Interpretation of Dissolved Gas Analysis (DGA) for Palm Fatty Acid Ester (PFAE) – Immersed Transformers

Kiyoshi Wakimoto,
Kazuki Shigemori

Keywords Transformer, Dissolved Gas Analysis (DGA), Palm Fatty Acid Ester (PFAE)

Abstract

Maintenance management of oil-immersed transformers is carried out by Dissolved Gas Analysis (DGA) of Transformer Oil. There are criteria for mineral oil such as the Electric Technology Research, but in the future, criteria for Palm Fatty Acid Ester (PFAE) will also be required. PFAE has a short history, however, and like mineral oil, it is difficult to create diagnostic criteria based on a large amount of DGA data.

As such, we tried to examine an approach to compensate for the existing mineral oil diagnosis criteria by utilizing the PFAE-related data obtained from experiments of overheating and discharges. According to the Warning Levels Ⅰ and Ⅱ by the Electric Technology Research, diagnostic criteria of abnormality levels, diagnostic diagrams, gas pattern diagnosis table, and the Duval Triangle, we determined our PFAE diagnostic criteria based on the ratio of mineral oils to the PFAE amount of gas generation. There is room, however, for consideration of consistency with the actual device, the handling of CO generation, and the replacement of the gas with the highest concentration. Considering these current results as the basic values for the diagnostic criteria, we will collect actual data and improve the diagnostic criteria in the future.

1 Preface

In recent years, environmental-friendly insulating oil has been developed with global environmental conservation in mind, and as such, we have been manufacturing transformers using Palm Fatty Acid Ester (PFAE) since 2009. As a general method for transformer maintenance management, it is performed by dissolved gas analysis (DGA) of transformer oil. For mineral oil, criteria such as the Electric Technology Research and IEC[1] have been established, but in the future such diagnostic criteria for PFAE will be also required. Diagnostic criteria for mineral oil are created based on DGA data of many normal operation equipment and defective equipment. However, PFAE has a short history, and it is difficult to take the same method. We aim to diagnose PFAE at the same level as mineral oil by using data from overheating and discharge experiments that simulate transformers, but if the reference values are created using only experimental data, the consistency with the actual equipment is unknown. This paper introduces a method to compensate the existing diagnostic criteria of mineral oil by IEC and the Electric Technology Research with experimental data for PFAE[2].

2 Overheating and Discharge Tests for Mineral Oils and PFAE

For the overheating test, data are available in regard to gas generation in mineral oils and PFAE at the respective temperatures as described in “Study on Decomposition Gases of Various Ester Insulating Oils by Local Heating”[3]. For the discharge test, data are available in regard to gas generation caused by partial discharges in mineral oils and PFAE as disclosed by “Partial Discharge Characteristics of Palm Fatty Acid Ester for Dissolved Gas Analysis”[4].

3 Examination of DGA Diagnostic Criteria

3.1 Warning Levels I and II and Abnormality Level Proposed by the Electric Technology Research

Causes of gas generation include overheating/discharging and aging deterioration. Warning Ⅰ Level is a state where it deviates from the normal state and cannot be judged as abnormal, but some internal change has occurred[5]. The main cause of the internal change was the overheating of the insulating oil. We compared the amount of gas generated when the mineral oil and PFAE were overheated at 500℃. As a result, the amount of gas generated in PFAE is about 0.5 times that of mineral oil, about 1.6 times that of CH_4, about 4.2 times that of C_2H_6, about 5 times that of C_2H_4, and about 2.4 times that of TCG, which is the total of combustible gas. **Table 1** shows the PFAE Warning Ⅰ diagnostic criteria values. Since the amount of CO generated by the decomposition of the ester group is large, it was excluded from the Warning Level Ⅰ this time. C_2H_2 was not detected below 700℃, but if detected, it may be abnormal. It was, therefore, set as low as possible like mineral oil, and the lower limit of quantification was 0.5 ppm[5]. The same method was used for Warning Ⅱ and Abnormality Level.

