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EFFECT OF TEMPERATURE IN PURIFICATION PROCESS ON THE PROPERTIES OF NATURAL ESTER INSULATING OILS

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ABSTRACT

The life span of a transformer usually depends on its insulation condition. In principle, materials used in transformer are subjected to ageing process during the operation that might lead to insulation failure. The interaction between transformer insulation with temperature, moisture and oxygen might commonly lead to the formation of gases, acid, sludge and moisture which accelerates the ageing process. Therefore, an appropriate oil treatment or purification process is required to delay the aging process by sustaining or improving the quality and properties of the insulation oil. Currently, in the field of oil treatment process, there are only a few studies done regarding the natural ester insulating oil (NEI) treatment compared to the mineral insulating oil (MI). In fact, there were no study done concerning the effect of temperature during treatment process toward NEI especially for the rapeseed and palm based oil. Thus, a drying treatment process was selected in studying the effect of temperature on NEI using a vacuum oven that have been set at two temperatures of 65℃ and 90℃with 0.09MPa pressure. The experimentwas conducted for one week with a time interval of one day (24 hours). Quality of the treatment oil were then examined by evaluating its moisture content, acidity and AC breakdown voltage. In addition, this paper also investigated the temperature effects in determining the optimum time taken for oil treatment process. The finding of this work is believed to able in assisting the planning of an appropriate maintenance strategy to keep the power transformer oil in healthy condition, and hence met the standard requirement.

Keyword: transformer, purification, moisture, acidity, breakdown voltage.

1. INTRODUCTION

Power transformer plays an important role in any electrical distribution network. The unexpected failure of power transformer will lead to a major disaster; not only for the distribution network, but it will also affect both environment and public safety. Basically, the insulation system of a transformer is very important as the transformer lifetime is associated with the condition of its insulation system that were categorized into two major parts of liquid and paper. Mineral insulating oil (MI) is normally used as a transformer insulating liquid due to its capability in withstanding high dielectric breakdown voltage [1]. However, MI has low fire point and is not biodegradable. Alternatively, the natural ester insulating oil (NEI) have a more superior hydrophobic properties which has been introduced to overcome the biodegradability and fire point issues[1]-[4].Hence, improving the transformer lifespan [5]. In identical to MI, it was also discovered that the properties of NEI deteriorates after a long run of transformer operation and therefore, a proper treatment is needed in order to maintain both the quality and condition of the NEI.

TheIEEE Guide for the Reclamation of Insulating Oil and Criteria for Its Use (IEEE 637)[6] have stated various practices for oil-purification to treat insulating oil. Besides, there were also a review that have been written in order to improve the insulating oil properties by Sharin *et al* that emphasized on the effect of reclamation technology on liquid insulating oils in power transformer applications[7][8]. This paper studies the effect of temperature on NEI properties (moisture content, acidity and AC breakdown voltage) to identify the optimum time of purification. This study was done in order to investigate the reasons behind the use of different temperature and duration by several researchers in treating insulating oil. The treatment process was also found to be different even though their objective was same. There was a difference noted in the water content removal method used during oil treatment by several researchers even though their objective were almost same, for instance, in the MI treatment done by N. Azis [9]. The thesis reported a filtering process that uses filter paper first which then followed bya heating in circulating oven for 24 hours at 105℃. On the other hand, R. Liao *et al* [10]was found to be using a vacuum box for 24 hours at 40 °C. Meanwhile, in another journal by M.-L. Coulibaly et al[11],the MI were only treated according to laboratory treatment (filtration under vacuum) without detail explanation. Diversely, for NEI the treatment process was summarized as follows. In the thesis of N. Azis[9], he was repeating the first step as previously performed for MI which then followed by heating in vacuum oven that is less than 10mbar for 72 hours at 85℃. While, N A. Raof[12]had done filtering process through a membrane filter and was dried in the oven for two days (48 hours) under 90°C temperature. In the journal of M.-L. Coulibaly*et al* [11] and R. Liao *et al*[10], it was discovered that both authors had correspondingly used the same techniques that had been applied for MI treatment on NEI. Contrarily, on another journal reported by W. Lu *et al*[13], there were no explanation given for the techniques used during pre-processing of the oil procedure which governs filtering, dehydrating and degassing in order to eliminate any possible negative effect of these impurities.

