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Original Article

Study of the Mixture of Rapeseed Oil and Waste Cooking Oil used for Insulation in Transformers

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Abstract: The blend of waste cooking oil and rapeseed oil was studied as an alternative to mineral oil in transformers. Waste cooking oil after filtering, neutralizing and drying was mixed with refined rapeseed oil. The ratio between waste cooking oil and rapeseed oil was determined based on the pour point. Physico-chemical parameters of the oil mixtures were measured according to the ASTM D6871, and the oil mixture was examined in both new and aged conditions. For ageing, the oil mixture was heated at 120 °C for 164 h with an air flow of 5.5 L/h. In addition, the influence of antioxidants on the breakdown voltage and ageing of the oil mixture was also studied. Experimental results showed that the mixture consisting of 15 vol.% of waste cooking oil and 85 vol.% of rapeseed oil met the standards of ASTM D6871. Tert-butylhydroquinone and propyl gallate significantly increased the oxidation stability index, breakdown voltage and ageing resistance of the the oil mixture.

Keywords: Breakdown voltage, rapeseed oil, waste cooking oil, transformer, antioxidant.

1. Introduction

Vegetable based insuating liquids were accepted for use in distribution transformers due to their high dielectric strength, high flash point and complete biodegradability [1-3]. However, disadvantages of this type of insulating liquid are its relatively high cost and low oxidation resistance compared to mineral oil. Therefore, it is necessary to reduce the cost and improve the oxidation stability of vegetable oils. Rapeseed oil was studied for use as an insulating liquid in transformers, and it was reported that the oil met the standards of ASTM D6871 [4]. However, low oxidation stability remains a problem for rapeseed oil [4]. Waste cooking oil from food premises consisting of mainly cheap palm oil was

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collected and produced biodiesel [5, 6]. Another way is to use waste cooking oil to produce methyl esters for application in transformers [7, 8]. However, high pour point, low flash point and low oxidation stability are limitations of methyl esters [7, 8]. In addtion, palm oil in waste cooking oil has high pour point, which does not conform to the ASTM D6871. Therefore, the combination of waste cooking oil, rapeseed oil and antioxidants were investigated in this work. Butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT) and tertiary butyl hydroquinone (TBHQ) were used to improve the oxidation resistance of vegetable oils, and it was found that TBHQ had the highest eficiency [3, 9]. Furthermore, propyl gallate (PG) showed high efficiency in biodiesel [10]. Therefore, the effects of both TBHQ and PG on the mixture of waste cooking oil and rapeseed oil were investigated in this study.

2. Experiments

2.1. Materials

Waste cooking oil (WCO) was collected from food premises in Ninh Kieu district, Can Tho city, Vietnam. At first, WCO was filtered to remove suspended particles and deposits by using a paper filter. And then, free fatty acids in WCO were neutralized with sodium hydroxide, and the soap formed was removed by a separatory funnel. Then, the WCO was washed with warm distilled water several times for removal of excess sodium hydroxide in the oil. Finally, the WCO was dried under a vacuum of ~ 10^3 Pa, at 85 ^oC for 24 h, and the refined waste cooking oil (RWCO) was finally obtained and ready for testing. Simply branded rapeseed oil (RSO) was purchased from Calofic, a local company. Before mixing with RWCO, RSO was first neutralized with sodium hydroxide, and then it was dried in a vacuum oven at 85 ^oC for 24 h. Antioxidants (TBHQ and PG) were purchased from HIMEDIA, India, and added into oil mixture samples at a concentration of 0.5 wt.%. These antioxidants act as free radical scavengers, preventing the development of auto-oxidation process.

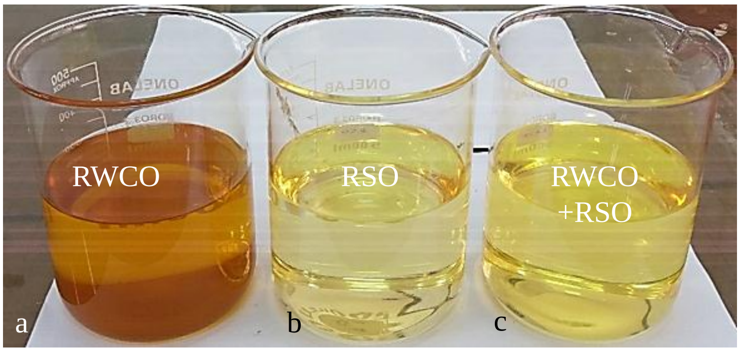

Figure 1. Oil samples: RWCO (a), RSO (b) and RWCO+RSO (c).

