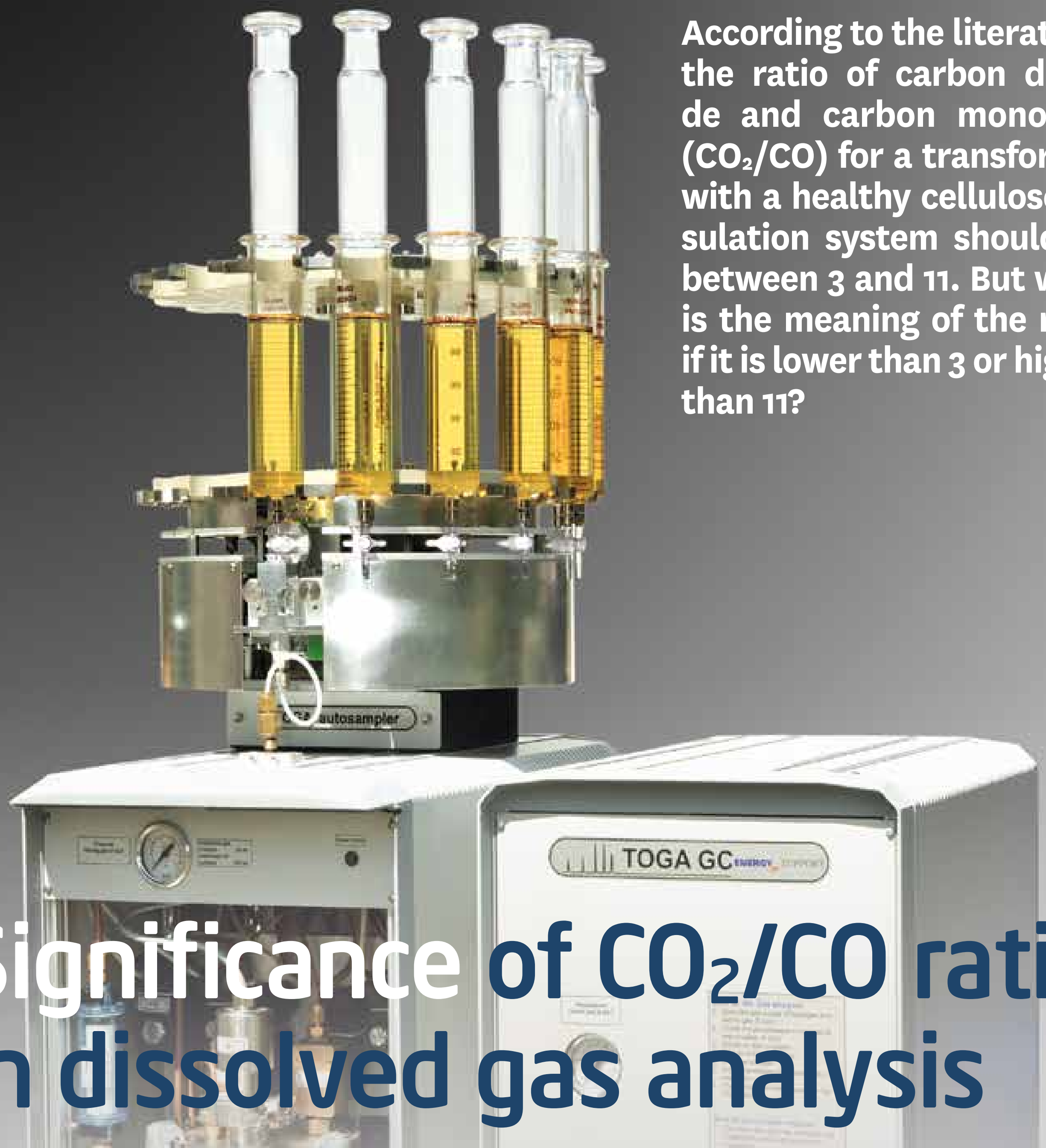

According to the literature, the ratio of carbon dioxide and carbon monoxide (CO_2/CO) for a transformer with a healthy cellulose insulation system should be between 3 and 11. But what is the meaning of the ratio if it is lower than 3 or higher than 11?