2. LIQUID INSULATION TREATMENT

During operation, the properties of transformer oil is deteriorating due to the increase of moisture and dirty particles in the oil[14]. In particular, these factors need to be controlled and removed since the performance of insulation system is worsen due to the moisture content and other contaminations[15]-[17]. Due to the problems, several treatment methods of liquid insulation have also been implemented in power transformer maintenance such as filtration and drying [18]. The details of each method in overcoming insulation failure are discussed as follows.

a) Filtration

Filtration is a process of removing unwanted solid particles in liquid insulation by using filtration paper. Filtration process not only remove unwanted particles, but also reduce free water in oils[19], [20].The efficiency of filtration process is subject to its pore size, the smaller the better. However, smaller pore size requires lengthier duration to complete a treatment process. Despite removing the unwanted particles, filtration process does not significantly change the acid, polar compound levels or remove dissolved water[20].

b) Drying

Drying or dehydration is the process of removing the dissolve water from liquid insulation by heating the transformer oil at certain temperature[20].In the journal of G. Gavrilovs and O. Borscevskis, the optimum treatment temperature were withinthe range of 65^0C to 90 ^{0}C[20]. During heating process, the moisture and gases are being separated from the oil. In contrast with filtration method, drying process could not remove unwanted particles from inside the oil.

Oven and air stripping dehydrator are commonly used to heat the insulating oil[15], [16]. In this paper, purification process drying is selected by using vacuum oven to treat the NEI properties.

3. METHODOLOGY

A. Sample preparation

Two different types of natural ester insulating oil, palm and rapeseed based are examined in this study. Initial properties of dielectric breakdown voltage, moisture content and acidity for both NEI types are determined in accordance to Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids(ASTM D1816[21]), Standard Test Method for Water in Insulating Liquids by Coulometric Karl Fischer (ASTM D1533[22]), and Standard Test Method for Acid Number of Petroleum Products by Potentiometric (ASTM D664[23]) respectively. Results are shown in Table-1.

Table-1. Initial properties of liquid insulation.

Properties	Rapeseed based oil	Palm based oil
Moisture content (ppm)	166.58	149.00
Acidity (mgKOH/g)	0.1001	0.0358
AC Breakdown Voltage (kV), 1mm gap	26.30	26.27

In the next stage, each NEI types are purified using vacuum oven at two different temperature, 65°C [24]and 90°C[25] as suggested by G. Gavrilovs and O. Borscevskis[20]. Then, vacuum pressure is set at 0.09 MPa. Both NEI types are heated at aforementioned temperature up to seven days (168 hours), while the dielectric breakdown voltage, moisture content and acidity are measured every 24 hours.

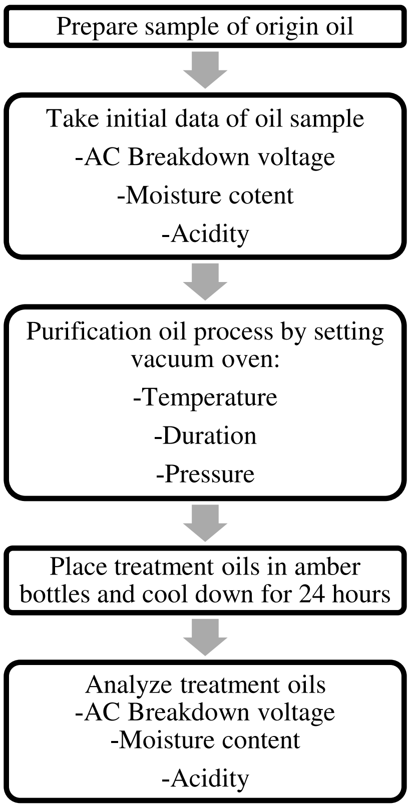

Figure-1. Flowchart of liquid insulation treatment.

4. RESULTS AND DISCUSSIONS

A. Moisture content

Results of moisture content after drying process for natural ester insulating oil rapeseed-based shown in Figure-2 and Figure-3. As for palm-based, the result are shown in Figure-4 and Figure-5. In the treatment of rapeseed-based oil at 65°C, the moisture increased for the first 48 hours before it starts diminished until reached 130ppm after 144 hours (six days) treatment. However, the moisture content started to increase again on day seven. Meanwhile, moisture content of rapeseed-based oil

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at 90°C is inconsistence for the first 96 hours before it reduced consistently after day five. Based on Figure-2 and Figure-3, the optimum improvement of moisture content in rapeseed-based oil can be achieved by heated the oil at 90°C for seven days (168 hours).

