DISSOLVED GAS ANALYSIS IN TRANSFORMER MAINTENANCE

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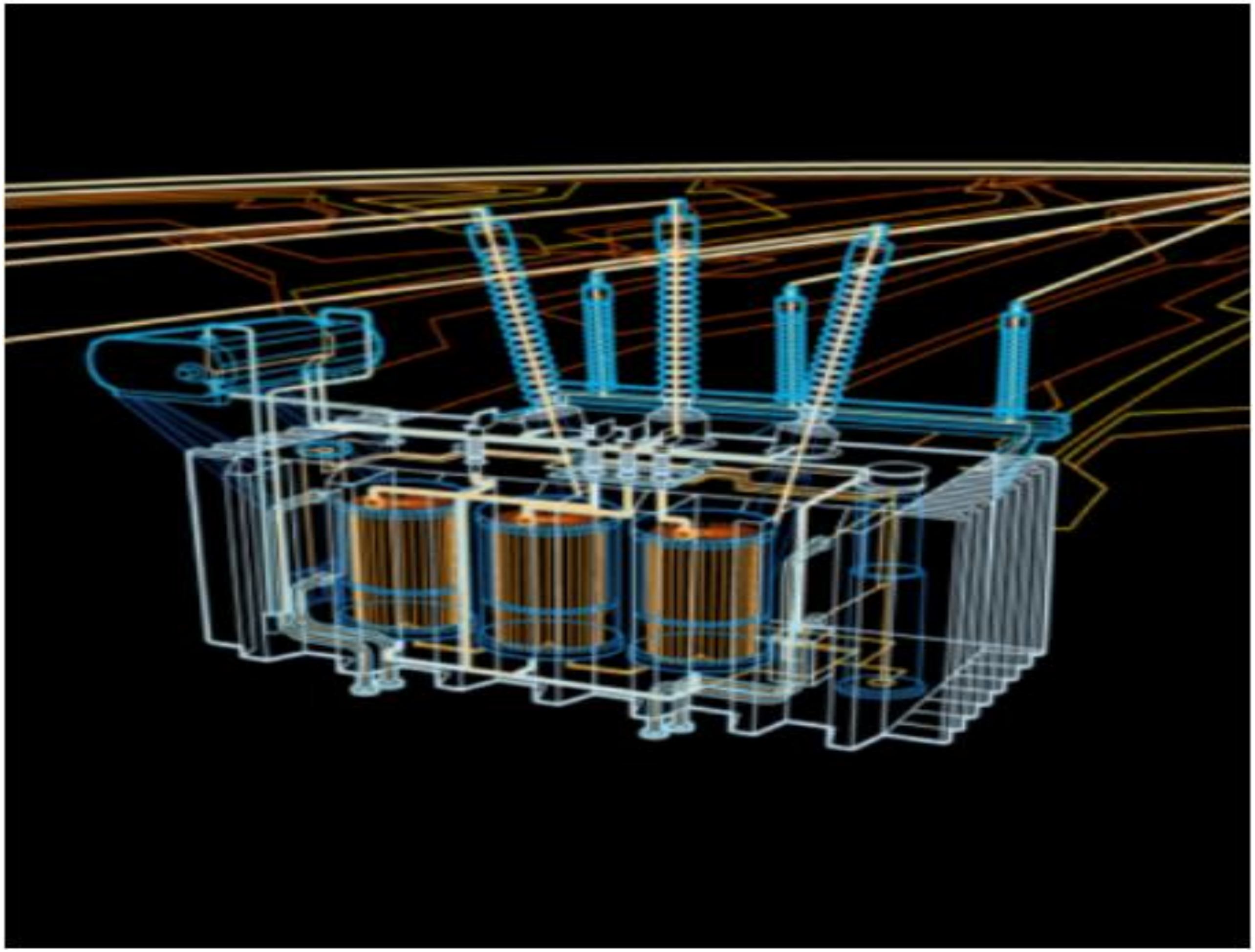
Agenda:

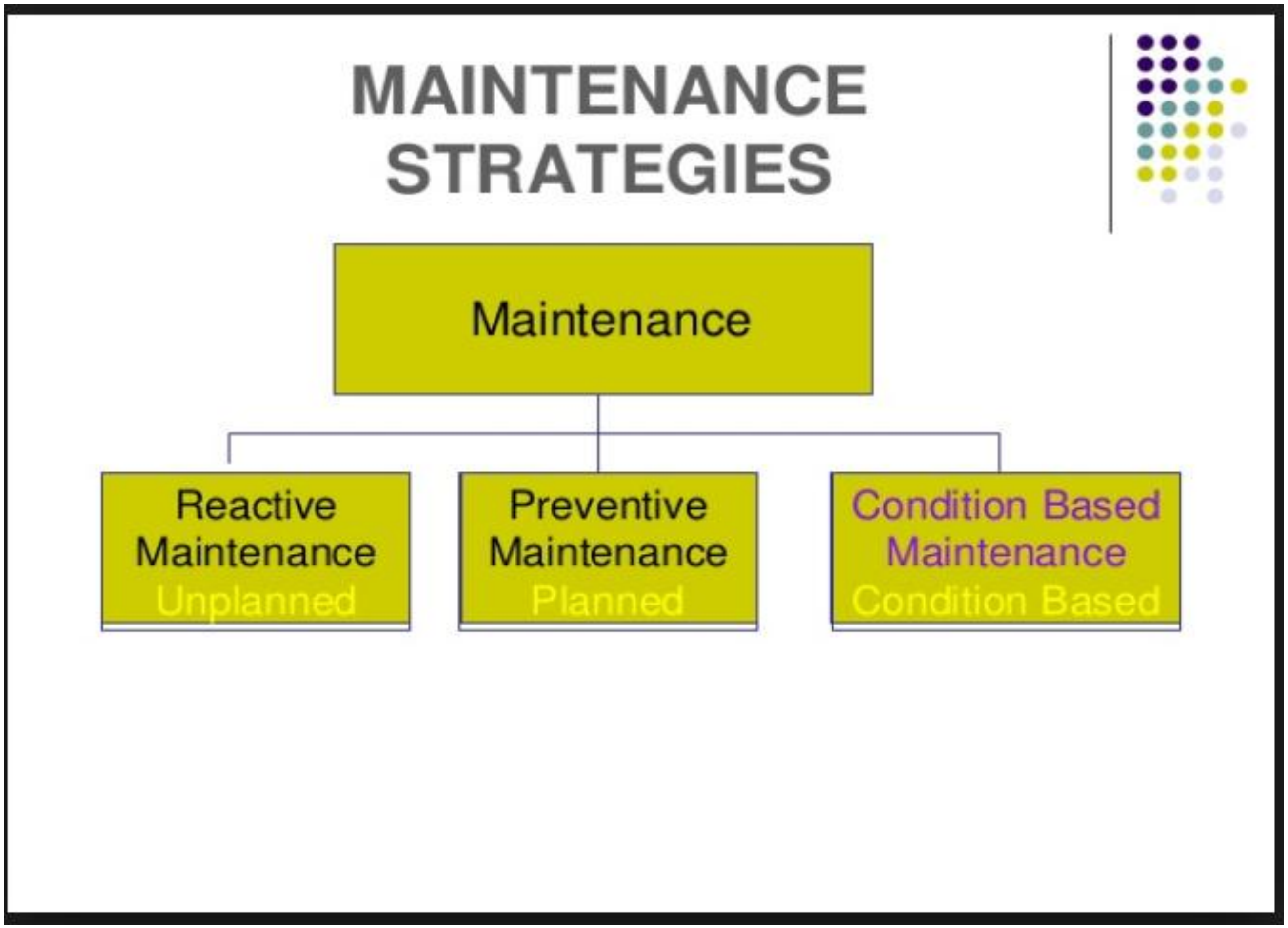
- Overview on Condition Based Maintenance Approach
- Transformer Asset Management
- Principle of Dissolved Gas Analysis
- Transformer Oil Sampling Procedures
- Case Study

Power Transformers



Failure: They Happen

Maintenance Strategy



Condition Based Maintenance (CBM)

Condition based maintenance (CBM) is a maintenance strategy that **monitors** the **actual condition** of the asset to **decide** what maintenance **needs to be done.**

CBM dictates that maintenance should only be **performed** when certain **indicators** show signs of **decreasing performance** or **upcoming failure.**

Types of Condition Based Maintenance

Vibration Analysis – rotating equipment such as compressor, pumps, motors all exhibit a certain degree of vibration. As they degrade, or fall out of alignment, the amount of vibration increases.

Infrared Thermography – IR cameras can be used to detect high temperature conditions in energized equipment.

Ultrasonic – detection of deep subsurface defects such as cracks, flaws like in generator rotor shaft.

CME

Types of Condition Based Maintenance

Partial Discharge Analysis – Used to monitor partial discharge activity on generator and motor stator winding insulation.

Oil Particle Counter – Used to monitor the cleanliness of turbine lube oil and transformer oil.

Videoscope / Boroscope – Used to visualize the internal status of small diameter pipe and hard to reach equipment parts.

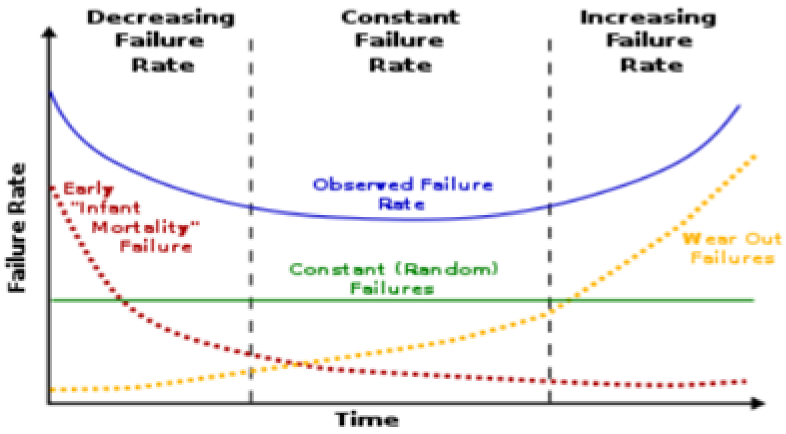
Types of Condition Based Maintenance

Dielectric Breakdown Voltage - Used for dielectric breakdown voltage test of transformer oil.

Dissolved Gas Analysis – Used to monitor the dissolved gases in the transformer insulating medium.

Transformer Asset Management

"Bathtub" curve



Transformer are a critical and costly element in the power system

Unplanned failures at any point in the transformer lifecycle have major consequences

DGA condition assessment has been recognized for over 50 years for improving reliability and lowering transformer asset maintenance costs

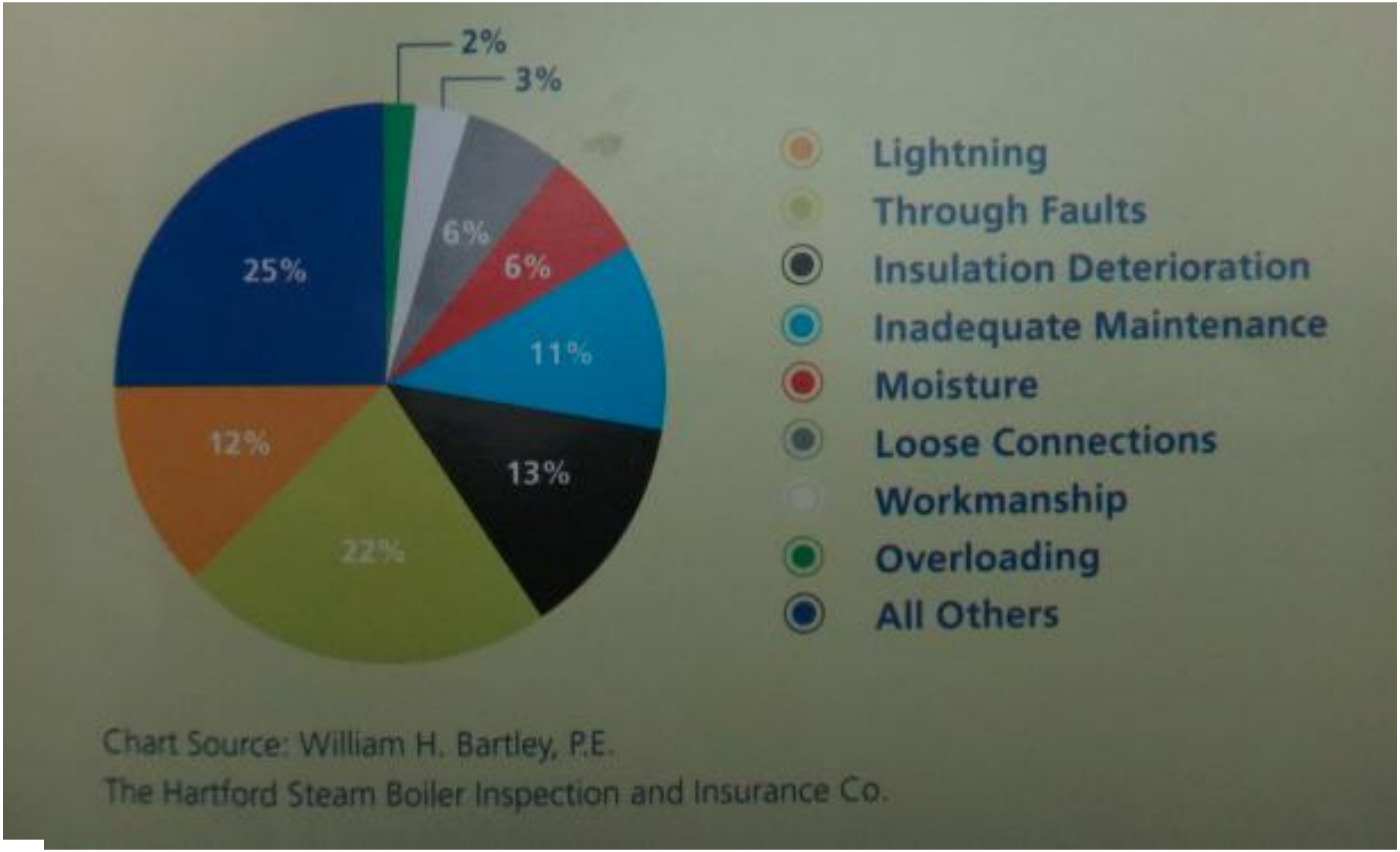
Function of Oil in the Transformer

- Provide Insulation
- Provide Cooling
- Help extinguish Arc
- Oil dissolved gases generated by oil degradation, moisture and gas from cellulose insulation, deterioration.

Dissolved Gas Analysis - DGA

DGA is the single most comprehensive asset condition assessment and management tool for an oil-filled power transformers.

