

DISSOLVED GAS ANALYSIS (DGA) OF NATURAL ESTER OILS UNDER ARCING FAULTS

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Published online: 10 September 2017

ABSTRACT

Dissolved gas analysis is one of diagnostic technique for monitoring the internal condition of transformer. However, DGA analyses for natural ester especially palm oil and rice bran oil still lacking. Therefore, this paper presents the investigation on natural esters regarding gassing behaviour under lightning impulse breakdown. Two type of natural ester oils were used namely Palm oil (PO) and Rice Bran oil (RBO). The DGA result showed that C₂H₂ and H₂ detected the highest amount of gases for both samples. The gaseous obtained from the experiments were interpreted in different DGA method such as Dornenburg ratio, Roger ratio, IEC Gas method and Duval Triangle method to find the best technique for natural ester oils. The conducted experiment shows that PO and RBO have comparable dielectric performance and gassing characteristics to mineral oil, but still requiring modification of design and operating parameters.

Keywords: natural ester oils; electrical breakdown voltage; lightning impulse; DGA; interpretation methods.

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doi: <http://dx.doi.org/10.4314/jfas.v9i3s.9>



1. INTRODUCTION

Power transformer is the most expensive component of the electric power generation and transmission system having at the same time a special strategic importance. That is why its safety is of a crucial importance for the operation of the power grid. Therefore, the utilities are very interested to evaluate the condition of transformer insulation [1]. Failure of transformer is devastating and costly experience because it causes an outage to the area the transformer is supplying power [2]. Due to transformer condition monitoring, DGA is a tool allowing a diagnosis on insulation oil. DGA used for several decades in transformer oil to check the condition of equipment, monitor the operating condition of equipment and enables to detect the earlier faults and can avoid failures and damage of transformer [3].

Currently, a lot of interests shown by researches to compare of electrical performances between natural ester and mineral oil. Almost previous studies were observed that natural ester oil was a good insulation performance instead of electrical stress [4-11]. However, there are lakes of diagnosis for faults in natural ester oils based on DGA techniques. Therefore, this paper presents the study of simulating electrical faults in transformers for palm oil (PO) and rice bran oil (RBO). Gasses dissolved in this two natural ester oils are analyzed by gas chromatography. The concentration gas and proportion of fault gases conditions in all samples are interpreted by referring limitation four ratio methods such as Dornenburg ratio, Roger ratio, IEC Gas method and Duval Triangle method.

2. METHODOLOGY

2.1. Sample Preparation

The samples used were two types of natural ester which is PO and RBO. Samples were obtained from readily available from manufactured. All samples were pre-treatment with filtered through a membrane filter with a pore size of 0.2 μm for 3 times. Next, the filtered samples were dried in oven for 48 hours at temperature 85 °C. The samples were rested for further 24 hours at ambient temperature before tested.

2.2. Lightning Impulse Breakdown Test

The lightning impulse breakdown voltage was carried out per IEC 60897. The test configuration can be seen in Fig. 1 [8-9]. Sphere to sphere copper electrode configuration was used to represent the uniform field at a gap distance of 6 mm. The diameter of the sphere electrodes is 12.7 mm. The breakdown voltage of natural ester oils was investigated using negative polarity 1.2/50 μ s lightning impulses. An 8-stage impulse generator by BHT with a maximum voltage of 800 kV was used to deliver the standard lightning impulse (1.2/50 μ s). A current limit resistor of (20 k Ω) was added in the circuit to limit the current of breakdown arc, further to protect the oil samples and electrodes. LIBDV was applied across the electrodes of the test cell with an ascending rate of 2kV/s. A total of 50 measurement of breakdown voltage were recorded for each type of samples.

