Breakdown Strength Characteristic of RBDPO and Mineral Oil Mixture as an Alternative Insulating Liquid for Transformer

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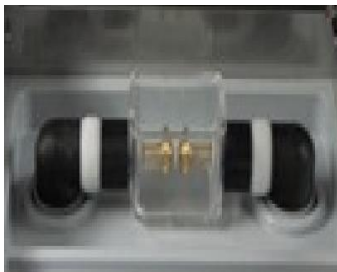*Corresponding author: eekamarol@eng.usm.my

Graphical abstract

Abstract

Mineral oil (MO) works as an important electrical insulation and coolant in transformer which is non-biodegradable and nearly running out. Therefore, for sustainable and environmental concern, an alternative biodegradable insulating oil that potential to replace the mineral oil is introduced. In view of that, the breakdown strength characteristic of Refined Bleached Deodorized Palm Oil (RBDPO) and MO mixtures were investigated by varying the mixing percentage of RBDPO from 0% to 100% at 40ºC. The results showed that the breakdown strength of the oil mixture abruptly decline to the minimum breakdown voltage of 50 kV at 20% of RBDPO mixture and gradually increased when the ratio of the RBDPO is added. The highest breakdown strength is achieved 87kv at 80% of RBDPO content. The result of kinematic viscosity is also presented.

Keywords: Refined bleached deodorized palm oil; breakdown strength; kinematic viscosity

Abstrak

Minyak mineral (MO) berfungsi sebagai penebat elektrik dan penyejuk yang penting di dalam transformer yang bukan sahaja tidak terbiodegradasikan malah hampir kehabisan. Oleh kerana itu, bagi pengekalan dan keprihatinan terhadap alam sekitar, minyak penebat alternatif baru yang mudah terbiodegradasikan dan berpotensi untuk menggantikan minyak mineral diperkenalkan. Sehubungan dengan itu, ciri-ciri kekuatan voltan pecah terhadap Minyak Sawit Bertapis, Di luntur dan Di nyah bau (RBDPO) yang dicampurkan dengan MO telah dikaji dengan mempelbagaikan peratusan campuran RBDPO daripada 0% hingga 100% pada suhu 40oC. Keputusan menunjukkan bahawa kekuatan voltan pecah minyak campuran menurun secara mendadak kepada voltan pecah minimum iaitu 50kV pada 20% campuran RBDPO dan beransur-ansur meningkat apabila nisbah RBDPO ditambah. Nilai kekuatan voltan pecah tertinggi dicapai pada 80% kandungan RBDPO iaitu pada 87kv. Keputusan kelikatan kinematik juga dibentangkan.

Kata kunci: Minyak sawit bertapis, di luntur dan di nyah bau; voltan pecah tebat; kelikatan kinematik

■1.0 INTRODUCTION

Petroleum based mineral oil (MO) is widely used in electrical power transformers for electrical insulation and cooling purposes. However, the petroleum based MO is a poorly biodegradable oil. This oil can contaminate soil and waterways if the oil is seriously spilled out of the transformer tank. Moreover, petroleum based MO is eventually going to run out in the future. Therefore the replacement of the MO should be considered [1]. One of the potential oils to replace the MO in the power transformer is vegetable oil.

Vegetable oil is a biodegradable oil and environmental friendly. Broad researches on vegetable oil as an alternative transformer oil has been carried out by many researchers [1,2,3].

Refined, Bleached and Deodorized Palm Oil (RBDPO) is one of the vegetable oils that has good potential to be used in electrical power transformer as insulating oil[4]. Although the researches on dielectric properties of the RBDPO has been carried out, there is also essential to know the electrical characteristic of the mixture of this oil with MO, since MO has been known of its capability as good insulating fluid in transformer. Compared to mineral oil, palm oil has more elevated breakdown voltage (BDV), flash point and fire point. However, it is also shown that one of palm oil properties does not comply with the standard which is its kinematic viscosity [5,6,7,8]. One of the suggestions is by mixing the RBDPO with MO in order to find out the electrical strength of this combination and to improve the physical properties of the RBDPO. As a result, this paper presented the investigation on

breakdown characteristics of RBDPO and MO mixture at 40˚C and the relation of kinematic viscosity of RBDPO and MO mixture with the breakdown voltage.

■2.0 EXPERIMENTAL

2.1 Samples Preparation

The samples used in the experiments are the mixtures of RBDPO with MO. RBDPO were added into MO from 0% to 100% of ratio. Figure 1 shows the mixture of RBDPO with different ratio varies from 10% to 100%.


Figure 1 Mixture of RBDPO with MO varies from 10% to 100% of RBDPO content

2.2 Breakdown Voltage Measurement

The breakdown voltage test was conducted by using BA100 Fully Automatic Portable Breakdown Analyzer. The test was performed according to IEC 60156 standards [9]. Figure 2 shows the test cell used in the experiment. The test cell has a volume capacity of 400 ml consists of mushroom-shaped electrodes with the gap of 2.5 mm. The specimens were directly heated until reach 40ºC on hot plate for 5 to 10 minutes and at the same time stirred at 250-300rpm to ensure the temperature equilibrium in the test cell.