DGA offers advanced detection of incipient fault condition leading to almost all of the failure modes of transformer faults.


2%
3%
6%
6%
25%
11%
12%
13%
22%
Lightning
Through Faults
Insulation Deterioration
Inadequate Maintenance
Moisture
Loose Connections
Workmanship
Overloading
All Others
Chart Source: William H. Bartley, P.E.
The Hartford Steam Boiler Inspection and Insurance Co.

Purpose of DGA

- To provide a non-intrusive means to determine if a transformer incipient fault condition exists or not
- To have a high probability that when entering a transformer a problem is apparent
- To prevent an unexpected outage
- To reduce risk to the unit, to the system it connected, to the company and most of all to the personnel monitoring that transformer.

DGA Application

- **Oil immersed transformer**
- **Oil immersed shunt reactors**
- **Oil type OLTC, Regulators**
- **Oil circuit breakers**
- **Oil type instrument transformers (CT,PT)**

When to conduct DGA for Transformers?

- **After high voltage and temperature rise test in the factory**
- **Commissioning period**
  - Energize under no load
  - Energize with load
- **Before lapsed of warranty period**
- **CBM**
  - Predictive maintenance
  - Faults
    - Transformer main protection trip
    - Buchholz relay activated
    - Pressure relay activated
    - Differential relay activated
  - Overloading
  - EOL

Gas Sources

- Gases in oil always result from the decomposition of electrical insulation materials (oil or paper), as a result of faults or chemical reaction in the equipment

- For example:
  - Oil is a molecule of hydrocarbons, containing hydrogen and carbon atoms linked by chemical bonds (C-H, C-C)

Gases develop in the transformer oil

Gas	HYDROGEN
Formula	**H_2**
Solubility in Oil @ 25°C	0.06
Solubility in Oil @ 70°C	0.07
Temperature at which Gas forms significant amount	<150°C for "cold plasma" ionization, (corona in oil) >250°C for thermal & electrical faults
Source of Gas	Partial discharge, thermal faults, power discharges, rust, galvanized parts, stainless steel, sunlight

Gases develop in the transformer oil

Gas	**METHANE**
Formula	**CH_4**
Solubility in Oil @ 25°C	0.44
Solubility in Oil @ 70°C	0.44
Temperature at which Gas forms significant amount	<150 -300°C
Source of Gas	Corona partial discharge, low & medium temperature thermal faults

Gases develop in the transformer oil

Gas	ETHANE
Formula	**C_2H_6**
Solubility in Oil @ 25°C	2.59
Solubility in Oil @ 70°C	2.09
Temperature at which Gas forms significant amount	200 -400°C
Source of Gas	low & medium temperature thermal faults

Gases develop in the transformer oil

Gas	**ETHYLENE**
Formula	**C_2H_4**
Solubility in Oil @ 25^{o}C	1.76
Solubility in Oil @ 70^{o}C	1.47
Temperature at which Gas forms significant amount	300 -700^{o}C
Source of Gas	High temperature thermal faults

Gases develop in the transformer oil

Gas	**ACETYLENE**
Formula	**C_2H_2**
Solubility in Oil @ 25°C	1.22
Solubility in Oil @ 70°C	0.93
Temperature at which Gas forms significant amount	>700°C
Source of Gas	Very hot spot; low-energy discharge (spitting from floating part); high energy discharge (arc)

Gases develop in the transformer oil

Gas	CARBON MONOXIDE
Formula	**CO**
Solubility in Oil @ 25°C	0.13
Solubility in Oil @ 70°C	0.12
Temperature at which Gas forms significant amount	105 -300°C (complete decomposition & carbonization occurs >300°C
Source of Gas	Thermal fault involving cellulose (paper, pressboard, wood blocks); slowly from oil oxidation

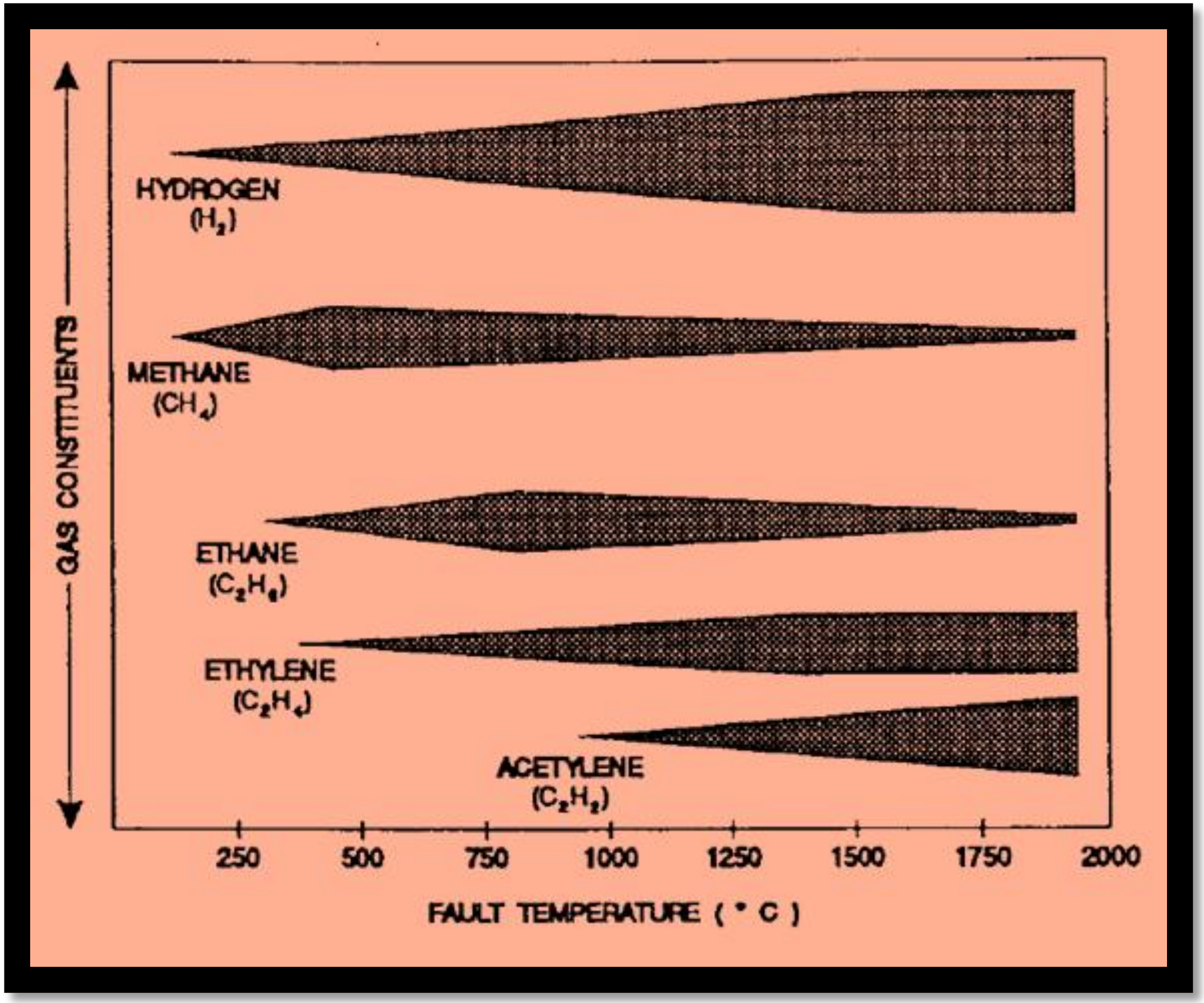
Gases develop in the transformer oil

Gas	CARBON DIOXIDE
Formula	**CO_2**
Solubility in Oil @ 25°C	1.17
Solubility in Oil @ 70°C	1.02
Temperature at which Gas forms significant amount	105 -300°C
Source of Gas	Normal aging (accelerated by amount of O_2-in-oil & H_2O-in-paper); thermal fault involving cellulose (paper, pressboard, wood blocks); accumulation from oil oxidation.

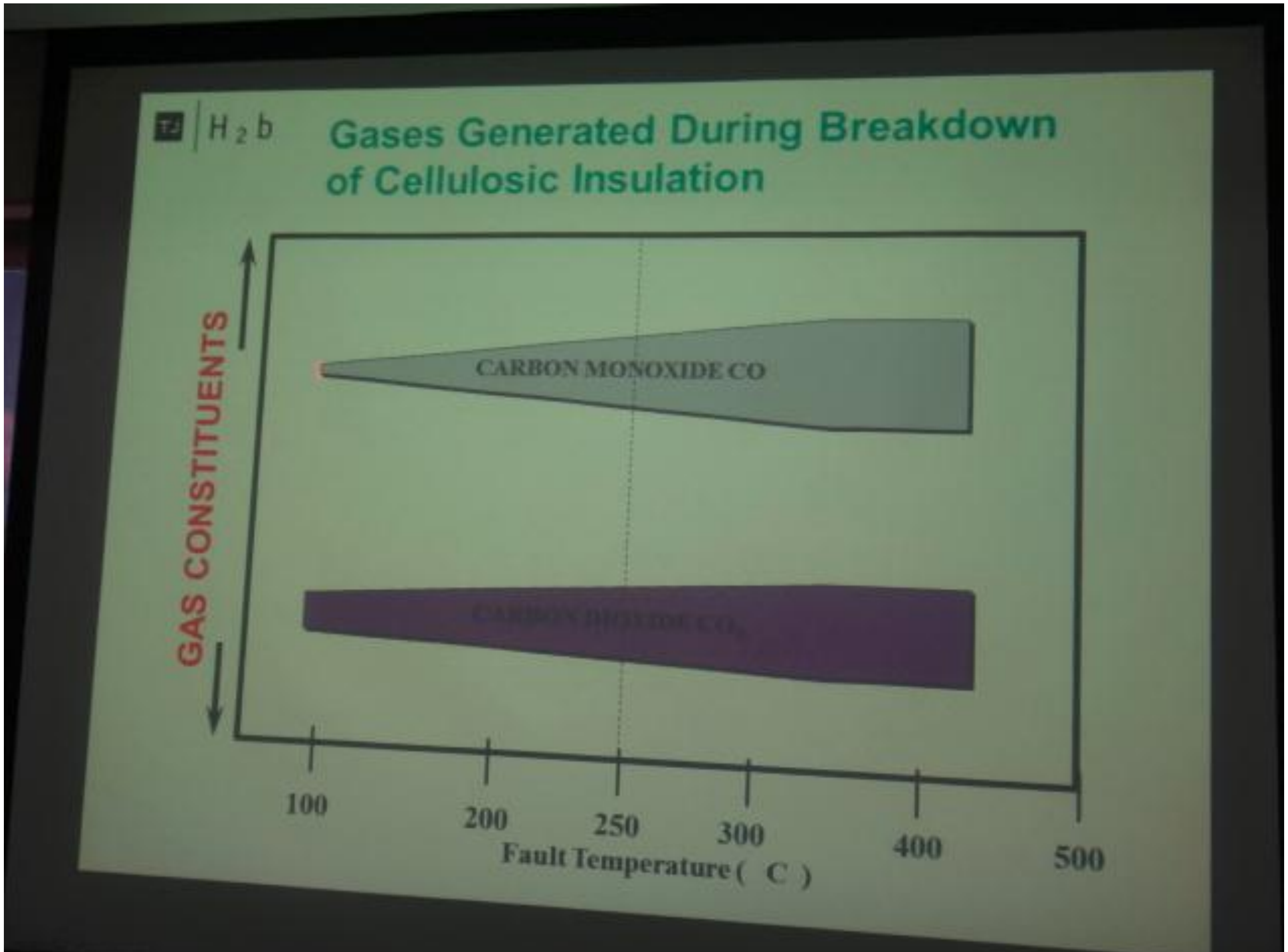
Gases develop in the transformer oil

Gas	OXYGEN
Formula	**O_2**
Solubility in Oil @ 25°C	0.18
Solubility in Oil @ 70°C	0.17
Temperature at which Gas forms significant amount	Following drop in oil temperature (vacuum)
Source of Gas	Exposure to atmosphere (air), leaky gasket (under vacuum), air breathing conservator, leaky bladder.

Gases generated during breakdown of dielectric oil



Gases Generated During Breakdown of Cellulosic Insulation



Gas Analyzed by DGA

- **Hydrogen*, H_2**
- **Methane*, CH_4**
- **Ethane*, C_2H_6**
- **Ethylene*, C_2H_4**
- **Acetylene*, C_2H_2**
- **Carbon monoxide*, CO**
- **Carbon dioxide, CO_2**
- **Oxygen, O_2**
- **Nitrogen, N_2**
- **TDCG (Total Dissolved Combustible Gases)**

