Dissolved Gas Analysis of Transformer Oils: Effects of electric arc

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Abstract: - In a power system, transformer plays an important role to convert the voltage level. Insulation is an important part of a power transformer. In general, solid and liquid insulation are widely used. During operation electric arc may take place a weak point with a high electric field in a power transformer. The electric arc may degrade the oil as well as solid insulations. It may enhance the dissolved gases in the oil. Recently, Dissolved gas Analysis (DGA) is widely used in diagnostics of the transformer condition. This paper reports the experimental results on the effects of arc on the dissolved gas in transformer oils. The samples used were several products of transformer oils. Electric arc was generated by using multi needles-plane electrodes. The samples were subjected to arc produced at needle tips under AC voltage. Arc energy was adjusted by electrode separation and the duration of arc application. The experimental results showed that the application of arc in transformer oils increased the concentration of combustible gases such as hydrogen, ethane, ethylene and acetylene. Dissolved gas analysis were done using Key gases, Roger's ratio and Duval Triangle methods. The experimental results showed that all methods resulting similar results. The DGA also indicated that large electric arc my be interpreted as overheating.

Key-Words: - DGA, transformer oil, electric arc, TCG, Key Gases, Roger's Ratio, Duval Triangle

1 Introduction

Transformer is one of the most important apparatusses in a power system. In general, solid insulation in the form of paper is used to cover the coils of a transformer. In additional liquid insulating materials in the form of transformer oils are commonly used. During the operational of a transformer, gasses may dissolved in liquid insulation. The gasses arise in the transformer oils as results of transformer faults such as arcing, corona (partial discharges), overheating of transformer oil or overheating of paper insulation (cellulose). The dissolved gases in transformer oil can be used to diagnose the faults experienced by the transformer[1]. Among the dissolved gasses the combustible gasses are the most dangerous since these gasses may cause the burning and or explosion of the transformer. The combustible gasses commonly appear in transformer oil are H_2 (hydrogen), C_2H_6 (Ethane), C_2H_4 (ethylene) and C_2H_2 (Acetylene). The appearance of the gases relates to the degree of heating experienced by transformer oil[2].

Arcing is one of the common faults in a transformer and promote the appearance of gasses in the liquid insulation. This paper reports the investigation results on the effects of arc on the dissolved gasses in transformer oils.

In this paper the dissolved gasses were interpreted using several methods. They are Total Combustible Gas-TCG, Key Gas Method , Roger's Ratio Method and Duval Triangle Each method was used to predict the transformer faults indicated by the species and the concentration of gasses from the DGA measurement.

2 Experiment

2.1 Sample

Samples used in this experiment were commercially used transformer oils with their abbreviation as M (Mictrans) and C (Conoco). The transformer oils are widely used in Indonesian Network. Each sample was treated at 10 different treatments. Therefore 20 samples were used in this experiment. The samples and treatments are shown in table 1.

Table 1
Samples and treatments

Oil	Sample	Treatment	
		Arc generating voltage (kV)	Arc Duration (minutes)
M	Mo	0	0
	M1	12	5
	M2	12	10
	M3	12	15
	M4	20	5
	M5	20	10
	M6	20	15
	M7	24	5
	M8	24	10
	M9	24	15
C	Co	0	0
	C1	12	5
	C2	12	10
	C3	12	15
	C4	20	5
	C5	20	10
	C6	20	15
	C7	24	5
	C8	24	10
	C9	24	15

2.2 Electrode arrangement

Electric arc was generated using 6 parallel steel needles-plane electrode system. The radius of curvature of the needle electrode was 3 μm. The distance between needle and plane electrode was 1, 2 and 3 mm to adjust the electric arc energy. Each sample was subjected to electric arc generated at the tip of needle electrodes under AC voltage. A series resistor was used to limit the current flew in the circuit. The electrode arrangement and experimental circuit is shown in Fig.1.