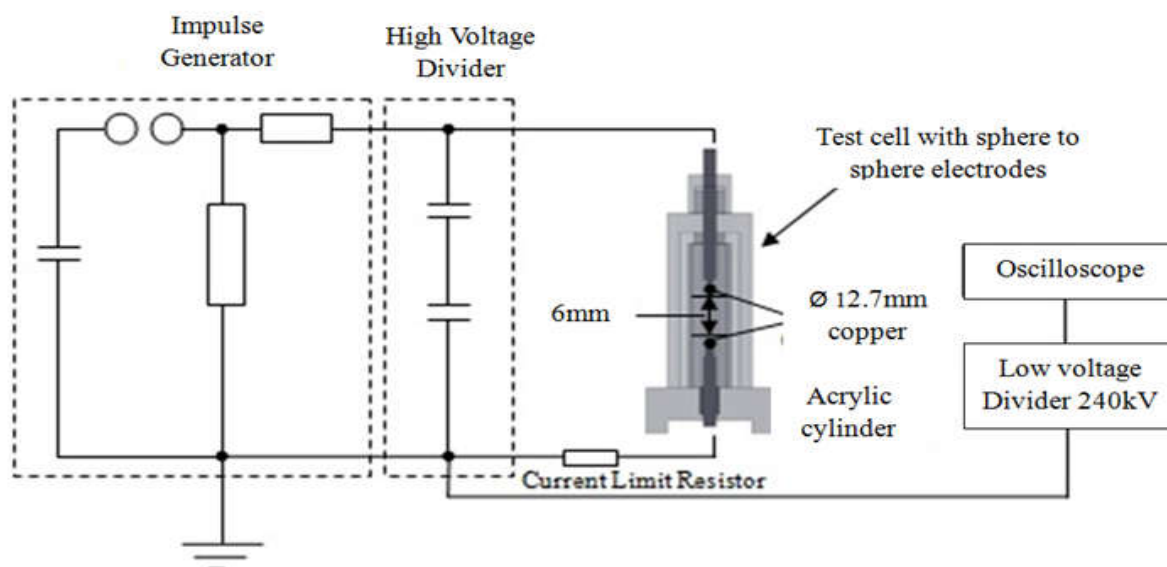


Fig.1. Test configuration for lightning impulse

2.3. DGA Process

The DGA method test was followed ASTM D 3612. The gases were sampling after 50 breakdowns for each sample using special glass syringe. Two samples of oils were sending to TJH2B for analysis. The gas analysis is done using gas chromatography.

3. RESULTS AND DISCUSSION

3.1. Impulse Breakdown Test

The results of lightning impulse breakdown tests are plotted in Fig. 2 and 3. The distribution

graph are in negative values because of LIBDV used negative polarity.

