

DGA - Method in the Past and for the Future

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THE METROPOLITAN-VICKERS GAZETTE

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The identity and significance of gases collected in Buchholz protectors

V. H. HOWE A.M.I.E.E., ASSOC.M.C.T.

L. MASSEY M.SC.TECH., A.S.I.C.

A. C. M. WILSON ASSOC.M.C.T.

1970

Doerenburg introduced the differentiation between electrical and thermal failure mode and introduced ratios for fault gases with similar solubility.

1973

Halstead developed the theoretical thermodynamic theory. The ratios are temperature dependent. With increasing the hotspot the amount of gases increases in the order: methane-ethane-ethylene.

1975

The evaluation scheme of the modern Gas-in-Oil Analysis is developed by Rogers, Mueller, Schliesing, Soldner (MSS).

1995

Development of In-Line Monitoring

Different phenomena in oil take place like:

dielectric

thermal

dynamic

chemical

Change/Ageing

▶ **Gas-in-Oil Analysis (DGA = Dissolved Gas Analysis)**

The measurement of dissolved gases
allow the knowledge on

- ▶ **Type**
- ▶ **Complexity**
- ▶ **Seriousness**

of event

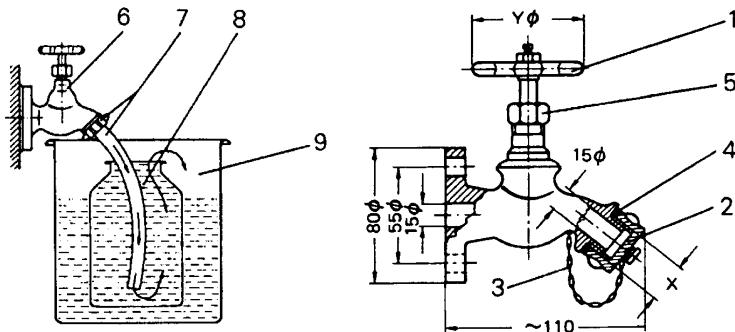
Sampling

Sampling Container

- ✓ **Perfectly cleaned & Dried**
- ✓ **Free from dust & moisture**
- ✓ **Airtight**
- ✓ **Glass or Metal cans, syringes**



- ✓ **Protect sample from direct light**
- ✓ **Avoid moisture & dust contamination**
- ✓ **Use the sampling containers exclusively for transformer oil sampling**



- 1 Handwheel
- 2 Sealing cap
- 3 Safety chain
- 4 Polyamid gasket
- 5 Nut
- 6 Drain valve
- 7 Hose and screw connector
- 8 Sampling bottle
- 9 Overflow vessel





Required information concerning oil sample(example)

Requested analysis:

Colour	ISO 2049	☐
Appearance	IEC 60422	☐
Neutralisation value	IEC 62021-1	☐
Breakdown voltage	IEC 60156	☐
Water content	IEC 60814	☐
Loss factor at 50 Hz	IEC 60247	☐
Interfacial tension	ISO 6295	☐
PCB-content	EN 12766-2	☐
Furananalysis (DGA)	IEC 61198	☐
Gas-in-oil-analysis	IEC 60567	☐
		☐
		☐
		☐

Please fill in the following data:

Manufacturer:	FTNR (Manufacturing No.):
Customer:	WNR (Order No.):
Location:	Sample No.:
Year of manufacture:	Date sample taken.:
Type:	Type of oil
Power:	Quantity of oil:
Rating:	Oil temperature in the sample taken:

Sample taken from:	☐ Oil sample valve	☐ Oil drainage device A 22/31/40 DIN 42 551	☐ Others
Tank:	☐ Top	☐ Middle	☐ Bottom
conservator	☐ Transformer	☐ OLTC	☐ Bushing
OLTC	☐ OLTC tank	☐	☐
Bushing	☐	☐	☐
Others:	☐	☐	☐

Reason for sample taking:

- ☐ Date of operation fault: _____
- ☐ Date of repair : _____
- ☐ Date of oil treatment/reclaiming _____
- ☐ Routine checkup: _____
- ☐ _____

Further informations and previous history:

Sample taker:

-----Date-----	-----Name in block letters-----	-----Company/ Department-----	-----Phone-----
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Lab information:

