

# Dissolved Gas Analysis for Transformers



by Lynn Hamrick  
ESCO Energy Services

**T**ransformer oil sample analysis is a useful, predictive, maintenance tool for determining transformer health. Along with the oil sample quality tests, performing a dissolved gas analysis (DGA) of the insulating oil is useful in evaluating transformer health. The breakdown of electrical insulating materials and related components inside a transformer generates gases within the transformer. The identity of the gases being generated can be very useful information in any preventive maintenance program. There are several techniques for detecting those gases and DGA is recognized as the most informative method. This method involves sampling the oil and testing the sample to measure the concentration of the dissolved gases. It is recommended that DGA of the transformer oil be performed at least on an annual basis with results compared from year to year. The standards associated with sampling, testing, and analyzing the results are ASTM D3613, ASTM D3612, and ANSI/IEEE C57.104, respectively. In this article, I will discuss why DGA is a useful, predictive, maintenance tool and review some methodologies for evaluating test results.

The two principal causes of gas formation within an operating transformer are electrical disturbances and thermal decomposition. All transformers generate gases to some extent at normal operating temperatures. Insulating mineral oils for transformers are mixtures of many different hydrocarbon molecules, and the decomposition processes for these hydrocarbons in thermal or electrical faults are complex. The fundamental chemical reactions involve the breaking of carbon-hydrogen and carbon-carbon bonds. During this process, active hydrogen atoms and hydrocarbon fragments are formed. These fragments can combine with each other to form gases: hydrogen ( $H_2$ ), methane ( $CH_4$ ), acetylene ( $C_2H_2$ ), ethylene ( $C_2H_4$ ), and ethane ( $C_2H_6$ ). Further, when cellulose insulation is involved, thermal decomposition or electric faults produce methane ( $CH_4$ ), hydrogen ( $H_2$ ), carbon monoxide (CO), and carbon dioxide ( $CO_2$ ). The gases listed above are generally referred to as key gases.

The gases listed above are considered key gases and are generally considered combustible (note that  $CO_2$  is not a combustible gas). The total of all combustible gases may indicate the existence of any one or a combination of thermal, electri-

cal, or corona faults. The rate at which each of these key gases are produced depends largely on the temperature and directly on the volume of material at that temperature. Because of the volume effect, a large, heated volume of insulation at moderate temperature will produce the same quantity of gas as a smaller volume at a higher temperature. Therefore, the concentrations of the individual dissolved gases found in transformer insulating oil may be used directly and trended to evaluate the thermal history of the transformer internals to suggest any past or potential faults within the transformer.

After samples have been taken and analyzed, the first step in evaluating DGA results is to consider the concentration levels (in ppm) of each key gas. It is recommended that values for each of the key gases be trended over time so that the rate-of-change of the various gas concentrations can be evaluated. Basically, any sharp increase in key gas concentration is indicative of a potential problem within the transformer. Below is a table which has been derived from ANSI/IEEE C57.104 information. The suggested action levels for key gas concentrations are also provided:

Gas Description		Key Gas Concentration (in ppm)		
		Normal Limits* (<)	Action Limits** (>)	Potential Fault Type
Hydrogen	H <sub>2</sub>	150	1,000	Corona, Arcing
Methane	CH <sub>4</sub>	25	80	Sparking
Acetylene	C <sub>2</sub> H <sub>2</sub>	15	70	Arcing
Ethylene	C <sub>2</sub> H <sub>4</sub>	20	150	Severe overheating
Ethane	C <sub>2</sub> H <sub>6</sub>	10	35	Local Overheating
Carbon monoxide	CO	500	1,000	Severe overheating
Carbon dioxide	CO <sub>2</sub>	10,000	15,000	Severe overheating
Total Combustibles	TDCG	720	4,630	

\* As the value exceeds this limit, sample frequency should be increased with consideration given to planned outage in near term for further evaluation.