TDCG=H2+CH4+C2H6+C2H4+C2H2+CO

* ***denotes combustible gas***

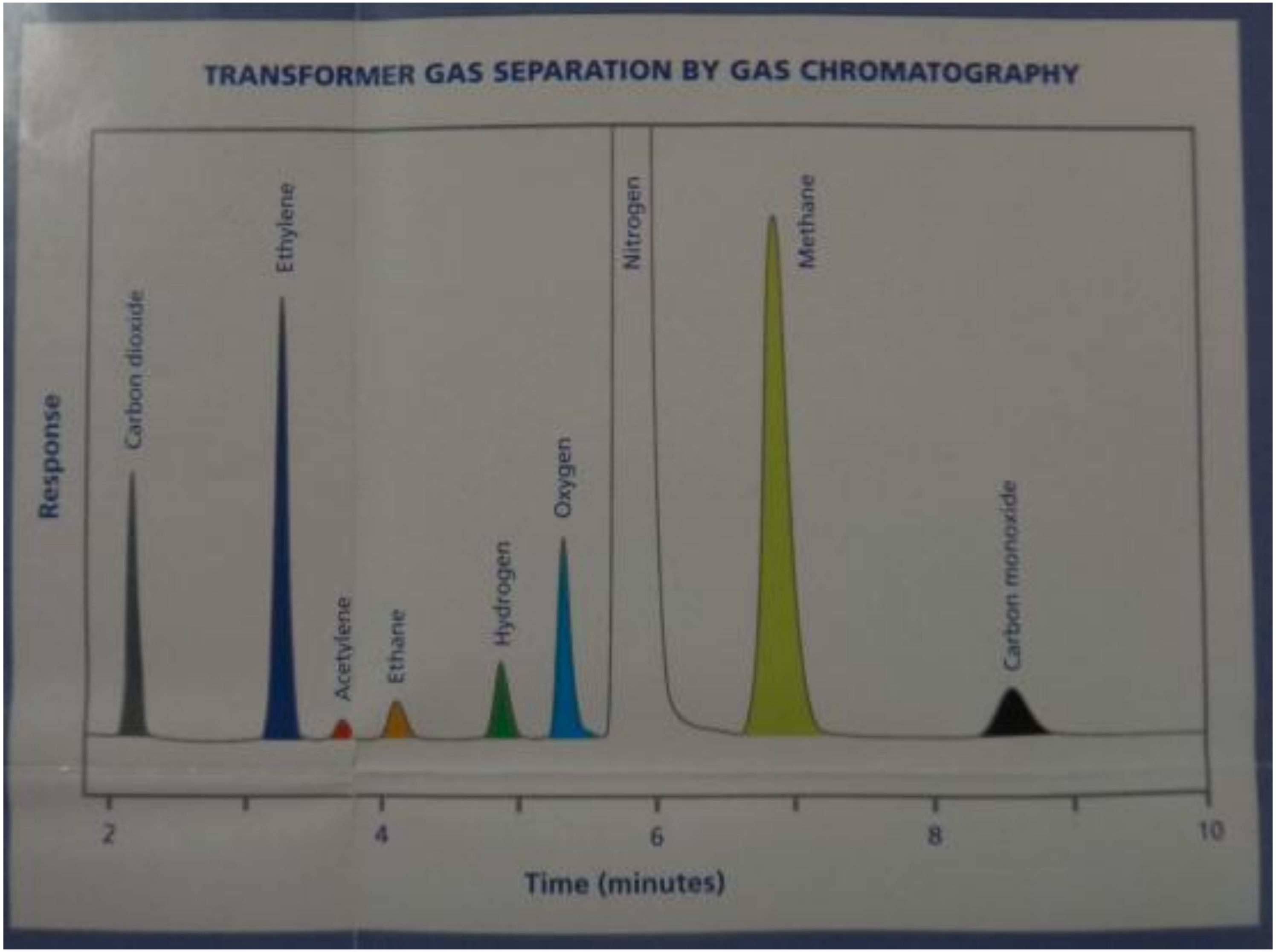
Solubility of Gases in Transformer Oil

• Hydrogen*	H_2	7.0% by volume
• Oxygen	O_2	16.0% by volume
• Nitrogen	N_2	8.6% by volume
• Methane*	CH_4	30.0% by volume
• Carbon Monoxide*	CO	9.0% by volume
• Ethane*	C_2H_6	280.0% by volume
• Carbon Dioxide	CO_2	120.0% by volume
• Ethylene*	C_2H_4	280.0% by volume
• Acetylene*	C_2H_2	400.0% by volume

* denotes combustible gas

ANALYSIS

- ASTM method D3612 and IEC 60567, specifies gas chromatography (GC) as the analysis method.
- The GC results are calibrated to known gas standards and normalized to standard temperature and pressure levels so that data obtained under different conditions may be compared meaningfully.
- GC separates each gas from the others and directly measures their concentrations individually.
- When recorded over time, the resulting detector signals is called a chromatogram.


TRANSFORMER GAS SEPARATION BY GAS CHROMATOGRAPHY
Response
Carbon dioxide
Ethylene
Acetylene
Ethane
Hydrogen
Oxygen
Nitrogen
Methane
Carbon monoxide
2
4
6
8
10
Time (minutes)

Faults Detectable by DGA

Symbol	Fault	Examples
PD	Partial Discharges	Discharges of the cold plasma (corona) type in gas bubbles or voids, with the possible formation of X-wax in paper
D1	Discharges of Low Energy	Partial discharges of the sparking type, inducing pinholes, carbonized punctures in paper. Low energy arcing inducing carbonized perforation or surface tracking of paper, or the formation of carbon particles in oil.
D2	Discharge of High Energy	Discharge in paper or oil, with power follow-through, resulting in extensive damage to paper or large formation of carbon particles in oil, metal fusion, tripping of the equipment and gas alarms.
T1	Thermal Fault, $T<300\ ^oC$	Evidenced by paper turning brownish (>200 ^oC) or carbonized (>300 ^oC)
T2	Thermal Fault, $300 < T < 700\ ^oC$	Carbonization of paper, formation of carbon particles in oil.
T3	Thermal Fault, $T>700\ ^oC$	Extensive formation of carbon particles in oil, metal coloration (800 ^oC) or metal fusion (>1000 ^oC).

CME

Standard and Guidelines Governing Dissolved Gas Analysis

Reference	Description
IEEE Std. C57.104.2008	IEEE Guide for the Interpretation of Gases Generated in Oil Immersed Transformers
IEEE Std. C57.12.80-2002	Terminology for Power and Distribution Transformer
IEC 60599-2007-05	Mineral Oil Impregnated Electrical Equipment in Service: Guide to the Interpretation of Dissolved and Free Gas Analysis
IEC 60599-2007-05	Reference to Duval Triangle Diagnostic Model and C_2H_2/H_2 Ratio Interpretation

Standards and Guidelines Governing Gas Extraction From Oil

REFERENCE	DESCRIPTION
ASTM D2945-90 (2003)	Standard Test Method For Gas Content of Insulating Oils
ASTM D3305-94 (2005)	Standard Practice for Sampling Small Gas Volume in a Transformer
ASTM D3612-02 (2009)	Standard Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography
ASTM D2759-00 (2010)	Standard Practice for Sampling Gas from a Transformer under Positive Pressure
IEC 60567-2011	Guide for the sampling of gases and oil from oil-filled electrical equipment and for the analysis of free and dissolved gases.

DGA DIAGNOSIS

INDIVIDUAL GAS AND TDCG METHOD (IEEE C57.104-2008)

CONDITION 1: *TDCG below this level indicates the transformer is operating satisfactorily. Any individual combustible gas exceeding specified levels should prompt additional investigation.*

Status	Dissolved key gas concentration limits in parts per million (ppm)							
	Hydrogen (H_2)	Methane (CH_4)	Acetylene (C_2H_2)	Ethylene (C_2H_4)	Ethane (C_2H_6)	Carbon Monoxide (CO)	Carbon Dioxide (CO_2)	TDCG
Condition 1	100	120	2	50	65	350	2500	720

Action based on Dissolved Combustible Gas

Status	TDCG levels (ppm)	TDCG rate (ppm/day)	Sampling intervals and operating procedures for gas generation rates	
			Sampling interval	Operating procedures
Condition 1	≤720	>30	Monthly	Exercise caution Analyze for individual gases Determine load dependence
		10 to 30	Quarterly	Continue normal operation
		<10	Annual	

CONDITION 2: *TDCG within this range indicates greater than normal combustible gas level. Any individual combustible gas exceeding specified levels should prompt additional investigation. Action should be taken to established trend. Faults(s) may be present.*

Status	Dissolved key gas concentration limits in parts per million (ppm)							
	Hydrogen (H_2)	Methane (CH_4)	Acetylene (C_2H_2)	Ethylene (C_2H_4)	Ethane (C_2H_6)	Carbon Monoxide (CO)	Carbon Dioxide (CO_2)	TDCG
Condition 2	101-700	121-400	2-9	51-100	66-100	351-570	2500-4000	721-1920

Action based on Total Dissolved Combustible Gas

Status	TDCG levels (ppm)	TDCG rate (ppm/day)	Sampling intervals and operating procedures for gas generation rates	
			Sampling interval	Operating procedures
Condition 2	721 to 1920	>30	Monthly	Exercise caution
		10 to 30	Monthly	Analyze for individual gases
		<10	Quarterly	Determine load dependence

Condition 3: ***TDCG within this range indicates a high level of decomposition. Any individual combustible gas exceeding specified levels should prompt additional investigation. Immediate action should be taken to establish trend. Fault(s) are probably present.***

Status	Dissolved key gas concentration limits in parts per million (ppm)							
	Hydrogen (H_2)	Methane (CH_4)	Acetylene (C_2H_2)	Ethylene (C_2H_4)	Ethane (C_2H_6)	Carbon Monoxide (CO)	Carbon Dioxide (CO_2)	TDCG
Condition 3	701-1800	401-1000	10-35	101-200	101-150	571-1400	4001-10 000	1921-4630

Action based on Total Dissolved Combustible Gas

Status	TDCG levels (ppm)	TDCG rate (ppm/day)	Sampling intervals and operating procedures for gas generation rates	
			Sampling interval	Operating procedures
Condition 3	1921 to 4630	>30	Weekly	Exercise extreme caution Analyze for individual gases Plan Outage Advise manufacturer
		10 to 30	Weekly	
		<10	Monthly	

Condition 4: ***TDCG within this range indicates excessive decomposition of cellulose insulation and/or oil. Continued operation could result in failure of the transformer. Need to retest.***

- There some transformer operating safely under this condition, however gases are stable.
- ***If TDCG and individual gases are increasing significantly (>30ppm/day), the fault is active, transformer should be de-energized.***

Status	Dissolved key gas concentration limits in parts per million (ppm)							
	Hydrogen (H_2)	Methane (CH_4)	Acetylene (C_2H_2)	Ethylene (C_2H_4)	Ethane (C_2H_6)	Carbon Monoxide (CO)	Carbon Dioxide (CO_2)	TDCG
Condition 4	>1800	>1000	>35	>200	>150	>1400	>10 000	>4630

Action based on TDCG

Status	TDCG levels (ppm)	TDCG rate (ppm/day)	Sampling intervals and operating procedures for gas generation rates	
			Sampling interval	Operating procedures
Condition 4	>4630	>30	Daily	Consider removal from service Advise manufacturer
		10 to 30	Daily	
		<10	Weekly	Exercise extreme caution Analyze for individual gases Plan Outage Advise manufacturer

- A sudden **increase in key gases** and the **rate of gas production** is more important in evaluating a transformer than the amount of gas.
- Any generation of amount of gas in ppm indicate high energy arcing. Can be generate a very hot thermal fault (1000^{o}C)
- Acetylene generated by internal arcing, sampling should be taken weekly to determine if there is an additional generation of gas.
- If no additional acetylene is found and level is within the standard the transformer may continue in service.
- Increase of Acetylene level the transformer has an internal arc and should be taken out of service.
- Operating transformer with high value of acetylene is extremely hazardous.

Table 1 – Dissolved gas concentration

Status	Dissolved key gas concentration limits in parts per million (ppm)*							
	Hydrogen (H_2)	Methane (CH_4)	Acetylene (C_2H_2)	Ethylene (C_2H_4)	Ethane (C_2H_6)	Carbon monoxide (CO)	Carbon dioxide (CO_2)	TDCG
Condition 1	100	120	2	50	65	350	2500	720
Condition 2	101–700	121–400	2–9	51–100	66–100	351–570	2 500–4 000	721–1920
Condition 3	701–1800	401–1000	10–35	101–200	101–150	571–1400	4 001–10 000	1921–4630
Condition 4	>1800	>1000	>35	>200	>150	>1400	>10 000	>4630

*The number shown in Table 1 are in parts of gas per million parts of oil (ppm) volumetrically and are based on a large power transformer with several thousand gallons of oil. With a smaller oil volume, the same volume of gas will give a higher gas concentration. Small distribution transformers and voltage regulators may contain combustible gases because of the operation of internal expulsion fuses or load break switches. The status codes in table 1 are also not applicable to other apparatus in which load break switches operate under oil.

Table 2 – Action based on TDCG

	TDCG levels (µL/L)	TDCG rate (µL/L/day)	Sampling intervals and operating procedures for gas generation rates	
			Sampling interval	Operating procedures
Condition 4	>4630	>30	Daily	Consider removal from service.
		10 to 30	Daily	Advise manufacturer.
		<10	Weekly	Exercise extreme caution. Analyze for individual gases. Plan outage. Advise manufacturer.
Condition 3	1921 to 4630	>30	Weekly	Exercise extreme caution.
		10 to 30	Weekly	Analyze for individual gases.
		<10	Monthly	Plan outage. Advise manufacturer.
Condition 2	721 to 1920	>30	Monthly	Exercise caution.
		10 to 30	Monthly	Analyze for individual gases.
		<10	Quarterly	Determine load dependence.
Condition 1	≤720	>30	Monthly	Exercise caution. Analyze for individual gases. Determine load dependence.
		10 to 30	Quarterly	Continue normal operation.
		<10	Annual	

Note:

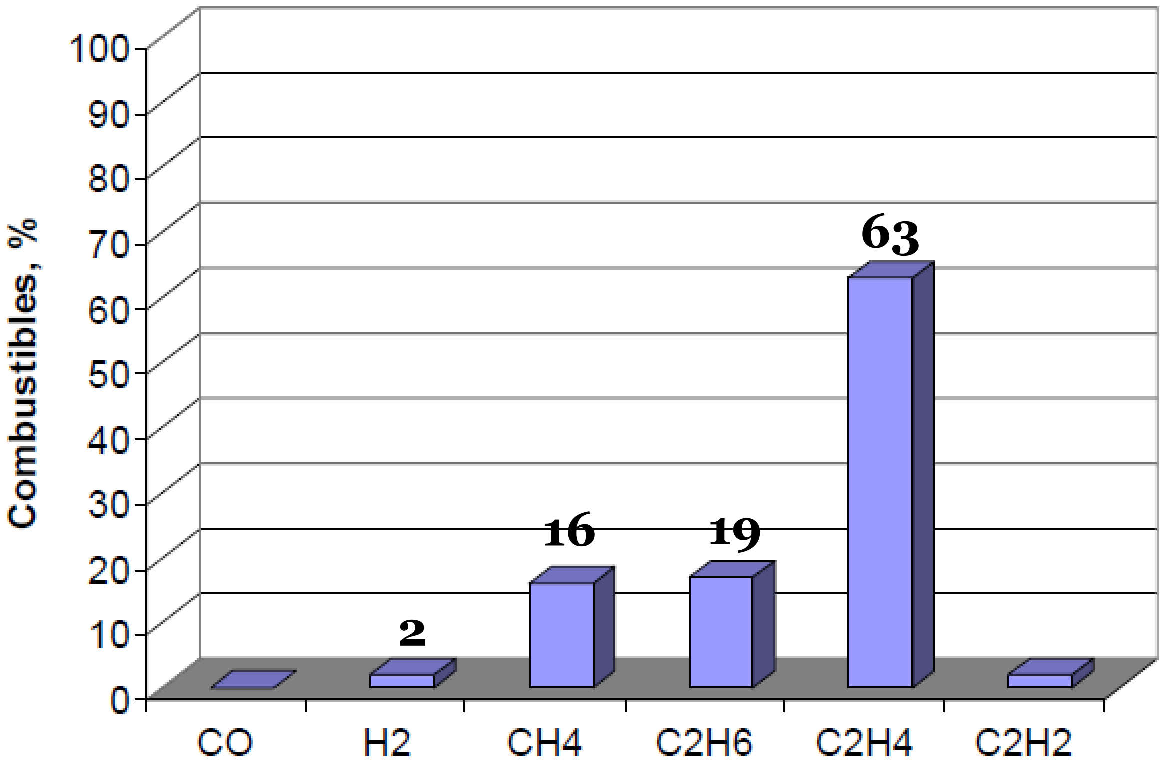
1. Either the HIGHEST CONDITION BASED on the INDIVIDUAL GAS or TDCG can determine the condition (1,2,3 and 4) Example If the TDCG is **1941 ppm this indicate condition 3. However Hydrogen is greater than 1800 ppm , The transformer condition 4.**
2. Determine Load Dependence Means if possible find out if the gas generation rate in ppm goes up or down. Perhaps the transformer is unloaded. Take sample every time load change, if load changes are too frequent this may not be possible.

