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Dissolved Gas Analysis Guide for Transformers Filled with Beta Fluid

Introduction

Analysis of dissolved gases in transformer dielectric oil is often the best method of detection certain problems that may eventually lead to failure of the transformer. All transformers generate different gases during normal operation. The detection and interpretation of certain key gases and gas quantity ratios allows the transformer operator to predict transformer problems. These techniques have been used with transformers filled with conventional transformer oil for years. They can now be applied to transformers filled with Beta Fluid.

In General, the solubilities and thermal decomposition products of Beta Fluid are very similar to those from conventional transformer oil. This means that the guidelines for interpretation of dissolved gas analysis (DGA) for conventional transformer oil can be followed when working with Beta Fluid.

Why Analyze Dissolved Gases?

Much in the same way that a doctor can analyze a patient's blood to determine certain health problems, the trained transformer owner can detect problems within the transformer by analyzing gases dissolved in dielectric fluid. These problems may include localized overheating, general overheating, arcing within the transformer, and corona discharge.

In a transformer, generated gases can be found dissolved in the insulating oil, in the gas blanket above the oil or in gas collecting devices. The detection of an abnormal condition requires an evaluation of the amount of generated gas present and the rate of gas generation. Some indication of the source of the gases and the kind of insulation involved may be gained by determining the composition of the generated gases.

(1) The theory of combustible gas generation in a transformer
(2) The interpretation of gas analysis
(3) Suggested operating procedures
(4) Diagnostic techniques, such as key gases, Dornenberg ratios, and Rogers ratios

Limitations. Many techniques for the detection and the measurement of gases have been established. However, it must be recognized that analysis of these gases and interpretation of their significance is at this time not a science, but an art, subject to variability. Their presence and quantity are dependent on equipment variables such as type, brand, geometry, and the fault temperature, solubility and degree of saturation of various gases in oil, the presence of an oil preservation system; the type and rate of oil circulation; the kinds of material in contact with the fault; and finally, variables associated with the sampling and measuring procedures themselves.

DGA interpretation is not an exact science, as there is a lack of positive correlation between laboratory data and field experience.

The result of various ASTM investigations indicates that the analytical procedures for gas analysis are difficult, have poor precision, and can be wildly inaccurate, especially between laboratories. Before taking any major action with a transformer, take a second sample to make sure that its analysis agrees with that of the first sample.

This guide is an advisory document. It provides guidance on specific methods and procedures to assist the transformer operator in deciding on the status and continued operation of a transformer that exhibits combustible gas formation. However; operators must be cautioned that, although the physical reasons for gas formation have a firm technical basis, interpretation of that data in terms of the specific cause or causes is not an exact science, but is the result of empirical evidence from which rules for interpretation have been derived.

References The following references should be used in conjunction with this

guide: ASTM D3613 Method for Sampling Gas from a Transformer:

ASTM D3612 Test Methods for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography

ASTM D6117, Methods for Sampling Electrical Insulating Oils for Gas Analysis and Determination of Water Content

ASTM D923, Method of Sampling Electrical Insulating Oil from a Transformer

Differences Between Dissolve Gas Analysis with Mineral Oil and with Beta Fluid

Gas Solubility: As the data below shows, the solubility of various gases in Beta Fluid is very similar to that in conventional transformer oil. In almost every case, the difference between the two fluids is less than 10%, which is well within the error inherent in extraction and analysis methods. This means that the gases, once generated in a transformer, will be soluble in Beta Fluid to the same extent that they are in mineral oil, and that the same analysis techniques can be used.

Ostwald Coefficients for Beta Fluid

Component Gas		Beta	Mineral Oil
Hydrogen	H_2	0.054	0.0558
Nitrogen	N_2	0.081	0.0968
Oxygen	O_2	0.150	0.179
Carbon Monoxide	CO	0.118	0.133
Carbon Dioxide	CO_2	1.13	1.17
Methane	CH_4	0.410	0.438
Ethane	C_2H_6	2.62	2.59
Ethylene (ethene)	C_2H_4	1.79	1.76
Acetylene (ethyne)	C_2H_2	1.39	1.22

Gas Generation in Beta Fluid:

The primary differences between the analysis of dissolved gases produced in Beta Fluid and with mineral oil are in the solubilities of the gases in the oil. Testing has shown that the causes for generation of various gases are the same, whether the fluid in question is conventional transformer oil or Beta Fluid. Overheated cellulose, for example, will generate the same quantity and type of gases, whether in Beta Fluid or mineral oil. The generation of acetylene in the presence of arcing will be the same with both fluids. It is only the generation of lower molecular weight carbon oxides that any appreciable difference between the two fluids is evident.

