A GUIDE TO TRANSFORMER OIL ANALYSIS

BY

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INTRODUCTION

The fault free operation of power transformers is a factor of major economic importance and safety in power supply utilities and industrial consumers of electricity.
In the current economic climate, Industries/Supply Utilites tighten their control on capital spending and make cutbacks in maintenance, an increased awareness is placed on the reliability of the existing electric power supply. Down time is at a premium. Often, the loading is increase on present units , as this will defer purchasing additional plant capacity. Thus the stress on the transformer increases. The net total effect of the thermal , electrical and mechanical stress brought on by increased service needs to be monitored to ensure reliability.

Regular sampling and testing of insulation oil taken from transformers is a valuable technique in a preventative maintenance program. If a proactive approach is adopted based on the condition of the transformer oil, the life of the transformer can be extended.

This paper reviews some of the transformer oil tests and there significance.

WATER CONTENT

Test Method IEC 814

Water, in minute quantities, is harmful in power equipment because it is attracted to the places of greatest electrical stress and this is where it is the most dangerous. Water accelerates the deterioration of both the insulating oil and the paper insulation, liberating more water in the process (heat catalysed).
This is a never ending circle and once the paper insulation has been degraded(loss of mechanical strength) it can never (unlike the oil) be returned to its original condition.

Origins of Water
Water can originate from two sources.

Atmospheric
Via the silica gel breather (dry silica gel is always blue).
Via leaks into the power equipment, i.e. bad gasketing, cracked insulation, a loose manhole cover, a ruptured explosion diaphragm etc. (if oil can get out, water can get in).

Internal Sources
Paper degradation produces water.
Oil degradation produces water.
Wet insulation contaminates the oil, (temperature dependent).

DIELECTRIC STRENGTH

Test Method: IEC 156

The dielectric strength of an insulating oil is a measure of the oils ability to withstand electrical stress without failure.
The test involves applying a ac voltage at a controlled rate to two electrodes immersed in the insulating fluid. The gap is a specified distance. When the current arcs across this gap the voltage recorded at that instant is the dielectric strength breakdown strength of the insulating liquid.
Contaminants such as water, sediment and conducting particles reduce the dielectric strength of an insulating oil. Combination of these tend to reduce the dielectric strength to a greater degree.
Clean dry oil has an inherently high dielectric strength but this does not necessarily indicates the absence of all contaminates, it may merely indicate that the amount of contaminants present between the electrodes is not large enough to affect the average breakdown voltage of the liquid.
Authorities now agree that careless sampling and testing technique has been the source of 99 percent of “bad “dielectric readings

ACIDITY OR NEUTRALISATION NUMBER(NN)
Test Method: ASTM D974

Acids in the oil originate from oil decomposition/oxidation products. Acids can also come from external sources such as atmospheric contamination.
These organic acids are detrimental to the insulation system and can induce corrosion inside the transformer when water is present.
An increase in the acidity is an indication of the rate of deterioration of the oil with SLUDGE as the inevitable by-product of an acid situation which is neglected.

The acidity of oil in a transformer should never be allowed to exceed 0.25mg KOH/g oil. This is the CRITICAL ACID NUMBER and deterioration increases rapidly once this level is exceed.

INTERFACIAL TENSION(IFT)
Test Method : ASTM D971

The Interfacial Tension (IFT) measures the tension at the interface between two liquid (oil and water) which do not mix and is expressed in dyne/cm.
The test is sensitive to the presence of oil decay products and soluble polar contaminants from solid insulating materials.

Good oil will have an interfacial tension of between 40 and 50 dynes/cm. Oil oxidation products lower the interfacial tension and have an affinity for both water (hydrophilic) and oil. This affinity for both substances lowers the IFT. The greater the concentration of contaminants, the lower the IFT, with a badly deteriorated oil having an IFT of 18 dynes/cm or less.