Table 1 Electric Technology Research: Warning Levels Ⅰ & Ⅱ and Abnormality Level

Based on the generated gas volume ratio of mineral oils to PFAE obtained from experiments, the diagnostic criteria of Dissolved Gas Analysis (DGA) was established.

Warning Ⅰ level

	TCG	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO
Mineral oil	500	400	100	150	10	0.5	300
PFAE	1200	200	160	630	50	0.5	

Warning Ⅱ level

Mineral oil	①C_2H_2≧ 0.5 ppm	②C_2H_4≧10 ppm and TCG≧500 ppm
PFAE	①C_2H_2≧ 0.5 ppm	②C_2H_4≧50 ppm and TCG≧1200 ppm

Note: Regarded as the warning Ⅱ level if either ① or ② is applicable.

Abnormality level

Mineral oil	①C_2H_2≧ 5 ppm	②C_2H_4≧100 ppm and TCG≧700 ppm
PFAE	①C_2H_2≧ 5 ppm	②C_2H_4≧500 ppm and TCG≧1700 ppm
		③C_2H_4≧100 ppm and TCG increment≧70 ppm/month
		③C_2H_4≧500 ppm and TCG increment≧170 ppm/month

Note: Regarded as the abnormal level if either ①, ②, or ③ is applicable.

3.2 Duval Triangle

The criteria for determining natural ester oils and synthetic ester oils are the Duval Triangle according to "IEEE Guide for Interpretation of Gases Generated in Natural Ester and Synthetic Ester-Immersed Transformers"[6]. This time, we examined the PFAE diagnostic criteria equivalent to that of Duval Triangle using the below method.

The Duval Triangle is a trigonometry method that uses the ratios of CH_4, C_2H_4, and C_2H_2. The boundary line (20%) between T1 and T2 is the ratio of C_2H_4 taken from the result of the amount of gas generation[3] of mineral oil and PFAE at 300℃, and the ratio of C_2H_4 is about 60%. The boundary line (50%) between T2 and T3 is the ratio at 700℃ and it becomes about 70%. The boundary line (23%) between D1 and D2 was about 24% based on the ratio of C_2H_4 from the result of the amount of gas generation[4] due to the discharge of mineral oil and PFAE. **Fig. 1** shows the Duval Triangle.

3.3 Abnormality Diagnostic Diagram by the Electric Technology Research

We examined the diagnostic criteria of mineral oils according to the literature Vol.65, No.1[5] by the Electric Technology Research, and the diagnostic criteria of PFAE equivalent to diagrams A and B of

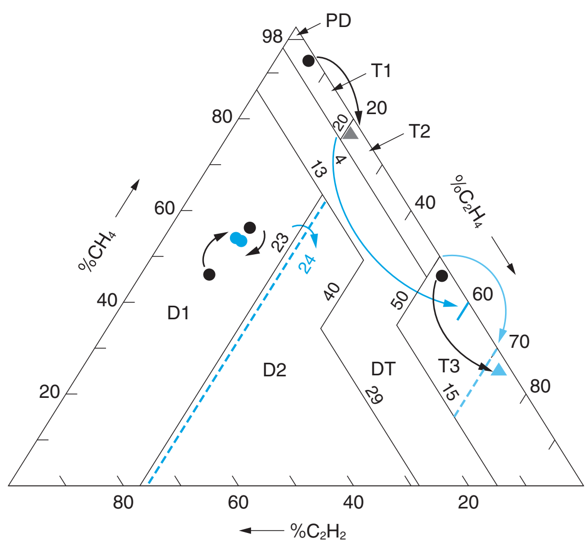

Fig. 1 Duval Triangle

Based on the generated gas volume ratio of mineral oils to PFAE obtained from experiments, the boundary line of the Duval Triangle for mineral oils was shifted.

the abnormality diagnostic diagrams.

