point that it cannot withstand the system event (Srivastava 2015).

TABLE 1. Typical causes of transformer failure

Internal	External
Insulation deterioration	Lightning strikes
Loss of winding clamping	System switching operation
Overheating	System overload
Oxygen	System faults (short circuit)
Moisture	-
Solid contamination in the insulating oil	-
Partial discharge	-
Design & manufacture defects	-
Winding resonance	-

Insulation fluid in power transformers have two main functions which is to act as electrical insulation to withstand the high voltage inside the transformer. The other function of insulation fluid inside the power transformer is it will act as a cooling medium to dissipate heat generated within the transformer windings. Therefore, the oil is used as insulation fluid and must have good electrical properties while resisting thermal degradation and oxidation. Up to this day, mineral oil derived from crude petroleum is the most widely used as insulating and cooling liquids in electrical equipment, especially in power transformer (Rajab et al. 2011). Many researchers nowadays are trying to find other alternative resources to replace use of mineral oil as the amount of mineral oils worldwide are depleted.

One of the alternative resources is palm oil. Investigation on chemical and physical properties of palm oil shows that the oil contains good properties to replace mineral in usage of high voltage equipment (Rajab & Abdul 2009). The chemical characteristics of palm-based oil are really similar to natural ester such as it is bio-degradable, has high flash-fire point, and it also non-toxic because almost all of the palm based oil is from food grade type (Abdullahi et al. 2004). Palm based oil also has a wide composition of fatty acids that include a carbon which explans the good oxidation stability as compared to other types of vegetable oils (Kanoh et al. 2008; Kano et al. 2012). The range of AC breakdown voltage for RBDPO is between 52 kV and 86 kV. Many researches conducted nowadays are to enhance the performance of palm oil with presence of another particle in the transformer oil. The reason of dispersing another particle in the transformer oil is to enhance the thermal properties as well as increase the dielectric strength of the transformer oil.

In this paper, a study will be conducted to concern the effect of recycled organic material (pepper seed) doping on AC breakdown voltage of Refined Bleached Deodorized Palm Oil (RBDPO). The different concentration of 0.01%, 0.05%, 0.1%, 0.15%, 0.2%, 0.4%, and 0.5% will be concerned. Several parameters other than AC breakdown voltage will be concerned such as dielectric dissipation factor, relative permittivity, and resistivity. Pepper seed is chosen due to its ability to reduce the fat content in the oil and expected to increase the transformer performance.

LITERATURE REVIEW

Dielectric liquid is considered as almost never completely pure due to the presence of foreign particles. Examples of the foreign particles are the gaseous bubble in the liquids, water droplets, and the cellulose fibers from the system of the paper-based insulation. The presence of these foreign particles in dielectric liquid will effect the decrease of the breakdown strength of the dielectric liquid. The breakdown mechanism in liquid depends on several factors such as liquid physical properties, condition of the electrodes as well as the present of impurities, and gases in the liquid. Breakdown in liquids have been sorted in some theories of liquid breakdown mechanism which are electronic breakdown, the cavitation and bubble mechanism, and mechanism of suspended particle (Holtzhausen & Vosloo 2010). From the theory of the electronic breakdown, the electron is discharged from the cathode because of the high

concentration in the electric field. The electrode collides with the atoms of liquid molecules on their way to the anode. Several electrons would be hit off their atoms if there were enough energy being transferred during collision, hence electron avalanche will be generated in the liquid resulting in breakdown to occur as shown in Figure 1 (Naidu 1996).

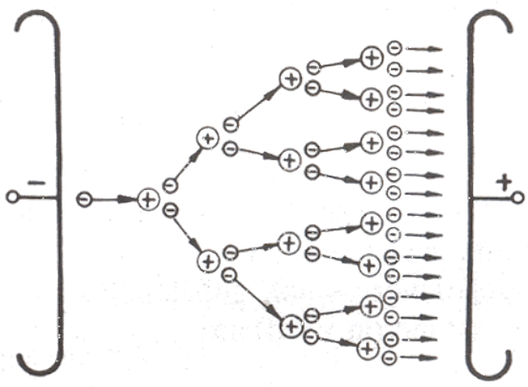

FIGURE 1. Formation of electron avalanche
Source: Naidu (1996)

Besides, the existing of micro roughness areas causes the electrodes surface to become rough which the applied electric field tend to focus at the point of micro roughness area as illustrated in Figure 2. High concentration of electric field will cause the formation of the gas bubble near the micro roughness area (Naidu 1996).