Consecutive no.: _____

Date sample received: _____

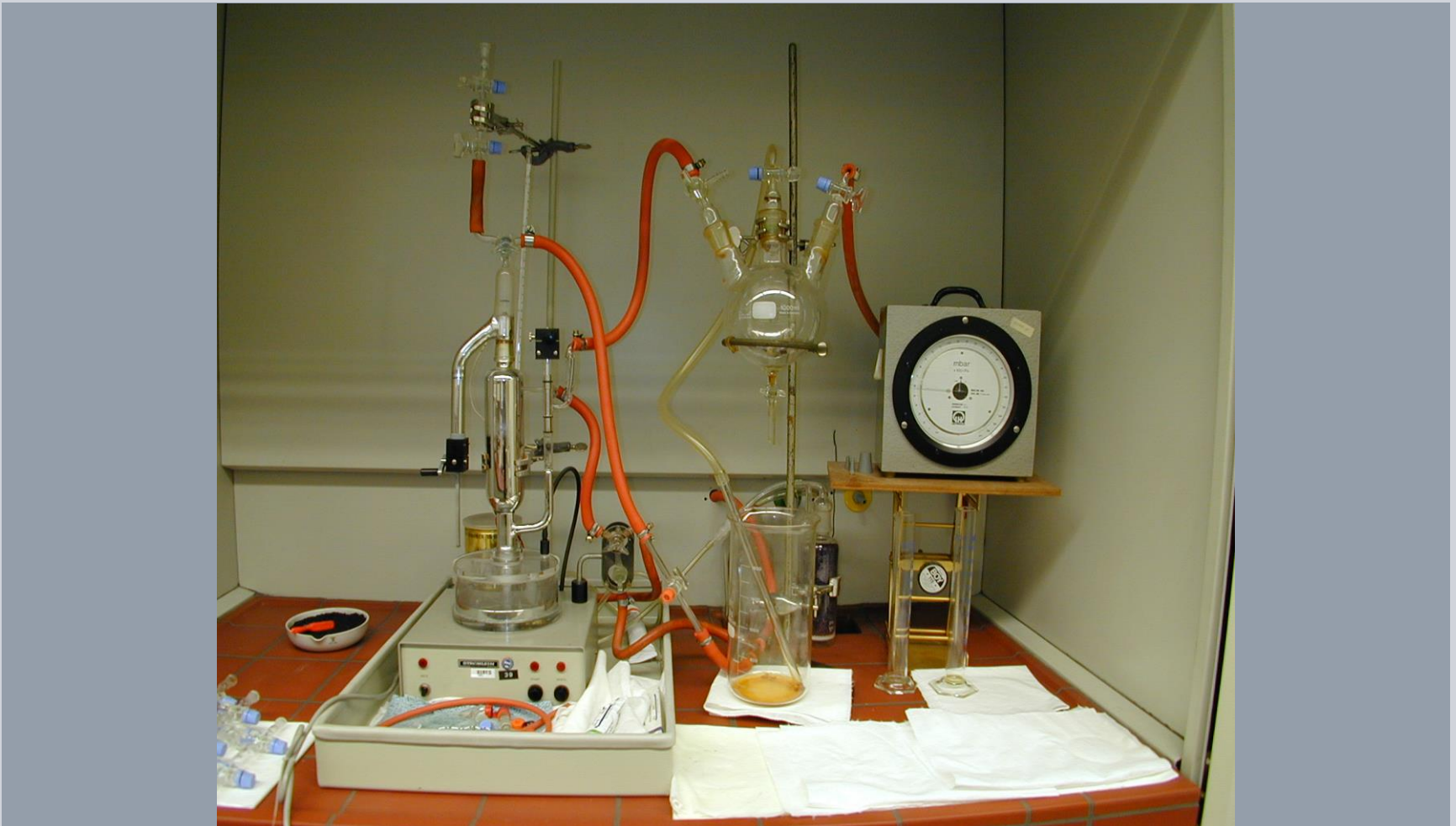
Date sample analysed: _____

Type of sample container: _____

special features:

