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THE EFFECT OF ANTIOXIDANTS ON THE PERFORMANCE OF VEGETABLE OIL IN HIGH VOLTAGE APPLICATIONS

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ABSTRACT

Mineral oil has been used as a dielectric medium in a transformer. Nowadays, due to the environmental issue, the properties and characteristics of vegetable oils are investigated in order to check its suitability to be used in power transformers. However, vegetable oils have its limitations on costing, period of use and oxidation stability. Vegetable oils used are palm oil and coconut oil which are highly possible to oxidize rapidly. To reduce oxidation from happen, antioxidants *tert*-butyl-hydroquinone (TBHQ) and α-tocopherol are used. Samples were electrically and physically tested and comparisons were made with the mineral oil. Electrical test such as the breakdown voltage was conducted. Besides that, chemical properties such as dynamic viscosity and moisture content were also being investigated. Results from the laboratory studies have shown that each tested sample has their own advantages and disadvantages. TBHQ and α-tocopherol were found to reduce viscosity and moisture content, as well as increase the breakdown strength and aging resistance of oil.

Keywords: antioxidant, palm oil, coconut oil, oxidation, *tert*-butyl-hydroquinone, α-tocopherol, breakdown voltage, dynamic viscosity, moisture.

INTRODUCTION

Transformer is an electrical device used either to step up or step down AC voltages without altering the frequency [1]. Transformer is the inseparable part of a power system. A proper function of transmission and distribution are impossible without the transformer. Transformer oil is one of the very important components in oil immersed transformers. The life expectancy operation of transformers are mainly depends on the immersed oil. The transformer oil performs two of the most important functions; 1) creating an acceptable level of insulation and 2) acts as a coolant to extract heat from the core and the windings. The oil used in transformers is mineral oil [2-5].

Mineral oil is used as dielectric medium in high voltage plant but can be harmful to the environment [6]. Hence, vegetable oils such as palm oil and coconut oil is applied to be replaced with mineral oil. Both vegetable oils are either high in saturated or unsaturated fatty acids. Currently, vegetable oils are biodegradable and available in the market, which may have lower environmental impact during their use and final disposition [7].

Vegetable oils usually can act as a good lubricant but the major limitations are their short time of use, thermal and oxidation instability have limited their massive applications [7-8]. Commonly, vegetable oils have poor oxidation stability compared to mineral oils [9]. Oxidation stability of vegetable oils depends on the level of unsaturated fatty acids [14]. The lower the percentage of unsaturated fatty acids, the better the oxidative stability [8]. Vegetable oils are sensitive to temperature and will undergo oxidation rapidly [10]. To avoid oxidation, the suitable antioxidants are needed.

OXIDATION VERSUS ANTIOXIDANTS

Oxidation

Oxidation is a process interaction between oxygen molecules and all the different substances they may contact, from metal to cell. With the discovery of electrons, oxidation came to be more precisely defined as the loss of at least one electron when two or more substances interact. Those substances may or may not include oxygen. In this case, oxidation happens when some of the fatty acids of the vegetable oil are unsaturated.

Antioxidants

Antioxidant is any various substances capable of slowing or preventing the oxidation of other molecules. It is a specific organic compound that active in the prevention of very rapid harmful chemical chain reactions with oxygen, known as, oxidation. It can terminate these chain reactions by probably removing free radical intermediates, or by being oxidized themselves. Free radical is an oxidant that can damage the oil. It has an unpaired electron causing itself to be unstable and highly reactive. It will attack other molecule to steal electron to become stable and create new free radical. Antioxidant reacts with the free radicals before they are able to react with other molecules, thus providing protection from oxidation. The most common molecules which are easy to be ‘attacked’ by oxidation are unsaturated fatty acids, which then turn rancid and the physically damaged [14,15]. Figure-1 shows the reaction between antioxidant and free radicals. In this study, the antioxidants used are TBHQ and α-tocopherol.

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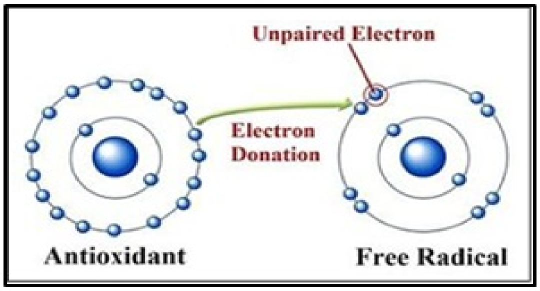

Figure-1. Reaction of antioxidant with free radicals [16].

