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THE EFFECT OF THERMAL STRESS AND MATERIALS TOWARDS STRAY GASSING FORMATION IN UNINHIBITED AND INHIBITED OIL

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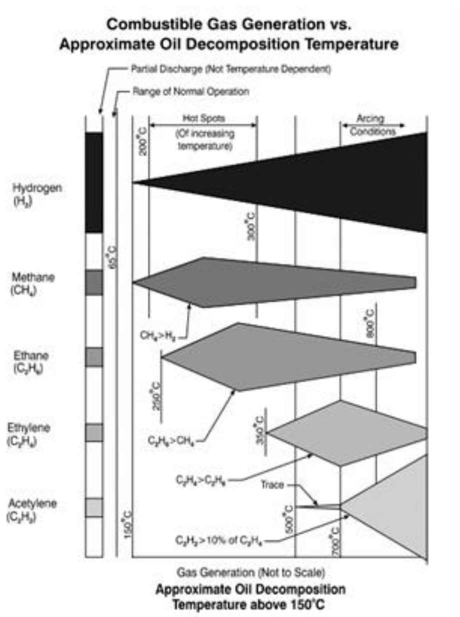
Graphical abstract



Abstract

Insulation oil is one of the most important components in an oil-insulated transformer. With the use of the dissolved gas analysis (DGA) tool, the condition of the transformer can be studied and predicted to prevent unwanted events from occurring. However, due to the rising of issues related to stray gassing phenomenon that causes false interpretations in the transformer condition, there is a need to find out the factors contributing to the formation of the stray gases in the transformer oil. In this research paper, thermal stress (85℃ and 120℃) on transformer oil with different transformer materials are studied to determine the effect towards the formation of stray gases in the transformer oil. The materials studied include diamond dotted paper, metal plate, coated metal plate, insulation glue and core metal. Both the uninhibited oil and inhibited oil are used for comparison. The metal plate, coated metal plate and core metal were found to be causing the generation of H2 gas at 120℃ while the cellulose ageing of insulation paper is causing the generation of CO and CO2 gases at 85℃ and above. The CH4 gas was found to be generated only at 120℃ and the insulation glue was determined to be the main cause for the C2H4 gas generation at 85℃ and above.

Keywords: Insulation oil, dissolved gas analysis (DGA), stray gas, thermal stress, transformer materials

Abstrak

Minyak penebat adalah salah satu komponen yang penting dalam sistem penebat alatubah. Dengan penggunaan alat analisis gas terlarut (DGA), kondisi alat ubah boleh dikaji dan diramal untuk mengelakkan kejadian yang tidak dingini daripada berlaku. Walau bagaimanapun, oleh sebab terdapat peningkatan isu berkaitan fenomena gas sesat yang menyebabkan kesilapan semasa mentafsirkan keadaan alatubah, perhatian pada kajian untuk mengetahui faktor-faktor yang menyumbang kepada pembentukan gas sesat dalam minyak alatubah adalah diperlukan. Dalam kertas kajian ini, faktor perbezaan suhu 85℃ dan 120℃, dan campuran minyak alatubah dengan bahan alatubah yang berbeza dikaji untuk mengetahui kesan kepada pembentukan gas sesat dalam minyak alatubah. Bahan yang dikaji termasuk kertas bertitik berlian, plat logam, plat logam bersalut, gam penebat dan logam teras. Kedua-dua minyak tak terhalang dan minyak terhalang digunakan untuk tujuan perbandingan. Plat logam, plat logam bersalut dan logam teras didapati telah menyebabkan penjanaan gas H_2 pada 120 °C manakala penuaan selulosa kertas penebat menyebabkan penjanaan gas CO dan CO_2 pada 85 °C dan ke atas. Gas CH_4 didapati hanya terhasil hanya pada 120 °C dan gam penebat ditentukan sebagai punca utama penjanaan gas C_2H_4 pada 85 °C dan ke atas.

Kata kunci: Minyak penebat, analisis gas terlarut (DGA), gas sesat, tekanan suhu, bahan pengubah

1.0 INTRODUCTION

Transformer insulation oil is an electrically insulating liquid that acts as an insulation medium to protect the internal live parts of the transformer and also serves as an effective coolant [1]. Besides that, transformer oil is also used in the transformer maintenance process to indicate and predict the transformer's conditions based on analytic results obtained from dissolved gas analysis (DGA) and oil quality tests. Although there are other maintenance tests on the transformer, such as the partial discharge assessment as discussed in [2], assessment using transformer oil is widely used due to the ability to detect various fault types that exist in an operating transformer and can be performed during transformer online. Recent campaigns on green and sustainable technology had led to the increasing use of ester oil as the insulating oil in the transformer due to its biodegradable characteristic [3]. However, mineral oil is still predominantly used for most of the oil insulated transformers around the world based on the transformer oil market report published in 2021 [4].

