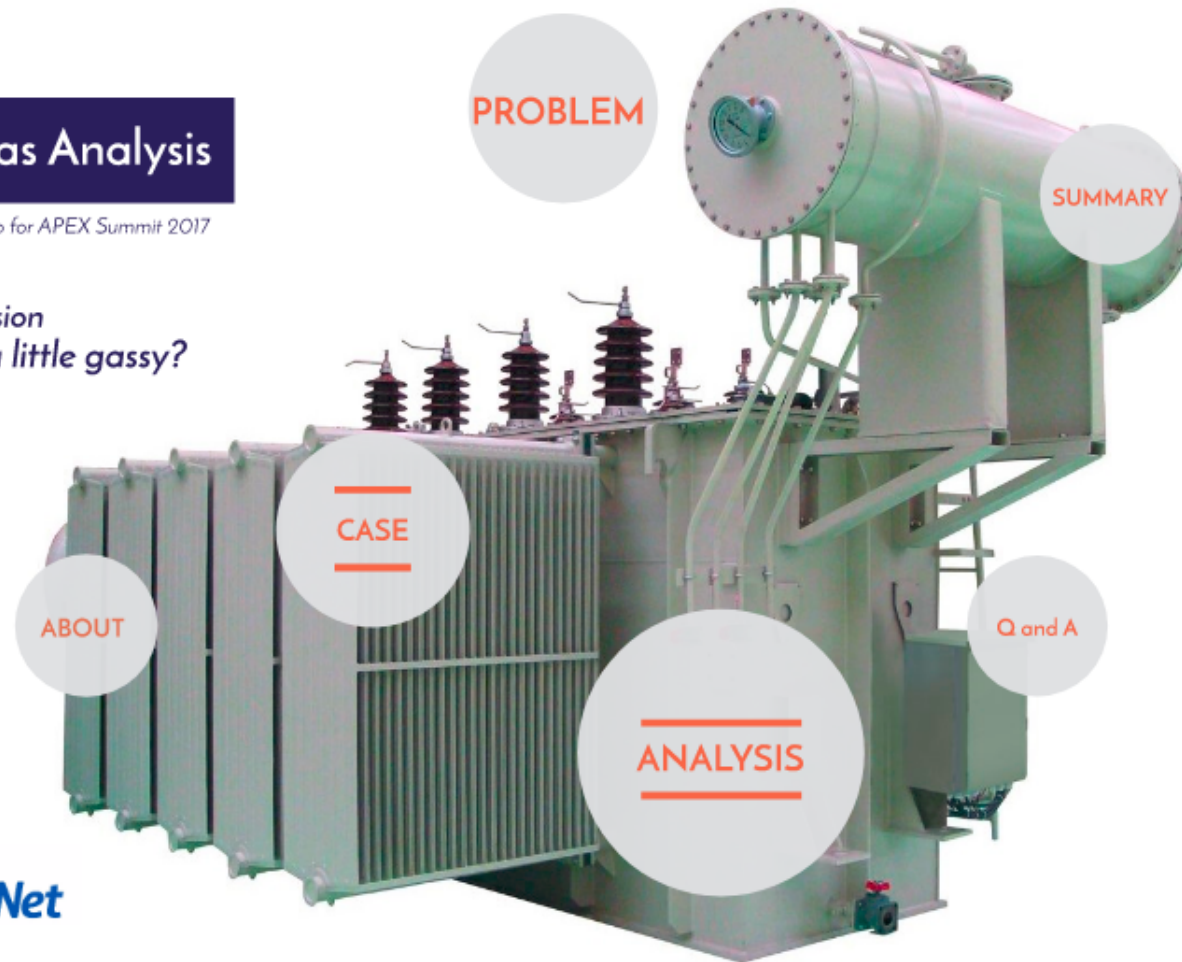


Dissolved Gas Analysis

Presented by Maria Fernando for APEX Summit 2017

*Imminent explosion
...or just a little gassy?*





TRANSFORMER OIL

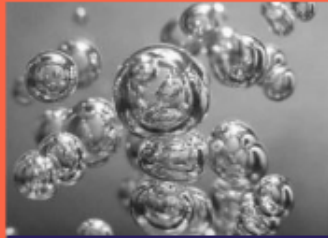
Transformer oil performs numerous functions within a transformer:

- Insulation
- Cooling
- Extinguishes Arcs

It also absorbs gases from the environment it is in.

GASES

Transformer health can be based on the percentage of five dissolved gases



Hydrogen (H_2)

DISSOLVED GASES



Methane (CH_4)

Ethane:
used in
anti-freeze



Ethane (C_2H_6)

Acetylene:
...is just bad

Ethylene:
known for
ripening fruit



Ethylene (C_2H_4)



Acetylene (C_2H_2)

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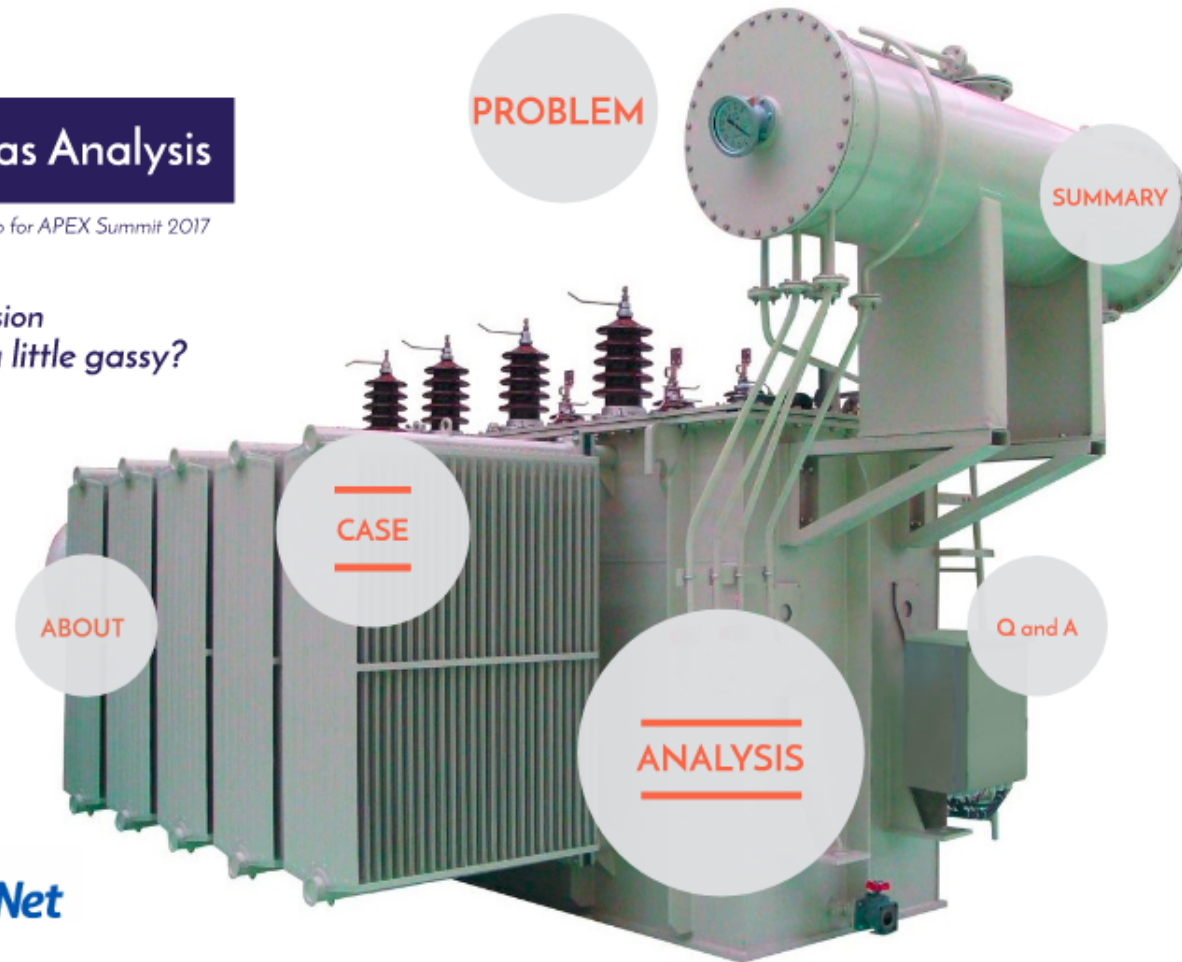




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THE PROBLEM

The formation of gases is normal as transformers age. However, under the wrong conditions, gas formation can accelerate. So what rate of gas formation is dangerous?

