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Exploration of the Potential of Reclaimed Waste Cooking Oil for Oil-Immersed Power Transformers

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Abstract

In this study, reclaimed waste cooking oil is proposed as an alternative insulating liquid for oil-immersed power transformers. Reclamation is carried out by heating a mixture of waste cooking oil and Fuller's Earth adsorbent and followed by filtration. Propyl gallate antioxidant is then added into the filtered oil. Four oil samples are investigated in this study: (1) new cooking oil (NCO), (2) waste cooking oil (WCO), (3) reclaimed oil (RWCO) and (4) reclaimed oil with propyl gallate antioxidant (RWCOPG). The AC breakdown voltage, moisture content and total acid number is measured for all oil samples according to the ASTM D1816, ASTM D1533 and ASTM D974 standard test method, respectively. The results show that the AC breakdown voltage is highest for the RWCOPG sample (28.08 kV), which is 0.4% higher than the standard requirement of 20 kV. The moisture content for this sample is 180.60 ppm, which is still below the allowable limit of 200 ppm. However, the total acid number is highest for the RWCOPG sample which suggests that it has high acidity. It is indicated that the antioxidant-reclaimed waste cooking oil has potential to be used as an insulating liquid for oil-immersed power transformers, but much work is still needed to reduce the total acid number of this oil.

Keywords*: reclaimed waste cooking oil, propyl gallate antioxidant, breakdown voltage, moisture content, total acid number.*

1. Introduction

For many years, power transformers are typically filled with mineral oils because of their good compatibility with Kraft insulating paper. Mineral oils do not only serve as a liquid coolant but they also serve as an electrical insulator because of their favourable properties including good electrical arc quenching. In addition, mineral oils are widely available in the market due to their low cost. However, mineral oils also pose a threat to the environment because of their toxicity and non-biodegradability and this is even more alarming when there is accidental leakage in the transformer [1, 2]. In order to address this issue, one of the solutions is to reduce the disposal of aged mineral oils either by reusing them through a process known as 'reclamation' or replacing mineral oils with vegetable-based insulating oils.

The reclamation process helps improve the dielectric strength and dissipation factor [3] of aged mineral oils by reducing the contaminants present in these oils such as sludge, acids, ketones as well as moisture resulting from oil degradation [4]. At present, there are several adsorbents available to remove contaminants from aged mineral oils through the reclamation process. These adsorbents help restore the properties of aged mineral oils and therefore, the properties of reclaimed oils are comparable (if not superior) to those for new oils. These adsorbents are mostly produced from clay materials and are typically used in various industries as fertilizers, cleaning agents and pesticides.

The reclamation process can also be used to reclaim other types of oil such as lubricants. Reclaiming aged insulation oils is a cost-effective solution in the long term for energy providers since it reduces the need to purchase new oils which can be rather costly. Vegetable-based insulating oils appear to be promising insulating liquids for transformers in recent years since these oils reduce the safety and environmental hazards associated with mineral oils.

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These insulating oils are produced from vegetable oils such as soybean oil, sunflower oil, coconut oil, olive oil as well as oil extracted from the seeds of *Moringa oleifera*. Sunflower oil is 100% environmentally friendly and has been used as transformer insulation oil for special applications. There are two vegetable-based insulation oils commonly used on a commercial scale nowadays, namely Envirotemp^{TM} FR3^{TM}, which was introduced by Cooper Power Systems in 1996 [5], and BIOTEMP$^{®}$, which was developed by ABB in 1999 [6]. These products are used in small power and distribution transformers across the United States [7, 8].

According to one study [9], palm oil is a promising alternative for transformer insulation oil since it is widely available locally. Moreover, palm oil has excellent AC breakdown voltage, which is a property of paramount importance to dielectric fluids. Palm oil also has good biodegradability, which means that it is environmentally friendly compared to petroleum-derived mineral oils.