Many researches had been conducted based on transformer oil which covers fault prediction interpretation, such as in [5], [6] and factors affecting the quality of transformer oil to improve the diagnosis of the transformer oil. Soitirios Missas *et al*. in their paper studied the factors affecting the ageing of transformer oil based on the oil quality tests, which are oil colour, dielectric strength, moisture, interfacial tension, and dielectric dissipation factor (tan delta) [7]. Dielectric strength and dielectric dissipation factor are determined to be the main factors related to oil ageing while the other parameters sometimes do not indicate directly to the oil quality. Therefore, a more detailed study will still be required to further look into possible fault information provided by the transformer oil. The insulation characteristics of transformer oil at low temperatures were also shown in a study conducted by Ming Gao *et al*. where the water and impurity content were determined to be the main factors affecting the insulation breakdown of the transformer oil [8]. However, good oil quality does not always indicate good gassing condition of the oil. There are certain cases found where the oil quality and transformer are in good condition but a significant increase in fault gases weas detected based on DGA [9]. This phenomenon is known as the stray gassing event.

In order to detect the stray gassing in the transformer oil effectively, ASTM D7150-13 [10] was published in 2013 with the test procedure stated to differentiate the stray gassing event from the faults based on DGA. Several studies were conducted to determine the factors that contribute to the formation of the fault gases but do not correlate to the fault. This was shown in the study which investigated the effect of metal deactivators on the formation of stray gassing under electrical and thermal stress [11]. According to this study, the triazole derivatives and benzotriazole derivatives oxidation are the main cause of the formation of hydrogen gas due to unstable molecular structure. In 2018, Steve Eeckhoudt et. al. carried out a series of experiments to investigate the impact of copper strip, oxygen content, the addition of additives, incubation time and temperature, and the relationship to oxidation stability to obtain the causes of stray gasses in transformer insulating oil [12]. Copper is found to be catalysing the oxidation process, which leads to the formation of stray gasses in the insulating oil. Besides that, the inhibitor oil was found to be yielding less amount of stray gases, and the presence of oxygen results in higher stray gas levels. At low temperatures, the addition of inhibitors in the oil largely decreases the formation of stray gases.

Previous studies showed that stray gassing events tend to occur when the insulating oils are mixed with certain transformer materials or when certain conditions are met. However, there are still many others transformer materials not covered in the study which may contribute to the formation of stray gases. Therefore, in this paper, uninhibited and inhibited transformer oils will be mixed with different transformer materials, such as diamond dotted paper, metal plate, coated metal plate, insulation glue, and core metal to find out the effect of these materials on stray gas formation. The effect of temperature will also be looked into.

2.0 METHODOLOGY

In this section, subsection 2.1 shows a brief concept on the uninhibited and inhibited oils, subsection 2.2 explains on the DGA and the experiment setup is shown in subsection 2.3.

2.1 Uninhibited and Inhibited Oils

The definition, advantages and disadvantages of uninhibited and inhibited transformer oil are summarized in Table 1. Comparing both types of oil, inhibited oil has more benefits that help in making the electrical system more consistent where the ageing process can be more predictable and measurable.

Table 1 Comparison between Uninhibited and Inhibited Oil [13], [14]

Transformer Oil	Uninhibited	Inhibited
IEC60296 Definition	Mineral insulating oil, containing no antioxidant additives, but may contain other additives	Mineral insulating oil containing a minimum of 0.08% and a maximum of 0.40% antioxidant additive together with other additives.
Advantages	Less prone to oxidation	-More predictable -Greater purity -More oxidation resistant -Longer oil life
Disadvantages	-Less predictable -More impurity -Less oxidation resistant -Shorter oil life	Prone to oxidation if synthetic inhibitor is not added

2.2 Dissolved Gas Analysis

According to IEEE C57.104-2019, dissolved gas analysis is defined as the identification, measurement, and interpretation of gases dissolved in the insulating liquid of electrical equipment [15]. The gases measured include hydrogen (H_2), oxygen (O_2), nitrogen (N_2), methane (CH_4), ethylene (C_2H_4), ethane (C_2H_6), acetylene (C_2H_2), carbon monoxide (CO), and carbon dioxide (CO_2) as stated by IEC 60599 [16].