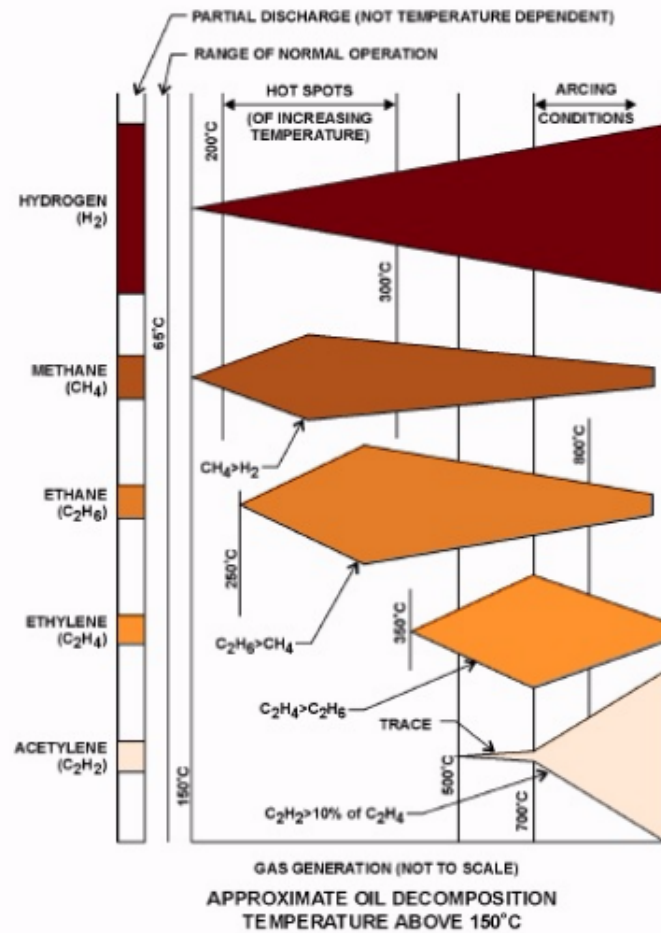
We will investigate common fault types and look into Duval's diagnostic methods used in DGA analysis.

GAS FORMATION

FAULTS

METHODS

COMBUSTIBLE GAS GENERATION VS.
APPROXIMATE OIL DECOMPOSITION TEMPERATURE



GAS FORMATION

As a transformer spends sustained periods at higher temperatures, more harmful gases are formed.

6. Transformer Oils, GlobeCore. Oil Purification Systems, 29-Sep-2016. [Online]. Available: <https://globecore.com/6-transformer-oils.html>. [Accessed: 11-Aug-2017].

"BASIC" FAULT TYPES

PD Partial Discharge - Corona or Sparking occurs

D1 Discharges of Low Energy (Sparking)

D2 Discharges of High Energy (Arcing)

T1 Thermal Fault - occurs in oil/paper below 300 °C

T2 Thermal Fault - occurs in oil/paper above 300 °C and below 700 °C

T3 Thermal Fault - occurs in oil/paper above 700 °C

"ADVANCED" THERMAL FAULT TYPES

T3-H

Thermal faults in oil > 700°C

C

Thermal faults due to carbonization of paper

O

Overheating < 250°C

S

Stray gassing of mineral oil at 120°C

These four faults are specifically found in mineral oil transformers and are more precisely defined than the basic faults.

DGA METHODS

01. Baseline Testing

02. Duval's Triangles

03. Duval's Pentagon

Tests	Condition Ranges			
	1	2	3	4
	Good	Fair	Poor	Action
Hydrogen (H2) ppm	<101	>100 <1000	>1000 <2000	>2000
Hydrogen (H2) ppm generation/6 month	<60	>54 <180	>174 <300	>294
Methane (CH4) ppm	<121	>120 <401	>400 <1001	>1000
Methane (CH4) ppm generation/6 month	<48	>42 <138	>132 <228	>222
Ethane (C2H6) ppm	<66	>64 <101	>100 <151	>150
Ethane (C2H6) ppm generation/6 month	<48	>42 <138	>132 <228	>222
Ethylene (C2H4) ppm	<51	>50 <101	>100 <201	>200
Ethylene (C2H4) ppm generation/6 month	<48	>42 <138	>132 <228	>222
Acetylene (C2H2)	<36	>35 <51	>50 <81	>80
Acetylene (C2H2) generation/6 month	<0.5	>0.4 <1.5	>1.49 <2.5	>2.49
Carbon Monoxide (CO) ppm	<351	>350 <571	>570 <1401	>1400
Carbon Monoxide (CO) ppm generation/6 month	<420	>414 <1320	>1314 <2100	>2094
Carbon Dioxide (CO2) ppm	<2501	>2500 <4001	>4000 <10001	>10000
Carbon Dioxide (CO2) ppm generation/6 month	<4200	>4194 <12600	>12594 <21000	>20994
CO2/CO Ratio	>10	<10.1 >6	<6.1 >3.9	<4
Oxygen (O2) ppm	<3501	>3500 <7001	>7000 <10001	>10000
Total Combustible Gas ppm	<721	>720 <1921	>1920 <4631	>4631
Moisture in Oil ppm	<10	>9 <16	>15 <21	>20
Interfacial Tension (dynes per cm)	>45	<46 >35	<36 >25	<26
Acid Number (KOH in milligrams)	<.05	>0.04 <0.2	>.19 <5.1	>0.5

This table represents a composite of IEEE C57-104 & IEC 60599 standards

BASELINE TESTING

Is there a problem?