Evaluation of possible fault type by the Key Gas Method

Key gases defined in the IEEE guide as “gases generated in oil-filled transformers that can be used for ***QUALITATIVE*** determination of faults types, based on which gases are typical or predominant at various temperatures.

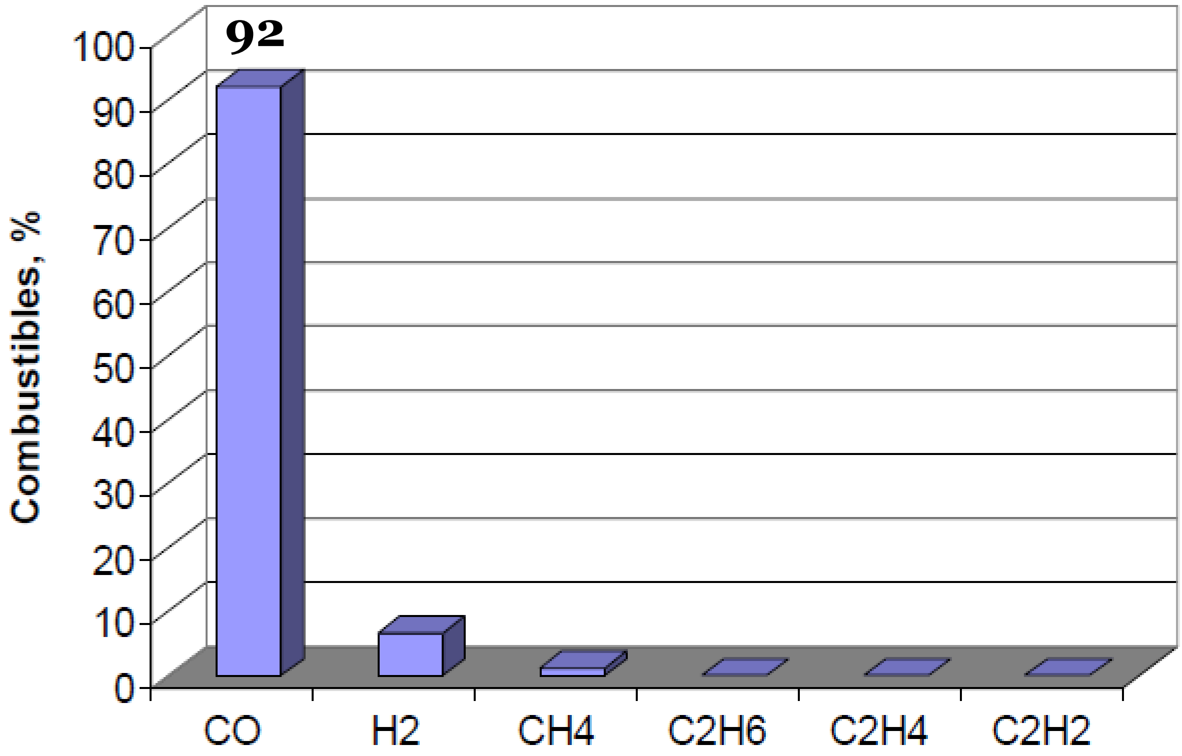
Key Gas	Fault Type	Typical proportion of generated combustible gases
Ethylene - C_2H_4	Thermal Oil	Decomposition products include C_2H_4 and CH_4, together with smaller quantities of H_2 and C_2H_6. Traces of C_2H_2 may be formed if the fault is severe or involves electrical contacts.
Carbon Monoxide - CO	Thermal Cellulose	Large quantities of CO_2 and CO are evolved from overheated cellulose. Hydrocarbon gases. Such as CH_4 and C_2H_4, will be formed if the fault involves an oil-impregnated structure.
Hydrogen - H_2	Electrical Low Energy Partial Discharge	Low energy electrical discharges produce H_2 and CH_4, with small quantities of C_2H_6 and C_2H_4. Comparable amount of CO and CO_2 may result from discharge in cellulose.
Acetylene - C_2H_2	Electrical High Energy (arcing)	Large amount of H_2 and C_2H_2 are produced, with minor quantities of CH_4 and C_2H_4. CO_2 and CO may also formed if the fault involves cellulose. Oil may be carbonized

Overheated Oil



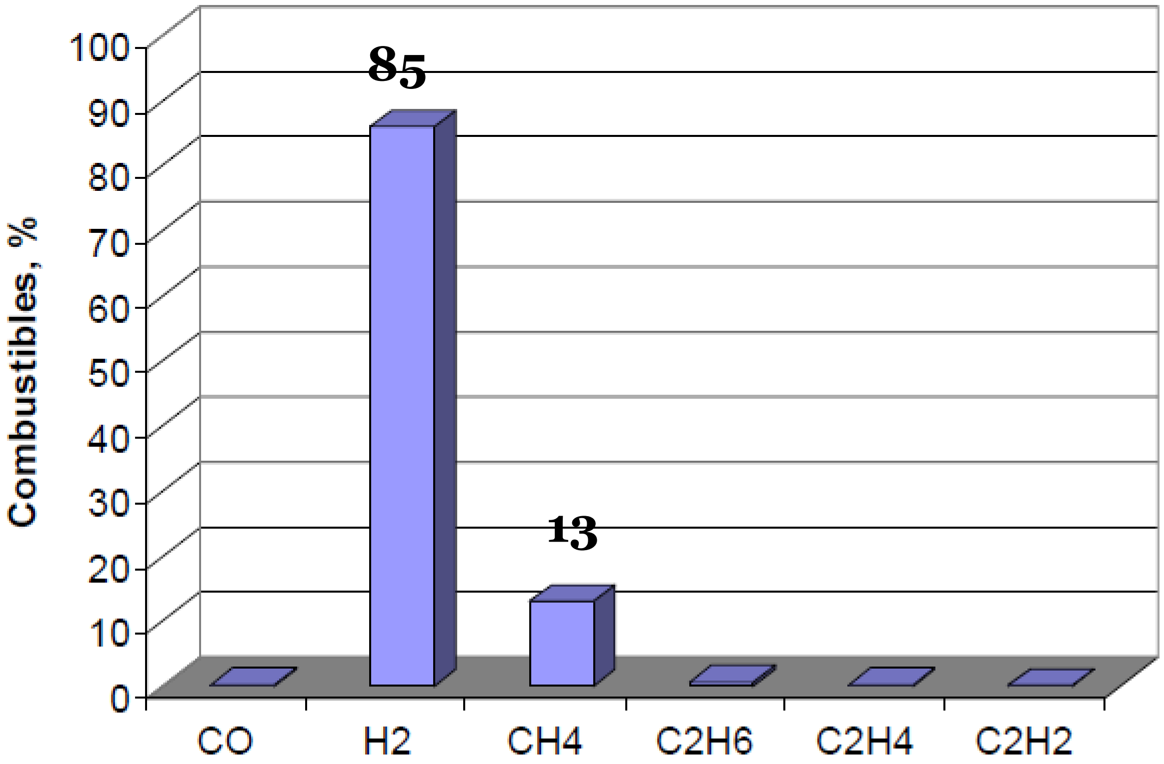
Principal Gas - Ethylene

Overheated Paper (Cellulose)



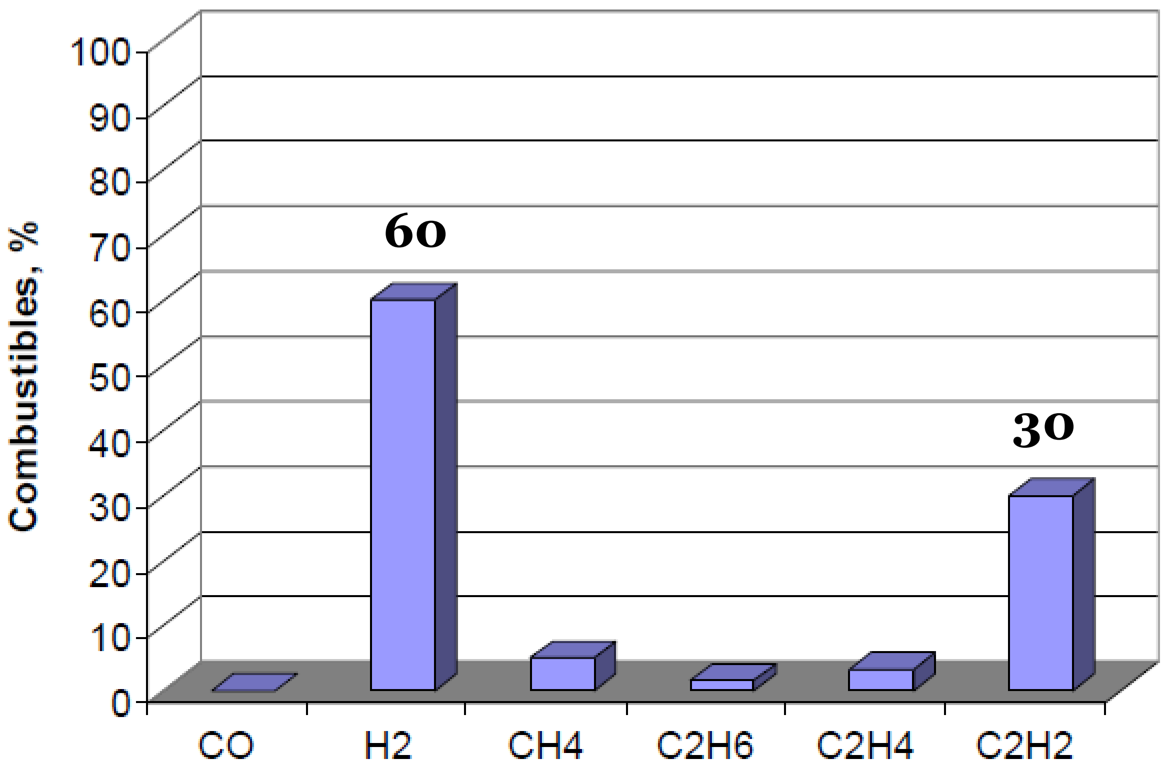
Principal Gas – Carbon Monoxide

Partial Discharge in Oil



Principal Gas – Hydrogen

Arcing in Oil



Principal Gas – Acetylene

Evaluation of possible fault type by Rogers Ratio Method (IEEE C57.104.2008)

Case	R1 CH_4/H_2	R2 C_2H_2/C_2H_4	R3 C_2H_4/C_2H_6	Suggested fault diagnosis
0	>0.1 to <1.0	<0.1	<1.0	Unit normal
1	<0.1	<0.1	<1.0	Low-energy density arcing-PD
2	0.1 to 1.0	0.1 to 3.0	>3.0	Arcing-High energy discharge
3	>0.1 to <1.0	<0.1	1.0 to 3.0	Low temperature thermal
4	>1.0	<0.1	1.0 to 3.0	Thermal <700°C
5	>1.0	<0.1	>3.0	Thermal >700°C

There will be a tendency for the ratios R2 and R5 to increase to a ratio above 3 as the discharge develops in intensity

Basic Gas Ratios (IEC 60599-2007-05)

C_2H_2 / C_2H_4	CH_4 / H_2	C_2H_4 / C_2H_6	Suggested Fault Type
NS	<0.1	<0.2	Partial Discharge
>1.0	0.1 – 0.5	>1.0	Discharge of Low Energy (D1)
0.6 – 2.5	0.1 – 1.0	>2.0	Discharge of High Energy (D2)
NS	>1.0	<1.0	Thermal Fault, <300°C (T1)
<0.1	>1.0	1.0 – 4.0	Thermal Fault, <300°C - <700°C(T2)
<0.2	>1.0	>4.0	Thermal Fault, >700°C (T3)

NS- Non significant regardless of value

CIGRE SC15: New Guidelines for Interpretation of DGA in Oil-Filled Transformers, (Electra No.186 Oct 1999)

Name	Ratio	Value Significant	Indication
Key Ratio 1	C_2H_2 / C_2H_6	**>1**	Discharge
Key Ratio 2	H_2 / CH_4	**>10**	Partial Discharge
Key Ratio 3	C_2H_4 / C_2H_6	**>1**	Thermal Fault in Oil
Key Ratio 4	CO_2 / CO	**>10** indicate overheating of cellulose, <3 indicates degradation of cellulose by electrical fault	Cellulosic Degradation
Key Ratio 5	C_2H_2 / H_2	**>2 (>30ppm)** indicates diffusion from OLTC or through a common conservator	In Tank Load Tap Changer

INDICATION/FAULT GAS	CO	CO_2	CH_4	C_2H_2	C_2H_4	C_2H_6	O_2	H_2	H_2O
Cellulose aging	●	●							●
Mineral oil decomposition			●	●	●	●		●	
Leaks in oil expansion systems, gaskets, welds, etc.		●					●		●
Thermal faults-Cellulose	●	●	●				●	●	
Thermal fault s in oil @ 150^{o}C -300^{o}C			●		TRACE	●		●	
Thermal fault s in oil @ 300^{o}C -700^{o}C			●	TRACE	●	●		●	
Thermal fault s in oil @ 700^{o}C			●	●	●			●	
Partial Discharge			●	TRACE				●	
Arcing			●	●	●			●	
Guidelines for surveillance range for type 1 transformer (IEEE PC57.104 D11d)	N<350 C350-570 W>570		N<120 C120-400 W>400	N<2 C2-5 W>5	N<50 C50-100 W>100	N<65 C65-100 W>100		N<100 C100-700 W>700	
ppm for	N-normal	C-caution	W-warning						

IEC 60599-2007-05

Name	Ratio	Value Significant	Indication
CO_2 VS. CO Ratio	CO_2 / CO	<3 Excessive	Thermal Cellulosic Degradation

NOTE: Ratio valid when levels exceed minimums:
CO > 500 ppm, CO_2 > 5000 ppm

C_2H_2 / Ratio (IEC 60599-2007-05)

OLTC's (On Load Tap Changer) produce gases corresponding to discharges of low energy.

The pattern of oil decomposition in the OLTC differs from the pattern of oil decomposition in the main tank resulting from low energy discharges.