Fig. 2 shows the abnormality diagnostic diagram A proposed by the Electric Technology Research. **Fig. 3** shows the abnormality diagnostic diagram B. For the abnormality diagnostic diagrams A and B, C_2H_4/C_2H_6 is expressed on the axis of abscissas. It judges the overheating domain in 3 ranges: low overheating (300℃ or lower), medium overheating (300～700℃), and high overheating (700℃ or higher). For this border line, the method of Duval Triangle is applied based on the result of gas generation(3) for mineral oils and PFAE at 300℃ and 700℃ to determine the position of C_2H_4/C_2H_6. The axis of ordinate is used to judge overheating, discharge, and overheating + discharge (Abnormality Diagnostic Diagram A for C_2H_2/C_2H_4 and Diagram B for C_2H_2/C_2H_6). For these border lines, the location of each border line is computed based on the result of discharge-derived gas generation(4) for mineral oils and PFAE.

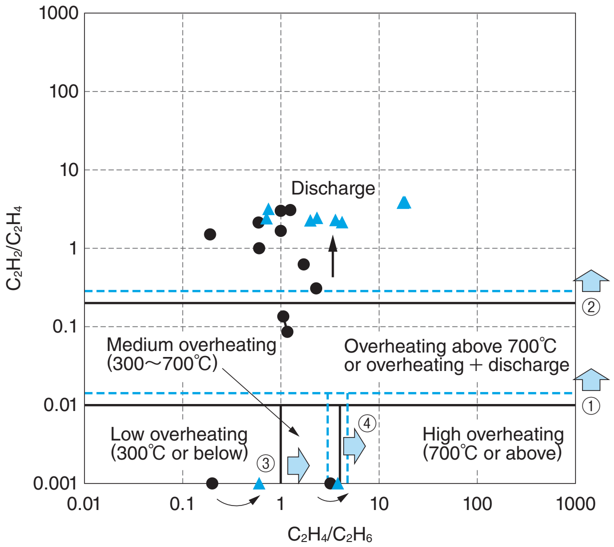

Fig. 2 Electric Technology Research: Abnormality Diagnostic Diagram A

Based on the generated gas volume ratio of mineral oils to PFAE obtained from experiments, the boundary line of the Abnormality Diagnostic Diagram A for mineral oils was shifted.

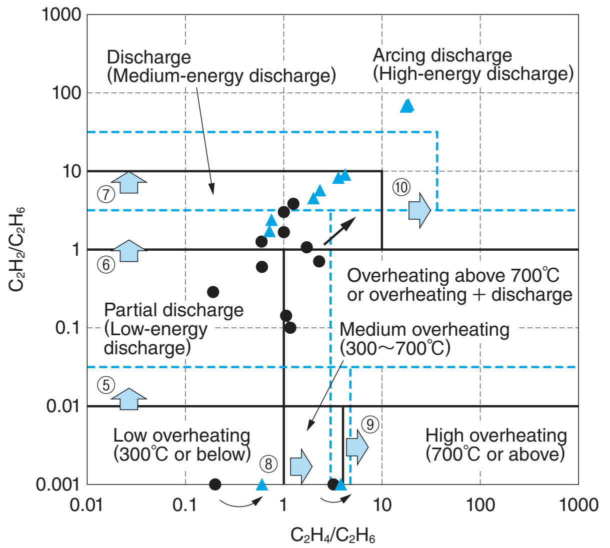

Fig. 3 Electric Technology Research: Abnormality Diagnostic Diagram B

Based on the generated gas volume ratio of mineral oils to PFAE obtained from experiments, the boundary line of the Abnormality Diagnostic Diagram B for mineral oils was shifted.

3.4 Gas Pattern Diagnostic Table by the Electric Technology Research

We examined the diagnostic criteria of mineral oils according to the literature Vol.65 No.1(5) by the Electric Technology Research and the PFAE interpretation equivalent to the Gas Pattern Diagnostic Table.