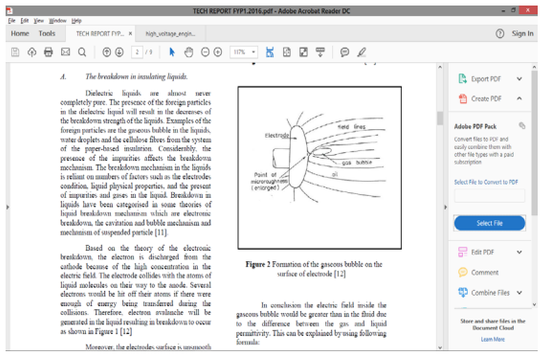

FIGURE 2. Formation of the gaseous bubble on the surface of electrode

In conclusion, the difference between the gas and liquid permittivity will affect the electric field inside the gaseous bubble would be greater than in the fluid. The most common parameter used to evaluate the electrical performance of dielectric insulating fluid is AC breakdown voltage. It is vital to certify the AC breakdown voltage for the new oil is high since after ageing, the value could have decreased due to presence of contaminants such as ageing by product (Wang & Wang 2012). Table 2 shows the AC breakdown voltage of different types of palm oil. From the table, AC breakdown voltage of RBDPO is slightly higher than Redefined, Bleached and Deodorized Palm Oil Olien (RBDPO Olien) with value ranging between 52 kV to 86 kV and 44.78 kV to 60 kV, respectively. Based on Table 2, Crude Palm Oil (CPO) has the lowest AC breakdown voltage which is 17 kV to 23 kV while the higher AC breakdown voltage is between 81 kV to 84 kV which is obtained from Palm Fatty Acid Ester (PFAE). The performance of RBDPO and RBDPO Olien can be enhanced by reducing the amount of fat content. By doing that, the range of breakdown voltage can be enhanced (Suwarno & Aditama 2005).

TABLE 2. AC breakdown voltage of different types of palm oil

Types of palm-based oil	AC breakdown voltage (kV) at 2.5 mm gap distance
CPO (Abdullahi et al. 2004; Suwarno et al. 2003).	17 - 23
RBDPO (Abdullahi et al. 2004; Suwarno et al. 2003).	52 - 86
RBDPO Olien (Rajab et al. 2011; Rajab et al. 2009).	44.78 - 60
PKO Alkyl Ester (AbdelMalek et al. 2011).	42.1 – 42.6 at 1mm gap distance
PFAE (Kanoh, et al. 2008; Kano et al. 2012).	81 – 84

Other than AC breakdown voltage, dissipation factor is one of the factors that needs to be focused on. Dissipation factor is a good indicator for determining any contaminations and evaluating dielectric losses of the oil. The dissipation factor is equal to the tangent of theta, where theta is obtaining by the angle of 90^0 minus 'theta' (Iwanusiw 2016). A rising of dissipation factor indicates oil ageing or oil contamination. If the value of theta is smaller, it indicates the resistive component of is smaller which means high resistive of insulating material. High resistive of insulation material indicates a good insulator. Therefore, it is desirable to obtain theta as small as possible.

From Table 3, the range of dissipation factor at 90^0C for RBDPO and CPO is between 0.0035 to 0.014 [11], [10], and 0.006 [10], respectively. Other than that, the dissipation factor for RBDPO Olein is slightly high with a value of 0.03 at 25 °C (Rajab et al. 2009).

TABLE 3. The dissipation factor and relative permittivity of different types of palm oils

Types of palm-based oil	Dissipation factor (%)
CPO (Abdullahi et al. 2004; Suwarno et al. 2003).	0.006 at 90 °C
RBDPO (Abdullahi et al. 2004; Suwarno et al. 2003).	Between 0.0035 to 0.014 at 90 °C
RBDPO Olien (Rajab et al. 2011; Rajab et al. 2009).	0.03 at 25 °C
PFAE (Kanoh et al. 2008; Kano et al. 2012).	Between 0.31 to 0.8 at 80 °C

In general, CPO, RBDPO, and RBDPO Olein have a good performance of dissipation factor compared to natural ester. However, the dissipation factor of PFAE is quite high as compared to other types of palm-based oils. Since there is a difference on the tested temperature, it is difficult to determine which oil has the best dissipation factor.