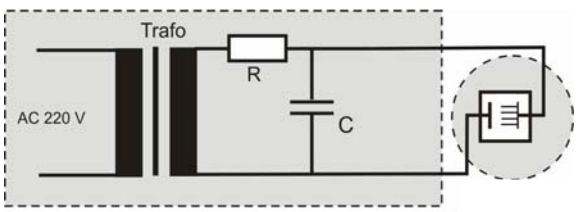


Fig. 1 The electrodes and experimental arrangement

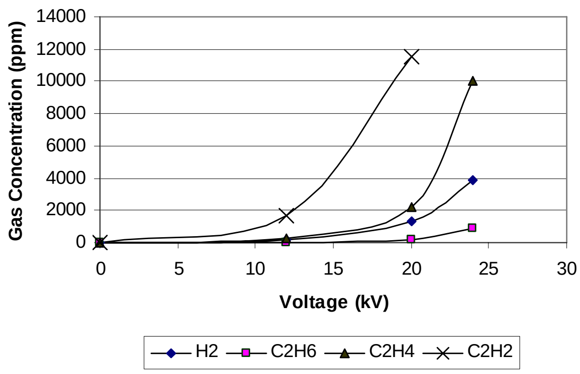
The applied voltage was varied from 12 kV, 20 kV and 24 kV depending on the electrode spacing. The duration of arc application was either 5, 10 or 15 minutes.

2.3 Dissolved Gas Analysis

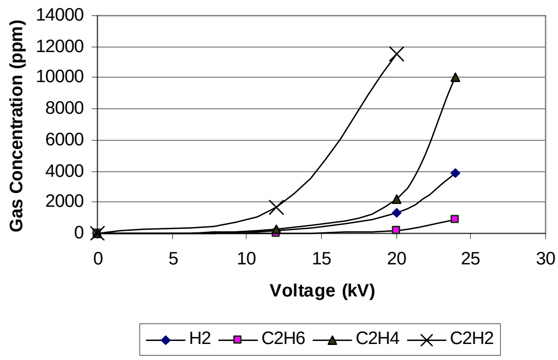
The Dissolved Gas was measured using a gas chromatograph HP 6890 integrated with Automated Liquid Samples HP 7649. The dissolved gas analysis of the transformer oils was done using total combustible gas (TCG), Roger's Ratio, Duval Triangle method and key gasses criteria.

3 Experimental Results and Analysis

3.1 The dependence of gases on arc voltage



(a) M



(b) C

Fig 2 The dependence of combustible gas concentration on the applied voltage for (a) M (b) C oil samples

Fig 2 shows the concentration of combustible gases in the sample oils as function of the applied voltage. The applied voltage represents the magnitude of arc. High voltage produced a big arc. The figure indicated that C_2H_2 gas is the biggest combustible gas generated by arc in both transformer oils. The figure also shows that the concentration of combustible gases increase almost exponentially (quadratically) with the applied voltage. This may indicate the role of arc energy in generating the combustible gases. The arc energy is quadratic function of voltage.

Fig 3 shows the dependence of total combustible gas (TCG) generated on the arc voltage. Similar to that individual gas, the TCG also increases non-linearly with voltage.

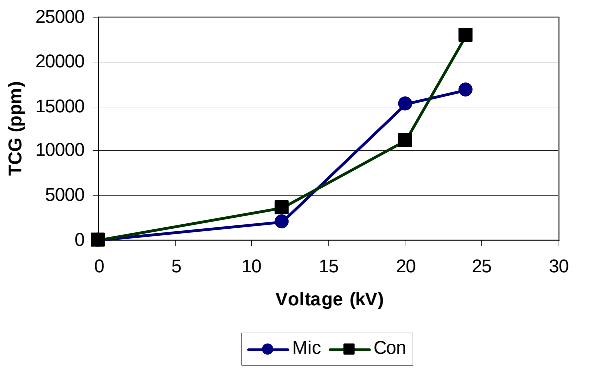
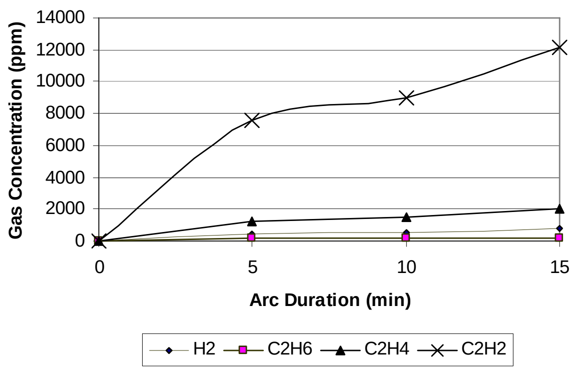
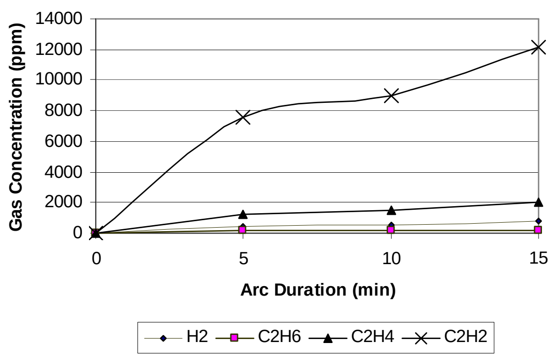