Extraction of Gases from the Oil

DGA. Toepler Pump



DGA. Partial Degassing



DGA. Headspace at Ambient Temperature



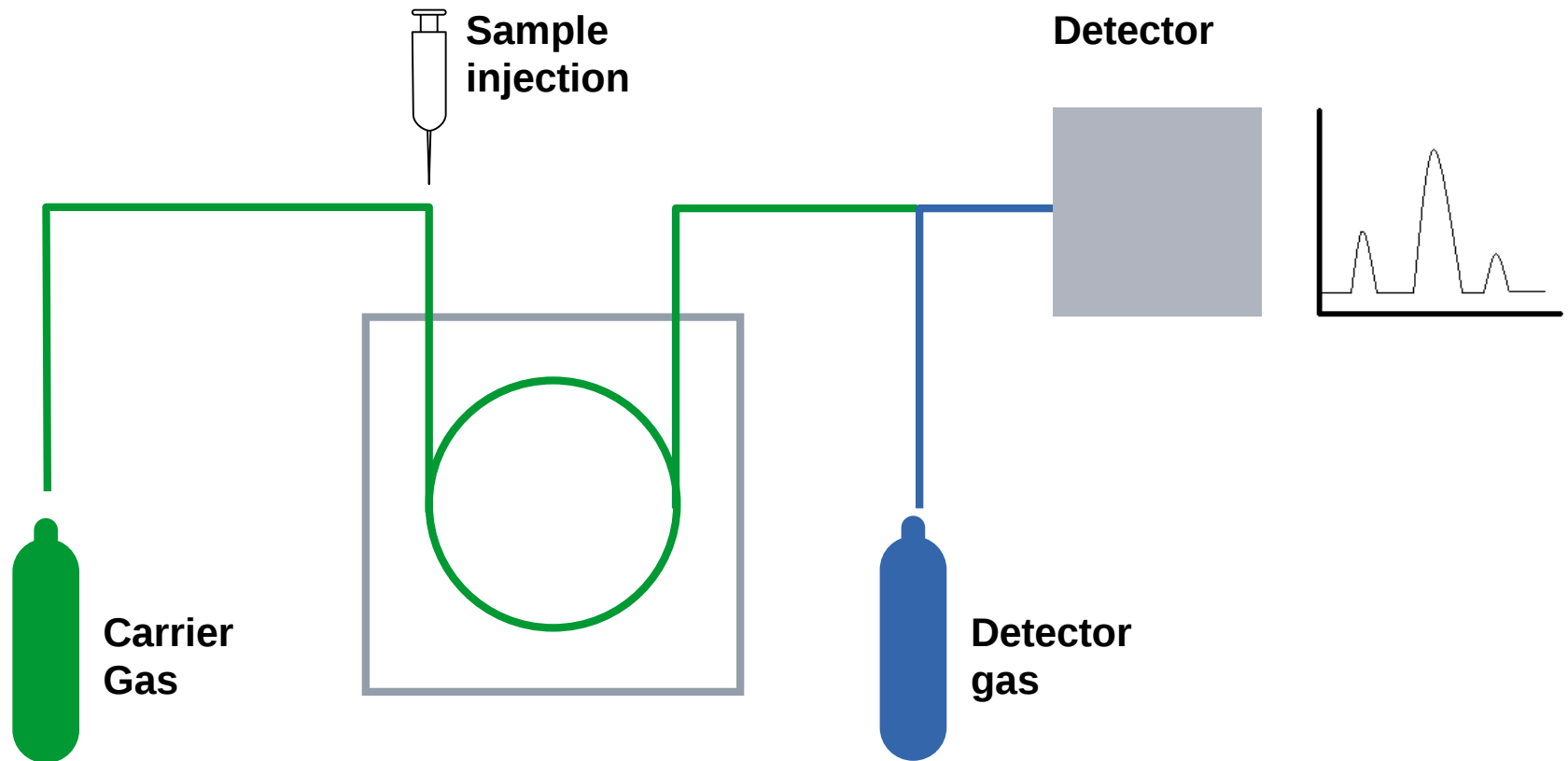
DGA. Headspace at 70°C



Gaschromatographic Analysis



Gaschromatographic Analysis



Failures which can be identified by DGA

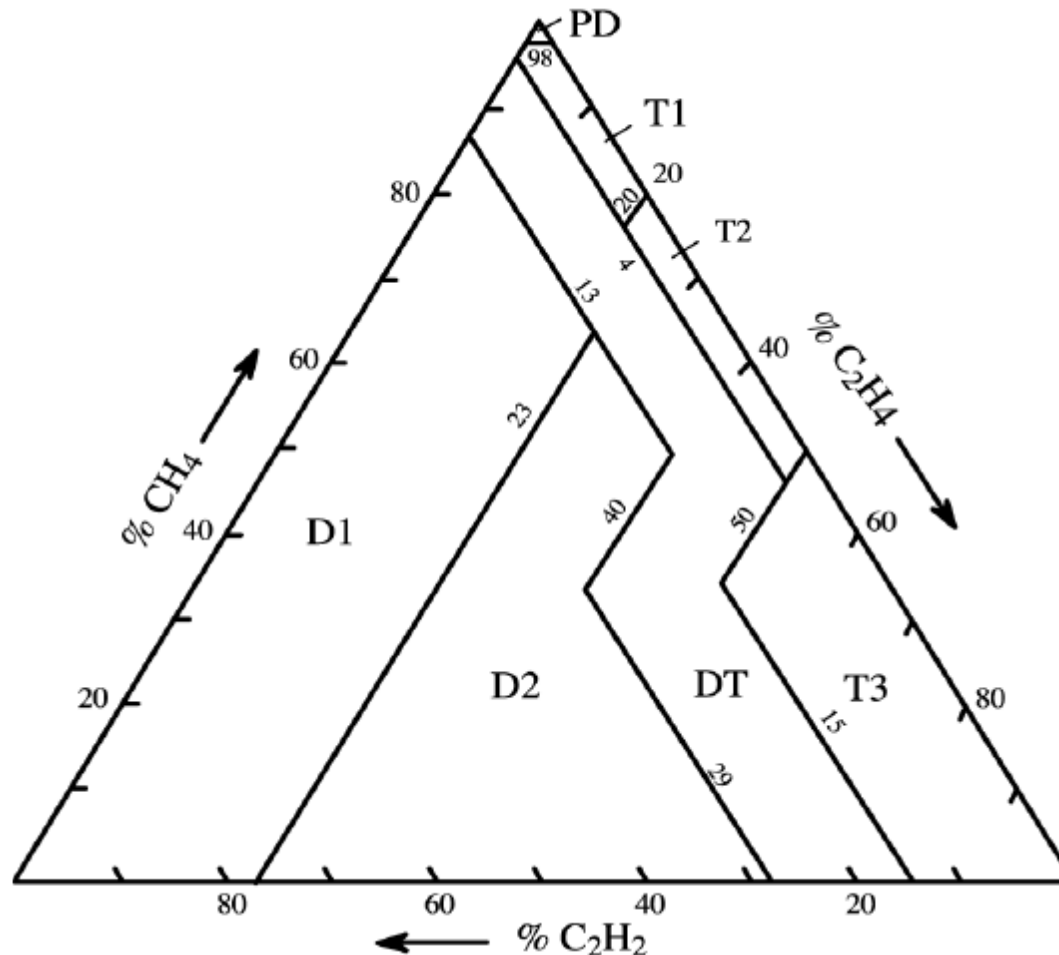
- ▶ **Partial discharges**
- ▶ **Electrical discharges**
- ▶ **Charcoal coating of contacts**
- ▶ **Accelerated cellulosic degradation**
- ▶ **Local overheating**
- ▶ **Untightness of OLTC tank**
- ▶ **Catalytic reactions of materials**
- ▶ **Additional information from BHR gas**