2.2. Experimental Setup

The antioxidant capacity of vegetable oils is expressed by oil stability index (OSI), which is determined by the setup shown in Fig. 2. This setup is in accordance with EN 14112. An oil sample having a mass of 3 g was heated at 110 ^oC with an air flow of 10 L/h. When oil oxidation occurs, fatty acids are broken down into volatile acids, which are piped into a beaker of distilled water. Therefore, the water conductivity will gradually raise with the heating time, and the OSI is determined at the point where the water conductivity increases suddenly.

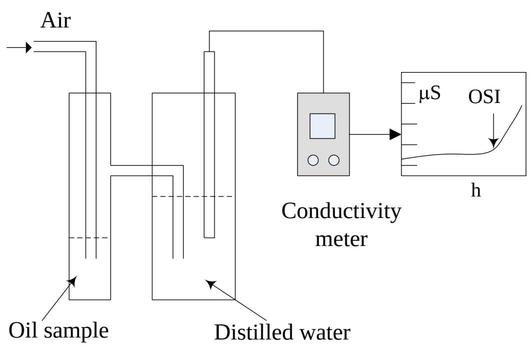

Figure 2. Experimental setup for OSI test.

Fig. 3 shows the experimental setup for breakdown voltage test according to ASTM D1816. The the gap distance was fixed at 2.0 mm, and the test was carried out with the AC testing transformer. The ageing test of oil samples was performed in accordance with IEC 61125C. A glass bottle containing 1L of oil sample was heated in an oil bath at 120 °C for 164 h with an air flow of 5.5 L/h under the presence of copper catalyst (Fig. 4).

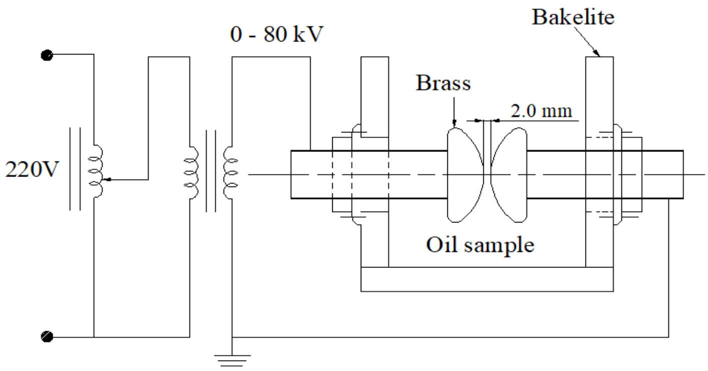

Figure 3. Experimental setup for breakdown voltage test.

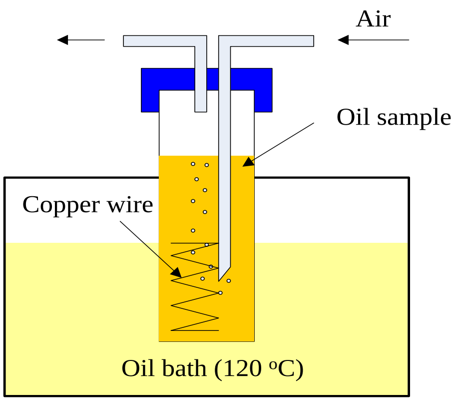

Figure 4. Experimental setup for ageing oil samples.

2.3. Experimental Procedure

To determine the OSI of the oil samples, the oil mixture samples of RWCO and RSO with and without TBHQ (0.5 wt.%) or PG (0.5 wt.%) were used. After each test, new oil samples were used, and the test was repeated three times.

For the ageing test, the oil mixture samples of RWCO and RSO with and without TBHQ (0.5 wt.%) or PG (0.5 wt.%) were also used. After ageing, the oil samples were used to determine the breakdown voltage and the acidity. The experiment was also repeated three times.

The AC breakdown test was carried out according to the ASTM D1816, and the oil samples were subjected to a slow AC ramp (1 kV/s) until breakdown occurred. The experiment was repeated five times to calculate the average value. This AC breakdown test was performed at the electrical material laboratory of Can Tho university. Other parameters of the oil sample were determined at Cantho technical center of standards metrology and quality (Catech) and Southern Electrical Testing Company (SPC-ETC).

