Comparison of Low Thermal Fault Gases of Various Fatty Acid Mono Esters

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***Abstract*—Proven to be a good substitute for mineral oil as insulation in distribution transformer, natural ester oils have been implemented in higher voltage of power transformer since 2002. Gases generated by such oils need to be examined to diagnose the presence of faults in natural ester immersed transformer in service, based on dissolved gas analysis (DGA) method. In this paper, the gas generations of chemically modified natural esters which are palm fatty acid monoesters under low temperature overheating ranging from 200 to 300 °C were analyzed. Localized thermal faults were conducted to simulate the real condition in transformer operation. Experiment on several kinds of fatty acid monoesters with similar and different molecular structure as well as mineral oil were also performed for comparison. Types of gases, concentrations and their trend against temperature variation were investigated. The differences of generated gases between the fatty acid monoesters having C-C double bond in their molecular structure and those without C-C double bond are discussed. Comparison of the gas generation trend between tested oils and commercially available natural ester insulation oil reported in the previous literature, as well as mineral oil are also elaborated. The possibility of generating gas ratio method to expect the overheating temperature is also evaluated.**

***Keywords*—dissolved gas analysis; gas ratio; insulating oil; low thermal fault; chemically modified natural ester; transformer.**

I. INTRODUCTION

Gaining a successful application in middle voltage of distribution transformer, natural ester oils were then implemented in higher voltage of power transformers since 2002 [1]. As the power transformers play a vital role in transmission and distribution and are one of the most expensive units in electrical power system, then the need for monitoring and diagnosis of natural ester oils filled transformer becomes inevitable. Dissolved gas analysis (DGA) is one of the most common method which was used to diagnose the presence of thermal or electrical faults in mineral oil immersed transformer. Gases generated by natural ester oils need to be examined to anticipate the use of DGA method to diagnose the presence of faults in natural ester immersed transformer in service.

Some investigation results on gases generated by natural esters have been reported [2-6]. Reference [2] stated that ethane is more likely to be produced in higher amount by the natural ester compared to that of the mineral oil under thermal fault. The similar observations are reported in [3]. Ethane accompanied by hydrogen, are also found in higher amount in the natural ester immersed transformer in service [4, 5]. The ethane was then suggested to be the key gas of natural ester for thermal fault, as reported in [6].

However, most of the previous results were obtained from the investigation on natural esters of triglyceride form. The results on gas generation of chemically modified natural ester which is monoester type were still rare. In our previous work [7, 8], we have studied the gases generated by palm fatty acid esters (PFAE) in the temperatures ranging from 200 to 300 °C and compared the results with that of mineral oil. The PFAE is a chemically modified natural ester of monoester type synthesized from palm oil which is expected to become an alternative to mineral oil due to its high fluidity and strong dielectric characteristics [9].

This paper presents gas generation under low thermal fault of PFAE and other fatty acid monoesters as well as mineral oil. The differences of generated gases between fatty acid mono esters having C-C double bond in their molecular structure and those without C-C double bond are discussed. Comparison of the gas generation trend between tested oils and commercially available natural ester insulation oil reported in the previous literature, as well as mineral oil are also elaborated. The possibility of generating gas ratio method to expect the overheating temperature is also evaluated.

II. EXPERIMENT

A. Samples

Samples used in the experiment were fatty acids monoester synthesized from palm oil (PFAE, M12, and 2H-08), soybean methyl ester, and rice bran methyl ester oils. PFAE is a chemically modified natural ester fluids which was developed to be used for oil immersed transformer, M12 and 2H-08 consist of methyl laurate and caprylic acid ester, respectively. All monoester oils were manufactured and supplied by Lion Co., Ltd. Japan. Mineral oil (MO) was also used for comparison. Some properties of the oils are listed in table I. Iodine value is often used to determine the amount of unsaturation in fatty acids and their derivatives. The higher the iodine value, the more C-C double bonds are present in the fats and their derivatives. Accordingly, soybean and rice bran methyl ester oils contain significant number of C-C double bond, whereas PFAE, M12, and 2H-08 do not.

