Preliminary Study on the Basic Characteristics of Isopropyl Esters Used As Insulating Liquid

A Rajab\textsuperscript{1}, J Ramadhani\textsuperscript{1}, R Kurniawan\textsuperscript{1}, K Qibran\textsuperscript{1}, M Latief\textsuperscript{1}, MI Hamid\textsuperscript{1}.

Electrical Engineering Dept., Universitas Andalas, Kampus Limau Manis, Padang, Indonesia.

Corresponding author: a.rajab@eng.unand.ac.id

Abstract. The paper presents the basic properties evaluation of isopropyl esters for an insulating liquid in oil-filled transformer. Two kinds of isopropyl esters, namely, isopropyl palmitate and isopropyl stearate, were synthesized from isopropyl alcohol and palmitate and stearate acids. The resulted isopropyl esters were then evaluated for their basic properties such as breakdown voltage, viscosity, density, acidity, and water-based on the ASTM D 6871 standard specification. The investigation results show that the viscosity and the Density of both isopropyl esters meet the standard's values well. The breakdown voltage of isopropyl stearate is higher than the standard specification, whereas that of isopropyl palmitate is less than the standard value. The water content of both liquids is still much higher than the value specified by the standard.

1. Introduction

One of the essential components of an oil-filled transformer is the insulating liquid. This liquid functioned as insulation in conjunction with paper or pressboard and as a coolant. Besides, the liquid can also be a tool for diagnosing the health condition of the transformer. Mineral oil has been used worldwide for more than a century and still the primary choice nowadays. The oil is widely implemented due to some advantages like high breakdown voltage, less vulnerable to oxidative degradation, low viscosity, and low pour point\cite{1,2}. However, the oil is extracted from petroleum oil, which is considered to be non-renewable. The oil is also known as environmentally unfriendly due to the low biodegradability level\cite{3}. Some oils like silicone oils, halogenated oils, and askarel have been implemented as insulating also the mineral oils. Most of them are relatively more expensive, less biodegradable, and non-renewable. These restrict their use to some specific applications which require a high fire point liquid\cite{4}.

The increase of concern on the environmental issue motivates many researchers to reconsider natural esters from vegetable oil as alternative mineral oil substitutes. The natural ester fulfills the criteria which the mineral oil does not. The oil is fully biodegradable. Thus the oil is friendly to the environment. The oil is derived from the seed; hence, the availability can be sustained. The oil is readily produced from edible oils, which means that the oil is non-toxic\cite{5}. Vegetable oils are also known to have a higher fire point in comparison with mineral oil, which means less risk to the fire. The oil also possesses a low thermal expansion coefficient. Together with the higher relative
permittivity, which is recognized later, the low thermal expansion allows a more compact design of vegetable oil-filled transformer than that of mineral oil[6–9]. Currently, the transformer contained vegetable oil-based insulating liquid has been in service. Most of these vegetable insulating liquids are in triglyceride or tri-ester structure, leading to a high viscosity insulating liquid. The high viscosity liquid results in a less efficient heat transfer, which is less favourable as a cooling medium [10]. There is an urgency in developing an insulating liquid from the vegetable oil or natural ester resource but possesses a low viscosity and low pour point. This paper presents the preliminary investigation results on monoester use, especially isopropyl palmitate and isopropyl stearate, as the low viscosity insulating oil. The properties like breakdown voltage, viscosity, relative Density, acidity, and water content are measured. The measurement results are compared with the ASTM D6871 standard's values, the specification standard for new natural ester used for transformer insulation.

2. Material and methods

2.1. Sample
The samples used in the investigation were isopropyl palmitate and isopropyl stearate. The samples were synthesized from palmitate and stearate acids and isopropyl alcohol, based on the equation (1)[11]. The idea was to prepare samples in the monoester form in order to develop low viscosity insulating liquid. In addition, the choice of saturated fatty acids, namely, palmitate and stearate acids, is intended to develop a relatively stable monoester to the oxidative degradation. It is well-known that saturated fatty acids have higher oxidation stability than unsaturated ones.

2.2. Procedure
According to the ASTM D 6871 standard, natural esters or liquids derived from natural esters intended to be used as insulating liquid must fulfill some requirements, as listed in table 1. The measurement procedures to evaluate the required properties are also specified by the standard [12]. For instance, the procedure to measure the water content of an insulating liquid should follow ASTM D 1533 standard, and the specified value of the water content should not more than 200 ppm.