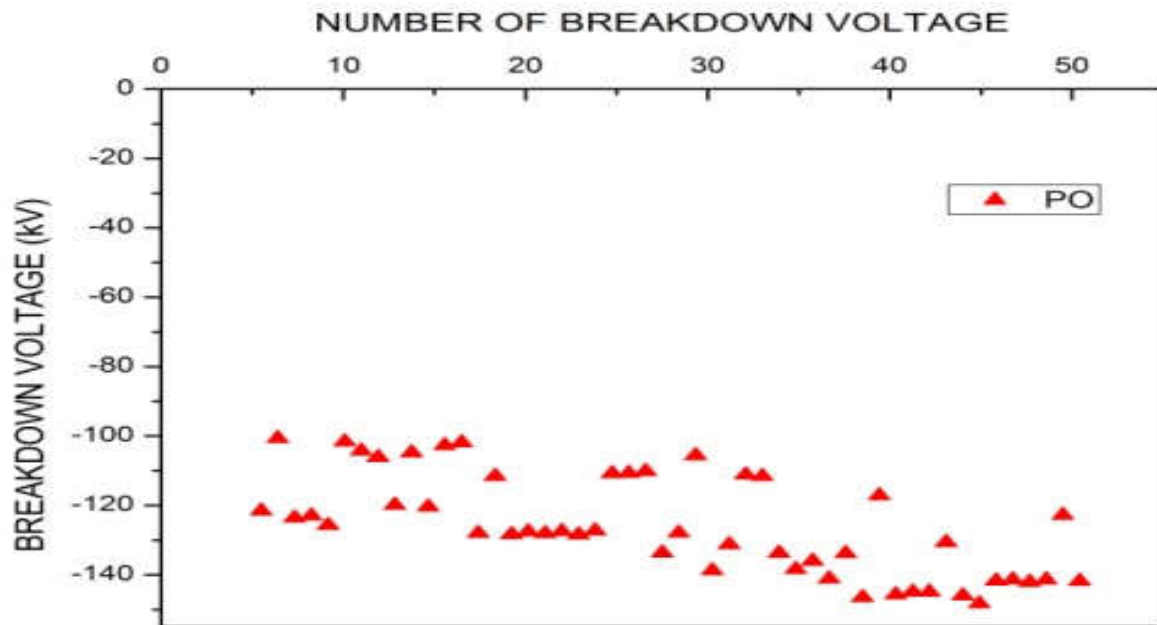


Fig.2. Distribution of breakdown voltage of PO

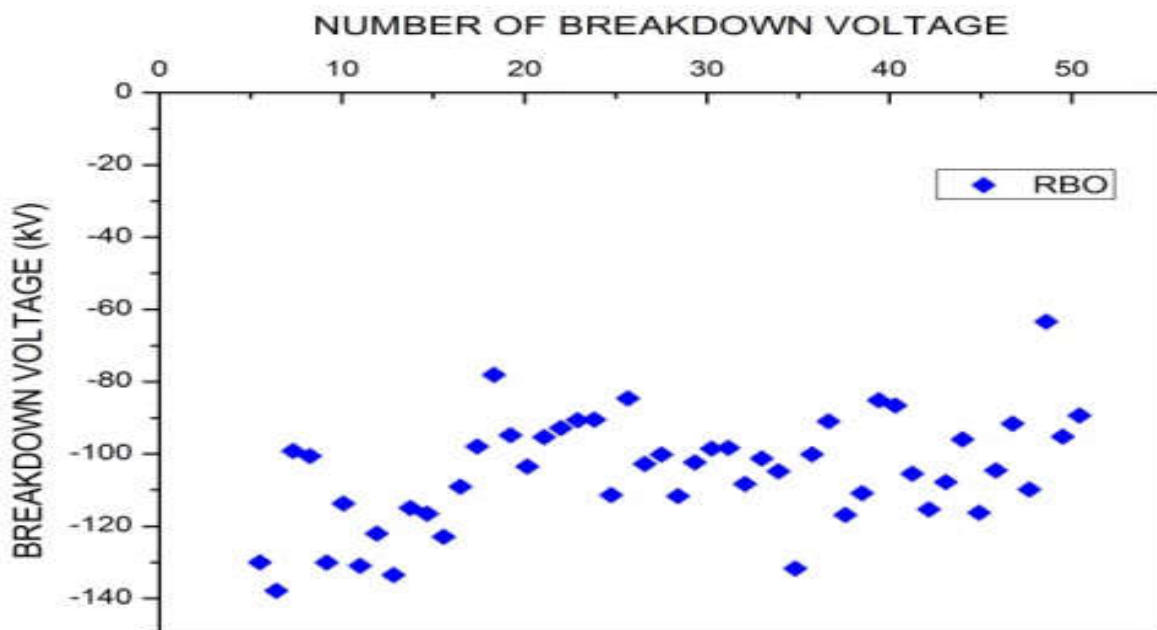


Fig.3. Distribution of breakdown voltage of RBO

From the figures, lightning impulse breakdown voltage for PO is generally higher than RBO. The trend for 50 breakdown voltages is continuously increased with the number of breakdown. However, RBO acts oppositely as the number of breakdown increase. The mean breakdown voltages of the PO and RBO are -125.13kV and -105.76kV respectively. This is

shown that the PO having better performance in term impulse breakdown voltage than RBO. The lowest impulse breakdown voltage for PO is -85.6kV and the maximum value is -148.26kV. Whereas for RBO, the minimum and maximum values for impulse breakdown voltage are -78.08kV and -138.8kV respectively.