EXPERIMENTAL WORK

Sample preparation

In order to investigate the effect of antioxidants on palm oil (PO) and coconut oil (CO) in high voltage performance, there are several samples have been used. Mineral oil (MO) also tested to be as the reference. Table-1 shows the oil composition for all samples. The number of 48 and 96 referred to the aging period in hours.

Table-1. Oil samples.

MO(unaged) MO(48) MO(96)
PO(unaged) PO(48) PO(96)
CO(unaged) CO(48) CO(96)
PO+TBHQ(unaged) PO+TBHQ(48) PO+TBHQ (96)
PO+α-tocopherol(unaged) PO+α-tocopherol(48) PO+α-tocopherol(96)
CO+TBHQ(unaged) CO+TBHQ(48) CO+TBHQ(96)
CO+α-tocopherol(unaged) CO+α-tocopherol(48) CO+α-tocopherol(96)

Experimental procedure

Aging process

This process was done using fan oven. The samples were heated at 100 °C for 48 and 96 hours. The beakers were covered with aluminium foil to avoid with the outer contacts that can cause oxidation as well as to reduce moisture content in the samples. The aging process was conducted for observing and comparing the effect of the process.

Dynamic viscosity

According to ASTM D7042 method, to get the viscosity of sample, a rotation method was applied. From Figure-2, 500 ml of sample is placed at the bottom of Viscometer. A metal spindle type S02 is attached to the viscometer and the maximum level of the sample must be higher than spindle marks. The spindle rotated in the sample at a fixed rpm and the torque required to rotate the spindle as well as the initial viscosity was measured. The reading taken for each sample was five times at 40°C temperature and the duration for each reading was five minutes.

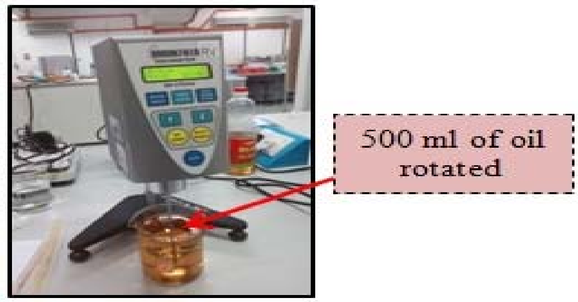

Figure-2. Viscosity process.

Moisture

The moisture content of all samples are measured using DBS 60-3 Absolute Moisture Meter in Figure-3. The reading taken for each sample was three times and the duration for each reading was 15 minutes.

Figure-3. Moisture process.

Breakdown voltage

The breakdown voltage of the oil samples was measured at room temperature (25 to 27 °C) according to IEC 60156:1995 standard using HV Diagnostic BA100 Breakdown Analyzer. According to the standard, the procedure for testing the breakdown requires the use of a test voltage obtained by using a step-up transformer supplied from an AC (48 Hz to 62 Hz) voltage source. The voltage increased uniformly from zero at the rate of 2.0 kVs^{-1} ± 0.2 kVs^{-1} until breakdown occurs [17]. The standard used an electrode gap of 2.5 mm as shown in Figure-4. The measurement sequence with 6 breakdowns

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and the standard deviation was done. The test voltage is automatically controlled and increased to a maximum level of up to 100 kV_{rms}.

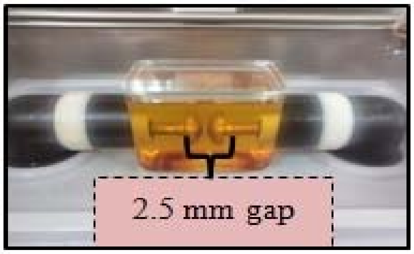

Figure-4. BDV analyzer test cell.

RESULTS AND DISCUSSION

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

Color changes

Figure-5 shows the color changes of oil samples.

