Study on Static Electrification of Palm FattyAcid Ester (PFAE) Oil Using Mini Static Tester

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***Abstract*—Palm fatty acid ester (PFAE) oil is an alternative insulating liquid of power transformer that has good biodegradable properties. As a part of insulating system of power transformer, PFAE should also has a low risk in term of static electrification that may degrade electrical strength of solid insulation due to charge accumulation at its surface during oil circulating. Charge potential value could describe the possibility of insulating oil in involving on charge accumulation at the surface of solid insulation. This can be calculated from charge density through electrostatic charge tendency (ECT) and volume resistivity. This study using mini-static-tester to measure ECT since it is easy to reproduce the specimen and suitable for standardization. Since PFAE has higher polarity than mineral oil, PFAE has larger charges than mineral oil. Even though static charges are estimated to generate on the pressboard surface easily, generated charges are estimated to escape from pressboard surface because of its lower resistivity. Variation of charge density and volume resistivity of several types (i.e. PFAE and mineral) and conditions (i.e. with-additives, non-additives, unused, and aged) of oil will influence to its charge potential**.

Keywords—power transformer; palm fatty acid ester (PFAE); static electrification; electrostatic charge tendency (ECT); volume resistivity; mini static tester

I. Introduction

In 1970's and 1980's several transformers failure due to static electrification were reported around the world. In 1970's several large capacity of power transformers failed in Japan that lead to studies that been held by Japanese manufacturers and research organization. In early 1980's, United States also reported 43 incidents that may related to static electrification [1]. At that time, Electricity Company in Texas, Dallas, TU Electric which now known as TXU Energy, experienced 2 large transformers due to flashover between winding and top main tank which has distance about 1 meter [2].

Now day, where environmental issues become a concern, PFAE oil which is a chemically modified natural ester of monoester type become alternative insulating oil for power transformer since it has good biodegradable properties and cooling performance compared to mineral oil. In general, natural esters offer the advantage of high fire point as well as good biodegradability, but all types of natural ester suffer from not being as oxidation stable as other types of insulating liquids [5]. On the other hand, PFAE has an excellent oxidative stability since it has no C-C double bond.

To determine the risk of charge accumulation at the surface of pressboards during circulating which may lead to partial discharge or more severe failure, study of charging potential between PFAE oil and mineral oil were conducted.

II. Experimental Descriptions

A. Oil samples

Four types of oil were chosen for this study. The first oil is palm fatty acid ester (PFAE) oil which has no additives contain, produced by Lion Corp, Japan. This oil was used as raw material to produce second oil type in this study.

TABLE I. Comparison of PFAE and Mineral Oil Properties

Properties	Unit	PFAE Oil	Mineral Oil
Density (15° C)	g/cm^3	0.86	0.873
Pour point	°C	-32.5	-35.0
Flash point (COC)	°C	186	146
Kinetic viscosity (40° C)	mm^2/s	5.06	8.43
Total acid value	mgKOH/g	0.005	0.00
Water content	ppm	10	-
Breakdown voltage	kV	81	73.0
Relative permittivity (80° C)	-	2.95	-
Tanδ (80° C)	%	0.8	-
Volume resistivity (80° C)	Ω.cm	$1.9x10^{13}$	-

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The second type of oil is palm fatty acid estrer (PFAE) oil which has additives contain and also produced by Lion Corp, Japan. The second oil has commercial name as Pastell Neo. The third oil is new mineral oil which confirms JIS C2320. The fourth oil is aged oil that taken from distribution transformer in Japan.

B. Preconditioning

To eliminate the possibility of moisture involvement during testing, all oil samples should be preconditioned through degassing process. Oil were stirred and vacuumed inside the oil chamber for 1.5 hours. In the end, to balance the pressure after vacuuming process, nitrogen gases were added.