If oil or gas contamination (communication) exists between the OLTC and the main tank, an incorrect diagnosis of the main tank may result.

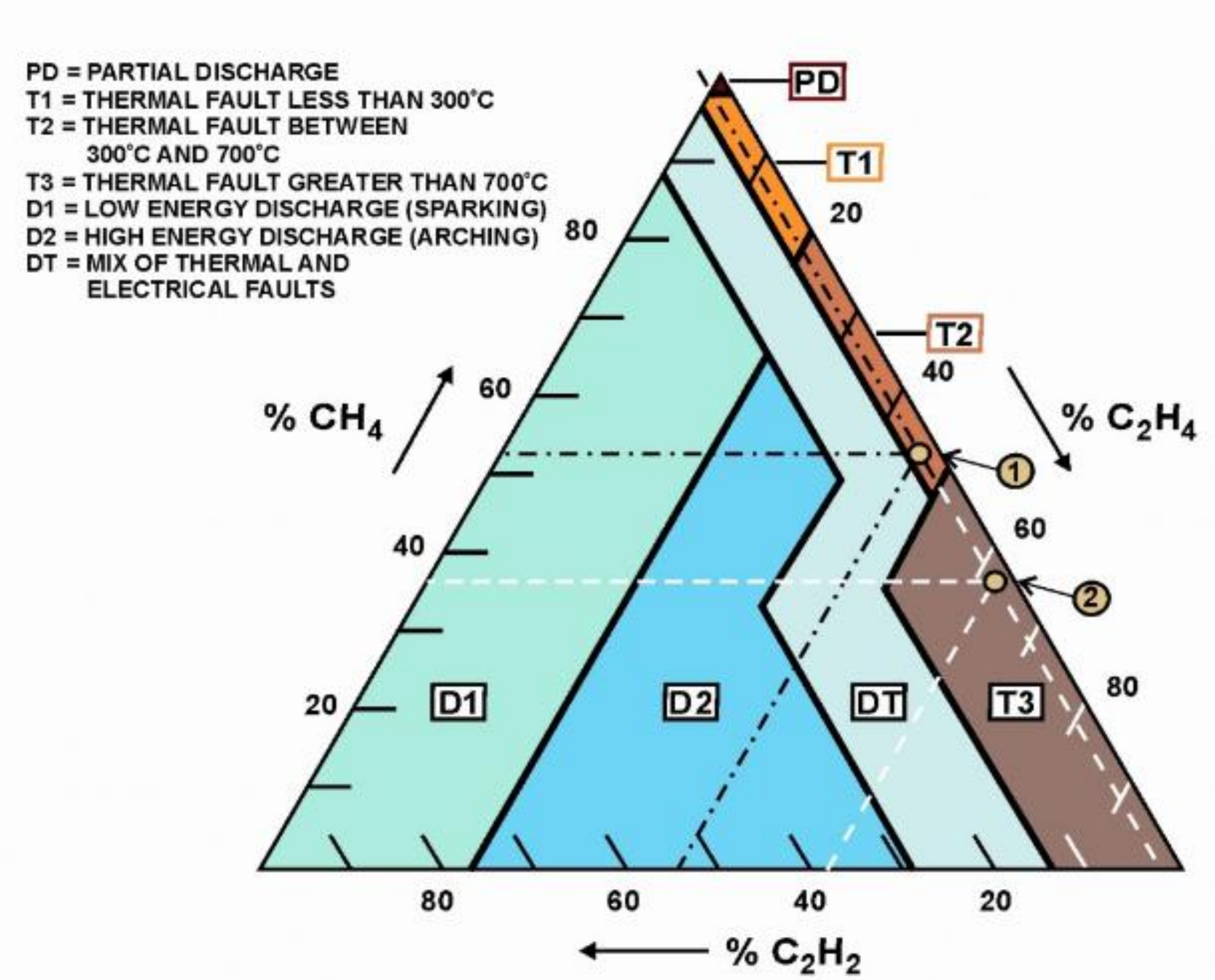
A C_2H_2/H_2 ratio ≥ 3.0 in the main tank indicates possible OLTC contamination.

CME

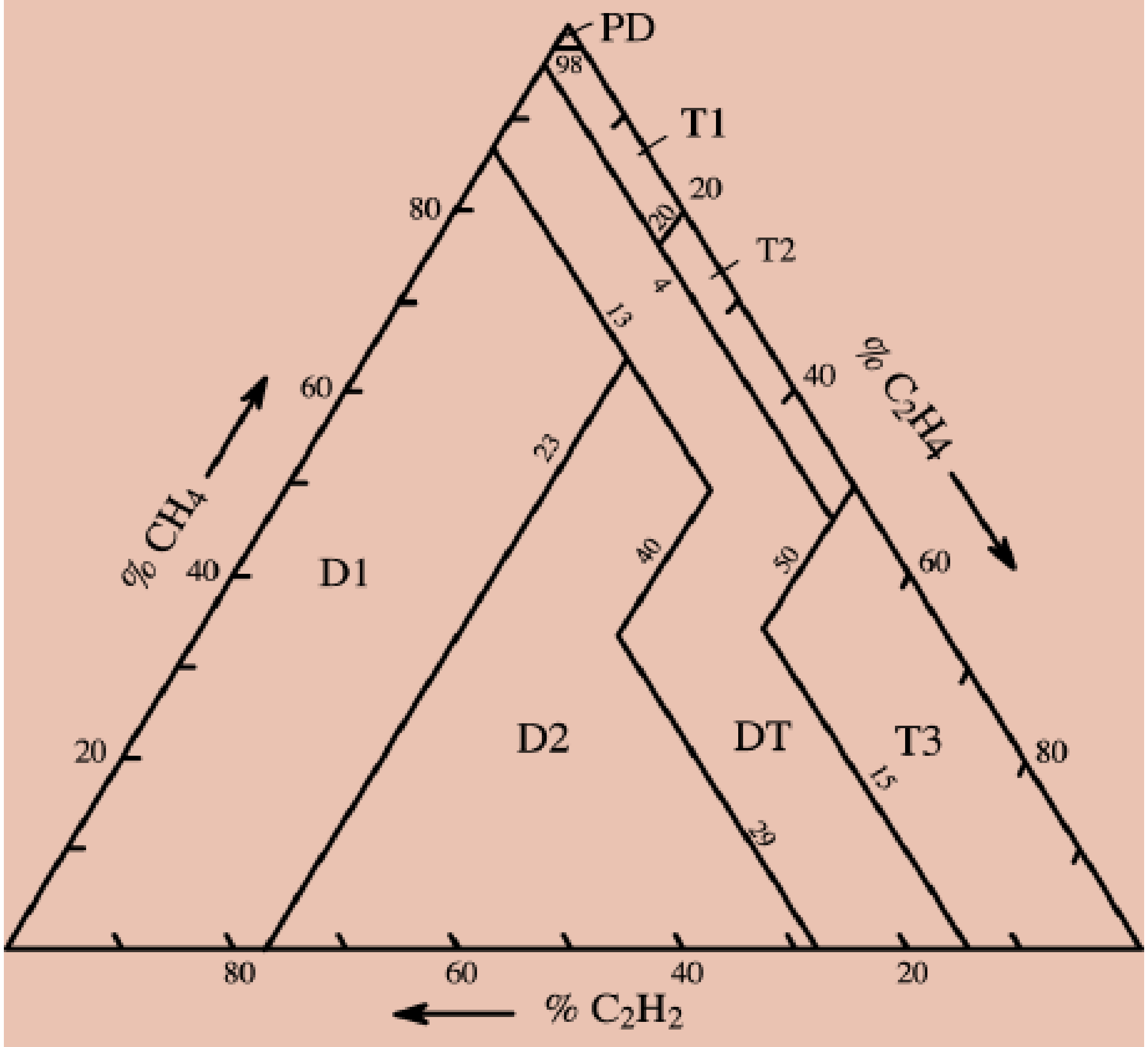
Dissolve Gas Analysis by Duval Triangle

- Proposed by Michel Duval.
- Developed empirically in the early 1970's.
- Seven different fault classes could be diagnosed
- Adopted in IEC 60599
- Uses three characteristics gases – CH_4, C_2H_4, and C_2H_2 corresponding to the energy levels of gas formation.
- One advantage of this method is that it always provide a diagnosis, with low percentage of wrong diagnosis.

DUVAL TRIANGLE



The triangle method.



Duval Triangle

- The triangle methods plots the relative % of CH_4, C_2H_4, and C_2H_2 on each side of the triangle from 0% to 100%.
- The 6 main zones of faults are indicated in the triangle, plus a DT zone (mixture of thermal and electrical faults)

How to use the triangle

If for example the DGA lab results are:

CH_4 = 100 ppm

C_2H_4 = 100 ppm

C_2H_2 = 100 ppm

First calculate: $CH_4+C_2H_4+C_2H_2$

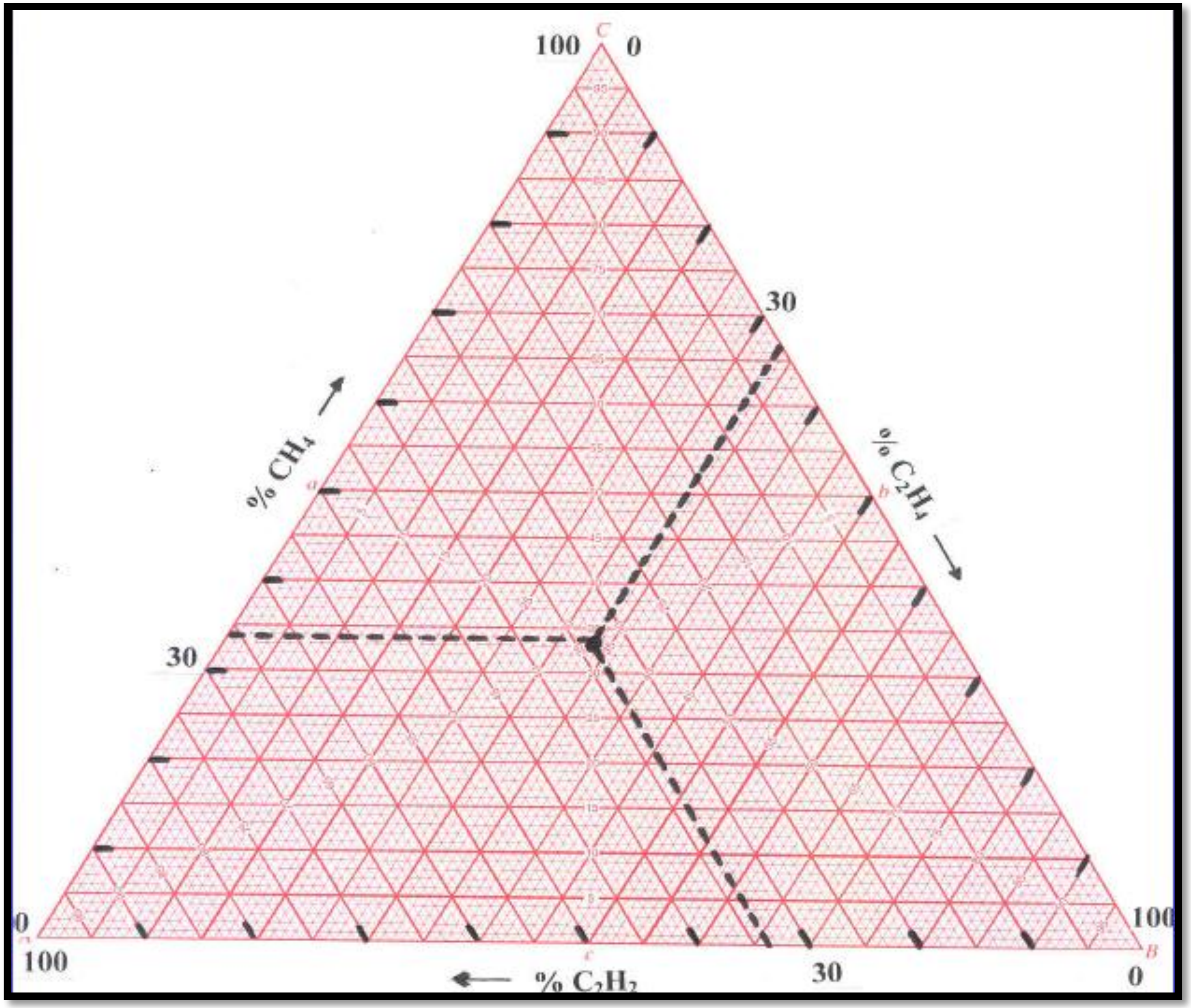
100+100+100 = 300 ppm

Then calculate the relative % of each gas:

- Relative % of CH_4 = 100 / 300 = 33.3 %
- Relative % of C_2H_4 = 100 / 300 = 33.3 %
- Relative % of C_2H_2 = 100 / 300 = 33.3 %

These values are the triangular coordinates to be used on each side of the triangle.

To verify that the calculation was done correctly, the sum of these 3 values should always give 100%, and should correspond to only ONE point in the triangle.


100
0
30
% CH_4
% C_2H_4
30
0
100
100
0
100
30
% C_2H_2
30
0

- Each DGA analysis received from the lab will always give only ONE point in the triangle.
- The zone on which the point falls in the triangle will identify the fault responsible for the DGA results.
- The Triangle, being a graphical method allows to easily follow the evolutions of faults with time, for instance from a thermal fault to a potentially much more severe fault such as D2.
- Several software packages are available for DGA interpretation using the triangle method.

The most severe faults:

- Faults D2 in paper and in oil (high energy arcing)
- Faults T2-T3 in paper (>300^{o}C)
- Faults D1 in paper (tracking, arcing)
- Faults T3 in oil (>700^{o}C)

The less severe faults:

- Faults PD/D1 in oil (corona, sparking)
- Faults T1 in paper (<300^{o}C)
- Faults T2 in oil (<700^{o}C)

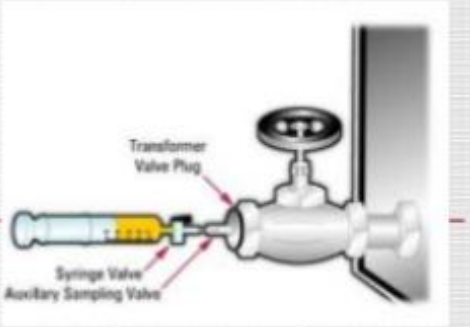
CO_2 / CO Ratio

- A fault in paper is generally considered as more serious than a fault in oil only, because paper is often placed in a HV area (windings, barriers
- A popular ratio to detect paper involvement is the CO_2/CO ratio.
- CO_2/CO ratio = 3 to 11, a healthy cellulose insulation

CO2 / CO Ratio

- If the CO2/CO ratio is <3, this is a strong indication of a fault in paper, either a hot spot or electrical arcing.
- If the CO2/CO ratio is >11, indicates cellulose ageing from thermal heating.
- CO2/CO ratio becomes significant when individual gases are above **5000**/**500** ppm.
- **Remember: Paper is irreversible**

8.Sampling



- ASTM D3613 requires that transformer oil sampling be taken via a syringe and stopcock system from a mineral-oil insulated transformer's drain point to ensure no oil contact with air.
- To minimise air ingress, it is important that the syringe not be pulled forcefully, i.e. the transformer oil's natural gravity flow should be allowed to work the oil into the syringe .