2.2.1 Stray Gas Measurement

Stray gassing measurement is described in both ASTM D7150 [10] and CIGRE Technical Brochure 296 [17]. According to both standards, the oil sample need to be degassed under vacuum or filtered, saturated with air or nitrogen and placed in glass syringes. The oil-filled syringe is then aged at 120℃ for 16 to 164 hours (CIGRE TB 296) and 164 hours (ASTM D7150). Finally, the oil sample is tested for the dissolved gas concentrations.

2.2.2 Gas Generation Chart

The gas generation chart is a chart showing the approximate oil decomposition temperature of the combustible gas generation which is similar to the gas formation in a petroleum refinery. From the chart in Figure 1, the partial discharge activity is shown to be independent of the temperature factor, and the H_2 gas generation is the highest compared to other fault gases. The normal operating temperature for the transformer is shown to be 65℃ and no abnormal generation of fault gases was happening at this temperature. When the temperature is further increased, H_2 and CH_4 begin to form at 150℃, C_2H_6 begin to form at 250℃, C_2H_4 begin to form at 350℃ and C_2H_2 will begin to form at a temperature between 500℃ to 700℃. It is noticed that H_2 and CH_4 gases were generated at every temperature higher than 150℃. This approximate temperature of the oil decomposition is important to help in understanding more about the gassing behaviour of the insulating oil.

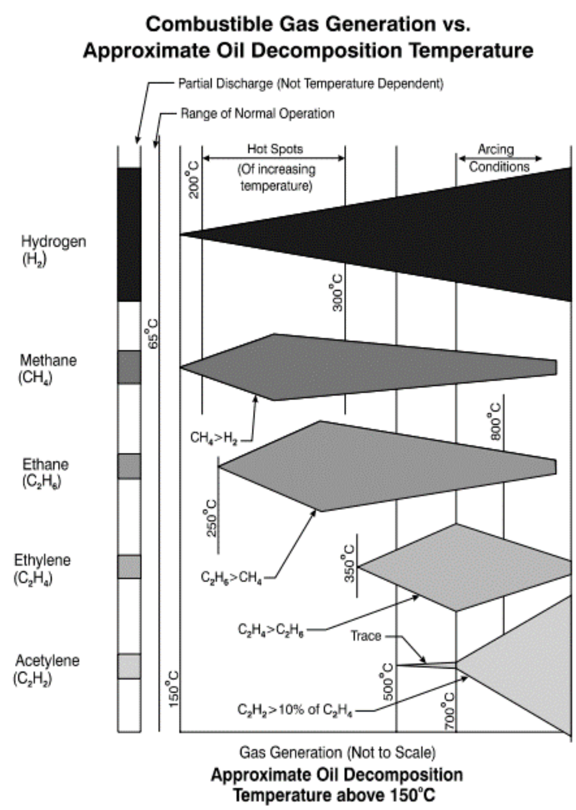


Figure 1 Combustible Gas Generation against Temperature [18]

2.3 Experimental Setup

In this experiment, both inhibited and uninhibited transformer oils were tested. Based on standard ASTM

D7150, all the oil samples are sparged with dry air for 30 minutes. The oil samples are then prepared in a glass bottle. Materials in the transformer are added to some of the oil samples to determine the effect of the formation of stray gases in transformer oil. The combination of transformer oil and materials are represented as follows:

- Insulating Oil only (O)
- Insulating Oil + Diamond Dotted Paper (O + P)
- Insulating Oil + Metal Plate (O + M)
- Insulating Oil + Coated Metal Plate (O + CM)
- Insulating Oil + Glue (O + G)
- Insulating Oil + Core Metal (O + C)

The experiment is conducted with the temperature set at 120℃ and the heating time is up to 164 hours as stated in standard ASTM D7150 [10]. The temperature 120℃ is assumed to be the summation of the highest ambient temperature allowance (40 ˚C) and highest winding temperature rise (80 ˚C), as stated in the IEEE standard C57.12.00-2021 [19]. However, since the normal operating transformer temperature will not reach as high as 120℃ in actual, therefore, a much lower temperature of 85℃ is additionally taken to monitor the gassing behaviour under lower temperature conditions. Figure 2 shows the materials to mix with transformer oil and Figure 3 shows the transformer oil and materials prepared in syringes after sparging with dry air.