On the other hand, moisture content of palm-based oil which treated at 65°C shows an improvement on day seven (168 hours) by 11.7% reducing from its initial condition. However, there is no significant improvement of moisture content observed at 90°C treatment results. In fact, the moisture content became worst compared before treatment and exceed limit of moisture content in ester oil based on ASTM D6871[26] standard (maximum moisture content is 200 ppm).

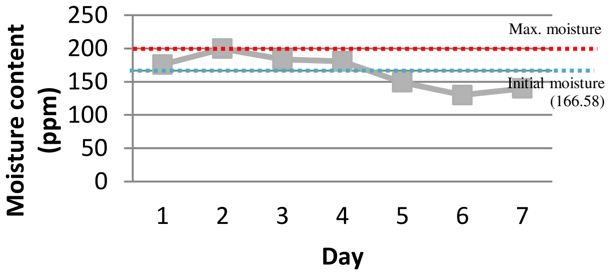

Figure-2. Moisture content for rapeseed-based oil at 65°C.

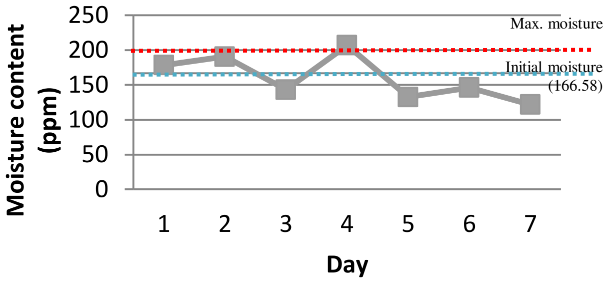

Figure-3. Moisture content for rapeseed-based oil at 90°C.

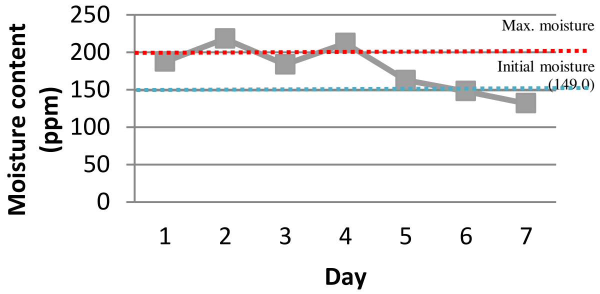

Figure-4. Moisture content for palm-based oil at 65°C.

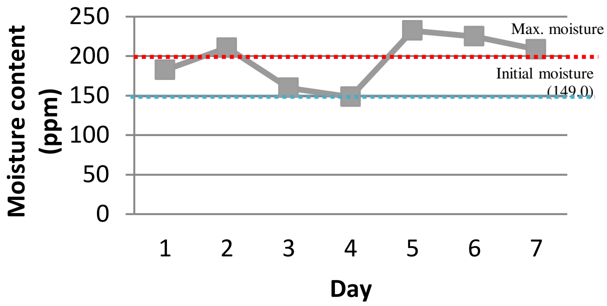

Figure-5. Moisture content for palm-based oil at 90°C.

B. Acidity

Acidity results after treatment were shown in Figure-6 and Figure-7for rapeseed-based. Meanwhile, acidity for palm-based as Figure-8 and Figure-9. Significant improvement of acidity in rapeseed-based can be observed on day six (after 144 hours) at 65°C treatment temperaturewhich dropped by 54.8% from its initial condition. Meanwhile, the acidity in rapeseed-based oil for treatment at 90°C shows inconsistency results from day one to day four. However, acidity constantly increased from its initial condition after 120 hours treatments (day five onwards).

In the palm-based insulating oil, variation of results between 65°C and 90°C treatment temperatures can be observed. Acidity in oil is reduced significantly by 68.7% after 24 hours heated at 65°C, but unexpectedly increased on day two beyond its initial condition. On the other hand, acidity in palm-based insulating oil increased for the first 48 hours of treatment at 90°C,which then improved about 50% on day three. After that, acidity level in palm-based oil increased again and became worst on day seven which exceed the maximum allowable limit of acidity in ester oil based on ASTM D6871 [26]standard (maximum acidity is 0.06 mg KOH/g).