IFT-NN Relationship

Studies have shown that a definite relationship exists between acid number(NN) and Interfacial Tension(IFT). An increase in NN should normally be followed by a drop in IFT. The IFT test is a powerful tool for determining how an insulating oil has performed and how much life is left in the oil before maintenance is required to prevent sludge.
The IFT provided an excellent back up test for the NN.
IFT not accompanied by a corresponding increase in NN indicates polar contamination which have not come from normal oxidation.

Although a low IFT with a low NN is an unusual situation , it does occur because of contamination such as solid insulation materials, compounds from leaky pot heads or bushings, or from a source outside the transformer.

HISTORICAL DATA BASE ESTABLISHING CORRELATION BETWEEN NEUTRALIZATION NUMBER-INTERFACIAL TENSION AND SLUDGE FORMATION IN OIL FILLED TRANSFORMERS		
Neutralization Number vs Sludge (A)		
NN mg/KOH/g	Percent of 500[1]	Units Sludged
0.00-0.10[2]	0	0
0.11-0.20	38	190
0.21-0.60	72	360
0.60 and up	100	500
Interfacial Tension vs Sludge (B)		
IFT Dynes/cm	Percent of 500[1]	Units Sludged
1) Below 14	100	500
2) 14-16	85	425
3) 16-18	69	345
4) 18-20	35	175
5) 20-22	33	165
6) 22-24	30	150
7) Above 24	0	0

[1] ASTM - 11 year test on 500 transformers(1946-57).
[2] Realistic value of 0.03-0.10.

QUALITY INDEX SYSTEM

Dividing the Interfacial Tension(IFT) by the Neutralisation Number(NN) provides a numerical value that is an excellent means of evaluating oil condition. This value is known as the Oil Quality Index(OQIN) or Myers Index Number(MIN).
A new oil , for example has a OQIN of 1500.

$$OQIN = \frac{IFT}{NN} \qquad 1500 = \frac{45.0(\text{typical new oil})}{0.03(\text{typical new oil})}$$

TRANSFORMER OIL CLASSIFICATIONS*		
1.	**Good Oils**	
	NN	0.00 - 0.10
	IFT	30.0 - 45.0
	Colour	**Pale Yellow**
	OQIN	300-1500
2.	**Proposition A Oils**	
	NN	0.05 - 0.10
	IFT	27.1 - 29.9
	Colour	**Yellow**
	OQIN	271 - 600
3.	**Marginal Oils**	
	NN	0.11 - 0.15
	IFT	24.0 - 27.0
	Colour	**Bright Yellow**
	OQIN	160 - 318
4.	**Bad Oils**	
	NN	0.16 - 0.40
	IFT	18.0 - 23.9
	Colour	**Amber**
	OQIN	45 - 159
5.	**Very Bad Oils**	
	NN	0.41 - 0.65
	IFT	14.0 - 17.9
	Colour	**Brown**
	OQIN	22 - 44
6.	**Extremely Bad Oils**	
	NN	0.66 - 1.50
	IFT	9.0 - 13.9
	Colour	**Dark Brown**
	OQIN	6 - 21
7.	**Oils in Disastrous Condition**	
	NN	1.51 or more
	Colour	Black

The four functions of insulating oil is to provide cooling, insulation, protection against chemical attack and prevention of sludge buildup.

The first category is Good in which these functions are efficiently provided.

The second category Proposition A provides all the required function , a drop in IFT to 27.0 may signal the beginning of sludge in solution.

The insulating oil in the third category, Marginal Oils is not providing proper cooling and winding protection. Organic acids are beginning to coat winding insulation, sludge in insulation voids is highly probable.

The categories 4 to 6 Bad Oils, sludge has already been deposited in and on transformer parts in almost 100 percent of these units. Insulation damage and reduced cooling efficiency with higher operating temperatures charactergise the Very Bad and Extremely Bad categories.

The last category “Disaster City” the concern should be how much life remains in the transformer, not just the oil condition.

Once the oil colour changes from the yellows into amber’s and browns, the oil has degraded to the point where the insulation system has been affected Radical colour changes may be caused by: Electrical problem, Pot head or bushing compounds, uncured varnishes or polymers, new oil in a dirty unit.