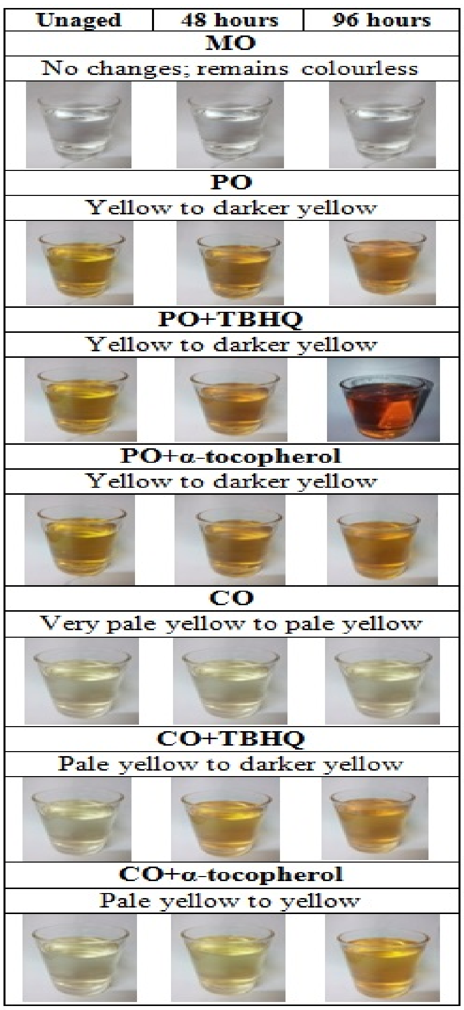

Figure-5. Color changes results.

Dynamic viscosity

Figure-6, 7 and 8 shows the result of viscosity for MO-PO-CO, three types of different PO and three types for different CO respectively. From the graphs, it shows that the viscosity value increases as aged.

In Figure-6, the original PO stated the highest viscosity compared to original CO and MO as the lowest viscosity. This might be due to the high saturated fatty acids that contains in the PO. Meanwhile, CO shows the line of the viscosity value in the middle as the oil properties is higher in saturated fatty acids compared to PO. MO shows a low viscosity level where the ideal viscosity for transformer oil is a low viscosity.

From Figure-7, the viscosity values for each sample at three different aging duration does not show much difference. The sample of PO+α-tocopherol shows the highest viscosity compared to samples of original PO and PO+TBHQ as the lowest viscosity. PO+α-tocopherol shows an almost similar viscosity value for unaged sample and 96 hours aging compared to the original PO. The differences between unaged sample and 96 hours aging are 6.28 mPa.s and 6.44 mPa.s for PO+TBHQ and PO+α-tocopherol respectively. The sample of PO+TBHQ shows the lowest viscosity value in this graph.

In Figure-8, the viscosity of the sample of the original CO shows the lowest value for unaged sample and highest value during 48 and 96 hours compared to CO+TBHQ and CO+α-tocopherol. The values for CO+TBHQ and CO+α-tocopherol for the aging duration of unaged sample and 96 hours aging are almost the same value where the differences are 7.12 mPa.s and 6.16 mPa.s respectively. The line of CO+TBHQ is higher compared to CO+α-tocopherol. The sample of CO+α-tocopherol shows the lowest viscosity value in this graph.

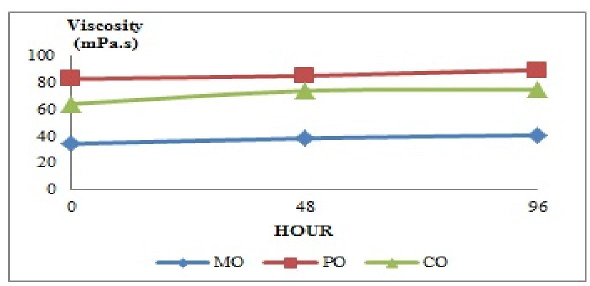

Figure-6. Viscosity for MO-PO-CO.

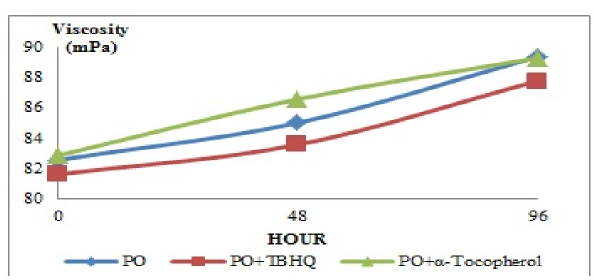

Figure-7. Viscosity of three types for different PO.

