Application Note 10348

Advantages of the TOGA-Transformer Oil Gas Analyzer Involving Headspace-GC Analysis and a DGA System

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Introduction

Dissolved Gas Analysis (DGA) is one of the most widely used diagnostic tools for detecting and evaluating faults in the electrical equipment. Faults in the electrical transformers can result in the production of gases, which remain dissolved in the transformer fluid. The transformer oil and the insulating materials are broken down into characteristic by-products when subjected to possible fault conditions. These indicative gases that are generated in the transformer provide insight to the type of the fault. The transformer gases formed are H_2, CO, and CO_2, found along with the hydrocarbons such as CH_4, C_2H_2, C_2H_4, C_2H_6 and C_3H_8. The identification and quantification of these gases can provide an early indication of problems developing in the electrical equipment. This is useful for a preventive maintenance program.

The present method involves extracting the gas by headspace which is injected into the Thermo Scientific™ TRACE™ 1110 GC system. The analytical conditions and results of analysis of dissolved gases are discussed in the present work.

DGA Analysis Background

The most widely used method for the detection of fault gases is the Dissolved Gas Analysis (DGA) technique. In this method, a sample of the oil is taken from the unit, and the dissolved gases are extracted. The extracted gases are then separated, identified and quantitatively determined. At present, this entire technique is best performed in the laboratory since it requires precision operation. As this method uses an oil sample, it is applicable to all types of transformer units, and like the gas blanket method, it detects all the individual components. The main advantage of the DGA technique is that it detects the gases in the oil phase, providing the earliest possible detection of the incipient fault.

ASTM Methods for DGA

The ASTM methods including D-3613, D-2945, and D-3612, respectively, describe in detail the sampling, gas extraction, and analytical procedures. IS-9434-92 gives the guidelines for sampling and analysis of free and dissolved gases, and the equipment, which is specially required for this purpose, is commercially available in the market.

Methods of Interpretation

Permissible concentrations of dissolved gases in the oil of a healthy transformer are listed in Table 1 [1].

The flagpoints for various DGA gases are presented in Table 2.

Table 2. Flag points for various DGA gases.

Gas	Flagpoint [ppm]
Hydrogen	1500
Methane	35
Ethylene	150
Acetylene	7
Carbon monoxide	1000
Carbon dioxide	10,000

Table 1. Permissible range of concentrations of dissolved gases in the transformer oil depending on the years in service.

Gas	< 4 years [ppm]	4 to 10 years [ppm]	>10 years [ppm]
Hydrogen	100-150	200-300	200-300
Methane	50-70	100-150	200-300
Acetylene	20-30	30-50	100-150
Ethylene	100-150	150-200	200-400
Ethane	30-50	100-150	100-150
Carbon monoxide	200-300	400-500	800-1000
Carbon dioxide	3000-3500	4000-5000	9000-12000

Table 3. The ratios and type of faults as per Roger's method.

Code				Diagnosis
CH_4/H_2	C_2H_6/CH_4	C_2H_4/C_2H_6	C_2H_2/C_2H_4	
0	0	0	0	Normal
5	0	0	0	Partial discharge
1.2	0	0	0	Slight overheating 150°C
1.2	1	0	0	Slight overheating 150-200°C
0	1	0	0	Slight overheating 200-300°C
0	0	1	0	General conductor overheating
1	0	1	0	Winding circulating currents
1	0	2	0	Core, tank circulating currents, overheated joints
0	0	0	1	Flashover, no power follow thigh
0	0	1.2	1.2	Arc, with power follow through
0	0	2	2	Continuous sparking to floating potential
5	0	0	1.2	Partial discharge with cracking (note CO)
CO_2/CO				Diagnosis
>11				Higher than normal temperature in insulation

Roger's Method

This method is used for hydrocarbon gases. By evaluating the gas ratios, the type of fault is detected. This is a reliable method, as it eliminates the effect of oil volume. In this method, four ratios are used: methane/hydrogen, ethane/methane, ethylene/ethane, and acetylene/ethylene[1]. The value of ratios can be greater or less than unity. The ratios and type of faults are given below in Table 3.

The official method ASTM D-3612 offers three methods for the DGA analysis [2].

A.) Vacuum extraction:

Dissolved gases from the transformer oil are extracted by vacuum using a glass apparatus and then analyzed by a GC system.

B.) Stripper column method:

In this method, gases are extracted by using a high surface area bead stripper column, and the gases from the said column are analyzed on GC system.

C.) Head Space Sampling (HSS) method:

In this method, the oil sample is kept in a headspace sampling vial, and the headspace is purged with argon gas, which in turn is analyzed on a GC system.