3.2. DGA for Electrical Stress

From experiments the highest amount of key gas for PO and RBO are H₂ and C₂H₂. Fig. 4 shows the relative percentages of fault gases except CO₂, under electrical breakdown. In all cases, a significant amount of H₂ and C₂H₂ are generated. It indicates that for PO and RBO, the main fault gases of a breakdown fault are the same. However, PO generates more amount of C₂H₂ as compare to RBO. Based on IEEE standard guide for DGA interpretation, arcing faults produced large of amount gas of H₂ and C₂H₂. The carbonized of oil caused the significant amount of CO occurred in both type of oils [12].

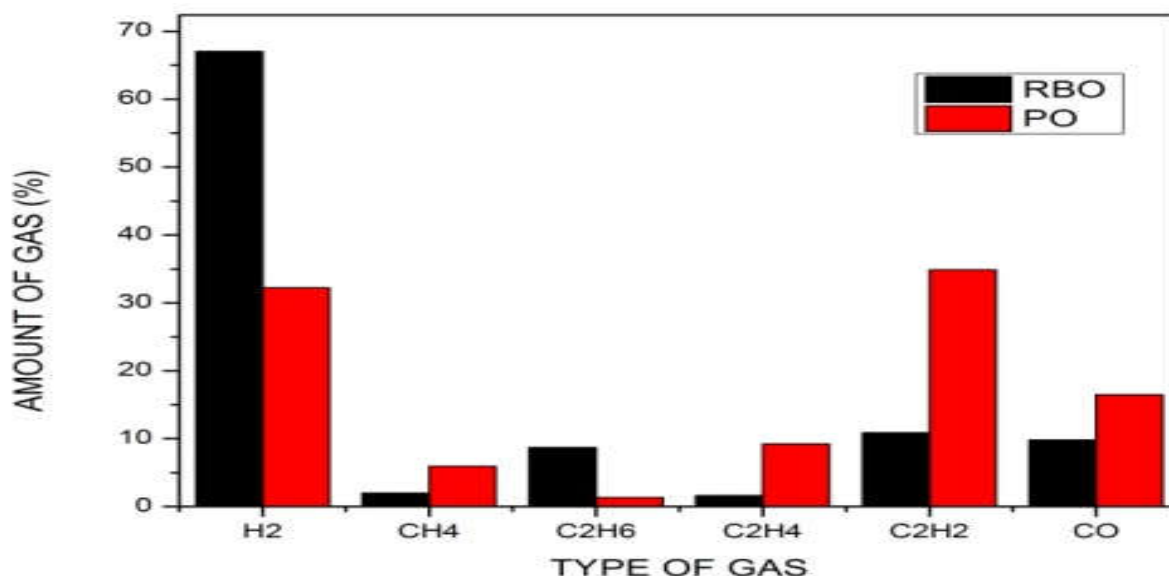


Fig.4. Percentage amount of gas in PO and RBO

3.3. DGA Interpretation

Gas generation for PO and RBO were interpreted under three type of ratio methods and Duval triangle method. Three ratios methods are Dornenburg ratio, Roger ratio and IEC ratio. There have five concentration gas ratios to indicate the possibility type of faults. The five ratios are followed Equation (1)-(5):

$$\text{Ratio R1} = \text{CH}_4/\text{H}_2 \quad (1)$$

$$\text{Ratio R2} = \text{C}_2\text{H}_2/\text{C}_2\text{H}_4 \quad (2)$$

$$\text{Ratio R3} = \text{C2H2/CH4} \quad (3)$$

$$\text{Ratio R4} = \text{C2H6/C2H2} \quad (4)$$

$$\text{Ratio R5} = \text{C2H4/C2H6} \quad (5)$$

The value concentration gas ratio for PO and RBO after LIBDV was shown in Table 1. Concentration gas ratio between PO and RBO shows obviously different. Only on concentration ratio gas of R3 value is almost similar. These concentrations gas ratio were proved the same condition of fault in sample PO and RBO under interpretation methods.