Significance of CO_2/CO ratio in dissolved gas analysis

Exchanging experiences about dissolved gas interpretation

ABSTRACT

According to the literature, the ratio of carbon dioxide and carbon monoxide (CO2/CO) for a transformer with a healthy cellulose insulation system should be between 3 and 11. If results of the dissolved gas analysis (DGA) of oil from transformers in service give the ratio value of CO2/CO less than 3, it means that the cellulose insulation is degrading rapidly. What is the meaning of this ratio if it is high; say greater than 15 or 20?

KEYWORDS

carbon monoxide, carbon dioxide, ratio, dissolved gas analysis

Introduction

DGA is an interesting topic which introduces several interpretative methods. The most popular ones are key gases, Dornenberg, Rogers ratio and Duval Triangle. The standards IEC 60599 and IEEE C57.104 provide in-depth guidelines, focusing primarily on more expensive and large sized power transformers. Individual gas concentrations provide some information but the ratio and especially the rate of change provides much more helpful information about transformer health.

Carbon monoxide and carbon dioxide in transformer oil

Basically, CO and CO_2 gases are found in oil, originating from the oxidation of cellulose insulation. Combustible gases like hydrogen H_2, methane CH_4, acetylene C_2H_2, ethylene C_2H_4, and ethane C_2H_6 are generated by thermal process such as local overheating and in small concentrations due to partial discharge which decomposes the mineral oil. Normal gas values are shown in the Table 1. These values may vary as per interpreter. One should generate Caution and

Table 1: Widely accepted normal gas value levels

H_2 / ppm	CH_4 / ppm	C_2H_2 / ppm	C_2H_4 / ppm	C_2H_6 / ppm	CO / ppm
<100	<120	<2	<50	<65	<350

Warning level to immediately respond or follow up with sample verification or supervision and schedule as needed.

What is considered normal values? What happens if the value (concentration) of one or more gases is higher?

First it is necessary to mention that 'normal' values are determined mostly by using any statistic operation on some large data set. For instance, IEC 60599 defines normal (typical) concentration values as the range of 90 % typical gas concentration values observed in power transformers. In other words, 90 % power transformers have concentration of gases under this range. Nobody can tell whether transformer has a local malfunction if some value is slightly elevated. Each device has to be assessed individually with insight in its history, which means comparing the actual values with historical values.

Meaning of the ratio also relates to the individual CO and CO_2 concentrations. Dividing concentrations as in cases shown in Table 2 provides the same result. However, while the first case is not problematic, the second one can be.

Table 2: Cases with the same CO_2/CO ratio where its meaning can vary

CO_2 / ppm	CO / ppm	CO_2/CO
150	60	2.5
2500	1000	2.5

Table 3: A reported case with high CO_2/CO ratio

CO_2 / ppm	CO / ppm	H_2 / ppm	C_2H_4 / ppm	C_2H_6 / ppm	CO_2/CO
6006	377	42	459	65	15.9

Meaning of the CO_2/CO ratio also depends on the CO_2 and CO historical values (in IEC 60599 clause 6.1 and 9).

The CO_2/CO ratio becomes significant when individual gases are above 5000/500 ppm. A ratio below 3 indicates ageing of insulation by arcing. A ratio above 10 indicates cellulose ageing from thermal heating.

If the paper is degrading due to the local overheating, other gases (H_2, C_2H_2, C_2H_4) have to be present in higher concentrations. The paper is impregnated with oil so the oil is also in contact with hot place and combustible gases should be formed.

If this ratio is less than 3 and higher than 10, one should consider other gases, like H_2, CH_4, C_2H_2, C_2H_4, etc.

Case studies

Case 1

In the reported case showed in Table 3, it was concluded that "paper is degrading and the transformer has a hot spot of about 730 °C." It is not clear whether the conclusion in the reported case was made solely on the basis of DGA or whether some other measurements also supported the diagnosis.