The present work employs method C by using a HSS-GC system-TOGA(Transformer oil gas analyzer) [2].

Experimental

Sample Preparation

The calibration standard is carefully transferred into the headspace vial. The gases are extracted from the oil by means of the Thermo Scientific™ TriPlus™ 300 Headspace autosampler and injected onto a Thermo Scientific TRACE™ 1110 GC with two detectors. The thermal conductivity detector (TCD) was used for the analysis of H_2, O_2, and N_2. The FID with methanizer was used for the analysis of CH_4, CO, CO_2, C_2H_6, C_2H_4, C_2H_2 and C_3H_8.

The fraction containing hydrogen, oxygen, nitrogen, CO, and methane is analyzed by a molecular sieve-5 Å column. Hydrogen, oxygen, and nitrogen are detected by the TCD. After passing through the methanizer, CO and methane are detected by the FID. When the molecular sieve column is bypassed, CO_2 and the C_2-C_3 isomers are separated and eluted from the porous polymer Porapak-N column and detected by the flame-ionization detector (FID) after passing through the methanizer.

Instrumentation

The headspace sampling was performed using the TriPlus 300 headspace autosampler system coupled with a TRACE 1110 GC. The schematic diagram of the GC system is shown in Figure 1. The GC parameters are shown in Table 4.

GC Configuration and Analytical Conditions

Table 4. TriPlus 300 HS sampling and injection conditions

Equilibration time	20 min
Vial shaking	20 min
Oven temperature	70 °C
Manifold temperature	110 °C
Transfer line temperature	135 °C
Pressurization time	10 s
Aux gas pressure	1 bar
Pressure equilibration time	10 s
Loop filling time	5 s
Loop size	3 mL
Injection mode	Standard
Injection time	30 s
Sample line purge	10 s

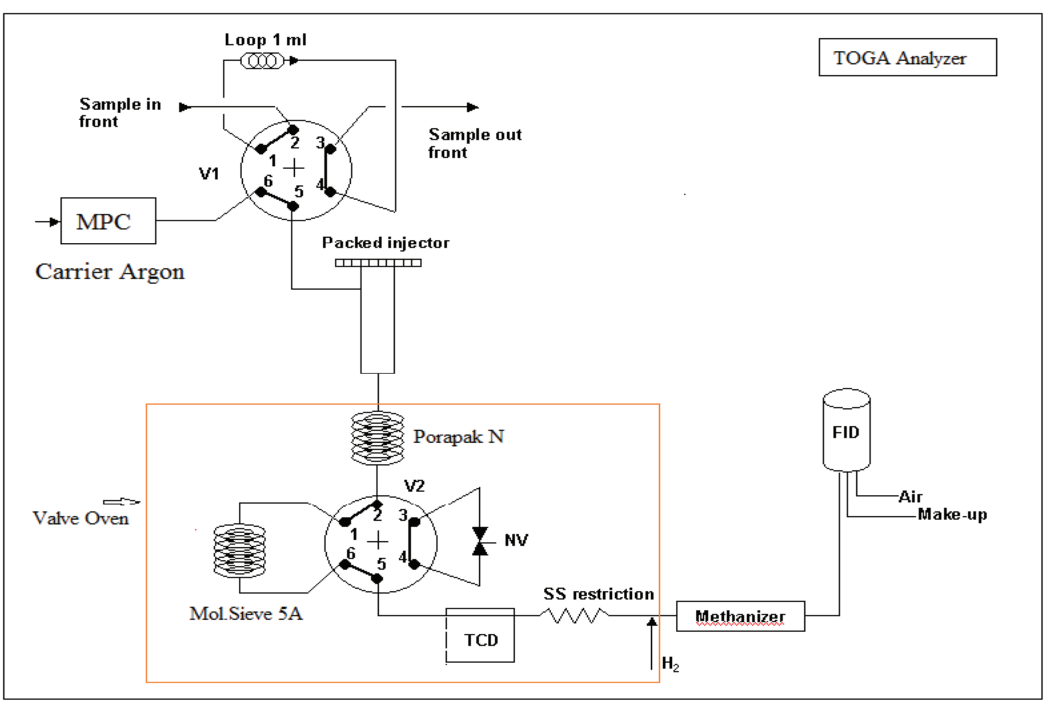


Figure 1. Schematic diagram of the pneumatics of the TRACE 1110 GC TOGA turnkey analyzer.