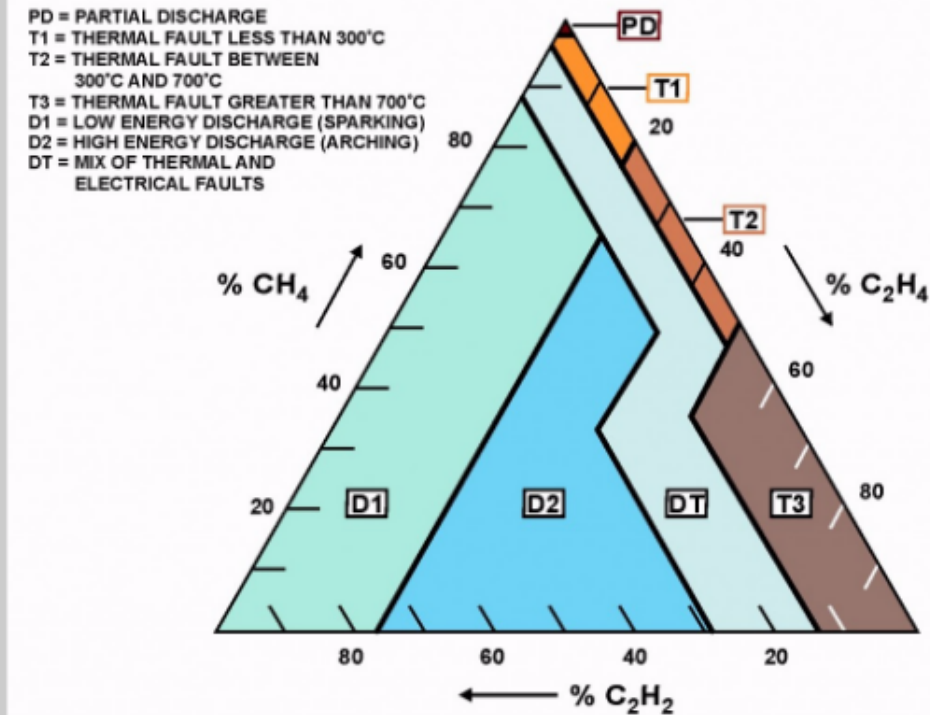
These are baseline figures from IEEE and IEC standards which provide acceptable ranges for DGA test results.

Although gas levels may be high, it is the rate of generation which is more important.

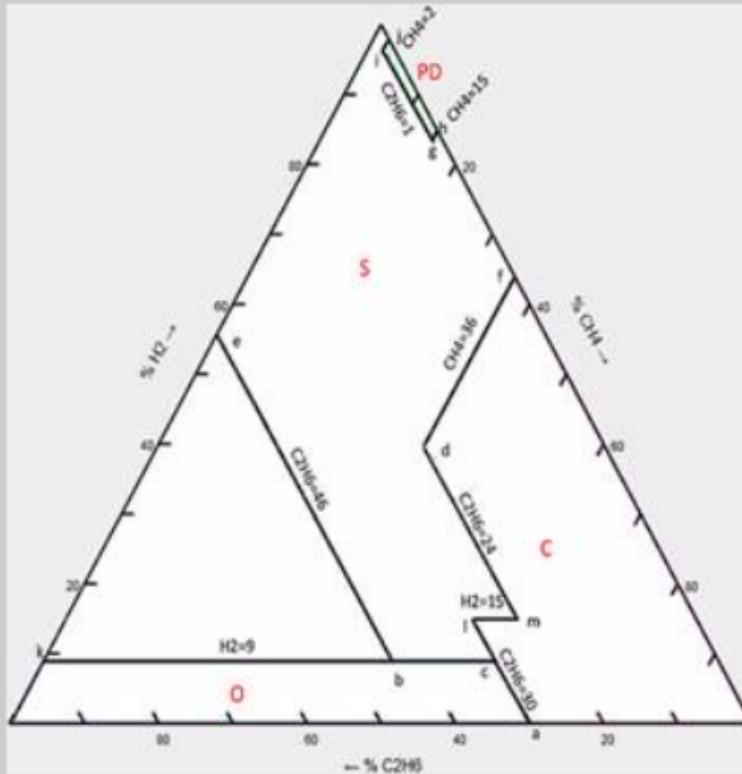
From this initial test, we can decide if there actually is a problem.

The CO₂/CO Ratio indicates whether there is paper/cellulose involvement in a fault.

DUVAL'S TRIANGLE ONE

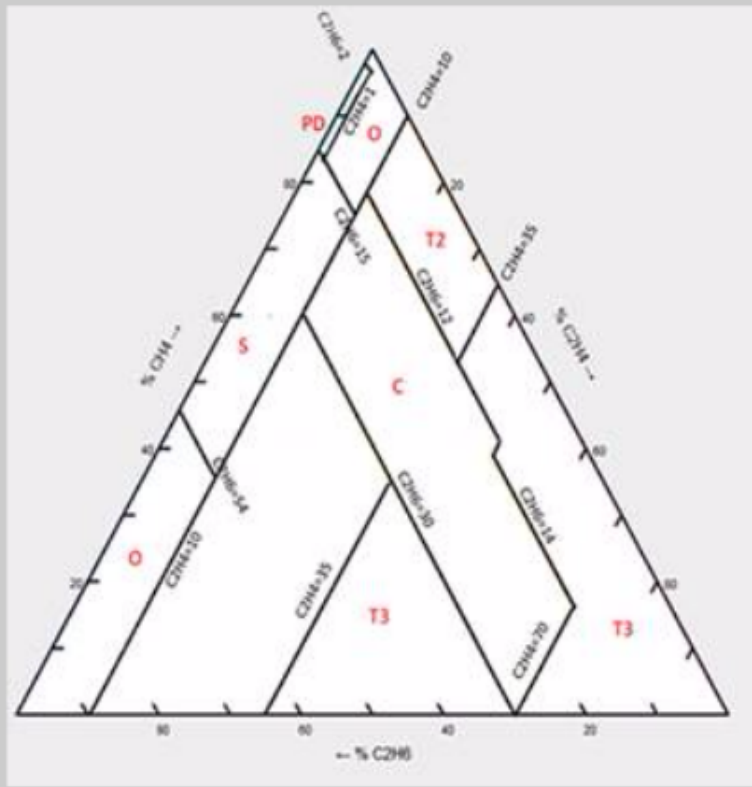


- This is the classic Duval's Triangle for oil-filled transformers
- Each side is expressed as a percentage of its sum
- The triangle interior is split into fault zones
- The chart only identifies fault types. It cannot indicate whether a fault is actually present.



DUVAL'S TRIANGLE FOUR

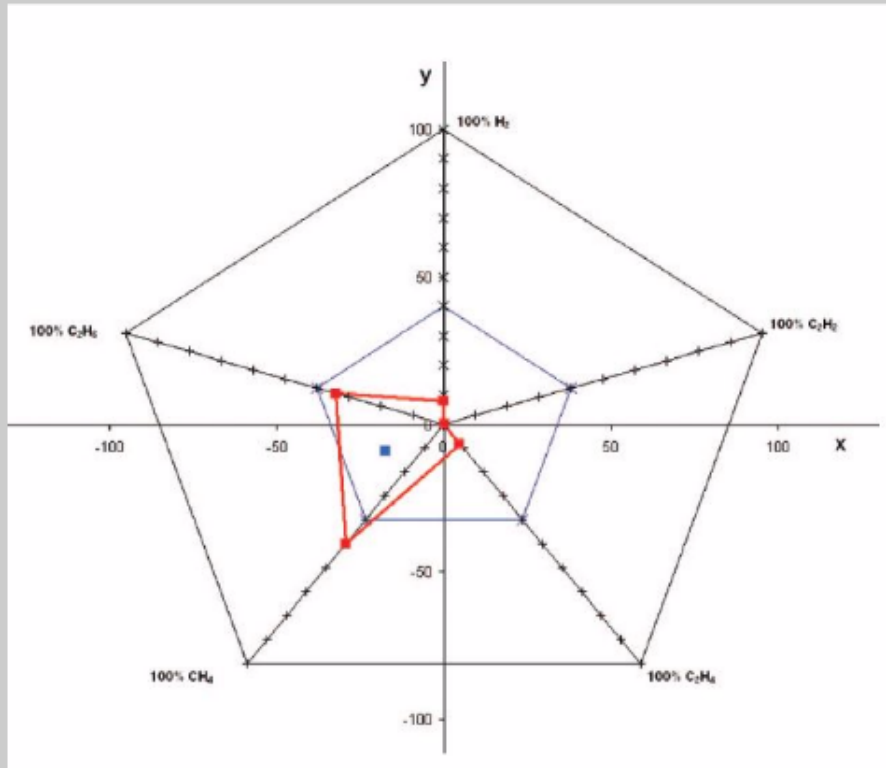
- Triangle Four is for the diagnosis of low temperature faults in oil-filled transformers
- It can be used when Triangle One indicates a PD, T1 or T2 fault.
- It uses Hydrogen, Methane and Ethane.
- It's fault zones include the 'advanced' faults, which are PD, S, C, O as well as ND (Not Determined)