Palm based oil can be obtained by processing the palm nut which is extracted from the palm bunch. The palm nut consists of hard seed known as kernel. It is covered by a shell known as endocarp which is surrounded by flush husk known as mesocarp as shown in Figure 3 (Sime Darby 2013).

FIGURE 3. Cross section of the palm nut
Source: Sime Darby (2013)

In general, there are two types of oil that can be obtained from palm nut which are Crude Palm Oil (CPO) and another one is Palm Kernel Oil (PKO). Under degumming, bleaching and deodorization, CPO can be further refined to become RBDPO. The RBDPO can be separated through fractionation process to produce the RBDPO Olein (Gunstone 1987). Other than that, PKO Alkyl Ester can be obtained by further synthesis of PKO and Palm Fatty Acid Ester (PFAE) can be obtained by mainly deriving the unsaturated fatty acids of palm oil.

In this study, black pepper will be used as pepper seed to mix with palm oil. Black pepper is selected because it has the ability to increase the viscosity of bonding in the palm oil. Other than that, black pepper will also increase the saturated fatty acid inside the oil which causes the limitation of formulation of ions. These two factors will cause the breakdown voltage of the oil to increase (Kalam & Masjuki 2002).

METHODOLOGY

PREPARATION OF SAMPLE

Unused oil is not 100% clean as it may have foreign substances or it is polluted if it is not properly covered during storage. As the amount of foreign particle level increase, the efficiency of the oil as an insulating material will decrease. Usage of oil without filtration process can lead to arching, corona discharge as well as decrease in quality of insulation. If filtration is conducted, foreign substances can be filtered out from the oil. Oil filtration will also increase the life span of transformers since there is 70% chance that a transformer experiences breakdown due to oil contamination. Filtration process are conducted by using vacuum from Fisherbrand fb 70155 as shown in Figure 4 connected to Nalgene Rapid-Flow sterile disposable filter units with PES membrane in Figure 5. Filtration process needs to be repeated thrice before moving to the next process.

FIGURE 4. Fisherbrand fb 70155

FIGURE 5. Nalgene Rapid-Flow sterile disposable filter units with PES membrane

The original size of black pepper is too big for doping with palm oil substance. If the original size is used, the black pepper will not dissolve in the oil and the chemical reaction may not be complete. Grinding process needs to be done on the amount of black pepper used to ensure chemical reaction between the black pepper and oil occurs. In this study, this grinding process was conducted using test sieve with 150 mm, 300 mm, and 600 mm. The black pepper is blended before placing them into the test sieve. Figure 6 shows the test sieve used in this process.

FIGURE 6. Test sieve

The mixture of filtered palm oil and grinded black pepper process will be done by using magnetic stirrer. The magnetic stirrer was set to 800 rpm and it is left for 30 minutes. The mixture-doped sample was left for one day before the next process is started. Figure 7 shows the magnetic stirrer used in this process.

FIGURE 7. Magnetic stirrer

DRYING PROCESS

This process is used to reduce the moisture level inside the palm oil. The vacuum oven VO200 Memmert as shown in Figure 8, was used to dry the palm oil with black pepper doping at the temperature of 85 °C and left for at least 2 days.

FIGURE 8. Vacuum oven VO200 Memmert

The palm oil with black pepper doping cannot be mixed with the other oils when it is being dried in oven. This precaution step is to prevent the moisture from other fluids being absorbed resulting a change in quality of the palm oil with black pepper doping. Finally, the palm oil with black pepper doping is left at environment temperature for 30 minutes before the AC breakdown test takes place.

AC BREAKDOWN VOLTAGE MEASUREMENT

The AC breakdown voltage was conducted based on standard IEC 60156 procedure at ambient temperature by using BAUR DTA 100C as shown in Figure 9. Every concentration was conducted for 50 times by following IEC standard and the testing data was collected in order to measure the dielectric breakdown voltage with variety of concentration which are 0.01%, 0.05%, 0.1%, 0.15%, 0.2%, 0.4%, 0.5%.