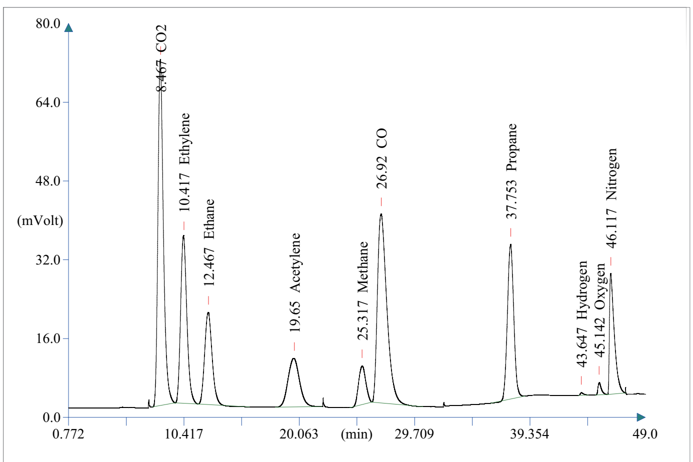
Note: Hydrocarbon components are analyzed on the methanizer and FID while permanent gas components (H_2, O_2, N_2) are analyzed on TCD.

Table 5. TRACE 1110 GC analytical conditions

Carrier gas	Argon
Carrier Gas flow mode	Constant flow, 15 mL/min
Oven program	50 °C, 25 min
	5 °C/min to 120 °C, 1 min
Run time	44 min
Packed injector temp	100 °C
Column 1	10'x 1/8" Porapak™ N+
Column 2	6'x1/8" Mol. Sieve 5A
Valve oven temperature	70 °C
Methanizer temperature	380 °C
TCD detector parameters	
Detector base temperature	200 °C
Detector cell temperature	170 °C
Reference flow	25 mL/min
Make-up flow	10 mL/min
Current and voltage	70 mA at 5 V
FID detector parameters	
Detector temperatures	250 °C
Hydrogen	45 mL/min
Air	300 mL/min
Makeup	10 mL/min
Program flow	
Inject	@ 0.3 min, valve 1
Baypass Mol.Sieve column	@ 7.2 to 22 min, and from 32 to 44 min, valve 2

Results and Discussions

The typical GC analysis chromatogram acquired on the TRACE 1110 GC pertaining to TOGA calibration gas mixture is shown in Figure 2, and the repeatability data for the retention time (RT), area counts, and concentrations for the TOGA components are given below in Table 5.



Retention Time (min)	Area (.1*uV*sec)	PPM	Component Name
8.467	22363070	5178.000	CO2
10.417	12319760	1194.000	Ethylene
12.467	8005859	994.000	Ethane
19.650	6606617	1016.000	Acetylene
25.317	3264635	943.000	Methane
26.920	20968160	5341.000	CO
37.753	11536140	860.000	Propane
43.647	93917	1112.000	Hydrogen
45.142	469693	543000.000	Oxygen
46.117	6870804	934000.000	Nitrogen
	92498660	1493638.000	

Figure 2. Typical GC chromatogram of a TOGA calibration gas mixture.

Table 6. Precision data for retention time, peak area and concentration of the Trace 1110 GC TOGA Analyzer