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TABLE I. SOME PROPERTIES OF OILS

Oil Type	*Iodine Value (g/100g)*	*Kinematic Viscosity (mm²/s, 40 °C)*	*Breakdown Voltage (kV/2.5 mm)*
PFAE	0	5.1	81
2H-08	0	2.8	83
M12	0	2.4	84
Soybean	120	4.3	84
Rice bran	107	4.3	89
Mineral oil	-	8.7	75

B. Experimental Arrangement and Procedure

Fig. 1 shows photographic and schematic views of the equipment used in the experiment. They consist of DC power supply, temperature and time controller, oil chamber and graph recorder. The DC power supply was used to provide DC current for ceramic heater immersed in oil sample. The controller worked to maintain the heater temperature at a given value and to stop the heating process, when the oil's temperature reaches at 84 °C, or when the setting duration of heating time comes. The graph recorder was used to continuously monitor and record heater and oil's temperatures. This experiment was carried out under constant room temperature at 21 °C.

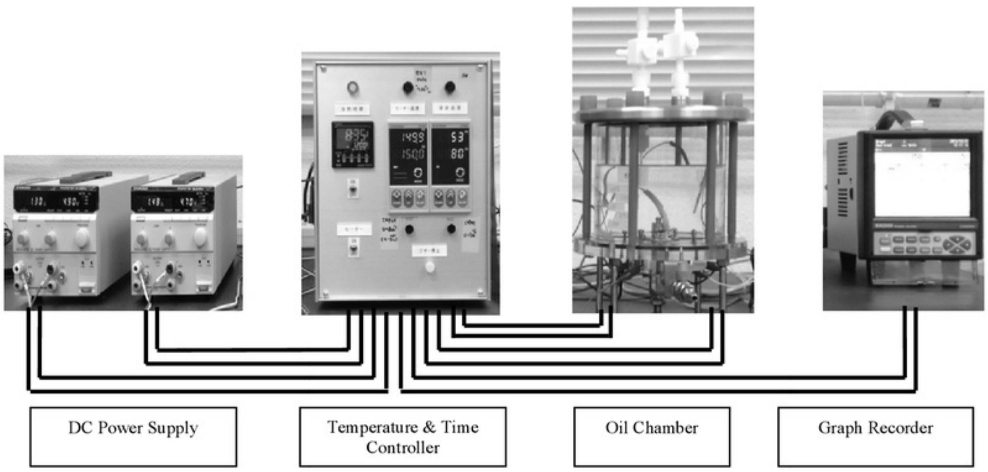

Fig. 1. Experimental Arrangement

The chamber was firstly vacuumed to evacuate the air before the oil sample was inserted into the chamber. The oil sample was filtered while being inserted into the chamber, and the filling process was stopped when the volume of oil reach 1000 ml. Then, degassing the oil and argon gas was introduced into the chamber to occupy the space above the oil and bring the oil system to the ambient pressure. Based on these operations, contamination by surrounding air can be minimized.

Low thermal fault was performed to simulate local heating which is usually the case in transformer. The detail explanation of the procedure can be found in [10].

III. RESULTS AND DISDUSSION

A. Distribution of Generated Gases

The gases of concern for the experiment were combustible gases, i.e. hydrogen, methane, ethane, ethylene, acetylene, and carbon monoxide, and the typical graph of distribution of combustible gases generated by fatty acid monoesters and mineral oil, taken at the temperature of 250 °C, is shown in Fig. 2. Under low thermal fault within the temperature of 200 to 300 °C, ethylene and acetylene were not found in all tested oils. Carbon monoxide was found to be generated in the highest amount by all tested oils, and then followed by methane. An exception was found in soybean and rice bran methyl ester oils, where the second highest amount of generated gas was ethane. A small, but distinguishable, amount of hydrogen was also found in soybean and rice bran methyl ester oils. The generation rate of hydrogen by oils can be seen in more detail in Fig. 3.

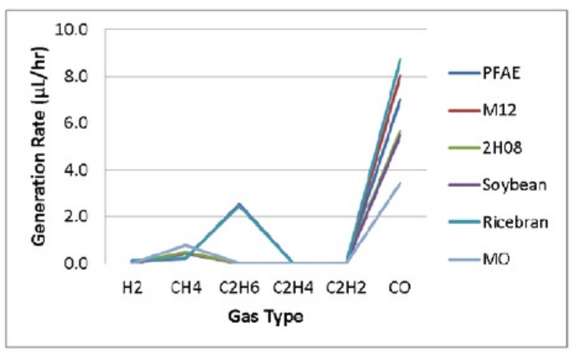

Fig. 2. Generation rate of combustible gases of fatty acid monoester and mineral oils under low thermal fault.