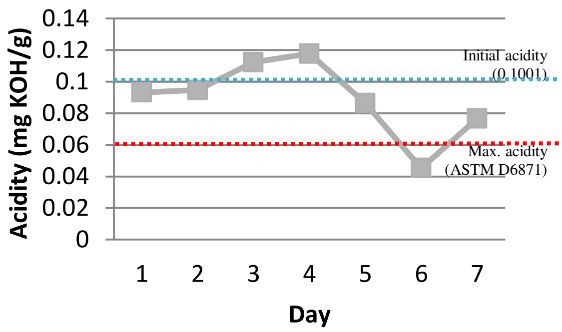

Figure-6. Acidity for rapeseed-based oil at 65°C.

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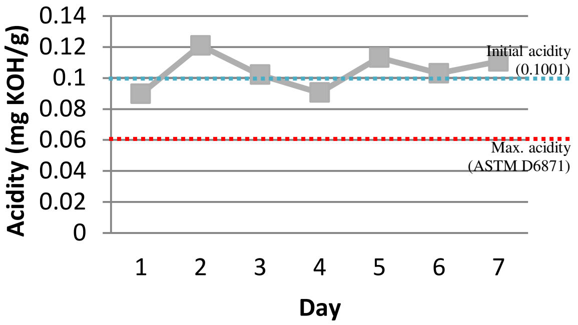

Figure-7. Acidity for rapeseed-based oilat 90°C.

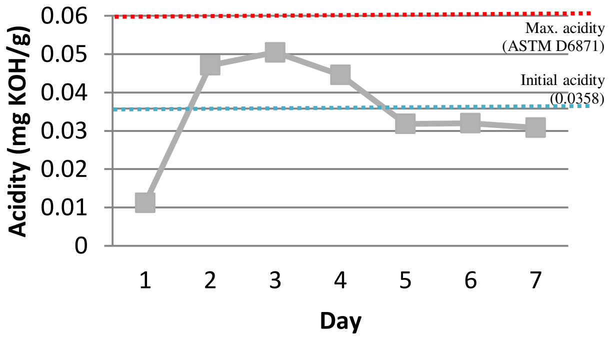

Figure-8. Acidity for palm-based oil at 65°C.

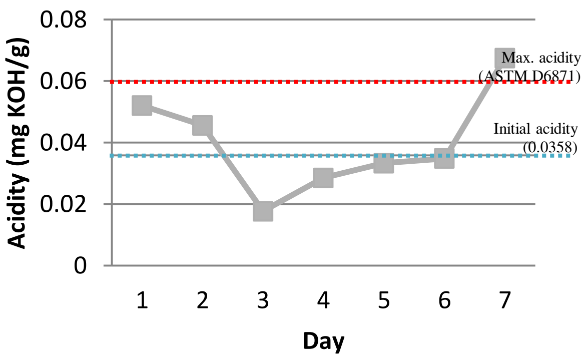

Figure-9. Acidity for palm-based oil at 90°C.

C. AC Breakdown voltage

Meanwhile, Figure-10 and Figure-11illustrate the AC breakdown voltage (BDV) after purification for rapeseed-based oil and Figure-12 with Figure-13 for palm-based oil respectively. Figure-10 shows fluctuate BDV trends on rapeseed-based oil for temperature 65°C. The improvement of BDV can only be observed after day five onward and achieved 49.8% improvement on day seven from its initial condition. Meanwhile, for 90°C, an increment of BDV is observed within day oneto day three before it's became in consistence on day four onward.

On the other hand, BDV for palm-based oil only shows a significant improvement on day six with 18.4% at 65°C as shown in Figure-12. Meanwhile, results for 90°Cdid not show any improvement within seven days treatment.

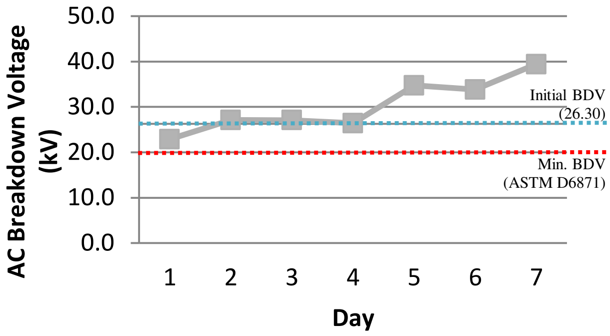

Figure-10. AC breakdown voltage for rapeseed-based oil at 65°C.