Retention time repeatability [min]												
Group	Sample name	Filename	CO2	Ethylene	Ethane	Acetylene	Methane	CO	Propane	Hydrogen	Oxygen	Nitrogen
3	TOGA std mix	Ch_FID_ 017	8.50	10.42	12.49	19.66	25.31	26.89	37.68	43.66	45.16	46.13
3	TOGA std mix	Ch_FID_ 018	8.47	10.42	12.47	19.65	25.32	26.92	37.75	43.65	45.14	46.12
3	TOGA std mix	Ch_FID_ 019	8.50	10.44	12.51	19.69	25.39	26.99	37.74	43.67	45.19	46.17
3	TOGA std mix	Ch_FID_ 020	8.50	10.45	12.52	19.67	25.39	26.97	37.78	43.68	45.19	46.17
3	TOGA std mix	Ch_FID_ 021	8.50	10.45	12.52	19.67	25.35	26.89	37.81	43.68	45.19	46.15
		AVERAGE	8.49	10.44	12.50	19.67	25.35	26.93	37.75	43.67	45.18	46.15
		STDEV	0.01	0.02	0.02	0.02	0.04	0.05	0.05	0.01	0.02	0.02
		RSD %	0.18%	0.15%	0.17%	0.08%	0.15%	0.18%	0.13%	0.03%	0.05%	0.05%
		Conclusion : Retention time precision RSD < 0.2%										
Area repeatability of TOGA components [area cts]												
Group	Sample name	Filename	CO2	Ethylene	Ethane	Acetylene	Methane	CO	Propane	Hydrogen	Oxygen	Nitrogen
2	TOGA std mix	Ch_FID_ 017	22317962	12267527	8125045	6953989	3289601	21128208	11828644	92569	476695	6852220
2	TOGA std mix	Ch_FID_ 018	22363072	12319759	8005859	6606617	3264635	20968158	11536142	93917	469693	6870804
2	TOGA std mix	Ch_FID_ 019	21506660	11851886	7859764	6511147	3394139	21651964	11821016	95812	475550	6950548
2	TOGA std mix	Ch_FID_ 020	21641406	11951986	7957841	6494460	3243233	20875176	11589710	96849	483337	6933555
2	TOGA std mix	Ch_FID_ 021	22006936	12152279	8071526	6664818	3215781	20937436	11661285	95302	473541	6937158
		AVERAGE	21967207	12108687	8004007	6646206	3281478	21112188	11687359	94890	475763	6908857
		STDEV	387158	201360	102652	185683	68595	315861	133142	1673	5002	44172
		RSD %	1.76%	1.66%	1.28%	2.79%	2.09%	1.50%	1.14%	1.76%	1.05%	0.64%
		Conclusion : Peak area precision RSD < 3%										
Repeatability of TOGA component concentrations [ppm]												
Group	Sample name	Filename	CO2	Ethylene	Ethane	Acetylene	Methane	CO	Propane	Hydrogen	Oxygen	Nitrogen
4	TOGA std mix	Ch_FID_ 017	5168	1189	1009	1069	950	5382	882	1096	551095	931474
4	TOGA std mix	Ch_FID_ 018	5178	1194	994	1016	943	5341	860	1112	543000	934000
4	TOGA std mix	Ch_FID_ 019	4980	1149	976	1001	980	5515	881	1134	549772	944840
4	TOGA std mix	Ch_FID_ 020	5011	1158	988	999	937	5317	864	1147	558774	942530
4	TOGA std mix	Ch_FID_ 021	5096	1178	1002	1025	929	5333	869	1128	547449	943020
		AVERAGE	5086	1174	994	1022	948	5378	871	1124	550018	939173
		STDEV	90	20	13	29	20	80	10	20	5782	6005
		RSD %	1.76%	1.66%	1.28%	2.79%	2.09%	1.50%	1.14%	1.76%	1.05%	0.64%
		Conclusion : Concentration precision RSD < 3%										

The DGA gases generated in transformer oil can be classified into three groups:

1.) Hydrocarbons and hydrogen: Methane, ethane, ethylene, acetylene and hydrogen

2.) Carbon oxides: Carbon monoxide and carbondioxide

3.) Non-fault gases: Nitrogen and oxygen

The gases from groups 1 and 2 above are critically important to be monitored for insight about the fault in the transformer. The technique explained above can be used to detect and determine fault gases at the desired trace ppm levels.

Classical DGA systems falls under ASTMD-3612 Method A, and utilize a glass system with mercury for dissolved gas extraction from transformer oil [2]. This glass system involves a vacuum pump with mercury vacuum gauge. The following difficulties are faced with this type of glass gas extraction system:

- Glassware is fragile, yet expensive and needs to be handled carefully.
- A large quantity of mercury is required, which is expensive.
- Mercury is highly toxic and banned in many countries.
- Care must be taken about the leakage of the system.
- The vacuum pump may not have a consistency in its performance, and as a result the reproducibility of results may get adversely affected.
- The method of gas extraction is cumbersome and time consuming.

On a contrary there are significant advantages using a DGA system that falls under ASTM D-3612 method C. This system utilizes a Head Space Sampler (HSS) system with a transfer line for gas extraction from transformer oil. The advantages are the following:

* Headspace sampler with heated, inert and flexible transfer line
* reliable, automated headspace sampling
* Heated incubation oven for samples with integrated shaker
* Carrier gas controlled from GC
* Totally automated system
* No use of fragile glassware and highly toxic mercury
* Flexibility of using HSS sampler or manual injection
* Excellent reproducibility and accuracy
* Robust method setup

Conclusion

The advanced TRACE 1110 GC in the configuration for TOGA with automatic headspace sampler offers a fast, accurate, reproducible, rugged, mercury-free, attractive, and simple GC system with both packed and capillary options. It has several advantages over classical DGA system with glass apparatus, as discussed in this technical support article.

References

[1] Sitharaman, B., Vivek, D., Soundankar, A. Instrum. Control J. 2004, Jan-Feb, 16-20.

[2] ASTM D-3612: Standard Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography.

[3] DiGiorgio, J.B., Dissolved gas analysis of mineral oil insulating fluids, Technical article, Northern Technology and Testing (NTT) Bulletin.

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