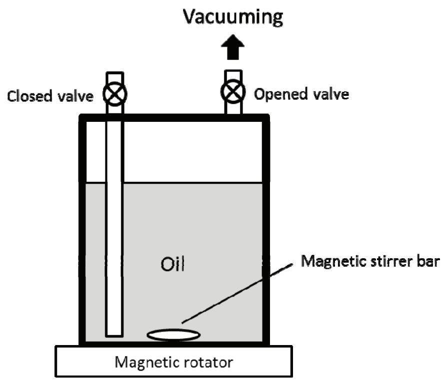

Fig.1. Preconditioning system

C. Electrostatic charge tendency

To measure electrostatic charge tendency (ECT), mini static tester was used to measure the ECT at the surface of filter paper that passed by oil sample in certain flow rate. Mini static tester that been used in this study (fig.2.) is an adaptation from Exxon mini static tester (Young, Exxon Research) that firstly used at 1972 [3]. This method also standardized by Electric Technology Research Association (ETRA) Japan [4] and recommended by Transformer Working Group of Cigre [1].

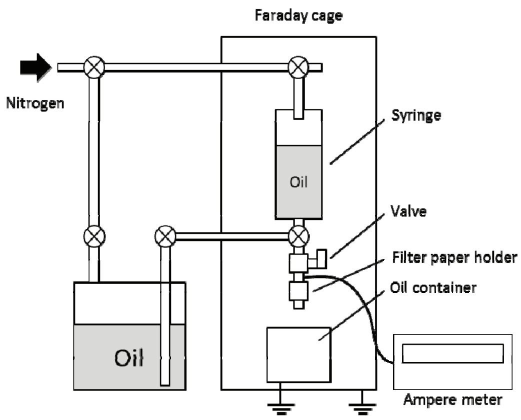

Fig.2. Mini static tester

Mini static tester consists of:

- 50 ml syringe
- Charge separator (a filter paper)
- Measuring device (Ampere meter, recorder or computer)

Basically, when oil sample was forced through filter paper, charge separation that contained in oil sample occurs. Charges that accumulated at the surface of filter paper usually negatives and will be measured by ampere meter. This mechanism simulates the charge separation that happens inside power transformer which actually separate due to friction between oil and pressboard duct. Both charge separation are principally the same since both are using cellulose material.

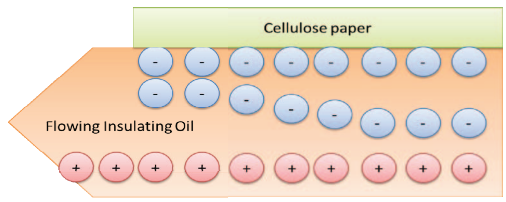

Fig.3. Charge separation at pressboard duct of power transformer-due to friction

ECT is a unit that used to describe charge tendency of some insulating oil. ECT described as amount of charges that generated per unit volume of oil during flowing process through filter paper.

$$ECT = q / v = \int i dt / v \qquad (1)$$

Where, q is charge, v is oil volume, i is charging current and t is flow time. If i is taken to be average current, then the formula could describe as

$$ECT = it / v = \text{Charging current} / \text{flow rate} \qquad (2)$$

This means for a given sample, the ECT is independent of the flow rate. This was verified for flow rate ranging from 1 ml/second to 2 ml/second. The recommended flow rate is 1.67 ml/second [3]. The common unit for ECT of insulating oil is pC/ml or uC/m^3.

D. Volume resistivity

In terms of static electrification, volume resistivity of insulating oil will influence to resistivity of pressboard that immersed by the oil. The value of oil-immersed-pressboard resistivity will influence to its capability to absorb or neutralize the charge that accumulated at its surface.

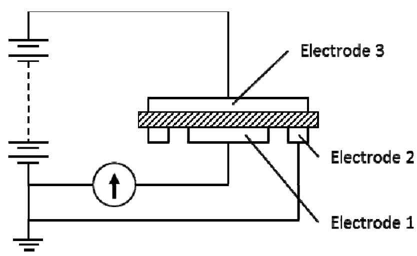

Fig.4. Basic connection for guarded electrodes

Higher resistivity means that accumulated charges are hard to neutralized or move through pressboard. This condition is harmful for pressboard since it has more potential to be hold. When resistivity is lower, charges are easy to neutralized or move through the pressboard and the accumulated charges at its surface will remain low and harmless.