DUVAL'S TRIANGLE FIVE

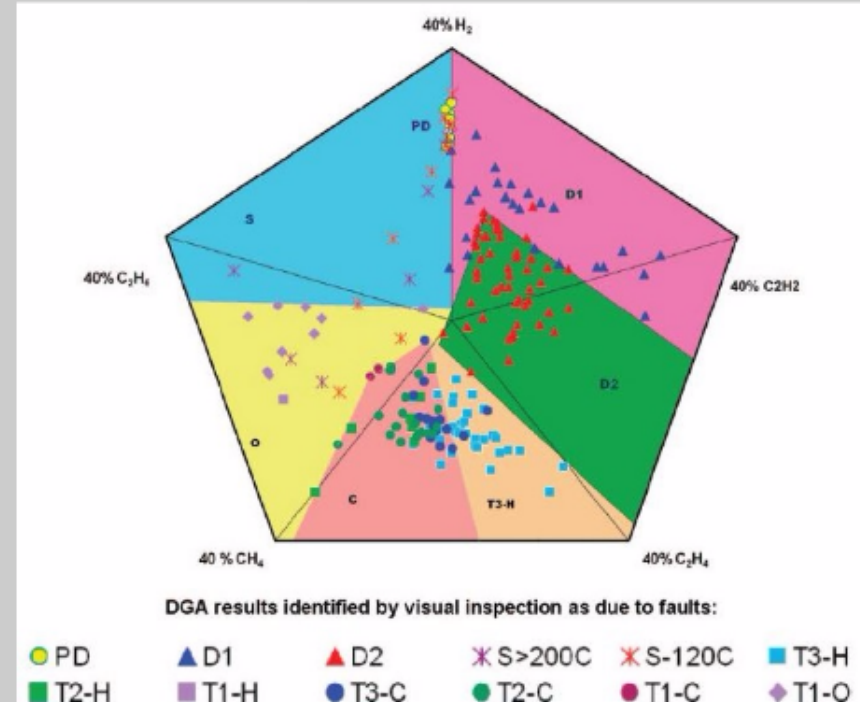
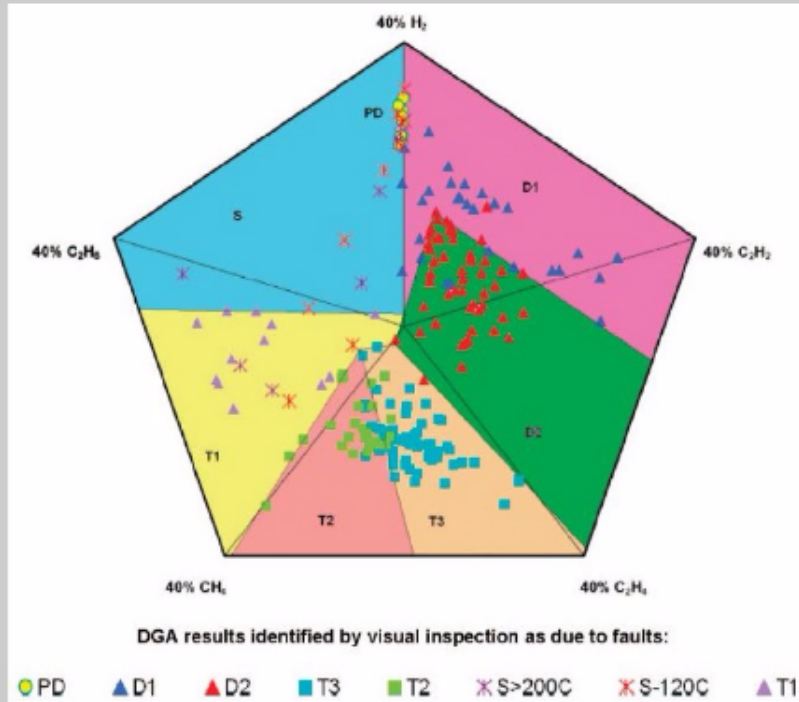
- Triangle Five is also for the diagnosis of low temperature faults in oil-filled transformers
- It can be used when Triangle One indicates a PD, T1 or T2 fault.
- It uses Methane, Ethylene and Ethane.
- It's fault zones include the 'advanced' faults, which are PD, S, C, O, T3 as well as ND (Not Determined)

DUVAL'S PENTAGONS



- Provides a graphical interpretation of DGA results in a single representation.
- Not intended to replace the Triangles but to complement them (in the case of having more than one fault)
- Each gas is represented by one of the five sets of coordinates in the centroid, the average is then taken to find the center.