Failures which can not be identified by DGA

- ▶ **Incipient Failures**
- ▶ **Long lasting temperatures $< 150\text{ °C}$**

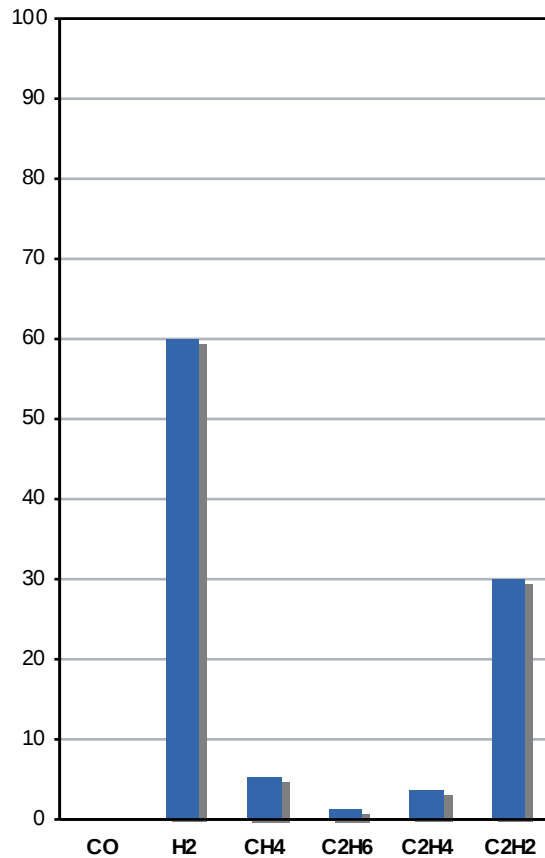
Interpretation Schemes

Duvals Triangle

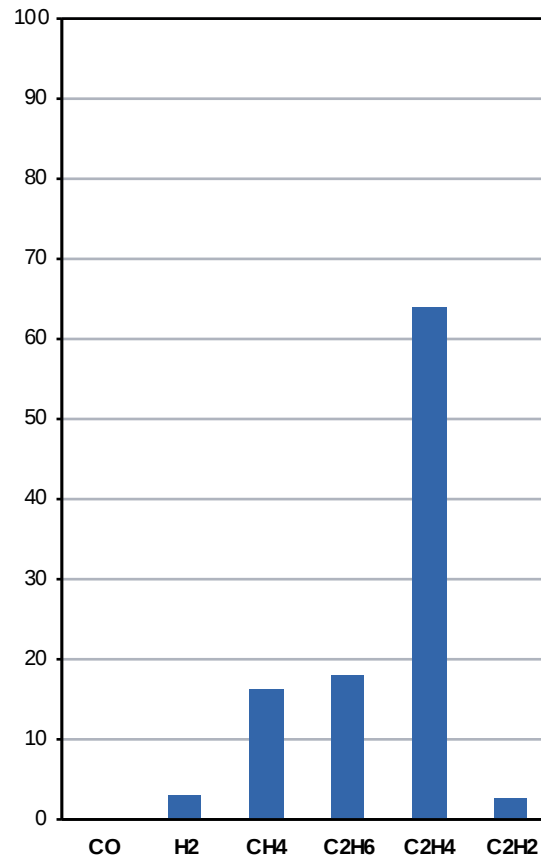


Patterns

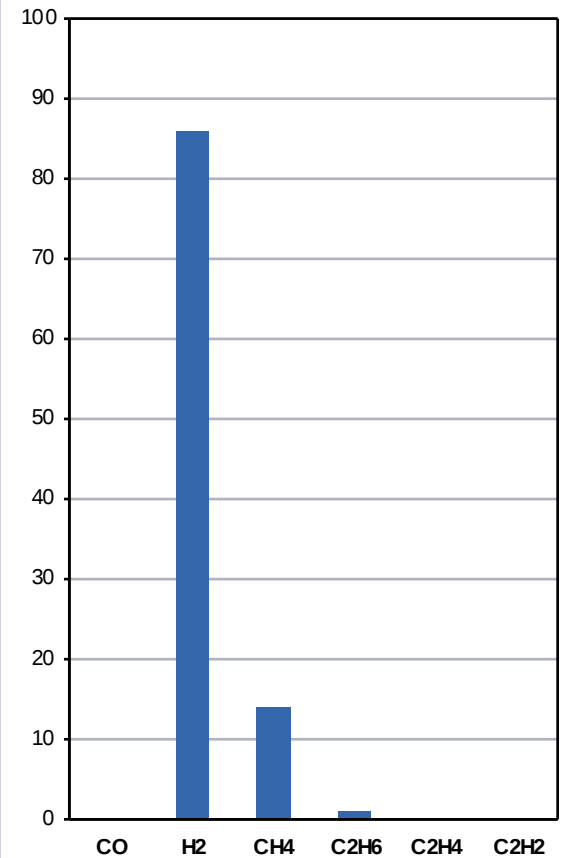
Electrical Discharges



Thermal Problem



Partial Discharges



MSS Scheme

Ratio ranges	Ratio numbers				
	$\frac{[C_2H_2]}{[C_2H_6]}$	$\frac{[H_2]}{[CH_4]}$	$\frac{[C_2H_4]}{[C_2H_6]}$	$\frac{[C_2H_4]}{[C_3H_6]}$	$\frac{[CO_2]}{[CO]}$
<0.3	0	0	0	0	1
0.3 to < 1.0	1	0	0	1	1
1.0 to < 3.0	1	1	1	2	1
3.0 to < 10.0	2	2	1	3	0
≥ 10.0	2	3	1	3	2
Diagnosis	Number sequences				
Normal ageing of insulators	0	0	0	0	0
Discharge of high energy	2	1	1	2/3	1
Discharge of low energy	2	2	1	2/3	1
Partial discharge with high energy	1	3	0	n.i.	0
Partial discharge with low energy	1	3	0	n.i.	0
Local overheating up to 300 °C	0	0	0	1	2
Local overheating from 300 °C to 1000 °C	0	0	1	2	2
Local overheating over 1000 °C	1	0	1	2/3	2
Local overheating and discharge	1	1	1	2	2
Local overheating and partial discharge	0	3	1	2	2

n.i. = not indicative

IEC Scheme

Case	Characteristic fault	$\frac{C_2H_2}{C_2H_4}$	$\frac{CH_4}{H_2}$	$\frac{C_2H_2}{C_2H_6}$
PD	Partial discharges (see notes 3 and 4)	NS ¹⁾	<0,1	<0,2
D1	Discharges of low energy	>1	0,1 – 0,5	>1
D2	Discharges of high energy	0,6 – 2,5	0,1 – 1	>2
T1	Thermal fault $t < 300\text{ °C}$	NS ¹⁾	>1 but NS ¹⁾	<1
T2	Thermal fault $300\text{ °C} < t < 700\text{ °C}$	<0,1	>1	1 – 4
T3	Thermal fault $t > 700\text{ °C}$	<0,2 ²⁾	>1	>4

NOTE 1 In some countries, the ratio C_2H_2/C_2H_6 is used, rather than the ratio CH_4/H_2 . Also in some countries, slightly different ratio limits are used.

NOTE 2 The above ratios are significant and should be calculated only if at least one of the gases is at a concentration and a rate of gas increase above typical values (see clause 9).

NOTE 3 $CH_4/H_2 < 0,2$ for partial discharges in instrument transformers.
 $CH_4/H_2 < 0,07$ for partial discharges in bushings.

NOTE 4 Gas decomposition patterns similar to partial discharges have been reported as a result of the decomposition of thin oil film between overheated core laminates at temperatures of 140 °C and above (see 4.3 and [1] of annex C).

¹⁾ NS = Non-significant whatever the value.

²⁾ An increasing value of the amount of C_2H_2 may indicate that the hot spot temperature is higher than 1 000 °C.