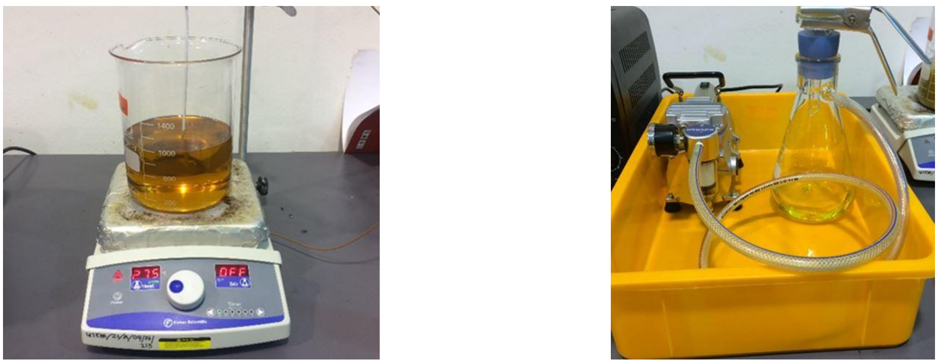
Nonetheless, the use of waste cooking oil as an electrical insulating medium has not been explored extensively by other researchers in this field. Hence, the objective of this study is to explore the potential of waste cooking oil reclaimed using an adsorbent as an alternative insulating liquid for oil-immersed power transformers. It is believed that the results of this study will provide useful insight on the potential of reclaimed waste cooking oil as an electrical insulating medium, which will spark new research ideas.

In this paper, three waste cooking oil-based fluids were prepared. Properties of these fluids such physical appearance, breakdown voltage, moisture content and total acid number were investigated.

2. Research Method

Four types of oil samples were prepared in this study: (1) new cooking oil (NCO), (2) waste cooking oil (WCO), (3) reclaimed waste cooking oil (RWCO), and (4) reclaimed waste cooking oil added with antioxidant (RWCOPG). The antioxidant chosen for this study was propyl gallate (PG).

The NCO sample is essentially oil that was taken fresh from the bottle. In contrast, the WCO sample is waste cooking oil that was used for frying foods several times and this sample was collected from a café. The RWCO sample is waste cooking oil reclaimed using Fuller's Earth adsorbent. In the reclamation process, 1 litre of waste cooking oil was poured into a beaker and then heated at 60°C. After a few minutes, 500 gram of Fuller's Earth were added into the beaker and the mixture was stirred continuously using a magnetic stirrer at a stirring speed of 750 rpm for 4 hours according to the procedure detailed in [3]. Figure 1(a) shows the waste cooking oil heated prior to the addition of Fuller's Earth adsorbent.Following this, a glass microfibre filter paper was used to separate the oil-adsorbent mixture based on a simple filtration technique. A pump was used to force the mixture to pass through the filter paper. The filtered oil was collected in an Erlenmeyer flask, as shown in Figure 1(b).



(a) (b)

Figure 1. (a) Waste cooking oil heated at 60°C prior to the addition of Fuller's Earth adsorbent; (b) Filtration of reclaimed waste cooking oil

Once the filtering process was complete, the reclaimed oil was poured into an amber glass bottle, blanketed with nitrogen, sealed tightly and labelled accordingly. Nitrogen blanketing was carried out to prevent oxygen from being trapped inside the amber glass bottle.

In order to prepare the RWCOPG sample, the mass of the PG antioxidant was fixed at 0.3% of the total mass for the RWCO sample. Once the mass of the PG was measured, the PG was added into the beaker containing RWCO. The mixture was heated at 149°C (melting point of PG) for 7 minutes. Following this, the mixture was left to cool in a vacuum oven for one day before the sample was stored in an amber glass bottle, blanketed with nitrogen, tightly sealed and labelled accordingly as other oil samples.

The AC breakdown voltage (BdV), moisture content and total acid number (TAN) was measured for all oil samples in accordance with the ASTM D1816 [10], ASTM D1533 [11] and ASTM D974 [12] standard test method, respectively. The AC BdV tests were conducted using Megger OTS60PB portable oil tester, as shown in Figure 2.

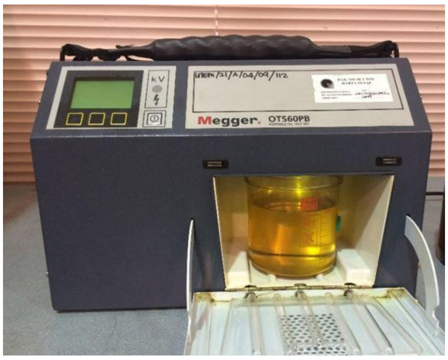


Figure 2. Megger OTS60PB portable oil tester used for AC breakdown voltage measurements

The minimum volume for each oil sample was 350 ml in these tests. The portable oil tester has two electrodes which need to be cleaned prior to the AC BdV tests. The gap distance between the electrodes was kept fixed at 1 mm and the rate of voltage was 2.0kV/s. Each oil sample was poured into two beakers, labelled *A* and *B*. Each beaker containing the oil sample was tested up to 25 AC BdV occurrences, resulting in a total of 50 tests. The mean AC BdV for each oil sample was determined from the Weibull probability plots.