3. Results and Discussion

3.1. The Mixture of Waste Cooking Oil and Rapeseed Oil

Physico-chemical parameters of WCO, RWCO and RSO measured at Can-Tho university, Catech and SPC-ETC are shown in Table 1. After purification, the quality of RWCO is significantly improved such as water content, breakdown voltage and acid number. However, the pour point is still high and does not meet the ASTM D6871. For RSO, its parameters conform to the ASTM D6871 except acid number, so sodium hydroxide was used to neutralize the free fatty acids in RSO before mixing it with RWCO as mentioned above.

Table 1. Physico-chemical parameters of oil samples

No	Parameters	WCO	RWCO	RSO	RWCO+RSO	ASTM D6871
1	Viscosity at 40 ^oC (cSt)	45.9	45.8	35.2	37.2	≤ 50
2	Pour point (^oC)	9.0	9.0	-21	-12	≤ -10
3	Flash point (^oC)	320	320	342	336	≥ 275
4	Density at 40 ^oC (g/ml)	0.92	0.914	0.92	0.92	≤ 0.96
5	Water content (mg/kg)	500	98.1	95.1	96.2	≤ 200
6	Breakdown voltage at 2.0 mm (kV)	14	35.2	41	37.6	≥ 35
7	Corrosive sulfur	Non-corrosive	Non-corrosive	Non-corrosive	Non-corrosive	Non-corrosive
8	Acid number (mg KOH/g)	1.35	0.05	4.0	0.05	≤ 0.06

Figure 5 shows the correlation between the pour point and the percentage of RWCO in the oil mixture samples. It was observed that the pour point increased linearly with the amount of RWCO in the oil blend samples, and a value of -10 ^oC was obtained when the RWCO content in the oil mixture sample decreased to about 15% by volume. Therefore, the oil mixture sample containing 15% of RWCO and 85% of RSO was used for further investigation in this study. The physico-chemical parameters of this oil mixture sample are also presented in Table 1. It can be seen that all the parameters of the oil mixture sample are in accordance with the ASTM D6871.

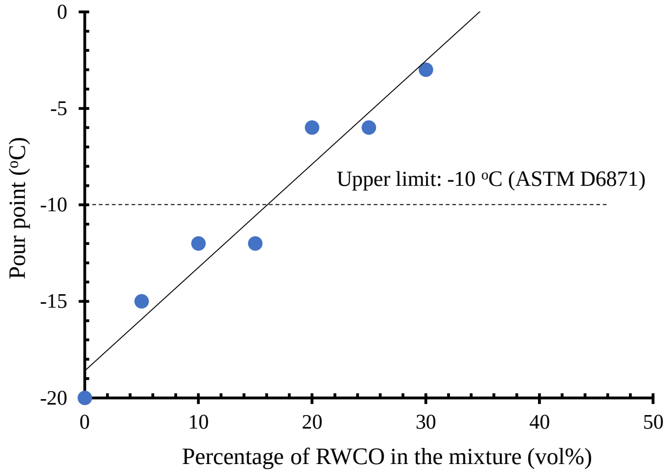

Figure 5. The pour point versus the percentage of RWCO in the mixture.

3.2. Oil Stability Index

The effects of TBHQ and PG on the OSI of the oil mixture samples are shown in Table 2. It was observed that the OSI of the oil mixture sample was similar to that of RSO (~ 2.1 h). In addition, the existence of TBHQ or PG significantly raised the OSI of the oil mixture sample. This confirms the antioxidant efficacy of TBHQ and PG on the studied oil blend. Similar results were reported in previous studies [3, 9]. However, the performance of TBHQ is better than that of PG (8.9 h for TBHQ case; 5.4 h for PG case). Both TBHQ and PG are considered as primary antioxidants, which act as free radical scavengers [11]. It is well known that free radicals are oxidants that attack unsaturated fatty acids in vegetable oils and generate new free radicals causing further oxidation. This process is called auto-oxidation. Therefore, TBHQ and PG can effectively prevent the auto-oxidation of vegetable oil, leading to increase the OSI.

