

Practical Experience Gained from Dissolved Gas Analysis at an Aluminium Smelter

As Presented at EuroTechon 2011

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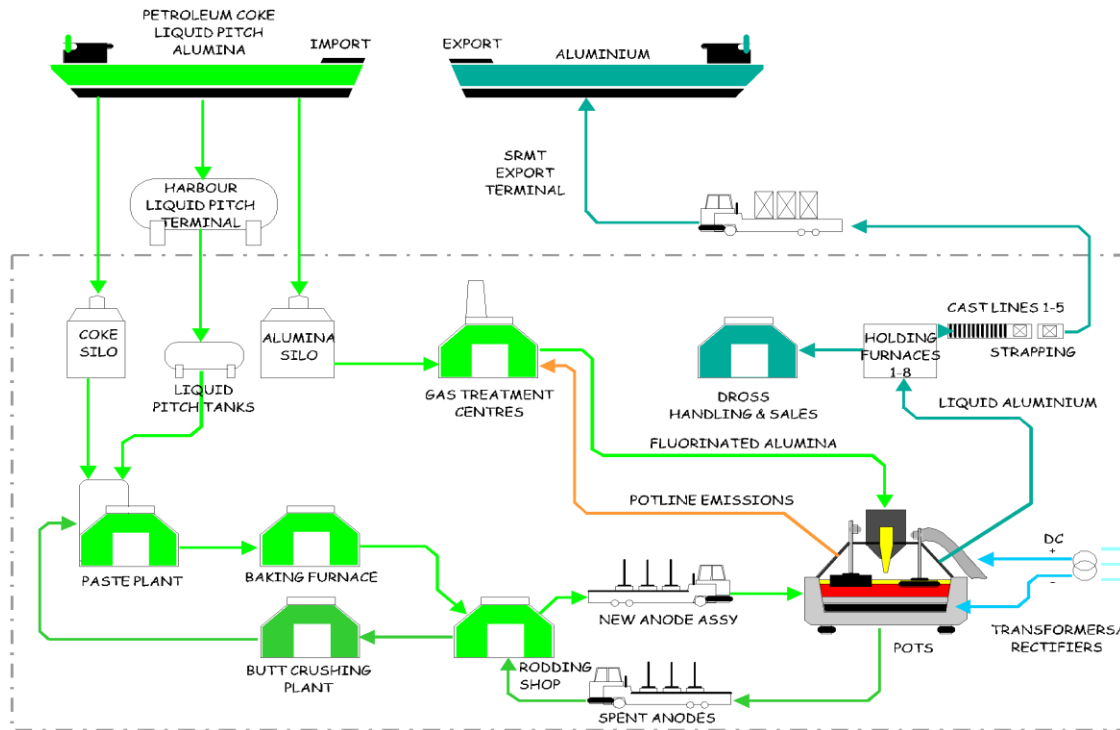
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 <p>Mnr IA Gray Date Issued: 14 January 2020 Membership No: 51954</p> <p>Valid from: 01 July 2019 to 30 June 2022</p> <p>CORPORATE MEMBERSHIP Recognised as a Professional Body by SAQA</p>  <p>www.saci.co.za</p>	 <p>The South African Chemical Institute Mnr IA Gray Valid from: 01 July 2019 to 30 June 2022</p> <p>CORPORATE MEMBERSHIP</p> <table><tr><td> Prof Z Tshentu Executive Secretary</td><td> Prof PE Mallon President</td></tr></table>  <p>Recognised as a Professional Body by SAQA (PB0000081)</p>	 Prof Z Tshentu Executive Secretary	 Prof PE Mallon President
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Largest aluminium smelter in the Southern hemisphere

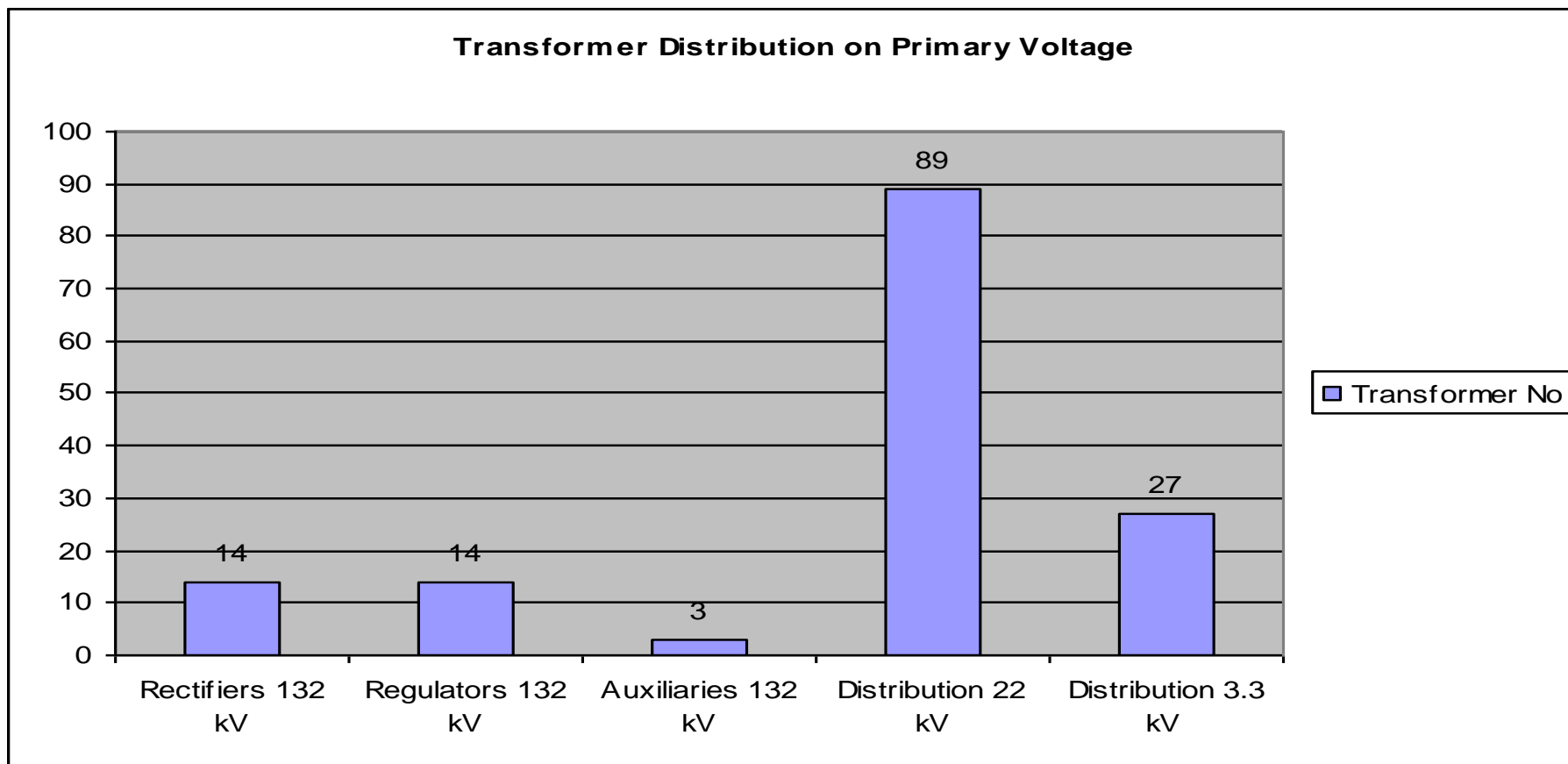
South Africa's major producer of primary aluminum

It is one of the worlds most advanced and efficient AP30 smelters and produces T-bars and primary aluminum ingots.

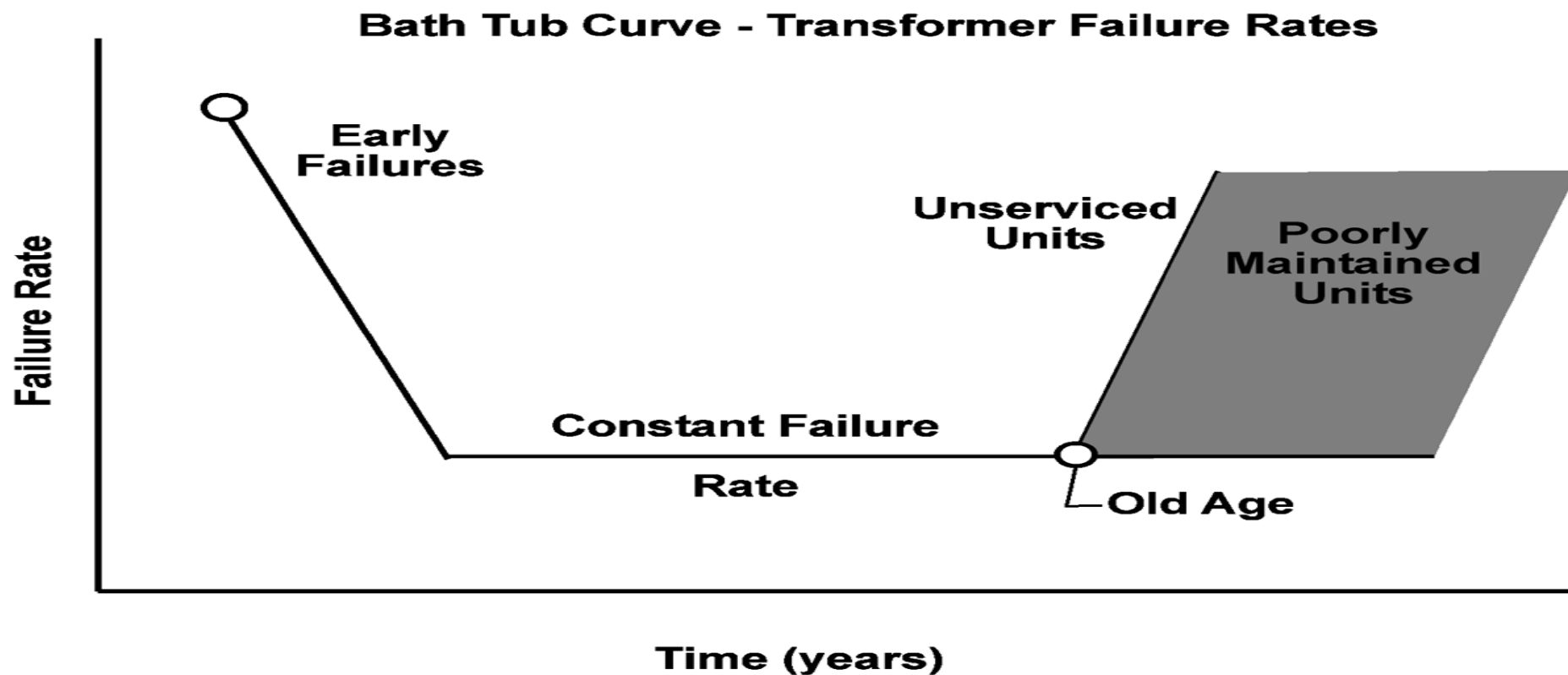


The Hillside smelter consumes 1 100MW of Electrical power,

With approximately 147 installed transformers at 1995.



This paper will provide a summary of Hillside Smelter Transformer faults detected by Dissolved Gas analysis at Early Life



When the transformer should be removed from service

Transformer Comparisons between the 1970's and 1980's

<ul style="list-style-type: none">• 12% decrease in total weight
<ul style="list-style-type: none">• 11% decrease in case weight
<ul style="list-style-type: none">• 10% decrease in oil weight
<ul style="list-style-type: none">• 13% decrease in core & coil weight
<ul style="list-style-type: none">• 7 to 33% decrease in electrical clearances
<ul style="list-style-type: none">• 9% decrease in no-load losses
<ul style="list-style-type: none">• 3.5% decrease in load losses
<ul style="list-style-type: none">• 25% increase in number of pumps



**1,500 KVA
1945**



**1,500 KVA
1970**

The modern power transformer is designed with far less insulation material and electrical clearances due to the pressure of driving down costs

What Causes a Power Transformer to Fail?