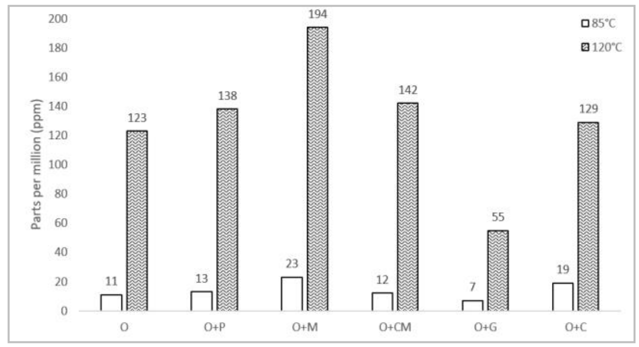
Figure 2 Materials to mix with Transformer Oil

Figure 3 Syringes filled with Transformer Oil mix with Transformer Materials for Heating

3.0 RESULTS AND DISCUSSION

3.1 Effect of Temperature and Material on H_2 Formation

Figure 4 shows the formation of H_2 gas due to the various temperatures and materials. For uninhibited oil, at 85 ℃, there is only 11 ppm of H_2 gases present inside the oil after being heated for 164 hours. The H_2 gases generated in the mixture of uninhibited oil with a diamond dotted paper and with the coated metal plate are almost the same which are 13 ppm and 12 ppm respectively.



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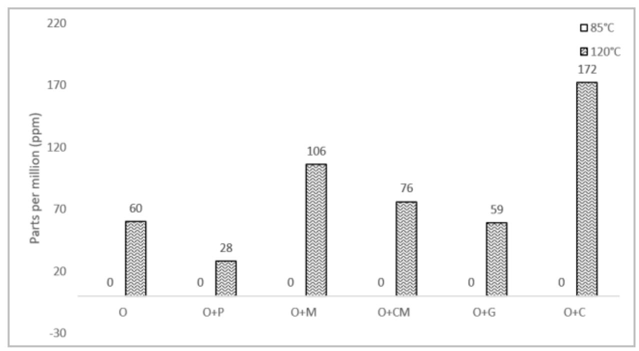


(b)

Figure 4 Effect of Temperature and Materials towards Formation of H_2 in (a) Uninhibited Oil (b) Inhibited Oil Heated for 164 Hours

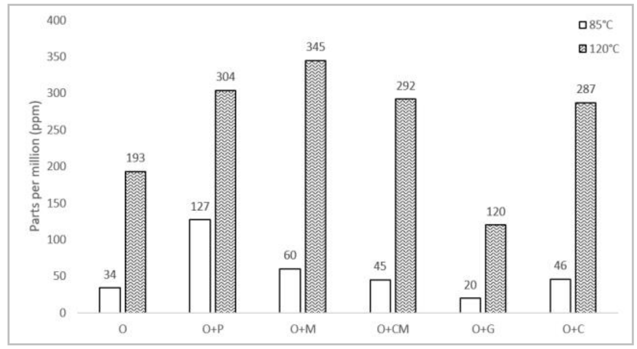
This means that these two materials will not cause the generation of more H_2 gases at 85 ℃. For the uninhibited oil mixed with metal plate and with core metal, there is a slight increase in the H_2 gases generated while the mixture of uninhibited oil and insulation glue shows a slight decrease in the H_2 gases generated. Therefore, the metal compounds will cause the generation of H_2 gases when heated with uninhibited oil while the insulation glue will reduce the H_2 gases in the uninhibited oil. With the thermal stress increased to 120℃, H_2 generation in the uninhibited oil also increased significantly to 123 ppm. The H_2 gases generated in the uninhibited oil mix with a diamond dotted paper, coated metal plate, and core metal show only a slight increment compared to the uninhibited oil only from 9 to 19 ppm. For uninhibited oil mixed with a metal plate, the

H_2 gases increased to 194 ppm. Therefore, at 120 ℃, the metal plate will cause the generation of high H_2 concentration, and a diamond dotted paper, coated metal plate and core metal will cause a slight increase in H_2 concentration. As for uninhibited oil mixed with insulating glue, the behaviour of H_2 generation is similar to as 85 ℃ where the H_2 generated is decreased compared to uninhibited oil only, to 55 ppm.

For inhibited oil, no H_2 gases were detected in the transformer oil even after being heated for 164 hours at 85 ℃. The mixture of the transformer materials with the inhibited oil also did not produce any H_2 gas at this temperature. This means that the inhibited oil is more stable than the uninhibited oil under an operating temperature of 85 ℃ and below. When the thermal stress is increased to 120 ℃, the H_2 gas generated in the inhibited oil increases to 60 ppm. Even at this temperature, the increment of H_2 gas is still lower compared to the uninhibited oil. Mixing of the core metal and the inhibited oil at 120 ℃ generates the highest H_2 gases, which is 172 ppm, followed by a metal plate with 106 ppm and coated metal plate with 76 ppm. Therefore, metal materials were found to be causing an increment in H_2 gas generation in both inhibited and uninhibited oil. For the mixture between the inhibited oil and insulating glue, there are almost no changes to the H_2 gases in the oil. As for the mixture between diamond dotted paper and inhibited oil, the H_2 in the oil decreased to only 28 ppm.