General Theory of Gas Generation

The two principal causes of gas formation within an operating transformer are thermal and electrical disturbances. Conductor loss due to loading produce gases from thermal decomposition of the oil and solid insulation Gases are also produced from the decomposition of oil and insulation exposed to arc temperatures. Generally, where decomposition gases are formed by ionic bombardment, there is little or no heat associated with low energy discharge and corona.

Decomposition of Cellulose. The thermal decomposition of oil-impregnated cellulose insulation produces carbon oxides (CO, CO2) and some hydrogen or methane (H2, CH4). The rate at which they are produced depends exponentially on the temperature and directly on the volume of material at that temperature. Because of ale 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.

Decomposition. Mineral oils, including Beta Fluid, are mixtures of a wide range of hydrocarbon molecules. The decomposition of these molecules starts with the breaking of carbon-hydrogen and carbon-carbon bonds. Active hydrogen atoms and

Hydrocarbon fragments are formed. These free radicals can combine with each other to form gases, molecular hydrogen, methane, ethane, or can recombine to form new, condensable molecules. Further decomposition and rearrangement processes lead to the formation of products such as ethylene and acetylene. These processes are dependent on the presence of individual hydrocarbons, on the distribution of energy and temperature in the area of the fault, and on the length of time during which the oil is thermally or electrically stressed.

Application to Equipment: As stated above, all transformers generate gases to some extent at normal operating temperatures. But occasionally a gas-generating abnormality does occur within an operating transformer such as a local or general overheating, dielectric \problems, or a combination of these-In electrical equipment, these abnormalities are called faults. Internal faults in Beta Fluid produce the gaseous byproducts hydrogen (H2), methane (CH_4), acetylene (C_2H_2), ethylene (C2H4), and ethane (QC2H6). When cellulose is involved in the overheating, the faults produce methane (CH4), hydrogen (H2), carbon monoxide (CO) and carbon dioxide (CO2). Each of these types of faults produce certain gases that are generally combustible. The total of all combustible gases may indicate the presence of any one or a combination of thermal, electrical, or corona faults. Certain combinations of each of the separate gases determined by chromatography are unique for different temperatures. Also, the ratios of certain key gases have been found to suggest fault types. Interpretation by the individual gases earl become difficult when there is more than one fault, or when one type of fault progresses to another type, such as an electrical problem developing from a thermal condition.

Establishing Baseline Data. Establishing a reference point for gas concentration in new or repaired transformer - and following this with a routine monitoring program is a key element in the application of this guide. Monitoring the health of a transformer must be done on a routine basis and can start anytime, not just for new units

In general, daily or weekly sampling is recommended after start-up, followed by monthly or longer intervals Routine sampling intervals may vary depending on application and individual system requirements.

Recognition of a Gassing Problem-Establishing Operating Priorities. Much information has been acquired over the past 20 years on diagnosing incipient fault conditions in transformer systems, both with oil cooling, or in Beta Fluid. . This information is of a general nature but is often applied to very specific problems or situations. One consistent finding with all schemes for interpreting gas analysis is that the more information available concerning the history of the transformer and test data, the greater the probability for a correct diagnosis the health the uni

Interpretation of Gas Analysis

Thermal Faults

The decomposition of all mineral oils, including Beta Fluid, produces relatively large quantities of the low molecular weight gases, such as hydrogen and methane, and trace quantities of the higher molecular weight gases ethylene. As the fault temperature in Beta Fluid increases, the hydrogen concentration exceeds that of methane, but now the temperatures are accompanied by significant quantities of high molecular weight gases, first ethane and then ethylene. Al the upper end of the temperature range, increasing quantities of hydrogen and ethylene and traces of acetylene (C2H2) may be produced. In contrast with tile thermal decomposition of Beta Fluid, the thermal decomposition of cellulose and other solid insulation produces carbon monoxide (CO), carbon dioxide ($C0_2$), and water vapor at temperatures mach lower than the decomposition of oil and at rates exponentially proportional to the temperature. Because the paper begins to degrade at lower temperatures than the Beta Fluid, its gaseous byproducts are found at normal operating temperatures in the transformer.

Electrical Faults – Low Intensity Discharge

Low Intensity discharge such as partial discharge or intermittent arcing produces mainly hydrogen with small quantities of methane and acetylene. As the intensity of the discharge increases, the acetylene and ethylene concentrations rises significantly.

Electrical Faults; High Intensity Arcing. As the intensity of the electrical discharge reaches arcing or continuing discharge proportions that produce temperatures from 700 ~C to 1800 "C, the quantity of acetylene produced becomes pronounced.