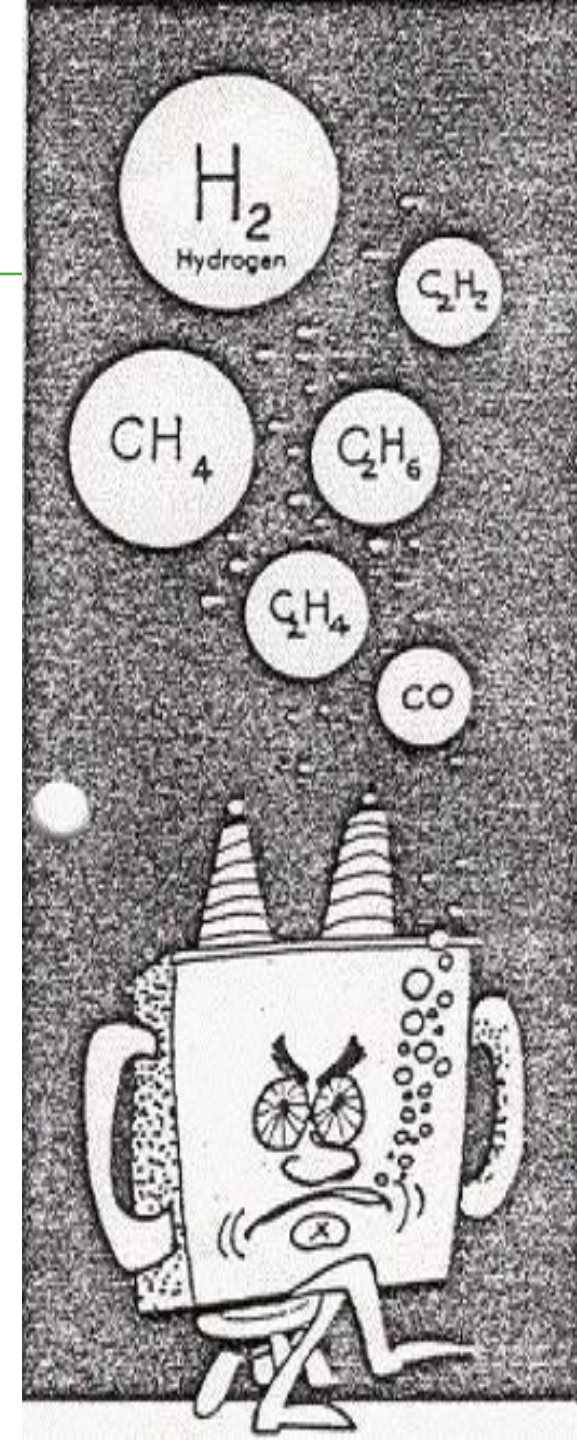
It is generally believed that failure occurs when a transformer component or structure is no longer able to withstand the stresses imposed on it during operation



In the event of failure , the force applied to the structure may approximate 360 PSI due to the steep wave front and high velocity , representing a loading sufficient to distort the container or shear the holding bolts and possibly cause a transformer oil fire.

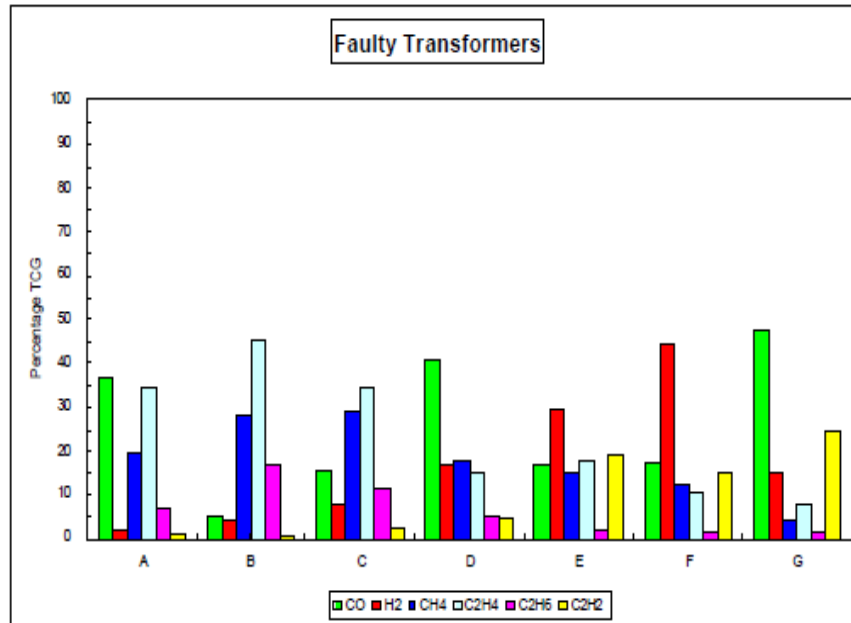
Dissolved Gas (DGA)

- Universal accepted method of choice to locate incipient thermal and electrical faults
- DGA methodology and applicability have evolved significantly since its inception 30 years ago.
- There are various interpretation Codes for diagnosis
- There are advantages and disadvantages of the various Codes and guidelines

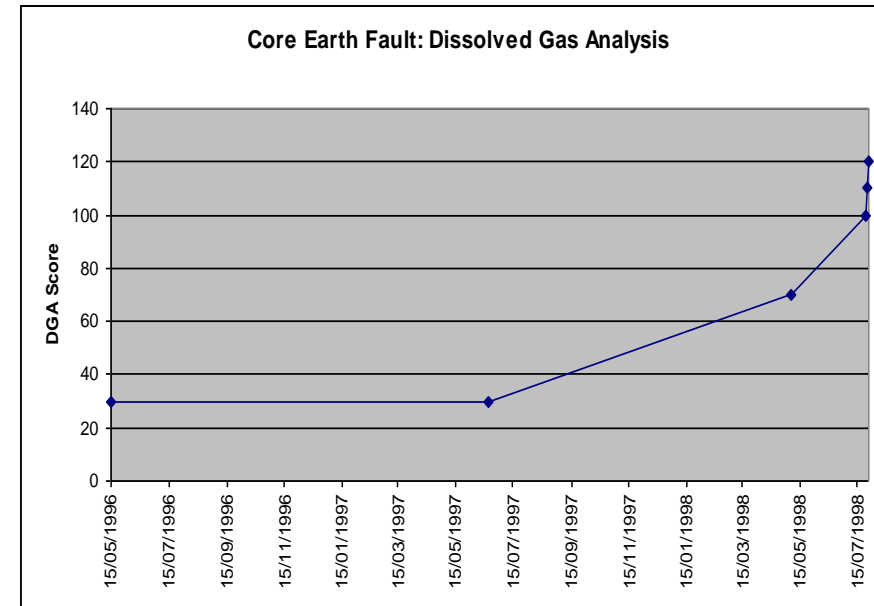


NEW DGA DIAGNOSTIC METHODS

- ***DGA Signature***



- ***Doble Scoring System***

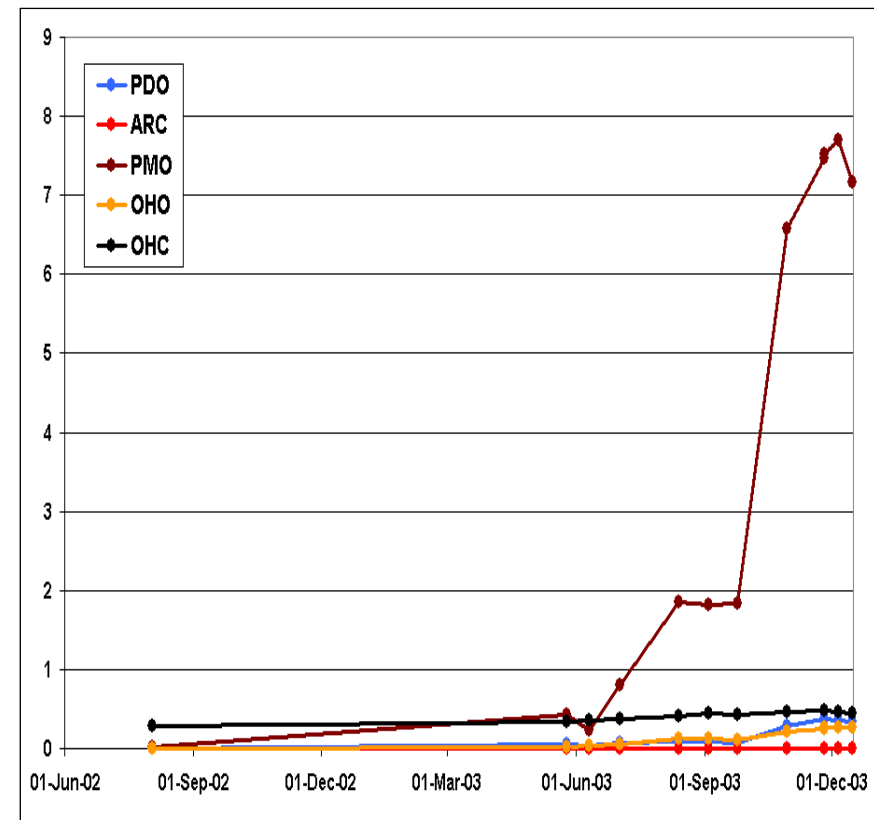
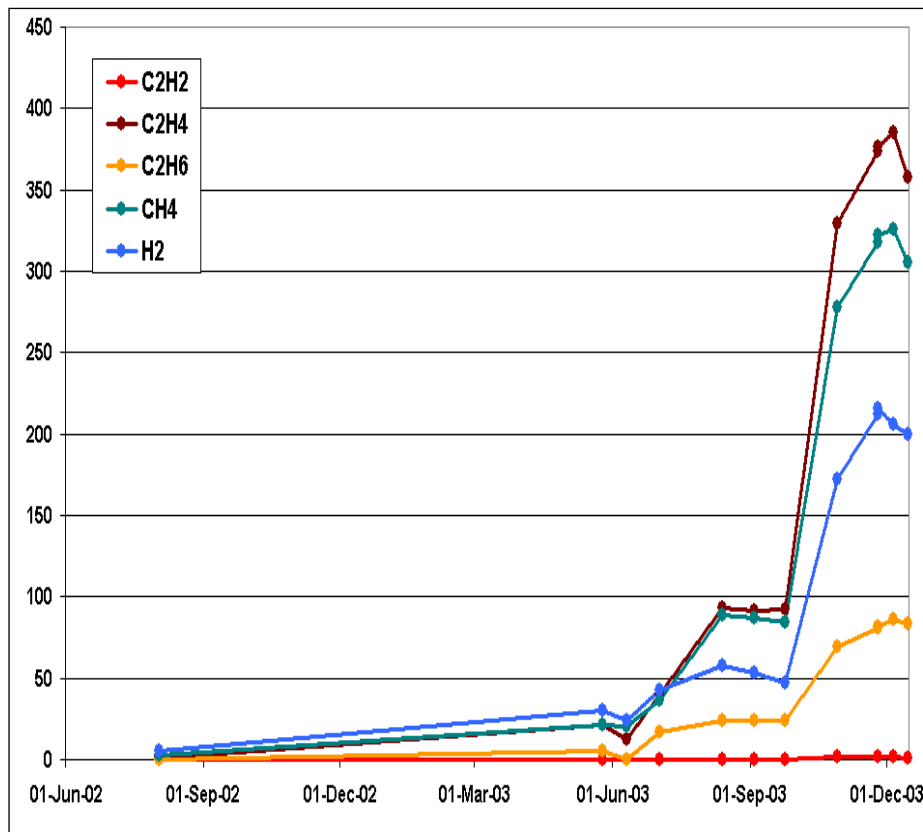


DGA Signature

- The relative proportions of the combustible gases are displayed as a bar chart to illustrate the gas signature
- The DGA score reflects the seriousness of the signature

The Vector Algorithm

Based on the chemical and physical principles of the Rogers Ratios and Duval Triangle.