FIGURE 9. BAUR DTA 100C

The breakdown voltage of the palm oil with black pepper doping is measured using DTA 100 C. To measure the breakdown voltage, the test vessel is rinsed three times with the product oil. The test vessel is filled with the sample until the electrodes are fully immersed and set at the desired gap. This test will take 50 measurements and from the result, the average breakdown voltage will be calculated.

STRUCTURE AND PHYSICAL PROPERTIES MEASUREMENT

This measurement will be used to see the structure and physical properties of the palm oil with black pepper doping. In this study, the structure concerned is the viscosity of lactic acid bonding between molecules. The higher the viscosity level represents high resistive which means the more energy need to be used in order to break the bonding between the molecules. This measurement was conducted using Renishaw Raman microscope as shown in Figure 10.

FIGURE 10. Renishaw Raman microscope

RESULT AND DISCUSSION

DIFFERENT GAP USE IN AC BREAKDOWN TEST

In this test, palm oil without black pepper doping is conducted in BAUR DTA. In order to obtain a higher breakdown voltage in this study, varieties of gap such as 1.5 mm, 2.0 mm, and 2.5mm have been implemented. The result obtained as shown in Figure 11.

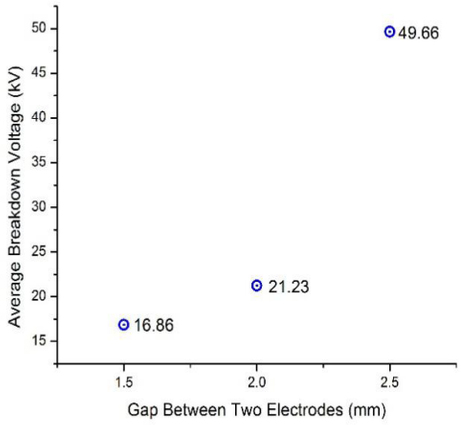

FIGURE 11. Average breakdown voltage vs gap between two electrodes

From Figure 11, it shows that the breakdown voltage increases as the gap between two electrodes increased. It concludes that by using 2.5 mm gap between two electrodes, it will obtain the highest AC breakdown voltage which is with average of 49.66 kV compared to 21.23 kV and 16.86 kV for 2.0 mm and 1.5 mm, respectively. This is proven by the formula below, it shows that the bigger the gap between two electrodes, the higher the breakdown voltage with constant of electric field.

$$E = \frac{V}{d} \quad (1)$$

Where E = electric field
V = breakdown voltage
d = gap between two electrodes

SIZE OF THE BLACK PEPPER TEST

In order to achieve a higher breakdown voltage, variety of size such as 150 mm, 300 mm, and 600 mm need to be concerned. Concentration of 0.2% black pepper doping will be used in the test. The result obtained will be tabulated in a graph as shown in Figure 12. Based on the result obtained, the breakdown voltage decreases as the size of black pepper increase as shown in Figure 12. This indicates that the smallest size which is 150 mm produced the highest breakdown voltage compared to the other two sizes. This occurred due to the black pepper with size of 300 mm and 600 mm did not fully dissolve inside the palm oil and become other impurities causing the breakdown voltage to reduce.

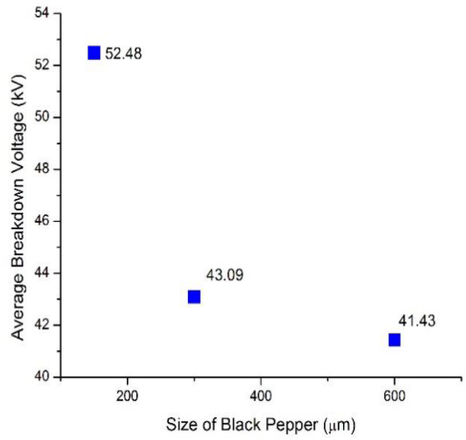

FIGURE 12. Average breakdown voltage vs size of black pepper

Figure 13 shows the test conducted to obtain structure and physical properties of palm oil with different size black pepper doping.

