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Study of extra virgin olive oil as liquid insulation in transformer

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Abstract. Mineral oil, which is the basis of petroleum, has long been used as an insulating and cooling medium for transformers. In fact the petroleum has a limited supply, over time it will run out, cannot be renewed, even petroleum is poisonous, cannot be decomposed. In this study, researchers used vegetable oil that is renewable, biodegradable, and safe for living things and the environment, namely olive oil with good quality, from the first pressed of olives, which is called extra virgin olive oil to be applied to transformers as an insulating and cooling medium. To determine the feasibility of using extra virgin olive oil as transformer oil, the test is to determine the value of the breakdown voltage. Breakdown voltage is the voltage value when the transformer components become connected because oil cannot perform its function as insulation. Tests carried out according to international standards IEC 156, 296 and SPLN 49-1. The breakdown voltage value at room temperature (28°C) is 46.73 kV, at a temperature of 50°C where the transformer operates is 48.31 kV. At a temperature of 50°C the breakdown voltage value is higher due to heating which causes water content, air bubbles, and voids to be reduced.

1. Introduction
Mineral oils have been used as coolant and insulator for over a century [1]. Mineral oil as a dielectric coolant extracted from petroleum was first patented by Elihu Thomson in 1882. But the idea was only realized in transformers, after a decade later in 1892 [2]. The availability of petroleum-based mineral oil continuously decrease every year and less safe and unfriendly to the environment because it is difficult to degrade and also flammable. Vegetable oil is needed as insulating liquid material that can be completely degraded, from organic materials that are environmentally friendly, non-toxic, have a high fire point, biodegradable and can be renewed (renewable) [1-3]. The advantages of vegetable oil can be biodegraded quickly and completely. The biodegradation rate of vegetable oil is up to 97%, much higher than mineral oil which is only 30% [5]. With a higher level of biodegradation, of course vegetable oil will be more environmentally friendly and renewable [6].

Moreover, it shows extremely low or no toxicity as compared to mineral oils. The mineral oil as transformer oil can generate poisonous substances due to oxidative instability [7]. In fact the volume of transformer oil reaches hundreds of kilograms or liters in a single-phase distribution transformer and even thousands of kilograms or liters in three-phase distribution transformers and power transformers. This becomes dangerous when mineral oil used for transformers leaks or spills on agricultural land, plantations, livestock, fisheries and water sources.

This consideration is also supported by the regulatory limits issued by the United states Environmental Protection Agency (US EPA) and the regulations on the Toxic Substance Control Act
of 1976 concerning the PCB toxic substance control law, the main component of Asceral, which states that the manufacture, processing, use, or disposal of chemicals or mixtures or any combination of these activities is expected not to carry an unreasonable risk of injury to health and the environment [8]. US EPA regulatory restrictions are periodically followed and modified up to the most recent change in 1998 [9]. This is principally due to the fact that vegetable oil dielectric fluids do not contain polynuclear aromatics, volatile or semi-volatile organics, halogens, or other compounds that can be present in mineral oils or other dielectric fluids [10], [11].

Transformer oil mostly can acts as an insulating and cooling medium in transformers. This insulating oil fills up the pores in the fibrous insulation such as paper. In addition, insulating oil also fills up the gaps between the turns of the winding and the spacing between the winding and the tank. Moreover, the oil not only functioning as a dielectric but also works as a cooling medium [12]. During operation, transformer oil generates heat in the winding, and transferred that heat to the oil. Then, heated oil flows to the radiators by convection. Oil supplied from the radiators, being relatively cool, cools the winding. There are many important properties of oil to qualify as transformer oil, such as dielectric strength, flash point, viscosity, specific gravity and pour point. The quality of the oil is very essential. At high voltages, heavily loaded, transformers require better quality of oil. In the other hands, at low voltages, lightly loaded, the quality of oil is not too critical [1-2], [13], [14].

Olive oil is considered as family of vegetable oils since it is obtained from the flesh of the fruit (olives) of the olive tree. Olive oil contains unsaturated fatty acids is 84.2%, the most dominant is oleic acid, 71% monounsaturated fatty acids and 13.2% linoleic acid, compound unsaturated fatty acids and has 15.8% saturated fatty acids. The breakdown voltage of olive oil can reaches up to 60 kV/2.5 mm. This is the highest compared to the breakdown voltage of palm oil and virgin coconut oil [15].