Dissolved Gas Measurement

Frequent sampling and analysis will produce variation in Dissolved Gas results

- *The sampling procedure*
- *The Dissolved Gas analytical procedure*

With any Analytical Chemistry test there will always be variation, this is referred to as Analytical variation or **Uncertainty of Measurement**



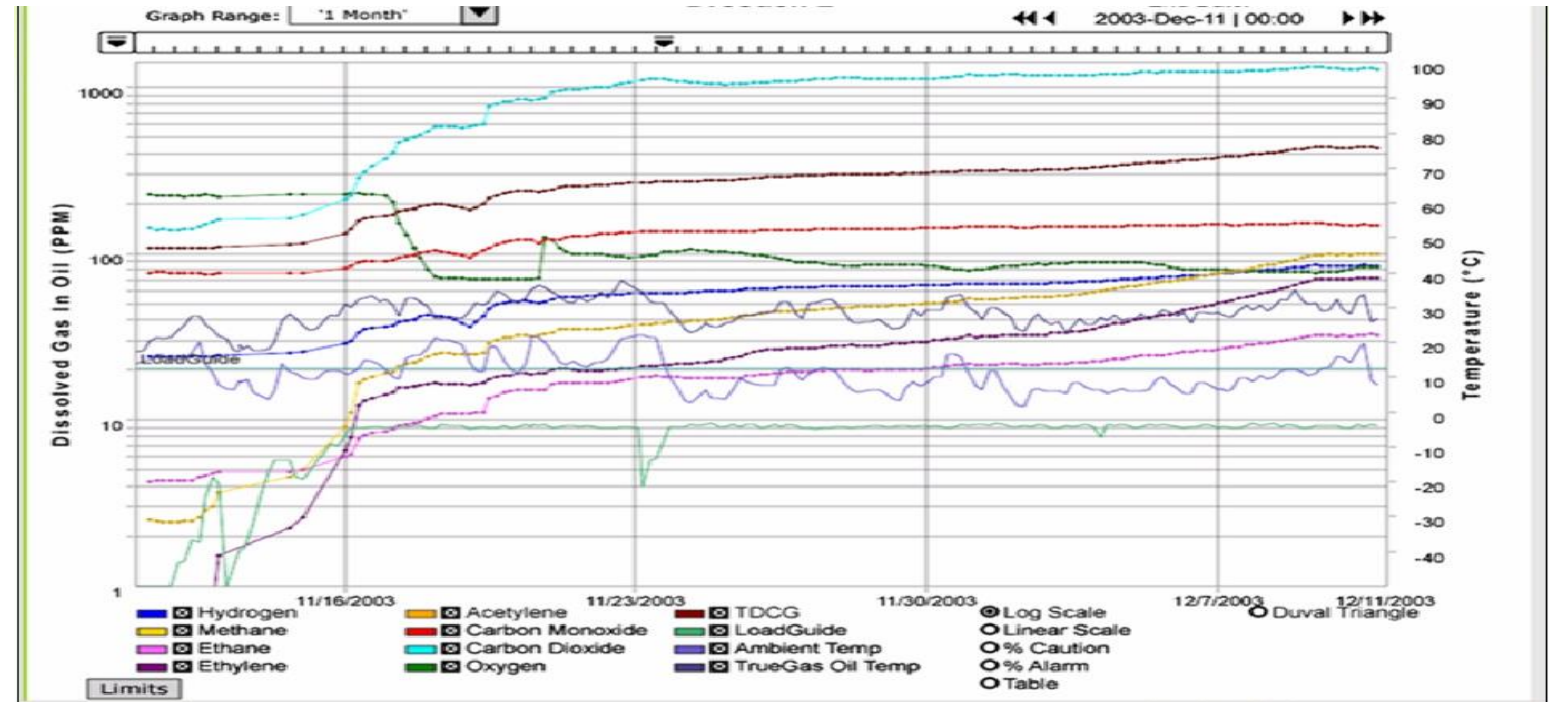
TABLE 7 Interim Precision Statement for Repeatability for One Laboratory

Run	H ₂	O ₂	N ₂	CH ₄	CO	CO ₂	C ₂ H ₄	C ₂ H ₆	C ₂ H ₂	C ₃ H ₈	% Gas
#1	21	9636	42123	19	813	7300	248	27	94	8	6.0
#2	20	9727	42306	19	819	7332	248	27	91	9	6.1
#3	20	9906	43632	19	839	7382	251	29	88	9	6.2
#4	17	9847	43288	20	843	7566	262	30	91	9	6.2
#5	20	10303	44100	19	824	7165	242	27	83	9	6.3
#6	22	9483	43011	20	822	8170	281	33	94	9	6.2
#7	21	9831	42619	19	743	7615	262	30	86	9	6.1
#8	24	10588	45971	20	880	7736	264	31	87	9	6.6
#9	20	9865	42422	19	815	7629	262	28	85	9	6.1
#10	14	8964	38558	19	760	7477	266	31	86	9	5.6
#11	21	10636	45149	19	843	7461	255	30	83	9	6.5
#12	23	10612	50340	21	947	7818	261	29	88	9	7.0
Average	20	9950	43627	19	829	7554	258	29	88	9	6.2
SD	3	506	2792	1	52	270	10	2	4	0.3	0.3
RSD, %	13	5	6	4	6	4	4	6	4	3	5.4

The Dynamic Behaviour in the Transformers Insulation system

Dissolved Gas concentration varies within the insulating oil due the following:

- **Absorption**
- **Diffusion**
- **Partitioning**
- **Loading**



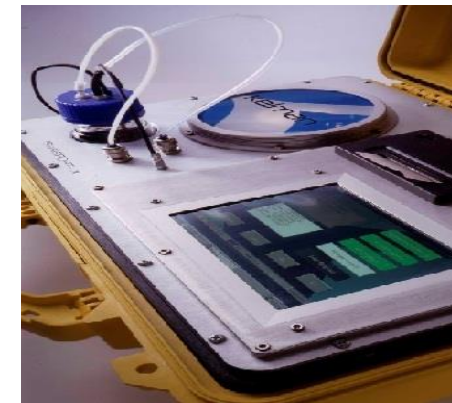
Variation of Dissolved Gas measured by an On line Gas Chromatograph

Comparison of Different DGA Methods

Traditional oil testing methods are off-line sampling and laboratory techniques.



Modern technology has permitted the development and commercialisation of mobile on-site test and on-line methods.

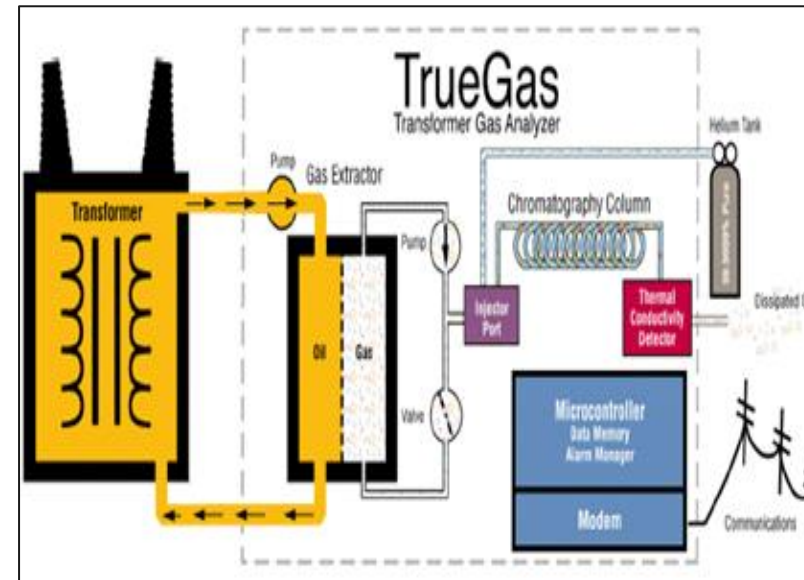
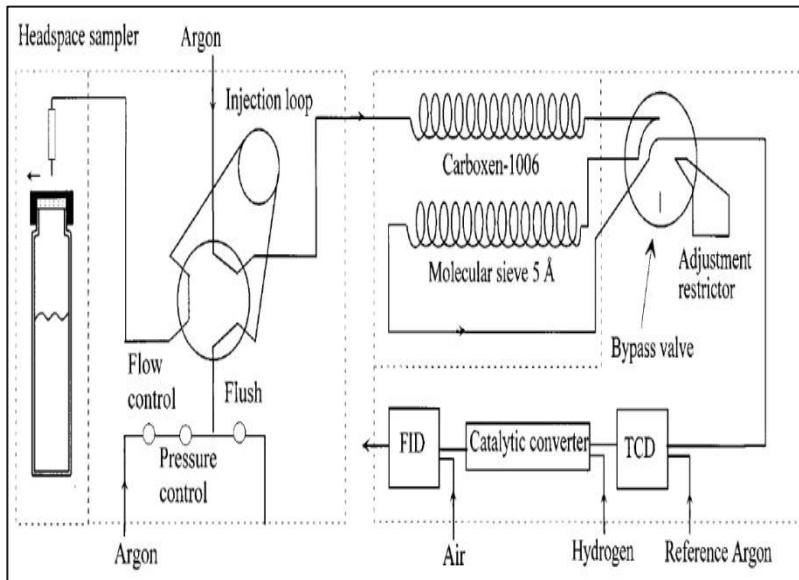


Is the future of oil testing exclusively in on-line predictive diagnostics?

Comparison of DGA (Off-On Line)

Established off-line tests provide virtually all of the information required to determine the condition and operating status of a transformer.

In general the DGA tests performed in laboratory environments use far more sensitive equipment when compared to these portable and on line dissolved gas analysers



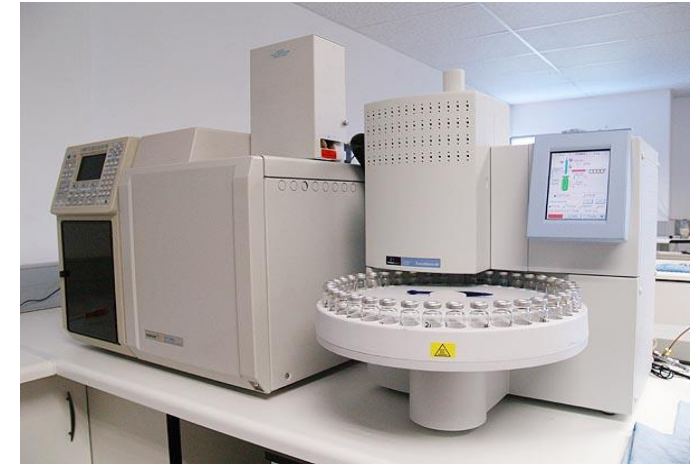
On Line DGA Monitors

- Costly and suffer from maintenance and calibration issues
- Questions about their capability of operating in extreme environments.
- Do not measure DGA real time as there is an interval between samples.
- Test process normally takes about 20 minutes depending on the equipment
- Produce enormous amounts of Data
- Limited Diagnostic capability.
- Data needs to be reviewed by an expert
- Application in the most urgent and critical situations where there is a cost benefit



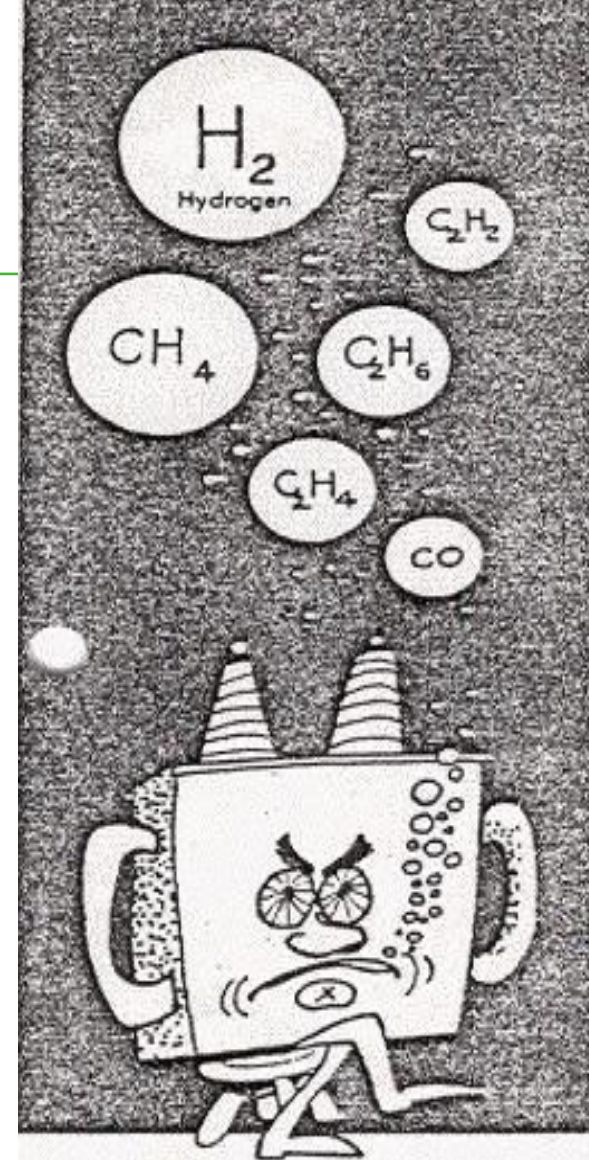
Traditional periodic DGA oil testing

- offers the advantages of presenting a complete picture of the condition and operating status
- risk of not detecting rapidly developing faults
- will always have its place for reasons of lower cost and more comprehensive diagnostics capability.