\*\* As value exceeds this limit, removal of transformer from service should be considered.

This table is derived from information provided within ANSI/IEEE C57.104

Where DGA results include a sharp increase in key gas concentration levels and/or normal limits have been exceeded, it is suggested that an additional sample and analysis be performed to confirm the previous evaluation and determine if the key gas concentrations are increasing. As key gas concentration levels approach the action levels, consideration should be given to taking the transformer out of service for further testing and inspection.

Once key gas concentrations have exceeded normal limits, other analysis techniques should be considered for determining the potential problem within the transformer. The techniques involve calculating key gas ratios and comparing these ratios to suggested limits. Some of the most commonly used techniques include the application of Doernenburg ratios, Rogers ratios, and Duval's Triangle Model.

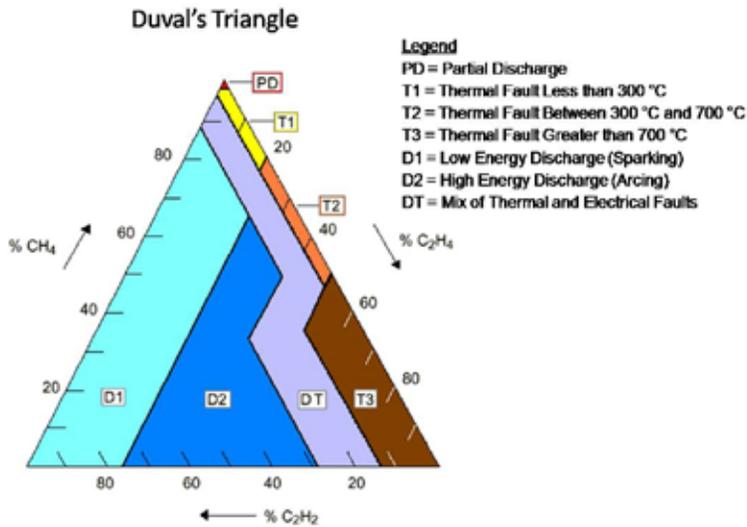
Doernenburg ratios and Rogers ratios are recognized in the ANSI/IEEE C57.104 and are equivalent to the "Basic Gas ratios" in the International Electrotechnical Commission (IEC) standards. The evaluation method applied for Doernenburg ratios and Rogers ratios utilizes the following gas ratios: CH<sub>4</sub>/H<sub>2</sub>, C<sub>2</sub>H<sub>2</sub>/C<sub>2</sub>H<sub>4</sub>, C<sub>2</sub>H<sub>2</sub>/CH<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>/C<sub>2</sub>H<sub>4</sub> and C<sub>2</sub>H<sub>4</sub>/C<sub>2</sub>H<sub>6</sub>. The use of ratios is warranted due to the varying rates of the combustible gas generation with temperature and energy variations for different fault modes. They also allow for different rates that the gases are dissolved into the mineral oil. Diagnosis of faults is accomplished via a simple scheme based on ranges of the ratios. A table of these ranges is provided below.