The moisture content was determined for each oil sample using a coulometer based on the Karl Fischer titration method, as shown in Figure 3. Unlike other instruments, this instrument is capable of tracing low levels of free, emulsified and dissolved water accurately. The Karl Fischer titration method is based on the oxidation of sulphur dioxide by iodine in methanolic hydroxide solution. The titration can be carried out volumetrically or coulometrically.

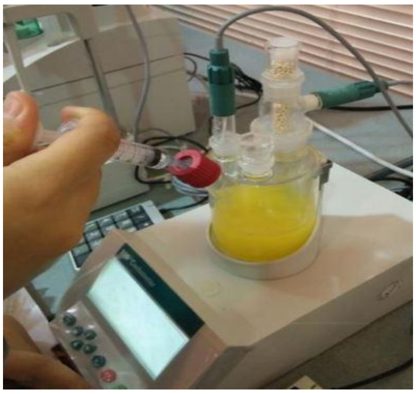


Figure 3. Coulometer used for moisture content measurements

The total acid number (TAN) is indicative of the total acidity of the oil sample and it was measured using a TAN analyser, as shown in Figure 4. The TAN was measured based on the amount of potassium hydroxide (in mg) required to neutralize hydrogen ions (H^+) in 1 g of oil.

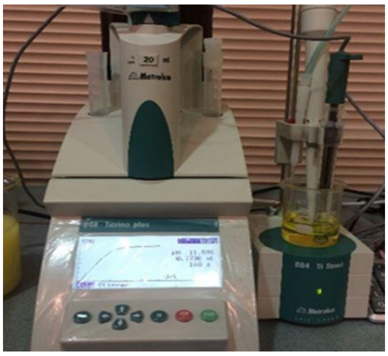


Figure 4. TAN analyser used for total acid number measurements

3. Results and Analysis

The results obtained from the tests are presented and discussed in this section. This discussion is centred on the AC BdV, moisture content and TAN of the NCO, WCO, RWCO and RWCOPG samples.

3.1. Physical Appearance of Oil Samples

Figure 5 shows the physical appearance of the used oil, reclaimed oil and new oil samples. It can be observed that the the colour of the used oil (WCO) sample is dark yellow, which signifies that the sample experiences a change in its properties as a result of frying foods at high temperatures and the sample is contaminated with impurities from the frying process. It can be expected that the colour of the WCO will further darken over time as the oil deteriorates [13] It is evident that the reclamation process using Fuller's Earth adsorbent affects the physical appearance of the WCO sample since the reclaimed oil (RWCO) sample has a light yellow colour. This colour change is a clear indication that most of the contaminants present in the WCO sample have been removed successfully by the adsorbent. It is also evident from Figure 5 that the colour of the RWCO sample is similar to that for new oil (NCO). Hence, it can be deduced here that impurities contained in the WCO have been adsorbed by the Fuller's Earth adsorbent during the reclamation process over a period of 4 hours.

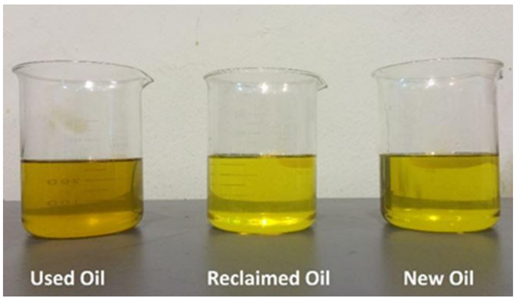


Figure 5. Physical appearance of the used oil (WCO), reclaimed oil (RWCO) and new oil (NCO) samples

3.2. AC breakdown voltage

The AC breakdown voltage is a vital parameter used to assess the dielectric performance of insulation oils. The factors that influence the AC breakdown voltage of insulation oils are the presence of moisture, air bubbles and suspended particles in the oils and acidity of the oils. In this study, AC BdV tests were carried out for four types of oil samples, *i.e.* NCO, WCO, RWCO and RWCOPG. Each oil sample was poured into two beakers and the AC BdV test was conducted 25 times for each oil-filled beaker, resulting in a total of 50 tests.The AC BdV tests were conducted in accordance with the ASTM D1816 standard test method, whereby the gap distance between the electrodes was kept fixed at 1 mm. The Weibull probability plots were constructed to determine the AC BdV of the oil samples, as shown in Figure 6(a)–(d). This Weibull probability corresponds to the time of failure of the specimen tested [14, 15].