The situation where NN and IFT were bad , but the colour was light may indicate contamination from sources other than oxidation i.e. a refining problem.

DISSIPATION FACTOR

Test Method: IEC 247

The Dissipation test measures the leakage current through an oil, which is the measure of the contamination or deterioration i.e. Reveals the presence of moisture resin, varnishes or other products of oxidation oil or of foreign contaminants such as motor oil or fuel oil. The test is not specific in what it detects i.e. is more a screening test.

POLYCHLORINATED BIPHENYL

Polychlorinated biphenyl's (PCB) is a synthetic transformer insulating fluid, that has found its way into mineral insulating oil via cross contamination .

POLYCHLORINATED BIPHENYL: Non-specific methods that determines Chlorine in oil, as all PCBs contain some amount of Chlorine.
This test is susceptible to false positive results, i.e. the test indicates the presence of PCB when actually there is none present.

POLYCHLORINATED BIPHENYL: Specific method (ASTM D4059-Gas chromatography/Electron Capture) that differentiates between PCBs and a related compound e.g. trichlorobenzene.
All commercially produced PCB are complex mixtures of many different congeners (A congener is a PCB molecule containing a specific number of chlorine molecules at specific sites)
Analysing for PCB, therefore, is not a case of simply finding an easily quantifiable compound, but of quantifying a complex mixture of compounds.

The main reasons for stopping further use are the environmental risks. PCB is very stable and its degradation process is slow, it is also Biological accumulative in the food chain.

PCB liquid is not more toxic than many other common fluids. The lower the figure, the higher the toxicity

Chemical	LD50 g/Kg
PCB	8.7
Trichloroethylene	5.2
Acetone	9.8
Methyl alcohol	12.9
Polychlorinated dibenzofuranes	<0.001

Far more serious are the risks of a fire or an explosion. At temperatures around 500 degrees C extremely toxic compounds Polychlorinated dibenzfuranes are formed. Small amounts of these compounds have been found at accidents where transformers and capacitors have been exposed to fire or have exploded. Even if the amounts have been extremely small and have caused no personal injuries, it has been necessary to perform very extensive and costly decontamination work.

Evaluation of Transformer Solid Insulation

Direct Evaluation

The mechanical properties of insulating paper can be established by direct measurement of its tensile strength or degree of polymerization (DP). These properties are used to evaluate the end of reliable life of paper insulation. It is generally suggested that DP values of 150-250 represent the lower limits for end-of-life criteria for paper insulation; for values below 150, the paper is without mechanical strength. Analysis of paper insulation for its DP value requires removal of a few strips of paper from suspect sites. This procedure can conveniently be carried out during transformer repairs. The results of these tests will be a deciding factor in rebuilding or scrapping a transformer.

Furaldehyde Analysis

Direct measurement of these properties is not practical for in-service transformers. However, it has been shown that the amount of 2-furaldehyde in oil (usually the most prominent component of paper decomposition) is directly related to the DP of the paper inside the transformer.

Paper in a transformer does not age uniformly and variations are expected with temperature, moisture distribution, oxygen levels and other operating conditions. The levels of 2-furaldehyde in oil relate to the average deterioration of the insulating paper. Consequently, the extent of paper deterioration resulting from a "hot spot" will be greater than indicated by levels of 2-furaldehyde in the oil.

For typical power transformer, with an oil to paper ratio of 20:1, the 2-furaldehyde levels have the following significance:

Furaldehyde Content (ppm)	DP Value	Significance
0-0.1	1200-700	Healthy transformer
0.1-1.0	700-450	Moderate deterioration
1-10	450-250	Extensive deterioration
>10	<250	End of life criteria

Other Diagnostic Compounds

The presence of phenols and cresols in concentrations greater than 1 ppm indicate that solid components containing phenolic resin (laminates, spacers, etc.) are involved in overheating.