In case of quotient information it must be clear, that quotients are only representative, if following values of the fault gases (in ppm) are exceeded:

C_2H_2	≥ 1
H_2	≥ 15
$\sum [\text{CXHY}] \text{ x}=1;2;3$	≥ 50
CO	≥ 80
CO_2	≥ 200

DGA

Example – thermal Problem

MSS-Code 00120

Fault gas		ppm
Hydrogen	H ₂	1967
Methane	CH ₄	8008
Ethane	C ₂ H ₆	2013
Ethylene	C ₂ H ₄	8323
Acetylene	C ₂ H ₂	57
Propane	C ₃ H ₈	401
Propylene	C ₃ H ₆	4824
Carbon monoxide	CO	253
Carbon dioxide	CO ₂	1903
Oxygen	O ₂	18222
Nitrogen	N ₂	61662



MSS-Code 00120

Fault gas		ppm
Hydrogen	H ₂	537
Methane	CH ₄	1041
Ethane	C ₂ H ₆	295
Ethylene	C ₂ H ₄	1726
Acetylene	C ₂ H ₂	25
Propane	C ₃ H ₈	83
Propylene	C ₃ H ₆	1012
Carbon monoxide	CO	1047
Carbon dioxide	CO ₂	6158
Oxygen	O ₂	11805
Nitrogen	N ₂	58084

Manufacturing year 1970
360 MVA
Carbon deposits on PLTC Contacts



Gas-in-Oil Analysis

Turn-to-Turn Failure

MSS-Code

21121

Fault gas		ppm
Hydrogen	H ₂	4973
Methane	CH ₄	1758
Ethane	C ₂ H ₆	243
Ethylene	C ₂ H ₄	2813
Acetylene	C ₂ H ₂	8236
Propane	C ₃ H ₈	58
Propylene	C ₃ H ₆	1320
Carbon monoxide	CO	1196
Carbon dioxide	CO ₂	2431
Oxygen	O ₂	6743
Nitrogen	N ₂	44120



DGA

Thermal Problem with Partial Discharges

MSS-Code 00101

Fault gas		ppm
Hydrogen	H ₂	1060
Methane	CH ₄	2481
Ethane	C ₂ H ₆	703
Ethylene	C ₂ H ₄	2187
Acetylene	C ₂ H ₂	4
Carbon monoxide	CO	450
Carbon dioxide	CO ₂	995

Manufacturing year 1991
234 MVA, 330 kV
Defective welding joint



DGA

Catalytical Effects

MSS-Code ?3??0

Fault gas		ppm
Hydrogen	H ₂	488
Methane	CH ₄	1
Ethane	C ₂ H ₆	< 1
Ethylene	C ₂ H ₄	< 1
Acetylene	C ₂ H ₂	< 1
Propane	C ₃ H ₈	< 1
Propylene	C ₃ H ₆	< 1
Carbon monoxide	CO	67
Carbon dioxide	CO ₂	222
Oxygen	O ₂	5180
Nitrogen	N ₂	23700