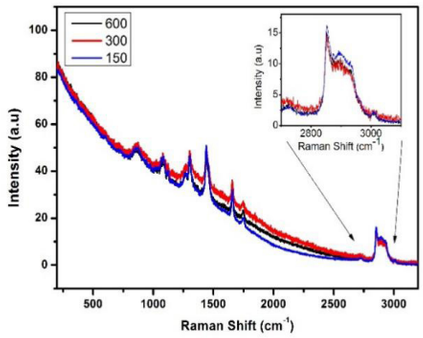

FIGURE 13. Raman spectrum pattern for different size of black pepper

Based on Figure 13, the peak highlighted represent the viscosity of lactic acid bonding between molecules. Size of 150 mm shows more stability compared to other sizes and results in having highest breakdown voltage.

CONCENTRATION OF THE BLACK PEPPER TEST

This test is conducted with the purpose to determine the higher breakdown voltage of palm oil by using the best result obtain in the previous test which is with 2.5 mm gap and with 150 mm size of black pepper. In this test, concentration of 0.01%, 0.05%, 0.1%, 0.15%, 0.2%, 0.3%, 0.4%, and 0.5% of black pepper will be concerned. The result of this test is shown in Figure 14.

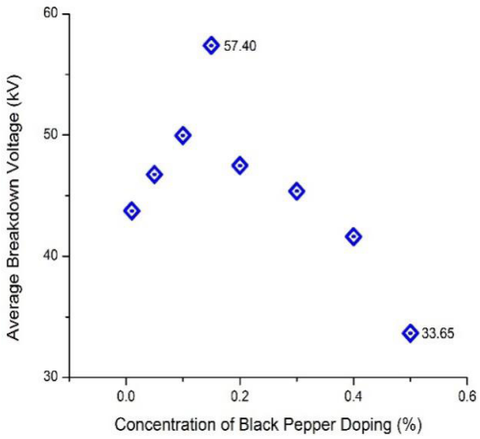

FIGURE 14. Average breakdown voltage vs concentration of black pepper doping

From Figure 14, the average breakdown voltage increased from 0.01% to 0.15% and started to decrease from 0.2% until 0.5%. The performance of breakdown voltage started to decrease at 0.2% due to the residual black pepper presence in the mixture and this residual becomes worst as they become other impurities that causes the breakdown voltage to decrease. It can be concluded that concentration of 0.15% is the best concentration of black pepper doping that can be used in order to obtain highest breakdown voltage compared to the other concentrations. The test was continued using Rama spectrum measurement and the result is shown in Figure 15.

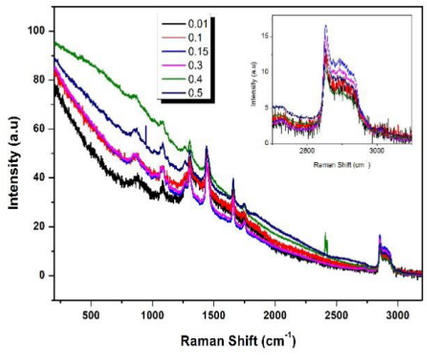

FIGURE 15. Raman spectrum pattern for different concentration of black pepper doping

From Figure 15, the peak highlighted represent the level of viscosity of the bonding between molecules. The viscosity started to increase from 0.01% until 0.15% and started decrease from 0.2% until 0.5%. This result has a similar pattern compared to the result in Figure 14. At 0.15%, concentration of black pepper is at its highest in terms of its viscosity which represents as more stability on its structure.

CONCLUSION

Based on test that had been conducted, it shows that by using 2.5 mm gap between two electrodes will obtain the highest breakdown voltage. Other than that, by using the smallest size of black pepper which is 150 mm and with concentration of 1.5%, it will also obtain the highest breakdown voltage. In conclusion, with black pepper doping inside palm oil, it will improve the performance of breakdown voltage up to 13% from 49.66 kV to 57.4 kV. For future study, it is recommended to heat the palm oil before mixing it with black pepper to ensure the black peppers are fully dissolved to reduce the amount of black pepper residuals inside the mixture.

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DECLARATION OF COMPETING INTEREST

None

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