Each electrode has a constant value (*K*) which calculated from the effective area of the guarded electrodes in square centimeters divided by the average thickness of specimens in centimeters. Volume resistivity itself calculated as

$$R_x = V / I_0 \quad (3)$$

$$\rho = K.\ R_x \quad (4)$$

Where,

- ρ is volume resistivity (Ω.cm)
- R_x is resistance value of oil (Ω)
- V is voltage applied (Volt)
- I_0 is current value at 0 minute (Ampere)
- K is constant (cm)

III. RESULT

A. Electrostatic charge tendency

Each filter paper designed to be flowed for 3 times. Only second and third results were taken. The final ECT value is average from 4 filter paper result which consists of 8 readings. New mineral oil has the lowest ECT and followed by the aged mineral oil. PFAE oil non-additives have 50 times higher of ECT compared to new mineral oil, and PFAE with additives has 120 times higher.

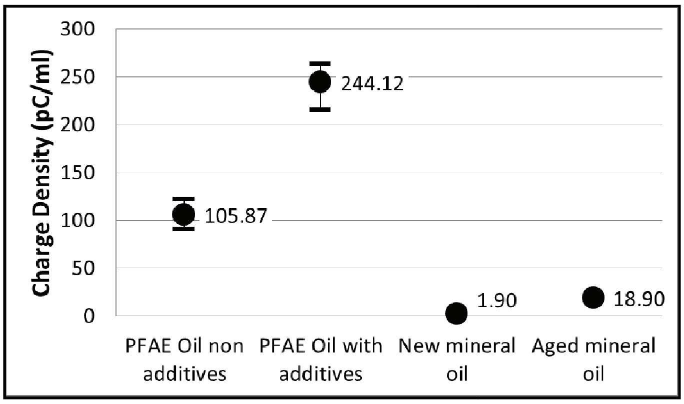

Fig.5. ECT on several sample oil

The resistivity of PFAE is lower than mineral oil. The ECT has inverse proportionality to resistivity. So, ECT of PFAE is higher than mineral oil. The mechanism of increasing ECT in mineral oil due to sulfur compound is shown in Fig. 6.

In the case of using additive, ECT in oil is higher than that of non-additive because with additive oil has lower resistivity. The ECT has inverse proportionality to resistivity.

In PFAE there are no sulfur compounds, and the mechanism of ECT should be clear through former studies.

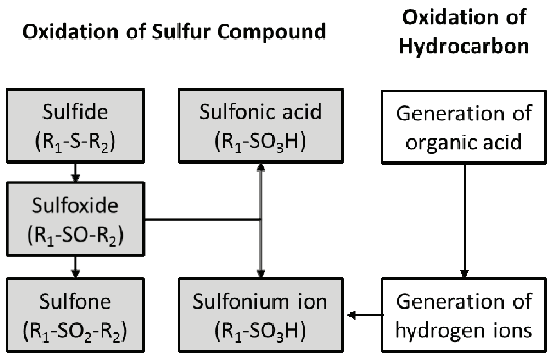

Fig.6. Mechanism of increasing ECT in mineral oil due to sulfur compound [5]

B. Volume resistivity

The volume resistivity on each type of oil is shown in Fig.7. The resistivities of mineral oils have higher resistivity than PFAE because PFAE has higher polarity than mineral oils.

And PFAE with additive has lower resistivity than PFAE without additive. Additive is affected resistivity.