DUVAL'S PENTAGON ONE & TWO

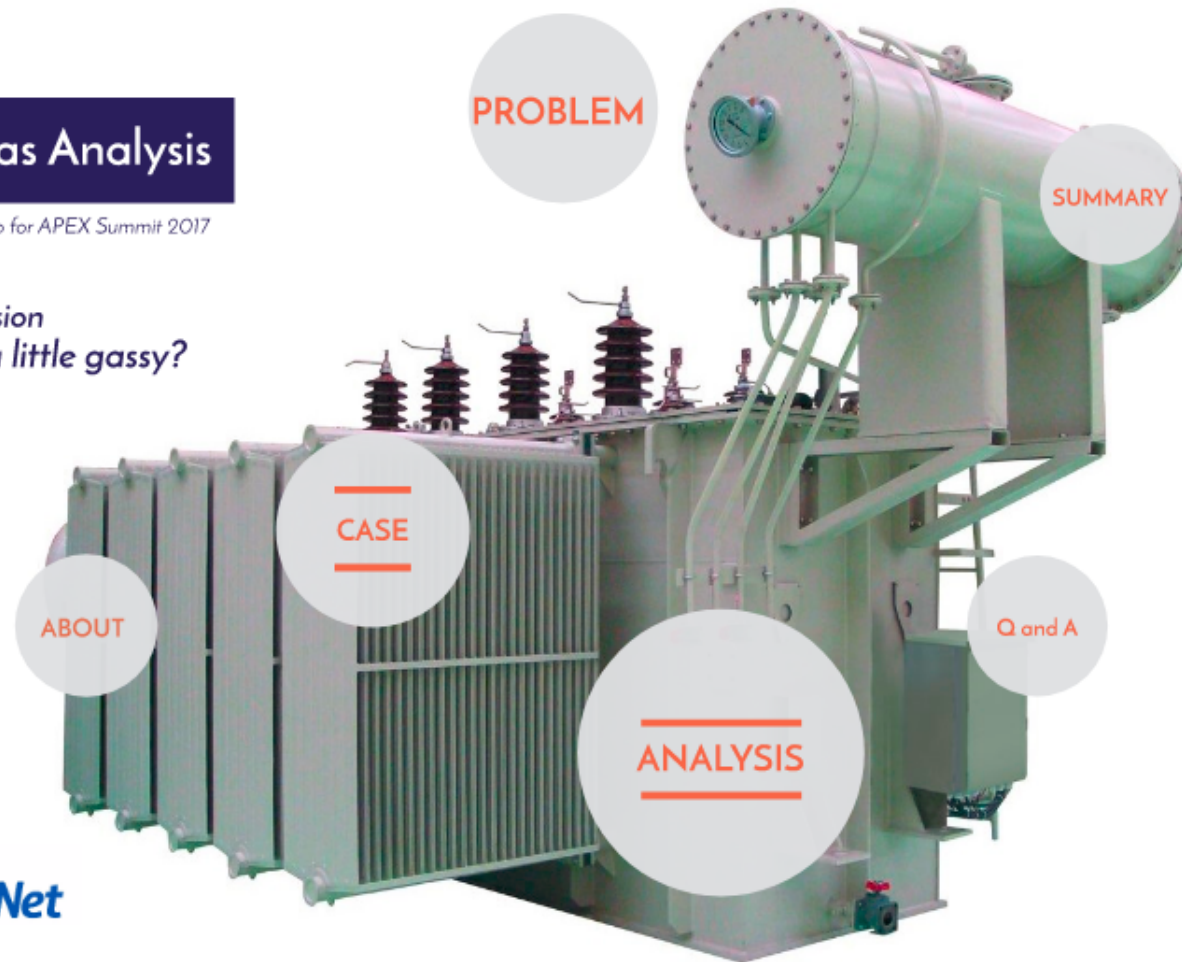


Pentagon One represents the six 'basic' faults whereas Pentagon Two represents the 'advanced' ones

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Michel Duval

BASELINE TESTS

ANALYSIS

Baseline tests and Duval's methods were used to analyse the three transformers.

Duval's
Triangles

Duval's
Pentagon

CH₄

C₂H₆

C₂H₄

C₂H₂

Tests	Condition Ranges			
	1	2	3	4
	Good	Fair	Poor	Action
Hydrogen (H2) ppm	<101	>100 <1000	>1000 <2000	>2000
Hydrogen (H2) ppm generation/6 month	<60	>54 <180	>174 <300	>294
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Interfacial Tension (dynes per cm)	>45	<46 >35	<36 >25	<26
Acid Number (KOH in milligrams)	<.05	>0.04 <0.2	>.19 <5.1	>0.5

This table represents a composite of IEEE C57-104 & IEC 60599 standards

BASELINE TESTING

*Is there a problem?
Don't proceed unless there is.*

These are baseline figures from IEEE and IEC standards which provide acceptable ranges for DGA test results.

From this analysis, we can decide if there actually is a problem.

ONE	Tests	Value	Condition Status			
			1 Good	2 Fair	3 Poor	4 Action
	Hydrogen (H2) ppm	5133				
	Hydrogen (H2) ppm generation/6 month	37	█			
	Methane (CH4) ppm	358		█		
	Methane (CH4) ppm generation/6 month	16	█			
	Ethane (C2H6) ppm	84		█		
	Ethane (C2H6) ppm generation/6 month	7	█			
	Ethylene (C2H4) ppm	1	█			
	Ethylene (C2H4) ppm generation/6 month	0.5	█			
	Acetylene (C2H2)	0.5	█			
	Acetylene (C2H2) generation/6 month	0	█			
	Carbon Monoxide (CO)	168	█			
	Carbon Monoxide (CO) generation/6 month	1	█			
	Carbon Dioxide (CO2)	1303	█			
	Carbon Dioxide (CO2) generation/6 month	372	█			
	CO2/CO Ratio	7.76			█	
	Oxygen (O2) ppm	25326				█
	Total Combustible Gas	5744				█
	Moisture in Oil ppm	5	█			
	Interfacial Tension (dynes per cm)	50.35	█			
	Acid Number (KOH in milligrams)	0.006	█			

This table represents a composite of IEEE C57-104 & IEC 60599 standards

TESTING TRANSFORMER ONE

*Is there a problem?
Don't proceed unless there is.*

- Transformer one shows mostly good result
- Existing levels of combustible gases skew TCG
- Acceptable, but one to keep an eye on in future

TWO	Tests	Value	Condition Status			
			1 Good	2 Fair	3 Poor	4 Action
	Hydrogen (H2) ppm	116				
	Hydrogen (H2) ppm generation/6 month	40				
	Methane (CH4) ppm	2				
	Methane (CH4) ppm generation/6 month	0				
	Ethane (C2H6) ppm	0.1				
	Ethane (C2H6) ppm generation/6 month	0				
	Ethylene (C2H4) ppm	0.1				
	Ethylene (C2H4) ppm generation/6 month	0				
	Acetylene (C2H2)	0.1				
	Acetylene (C2H2) generation/6 month	0				
	Carbon Monoxide (CO)	154				
	Carbon Monoxide (CO) generation/6 month	67				
	Carbon Dioxide (CO2)	437				
	Carbon Dioxide (CO2) generation/6 month	163				
	CO2/CO Ratio	2.84				
	Oxygen (O2) ppm	26140				
	Total Combustible Gas	272				
	Moisture in Oil ppm	5				
	Interfacial Tension (dynes per cm)	50.2				
	Acid Number (KOH in milligrams)	0.006				

This table represents a composite of IEEE C57-104 & IEC 60599 standards

TESTING TRANSFORMER TWO

*Is there a problem?
Don't proceed unless there is.*


- Transformer two shows all good results after refurbishment
- CO2/CO Ratio is inaccurate due to low levels of gases.
- Acceptable ✓

THREE	Tests	Value	Condition Status			
			1 Good	2 Fair	3 Poor	4 Action
Hydrogen (H2) ppm	5823					
Hydrogen (H2) ppm generation/6 month	1252					
Methane (CH4) ppm	268					
Methane (CH4) ppm generation/6 month	52					
Ethane (C2H6) ppm	59					
Ethane (C2H6) ppm generation/6 month	20					
Ethylene (C2H4) ppm	30					
Ethylene (C2H4) ppm generation/6 month	29					
Acetylene (C2H2)	0.1					
Acetylene (C2H2) generation/6 month	0					
Carbon Monoxide (CO) ppm	1520					
Carbon Monoxide (CO) ppm generation/6 month	-41					
Carbon Dioxide (CO2) ppm	5949					
Carbon Dioxide (CO2) ppm generation/6 month	191					
CO2/CO Ratio	3.91					
Oxygen (O2) ppm	8524					
Total Combustible Gas ppm	7700					
Moisture in Oil ppm	7					
Interfacial Tension (dynes per cm)	46.2					
Acid Number (KOH in milligrams)	0.006					