3.2 Effect of Temperature and Material on Co and Co2 Formations

In this section, the discussions for CO and CO_2 gases are combined since both are the key gases in indicating cellulose ageing in paper insulation. Referring to the uninhibited oil itself heated at 85 ℃ for 164 hours as shown in Figure 5 and Figure 6, there are not many CO (34 ppm) and CO_2 (211 ppm) gases generated. When the uninhibited oil is heated together with the metal plate, coated metal plate, and core metal, there is a small increment in the CO and CO_2 generation in the oil. For the mixture of uninhibited oil and glue, the CO and CO_2 gases lowered to 20 ppm and 209 ppm respectively. The small changes in the CO and CO_2 concentration are explained in Cigre Brochure 323-2007 [20] as the oxidation products of the oil. The CO and CO_2 gases for the uninhibited oil itself under high thermal stress increase to about 190 ppm and 399 ppm respectively. As for the mixture of uninhibited oil with the metal plate, coated metal plate, and core metal, the CO gas increases from less than 60 ppm to about 300 ppm. The mixture of uninhibited oil and insulation glue also increases the CO gas from 20 ppm to 120 pm. For the CO_2 gas generation in the mixture of uninhibited oil with metal plate and core metal, the CO_2 gas increases from less than 300 ppm to nearly 1000 ppm while the mixture of uninhibited oil with insulation glue and core metal, the CO_2 gas increases from less than 300 ppm to nearly 700 ppm.



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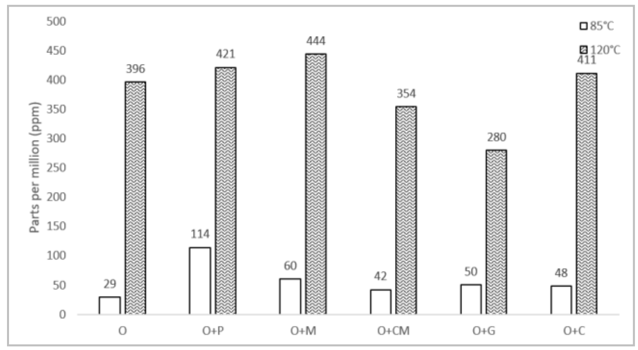

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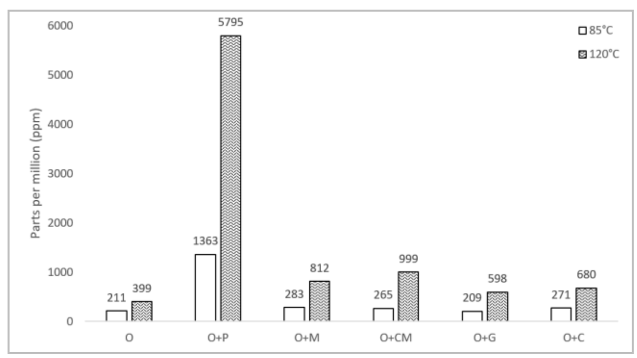
Figure 5 Effect of Temperature and Materials towards Formation of CO in (a) Uninhibited Oil (b) Inhibited Oil Heated for 164 Hours



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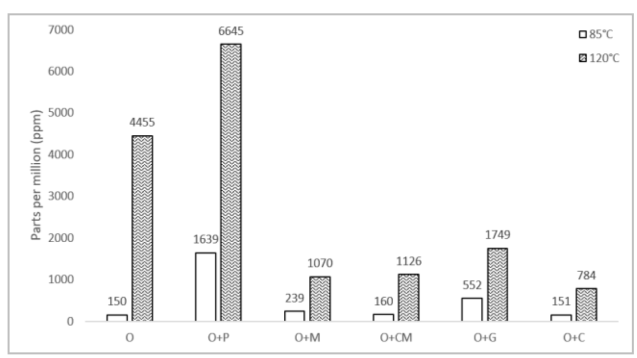


(b)

Figure 6 Effect of Temperature and Materials towards Formation of CO_2 in (a) Uninhibited Oil (b) Inhibited Oil Heated for 164 Hours

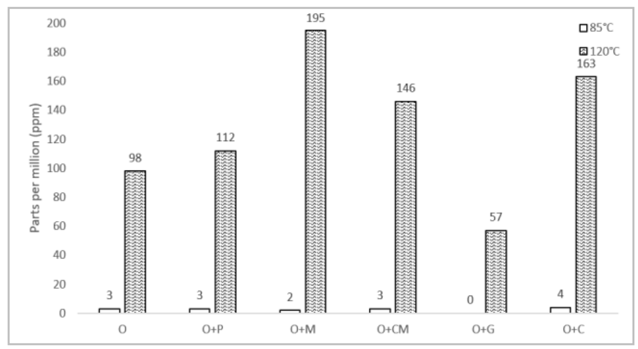
This CO and CO_2 increment is due to the rapid oxidation process in the oil due to a higher thermal environment. For the mixture of uninhibited oil with a diamond dotted paper, the CO gas increases to 304 ppm while the CO_2 gas increases about 5 times to 5795 ppm. Therefore, the paper ageing process will increase when the temperature is increased.