Dissolved Gas (DGA)

The interpretation should be left to a specialist and his advice and recommendations should be followed.



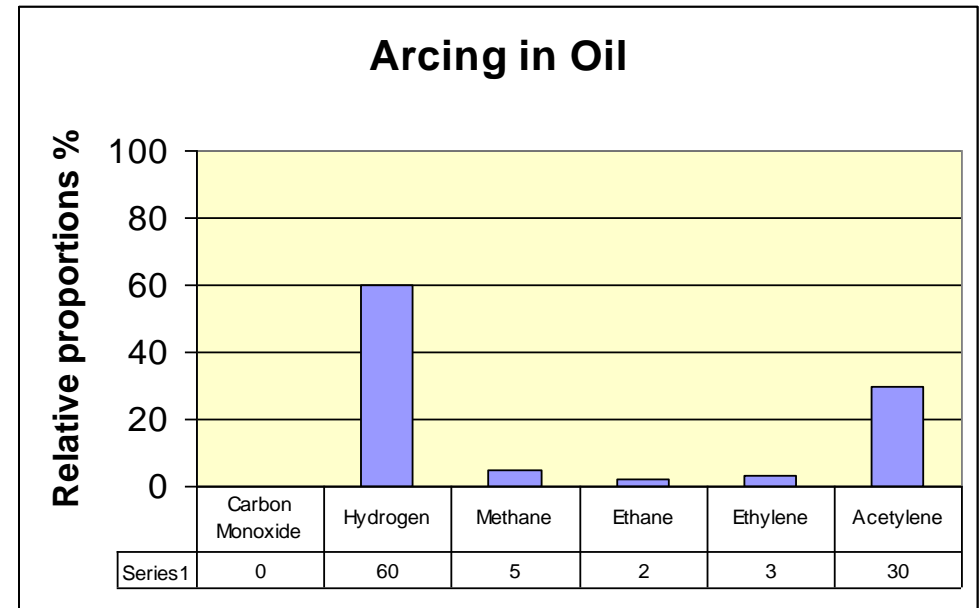
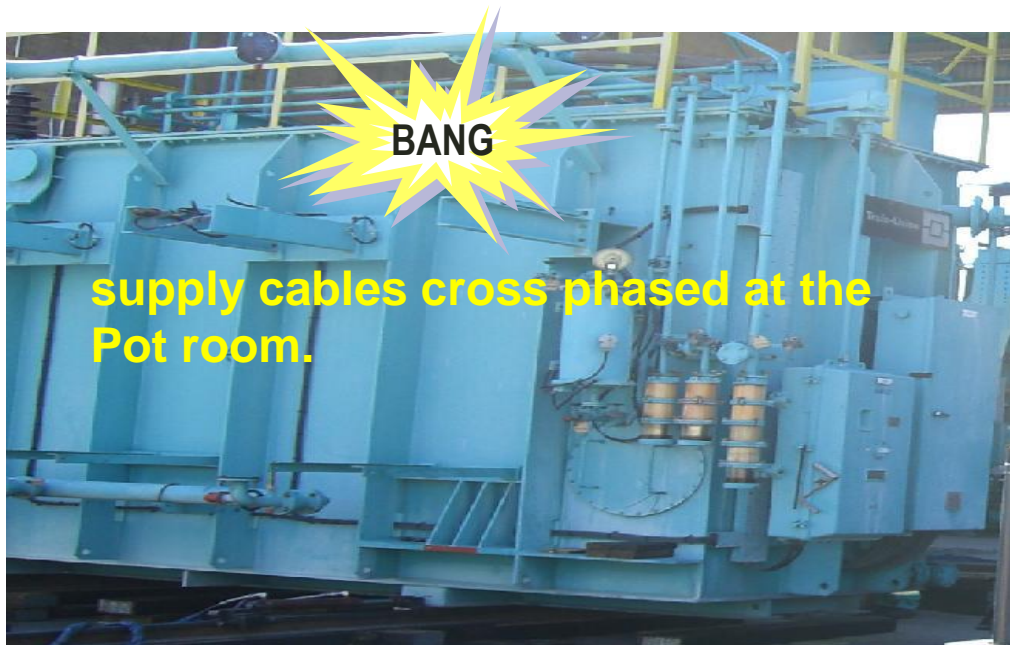
**The incorrect diagnosis can lead to costly
Transformer failure**

Failure Event Regulator Transformers

Make: TRAFU UNION
Rating: 90.8 MVA
Tap Changer: On Load

Year Manufactured: 1994
Vector Group: YNo2.5,d15
Oil Volume Liters: 35057

Primary Voltage: 132
Impedance: 0.69%
Conservator: YES



Internal Inspection

It was found that there was major damage to the internal 22kV reactor in both cases.

Root Cause and the next step

The root cause was found to be a weakness in the Regulator transformer design.

The manufacturer had to change the design to an External 22kV Reactor for each Regulator transformer



Also one additional Transformer Bay was required for Potline 1 and 2 at a cost of approximately R 70 Million per transformer bay

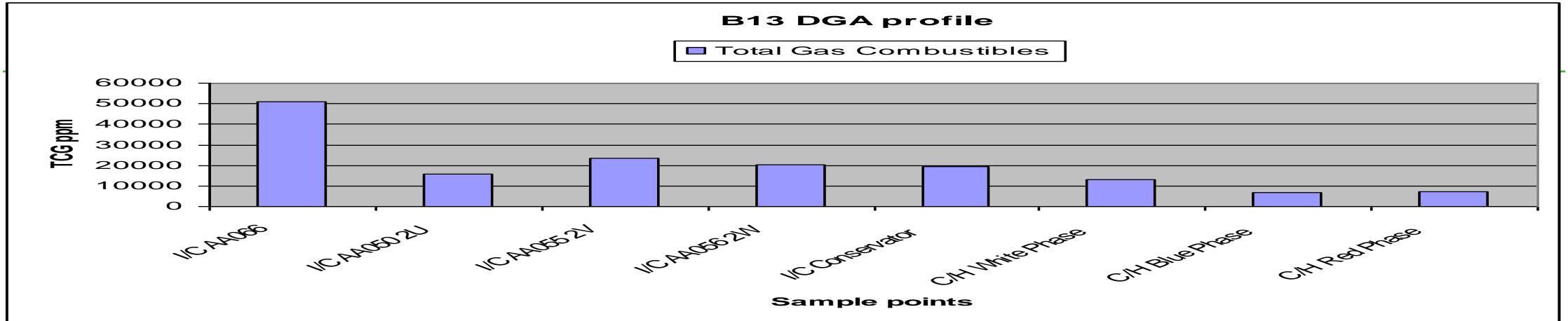
Failure Event Interconnector

On the 23rd October 2005, a gas alarm was triggered by the Buchholz relay



The OEM suspected a Corona (Partial Discharge-PD) problem on the Cable housing

DGA profile of samples



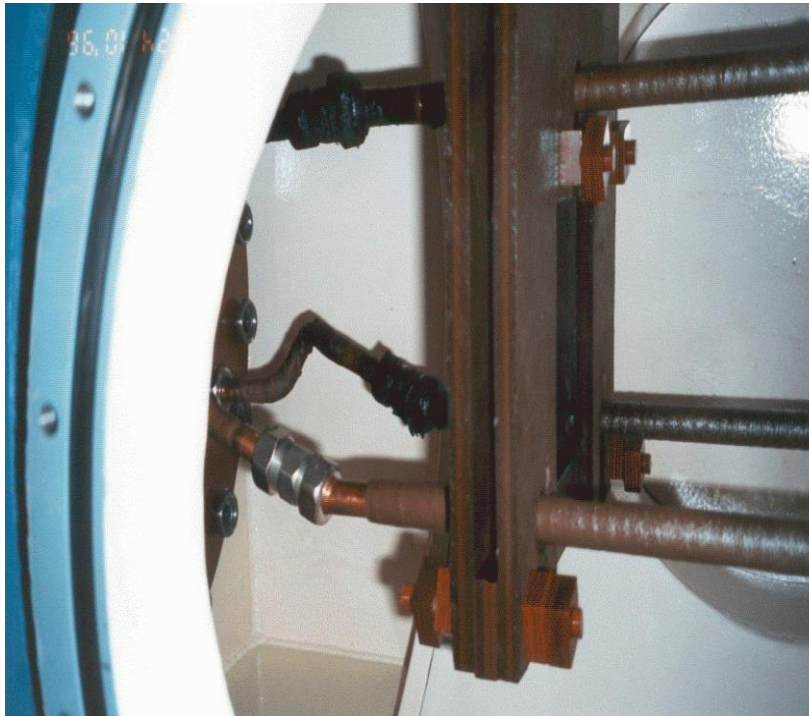
IEC 599 DIAGNOSIS: **Thermal fault of medium temperature range 300°C-700°C**

IEEE (c57.104-1991): **Condition Code 4:**
OPERATING PROCEDURE-
Exercise extreme caution. Plan outage.

DGA ppm	Buchholz Gas	I/C AA066
Hydrogen H ₂	12034	12299
Methane CH ₄	25855	14892
Ethylene C ₂ H ₄	16722	12220
Ethane C ₂ H ₆	5120	11295
Acetylene C ₂ H ₂	20	65
Carbon Monoxide CO	560	424
Carbon Dioxide CO ₂	2885	3733
TCG	51195	12299

Internal Inspection and findings

The internal inspection of the Main Chamber found burnt (overheated) connections



Root Cause and Savings

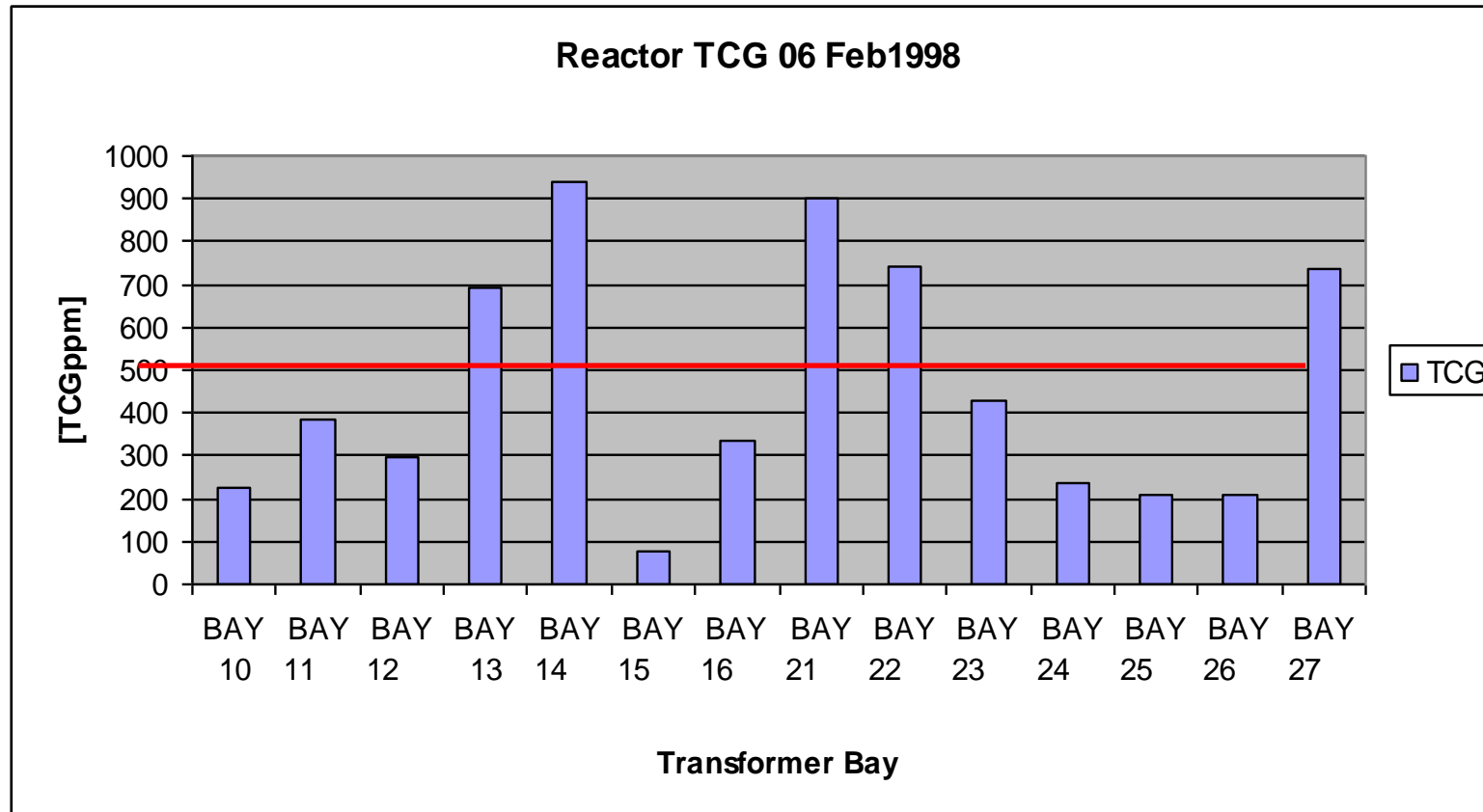
The root cause was found to be being non-conforming quality control during installation

Savings in the R Million range:

Predicted fault on the Reactor Transformers.