Ratio Description	Gas Ratio	Fault Type				
		T1 Thermal Fault < 300 deg C	T2 Thermal Fault 300-700 deg C	T3 Thermal Fault >700 deg C	D1 Low Energy/ Partial Discharge	D2 High Energy Discharge
<b>Doernenburg Ratios</b>						
R1 - Methane/Hydrogen	CH <sub>4</sub> /H <sub>2</sub>		1.0 < R1		R1 < 0.1	0.1 < R1 < 1.0
R2 - Acetylene/Ethylene	C <sub>2</sub> H <sub>2</sub> /C <sub>2</sub> H <sub>4</sub>		R2 < 0.75			0.75 < R2
R3 - Acetylene/Methane	C <sub>2</sub> H <sub>2</sub> /CH <sub>4</sub>		R3 < 0.3		R3 < 0.3	0.3 < R3
R4 - Ethane/Acetylene	C <sub>2</sub> H <sub>6</sub> /C <sub>2</sub> H <sub>2</sub>		R4 < 0.4		0.4 < R4	R4 < 0.4
<b>Rogers Ratios</b>						
R1 - Methane/Hydrogen	CH <sub>4</sub> /H <sub>2</sub>	1.0 < R1	1.0 < R1	1.0 < R1	R1 < 0.1	0.1 < R1 < 1.0
R2 - Acetylene/Ethylene	C <sub>2</sub> H <sub>2</sub> /C <sub>2</sub> H <sub>4</sub>	R2 < 0.1	R2 < 0.1	R2 < 0.1	R2 < 0.1	1.0 < R2 < 3.0
R5 - Ethylene/Ethane	C <sub>2</sub> H <sub>4</sub> /C <sub>2</sub> H <sub>6</sub>	1.0 < R5 < 3.0	1.0 < R5 < 3.0	3.0 < R5	R5 < 1.0	3.0 < R5

Duval's Triangle Model is recognized in the IEC Guidelines. The Duval Triangle Model (IEC 60599) combined field service evidence with laboratory experiments published in 1989 followed by enhancements in 2002. Once a potential problem has been determined using the key gas concentration, one calculates the total accumulated amount of three of the key gases, methane (CH<sub>4</sub>), acetylene (C<sub>2</sub>H<sub>2</sub>), and ethylene (C<sub>2</sub>H<sub>4</sub>), and divides each gas by the total of the three gases to find the percentage associated with each gas. These values are then plotted on the triangle below to arrive at a diagnosis. Sections within the triangle designate: thermal fault < 300 °C; thermal fault 300-700 °C; thermal fault > 700 °C; low-energy discharge; high energy discharge; and partial discharge.

The ratio of CO<sub>2</sub>/CO is sometimes used as an indicator of the thermal decomposition of cellulose. The rate of generation of CO<sub>2</sub> typically runs 7 to 20 times higher than CO. Therefore, it would be considered normal if the CO<sub>2</sub>/CO ratio were above 7. If the CO<sub>2</sub>/CO ratio is 5 or less, there is probably a problem. If cellulose degradation is the problem, CO, H<sub>2</sub>, CH<sub>4</sub>, and C<sub>2</sub>H<sub>6</sub> will also be increasing significantly. At this point, it is recommended that additional furan testing be performed. If the CO<sub>2</sub>/CO ratio is 3 or under with increased furans, severe and rapid deterioration of cellulose is occurring and consideration should be given for taking the transformer out of service for further inspection.

When cellulose insulation decomposes due to overheating, chemicals, in addition to CO and CO<sub>2</sub>, are released and dissolved in the oil. These chemical compounds are known as furanic compounds, or furans. In healthy transformers, there are no detectable furans in the oil (<100 ppb). As the cellulose degrades, the furan levels will increase. Furan levels of 500 to 1000 ppb are indicative of accelerated cellulose aging, with furan levels >1500 ppb having a high risk of insulation failure.



increase significantly from one sample to the next, one should perform another sample to verify the results of the previous sample. Once it has been confirmed that the concentrations have increased, use trending and the presented diagnostic techniques to determine what the problem may be. Based on that diagnosis, plan an outage to investigate further and, ultimately, to resolve the problem.

As Operations Manager of ESCO Energy Services Company, Lynn brings over 25 years of working knowledge in design, permitting, construction, and startup of mechanical, electrical, and instrumentation and controls projects as well as experience in the operation and maintenance of facilities.

Lynn is a Professional Engineer, Certified Energy Manager and has a BS in Nuclear Engineering from the University of Tennessee.

In summary, the greatest indicator of potential problems within transformers should not be limited to the concentration levels of the key dissolved gases. By trending the dissolved gas levels, problems can be identified and evaluated further before they cause a catastrophic failure of the transformer. If key gas concentrations