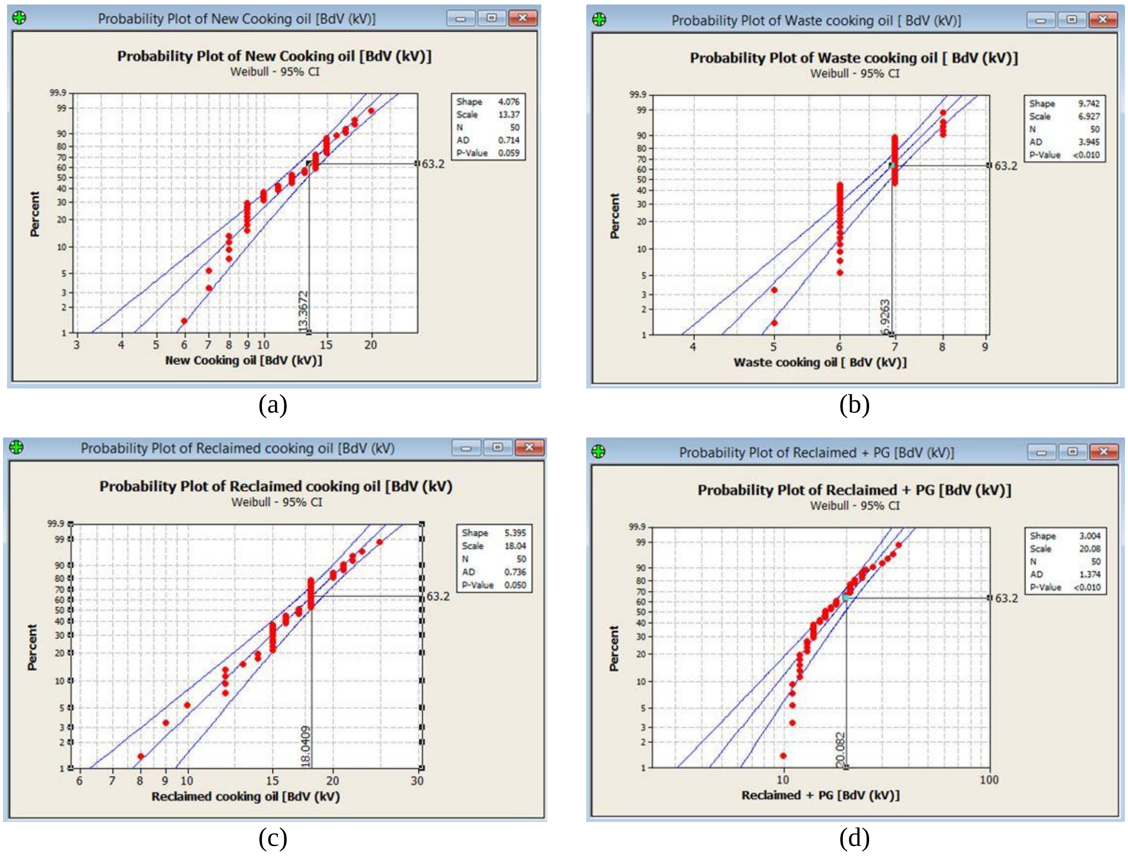


Figure 6. Weibull probability plot for: (a) NCO, (b) WCO, (c) RWCO and (d) RWCOPG oil sample

It can be seen that the AC BdV is the lowest for the WCO sample (6.93 kV) at a Weibull probability of 63.2%. In contrast, the AC BdV of the reclaimed oil (RWCO) sample increases significantly to 18.04 kV, which indicates that the reclamation process enhances the dielectric strength of the oil significantly. The reclaimed oil added with PG antioxidant (RWCOPG) has superior dielectric strength among all oil samples, whereby the AC BdV is 20.08 kV. This value is indeed higher than the dielectric strength requirement of transformer oils, which is 20 kV. Both the RWCO and RWCOPG oil samples have higher AC BdV than that for new cooking oil (NCO) which has AC BdV of only 13.37 kV. This shows the advantage of the reclamation process and propyl gallate antioxidant in enhancing the dielectric performance of waste cooking oil. The AC BdV values of the four types of oil samples investigated in this study are summarized in Table 1.