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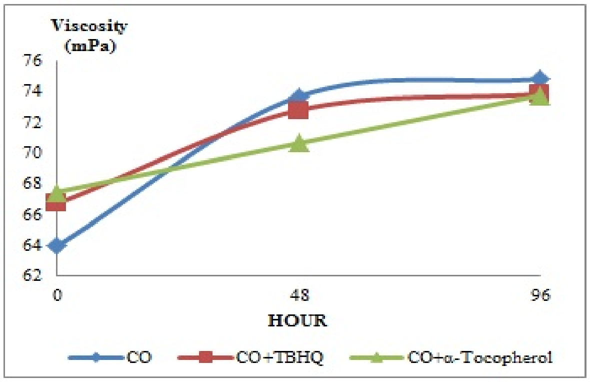

Figure-8. Viscosity of three types for different CO.

Overall, the viscosity of the oil samples increased as the aging period increased. This is because the oil (liquid) becomes more viscous as the heating period increases and at the same time reduced the water contents of the oil. During the aging process, oxidation happened leading to the formation of peroxide and moisture losses. The addition of TBHQ and α-tocopherol in both vegetable oil does help in reducing the viscosity. Good insulating oil has a lower viscosity and high flow resistance as the oil aged. Figure-9 shows the overall viscosity results for vegetable oil samples.

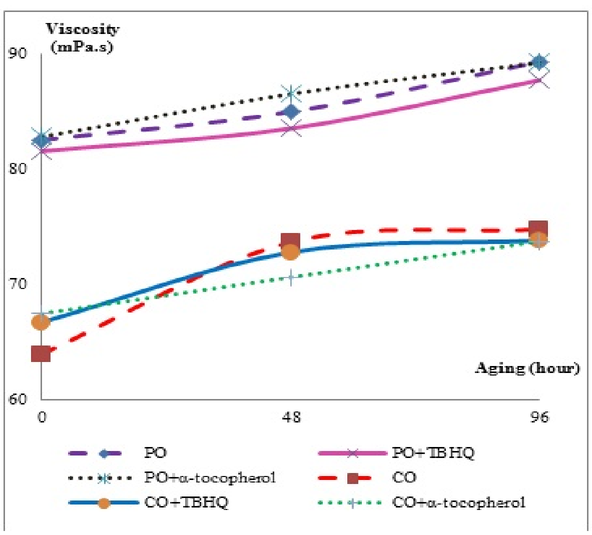

Figure-9. Viscosity results.

Moisture

The moisture decreases as aging. This is because the oil (liquid) has lesser moisture as the heating period increase. From Figure-10, The MO stated the highest moisture content compared to the others vegetable oil where the difference values are too big. The differences moisture value between unaged and 96 hours for each sample; MO, PO, CO, PO + TBHQ, PO + α-tocopherol, CO + TBHQ and CO + α-tocopherol is 2.61, 0.42, 0.12, 0.11, 0.09, 0.10 and 0.09 respectively. The addition of TBHQ and α-tocopherol in both vegetable oil does help in reducing the moisture.

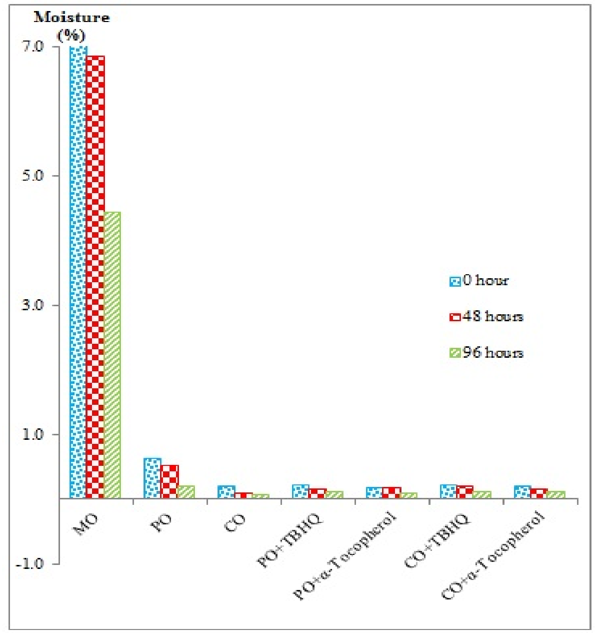

Figure-10. Moisture results.

Breakdown voltage

Figure-11 shows the breakdown voltages for all samples. All samples show an increment of breakdown voltage as the aging duration increases. For comparisons, PO achieves the highest average breakdown voltage which is 71 kV (unaged) and 78 kV (96 hours). Meanwhile, MO and CO achieve an average breakdown voltage at 16 kV (unaged), 24 kV (96 hours) and 25 kV (unaged), 46 kV (96 hours) respectively.