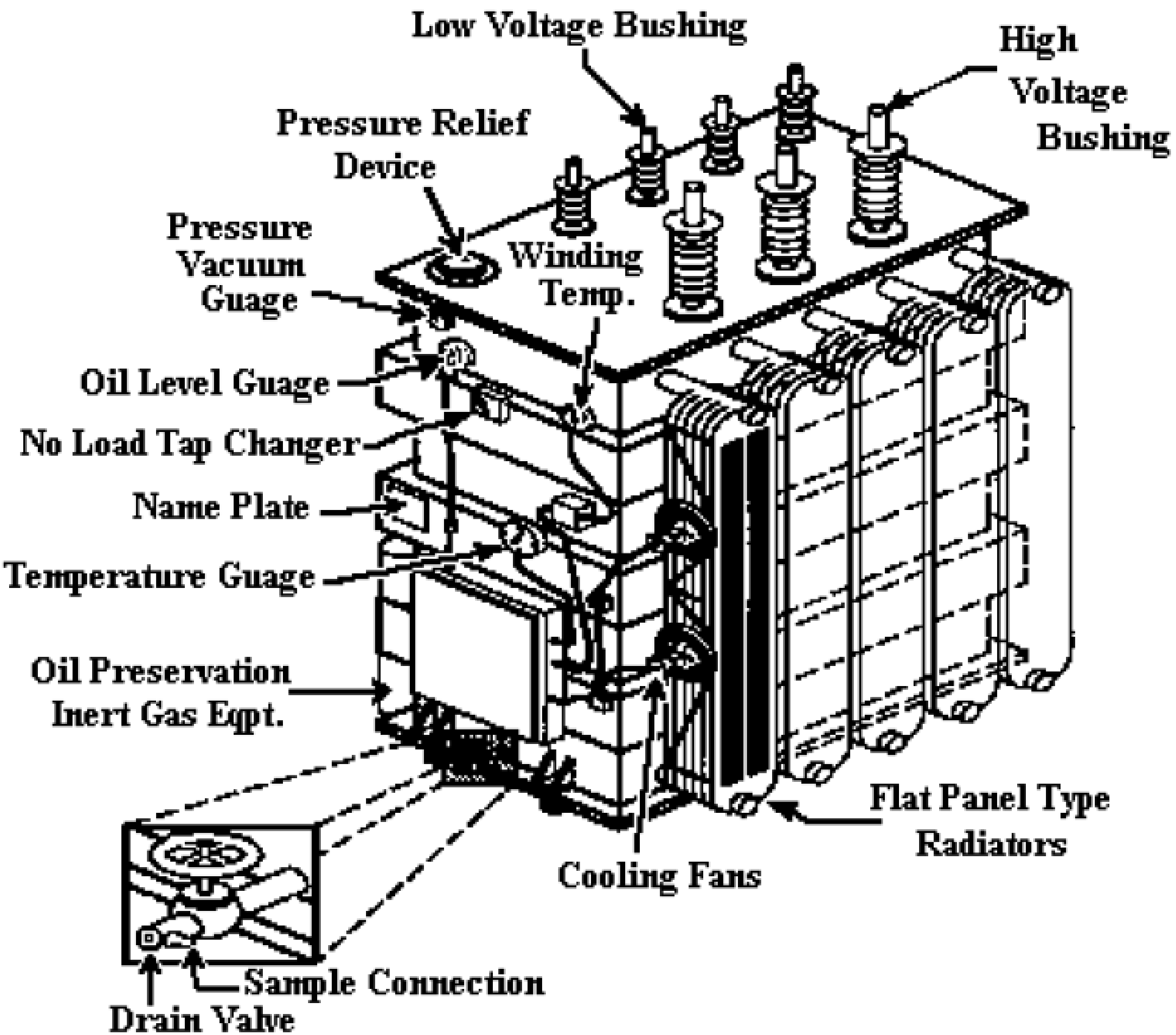
Practice Procedure of Transformer Oil Sampling: IEC 60475

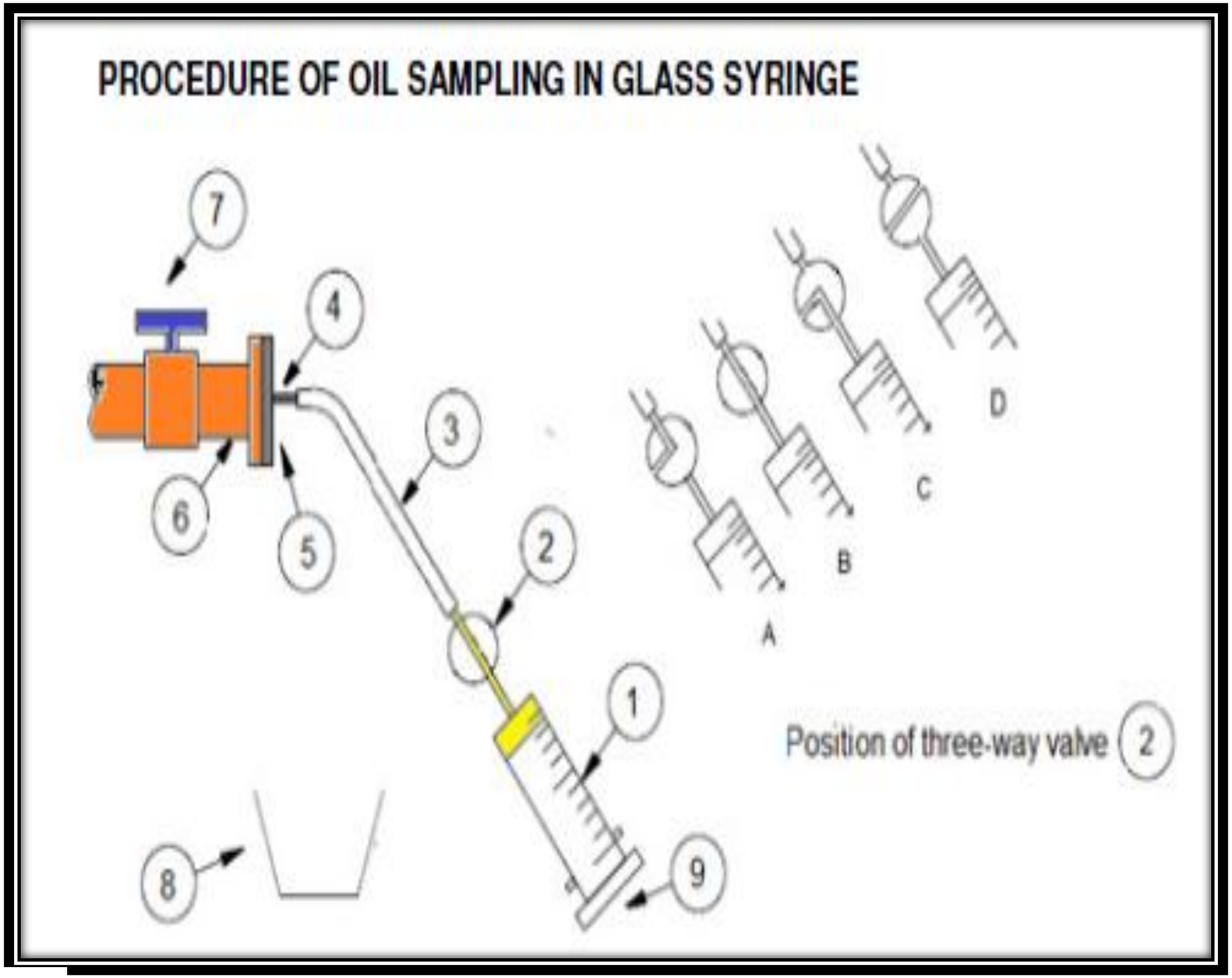
- The apparatus to be sampled should be under positive pressure. For transformer sealed with an inert gas, check the pressure gauge to make it sure it does not indicate a negative pressure.
- To ensure that the vacuum will not draw air into the transformer, attach a length of Tygon tubing filled with clean oil to the sampling valve before cracking the valve open.
- Carefully observe the direction of oil movement in the tube and close the valve immediately if the oil flow is towards the transformer.

CME

Sampling Procedure

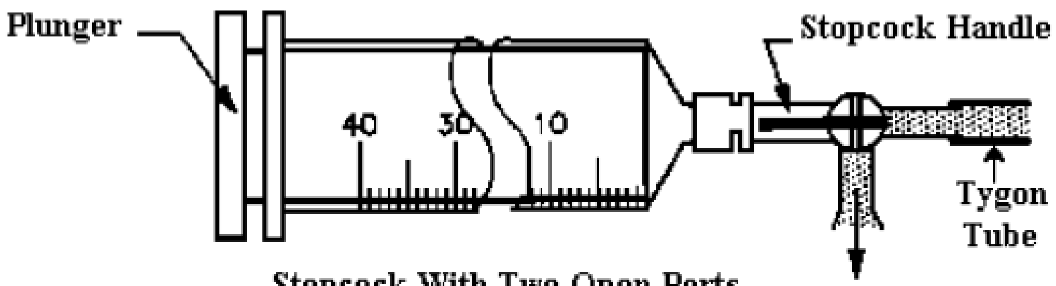
- Do not allow air to be drawn into the transformer. Air can only enter the transformer when it is under a vacuum condition.
- The valve through which the sample is to be taken should be flushed by allowing about half of a gallon of oil to flow to a waste container.


Low Voltage Bushing
High
Voltage
Bushing
Pressure Relief
Device
Pressure
Vacuum
Guage
Winding
Temp.
Oil Level Guage
No Load Tap Changer
Name Plate
Temperature Guage
Oil Preservation
Inert Gas Eqpt.
Flat Panel Type
Radiators
Cooling Fans
Sample Connection
Drain Valve

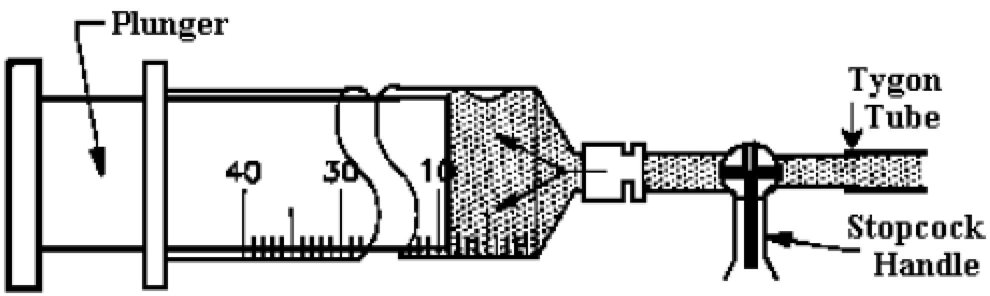


LEGEND:

1-50ml glass syringe
2-three-way syringe valve
3-tygon tube
4-nozzle
5-adapter
6-sampling port
7-drain valve
8-waste container
9-syringe plunger