Manufacturing year 1977
Closed type
Color 0,5 / Acidity 0,01

DGA

Untight OLTC

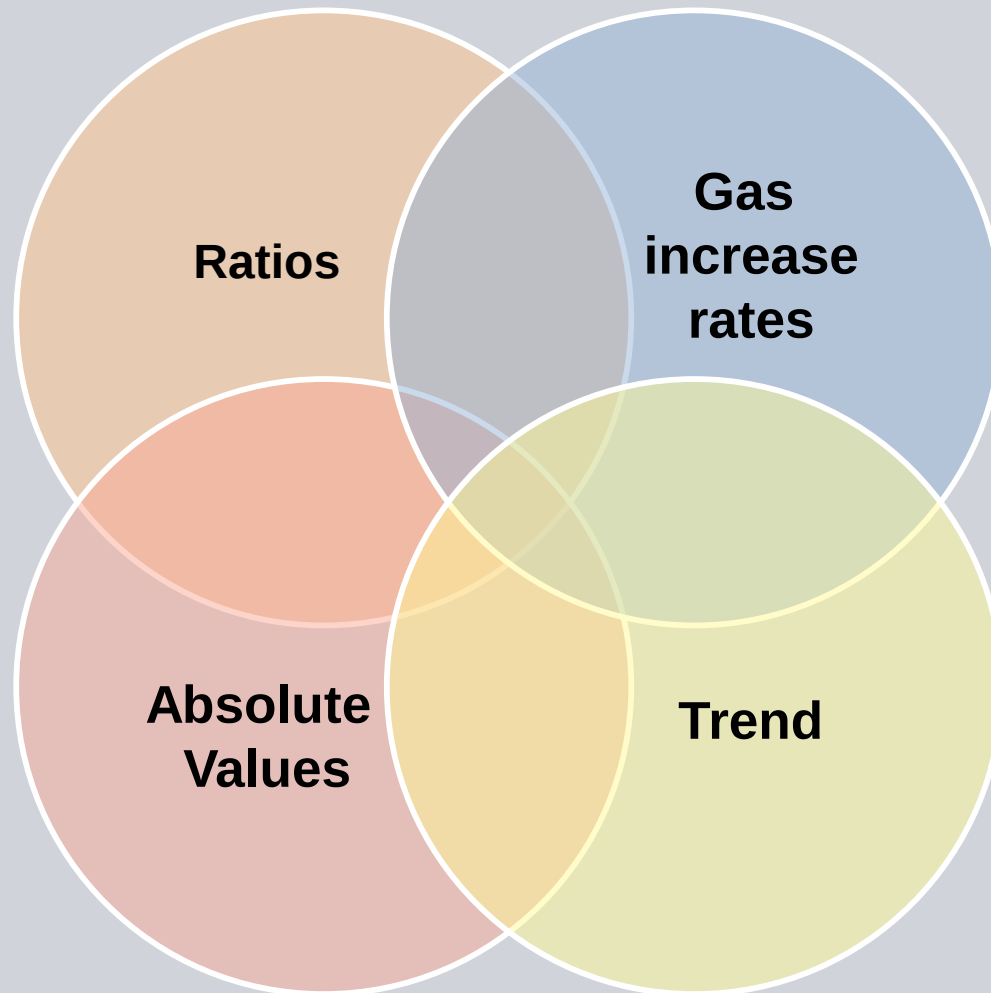
MSS-Code 22122

Fault gas		ppm
Hydrogen	H ₂	128
Methane	CH ₄	25
Ethane	C ₂ H ₆	5
Ethylene	C ₂ H ₄	81
Acetylene	C ₂ H ₂	288
Propane	C ₃ H ₈	5
Propylene	C ₃ H ₆	50
Carbon monoxide	CO	143
Carbon dioxide	CO ₂	1920
Oxygen	O ₂	24600
Nitrogen	N ₂	52000



DGA

Diagnostic Importance in Service



Absolute Values

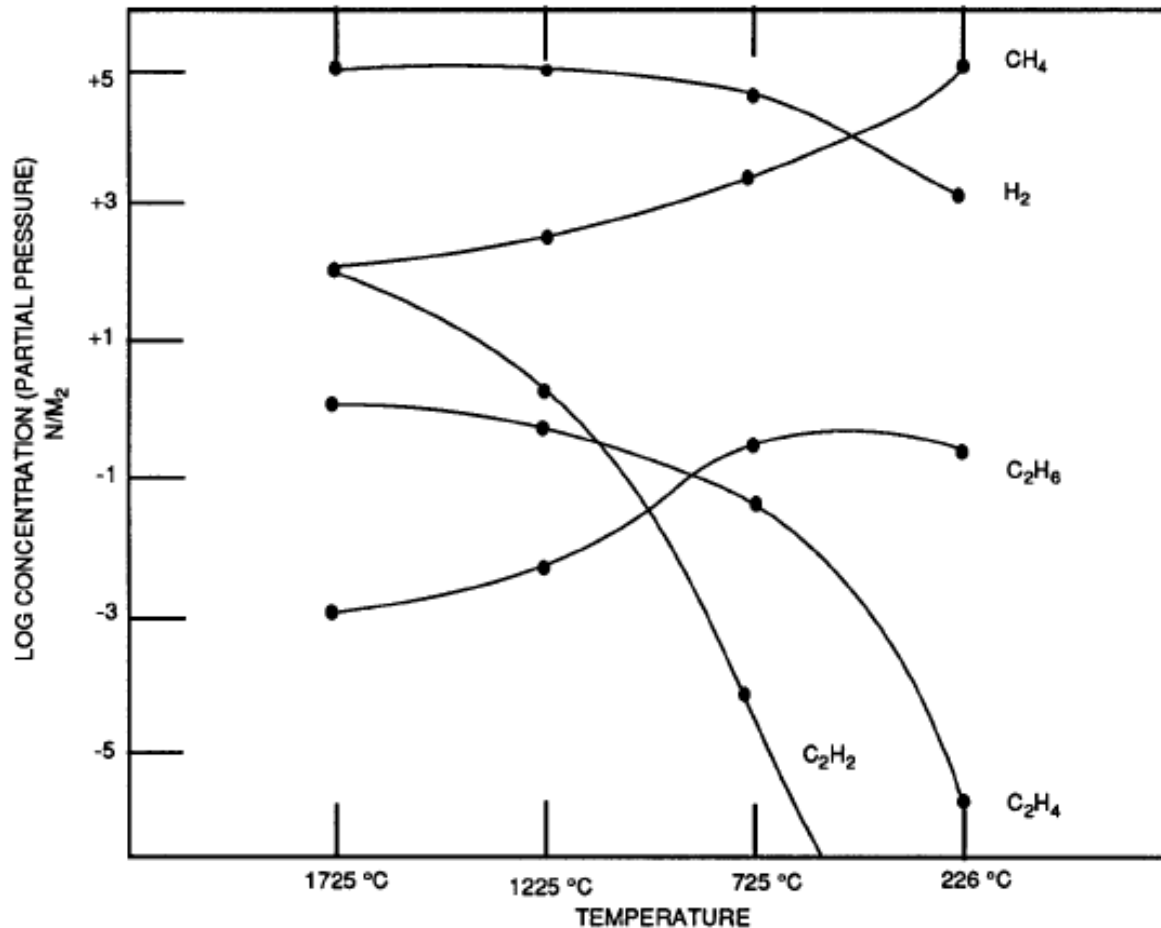
IEC 60599 (VDE 0370-7)

	C_2H_2	H_2	CH_4	C_2H_4	C_2H_6	CO	CO_2
All transformers		50 ↓ 150	30 ↓ 130	60 ↓ 280	20 ↓ 90	400 ↓ 600	2800 ↓ 14000
No OLTC	2 ↓ 20						
Communicating OLTC	60 ↓ 280						

Ratios

- a) Eliminates the effect of the oil volume
- b) Eliminates some effects of sampling
- c) Especially interesting is the ratio formation for fault gases which exhibit similar solubilities, but their development is temperature dependent –
e. g. the thermodynamic considerations of Halstead.