Table 1. As-Received New natural ester Property Requirements for transformer use.

| Property                        | Limit   | Test Method |
|---------------------------------|---------|-------------|
| Fire Point, min, °C             | 300     | D 92        |
| Pour Point, max, °C             | -10     | D 97        |
| Relative Density, 15 °C/15 °C, max | 0.96   | D 1298      |
| Viscosity (40 °C), max, cSt     | 50      | D 445       |
| Breakdown voltage, min, kV      | 35      | D 1816      |
| Dissipation factor at 60 Hz, 25 °C, max, % | 0.2    | D 924       |
| Acid number, max, mg KOH/g      | 0.06    | 974         |
| Water content, max, mg/kg       | 200     | D 1533      |
3. Results and discussions

3.1. Electrical Property
The most critical parameter in characterizing a liquid intended for insulation purposes is the breakdown voltage. The measurement results of the breakdown voltage of two isopropyl esters samples, namely isopropyl palmitate and isopropyl stearate, are shown in Table 2. The mentioned results are the averages of six individual measurements, as suggested by the D1816 standard procedure. It is found that the breakdown voltage of isopropyl stearate complies well with the value specified by the ASTM D6871 standard, whereas that of isopropyl palmitate does not.

It is also seen that the breakdown voltage of the isopropyl palmitate is significantly higher than that of the isopropyl stearate. This result differs from that found in the literature[13]. The change in the number of carbon atoms present in monoester esters does not cause a significant difference in their breakdown voltage. A higher amount of impurities might remain in the isopropyl palmitate, causing a substantial drop in its breakdown voltage. If this is the case, then filtration is required to improve the oils' breakdown voltage performance.

| Electrical Properties | ASTM D6871 | Isopropyl- | Isopropyl- |
|-----------------------|------------|------------|------------|
| Breakdown voltage, kV | ≥ 35       | 24.5       | 38.7       |

3.2. Physical Properties
The next important parameter is the kinematic viscosity. It should be as low as possible to ensure the efficient cooling property of the liquid. For these reasons, the monoester form was chosen in this investigation instead of the original natural ester of triglyceride form. The measurement results of the kinematic viscosity of both tested samples are listed in Table 2. It is clear from the table that the kinematic viscosity of isopropyl palmitate and isopropyl stearate is in proper compliance with the ASTM D6871 specification standard.

Another physical property evaluated in this investigation is the relative Density. A liquid should have a relative density of equal or less than 0.96 g/cm$^3$ to be qualified as the insulation based on the ASTM D6871 specification standard. Table 3 shows that both tested samples fulfill the qualification as insulation from the relative density perspective. It can also be perceived from Table 3 that the relative Density of the isopropyl palmitate is slightly lower than that of isopropyl stearate. It might be due to the shorter hydrocarbon chain in isopropyl palmitate molecules compared to isopropyl stearate. The palmitate acid contains 16 Carbon atom numbers, whereas that of isopropyl stearate has 18 Carbon atoms. The shorter hydrocarbon chains owned by two adjacent straight molecules, the weaker Van Der Wall forces they have, which leads to the lower Density. The increase in the monoesters' viscosity with the increase of Carbon atom number owned by the oil molecules is also reported in [13].

| Physical Properties | ASTM D6871 | Isopropyl- | Isopropyl- |
|---------------------|------------|------------|------------|
| Kinematic viscosity, cSt | ≤ 50 | 5.5 | 2.4 |
| Relative density, g/cm$^3$ | ≤ 0.96 | 0.83 | 0.86 |
3.3. Chemical Properties
The evaluation of a liquid's water content intended to be used as insulation in electrical apparatus like a transformer is essential since the presence of water content in a relatively high amount can significantly drop the breakdown voltage of the liquid. Table 4 shows the measurement results on both isopropyl esters' water content and the corresponding value from the ASTM D 6871 specification standard. It is clear from the table 4 that both oils' water content does not meet with the value specified by the standard. The higher water content of both oils could be the main reason for the relatively low breakdown voltage of both oils. It should be noticed that the water is a by-product, which is resulted from the esterification process (See equation (1)). Hence, treatment needs to be conducted to reduce the water content if the oils would be applied in the transformer.

Table 4 also provides information on the acid number of the tested liquids. As we can see, the acid numbers of isopropyl palmitate and stearate are still higher than the value specified by the standard. This indicates that palmitate and stearate acids in the form of free fatty acids remain in both oils in a remarkable amount. The higher amount of free fatty acids could also be another factor causing the low breakdown voltage of tested oils. This phenomenon is reported in[14]. Like the water content parameter, the free fatty acids contents of both oils need further reduction before being used as insulation.

### Table 4. Chemical properties of tested samples and the comparison with the ASTM D6871 specification standard.

| Chemical Properties         | Values                      |
|-----------------------------|-----------------------------|
|                             | ASTM D6871 | Isopropyl- | Isopropyl- |
|                             |              | Palmitate | Stearate   |
| Water content, ppm          | ≤ 200        | 1900      | 3071.8     |
| Acidity number, mg KOH/Kg   | ≤ 0.06       | 0.86      | 1.04       |

4. Conclusion
The basic properties evaluation of isopropyl esters has been performed. It is found that the viscosity and the relative Density of both liquids meet well the specification of ASTM D 6871 standard, whereas their acidity and water content do not. The breakdown voltage of isopropyl stearate has fulfilled the standard's value, whereas that of isopropyl palmitate has not. Reduction of water content, acidity, and impurities are required to improve the breakdown voltage to bring these oils to their implementation as insulating liquids.

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