This table represents a composite of IEEE C57-104 & IEC 60599 standards

TESTING TRANSFORMER THREE

*Is there a problem?
Don't proceed unless there is.*

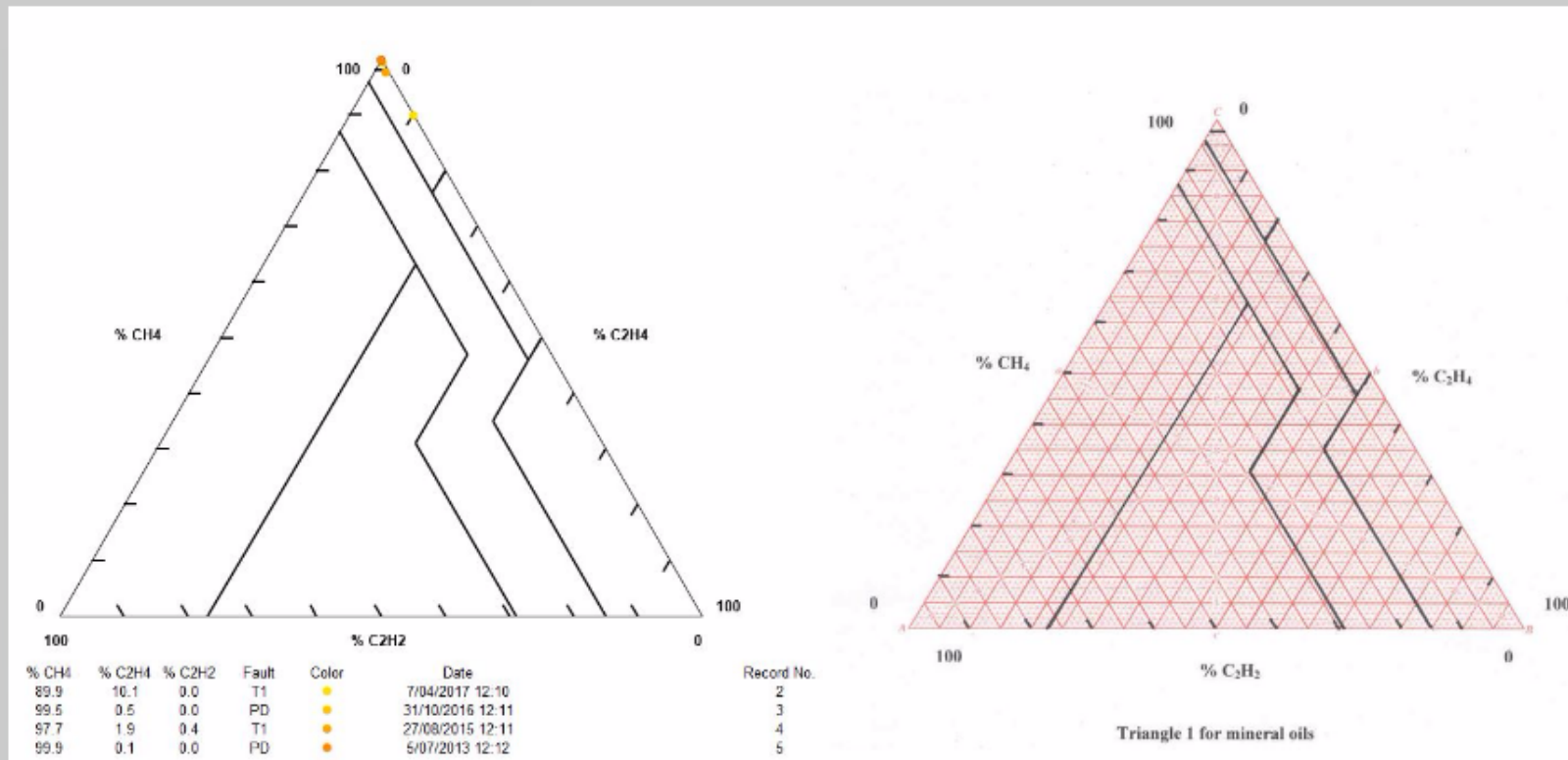
- Transformer three shows questionable results after refurbishment approximately 2 yrs ago
- High generation levels of hydrogen and methane, and ethylene suggesting PD and overheating
- Definitely a problem, investigate further 

Duval's Triangles

Duval's Triangles will always give you a problem if you input the results of any DGA test. There is no section for 'perfect' on the triangle.

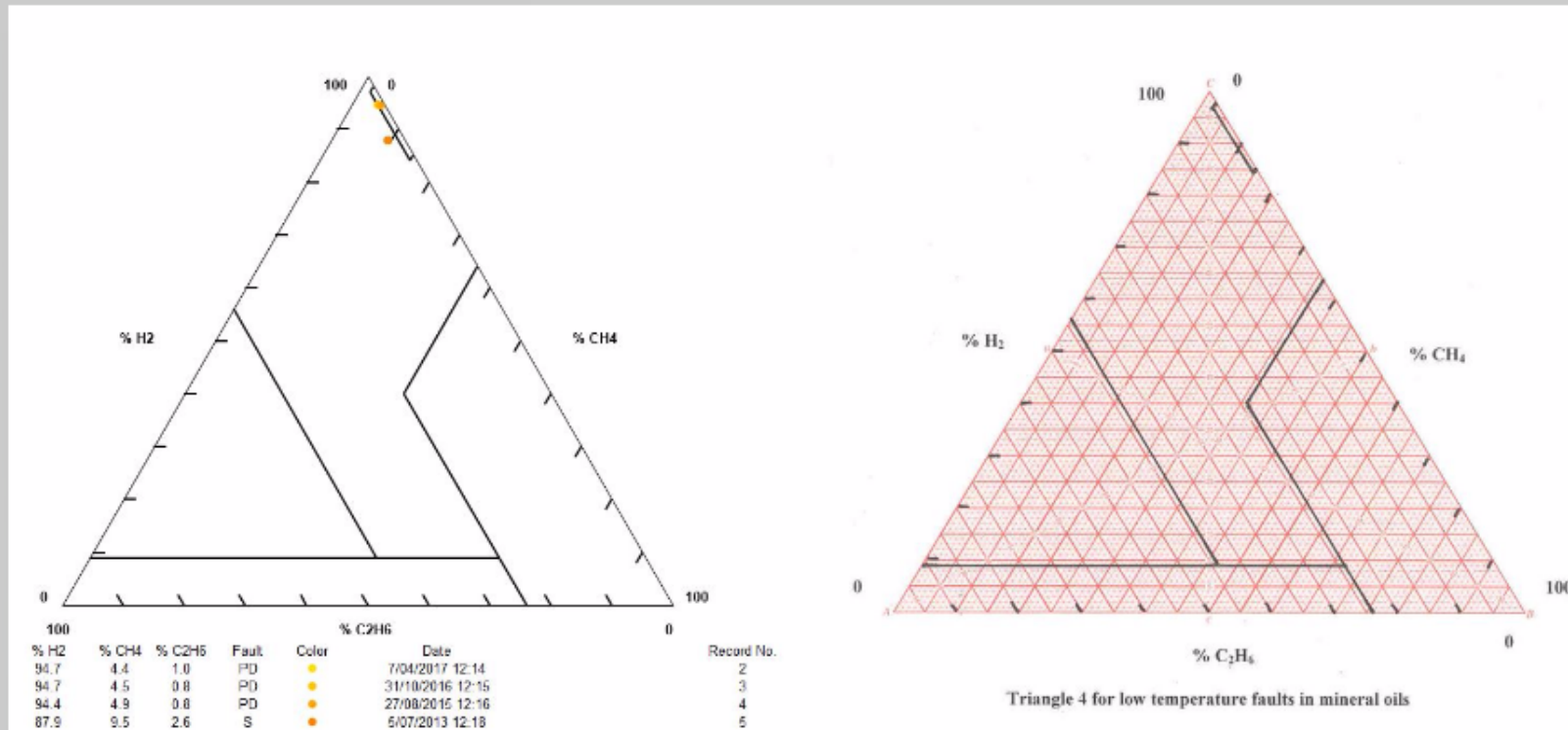
For this reason we will only be analysing Transformer Three.