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Case 2

Below data from two transformers (Table 4 and Table 5) show a special case of local overheating of solid insulation. Both units were built in 1985 as sister units (420/15.75 kV; 250 MVA; 40 tonnes of oil). They produced higher concentrations of carbon monoxide during entire service life, however combustible gases were low. The reason was discovered at the end of their life during disassembly. Lead exits of high voltage windings (420 kV) were packed by paper. Paper near the lead was overheated but its layer was so thick that oil was not able to penetrate so deep. Paper near the lead was slightly burnt. Combustible gases were not formed because the affected deep layers of paper were not well impregnated by the oil.

Table 4: DGA data from Unit 1

Year of sampling	Oil temp. °C.	TGC ppm	H_2 ppm	CO ppm	CO_2 ppm	CH_4 ppm	C_2H_6 ppm	C_2H_4 ppm	C_2H_2 ppm	CO_2/CO
2005	52	6,5	46	849	2289	11	4	26	5	2,69
2006	39	8,8	38	540	2042	9	5	31	6	3,78
2007	54	8,6	59	937	2887	9	5	32	7	3,08

Table 5: DGA data from Unit 2

Year of sampling	Oil temp. °C.	TGC ppm	H_2 ppm	CO ppm	CO_2 ppm	CH_4 ppm	C_2H_6 ppm	C_2H_4 ppm	C_2H_2 ppm	CO_2/CO
2005	52	6,9	72	940	2640	14	5	24	3	2,81
2006	38	6,4	45	463	1773	8	3	15	4	3,83
2007	55	7,9	63	926	2814	10	5	22	4	3,04

Case 3

Analysing transformers from a database including approximately 4100 transformers, 9.7 % (401 units) of the transformers were with CO>500 ppm, CO_2>5000 ppm, and CO_2/CO>15. Only 1.7 % (7 units) of those transformers were also confirmed by high Furan values >0.2 ppm, indicating cellulose degradation. For the remaining 8 % (394 units) Furan values were normal. DGA (gases other than CO and CO_2) results for the transformers with high CO_2/CO ratio were analysed and it was observed that only 0.7 % (29 out of 401 units) had abnormal gas values. All the rest were found normal. Gas trending for those transformers has not been performed yet but it is planned.

Table 6 provides a list of such transformers where CO, CO_2 and CO/CO_2 are high and other gasses have low values. Furan analysis was performed and in all cases it was below 0.02 ppm. The samples were taken at low load (<20 % of capacity) during winter with oil temperature of around 40 °C. The transformers tend to get fully loaded in the summer (from May to September) with higher ambient temperature (45÷50 °C in Qatar).

A database containing DGA data of approximately 4100 transformers was analysed regarding the levels of carbon monoxide and carbon dioxide

What could be the reason for high concentrations of CO and CO_2 and high CO_2/CO ratio, when all other gas concentrations are normal, and does it require any action? This question is essential because a significant number of transformers (394 units i.e. around 8 % of the population) are affected by this trend, which cannot be ignored.

The advice to be taken in the case above is that along with concentrations of carbon monoxide and carbon dioxide, the trending is also to be looked into and that

Table 6: Cases of distribution transformers 11/0.433 kV, 800-1600 kVA with high concentrations of CO and CO_2, high CO_2/CO ratio, and low concentrations of other gasses, as well as low furan concentration extracted from a database of about 4100 transformers

	Age	H_2 ppm	CH_4 ppm	C_2H_4 ppm	C_2H_6 ppm	C_2H_2 ppm	CO ppm	CO_2 ppm	N_2 ppm	O_2 ppm	CO_2/CO
Transformer 1	4 years	19	21	4	11	<1	532	14608	75639	9598	27.4
Transformer 2	2 years	77	9	2	<1	<1	401	7043	71416	6374	17.5
Transformer 3	15 years	101	8	2	<1	<1	299	6987	63289	6845	23.3
Transformer 4	7 years	14	10	5	3	<1	855	17945	68302	14685	21.0
Transformer 5	7 years	10	16	9	6	<1	1264	24240	69795	8642	19.2
Transformer 6	8 years	9	6	4	<1	<1	659	12594	68545	15065	19.1
Transformer 7	12 years	4	9	<1	3	<1	519	9087	69166	16913	17.5
Transformer 8	7 years	17	15	7	3	<1	1341	21989	80091	8692	16.4

the oxygen content will also indicate a problem, which is more likely to happen in sealed conservator type transformers.