In this research, a grade A of extra virgin olive oil was used due to its better quality olive oil than regular olive oil, since its came from first pressing olives. In addition, extra virgin olive oil is renewable oil, because the existence. Extra virgin olive oil is vegetable oil from olives which safe to use for human consumption or for beauty, cosmetics, soap, non-toxic, environmentally friendly and biodegradable. In this research, extra virgin olive oil has been tested to be applied in transformer oil by testing the breakdown voltage which refers to the International Electrotechnical Commission (IEC) standard of 156 and 296 where is breakdown voltage value is supposed to be feasible is ≥ 30 kV with the distance of the two ball electrodes of 2.5 mm and the diameter of the electrode is 12.5 mm and a voltage rise rate of 2 kV/s [16], [17].

2. Experimental Method

The experiment begun by prepared the sample of extra virgin olive oil from Borges (PT. Prambanan Kencana).

Figure 1. (a) Virgin olive oil Le Riche and (b) Extra virgin olive oil Borges
The tools used in this research (as shown in Figure 2) are involve of voltage generator kit, multimeter, testing chamber, electrode, heating element and pan, thermometer, wires, and grounding stick.

![Image](a) Step-up transformer, (b) control panel, and (c) testing chamber

The experiment carried out at in the high voltage laboratory of Faculty of Engineering, Universitas Gadjah Mada, Indonesia. Voltage generator consist of step-up transformer with maximum output capacity of 100 kV and control panel. Step-up transformer was used to increase the voltage until the breakdown voltage occurs. Control panel used to turn on and off and adjust the voltage up and down. Where the multimeter is used to display the primary voltage and set on the side of primary transformer. The testing chamber made of fiber glass is used to place the testing oil with volume of 200 ml and the two spherical electrodes (standard VDE, Verband Deutcher Elektrotechniker) with diameter of 12.5 mm made of copper and located on testing chamber where the distance of the electrodes can adjust accordingly. The electrode in the testing chamber is connected using a cable to the secondary side of the step-up transformer. The heating element is used to heat the oil until reach the desired temperature. Oil is cautiously placed in a pan then heated with a heating element. The grounding stick is used to remove residual or neutralizing voltage, by attaching the tip of the stick to the step-up transformer.

![Diagram](Figure 3. Schematic diagram for breakdown voltage testing)
The schematic diagram for breakdown voltage testing was shown in Figure 3. The switch button (ON/OFF) is used to turn on or turn off the control panel and the primary switch (PS) is a switch that is used to regulate or drive or rotate the servo motor. There are three positions in PS, first to decrease voltage, second to neutral, and third position is to increase voltage. When starting the test, voltage is in zero position. Then turn the PS to the third position to increase the voltage until a breakdown occurs. After the breakdown voltage occurs, the SS (Secondary Switch) which acts like a relay opened, so that the servo motor stops. Then, PS is turned to a neutral position and the value of voltage displayed on the multimeter is recorded. After the voltage is recorded then the PS is rotated to the first position, to turn the servo motor in the opposite direction or decrease the voltage so that the voltage becomes zero.

The experiment starts with dry cleaning the chamber and electrodes before placed to setup device. Then, pour 200 ml of oil sample into the chamber. Before switching on the panel control, take the grounding stick out from the device. After that, set the voltage up to there was spark occurred. The data as voltage value was obtained and recorded. Before switching off the panel, set the voltage down up to zero voltage. And the last step, set on the grounding stick to the initially position.

3. Results and Discussion
From the test results, at normal room temperature of 28 °C and at 50 °C, the values of the breakdown voltage were 46.73 kV and 48.38 kV respectively, the results obtained are the average of four trials. This is higher than breakdown voltage of virgin oil at the same temperature of 42.85 kV at 28 °C and 43.51 kV at 50 °C [14] as shown in Table 1 and Figure 4.