Duval Triangle 1



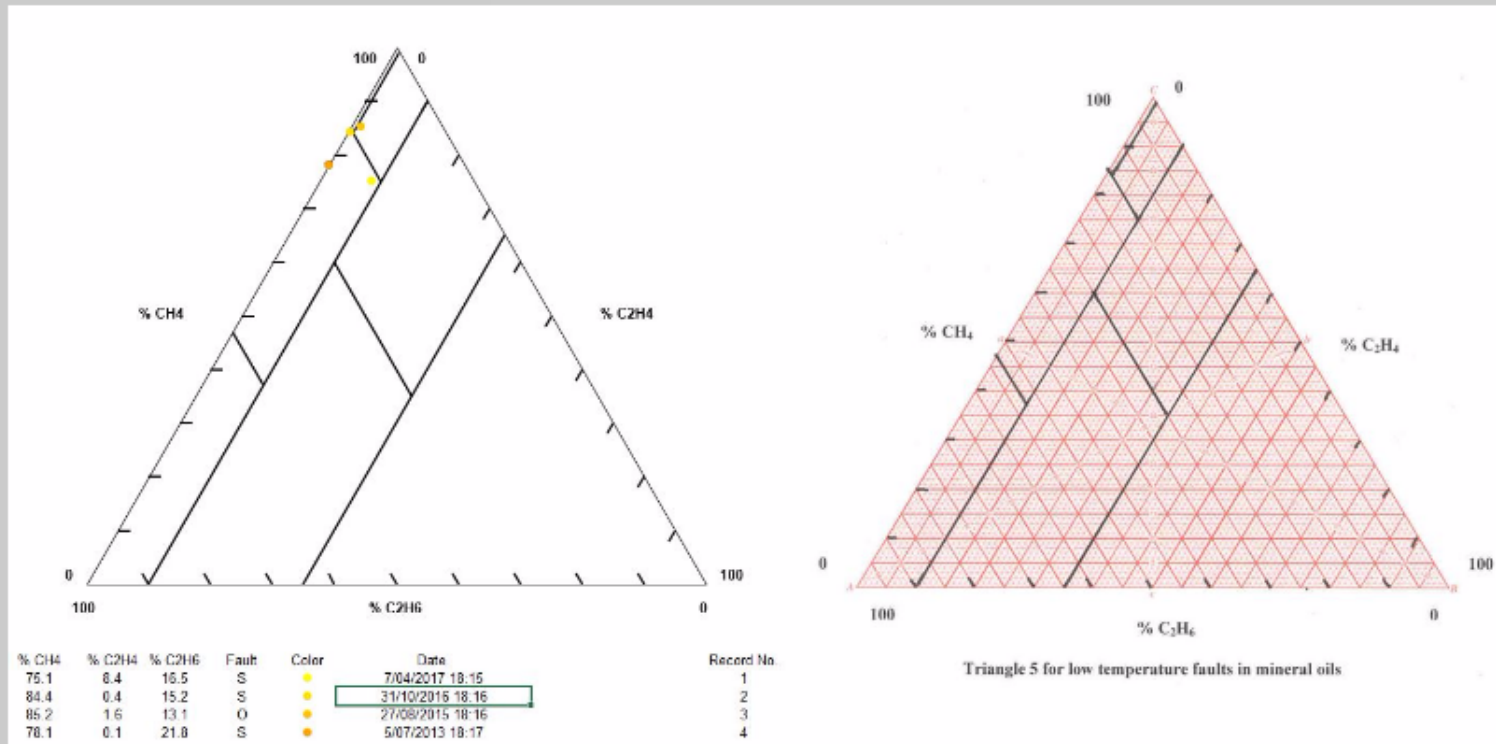
Triangle 1 shows T1 & PD is likely fault

Duval Triangle 4



Triangle 4 shows PD and S (stray gassing) is likely fault

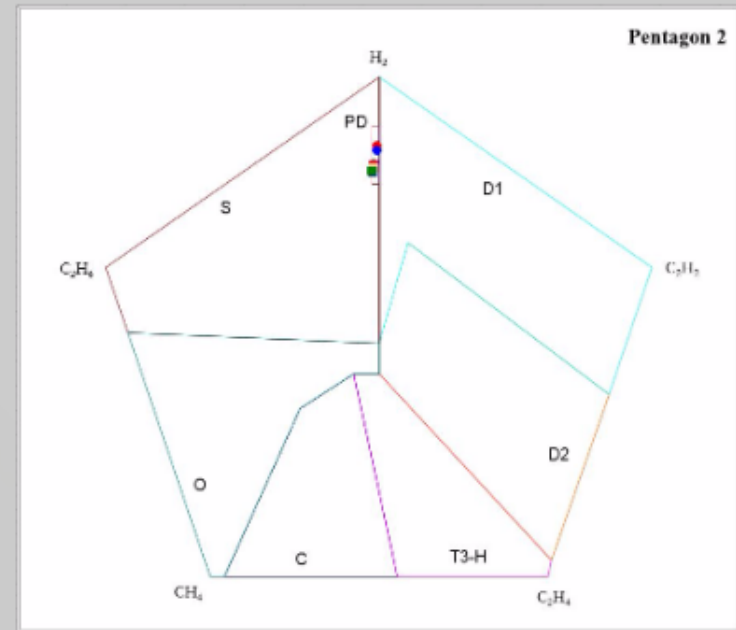
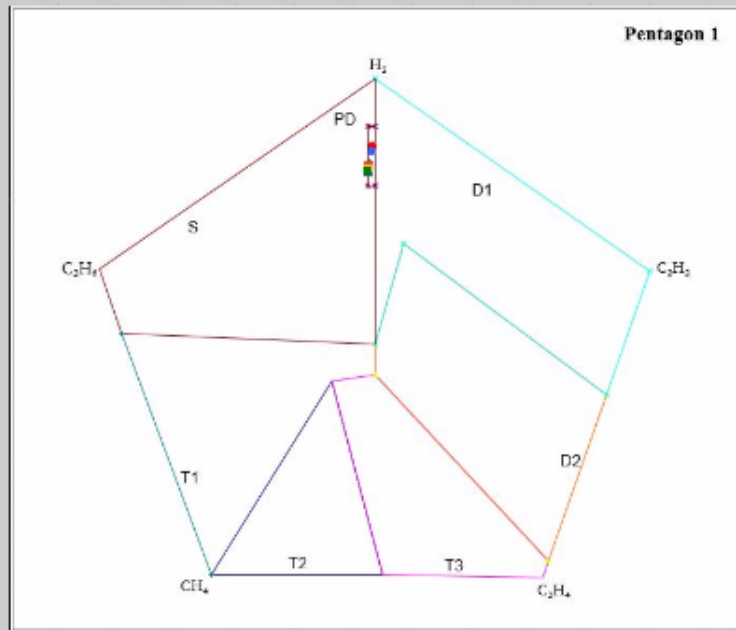
Duval Triangle 5



Triangle 5 shows S (stray gassing) and O (overheating) is likely fault

Duval's Pentagon

Further analysis of transformer three



ID #	Date	H2	CH4	C2H2	C2H4	C2H6	
07352-2	27/08/2015	501	26	0.1	0.5	4	•
07352-2	31/10/2016	4571	216	0.1	1	39	•
07352-2	7/04/2017	5823	268	0.1	30	59	•