Stopcock With Two Open Ports



Stopcock With Handle In Line Flushing Port

Figure 2

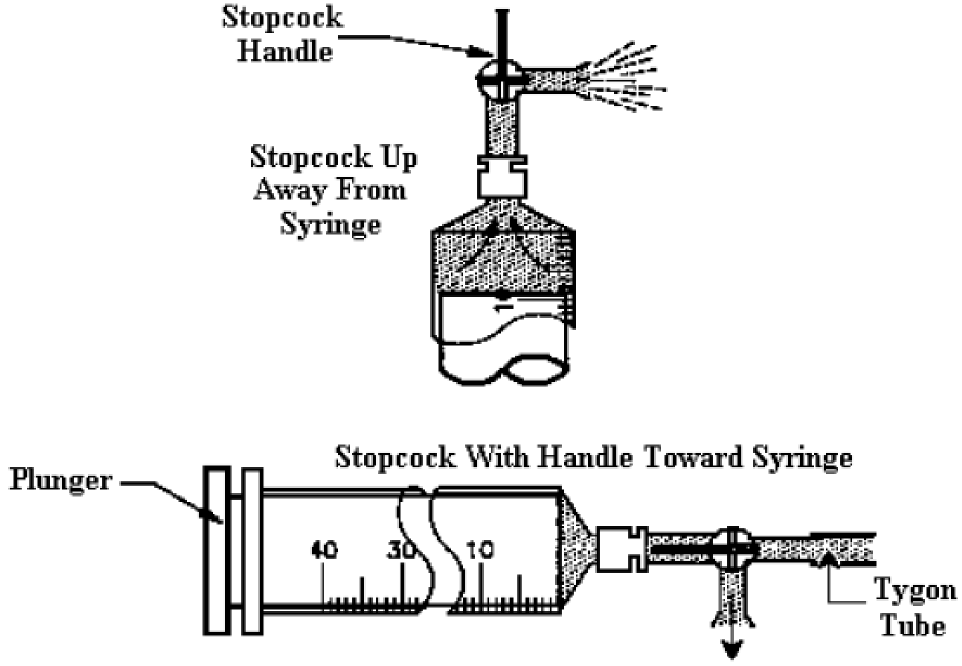
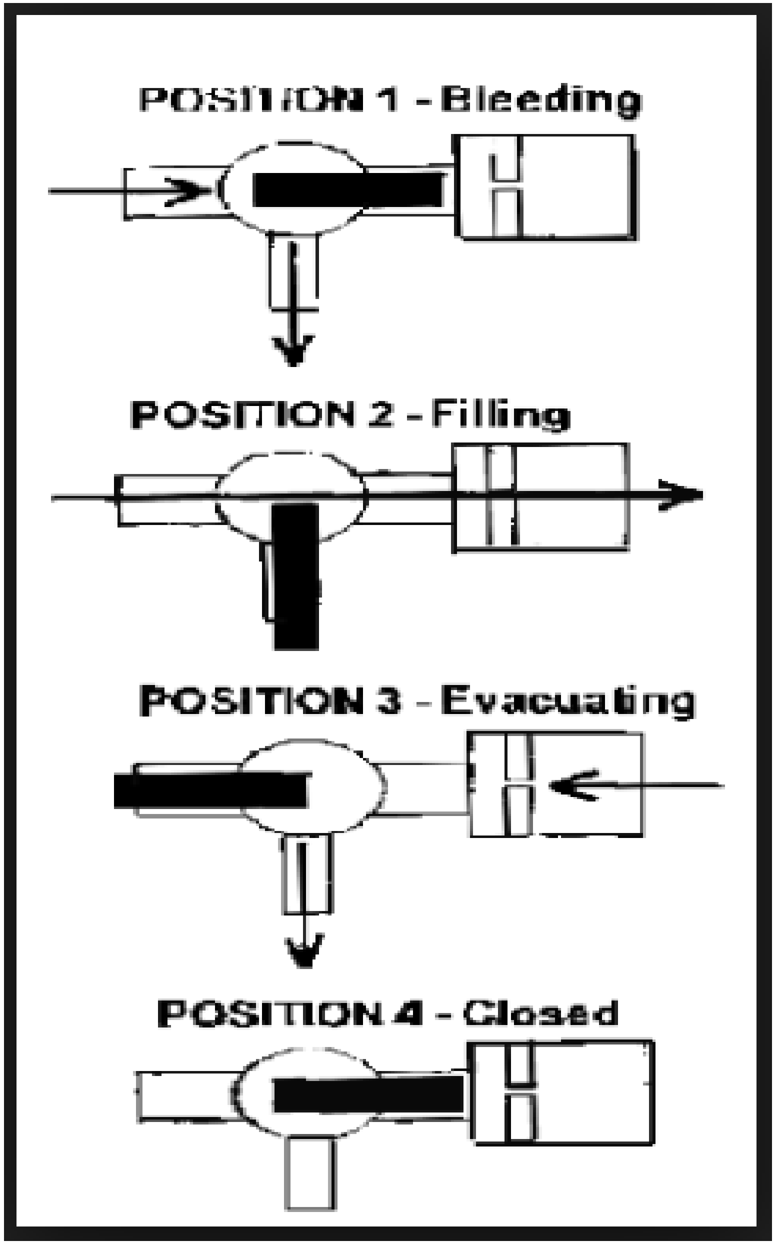
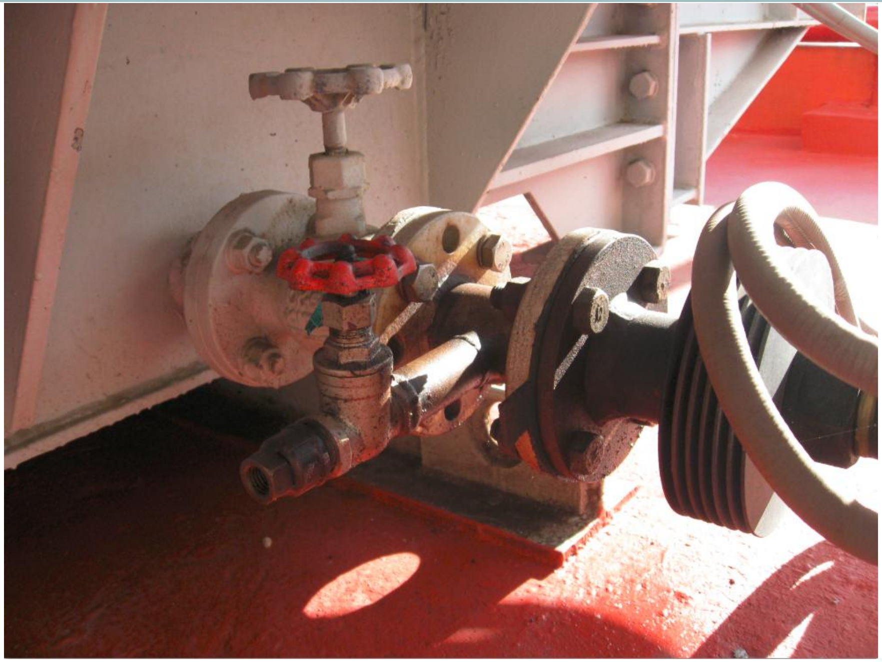

Stopcock
Handle
Stopcock Up
Away From
Syringe
Plunger
Stopcock With Handle Toward Syringe
40
30
10
Tygon
Tube

Figure 3


POSITION 1 - Bleeding
POSITION 2 - Filling
POSITION 3 - Evacuating
POSITION 4 - Closed




TJ
H2b
5
4
3
2
1


10 20 30 40 50cc
GE Energy
DGA


TxM
TxMONITOR

APRI - MAKBAN GEOTHERMAL POWER PLANT

DISSOLVED GAS ANALYSIS REPORT

EQUIPMENT USED: KELLMAN PORTABLE DGA ANALYZER "TRANSPORT X"

Analysis Report

Sample : *Transformer Oil*

Sample Source : *U2 UNIT TRANSFORMER, 9.375MVA, 13.8/4.16KV S#: 564622*

Sample code :

Date Sampled : *see table*

Date Sampled / *Time Sampled*	IEEE Action Limts	30-Nov-10	28-Dec-10	15-Apr-11	26-Apr-11	23-May-11	22-Dec-11	21-Jun-12	16-Jul-12	29-Oct-12	17-Mar-13	27-Jul-13	29-Jul-13	TJH2B LAST TEST 23-Oct-12	Furans/Paper Comment Estimated DP (from Furans)
Time Sampled		1000H	1000H	1000H	1000H	1000hrs	1000hrs	1000hrs	1400	1000H	1000H	1300H	1000H		
No. of days interval			28	108	11	27	213	182	25	105	139	132	2		
Load in MW														Potential 3	
Winding Temp. in °C															
Oil Temp. in °C				50	48	47	38	37	48						
Di-electric Strenght, kV	20.0 min.					31	32	14	9.9	36.8	30	25	14		
Moisture , ppm	20.0 max.								19.5						
TAN, mg KOH/g sample	0.030 max.														339
Dissolved Gases in ppm V/V :															Paper condition is
Hydrogen (H2)	700	76	82	54	48	50	34	17	12	16	25	255	369	80	severely reduced. Plan for
Oxygen (O)	-													8554	end of life and manage
Nitrogen (N)	-													66627	exposure to risk
Carbon Monoxide (CO)	570	639	615	493	445	458	519	479	455	513	464	627	593	521	
Methane (CH4)	400	123	124	145	132	145	166	132	106	97	128	846	760	112	
Carbon Dioxide (CO2)	4000	12004	12316	10043	9140	9353	10674	7047	6239	7126	6371	7380	6517	2735	
Acetylene (C2H2)	5	0	0	0	0	0	0	0.5	0.5	0	0	201.9	320.8	<1	
Ethylene (C2H4)	100	121	124	171	159	172	230	204	190	197	341	1629	1484	160	
Ethane (C2H6)	100	51	42	80	92	97	109	139	149	130	131	614	548	117	
Water (H2O)		36	41	52	54	56	43	69	72	57	72	85	83		
RS of Oil		28.5%	36.1%	49.9%	32.9%	35.5%	38.9%	41.7%	43.40%	40.50%	66.50%				
TDCG	1900	1008	985	941	875	920	1055	972	912	949	1086	4173	4075	990	

Remarks :

1 4. Transformer has been de-energized and replaced with same rating from Unit no.6 last July 31, 2031

2. Principal gas generated C2H4,C2H6,CO.CH4 AND C2H2 Based on Rogers Ration Method, internal thermal fault of hotspot @ 300 - 700 °C

3. Retest after 6 months. Establish trends and confirm condition.

Sampled/Test/Analyzed: Noted: Cc:

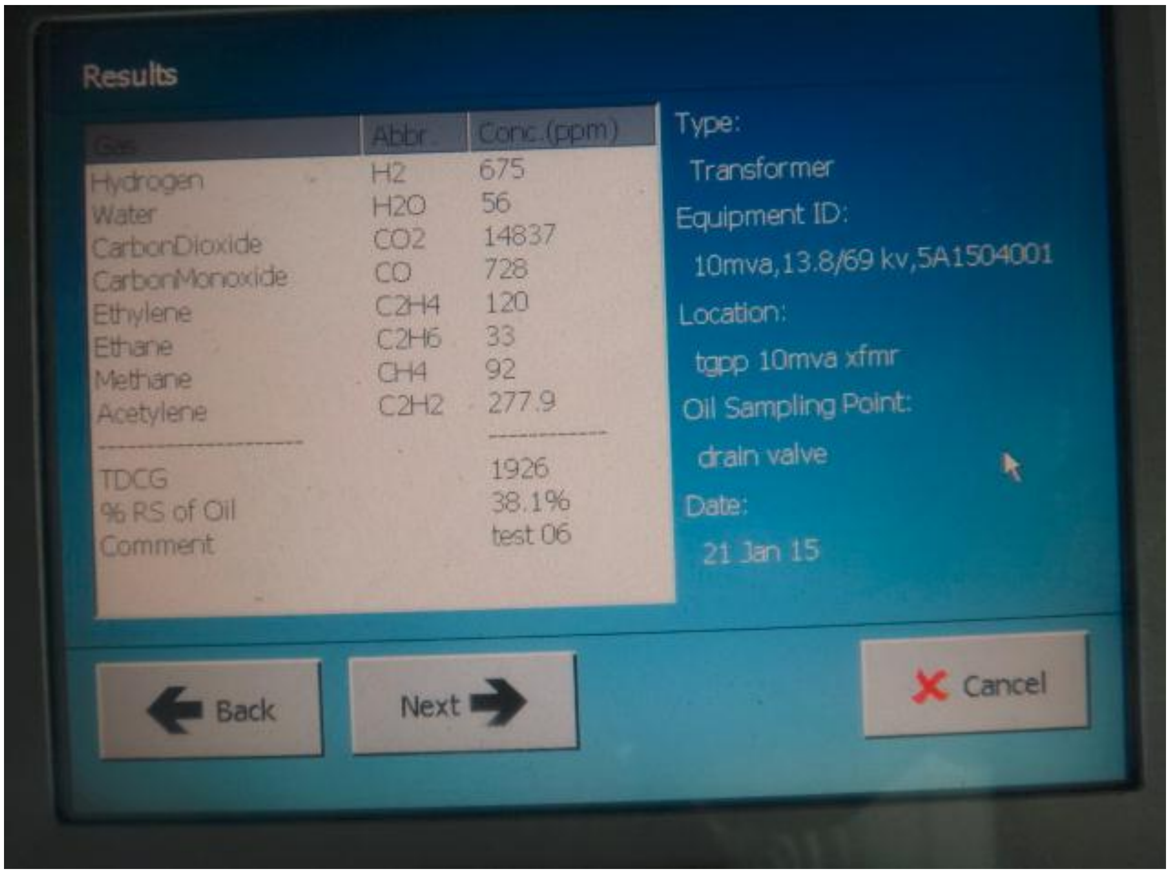
IÑIGO V. ESCOPETE, JR.
Condition Monitoring Engineer-TSG

JOSEPHINE C. PUCYUTAN
Manager, Technical Support Group

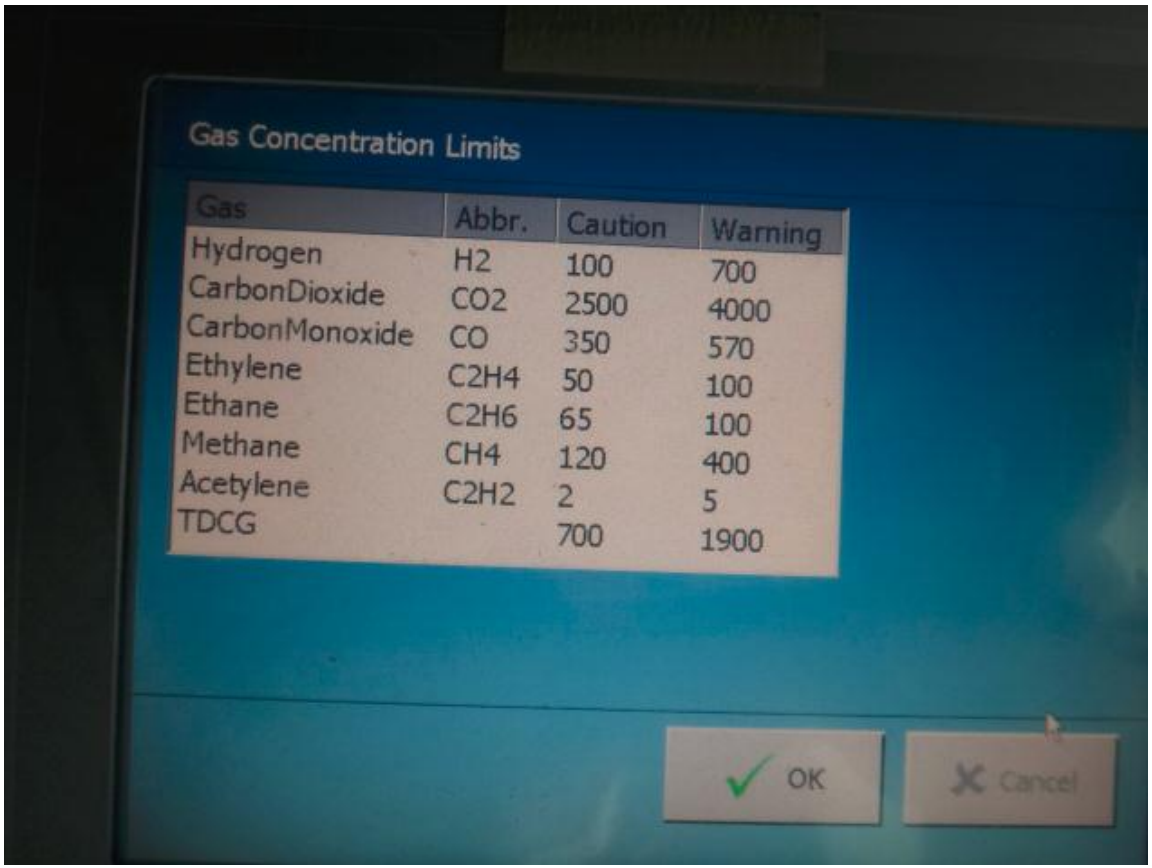
JM MARALIT
Facility Manager

KR BEAVERS
SVP Operations-APRI

Case Study


Results
Gas
Abbr.
Conc.(ppm)
Hydrogen
H2
675
Water
H2O
56
CarbonDioxide
CO2
14837
CarbonMonoxide
CO
728
Ethylene
C2H4
120
Ethane
C2H6
33
Methane
CH4
92
Acetylene
C2H2
277.9
TDCG
1926
% RS of Oil
38.1%
Comment
test 06
Type:
Transformer
Equipment ID:
10mva,13.8/69 kv,5A1504001
Location:
tgpp 10mva xfmr
Oil Sampling Point:
drain valve
Date:
21 Jan 15
Back
Next
Cancel