For the breakdown test, the AC voltage with frequency of 50Hz was applied automatically with increasing rate of 2kVs^{-1} until breakdown occurs. The breakdown voltage was taken in average of six measurements with 2 minutes pause between consecutive breakdowns. The experiment was conducted in the laboratory with the oil was tested immediately after heating at 40ºC.
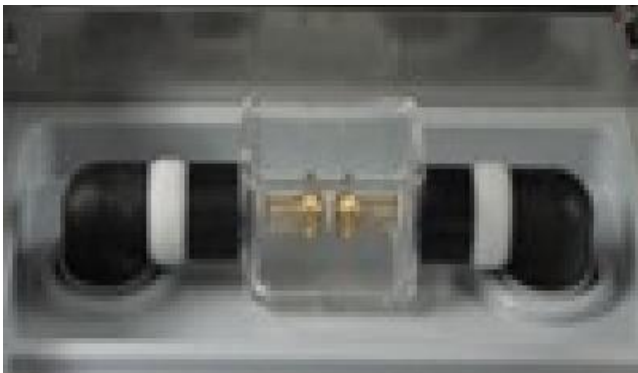
Figure 2 Test cell with mushroom-shaped electrodes of 2.5mm gap

2.3 Kinematic Viscosity Measurement

Figure 3 shows Gallenkamp Constant Temperature Viscosity Bath using with temperature controller/heater which is used to measure the kinematic viscosity. The kinematic viscosity is measured according to ASTM D445[10] and ISO 3104 [11]. Figure 4 shows the Cannon glass capillary viscometer constant 0.009404 No. 1 K930 Ubbelohde type. The glass capillary viscometer is rinsed by using toluene and dried using a dryer. Pipette is used to pour about 10 ml of oil sample into the viscometer. The capillary glass viscometer is placed into the holder and inserted into the Constant Temperature Bath. Approximately 20 minutes is taken to ensure the temperature of water and oil is equal at 40ºC. By using the vacuum pump, oil in the capillary glass viscometer is sucked until the oil level is about 5mm at capillary bulb in the viscometer. The efflux time is taken for the oil to flow from the high level to the low level of the viscometer. The experiment is repeated in average of six times.

Figure 3 Gallenkamp Constant Temperature Viscosity Bath

The kinematic viscosity is determined by using the following formula:

$$V = C \times t$$

Where, V = kinematic viscosity mm^2/s,(cSt)

C = viscometer constant mm^2/s^2, (cSt/s)

t = efflux time (s)

Figure 4 Cannon glass capillary viscometer Ubbelohde type

■3.0 RESULTS AND DISCUSSION

3.1 Breakdown Voltage Characteristics of Oil Mixture

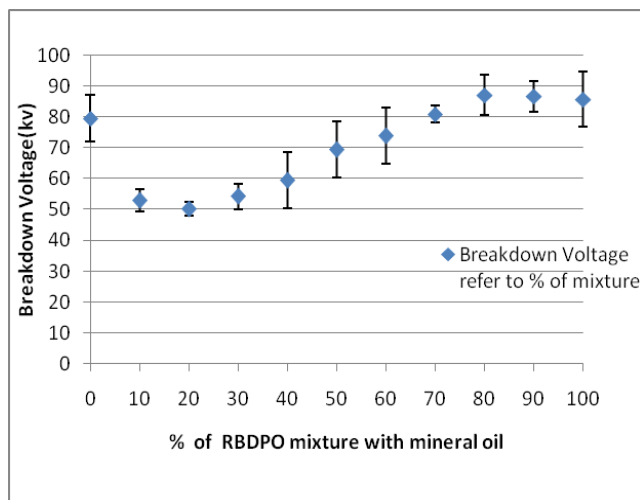Figure 5 shows the results of breakdown voltage at percentage of RBDPO mixture varies from 0-100% at 40ºC.

Figure 5 Shows the result of breakdown voltage as a function of mixture percentage of RBDPO varies from 0-100% at 40ºC

   The breakdown voltage decreases to 50 kV when the MO is mixed with 20% RBDPO. Then the breakdown voltage increases when the percentage of RBDPO mixture is increased further from 30% to 100%. The highest breakdown voltage achieved is 87kV at 80% RBDPO/20%MO which is slightly higher compared with 100% MO (85.7 kV). The breakdown voltages are varied with different mixture ratio of RBDPO.