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SUMMARY

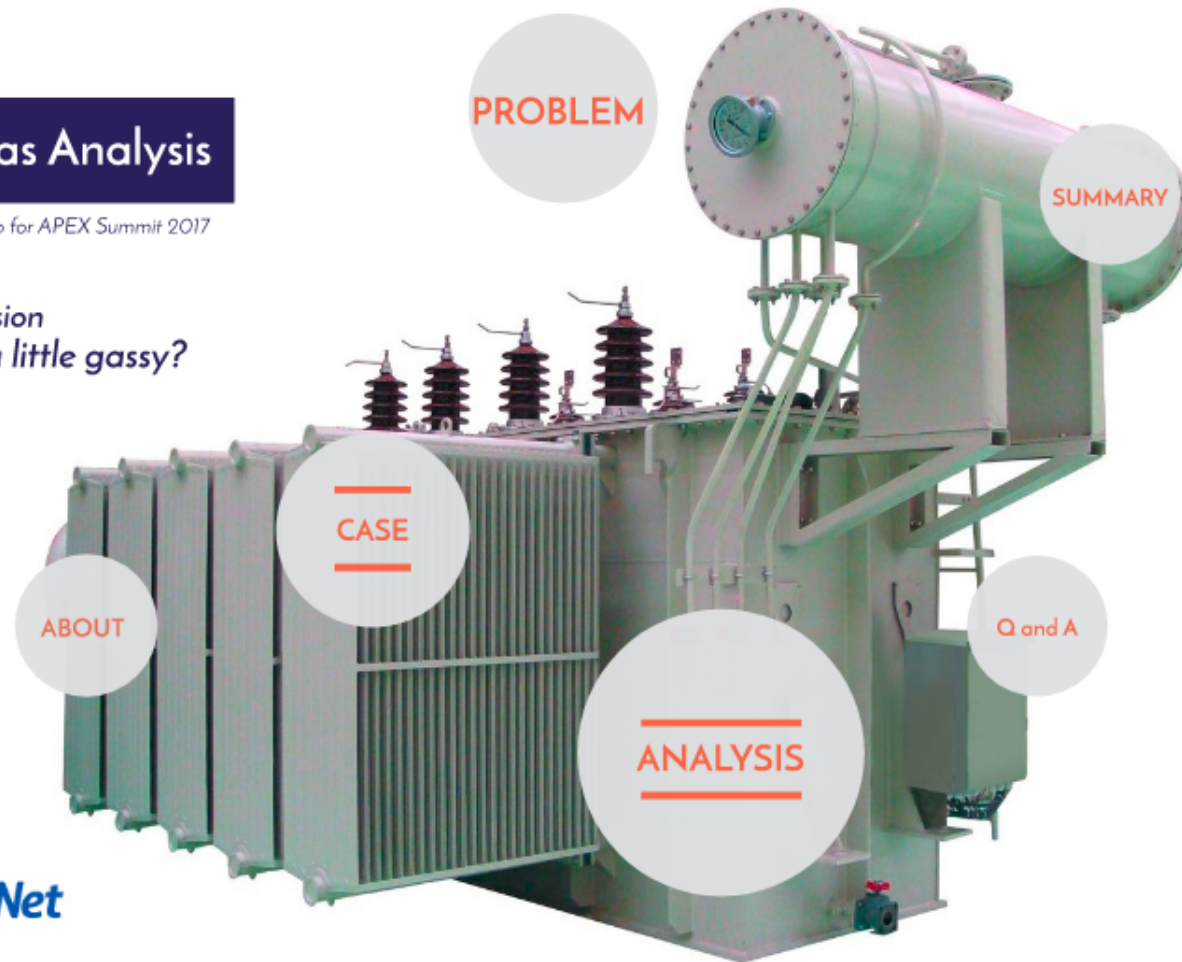
	Baseline	Triangle	Pentagon
one			 
two			
three		PD/TI	

It has been concluded that the site of transformer three is unsafe to enter. It will be replaced within the next financial year.

Dissolved Gas Analysis

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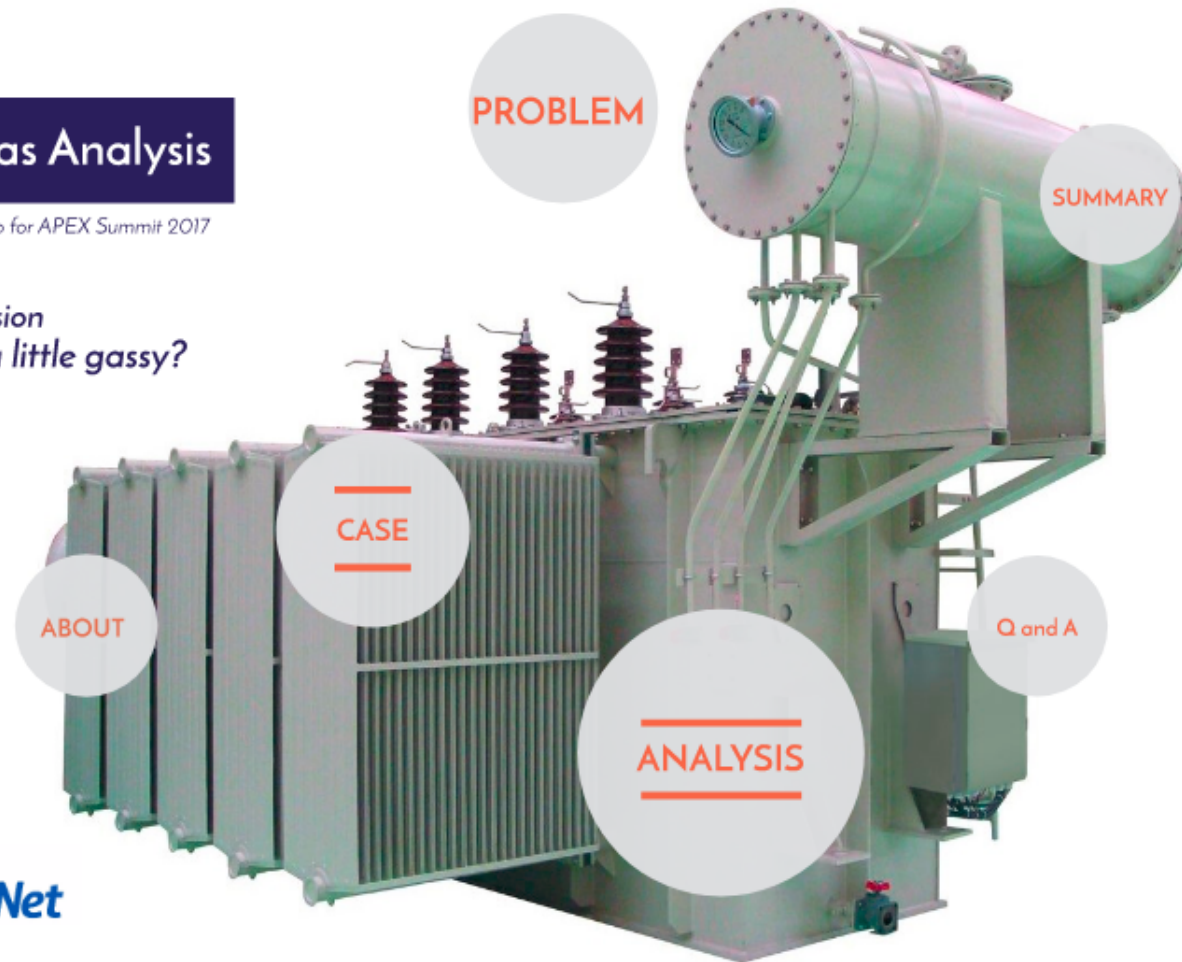
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Q and A

Any questions?

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