Table 2. OSI of oil samples

No	Samples	Antioxidants	OSI (h)
1	RWCO		2.0±0.4
2	RSO		2.1±0.3
3	RWCO+RSO		2.1±0.4
4	RWCO+RSO	TBHQ (0.5 wt.%)	8.9±1.0
5	RWCO+RSO	PG (0.5 wt.%)	5.4±0.8

3.3. Breakdown Voltage

Figure 6 shows the breakdown voltage (BDV) of oil samples. It can be seen that the BDV of RWCO met the minimum value as specified by ASTM D6871 (35.2 kV versus 35 kV), and the BDV of RSO was about 17% higher than that of RWCO. Thus, the BDV of the mixture of RWCO and RSO was 37.6 kV, which conforms to the ASTM D6871. It was also observed that the addition of TBHQ or PG significantly improved the BDV of the oil blend. With the presence of TBHQ (0.5 wt.%), the BDV of the oil mixture increased by about 21% (45.4 kV versus 37.6 kV) while PG (0.5 wt.%) enhanced the BDV of the oil mixture from 37.6 kV to 41.0 kV (~ 9%). This result is consistent with that obtained in other vegetable oils [9, 12]. In comparison with mineral, the BDV of the oil mixture supplemented with TBHQ (0.5 wt.%) was only about 11% lower (45.4 kV versus 50.8 kV). This confirms the effectiveness of using TBHQ on the oil blend in terms of BDV. TBHQ and PG are aromatic compounds, which were observed to increase the branching of streamers in both mineral and vegetable oils [13, 14]. Thus, it is suggested that these two antioxidants also cause the streamers to branch more, which reduces the speed of streamers and enhances the BDV of investigated oil samples.

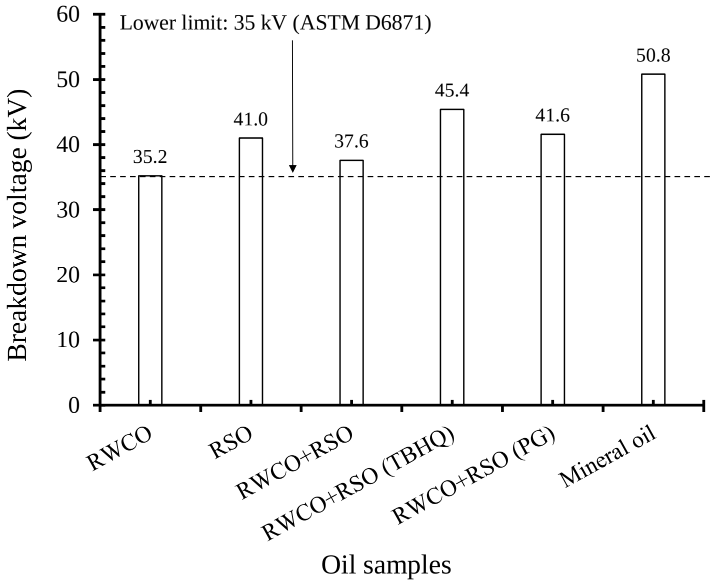

Figure 6. Breakdown voltage of oil samples.

3.4. Ageing Test

The influence of ageing on the BDV of oil samples is presented in Fig. 7. Experimental results showed that ageing had no significantly affect on the BDV of oil samples except mineral oil. After ageing, the BDV of the mixture of RWCO and RSO with and without TBHQ or PG increased slightly (~1-3%). Similar results were observed in other vegetable oils [9, 12]. In contrast, a decrease in the BDV of about 19% was observed in mineral oil. This finding shows an advantage of the vegetable oil blend over mineral oil in terms of the BDV of oil after ageing. With the addition of TBHQ (0.5 wt.%), the BDV of the aged vegetable oil blend was higher than that of the aged mineral oil (46.3 kV versus 41.3 kV). Similar to the case of new oil, TBHQ and PG were observed to significantly increase the BDV of aged oil samples (46.3 kV and 42.0 kV for samples with antioxidants versus 38.7 kV for virgin samples). This may indicate that TBHQ and PG still promote the streamer branching in aged oil samples, causing an increase in BDV.