Suggested Operating Procedures Utilizing the Detection and Analysis of Combustible Gases

There are several methods of interpreting Dissolved Gas Analysis data in transformers filled with Beta Fluid. The following are the methods that are recommended by Dielectric Systems, Inc.

Evaluation of Transformer Condition Using Individual and TDCG Concentrations:

Following the suggestion of IEEE Standard C57.104, a four level criterion has been developed to classify risks to transformers when previous dissolved gas history for a given transformer is unknown.

Refer to Table One (below) for concentrations of gases that correspond to the conditions set forth below:

Condition 1
TDCG below this level indicates that the transformer is operating in a satisfactory manner. If you find that any individual gas concentration exceeds the specified level, you should investigate further.

Condition 2
TDCG within this range indicates greater than normal combustible gas concentrations.
Any individual combustible gas exceeding specified levels should be investigated. You should check to see that a trend may be present.

Condition 3
TDCG within this range indicates a high level of decomposition. Any single combustible gas exceeding these levels should be investigated immediately. You should take immediate action to establish a trend, as faults are probably present.

Condition 4
TDCG within this range indicates excessive decomposition of Beta Fluid and cellulose.
Continued operation could result in failure of the transformer.

Table One:
Dissolved Gas Concentrations

Status	H2	Ch4	C2H2	C2H4	C2H6	CO	CO2	TDCG
Condition 1	100	120	35	50	65	350	2500	720
Condition 2	101-770	121-400	36-50	51-100	66-100	351-570	2500-4000	721-1920
Condition 3	701-1800	401-1800	51-80	101-200	101-150	570-1400	4001-10000	1921-4630
Condition 4	>1800	>1000	>80	>200	>150	>1400	>10000	>4630

The condition for a particular transformer is detrmined by finding the highest level for individual gases or the TDCG in Table 1.

Transformers less than a year old usually contain levels of gases that would fall well below Condition 1, and do not contain detectable levels of acetylene. Therefore, the degree of concern in the example would be much higher for a one month old transformer than for a twenty year old unit.

Determining the Transformer Condition and Operating Procedure with Total Combustible Gases (TCG) in the Gas Space Table 2 indicates recommended initial sampling intervals and operating procedures for various levels of TCG (expressed in percent)

	TCG Level, %	TCG Rate, %/day	Sampling Interval	Operating Procedure
Condition 4	>=5	>.03	Daily	Remove from service
Condition 4	>=5	.03-.01	Daily	Remove from service
Condition 4	>=5	<.01	Weekly	Exercise caution, analyze for individual gases, plan outage
Condition 3	<5 to >=2	>.03	Weekly	Exercise caution, analyze for individual gases, plan outage
Condition 3	<5 to >=2	.01-.03	Weekly	Exercise caution, analyze for individual gases, plan outage
Condition 3	<.01	<.01	Monthly	Exercise caution, analyze for individual gases, plan outage
Condition 2	<2 to >= 0.5	>.03	Monthly	Exercise Caution Analyze for individual gases Determine load dependence
Condition 2	<2 to >= 0.5	0.03-0.01	Monthly	Exercise Caution Analyze for individual gases Determine load dependence
Condition 2	<2 to >= 0.5	<0.01	Quarterly	Exercise Caution Analyze for individual gases Determine load dependence
Condition 1	<.5	>.03	Monthly	Normal operation
Condition 1	<.5	.03-.01	Quarterly	Normal operation

Condition 1	<.5	<.01	Annual	Normal operation

Determining the Transformer Condition and Operating Procedure with TDCG, dissolved gas in the oil Table 3 indicates recommended initial sampling intervals and operating procedures for various levels of TDCG (expressed in ppm)

	TDCG Level, ppm	TDCG Rate, ppm/day	Sampling Interval	Operating Procedure
Condition 4	>=4630	>30	Daily	Remove from service
Condition 4	>=4630	10-30	Daily	Remove from service
Condition 4	>=4630	<10	Weekly	Exercise caution, analyze for individual gases, plan outage
Condition 3	1921-4630	>30	Weekly	Exercise caution, analyze for individual gases, plan outage
Condition 3	1921-4630	10-30	Weekly	Exercise caution, analyze for individual gases, plan outage
Condition 3	1921-4630	<10	Monthly	Exercise caution, analyze for individual gases, plan outage
Condition 2	721-1930	>30	Monthly	Exercise Caution Analyze for individual gases Determine load dependence
Condition 2	721-1930	10-30	Monthly	Exercise Caution Analyze for individual gases Determine load dependence
Condition 2	721-1930	<10	Quarterly	Exercise Caution Analyze for individual gases Determine load dependence

Condition 1	<720	>30	Monthly	Normal operation
Condition 1	<720	10-30	Quarterly	Normal operation
Condition 1	<720	<10	Annual	Normal operation

Evaluation of Possible Faults by the Key Gas Method

The four general fault types have a tendency to produce a unique gas that indicates the fault type. While not as precise as the other methods, the "Key Gas Method" is often used as an indication of which fault type to examine in greater detail. The Key Gas Analysis method for use in Beta Fluid follows the method that is used with conventional transformer oil.