INTERPRETATION

The “predicted” DP (degree of polymerisation) indicates an average paper condition over the whole transformer (subject to factors such as effective circulation). New Kraft paper has a DP in excess of 1200, and paper with a DP of 200 or less is considered to be unfit (subject to interpretation).

The values can be optimistic if the oil has been regenerated within the last two years. This data should be evaluated in conjunction with routine chemical analysis and transformer history.

DP Range	**Remark**
<200	Test indicates extensive paper degradation exceeding the critical point. Strongly recommend that the transformer be taken out of service immediately and visually inspected.
200-250	The paper is near or at the critical condition. Recommend that the transformer be taken out of service as soon as possible and thoroughly inspected. Paper samples can be taken for direct DP testing.
260-350	The paper is approaching the critical condition. Suggest inspection be scheduled and/or re-sample within 1 year to reassess condition.
360-450	The paper is starting to approach the critical condition. Suggest a re-sample in 1-2 years time.
460-600	Significant paper deterioration but still well away from the critical point.
610-900	Mild to minimal paper ageing.
>900	No detectable paper degradation

TRANSFORMER OIL GAS ANALYSIS

Test Method IEC 567

Transformers are vital components in both the transmission and distribution of electrical power. The early detection of incipient faults in transformers is extremely cost effective by reducing unplanned outages. The most sensitive and reliable technique used for evaluating the health of oil filled electrical equipment is dissolved gas analysis (DGA). .

Insulating oils under abnormal electrical or thermal stresses break down to liberate small quantities of gases.The qualitative composition of the breakdown gases is dependent upon the type of fault. By means of dissolved gas analysis (DGA), it is possible to distinguish faults such as partial discharge (corona), overheating (pyrolysis) and arcing in a great variety of oil-filled equipment.

Information from the analysis of gasses dissolved in insulating oils is valuable in a preventative maintenance program. A number of samples must be taken over a period of time for developing trends. Data from DGA can provide

- . Advance warning of developing faults.
- . A means for conveniently scheduling repairs.
- . Monitor the rate of fault development

NOTE : A sudden large release of gas will not dissolve in the oil and this will cause the Buchholtz relay to activate.

GAS CHROMATOGRAPHY

By separating and quantifying (measuring) the gasses found dissolved in the oil, the specialist can identify the presence of an incipient fault (early warning).

The amounts and types of gases found in the oil are indicative of the severity and type of fault occurring in the transformer.

The separation, identification and quantification of these gases requires the use of sophisticated laboratory equipment and technical skills and therefore can only be conducted by a suitably equipped and competent laboratory.

Other higher hydrocarbon gases are produced, but these are not generally considered when interpreting the gas analysis data.

ORIGIN OF GASES IN TRANSFORMER OIL

Fault gases are caused by corona (partial discharge), thermal heating (pyrolysis) and arcing.

PARTIAL DISCHARGE is a fault of low level energy which usually occurs in gas-filled voids surrounded by oil impregnated material. The main cause of decomposition in partial discharges is ionic bombardment of the oil molecules.

The major gas produced is Hydrogen. The minor gas produced is Methane.

THERMAL FAULTS

A small amount of decomposition occurs at normal operating temperatures. As the fault temperature rises, the formation of the degradation gases change from Methane (CH_4) to Ethane (C_2H_6) to Ethylene (C_2H_4).

A thermal fault at low temperature (<300deg/C) produces mainly Methane and Ethane and some Ethylene.

A thermal fault at higher temperatures (>300deg/C) produces Ethylene. The higher the temperature becomes the greater the production of Ethylene.

ARCING is a fault caused by high energy discharge.

The major gas produced during arcing is acetylene. Power arcing can cause temperatures of over 3000deg/C to be developed.

NOTE : If the cellulose material (insulating paper etc.) is involved , carbon monoxide and carbon dioxide are generated.

A normally aging conservator type transformer having a CO_2/CO ratio above 11 or below 3 should be regarded as perhaps indicating a fault involving cellulose, provided the other gas analysis results also indicate excessive oil degradation.