Fig. 8 shows the effect of ageing on the viscosity of the vegetable oil mixture. After ageing, the viscosity of the oil mixture sample increased about 1.47 times from 37.18 cSt to 54.8 cSt. This is due to the oxidation of the oil sample under high temperature, and indicates the low antioxidant capacity of the vegetable oil blend. However, with the existence of TBHQ (0.5 wt.%) or PG (0.5 wt.%), the oxidation resistance of the oil blend was improved, which was demonstrated by a reduction in viscosity (48.17 cSt for TBHQ case or 50.9 cSt for PG case versus 54.8 cSt for virgin case) and evidenced by a significant increase in OSI as presented above. This result is in good agreement with the studies reported for other vegetable oils [3, 9, 15]. After ageing, the viscosity of vegetable oil blend containing TBHQ (0.5 wt.%) increased to about 29.6% (48.17 cSt versus 37.18 cSt), which is lower than the upper limit of 30% as specified by the IEC 62770. During the process of oxidation at high temperature, i.e. ageing, polymerization takes place to form polymers, which are produced by cross-linking of unsaturated fatty acids between two carbon atoms [16]. This increased the viscosity of aged oil samples as presented above. As observed, TBHQ and PG had the capability to suppress the oil oxidation, these two antioxidants, thus, will retard the polymerization of aged oil samples, manifested by a reduction in viscosity.

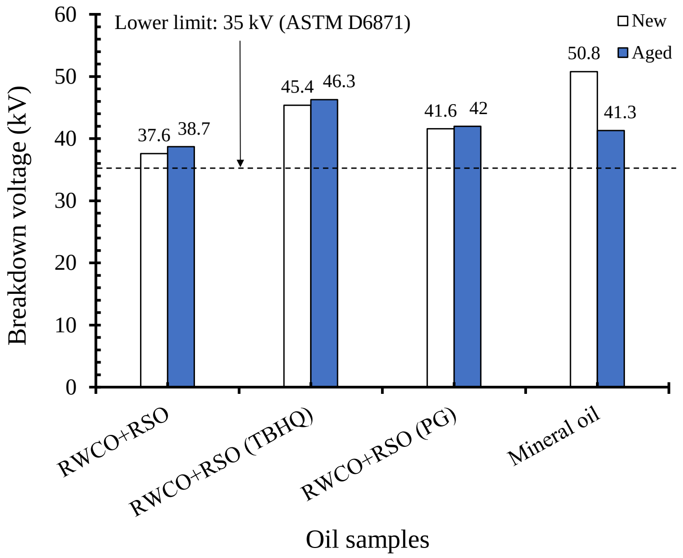

Figure 7. Effect of ageing on the breakdown voltage of oil samples.

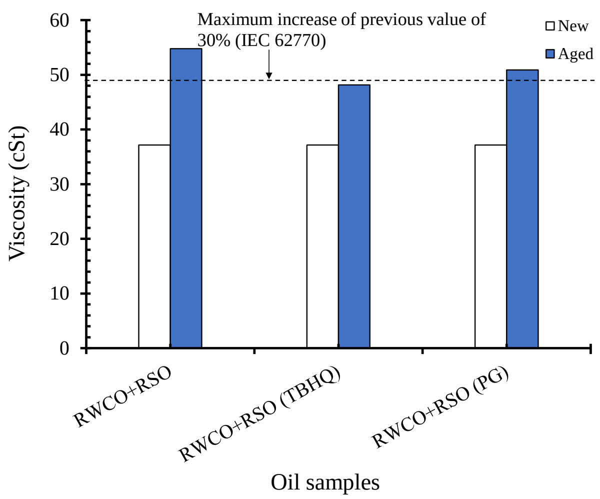

Figure 8. Effect of ageing on the viscosity of oil samples.

4. Conclusion

Waste cooking oil used for insulating in transformers was studied. The experimental results showed that adding 15% by volume of waste cooking oil to rapeseed oil could form a mixture conforming to the ASTM D6871. With the existence of antioxidants (the concentration of 0.5 wt.%), the oil stability index was increased by 4.2 times for TBHQ case and 2.6 times for PG case. Thus, these two antioxidants were also observed to slow down the ageing of the mixture at high temperature demonstrated by a decrease in viscosity of about 12% for TBHQ case and 7% for PG case. In addition, TBHQ and PG also enhanced the breakdown voltage of the oil blend by 9-21% for new oil samples and by 8.5-20% for aged oil samples. Ageing was seen to have a negligible effect on the breakdown voltage of the vegetable oil blend, while it significantly reduced the breakdown voltage of mineral oil (19%). This study confirms the prospect of using mixtures of waste cooking oil and rapeseed oil for insulating purpose in transformers.

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