Table 1. Concentration gas ratio of PO and RBO

Ratios	Concentration of Gas	
	PO	RBO
R1	0.18	0.03
R2	3.79	6.67
R3	5.89	5.45
R4	0.04	0.8
R5	7	0.19

3.2.1. Dornenburg Ratio

Dornenburg ratios only compared four concentration gas ratios as mentioned in Table 1 which are R1, R2, R3 and R4. Table 2 shows the limitation value of gases and condition suggested by Dornenburg. This limitation value of gas will be compared concentration gas ratio in oil due to condition in Table 2.

Table 2. Dorneburg ratio key gas [13]

Condition	R1	R2	R3	R4
Thermal	> 0.1	< 0.75	< 0.3	> 0.4
PD	< 0.1	x	< 0.3	> 0.4
Arcing	> 0.1-< 1.1	> 0.75	> 0.3	< 0.4

Based on Dornenburg ratio, the arching fault condition was detected for PO which is agreed with experimental work. However, for RBO there is no valid fault condition can be obtained using this method. Therefore, DGA analysis of PO is considered valid under Dornenburg ratio key gas but not for RBO.

3.2.2. Rogers Ratio

Rogers Ratio Method almost similar with Dornnenburg Ratio Method. However, it uses only three ratios which are R2, R1 and R5 for diagnosis of the fault.

Table 3. Rogers ratio key gas [13]

Case	C2H2/C2H4	CH4/H2	C2H4/C2H6	Suggested Fault Diagnosis
0	< 0.1	> 0.1 to < 1	< 1	Normal
1	< 0.1	< 0.1	< 1	Low energy density PD
2	0.1 to 3	0.1 to 1	> 3	Arcing
3	< 0.1	> 0.1 to 1	1 to 3	Thermal fault < 300°C
4	< 0.1	> 1	1 to 3	Thermal fault 300°C to 700°C
5	< 0.1	> 1	> 3	Thermal fault > 700°C

Based on Table 3, the concentration gas ratio of PO, only R1 can fit the Table 3 whereas R2 and R5 are out of the range. Therefore, Rogers Ratio Method cannot correctly diagnose electrical stress fault in PO. For interpretation of concentration gas ratio of RBO only R1 value (0.03) and R5 (0.19) fit the Roger's ratio table. This indicates that this method also could not diagnose correctly the fault for RBO. This method is not suitable to be used for PO and RBO in diagnosis the electrical fault.

3.2.3. IEC Ratio

IEC gas ratio used 3 types of ratio similar as Roger's ratio. However, IEC gas ratio suggested different limitation value of ratio and different diagnostic of faults in transformer oil as shown in Table 4.

Table 4. IEC ratio key gas [13]

Case	Characteristic Fault	C2H2/C2H4	CH4/H2	C2H4/C2H6
PD	Partial Discharge	NS	< 0.1	< 0.2
D1	Discharge of low energy	> 1	0.1-0.5	> 1
D2	High energy discharge	0.6-2.5	0.1-1	> 2
T1	Thermal fault < 300°C	NS	> 1 but NS	< 1
T2	Thermal fault 300°C to 700°C	<0.1	>1	1 - 4
T3	Thermal fault > 700°C	< 0.2	> 1	> 4

The concentration gas ratio of PO shown that R1 value (0.18), R2 value (3.79) and R5 value (7.00) diagnose same case which is fall in the case of D1 (Discharge of low energy) and D2 (High energy discharges). The IEC ratio gas method can predict correctly for impulse breakdown. However, the results valid for both cases D1 and D2. For RBO, only R2 can fit the Table which cause the IEC ration method cannot give the correct diagnosis for RBO.