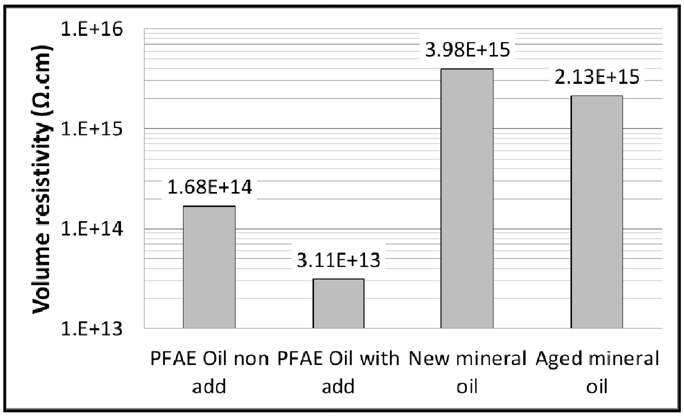

Fig.7. Volume resistivity on each type of oil

If we put all the measurement of ECT and volume resistivity result in the chart as shown in fig.8, we can see that total charges that contained in several types of oil will influence the ECT and volume resistivity value.

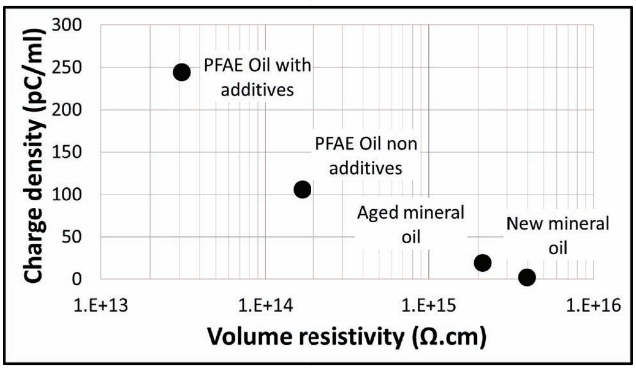

Fig.8. Relationship between charge tendency and volume resistivity

Higher number of total charge will tend to decrease volume resistivity and increase ECT. While lower number of total charge will tend to increase volume resistivity and decrease ECT.

C. Charging potential

Charging accumulation on the pressboard surface depends on both ECT and resistivity. In the case of higher ECT, the generating static charge on the cellulose surface is higher. In the case of higher resistivity, the generated charges on the cellulose surface are hard to escape. So, the static charges are accumulated on the cellulose surface with high ECT and high resistivity easily.

Charging potential on each type of oil is shown in Fig.9. PFAEs have not so high charging potential compare as new mineral oil.

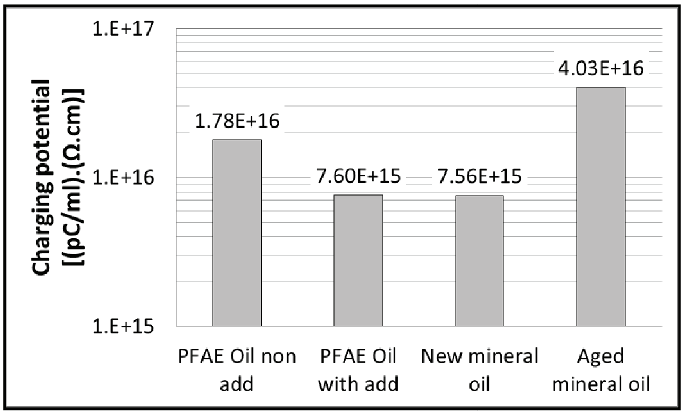

Fig.9. Charging potential on each type of oil

As fig.9 shown, new mineral oil and PFAE with additives oil has the same risk level of charge accumulation compared to PFAE non additives oil and aged mineral oil. Even though new mineral oil and PFAE with additives oil has an opposite level of ECT and volume resistivity, but the charging potential remains low. PFAE non additives oil has a higher charging potential and aged mineral oil has the largest charging potential.

IV. Conclusions

The result of ECT and volume resistivity measurement on several types of oil found that each oil has different level of ECT due to differences of total charge that contained by the oils. Though PFAEs have higher ECT than mineral oil, charging potential of PFAEs are almost same as new mineral oil

Charging potential of new mineral oil and PFAE oil are lower than aged mineral oil.

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