For the inhibited oil heated at 85℃, after 164 hours, there is only 29 ppm of CO gas and 150 ppm of CO_2 gas generated in the oil. When the inhibited oil is heated together with the transformer materials, most of the materials and the oil mixture show a slight increment in the gas concentration. The mixture of the inhibited oil with the metal plate, coated metal plate, insulation glue, and core metal show an increment in the CO gas concentration of about 10 to 30 ppm. As for the CO_2 gas concentration, the CO_2 gas generated in the mixture of inhibited oil with the coated metal plate and with core metal is about the same as the concentration of CO_2 gas in the inhibited oil itself. CO_2 gas is increased by about two times in the mixture of inhibited oil and metal plate, which is 239 ppm. The behaviour of CO and CO_2 gases generated in the inhibited oil is very similar when compared to the uninhibited oil, except for the mixture of inhibited oil with insulation glue, where a high CO_2 concentration is produced, which is 552 ppm. This indicates that the insulation glue will cause the production of CO_2 gas in the inhibited oil when deal with heat. The highest CO and CO_2 gases are produced in the mixture of inhibited oil with a diamond dotted paper, which is114 ppm of CO and 1639 ppm of CO_2, which are the products of cellulose ageing. For thermal stress of 120 ℃, the CO and CO_2 gases were found to be increasing to a much higher extent in the inhibited oil compared to the uninhibited oil. The CO gas increases from 29 ppm to 396 ppm while the CO_2 gas increases from 150 ppm to 4455 ppm. The mixture of inhibited oil with a diamond dotted paper, metal plate, coated metal plate, and core metal generated about 400 ppm of CO gas. The CO gas generated in the mixture of inhibited oil with glue at 120 ℃ is slightly lower, which is 280 ppm. As for the CO_2 gas, a mixture of inhibited oil with a metal plate and coated metal plate produced about 1100 ppm of CO_2. The CO_2 gas generated is lower in the mixture of inhibited oil with core metal, which is 784 ppm, and higher in the mixture of inhibited oil with insulation glue, which is 1749 ppm. Therefore, the insulation glue will cause a significant increase in CO_2 gas in inhibited oil, but this reaction does not occur in the uninhibited oil. For the mixture of inhibited oil with a diamond dotted paper, the highest amount of CO_2 gas is produced, which is 6645 ppm.

According to the transformer magazine published by Mladen Banovic *et al.*, the CO_2/CO ratio of more than 10 indicates the cellulose ageing from thermal heating [21]. The increase in the thermal stress to 120 ℃ also increases the oxidation rate of the cellulose and will greatly increase the generation of CO and CO_2 gases in the insulation oil. Therefore, based on the results obtained, the CO_2/CO ratio for the mixture of oil and a diamond dotted paper in the uninhibited oil is more than 10 when heated at 85 ℃ and the ratio increases to about 20 when the thermal stress of 120 ℃ is applied. As for the inhibited oil, the CO_2/CO ratio for the mixture of oil and a diamond dotted paper increases from about 14 to about 15 with the increasing thermal stress from 85 ℃ to 120 ℃.

3.3 Effect of Temperature and Material on Ch_4 Formation

In DGA, a significant increase in the hydrocarbon gases is mostly representing the discharging fault or thermal fault in the transformer. Referring to Figure 7, there is only 3 ppm of CH_4 detected in the uninhibited oil, even after heated for 164 hours at 85 ℃. The mixture of uninhibited oil with different transformer materials does not affect the increase of CH_4 gas in the oil with the detection of less than 4 ppm of CH_4 gas.