INTERPRETATION OF GAS ANALYSIS RESULTS

There are various international guidelines on interpreting dissolved gas analysis (DGA) data. These guidelines show that the interpretation of DGA is more of an art than an exact science.

Some of these guidelines are :

Dornenburg Ratio Method	
Rogers Ratio Method	(Table 1)
BS 5800/iec 599 Ratio Method	(Figure 1)
Key Gas Method - Doble Engineering	(Figure 1)
Amount of Key Gases - CSUS	(Table 2)
Total Combustible Gases-Westinghouse	(Table 3)
Combustible Concentration Limits	
CEGB/ANSI/IEEE	(Table 4)
HYDRO QUEBEC – Canada	(Table 5)
BBC - Switzerland	(Table 5)
OY STROMBERG - Finland	(Table 5)
SECR - Japan	(Table 5)
EDF - France	(Table 7)

The combustible Concentration Limits differ from country to country, continent to continent and transformer to transformer. It is not practical to set concentration limits because of the many variations involved.

The Gas Concentrations in the oil depend upon :

The volume of oil involved	(dilution factors)
The age of the transformer	(new or old)
The type of transformer	(Generator or Transmission)
	(Sealed or free breathing)
	(Construction of Tap changer)

Interpretation and Historical Data

TCS has one of the most comprehensive insulating oil data management systems and interpretation guide. This system does graphical trend analysis for gas-in-oil data. The reports contain recommended action based on the latest accepted guidelines and TCS's extensive experience. TCS will maintain all customers historical records. These data are used to update and improve the diagnostic process.

Results

All reports this included Graphs can be e-mailed to the customer ie full integration with Microsoft Office 2000.

Transformer Chemistry Services method of interpretation is based upon :

- **Key gases : CSUS values (Age compensated)**
- **BS 5800/IEC 599 ratios (providing the Total Combustible Gases present are above 300 ppm)**
- **Rogers Ratio's**
- **Trend (Production rates of gases) Morgan-Schaffer Tables**
- **Total Combustible Gas Production Rates TDCG(c57.104-1991)**
- **Total Combustible Gas Westinghouse Guidelines**
- **Age of transformer.**
- **History of transformer (Repaired, degasses, etc).**

CONCLUSION

Analysing insulating oil taken from transformers is a unique way of identifying problems occurring within a transformer.

By identifying and quantifying the gases found in transformer oil, the condition of the transformer can be monitored.

If faults are found to be occurring, outages can be planned ant the fault can be rectified before major damage can occur.

The interpretation of transformer oil gas analysis is still an art and not an exact science. The interpretation should be left to a specialist and his advice and recommendations should be followed. Samples should be taken regularly and records kept.

TABLE 2
CALIFORNIA STATE UNIVERSITY
SACREMENTO
GUIDELINES FOR COMBUSTIBLE GAS

GAS	NORMAL	ABNORMAL	INTERPRETATION
H2	< 150 ppm	> 1000 ppm	Arcing corona
CH4	< 25 ppm	> 80 ppm	Sparking
C2H6	< 10 ppm	> 35 ppm	Local Overheating
C2H4	< 20 ppm	> 100 ppm	Severe Overheating
C2H2	< 15 ppm	> 70 ppm	Arcing
CO	< 500 ppm	> 1000 ppm	Severe Overloading
CO2	< 10 000 ppm	> 15 000ppm	Severe Overloading
N2	1-10 %	NA	-
O2	0.03 %	> 0.5 %	Combustibles

Recommended Safe Fault Gas Levels in Oil Immersed Equipment (max., ppm)

Gas	Dornenburg/Stritt.	IEEE	Bureau of Reclam.	Age Compensated
Hydrogen	200	100	500	20n+50
Methane	50	120	125	20n+50
Ethane	35	65	75	20n+50
Ethylene	80	50	175	20n+50
Acetylene	5	35	7	5n+10
Carbon Monoxide	500	350 720	750	25+500 110n+710
TDCG(tot. above)	6000	2500	10000	100n+1500 n=yrs in service
Carbon Dioxide				