B. Comparison of Gases Generation between Fatty Acid Monoesters and Mineral Oil

Carbon monoxide was the most dominant gas generated by all tested oils (Fig. 2). The presence of carbon monoxide in oils can be due to the oxidation of oil molecule, and/or ingression by surrounding air [11]. And in case of ester type oils, such as natural ester, synthetic ester and fatty acid monoester have a possibility of carbon monoxide gas generation because of -COO- bond cleavage. That is why carbon monoxide is generated in higher amount in fatty acid monoester oils than that of mineral oil (Fig. 4). Methane, on the other side, seems to be produced by mineral oil in higher amount than that of fatty acid monoesters (Fig. 5). These results correspond to the previous report. [12].

The thermal energy inserted into the oil firstly breaks the weakest bond of oil molecules, namely -COO- bond in fatty acid monoester oils. The existence of oxygen atom, which have higher electronegativity than carbon atom, cause the depletion of electrons around -COO- bond and get the bond surrounding it weakened, and hence, the -COO- bond are easier to be cut than C-C bond in oil molecule. On the other hand, mineral oil composed of hydrocarbon such as aliphatic, alicyclic and aromatic hydrocarbon. And the most vulnerable point where the hydrocarbon would be cut is at the end of carbon chain in the oil molecule. Then, CH_4 is produced by combining with H_2 after cleavage at the end of carbon chain.

C. The Effect of C-C Double Bond

In our previous works regarding the gas generation of low thermal fault below 200 °C, we found that chemically modified natural ester oil of fatty acid monoester containing C-C double bond in their molecular structures tended to produce noticeable amount of ethane, whereas the oils without C-C double bond did not, or in some cases produced no significant amount of ethane [7]. PFAE, as well as mineral oil did not produce ethane although the oils were heated up to 300 °C [8]. Since the PFAE is fatty acid monoester oil without C-C double bond in its structure, and the mineral oil used was of naphthenic type, then the results partly confirmed the claim made in earlier work.

Additional data was obtained from our latest experimental works provide more detail information of gas generation of oils under low thermal faults in the temperature is set to the range from 200 to 300 °C. Soybean and rice bran methyl ester oils, both are known to have C-C double bond in their structures, generate ethane in remarkable amount at all heating temperature levels, as can be seen in Fig. 6. PFAE, M12, and 2H-08, which do not have C-C double bond in their structures, and mineral oil, do not generate ethane. These results seem to be in line with the claim made in our previous report that ethane generation phenomenon under low thermal faults was about the difference between oils with and without C-C double bond in their molecular structures, and that has nothing to do with the difference in oil type, ester oil or mineral oil [8].

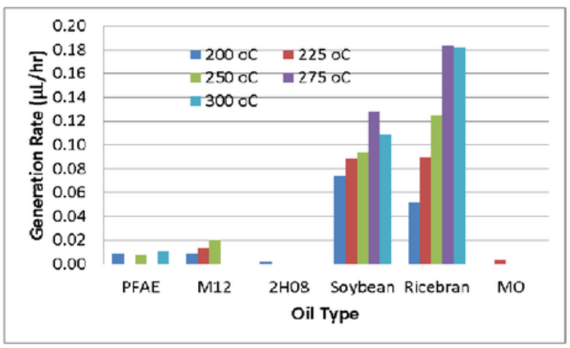

Fig. 3. Generation rate of hydrogen of fatty acid monoesters and mineral oil under low thermal fault.

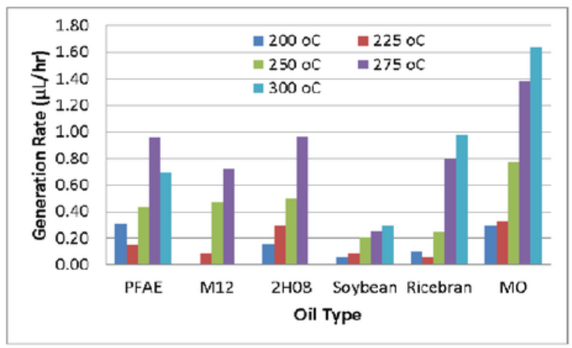

Fig. 5. Generation rate of methane of fatty acid monoesters and mineral oil under low thermal fault.