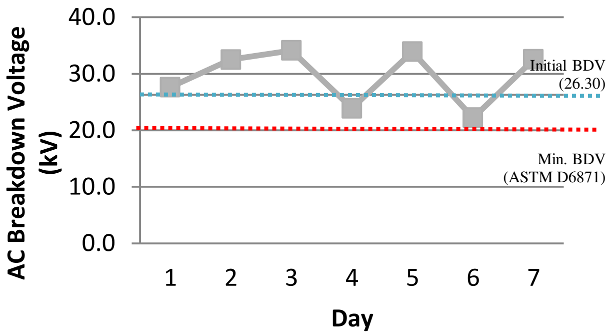

Figure-11. AC breakdown voltage for rapeseed-based oil at 90°C.

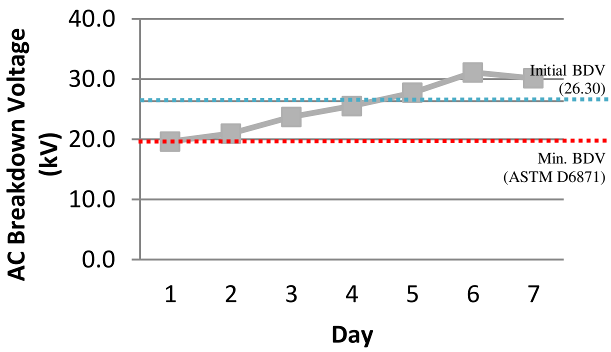

Figure-12. AC breakdown voltage for palm-based oil at 65°C.

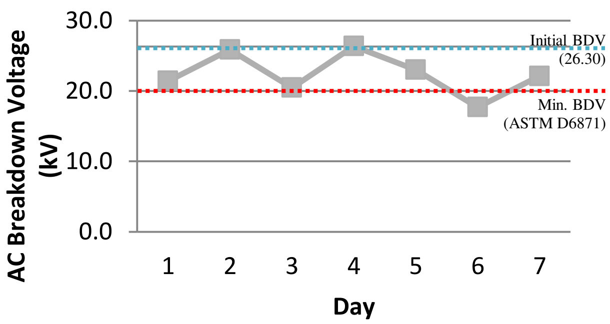

Figure-13. AC breakdown voltage for palm-based oil at 90°C.

Based on the results obtained, an ideal time for drying and degassing treatment of palm-based oil and rapeseed-based oil are summarized in Table-2. As for the rapeseed-based oil, at least a heating of 120 hours at 65°Cis required to enhance it properties. However, no appropriatecombination of time can be observed for temperature at 90°C. The optimum time for temperature 65°Cis at 144 hourswhereby the highest decrement value of moisture content and acidity is observed.

Table-2. Optimum time of treatment process for rapeseed based oil.

Temperature (^{0}C)	**Type of Test**	**Day**						
		1	**2**	**3**	**4**	**5**	**6**	**7**
65	Moisture content					√	√	√
	Acidity	√	√			√	√	√
	AC Breakdown voltage		√	√	√	√	√	√
Optimum time		Day five to Day seven						
90	Moisture content			√		√	√	√
	Acidity	√			√			
	AC Breakdown voltage	√	√	√		√		√
Optimum time		None						

On the other hand, palm-based oil required 96 hours at 90°C and at least 144 hours at 65°C to enhance its oil properties. However, there is no optimum time that can be observed at temperature 90°C since there is no significant decrement of moisture content obtained. In the interim, the optimum time for palm-based oil treatment at temperature 65°C can be obtained at 168 hours as shown in Table-3.

Table-3. Optimum time of treatment process for palm based oil.

Temperature (^{0}C)	**Type of Test**	**Day**						
		1	**2**	**3**	**4**	**5**	**6**	**7**
65	Moisture content					√	√	√
	Acidity	√				√	√	√
	AC Breakdown voltage					√	√	√
Optimum time		Day five to Day seven						
90	Moisture content				√			
	Acidity			√	√	√	√	
	AC Breakdown voltage				√			
Optimum time		Day four						

5. CONCLUSIONS

In this study, it is proven that temperature play an important role in the treatment process of liquid insulation. Different temperature produced difference effects on oil properties. The main challenges during treatments process is to control NEI properties from drastically change within the treatment period. Failures to control will generate an accelerated thermal aging experiment, which is an opposite of the treatment process. The optimum time and temperature of purification process for rapeseed-based and palm-based oils can be obtained at 65°Ctemperature and between day six to day seven.

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