Fig. 4 shows the Gas Pattern Diagnostic Table (C_2H_4 initiative type-A) proposed by the Electric Technology Research. Gases of H_2, CH_4, C_2H_6,

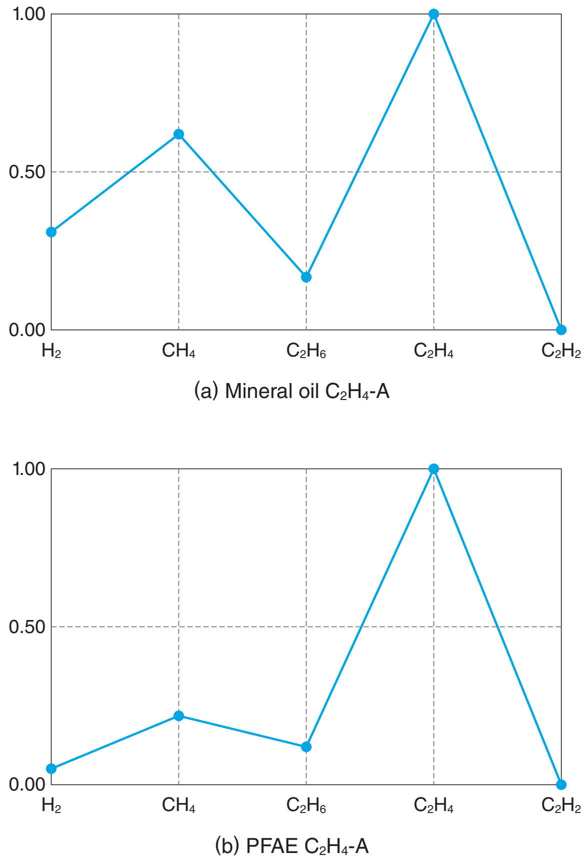

Fig. 4 Electric Technology Research: Gas Pattern Diagnostic Table (C_2H_4 initiative type-A)

Based on the generated gas volume ratio of mineral oils to PFAE obtained from experiments, the gas pattern diagnostic table for mineral oils was modified into the PFAE diagnostic table.

C_2H_4, and C_2H_2 are aligned on the axis of abscissas and the axis of ordinate is used to plot the ratios assuming that the maximum value is unity in gas components. According to the gas pattern of mineral oils, we presumed the overheating temperature (300～700℃) to assume the presence of discharges in conjunction with the C_2H_2 values. In the same manner as described previously, the ratios of mineral oils to PFAE were determined. Since the amount of gas generation is different between mineral oils and PFAE due to difference in temperatures, it is feasible that the gas with the highest concentration will be replaced. There is room for consideration.

4 Postscript

We examined the DGA diagnostic criteria for the PFAE by compensating the data by overheating and discharge experiments simulating a transformer. There may be, however, a difference in consistency with the actual device. There is room for consideration in terms of how to handle CO generation, and how to deal with the replacement of the gas with the highest concentration.

Considering that the results of this time are the basic values of the diagnostic criteria, we will improve the diagnostic criteria by collecting data on the actual equipment using the PFAE and examining experiments to bring it to a closer likeness to the actual equipment.

《**References**》

(1) "Mineral oil-filled electrical equipment in service-Guidance on the interpretation of dissolved and free gases analysis", IEC 60599, 2015

(2) Sano, Shigemori, Wakimoto: "Study of Dissolved Gas Analysis Criteria for Palm Fatty Acid Ester-Immersed Transformers", Annual Conference of Power and Energy Society IEE of Japan, No.298, 2019 (in Japanese)

(3) Kato, Ohta, Koide: "Study on Decomposition Gases of Various Ester Insulating Oils by Local Heating", Journal A of the Institute of Electrical Engineers of Japan, Vol.137, No.4, 2017, pp.208-214 (in Japanese)

(4) Yunwen He, Kiyoshi Wakimoto, Yang Xu, Shengtao Li: "PARTIAL DISCHARGE CHARACTERISTICS OF PALM FATTY ACID ESTER FOR DISSOLVED GAS ANALYSIS", Proceedings of the 21st International Symposium on High Voltage Engineering, 2020, pp.752-762

(5) "The Guideline for Refurbishment of Electric Power Transformers", the Electric Technology Research, Vol.65, No.1, 2009 (in Japanese)

(6) "IEEE Guide for Interpretation of Gases Generated in Natural Ester and Synthetic Ester-Immersed Transformers", IEEE C57.155, 2014