The lowest of BD voltage (50kV) at 20%RBDPO/80%MO mixture might due to fast movement rate of gas bubbles which cause a completely bridging the gap in a short time [12]. The gas bubbles might be produced from the dissociation of liquid molecules by electron collision under the influence of electric field intensity. The gas bubbles formation also might be influenced by the different of chemical bonding structure created between the two distinguishes oil in variety of ratios. This phenomenon might affected the shape of the oil molecules structure which will give rises to the local enhancement of the oil molecules. When the field exceeded the breakdown strength of the oil mixture, local breakdown will occur near the oil molecules and this will result to the formation of the gas bubbles [12]. The production of gas bubble at this mixture ratio might be also faster than that 80%RBDPO/20% MO mixture. The bridging process of the gas bubble can be explained according to the suspended particle theory [12]. The permittivity of the gas bubble ε_2 is smaller than the permittivity of the oil ε_1. Under the electric field intensity, the gas bubble experience a force directed towards areas of minimum stress. When the voltage applied approached the breakdown voltage, the number of gas bubbles formation is large and align between the electrodes due to the existing force. The gas bubbles finally form a stable chain bridging the gap and lead to the breakdown of the oil [12].

   The higher BD voltage at 80%RBDPO/20%MO mixture might due to slow movement rate of gas bubbles and it is completely bridged the gap when the voltage achieved 87kV.The mixture of 80%RBDPO and 10%MO is affected by the density of ratio, chemical bonding of oil, and the viscosity ratio. High viscosity of this mixture ratio causes the increment of flow resistance which slowing down the movement rate of gas bubbles to the electrode. When electric field is applied, the electrostatic repulsive forces between space charges of the oil molecules become sufficient to overcome the surface tension which produce the gas bubbles. However, the viscous liquid layer between the electrodes will restrict the acceleration of the gas bubbles, thus causing high breakdown voltage [12][13]. Therefore, it is implied the ability of 80%RBDPO/20%MO to maintain its dielectric properties under the action of strong electric fields. This result in aligned with Suwarno [14] which reported that mixture of 75% ester from palm oil with 35% MO gives the highest breakdown strength.

3.2 Kinematic Viscosity Measurement

Figure 6 shows the kinematic viscosity as tabulated in Table 1. It shows that 100%MO has the lowest viscosity which is 8.33 mm^2/s,(cSt) while 100%RBDPO has shown to have the highest viscosity compared to the other mixtures.
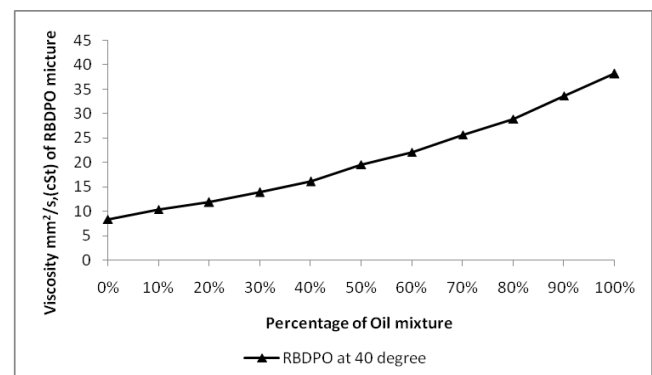

Figure 6 Kinematic viscosity of oil mixture

Table 1 Kinematic viscosity of oil at 40ºC

Percentage of Oil Mixture	Kinematic Viscosity mm²/s,(cSt)
1. 100% MO	8.33
2. 10%RBDPO/90%MO	10.4
3. 20%RBDPO/80%MO	11.86
4. 30%RBDPO/70%MO	13.72
5. 40%RBDPO/60%MO	16.06
6.50%RBDPO/50%MO	19.59
7.60%RBDPO/40%MO	22.12
8.70%RBDPO/30%MO	25.4
9. 80%RBDPO/20%MO	27.39
10. 90%RBDPO/10%MO	33.65
11.100%RBDPO	37.95

[a] All kinematic viscosity were measured at 40 °C and repeated at six measurement

The viscosity of liquid is one of important factors that effecting dielectric strength. Viscosity is arises due to internal molecular frictional within the fluid and could decelerates free ion pairs or particles in the liquid under applied electric fields.

Based on the results obtained in this paper, the breakdown voltage and viscosity at 40ºC shows to have a relation. 80% RBDPO mixed with 20% MO shows a good finding in term of electrical characteristic where the mixture reached the highest breakdown voltage with high viscosity as well. Although 20% RBDPO/80% MO showed the lowest of breakdown voltage(50kV), the level of viscosity is 11.86cSt which can be considered as approaching 10cSt, the standard maximum.

■4.0 CONCLUSION

The experiment of breakdown voltage and kinematic viscosity of RBDPO/MO mixture at 40ºC has been studied. From the experimental result, it can be concluded that the breakdown voltage decreases at the lowest point when the MO is mixed with 20% of RBDPO. The breakdown voltage result shows slightly increased with the increasing percentage of the RBDPO mixture where 80% RBDPO has achieved the highest breakdown voltage. All the breakdown voltage of RBDPO/MO was above 30kV which fulfilled the IEC standard The result of breakdown voltage of RBDPO/MO shows a significant related to its kinematic viscosity at 40˚C.

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