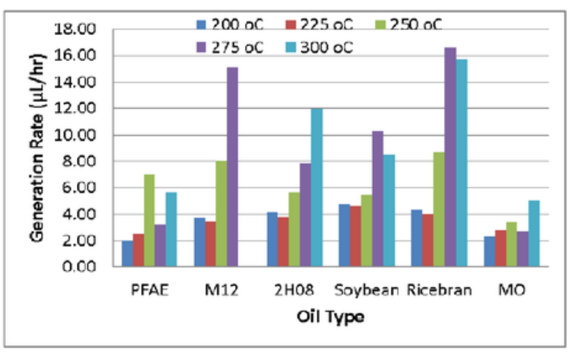

Fig. 4. Generation rate of carbon monoxide of fatty acid monoesters and mineral oil under low thermal fault.

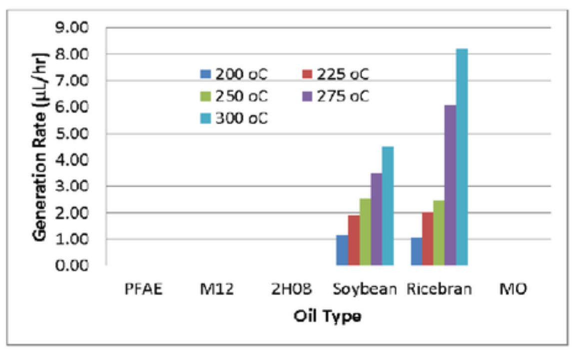

Fig. 6. Generation rate of ethane of fatty acid monoesters and mineral oil under low thermal fault.

The ethane generation from oils under thermal fault, according to the previous reports [6, 11], is strongly related to the oxidation. They proved this by their experimental evidence where the change in ethane generation, as well as others stray gassing phenomena, coincide with the change in the amount of oxygen in oil in reverse way which means oxygen was consumed during the process [3]. They suggested that the ethane is developed according to the peroxidation of lipids which is commonly taken place in omega-3 unsaturated fatty acids [11]. The process is not uniquely owned by ester oils, because some mineral oils was also reported generating significant amount of ethane, either from simulated low thermal fault in laboratory experiment [3], or from transformer in service [13]. However, ethane generation is more pronounced in natural esters than in mineral oil, the observation results reveal that ethane was used as the key gas for thermal fault of natural esters [6, 11]. This slightly differs from our results where no ethane generation found in chemically modified natural esters such as PFAE, M12 and 2H-08 which do not have C-C double bond in their structures. It should be noticed that the natural esters that commonly used in the previous studies were FR3 or Biotemp which are known to be in triglyceride form. In triglyceride structure, fatty acid chains occupying three branches of triglyceride are a random combination of saturated and unsaturated hydrocarbon.

D. Fault Temperature Estimation from CO/CH_4 Ratio

Under low thermal faults, where the amount of generated gases are very low, gas ratio methods such as IEC 60599 ratio, Rogers ratio, and Doernenberg ratio cannot be applied. Instead, alternative gas ratio is sometimes used to expect the heating temperatures. For instance, the ratio of C_2H_6/CH_4 was used in the previous report [14] to estimate the overheating temperature within the range of 100 to 200 °C. Our experimental results (Fig. 7), show the decrease in the ratio of CO/CH_4 as the heating temperature increased. These results indicated that the ratio of CO/CH_4 could possibly be used to estimate the temperature of low thermal faults. For instance, when the ratio of CO/CH_4 of Soybean methyl ester and Rice bran methyl ester is over 100, overheating temperature is estimated below 200 °C. When the ratio is between 10 and 100, overheating temperature is estimated from 200 to 300 °C. In the case of 2H-08, when the ratio of CO/CH_4 is less than 10, the overheating temperature is estimated over 250 °C. However, further investigations are required in order to obtain the more comprehensive understanding on how the ratio of CO/CH_4 varies to the change in overheating temperature.

