Basic properties evaluation of alkyl palmitate to be used as oil insulation

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Abstract. This paper discusses the evaluation of alkyl palmitate to be used as the oil insulation in an oil-filled transformer. Three kinds of alkyl palmitates, namely, Methyl-, Ethyl-, and Isopropyl-palmitates, were prepared through the esterification of methyl-, ethyl-, and isopropyl-alcohols, respectively, and palmitate acid. The resulted alkyl palmitates were then evaluated for their basic properties such as breakdown voltage, viscosity, density, acidity, and water content based on the ASTM D 6871 standard specification. The peroxide value of the alkyl palmitates was also examined to indicate their oxidation stability and compared the result with that of mineral oil. The results show that viscosity, water content, and density of all alkyl palmitates fulfill the values specified by the standard, whereas, the breakdown voltage and acidity do not. The peroxide value of all alkyl palmitates is still much higher than that of mineral oil.

1. Introduction

Oil insulation plays an important role in the operation of an oil-filled transformer. In addition to serving as insulation, the oil also works as a cooling medium and provides information on the health condition of the transformer [1,2]. Mineral oil has been using for more than a century and still the most widely used oil today [3–5]. It possesses some advantages like high oxidation stability, high dielectric strength, low kinematic viscosity, and low melting point [6]. However, the oil has a low fire point property makes it risky to be used in transformers located in an area like a hospital, populated area, etc. Besides, the oil is also recognized as a toxic substance, and poorly biodegradable. Therefore, the oil is unfriendly to the environment. Since the mineral oil derived from petroleum resources, it belongs to the non-renewable oil group [7]. Other oils like silicone oils, halogenated oils, and askarel have also been implemented as oil insulation due to their good characteristics. Their use is limited to some specific applications due to their high cost, low biodegradation level, and non-renewable nature. The existence of PCB constituent in Askarel oil leads to the banning of the oil in the USA and other countries having a strict environment regulation [8].

The need for renewable and environmentally friendly oil insulation in distribution and power transformers is emerging during the last three decades due to the rising concern on environmental consideration. The oil insulation derived from natural esters or vegetable oils is found to meet these criteria. The oils are non-toxic and fully biodegradable [9]. The natural ester or vegetable oils-based oil insulation are now commercially available as alternatives for mineral-based oils in transformer applications [10]. In addition to its traditional advantages like those mentioned earlier, natural esters have more benefits since the oils have a higher flash/fire points and low thermal expansion coefficient. The higher flash/fire points promote a low fire risk oil, whereas the lower thermal expansion
coefficient allows a more compact design of a natural ester oil-filled transformer compared to the mineral oil ones [11–14].

Nevertheless, the viscosity and pour point values of natural esters of triglyceride (tri-ester) type are generally much higher than those of mineral oils. These physical properties are essential and cannot be ignored. The viscosity is essential to serve as the cooling medium to dissipate heat generated in the transformer [15]. A lower viscosity oil allows a more efficient cooling capability [16]. The pour point is the lowest temperature at which oil could still flow. A low pour point is important, particularly in cold climates, to ensure an easy circulation of the oil to serve its function as a coolant. Even with addition pour point depressants, the pour point of a natural ester in its original form (tri-ester) cannot match that of a typical transformer mineral oil [6]. These obstacles motivate the development of low viscosity oil insulation from the natural ester, namely, monoester. This paper presents the basic properties evaluation of monoesters of alkyl palmitates. The properties like breakdown voltage, viscosity, relative density, acidity, water content, and oxidation stability are measured. The measurement results are compared with values specified by ASTM D6871 standard, the specification standard for as-received new natural ester used for transformer insulation.

2. Experiment

2.1. Sample Preparation

The sample used in the experiment was monoester of alkyl palmitate type. Three kinds of alkyl palmitate samples were prepared through the esterification of methyl-, ethyl-, and isopropyl-alcohols and palmitate acids based on the equation (1) [17].

\[
\text{RCOH} + \text{ROH} \rightarrow \text{R(OR') + H}_2\text{O}
\]  

(1)

The resulted samples are expected to have relatively high oxidation stability since the palmitate acid belongs to a saturated fatty acids group, whose oxidation stability is typically higher than those of the unsaturated ones. The use of monoester, instead of tri-ester, is intended to have an oil derived from natural oil resources having a lower viscosity.