Fig 3 Dependence of the total combustible gas on arc voltage

3.2 Effects of Arc Duration on the Combustible Gas



(a) M sample



(b) C sample

Fig 4 The Dependence of Gas concentration on the arc duration at 20 kV for (a) M (b) C samples

Figures 4 shows the concentration of dissolved combustible gasses in the M oil samples (a) and C oil samples (b) as function of the duration of arc application. The figure indicates that the concentration of combustible gas increases almost linearly with the duration of arc application. Similar trend was also observed for the total combustible gas (TCG) concentration as function of arc duration as shown in figure 5.

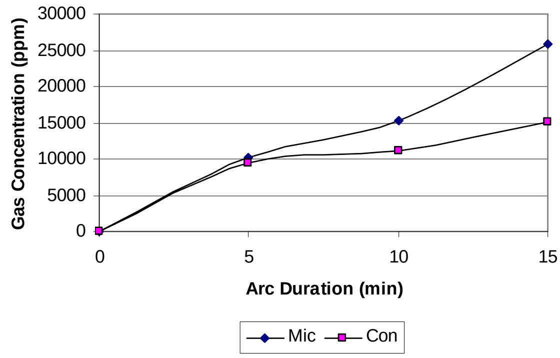


Fig 5 Dependence of Total Combustible Gas on arc duration at 20 kV

3.3 Interpretation of dissolved gas using Total Combustible Gas (TCG) Method.

Total Combustible Gases (TCG) Method is a method to predict the operating condition of a transformer. This method based on IEEE C57-104-1991 and ASTM D-3612 standards[3]. By using the standards the diagnostic result of each sample is shown in table 2.

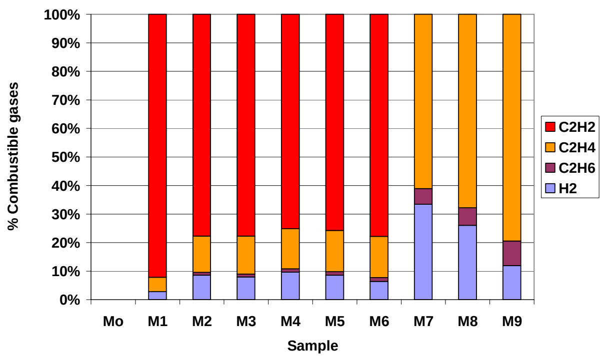
Table 2
Diagnostic results using TCG Method

Sample	Condition	Sample	Condition
Mo	1	Co	1
M1	3	C1	3
M2	3	C2	3
M3	3	C3	4
M4	4	C4	4
M5	4	C5	4
M6	4	C6	4
M7	4	C7	4
M8	4	C8	4
M8	4	C9	4

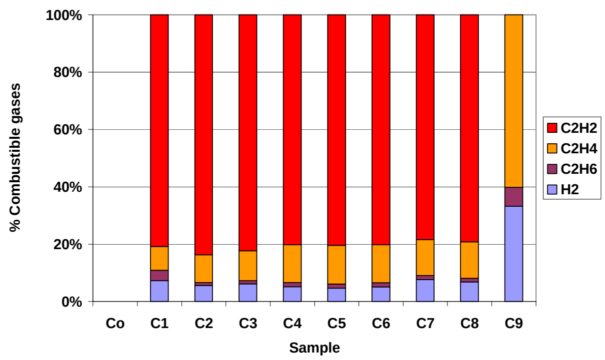
Table 2 indicates that arc application in this experiment produces a large amount of gases. The oil sample condition changed from condition 1 to condition 3 and 4 without condition 2.

3.4 Interpretation of dissolved gases using Key gas method

This method is used to predict the condition of transformer oil by comparing the combustible gas composition and high gas concentration as key gas in explained in IEEE C57.104[2]. Composition of gas concentrations from M and C samples are shown in figure 6. By using the dissolved gases composition the diagnostic of the transformer oils was done and the results are shown in table 3. From table 3 it is seen that M0 and C0 are normal. Samples M1-M6 indicated **C_2H_2** key gas and correlated with arcing. However, as arcing voltage increased to 24 kV at sample M7-M9 the diagnostic results changed from arcing to overheating of oil with key gas of **C_2H_4**. This results indicated that high arc released a large amount of energy and heated the oil. Similar results were observed for C oil sample.