TABLE 3

WESTINGHOUSE
GUIDELINES ON
TOTAL COMBUSTIBLE GASES(TCG)

TOTAL COMBUSTIBLE GASSES	RECOMMENDED ACTION
0 - 500 ppm	Normal Aging Analyse again in 6-12 months
501 to 1200 ppm	Decomposition maybe in excess of normal aging Analyse again in 3 months
1201 to 2500 ppm	More than normal decomposition Analyse in 1 month
2500 ppm and above	Make weekly analysis to determine gas production rates Contact manufacturer

Combustible gas generation in service also has to be determined. A generation of above 100ppm combustible gases in a 24hour period merits attention. Weekly or monthly samples may be necessary.

Actions based on TDCG(c57.104-1991)

Sampling intervals and Operating for Corresponding Gas Generation Rates

	TDCG Levels (ppm)	TDCG rates (ppm/day)	Sampling Interval	Operating Procedure
Condition 4	**>4630**	>30	Daily	Consider removal of service
		10-30	Daily	Advise Manufacturer
		<10	Weekly	Exercise extreme Caution. Analyse for individual gases Plan outage. Advise manufacturer
Condition 3	**1921-4630**	>30	Weekly	Exercise extreme caution Plan outage
		10-30	Weekly	Analyse for individual gases
		<10	Monthly	Advise manufacturer
Condition 2	**721-1920**	>30	Monthly	Exercise extreme caution Plan outage
		10-30	Monthly	Analyse for individual gases
		<10	Quarterly	Advise manufacturer
Condition 1	**≤ 720**	>30	Monthly	Exercise extreme Caution. Analyse for individual gases Determine load dependence
		10-30	Quarterly	Exercise extreme Caution. Analyse for individual gases Determine load dependence
		<10	Annually	Continue a normal operation

TABLE 4
CEGB/ANSI/1EEE GUIDE FOR
GAS CONCENTRATION LIMITS IN PPM V/V

GAS	GENERATOR TRANSFORMERS	TRANSMISSION
H2	240y	100
C0	580	350
CH4	160	120
C2H6	115	65
C2H4	190	30
C2H2	11	35

TABLE 5
OTHER INTERNATIONAL
GAS CONCENTRATION LIMITS
IN PPM V/V

GAS	HYDRO QUEBEC CANADA	BBC SWITZERLAND	OY STROMBERG FINLAND
H2	250	200	100
CO	850	1000	500
CH4	33	50	100
C2H6	15	15	150
C2H4	40	60	100
C2H2	25	15	30

TABLE 6
SECR - JAPAN
LIMITING VALUES
IN PPM V/V

GAS	TRANSFORMERS >275kV & >10MVA	TRANSFORMERS >275kV & <10MVA	TRANSFORMERS >500 kV
H2	400	400	300
CO	300	300	200
CH4	150	200	100
C2H6	150	150	50
C2H4	200	300	100
TCG	700	1000	400

TABLE 7
EDF - FRANCE
TRANSMISSION TRANSFORMERS
WITHOUT ON-LOAD TAP CHANGERS

GAS	GENERATOR TRANSFORMERS	TRANSMISSION TRANSFORMERS
H2	33	130
C0	770	1000
CH4	44	130
C2H6	33	150
C2H4	11	44
C2H2	0.4	0.4