Table 1. The breakdown voltage of virgin and extra virgin olive oil with different temperature

| Type of olive oil     | Breakdown voltage (kV) |
|----------------------|------------------------|
|                      | 28 °C  | 50 °C  |
| Virgin olive oil     | 42.85  | 43.51  |
| Extra virgin olive oil| 46.73  | 48.38  |

The test is carried out at a temperature of 50 °C because the transformer operates at that temperature, when the temperature is 60 °C the cooling fan automatically starts working.
The value of the breakdown voltage at 50 °C is higher due to the water content, voids, and bubbles were reduced, compared to normal temperatures. Bubbles will reduce the electric strength of transformer oil, and even result in the breakdown of the insulation [18]. The breakdown voltage value at both normal and 50 °C temperatures has exceeded the standard (≥ 30 kV). For the application according to IEC 422 : 1989 standards (as seen in Table 3) can be used for transformers at a voltage of 70-170 kV.

**Table 2. IEC 422: 1989 standards about isolation oil and breakdown voltage**

| Parameter      | Limitation of isolation oil |
|----------------|----------------------------|
| Breakdown voltage | 50 kV for voltage power 170 kV |
|                | 40 kV for voltage power 70 – 170 kV |
|                | 30 kV for voltage power < 70 kV |

The breakdown voltage value of extra virgin olive oil is higher than that of olive oil because it is or influenced by saturated and unsaturated fatty acids.

**Table 3. Composition of virgin and extra virgin olive oil**

| Parameter       | Virgin Olive Oil (Le Riche) | Extra virgin Olive Oil (Borges) |
|-----------------|-----------------------------|---------------------------------|
| Saturated fat   | 18.77 %                     | 15 %                            |
| Mono-unsaturated fat | 62.16 %                  | 75 %                            |
| Poly-unsaturated fat  | 13.69 %                   | 10 %                            |

These fatty acid components play an important role in determining the physical and chemical properties of vegetable oils [19]. The saturated fat content greatly affects the failure rate or the breakdown voltage of oil. The more saturated fatty acid content, the less or shorter the carbon bonds, which is indicated by the easier the freezing process [4]. Oils with less saturated fat content have a higher breakdown voltage than those containing high levels of saturated fat [20]. In general, the dielectric properties improved as the fat content is reduced [21]. This result due to extra virgin olive oil came from first pressing that contains more unsaturated fat than virgin olive oil.

Since extra virgin olive oil proven has a good quality to be an insulating liquid in transformers, it very recommended to electricity company which is utilized power transformer. Utilization of vegetable oil as a liquid insulator in electrical machinery is a best alternative in replacement of petroleum based mineral oil [22]. Furthermore, extra virgin olive oil was also confirmed as vegetable oil, nontoxic, sustainable, and renewable. Extra virgin olive oil (Borges) could also directly used as insulating liquid in transformer owing to guaranteed good quality and already tested from company for commercialization. The availability of this oil was also easy to obtain since it was distributed to around the world. In order to confirm that extra virgin olive oil is feasible for insulating oil in transformer, it has to meets the standard requirement of IEC and Standar Perusahaan Listrik Negara (SPLN, in Indonesia [23], [24]) regarding appropriate breakdown voltage.

The dielectric strength of extra virgin oil can be calculated using formula:

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Eb = \frac{V_b}{a}
\] (1)
Where $E_b$ is dielectric strength, $V_b$ is breakdown voltage, and $d$ is distance between electrode. Dielectric strength of this oil is 22.35 kV/mm which is agreeing with standard minimum required of transformer oil of 14 kV/mm for ASTM 12 kV/mm for IEC.

4. Conclusion
From this experiment it can be concluded that the breakdown voltage will continuously increase with increasing the oil temperature due to decreasing the water content and bubbles. In addition, besides being consumed by humans, extra virgin olive oil can also be used in an electric power system. Furthermore, the more unsaturated fatty acid content, result in increasing the breakdown voltage. In contrast with saturated fatty acid content, the more it contains, result in decreasing the breakdown voltage. It means saturated fatty acid has a negative correlation with breakdown voltage. It was also found that extra virgin olive oil can be applied on transformer with voltage ranging from 70 – 170 kV.

Comparing to virgin oil, extra virgin olive oil has a higher breakdown voltage value, so it is better used as a transformer oil.

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