2.2. Procedure

The standard procedure for testing an as-received new natural ester used for transformer insulation and the required value of each oil properties are listed in Table 1 [18]. For instance, the testing procedure for breakdown voltage follows the standard procedure ASTM D1816, and the required value for the breakdown voltage is not less than 35 kV.

| 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 Analysis

3.1 Breakdown Voltage
The breakdown voltage of all alkyl palmitate samples is shown in Figure 2. It seems that the difference in the number of carbon atom in a molecular structure does not correlate with the breakdown voltage of the alkyl palmitates. It should be noticed that methyl-, ethyl- and isopropyl-components have a different carbon atom number, which are 1, 2, and 3, respectively. It can also be seen from Figure 2 that the breakdown voltage of all alkyl palmitates is in the range of 31 to 32 kV, which are less than that specified by the ASTM D 6871 standard. These breakdown voltage values could be improved to the acceptable level. Our previous work on methyl ester shows that the breakdown voltage of the methyl ester can be enhanced by filtration and water reduction [19]. The improvement of the breakdown voltage would be conducted in the subsequent investigation.

![Breakdown Voltage](image)

**Figure 1.** The Breakdown voltage of alkyl palmitates and ASTM D 6871 standard specification.

3.2 Kinematic Viscosity
Monoester typically has a much lower viscosity compared to the tri-ester. The kinematic viscosity of all alkyl palmitate samples and the value specified by the ASTM D 6871 standard are shown in Figure 3. It is clear that the viscosity of all tested samples is much less than that specified by the standard. The kinematic viscosity of all tested oils is in the range of 0.8 – 2.0. These values are even lower than that of mineral oil, which means that the cooling efficiency of monoester is better than that of mineral.

3.3 Oxidation Stability
The oil insulation is usually used in the oil-filled transformer for a long time up to 40 years. One of the determinant factors in evaluating the long-term performance of oil insulation is the oxidation stability [7]. However, the oxidation stability property is not listed in the ASTM D 6871 standard, as shown in Table 1. Hence, the oxidation stability of mineral oil is used for comparison. In this study, the evaluation of the oxidation stability of all oil samples was performed by measure their peroxide value. The higher peroxide value means a higher amount of oil sample oxidized during the test. Figure 4 shows the peroxide value of all oil samples and mineral oil. It can be perceived from Figure 4 that the peroxide value of all alkyl palmitate samples is much higher than that of mineral oil, indicating that the alkyl palmitates are more vulnerable to the oxidation than the mineral oil.
3.4. Water Content

It is crucial to keep the water content of an insulation oil at a low level since the electrical properties of the insulation oil are susceptible to the water. The tolerable levels of relative water content are 30 % and 10 % for clean and unclean insulation oils, respectively [20]. For monoesters, these saturation levels correspond to the absolute water contents of approximately 300 ppm and 100 ppm, respectively [16].

The existence of water in the alkyl palmitate samples cannot be avoided. Water (H$_2$O) is another product resulted from the esterification process, in addition to alkyl palmitates, as indicated by equation (1). An attempt to reduce the water content of oil samples was conducted by filtering the oils using an anhydrate natrium sulfate (NaSO$_4$). This technique successfully reduces the water content of all tested samples to acceptable levels. Figure 5 shows the water content of all tested oils and the specification value from ASTM D 6871. It is clear that the water content of all alkyl palmitate samples is less than that specified by the standard.

**Figure 2.** The kinematic viscosity of alkyl palmitates and the ASTM D 6871 standard specification.

**Figure 3.** Peroxide value of alkyl palmitates and that of mineral oil.
As mentioned in section 2.1, the alkyl palmitates used in the experiment are resulted from the esterification reactions between alcohols and palmitate acid. During the esterification process, the acid palmitate does not completely react with the alcohols to form alkyl palmitates. Therefore, the existence of acid constituent in the resulted oils cannot be avoided, and it is reflected by the higher acid number owned by the oils, as depicted in Figure 6. The increase in the number of C atom from methyl- to iso-propyl palmitates does not seem to affect the change in the acid number of the tested oils. Figure 6 also shows that the acid number of all tested samples is much higher than the ASTM D 6871 standard specification. Treatment needs to be conducted to decrease the acid constituent of the oil since the presence of acid of a long carbon chain type with the acid number larger than 9 mg KOH/g can affect the breakdown voltage of the ester oil [21].
3.6. Relative Density

Figure 7 shows the measurement results on the relative density of methyl-, ethyl- and isopropyl palmitates and the specified value from the ASTM D 6871. According to the standard, the relative density for unused natural ester should not less than 0.96. Figure 7 shows that the relative density of all alkyl palmitates is well below that of the standard, indicating the suitability of the oils to be used as oil insulation from the relative density point of view.

![Figure 6. The density of alkyl palmitates and ASTM D 6871 Standard specification](image)

4. Conclusion

The basic properties of alkyl palmitates have been evaluated for possible use as oil insulation. Among six basic properties that have been studied, it is found that the viscosity, water content, and the relative density have complied with the specifications of the ASTM D 6871 standard, whereas the breakdown voltage and acidity have not fulfilled the standard. The oxidation stability of the oils is also less than that of the mineral oil. The breakdown voltage almost reaches the standard values, and it could be further enhanced. In addition, the acidity and oxidation stability will be also improved in the coning studied.

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