(a)



(b)

Fig 6 Percentage of gases concentration for (a) M and (b) C samples

Table 3
Diagnostics results using Key Gas method

Sample	**Key gas**	**Diagnosis**
Mo	-	Normal
M1-M6	C_2H_2	Arcing
M7-M9	C_2H_4	Overheating of oil
Co	-	Normal
C1-C8	C_2H_2	Arcing
C9	C_2H_4	Overheating of oil

3.5 Interpretation of dissolved gases using Roger's Ratio

Roger's ratio was obtained by comparing the concentration among key gases in the oil samples. By using this method the diagnostic of the transformer oils was done. The diagnostic results are tabulated at table 4. From the table M0 and C0 are normal. M1 – M6 were diagnosed as arc persistent sparking while M7-M9 were diagnosed as overheating. These results are similar to that of key gases method. For C samples similar results were also obtained. From these results it can be said that the effect of overheating may dominate the effect of discharge during big arc occurrence.

Table 4
Diagnostic results using Roger Ratio Method

Sample	**Ratio Rogers**				**Diagnosis**
	R1	**R4**	**R5**	**R2**	
Mo	0	-	-	-	Normal
M1-M6	0	-	1	1	Arc or persistent sparking
M7-M9	0	-	1	0	General conductor overheating
Co	0	-	-	-	Normal
C1-C8	0	-	1	1	Arc or persistent sparking
C9	0	-	1	0	General conductor overheating

3.6 Interpretation of dissolved gases using Duval Triangle

Duval Triangle method uses concentration of 3 key gases for diagnosing the transformer oil condition. The gases are CH_4, C_2H_4, C_2H_2. [4]. By drawing the coordinate of the 3 gases, the condition of the oil can be diagnosed. The triangle is shown in fig 7.

If the coordinate locate at PD region, this means partial discharge occurred. T1 indicates a thermal fault at temperature of less than 300°C while T2 indicates thermal faults between 300°C and 700°C and T3 zone represents a thermal faults with overheating of more than 700°C. D1 indicates a low energy discharge (spark) and D2 is high energy discharge (electric arc). DT zone represents a mix between thermal and electrical faults.

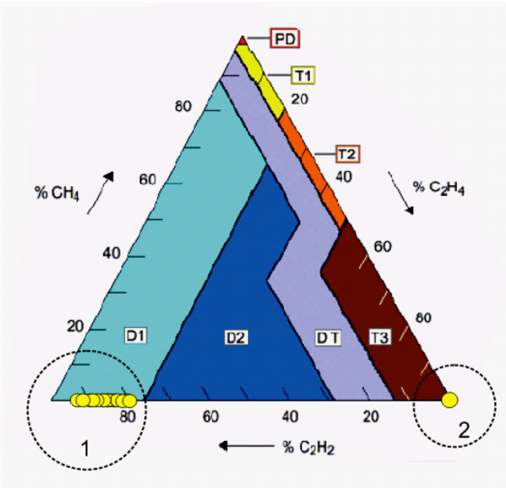


Fig. 7 Duval Triangle

Table 5
Diagnostic results using Duval Triangle Method

Sample	Area	Diagnosis
Mo	-	*Normal*
M1-M6	*D1*	*low energy discharging (sparking)*
M7-M9	*T3*	*thermal fault greater than 700°C.*
No	-	*Normal*
Co	-	*Normal*
C7-C8	*D1*	*low energy discharging (sparking)*
C9	*T3*	*thermal fault greater than 700°C.*

Table 5 shows that M0 and C0 are normal. M1 – M6 were diagnosed as low energy discharge while M7-M9 were diagnosed as thermal fault greater than 700°C. Similar results were obtained for C samples. The Duval Triangle method showed almost the same as key gases and Roger's Ratio methods.

4 Conclusion

From the experimental results some conclusions can be drawn as follows.

1. Arc greatly affects gases dissolved in transformer oils.
2. The concentration of gases increased non linearly (quadratically) with applied voltage and almost linearly with arc duration.
3. Big arc may release gasses similar to that overheating.
4. Similar diagnostic results were obtained from TCG, Key gas, Roger's Ratio and Duval Triangle methods suggesting the affectivity of the methods.

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