The program of installing External 22 kV Reactors onto the main Regulator started in July 1996

Routine DGA samples taken on 06/02/1998 showed a significant increase of Total Combustible Gas in a number of Reactors

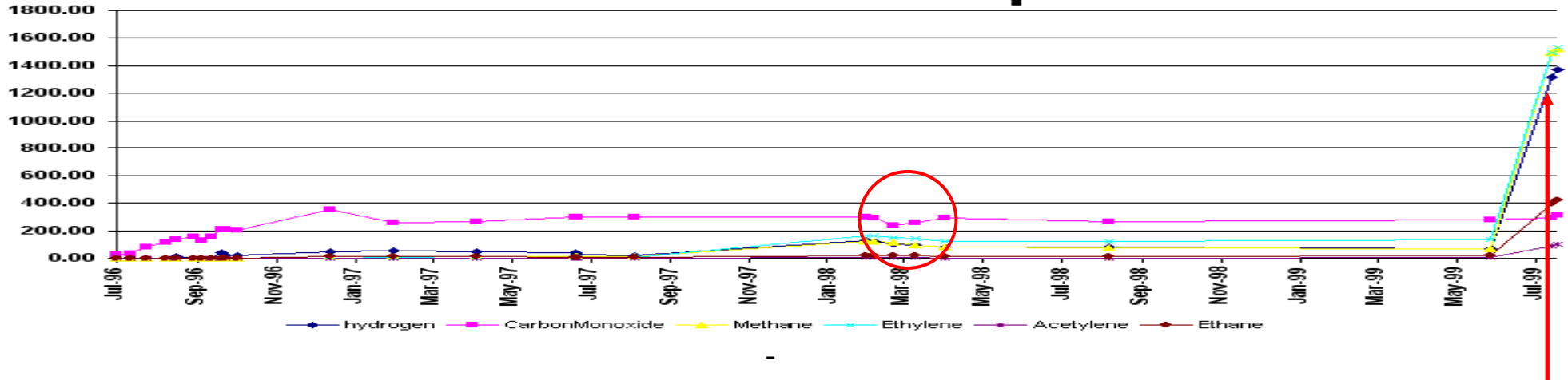


BAY 22 Reactor Transformer

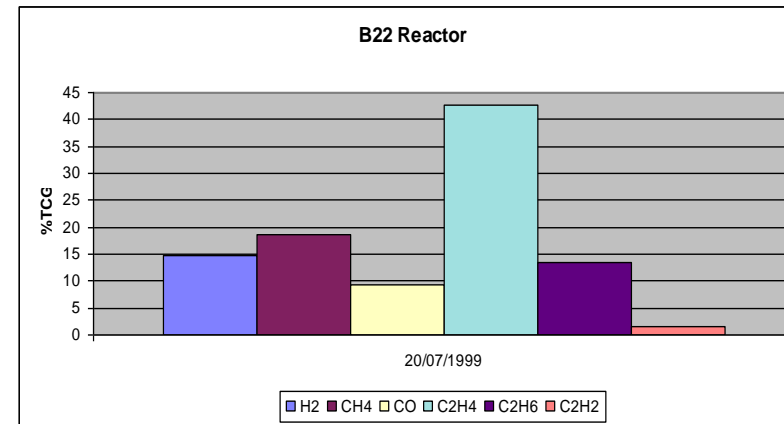
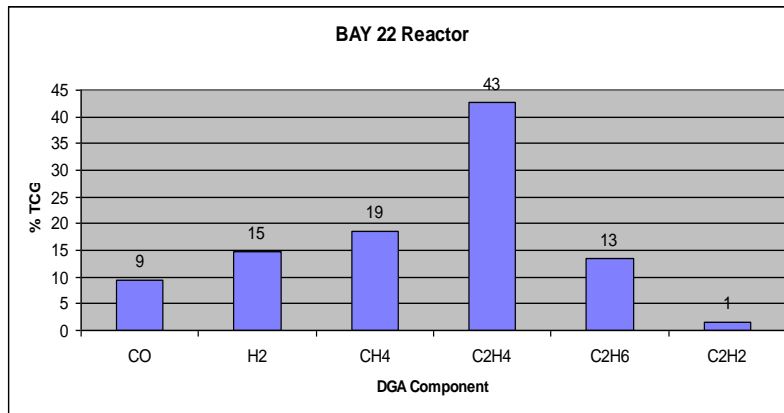
Client Name: SerialNumber:
 Substation: Transformer:

[Close Graph](#)

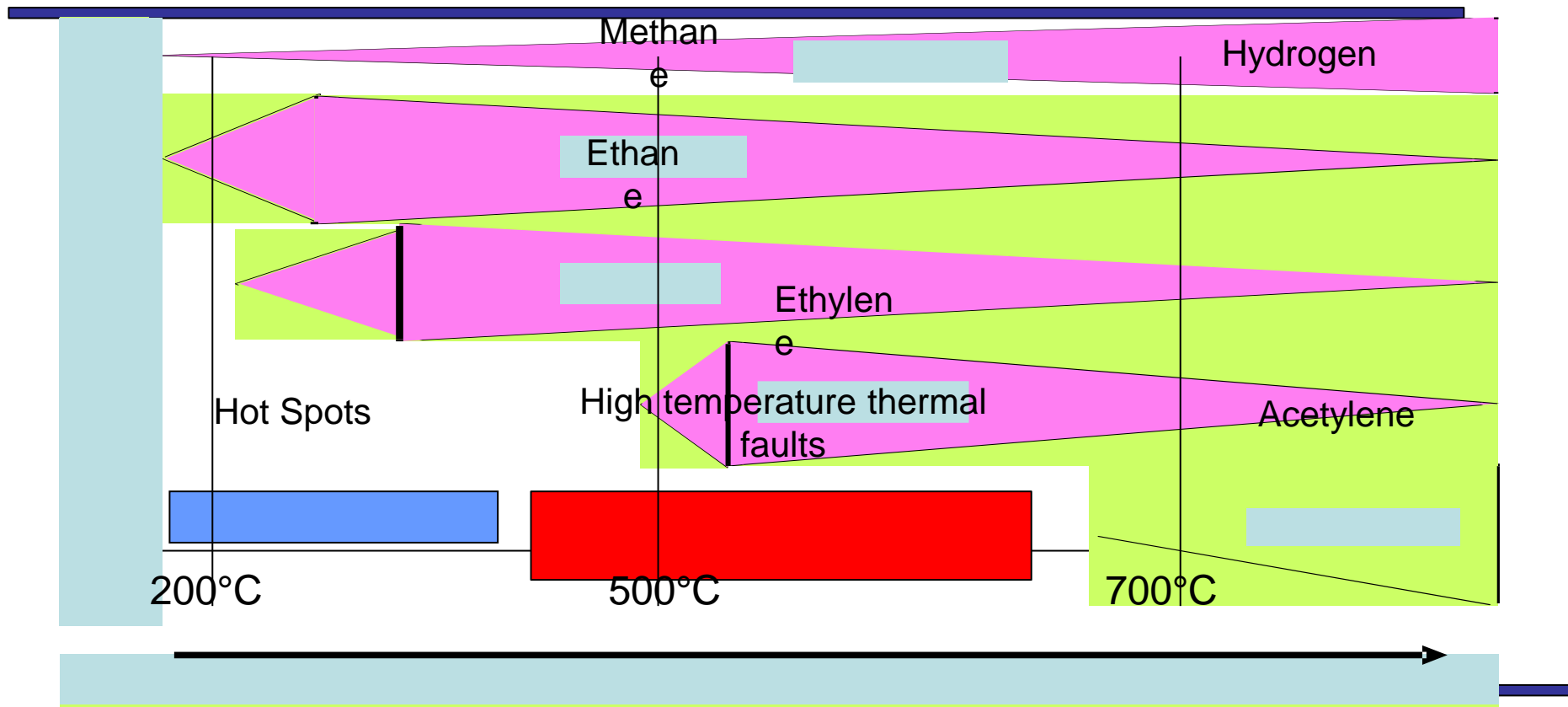
Dissolved Gas Graph



IEC 599 Ratio: Thermal fault of high temperature range >700°C.



Dissolved Gas Analysis (DGA)- Halstead 1973



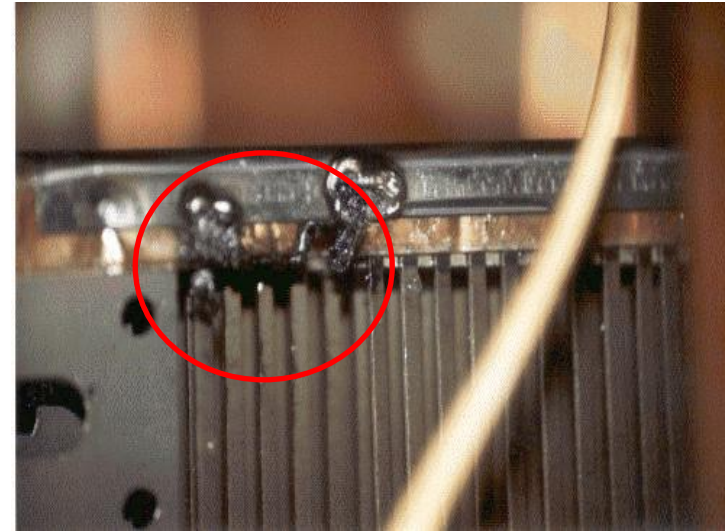
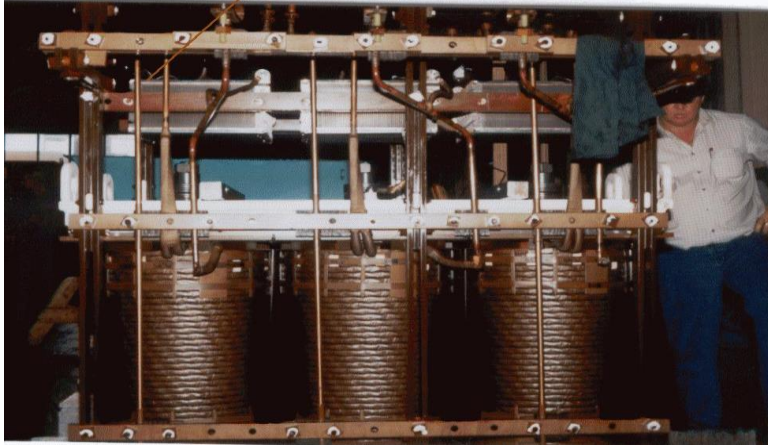
Chemical Reactor