Case Study



Gas Concentration Limits

Gas	Abbr.	Caution	Warning
Hydrogen	H2	100	700
CarbonDioxide	CO2	2500	4000
CarbonMonoxide	CO	350	570
Ethylene	C2H4	50	100
Ethane	C2H6	65	100
Methane	CH4	120	400
Acetylene	C2H2	2	5
TDCG		700	1900

OK Cancel

Duval Computation

$C_2H_2 + CH_4 + C_2H_4$

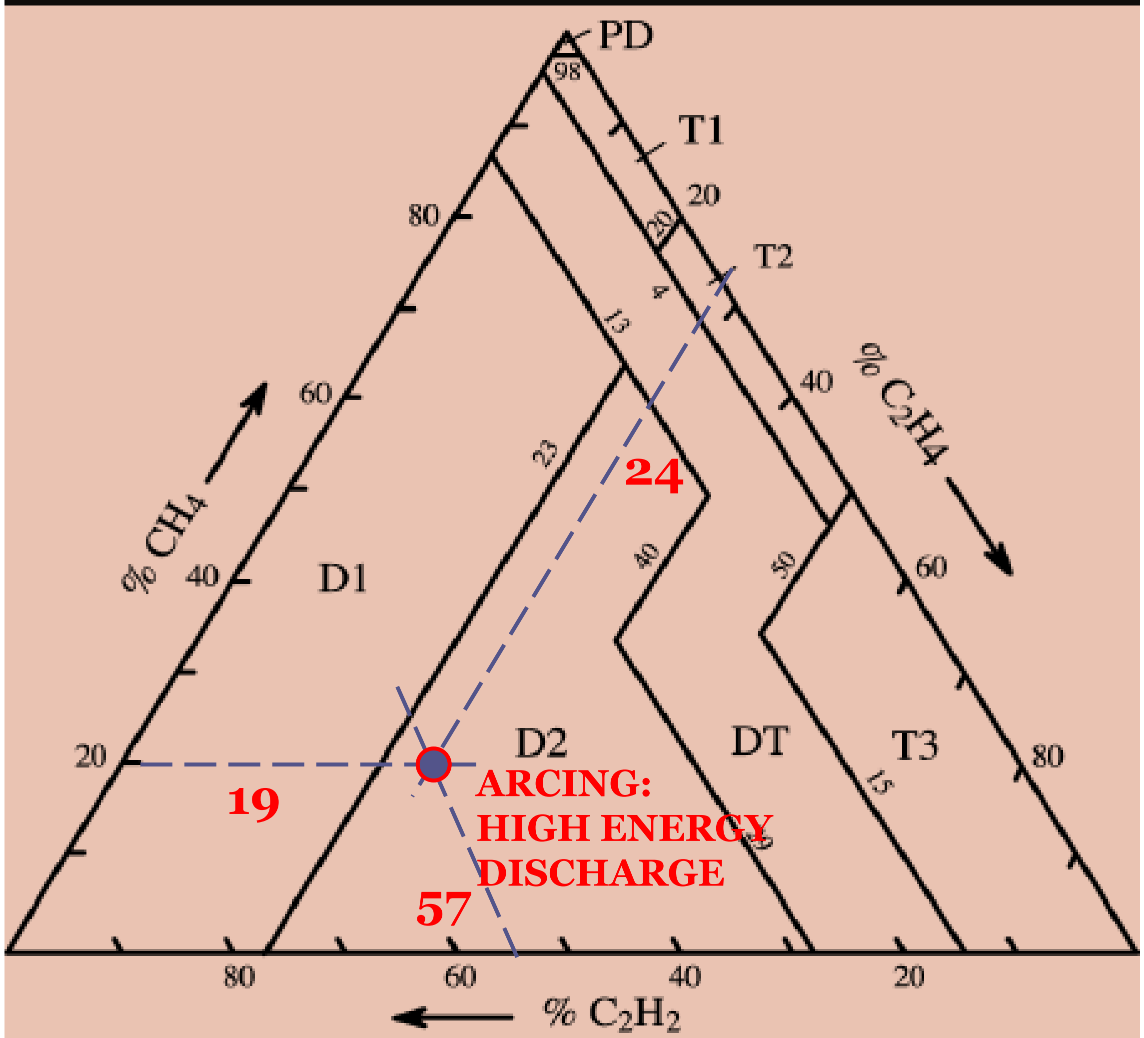
280 + 92 + 120 = **492**

% C_2H_2 = 280 / 492 x 100 = **57**

% CH_4 = 92 / 492 x 100 = **19**

% C_2H_4 = 120 / 492 = **24**

The triangle method.



Rogers Ratio Computation

R1 = CH_4 / H_2

= 92 / 675

= **0.136** (**CASE 2**)

R2 = C_2H_2 / C_2H_4

= 280 / 120

= **2.33** (**CASE 2**)

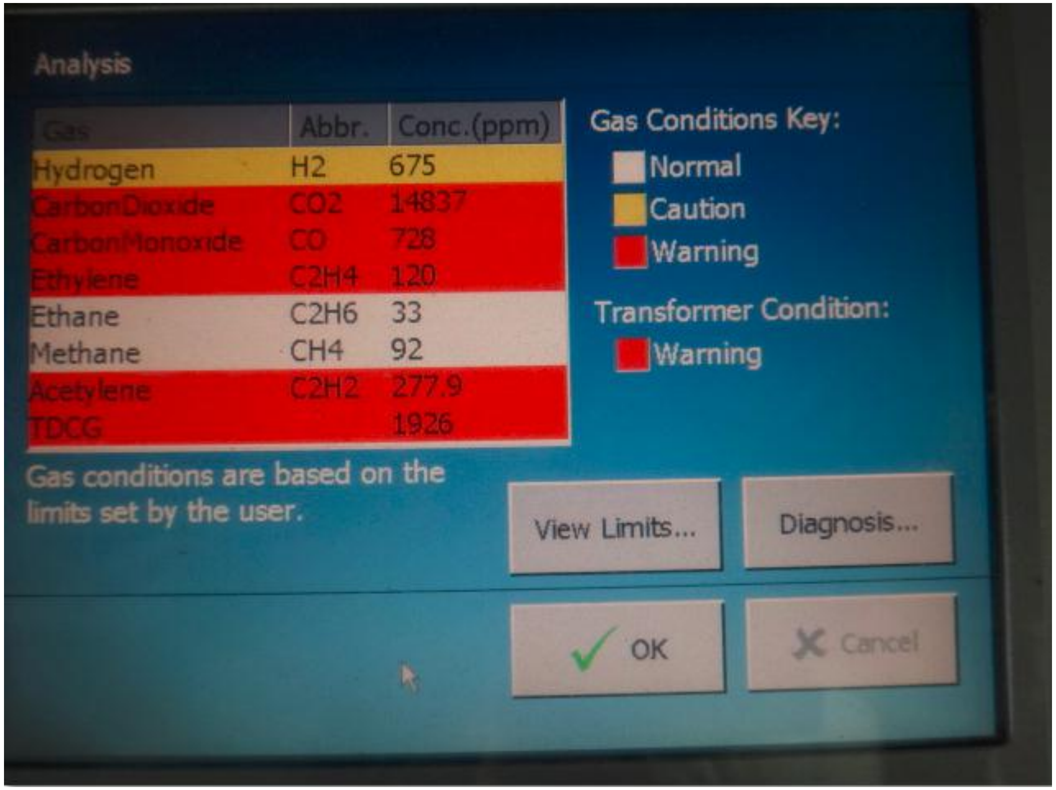
R3 = C_2H_4 / C_2H_6

= 120 / 33

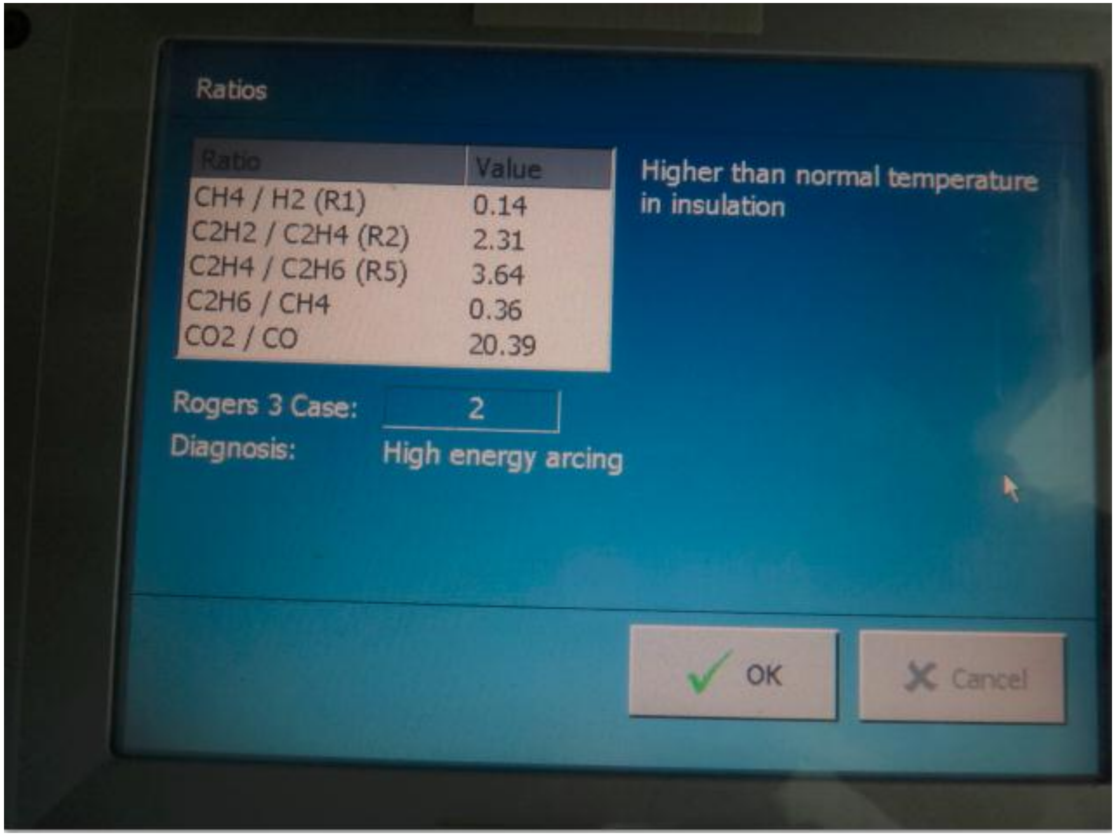
= **3.63** (**CASE 2**)

CASE 2 = **ARCING – HIGH ENERGY DISCHARGE**

Case Study:

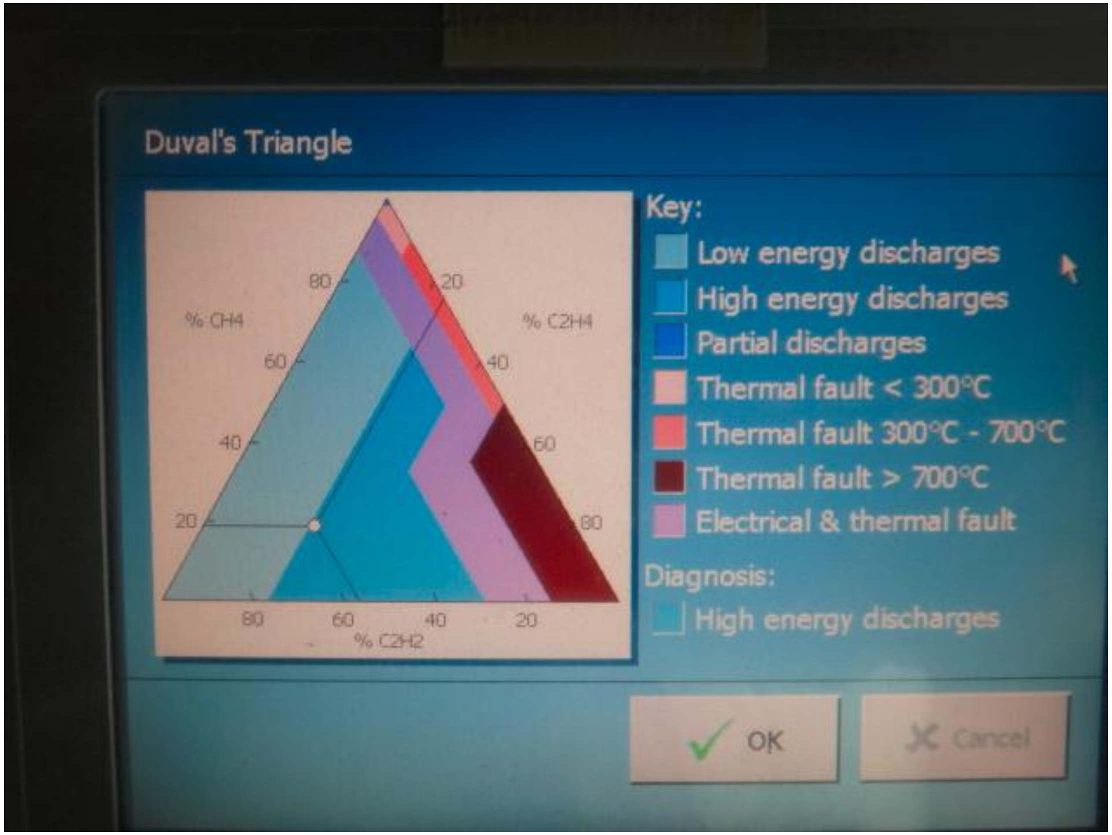

Analysis
Gas
Abbr.
Conc.(ppm)
Hydrogen H2 675
CarbonDioxide CO2 14837
CarbonMonoxide CO 728
Ethylene C2H4 120
Ethane C2H6 33
Methane CH4 92
Acetylene C2H2 277.9
TDCG 1926
Gas Conditions Key:
Normal
Caution
Warning
Transformer Condition:
Warning
Gas conditions are based on the limits set by the user.
View Limits...
Diagnosis...
OK
Cancel

Case Study



Ratios
Ratio
Value
CH4 / H2 (R1)
0.14
C2H2 / C2H4 (R2)
2.31
C2H4 / C2H6 (R5)
3.64
C2H6 / CH4
0.36
CO2 / CO
20.39
Higher than normal temperature in insulation
Rogers 3 Case:
2
Diagnosis:
High energy arcing
OK
Cancel

Case Study



Duval's Triangle
% CH4
% C2H4
% C2H2
80
60
40
20
Key:
Low energy discharges
High energy discharges
Partial discharges
Thermal fault < 300°C
Thermal fault 300°C - 700°C
Thermal fault > 700°C
Electrical & thermal fault
Diagnosis:
High energy discharges
OK
Cancel