As stated above, CO_2/CO ratio is significant when CO_2 is above 5000 ppm and CO is above 500 ppm. Below these values, the ratio will not result in correct situation awareness. Accordingly, all transformers from Table 6, except two transformers (Transformers 2 and 3) fulfil this criterion. Even in these cases the CO_2/CO ratio is greater than 10, concentrations of other gases are normal and the situation does not appear to be worrying.

Analysis of data from the other database with approximately 22500 DGA results collected since 1980 show that the limit of 5000 ppm for CO_2 could be too high. According to this study, more realistic limit for CO_2 would be 2000 ppm, while the limit of 500 ppm for CO is in agreement with commonly accepted level.

Influencing factors on concentrations of CO and CO_2

Air from the outside can increase CO_2 in oil. Certain types of synthetic rubbers (inadequately vulcanised) or resin impregnated woods used inside can generate high CO_2/CO ratio.

Furan analysis can indicate excessive ageing of cellulose (if furan is more than 1 ppm, this situation is expected).

Gas generation rate

As per IEEE std C57.104-2008, gas generation rate should be determined and Table 3 of the standard provides recommended actions.

As already mentioned, the rate of gas generation is much more important than a single gas value or a ratio of gases. Therefore, a follow-up of history values is a must to calculate gas generation rate which is a central key for decision making. The formula for calculation of gas generation rate is:

$$GGR = \frac{1}{T} \text{ x } (S_2 - S_1) \text{ x } \frac{100}{S_1} \qquad (1)$$

where:
GGR stands for gas generation rate,
S_1 stands for the first sample value,
S_2 stands for the second sample value, and T stands for the time between samples in days.

This formula was developed for use in traditional lab analysis, i.e. for offline DGA. Nowadays with the technology development, online DGA is available. Many different monitoring units have been introduced to the market. Using fully automated process sampling frequency has been significantly increased to hourly sampling instead of daily or monthly sampling. The formula for calculation of a gas generation rate can also be used with such systems.

Interpretation

Referring back to the eight transformers mentioned in the paragraph Case 3, all are fairly new and individual or total combustible gases are well below the caution level. Transformers 1, 2 and 7 have CO level between 350 and 570 ppm which may indicate that the sampling rate needs to be increased, unless the gas values were caused by a previous event. If CO level rises above 570 ppm and the growth rate is greater than 0.5 %, it indicates a severe problem which requires immediate inter-

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It is important to check the temperature of oil at which the sampling is performed. Solubility of CO_2 in oil drops down drastically with the increase in temperature

vention or removal from service. It is also noted that the O_2 level is well above 3000 ppm which indicates a possible leak and leads to higher CO and CO_2 value.

Recommendations

In the end it is worth to note that every type of oil generates some amount of gases without an evident cause and without a stress. Some studies discover that some mineral insulating oils are able to create hundreds of ppm of CO in the absence of thermal stress.

Some other questions can help to resolve such cases:

Does the service history of units show overloading for long periods?

Are there any continuing oil leaks from the unit?

It is also important to check the temperature of oil at which the sampling is performed. Solubility of CO_2 in oil drops down drastically with the increase in temperature. The solubility of CO and CO_2 (ppm by volume) in oil at the atmospheric pressure with temperature is given in Table 7.

Table 7: Solubility of CO and CO2 (ppm by volume) in oil at the atmospheric pressure

Temperature °C	CO	CO_2
0	118,859	1,434,285
66	134,265	731,742

Remark:

A major part of the content was extracted from the discussion held in Transformers forum. The main purpose of the article is to collect various experiences and present problems which can be faced in different regions of the world on the one hand, and on the other to enhance communication about technical problems on the global scale. Therefore, individual views of authors do not necessarily coincide with the views set out in this paper.

The discussion was started by Faisal Nouman.

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