That just happens to Transform Electricity



Internal Inspection and findings

Burning occurring on resistor bank

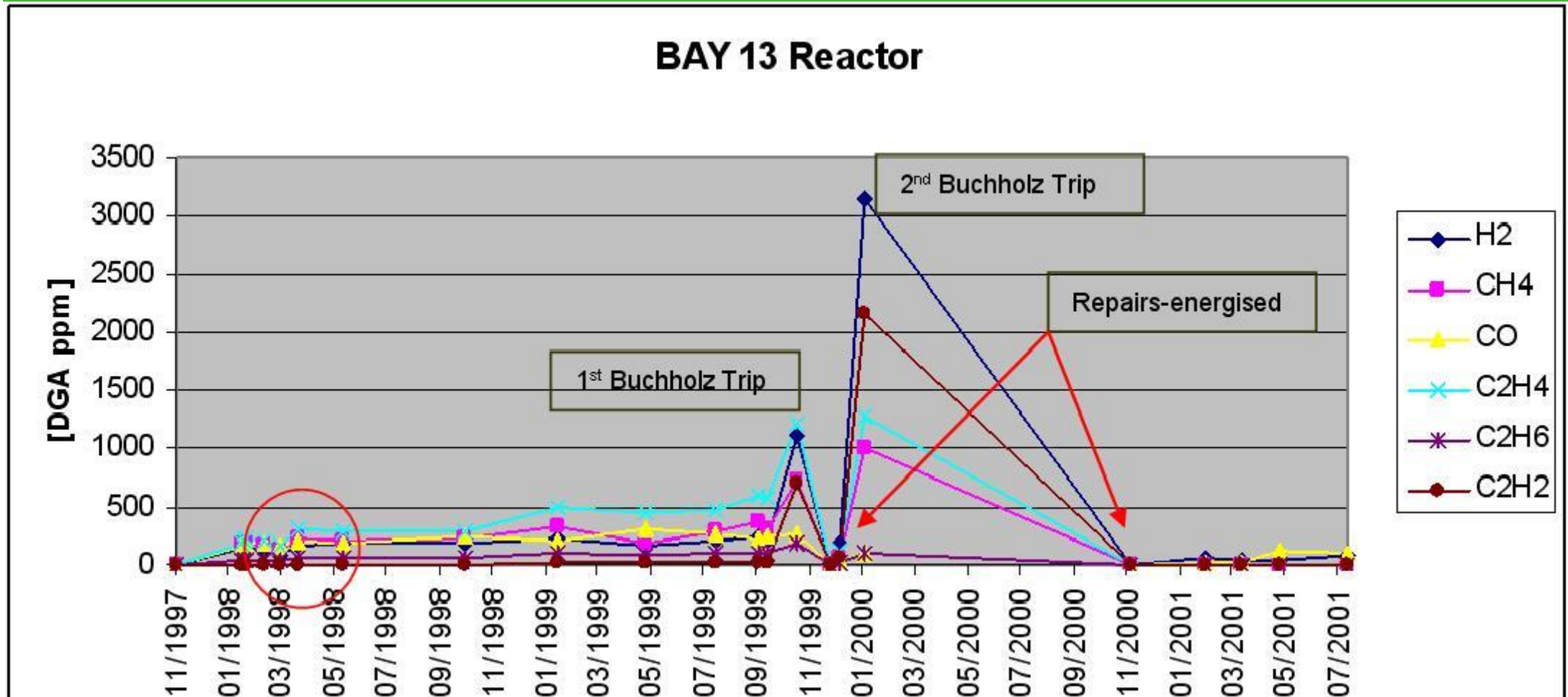


Root cause

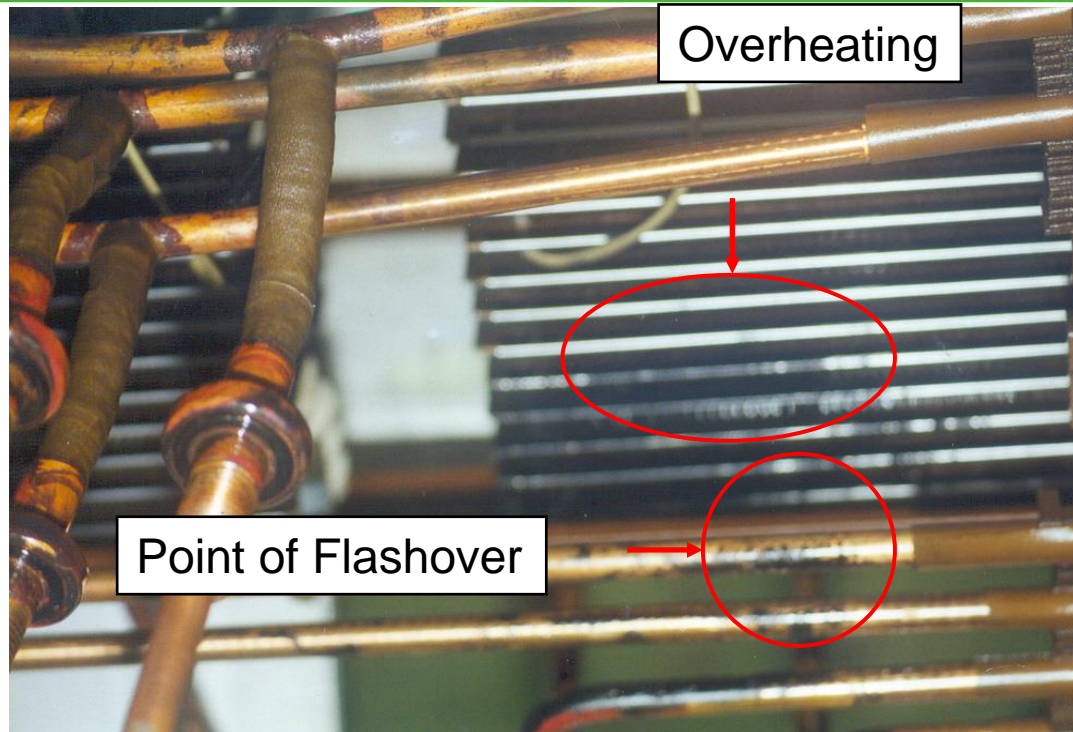
not established



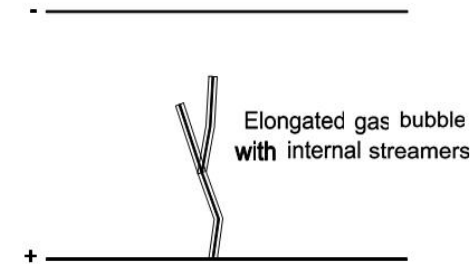
BAY 13 Reactor Transformer



Internal Inspection and findings



Mechanism of the flash-over-voltage stress caused gas bubble formation.



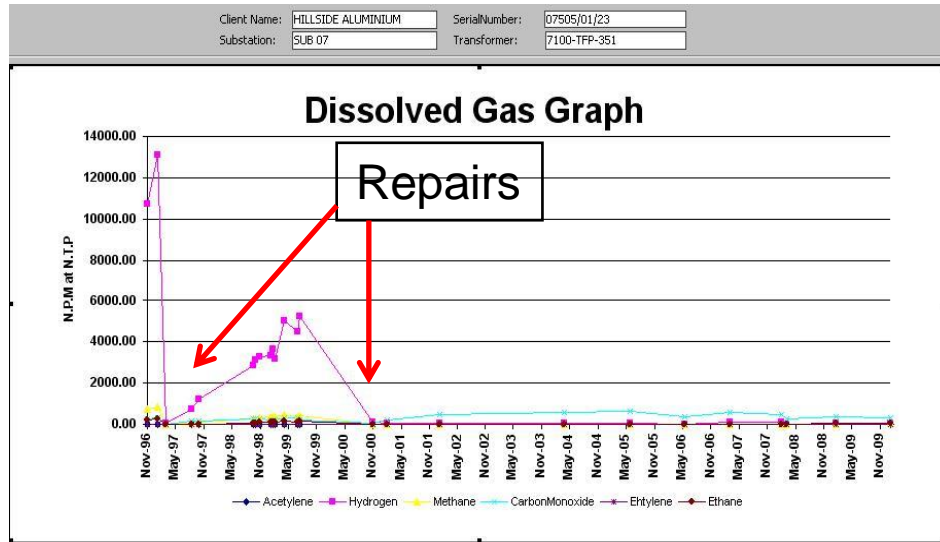
Gas bubbles elongate in the direction of the electric field

Root cause.

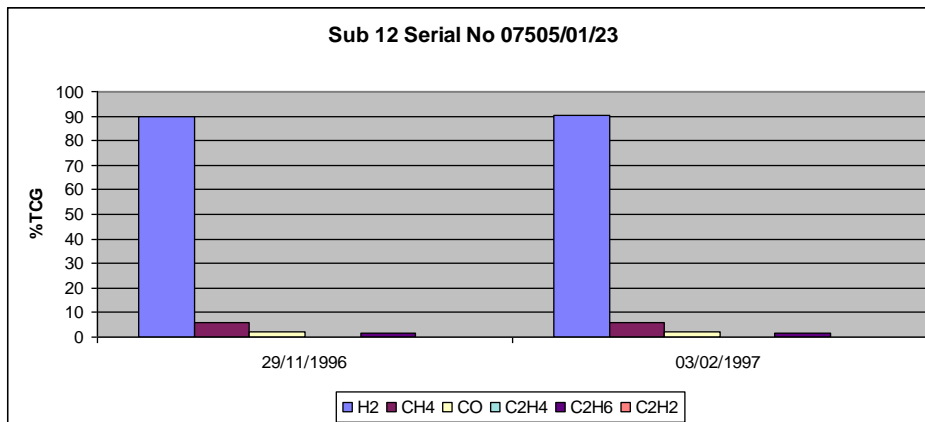
Fifth Harmonic being amplified within the transformer causing it be subjected to 10 times its rated current for a couple of milli-seconds. Design fault involving the power factor correction. (Weakness in design).

Case 1: Partial Discharge in 22 kV Transformers predicted by DGA

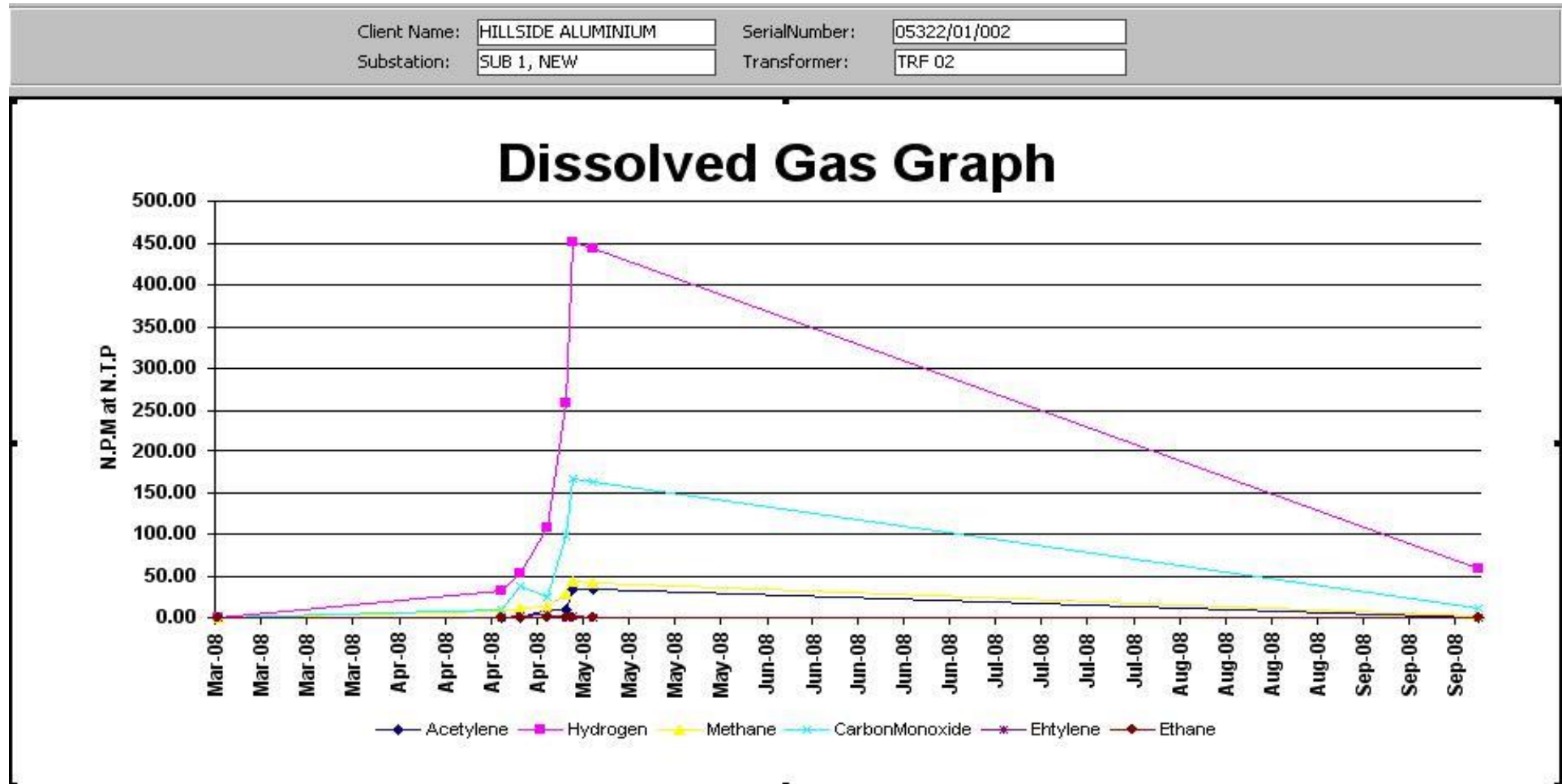
Passed all Electrical testing ?