3.2.4. Duval Triangle Method

Duval Triangle method is useful interpretation of DGA under monitoring faults in transformer oil. The types of faults are represented using percentage of relative gas concentration. Three percentage gases were uses in Duval Triangle Method which is %CH₄, % C₂H₄ and % C₂H₂. This percentage of relative gas concentration can be observed by followed Equation (6)-(8) and the value shows in Table 5.

$$\%CH_4 = CH_4 / (CH_4 + C_2H_4 + C_2H_2) \quad (6)$$

$$\%C_2H_4 = C_2H_4 / (CH_4 + C_2H_4 + C_2H_2) \quad (7)$$

$$\%C_2H_2 = C_2H_2 / (CH_4 + C_2H_4 + C_2H_2) \quad (8)$$

Table 5. Percentage of relative gas concentration

Gas	Percentage (%)	
	PO	RBO
CH ₄	11.60	13.6
C ₂ H ₄	18.5	11.3
C ₂ H ₂	69.9	75.1

Table 5 shows that the percentage concentration gas value for RBO at CH₄ and C₂H₂ higher than PO. However, percentage range values of relative gas concentration for both samples are almost same. These percentages will determine faults occurred using Duval Triangle graph in Fig. 5 and 6.

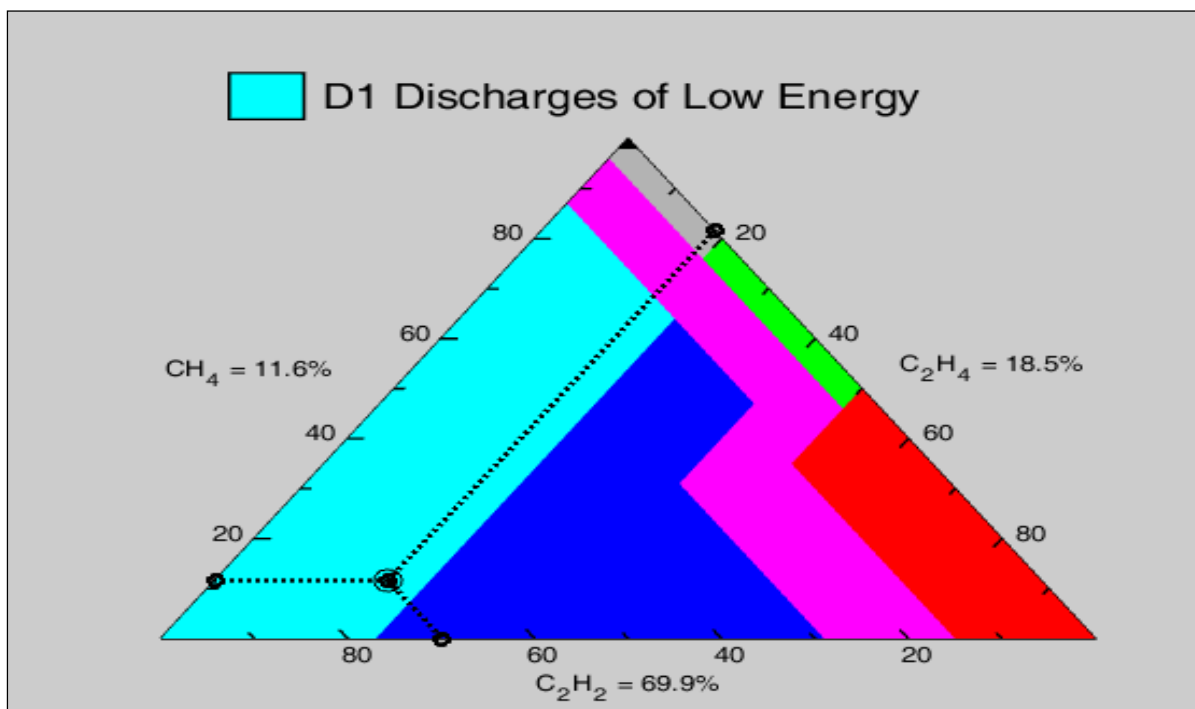


Fig.5. Duval triangle for PO after LIBDV

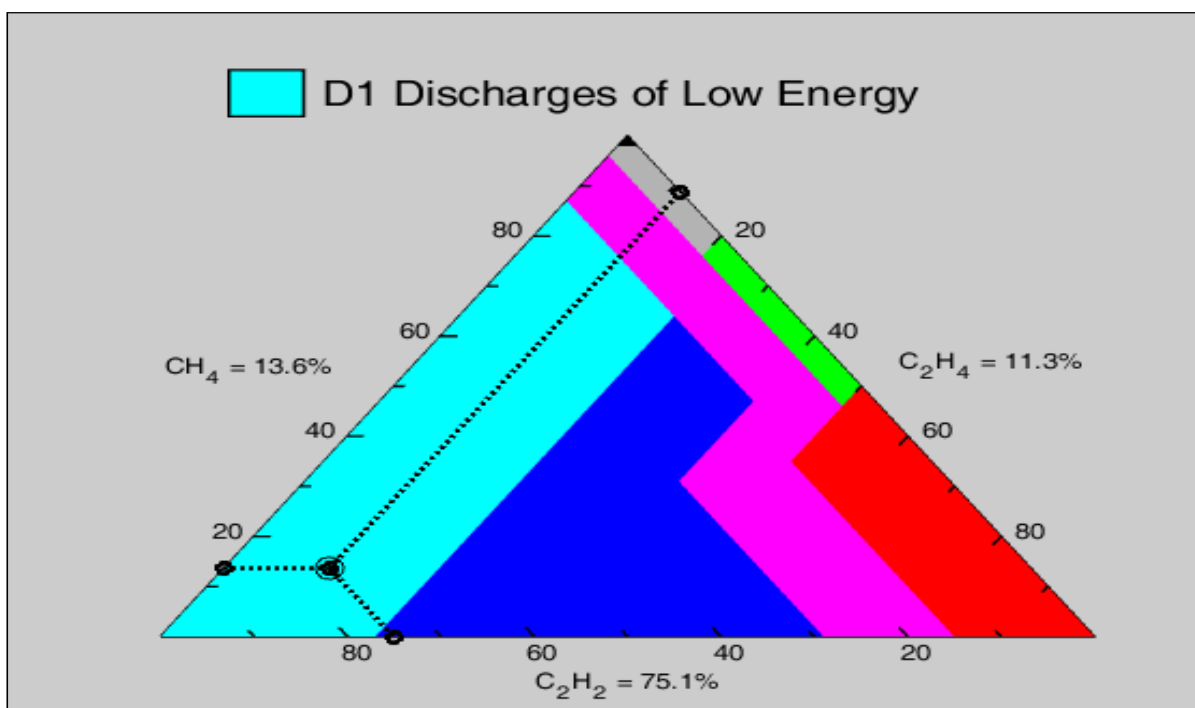


Fig.6. Duval triangle for RBO after LIBDV