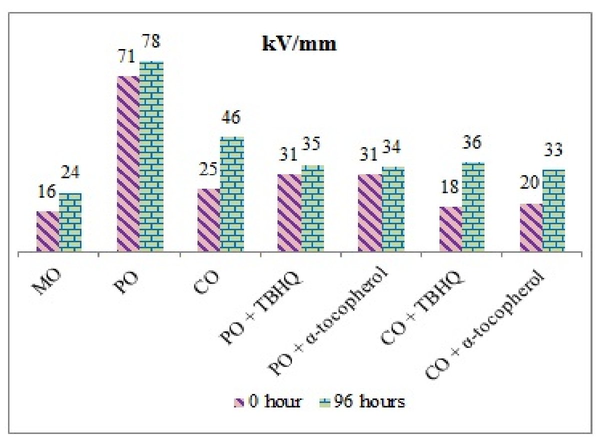

Figure-11. Breakdown voltage results for unaged samples and aged for 96 hours.

Compared to previous findings, the range of the breakdown voltage after aged for these three oils are in Table-2.

Table-2. Previous findings [18,19,20].

Sample	Breakdown voltage (kV/mm)
MO	Between 30 and 50
PO	Between 52 and 86
CO	Between 39 and 54

For the other samples; PO + TBHQ, PO + α-tocopherol, CO + TBHQ and CO + α-tocopherol, the breakdown voltages at unaged were 31 kV, 31 kV, 18 kV and 20 kV respectively. The breakdown voltages for the four samples were almost equal after the aging process (96 hours) between 33 kV to 35 kV. This shows the breakdown voltage value for the samples of vegetable oil and antioxidant composition were acceptable for high voltage applications.

Relationship between breakdown voltage and moisture

Figure-12 shows the graph of breakdown voltage against moisture of PO+TBHQ, PO+α-tocopherol, CO+TBHQ and CO+α-tocopherol. The breakdown voltage of the oil samples decreased when the moisture percentage increased and vice versa. This is consistent with the moisture test result. From the result obtained and according to the previous finding in Table-3, it shows that the relation between breakdown voltage and moisture value for the samples of vegetable oil and antioxidant composition were compatible, acceptable and in stable state. The samples composition has the potential to replace mineral oil due to its high breakdown voltage and low moisture content. In terms of breakdown voltage, the composition samples of vegetable oil and antioxidant is believe can withstand a higher stressed for power transformer application.

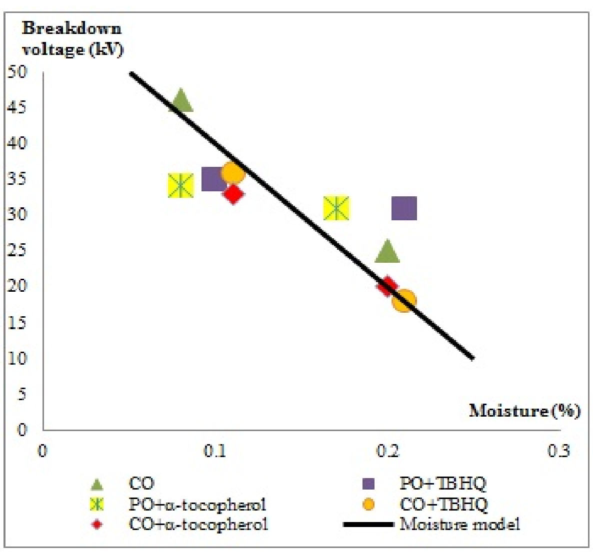

Figure-12. Breakdown voltage versus moisture.

Table-3. Previous finding [21].

Transformer oil	
Viscosity	30 mPa.s
Moisture	0.005 % or 50 ppm
Breakdown voltage	15 kV/mm

CONCLUSIONS

The addition of antioxidants TBHQ and α-tocopherol does help to increase the performance of both vegetable oil. The performance of PO+TBHQ and CO+α-tocopherol are to be follow the standard values for transformer oil and both can be used for power transformer. PO+TBHQ and CO+α-tocopherol are the best composition among samples used in this research to be used in high voltage applications. From this research, antioxidants are proved to:

- Reduce viscosity of vegetable oil
- Increase aging resistance of the oil by reducing the changes in viscosity as aged (resistance to oxidation)
- Reduce moisture content which is valid for sample PO
- Increase breakdown voltage as the samples are aged
- Have little effect on relative permittivity and dielectric loss

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