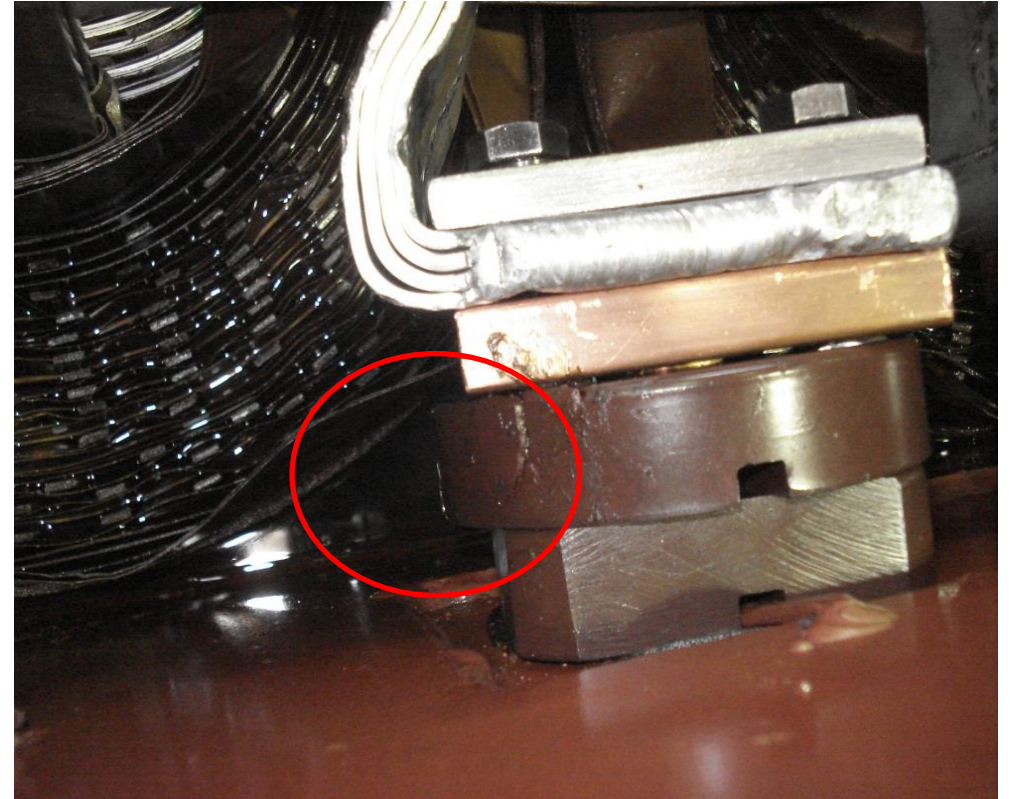
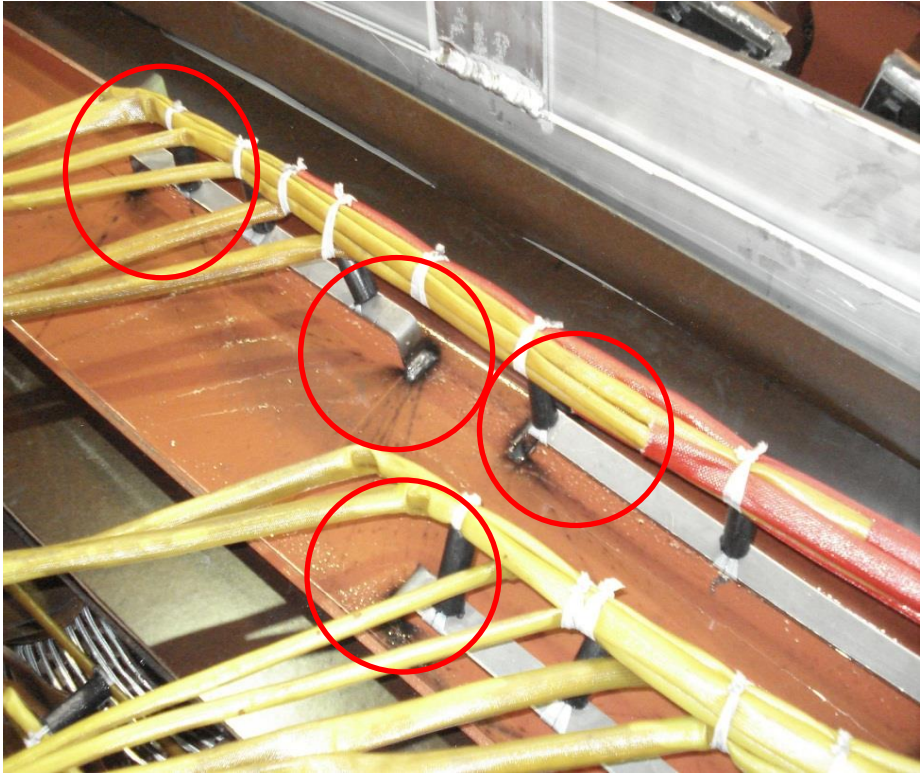
Loose internal earth strip



Case 2: Partial Discharge in 22 kV Transformers predicted by DGA



Internal Inspection and findings



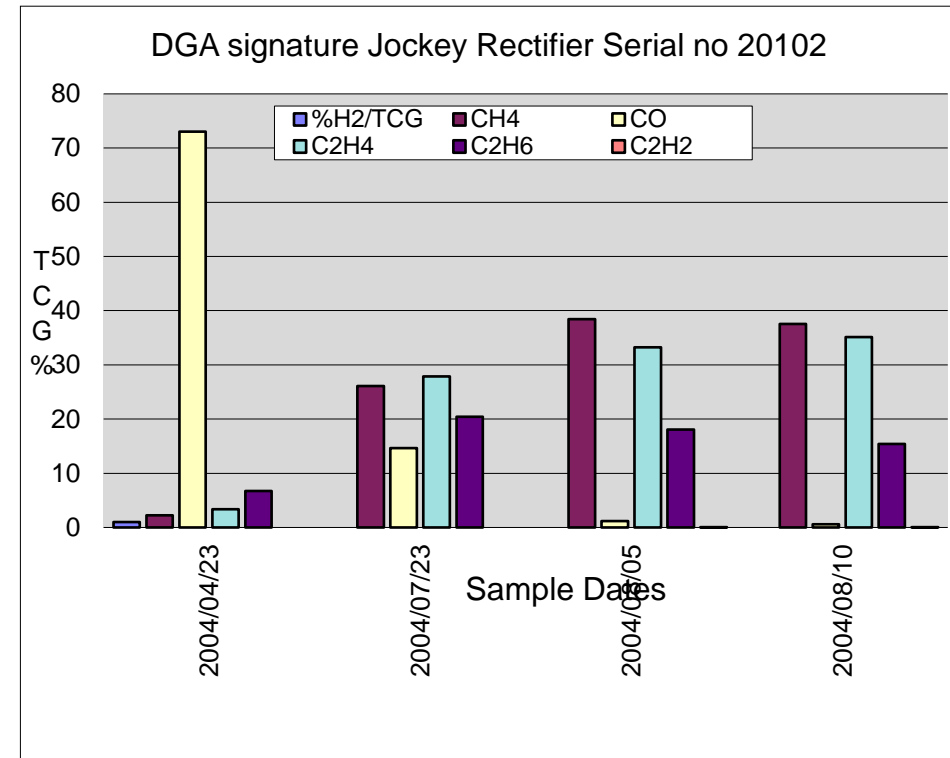
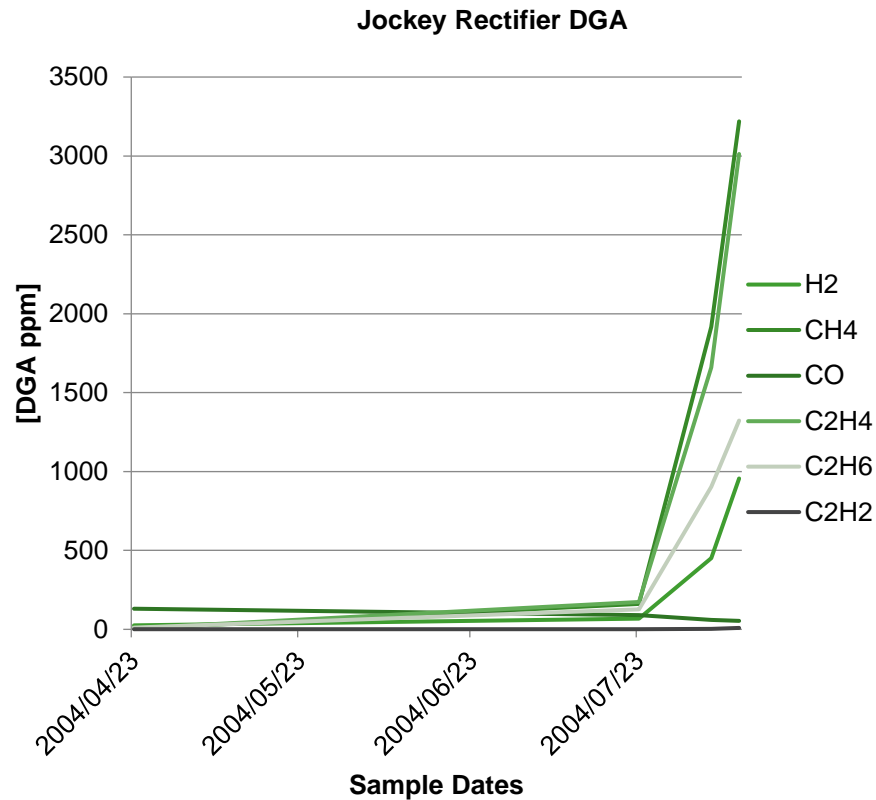
Root Cause and Savings

The root cause was established to be weakness of design and non-conforming quality control during manufacture.

Savings: The transformers were repaired under warranty.

Case Example : Jockey Rectifier Transformer

The DGA on this transformer showed abnormal gas production of H₂ CH₄ C₂H₄ and C₂H₆ about 3 months after Energisation



Internal Inspection and findings

Termination for potential connection became a hot spot due to circulating current