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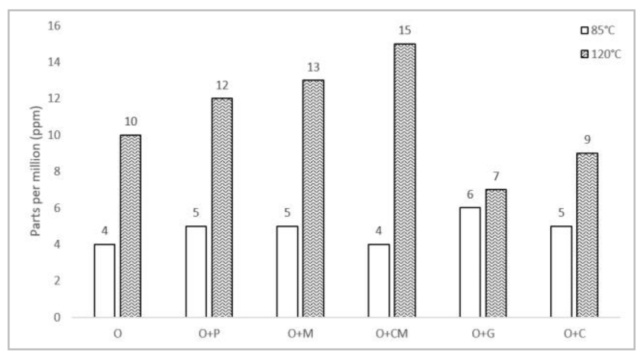


(b)

Figure 7 Effect of Temperature and Materials towards Formation of CH_4 in (a) Uninhibited Oil (b) Inhibited Oil Heated for 164 Hours

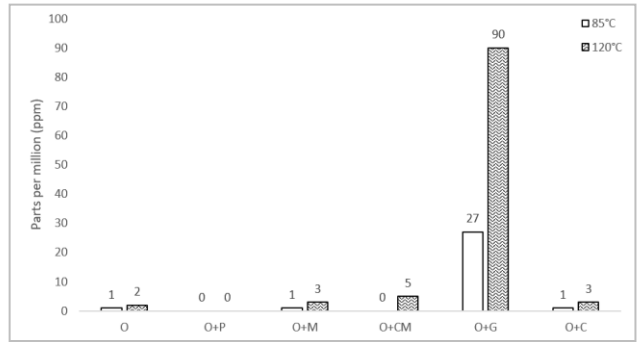
This means that the transformer fault will normally not occur under lower temperature. The increase in thermal stress to 120 ℃ increases the CH_4 generation in the uninhibited oil. For the uninhibited oil only, the CH_4 concentration increases to 98 ppm. The highest increase in the concentration of CH_4 gas is found in the mixture of uninhibited oil with a metal plate, in which the CH_4 increases to 195 ppm. Heating the mixture of uninhibited oil with other metal materials at

120 ℃ also resulted in the formation of high concentrations of CH_4 gas, such as in oil and core metal (163 ppm) and oil and coated metal plate (146 ppm). Therefore, the reaction of metal materials in the uninhibited oil at high temperatures is the main cause of the high concentration of CH_4 gas formation. For a mixture of uninhibited oil with a diamond dotted paper, although there is an increment in the CH_4 gas, the increment is only about 10 ppm. Only a mixture of uninhibited oil and insulation glue shows a decrease in terms of CH_4 gas generated, where the concentration of CH_4 lowered down to only 57 ppm.

For the inhibited oil, at 85 ℃, only 4 ppm of CH_4 gas is detected. Heating the mixture of inhibited oil with different transformer materials also shows a constant value of CH_4 concentration with only less than 6 ppm. Although the increase of thermal stress to 120 ℃ in the inhibited oil increases the CH_4 gas generated in the oil, only to a small extent. For the inhibited oil itself, the concentration of CH_4 increases from 4 ppm to 10 ppm. A mixture of inhibited oil with different transformer materials also resulted in the formation of CH_4 gas with concentrations of only less than 15 ppm. The highest increment in the CH_4 gas in inhibited oil is detected from the mixture of oil with a coated metal plate and with metal plate, which is 15 ppm and 13 ppm respectively. Therefore, in inhibited oil, a large amount of CH_4 gas will not be generated in normal condition, even at 120 ℃. The effect of metal materials on the generation of more CH_4 gas will also be greatly reduced in the inhibited oil. This indicates that the addition of an inhibitor in the oil is also helpful in limiting the decomposition of CH_4 at 120℃.

3.5 Effect of Temperature and Material on C_2H_4 Formation

Figure 8 represents the concentration of C_2H_4 in the transformer oil after being heated for 164 hours. At 85 ℃, there is almost no C_2H_4 gas detected in the uninhibited oil. Heating the mixture of uninhibited oil with a diamond dotted paper, with metal plate, a coated metal plate, and core metal at this temperature also did not produce any C_2H_4 gas, where the C_2H_4 gas concentration in the oil remains at less than 1 ppm. However, 27 ppm of C_2H_4 gas is detected in the mixture of uninhibited oil with insulation glue. This indicates that insulation glue is responsible for the production of a small concentration of C_2H_4 in the uninhibited oil. When increasing the thermal stress to 120 ℃, there is almost no difference in the C_2H_4 concentration in the uninhibited oil when compared to 85 ℃, where the C_2H_4 gas only rises for 1 ppm. Heating the mixture of uninhibited oil with most of the transformer materials investigated at 120 ℃ also show a very minor increment of C_2H_4 gas with only less than 5 ppm except for the insulation glue. The mixture of uninhibited oil and insulation glue heated at 120 ℃ produced even higher concentrations of C_2H_4 up to 90 ppm.