Fault Type: Thermal decomposition of Beta Fluid
Principal Gas: Ethylene
Characteristics: Decomposition products include ethylene and methane, along with small quantities of hydrogen and ethane.

Fault Type: Thermal decomposition of Cellulose
Principal Gas: Carbon Monoxide
Characteristics: Decomposition products of cellulose include CO and CO2. If the cellulose is saturated with Beta Fluid, the decomposition products will include hydrocarbon oxides (as above)

Fault Type: Corona –partial discharge:
Principal Gas: Hydrogen
Characteristics: Corona discharges produce hydrogen and methane. If the corona occurs in cellulose, the gas profile will also include CO and CO2

Fault Type: Arcing
Principal Gas: acetylene
Characteristics: Arcing always generates large amounts of acetylene and hydrogen. Carbon oxides may be present if the fault involves cellulose. Carbon may be present in the oil.

Evaluation of Possible Faults by the Rogers and Doernenburg Ratios

Many people believe that the use of ratios of gas concentrations, rather than the concentrations themselves, give a more accurate indication of possible faults inside the transformer. These ratios were developed with European data by Rogers and Doernenburg, and usually require a significant level of gases to be present in order to be used.

The following ratios are

used: Ratio 1 (R1):CH4/H2

Ratio 2 (R2)

C2H2/C2H

4 Ratio 3 (R3)

C2H2/CH4

Ratio 4 (R4)

C2H6/C2H

2 Ratio 5 (R5)

C2H4/C2H

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Doernenburg Ratio Method, Step 1

Collect gas sample from the headspace, above the oil level in a transformer

Doernenburg Ratio Method, Step 2

Check for validity of the method. In order for the ratio methods to be considered valid, at least one of the gas concentrations of H2, Ch4, C2H2 and C2H4 must be at least twice the L1 value (below) and one of the other three gases exceeds the values for limit L1, the transformer is considered faulty.

Also, at least one gas concentration in each ratio must exceed the L1 values given below:

Dissolved Gas	L1 Value, ppm
Hydrogen	100
Methane	120
Carbon Monoxide	350
Acetylene	35
Ethylene	50
Ethane	65

Doernenburg Ratio Method, Step 3

Assuming that the ratio analysis is valid for this transformer, check each ratio in order R1, R2, R3, and R4

Doernenburg Ratio Method, Step 4

If all succeeding ratios for a specific fault fall within the values given in Table 3, the suggested diagnosis is valid.

Doernenburg Ratios for Key Gases

Indicated Fault Diagnosis	Ratio 1	Ratio 2	Ratio 3	Ratio 4
Thermal Decomposition	0.1- 1.0	0.75 – 1.0	0.1 – 0.3	0.2 – 0.4
Corona	0.01 – 0.1	Not significant	0.1 – 0.3	0.2 – 0.4
Arcing	0.1 – 1.0	0.75 – 1.0	0.1 – 0.3	0.2 – 0.4

Rogers Ratios Method:

The Rogers method follows the same general procedure as the Doernenburg method, but only three ratios are used.

Ratio 2	Ratio 1	Ratio 5	Suggested Diagnosis
<0.1	0.1 – 1.0	<1.0	Unit Normal
<0.1	<0.1	>1.0	Corona
0.1 – 3.0	0.1 – 3.0	>3.0	Arcing
<0.1	0.1 – 1.0	1.0 – 3.0	Low temperature overheating
<0.1	>1.0	1.0 – 3.0	Overheating < 700C
<0.1	>1.0	>3.0	Thermal > 700 C.

Conclusion

This Guide provides methods of analysis and interpretation of gases generated in transformers filled with Beta Fluid. The procedures and rules that are used to analyze these gases are identical to those that are used with conventional transformer oil. Tests have shown that the types and quantities of gases that are produced by various types of faults in Beta Fluid are the same as those which are produced in conventional transformer oil. The solubilities of gases in Beta Fluid are within 10%, in most cases, of the solubility values for the same gases in transformer oil.

The analysis of gases in transformers, and their use in prediction of possible faults is an inexact science. This guide should be used as an advisory document only. The transformer users is urged to contact the equipment manufacturer for more detailed information.