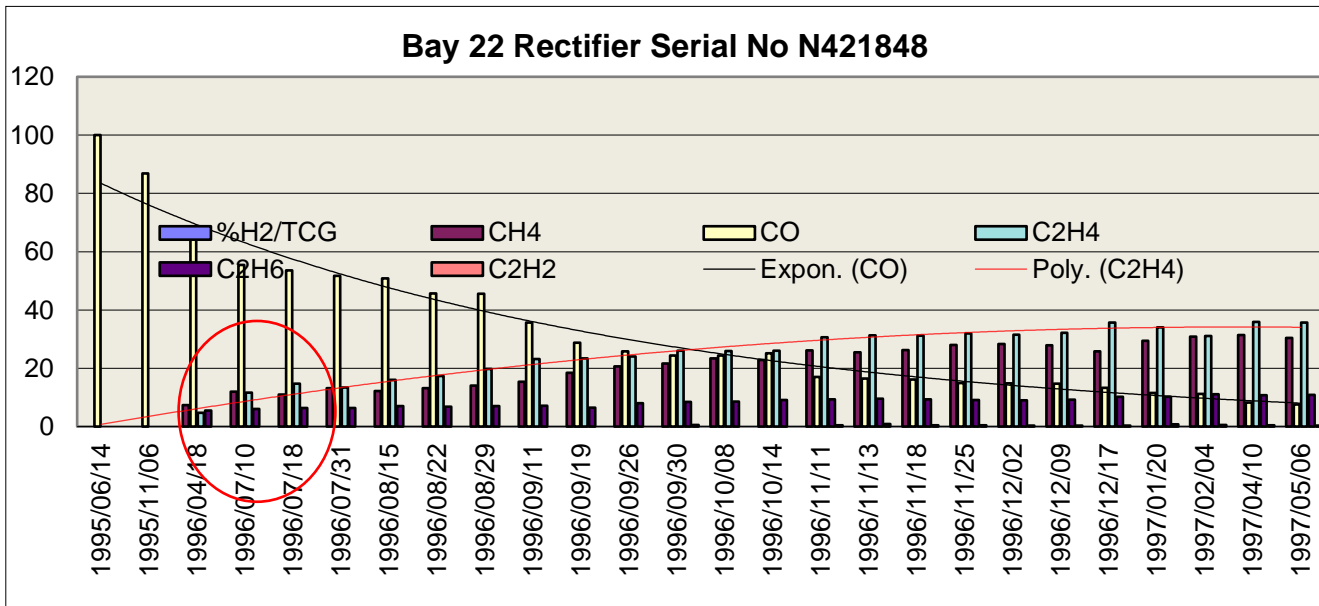
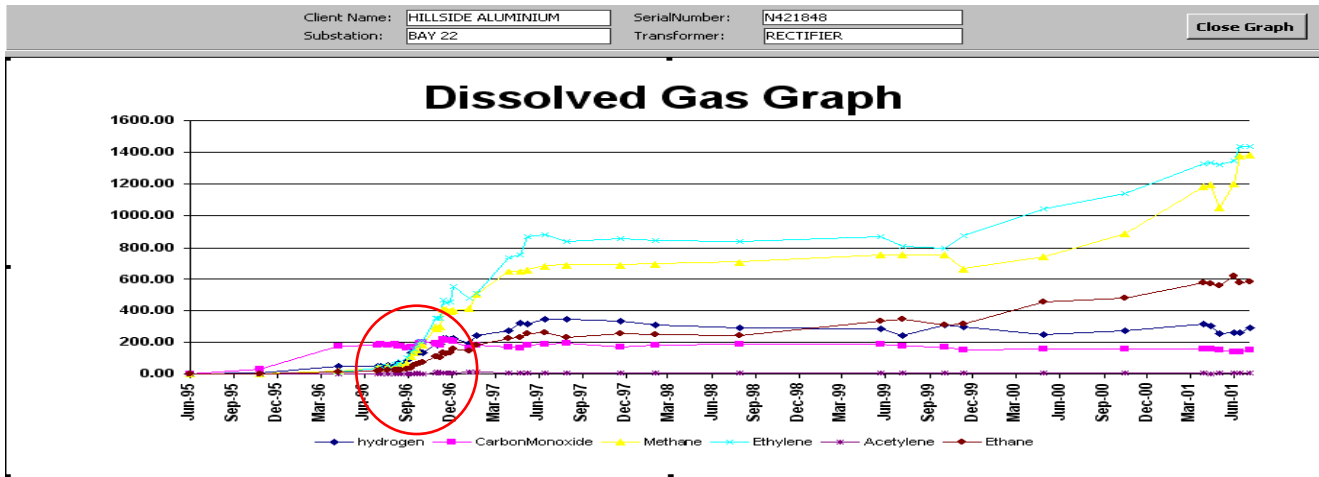


Conclusion

The transformer was repaired at a works facility under the warranty of the OEM.

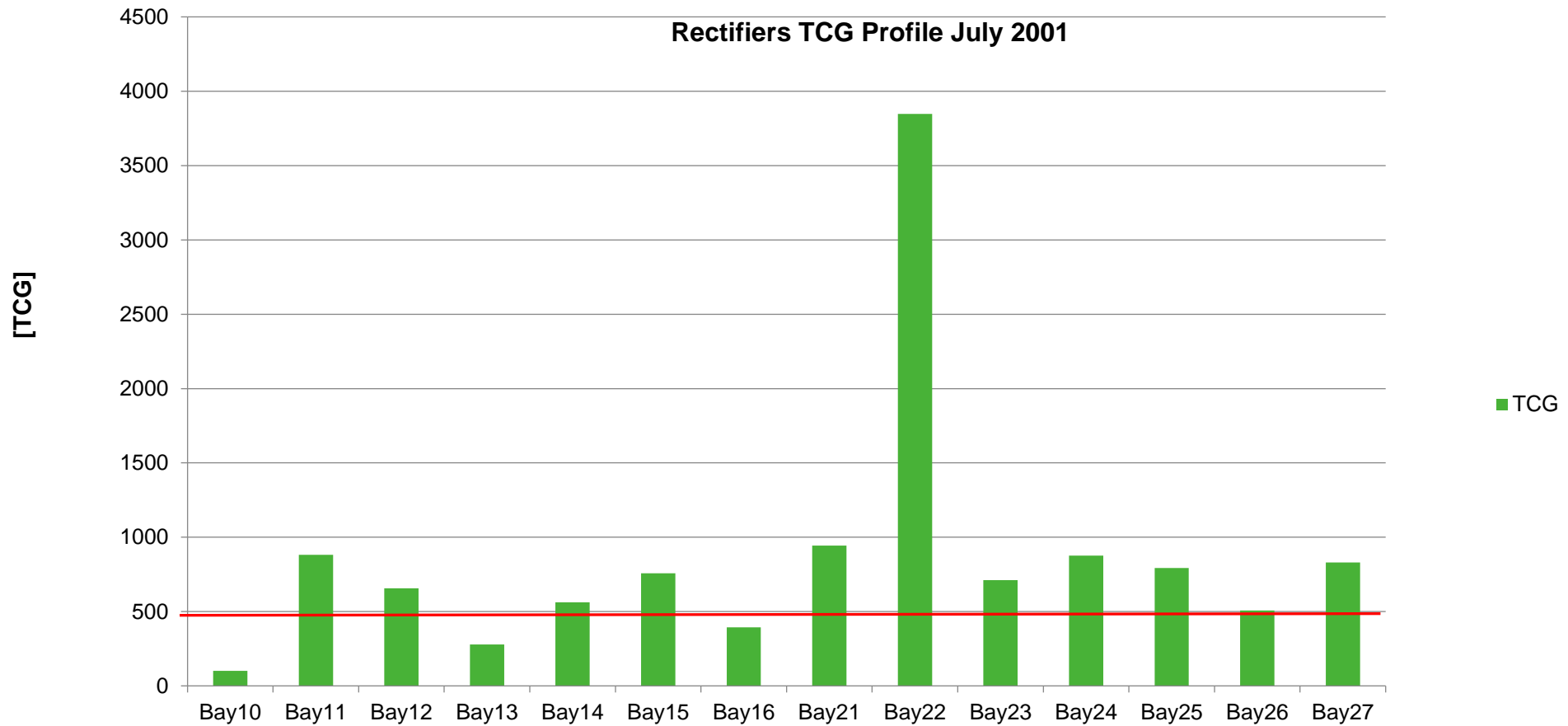
T22 Transformer Failure-93.5 MVA

The DGA on this transformer showed abnormal gas production of H_2 , CH_4 , C_2H_4 and C_2H_6 about 20 months after Energisation

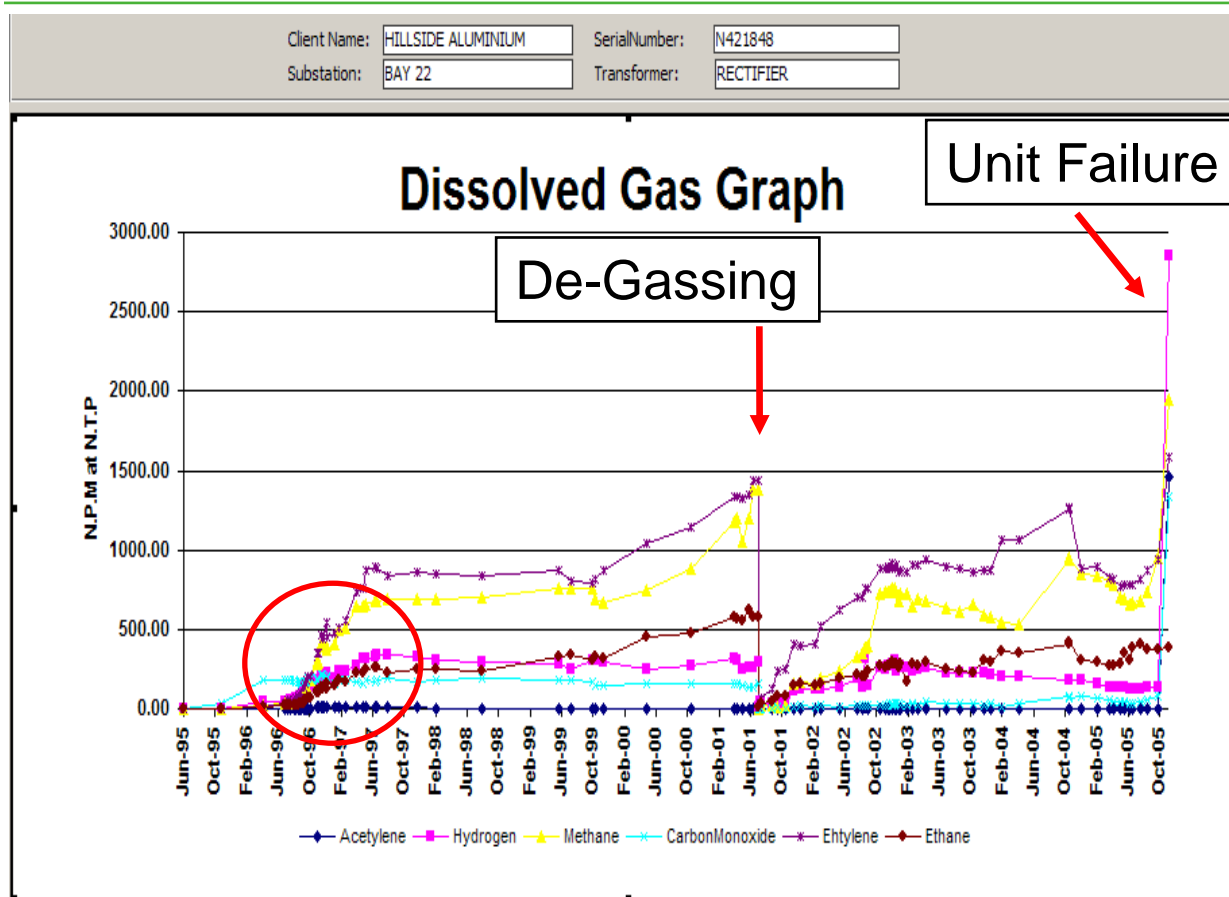


This transformer was ranked as having the highest risk of failure, based on the DGA-
Total Combustible Gas profile

The condition was monitored by regular oil samples. On-line DGA was considered



Failure Event At 16:32, on the 18 November 2005, Transformer T22



- When T22 transformer failure developed, the entire sequence of events, equipment failures and trips were over in **approximately one second.**

Consequence

- 900 MW wiped off the National Grid
- Potline 1 offline for 75 min
- Potline 2 offline for 145 min

- Major impact to Production (output and process stability)
- Damage to critical Control circuits
- Loss of N-1 redundancy in Transformer Supply

Disaster Averted

- **An outage > 180 mins often leads to a prolonged shutdown of an Aluminium plant – up to a year**
- **Zero injuries sustained**



Internal Inspection and findings

High Voltage winding open circuit and flashed to core



Burning in the vicinity of the top core earth strap



Overheating of the Core



Investigation: Bay 21 Rectifier

- Doble Engineering: Electrical diagnostic revealed problem.
- DGA scoring system scores this transformer between 80 and 100
- DGA signatures are indicative of a localized thermal fault probably of the 'bare metal' rather than 'covered conductor'
- SFRA revealed significant problems with the HV winding.

Internal Inspection and findings

Striking resemblance of core defect between T22 and T21



Root Cause and the next step

- Root cause of gassing was attributed to a poor shielding design or reduced cross sectional area of core
- Early retirement of all Rectifiers of this design.
- On Line DGA monitors installed



Conclusions

- The transformer problems at the Hillside smelter fit the Bath Tub Life Cycle Model
- The application of DGA was 100% successful in identify the faults at early life.
- DGA oil testing is typically a critical first step in any power transformer analysis
- Transformer manufacturers need to balance the cost of equipment with reliability
- Experience and understanding of the diagnostic methods is required to make DGA a more exact science and not an art.

Whew!!!!!!!: Questions



I'm out of here!

Thank you