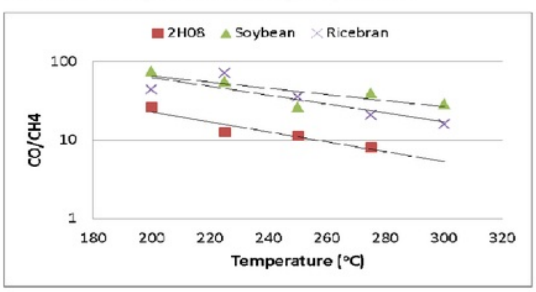

Fig. 7. The variation of CO/CH_4 ratio of fatty acid monoesters against temperature change.

IV. CONCLUSIONS

1. Fatty acid monoesters tend to generate higher amount of carbon monoxide, but less amount of methane than those of mineral oil.
2. Fatty acid monoesters having C-C double bond tend to generate noticeable amount of ethane.
3. It is indicative that ethane could be used as key gas for low thermal faults in oils having C-C double bond in their structure.
4. It seems that the ratio of CO/CH_4 could possibly be used to estimate the temperature of low thermal faults.

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REFERENCES

[1] WG A2.35, "Experiences in Service with New Insulating Liquids", CIGRE, 2010.

[2] Zhongdong Wang, Xioao Yi, Jinping Huang, and John V. Hinshaw, "Fault Gas Generation in Natural fatty acid methyl ester Fluid under Localized Thermal Faults", IEEE Electrical Insulation Magazine Vol. 28, No.6, Nov./Dec. 2012.

[3] I. Atanasova-Höhlein, "Stray gassing of Insulating Liquids – Manifestation and Influence on Diagnostics" IEEE International Conference on Liquid Dielectrics, Slovenia, June 30 – July 3, 2014.

[4] M. Duval and R. Baldyga, "Stray Gassing of FR3 Oils in Transformers in Service", The 76th Annual Intl. Doble Client Conference", 2009.

[5] Daniel Martin, Nick Lelekakis, Wenyu Guo, and Yuriy Udarenko, "Further Studies of a Vegetable Oil Filled Power Transformer, IEEE Electrical Insulation Magazine, Vol. 27, No. 5, Sep./Oct., 2011.

[6] I. Atanasova Hohlein, C. Rehorek and T. Hammer : "Gassing and Oxidation Behaviour of Insulating Fluids under Thermal Stress", CIGRE the 6th Southern Africa Regional Conference, 2009.

[7] Abdul Rajab, et. al., : "Study on Low Temperature Overheating and Thermal Properties of Natural Ester Oils", The 34th Technical Meeting on Insulating Oil Section, JPI, June, 2014.

[8] Abdul Rajab et. al. : "Gas Generation of Vegetable Oils under Various Levels of Low Temperature Overheating", The Technical Meeting on Static Apparatus, IEE Japan, December, 2014.

[9] T. Kano, et. al., "Analyses of Electro-Chemical Characteristics of Palm Fatty Acid Esters as Insulating Oil." 16th ICDL, S4-01, 2008.

[10] M. Tsuchie, M. Tien and M. Hikita, "Fundamental Study for Advancement of Dissolved Gas Analysis of Oil-immersed Transformer by LTOH" The 8th International Workshop & Japan-Korean Symposium on Electrical Discharge and High Voltage Engineering, Nov. 2012

[11] I. Atanasova Hohlein and Rainer Frotscher, "Carbon Oxides in the Interpretation of Dissolved Gas Analysis in Transformers and Tap Changers", IEEE Electrical Insulation Magazine, Vol. 26, No. 6, November/December, 2010.

[12] Pierre, M. Marugan, and A. Beroual, "DGA Comparison Between ester and Mineral Oils" IEEE Transaction on Dielectrics and Electrical Insulation, Vol. 19, No. 5, October, 2012.

[13] I. Atanasova Hohlein, "Unusual Cases of Gassing in Transformers in Service", IEEE Electrical Insulation Magazine, Vol. 22, No. 1, January/February, 2006.

[14] M. Tsuchie, Masahiro Kozako, Ei Sasaki, and Masayuki Hikita, "Modelling of Early Stage Partial Discharge and Overheating Degradation of Paper-oil Insulation" IEEE Transaction on Dielectrics and Electrical Insulation, Vol. 21, No. 3, June, 2014.

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