3.3. Moisture Content and Total Acid Number

The moisture content and TAN measurements were taken three times and the mean values were determined. The mean values for the moisture content and TAN for all oil samples are also summarized in Table 1.

It is most notable here that the WCO sample has the highest moisture content (1,210.60 ppm), which is indeed expected due to degradation of the oil from repeated frying. This is followed by the NCO sample, whereby the moisture content is 837.20 ppm. The most interesting finding here is that the addition of PG antioxidant into RWCO reduces the moisture content significantly. The RWCOPG sample has the lowest moisture content (180.60 ppm), which corresponds to a reduction of 85.08% relative to the moisture content for WCO, which is highly desirable for electrical insulation purposes. More importantly, the moisture content for this sample is below the prescribed limit for ester-based insulation oils (200 ppm) [16].

The TAN value is the lowest for the NCO sample (0.19 mg KOH/g). The WCO sample indeed has a higher TAN (1.07 mg KOH/g) and this value is reduced after the oil undergoes the reclamation process (0.78 mg KOH/g), which corresponds to a reduction of 27.10% relative to the TAN for WCO. However, despite the fact that the RWCOPG sample has the highest AC BdV, this sample also has the highest TAN (3.13 mg KOH/g), which indicates that it has higher acidity compared to all of the samples investigated in this study. This is undesirable since oils with higher acidity will likely lead to corrosion and therefore, it is important to reduce the TAN value of insulation oils.

Table 1. Mean AC breakdown voltage, moisture content and total acid number for all oil samples

Oil sample	Mean value		
	AC BdV (kV)	Moisture content (ppm)	Total acid number (mg KOH/g)
New cooking oil (NCO)	13.37	837.20	0.19
Waste cooking oil (WCO)	6.93	1,210.60	1.07
Reclaimed waste cooking oil (RWCO)	18.04	691.10	0.78
Reclaimed waste cooking oil + propyl gallate antioxidant (RWCOPG)	20.08	180.60	3.13

4. Conclusion

Reclamation is a process of removing contaminants from insulation oils such as solid impurities and by-products resulting from oxidation and chemical reactions that take place inside oil-immersed power transformers. In this study, reclamation is conducted on waste cooking oil (WCO) using Fuller's Earth adsorbent and it is found that this process helps restore the physical appearance of WCO close to that for new cooking oil (NCO), indicating that most of the contaminants present in the WCO have been removed by the adsorbent. Filtration is then carried out on the reclaimed waste cooking oil (RWCO) in order to separate the used adsorbent from oil. Propyl gallate is then added into the RWCO to prevent the oil from oxidation as well as improve the dielectric strength of the oil. It is found that the AC breakdown voltage of the RWCOPG sample improves by 289.75% relative to that for WCO. This is possibly due to the removal of contaminants from the WCO during the reclamation process as well as the addition of antioxidant. In general, antioxidants work to slow down the oxidation process and therefore, oil oxidation is minimized as long as there is an inhibitor present in the oil. In addition, the moisture content of the RWCOPG sample is reduced by 85.08% relative to that for WCO. However, the addition of propyl gallate into the RWCO also has an undesirable effect since it increases the TAN of the oil. Reclamation on its own helps reduce the TAN of WCO by 27.10%. Based on the results obtained in this study, it can be concluded that the RWCOPG sample has great potential to be used as an insulating liquid for oil-immersed power transformers since it helps tackle issues related to disposal of aged insulation oils – however, much work is needed to reduce the TAN value of this oil.

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Nomenclature

ABB	*ASEA Brown Boveri*
AC	Alternating Current
ASTM	American Society for Testing and Materials
BdV	Breakdown Voltage
NCO	New Cooking Oil
PG	Propyl Gallate
ppm	parts per million
rpm	revolutions per minute
RWCO	Reclaimed Oil
RWCOPG	Reclaimed Oil with Propyl Gallate Antioxidant
TAN	Total Acid Number
WCO	Waste Cooking Oil

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