TABLE 1

Code for examining analysis of gas dissolved in mineral oil

		Code of range of ratios			
	IEC 599	$\frac{C2H2}{C2H4}$	$\frac{CH4}{H2}$	$\frac{C2H4}{C2H6}$	
	Ratios of characteristic gases < 0.1 0.1-1 1-3 > 3	 0 1 1 2	 1 0 2 2	 0 0 1 2	
Case No.	Characteristic fault				Typical examples
0	No fault	0	0	0	Normal ageing
1	Partial discharges of Low energy density	0 but not significant	1	0	Discharges in gas-filled cavities resulting from incomplete impregnation, or super-saturation or cavitation or high humidity.
2	Partial Discharges of Low energy density	1	1	0	As above, but leading to tracking or perforation of solid insulation.
3	Discharges of low energy(see Note 1)	1-2	0	1-2	Continuous sparking in oil between bad connections of different potential or to floating potential. Breakdown of oil between solid materials.
4	Discharges of High Energy	1	0	2	Discharges with power follow-through. Arcing-breakdown of oil between windings or coils, or between coils to earth. Selector breaking current.
5	Thermal fault of Low Temperature <150°C(see Note 2)	0	0	1	General insulated conductor overheating
6	Thermal Fault of Low Temperature range 150°C-300°C(see Note 3)	0	2	0	Local overheating of the core due to concen-trations of flux. Increasing hot spot tempre-tures;varying from small hot spots in core, overheating of copper due to eddy currents, bad contacts/joints(pyrolitic carbon formation) up to core and tank circulating currents.
7	Thermal fault of Medium temperature range 300°C-700°C	0	2	1	
8	Thermal fault of high temperature >700°C(see Note 4)	0	2	2	

Notes 1. - For the purpose of this table there will be a tendency for the ratio $\frac{C2H2}{C2H4}$ to rise from a value between 0.1 and 3 to above 3 and for the ratio $\frac{C2H4}{C2H6}$ from a value between 0.1 and 3 as the spark develops in intensity.

2. - In this case the gases come mainly from the decomposition of the solid insulation, this explains the value of the ratio $\frac{C2H4}{C2H6}$

3. - This fault condition is normally indicated by increasing gas concentrations. Ratio $\frac{CH4}{H2}$ is normally about 1; the actual level of temperature and oil quality.

4. - An increasing value of the amount of C_2H_2 may indicate that the hot point temperature is higher than 1000°C

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General remarks: 1) Significant values quoted for ratios should be regarded as typical only.

2) Transformers fitted with in-tank on-load tap-changers may indicates faults of Type 202/102 depending on seepage or transmission of arc decomposition products in the diverter switchtank into the transformer tank oil.

3) Combinations of the ratios not included in Table 1 may occur in practice. Consideration is being given to the interpretation of such combinations.

SUGGESTED DIAGNOSIS FROM GAS RATIOS-ROGERS RATIO METHOD

$\frac{CH_4}{H_2}$	$\frac{C_2H_6}{CH_4}$	$\frac{C_2H_4}{C_2H_6}$	$\frac{C_2H_2}{C_2H_4}$	Suggested Diagnosis
>0.1 <1.0	<1.0	<1.0	<0.5	Normal
≤0.1	<1.0	<1.0	<0.5	Partial Discharge corona
≤0.1	<1.0	1.0	≥0.5 or ≥3.0 <3.0	Partial Discharge- corona with tracking
>0.1 <1.0	<1.0	≥3.0	≥3.0	Continuous discharge
>1.0 <1.0	<1.0	≥1.0 or ≥3.0 <3.0	≥0.5 or ≥3.0 <3.0	Arc - with power follow through
>1.0 <1.0	<1.0	<1.0	≥0.5 <3.0	Arc - no power follow through
≥1.0 or ≥3.0 <3.0	<1.0	<1.0	<0.5	Slight Overheating- to 150°c
≥1.0 or ≥3.0 <3.0	≥1.0	<1.0	<0.5	Overheating 150°-200°C
>0.1 <1.0	≥1.0	<1.0	<0.5	Overheating 200°-300°C
>0.1 <1.0	>1.0	≥1.0 <3.0	<0.5	General conductor overheating
≥1.0 <3.0	<1.0	≥1.0 <3.0	<0.5	Circulating currents in windings
≥1.0 <3.0	<1.0	≥3.0	<0.5	Circulating currents core and tank; overloaded joints

Fault gas generation rates for transformer with 50 m^3 of oil

	Normal	Serious
H_2	Less than 0.1 ppm/day	more than 2ppm/day
CH_4	0.05	6
C_2H_2	0.05	6
C_2H_4	0.05	6
C_2H_6	0.05	1
CO	2	10
CO_2	6	20