Fig. 4 and 5 was the Duval triangle software to diagnose the fault of the insulation oil. From the figures, both of natural ester oils PO and RBO represent same fault condition which is D1-Discharge of low energy. This shows that Duval triangle method can correctly diagnose electrical stress faults in PO and RBO in simulated situation. Further, need to be done to

check the suitability of Duval Triangle in diagnose the fault for PO and RBO.

4. CONCLUSION

The LIBDV for PO and RBO and the concentration gas are discussed. LIBDV for PO showed slightly increase than RBO. However, the value of LIBDV for both natural ester oils not much different. DGA for PO and RBO has indicated H₂ and C₂H₂ was the highest amount of concentration gas. Theoretically, it was arcing fault condition. From the interpretation methods discussed, not all methods especially ratios methods are suitable to use. Only Duval Triangle Method gives same prediction condition of faults for PO and RBO.

5. ACKNOWLEDGEMENTS

The author acknowledged the financial support from Ministry of Education Malaysia (MOHE) in term of scholarship. The authors would like to thank Ministry of Education and National Defence University of Malaysia for the funding under FRGS scheme (FRGS/2/2014/TK03/UPNM/02/01).

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How to cite this article:

Hamid MHA, Ishak MT, Arifin MM, Amin NAM, Katim NIA, Azis N, Hashim FR, Md Din MF. Dissolved gas analysis (dga) of natural ester oils under arcing faults. J. Fundam. Appl. Sci., 2017, 9(3S), 105-115.