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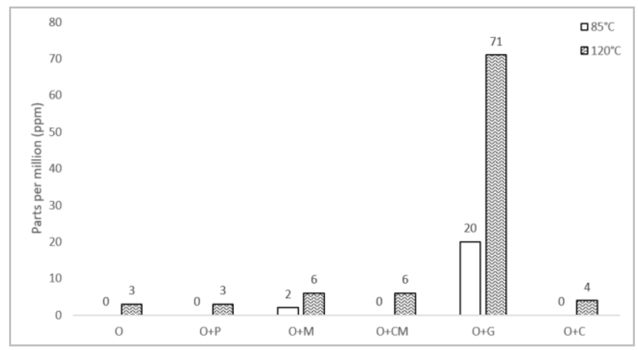

(b)

Figure 8 Effect of Temperature and Materials towards Formation of C_2H_4 in (a) Uninhibited Oil (b) Inhibited Oil Heated for 164 Hours

The behaviour of C_2H_4 generation in inhibited oil is almost the same as in the uninhibited oil. At 85 ℃, no C_2H_4 gas is detected in the inhibited oil. For the mixture of inhibited oil with a diamond dotted paper, metal plate, coated metal plate, and core metal, there are also almost no C_2H_4 gas being detected. Similarly, C_2H_4 gas is only detected in the mixture of inhibited oil with insulation glue, which is 20 ppm. Increasing the thermal stress to 120 ℃ also has only a slight effect on the C_2H_4 gas generation in inhibited oil, where only 3 ppm of C_2H_4 gas is generated. Except for mixture of inhibited oil with insulation glue, only less than 6 ppm of C_2H_4 gas is generated in the mixture of inhibited oil and other investigated transformer materials. A mixture of inhibited oil with insulation glue at 120 ℃ generated 71 ppm of C_2H_4 gas. Although there is some C_2H_4 gas being detected in the inhibited oil, the concentration is still within the acceptable range as stated by the IEEE dissolved gas concentration limit, which is probably produced from the insulation glue.

3.6 Summary of Findings

Based on the results and discussion from previous sections, Table 2 summarizes the important findings from the dissolved gases in both uninhibited and inhibited transformer oil.

Table 2 Findings from Effect of Temperature and Materials

Gas	Oil Type	Findings
H_2	Uninhibited	Metal plate, coated metal plate and core metal are the main cause of the generation of H_2 in the oil at 85℃ and 120℃.
	Inhibited	Transformer materials do not affect the H_2 generation in the oil at 85℃. Metal plate, coated metal plate and core metal are the main cause of the generation of H_2 in the oil at 120℃.
CO, CO_2	Uninhibited	Insulation paper is the main cause of the generation of CO and CO_2 gases in the oil at 85℃ and 120℃. The CO_2/CO ratio increases from about 10 to about 20 with the increasing temperature from 85℃ and 120℃.
	Inhibited	Insulation paper is the main cause of the generation of CO and CO_2 gases in the oil at 85℃ and 120℃. The CO_2/CO ratio increases from about 14 to about 15 with the increasing temperature from 85℃ and 120℃.
CH_4	Uninhibited	Transformer materials do not affect the generation of CH_4 in the oil at 85℃. Metal plate, coated metal plate and core metal are the main cause of the generation of CH_4 in the oil at 120℃.
	Inhibited	Transformer materials do not affect the generation of CH_4 in the oil at 85℃ and 120℃.
C_2H_4	Uninhibited	Insulation glue is the main cause of the generation of C_2H_4 in the oil at 85℃ and 120℃.
	Inhibited	Insulation glue is the main cause of the generation of C_2H_4 in the oil at 85℃ and 120℃.

4.0 CONCLUSION

In conclusion, stray gassing was more likely to happen in the uninhibited oil compared to the inhibited oil. This is shown where the metal materials generated a significant amount of H_2 gas in the uninhibited oil at 85 ℃ but did not affect the inhibited oil. However, H_2 gas generation in both the uninhibited and inhibited transformer oil is closely related to the metal materials used in the transformer when the transformer operating temperature reaches 120 ℃. The metal materials also caused the generation of CH_4 gas in the uninhibited oil at 120 ℃ but no effect was found in the inhibited oil. The diamond dotted paper was found the be the main cause for the generation of CO and CO_2 gases in both the uninhibited and inhibited oil under heat, even at 85 ℃, which is due to the cellulose ageing whereas the insulation glue was found to be the main cause for the generation of C_2H_4 gas in the uninhibited and inhibited oil under heat.

As some of the fault gases generated in the transformer oil are not obvious when compared based on temperatures of 85℃ and 120℃, therefore, a set of controlled specimens at room temperature should also be included to provide better comparison and indication of findings.

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