Thermodynamical considerations of Halstead



Gas Increase Rates – information on seriousness of failure

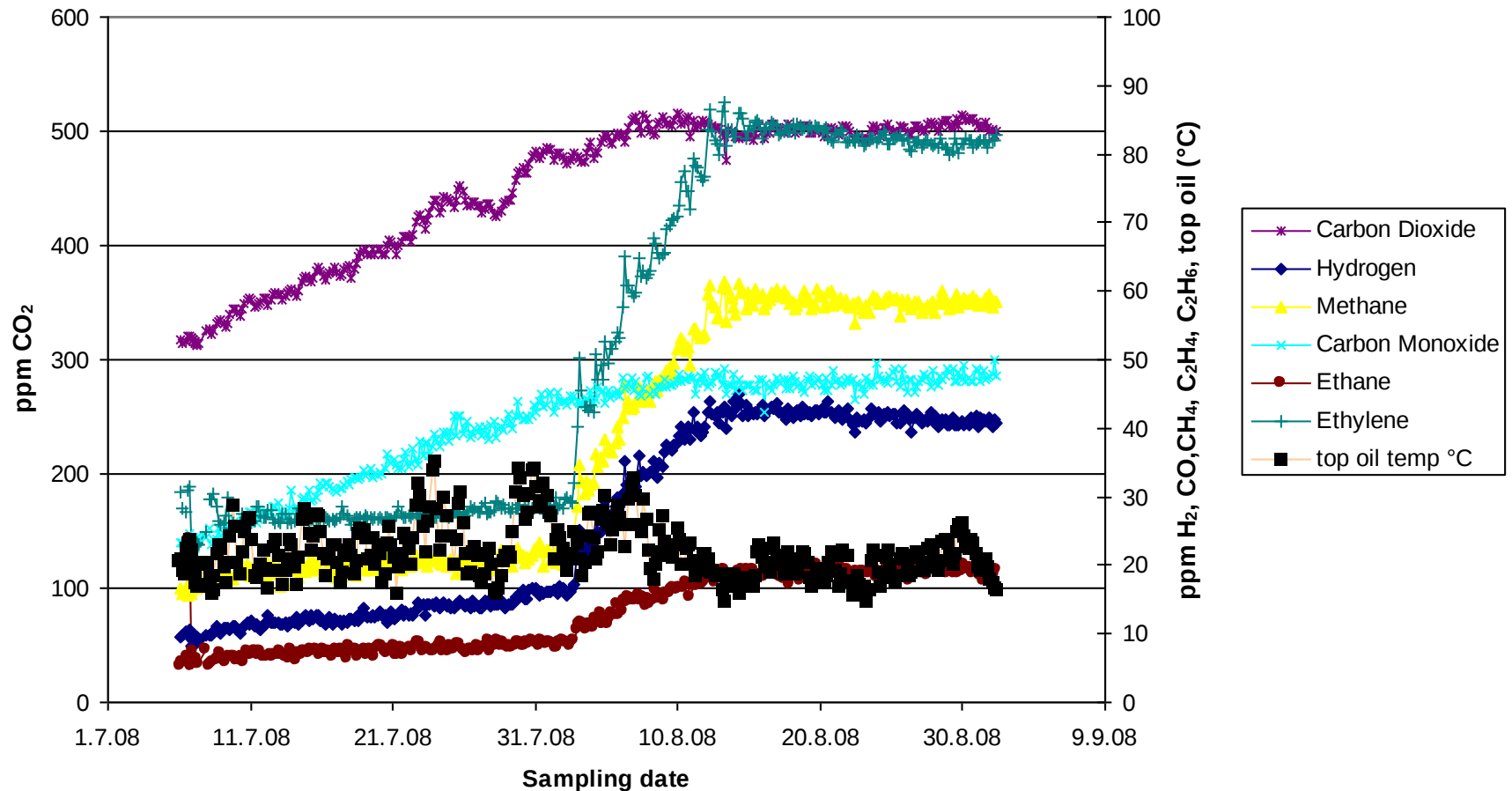
	C_2H_2	H_2	CH_4	C_2H_4	C_2H_6	CO	CO_2
All transformers	0,01	0,36	0,33	0,40	0,25	2,9	27

► 90% gas increase source: Cigre TF11 in ppm/day

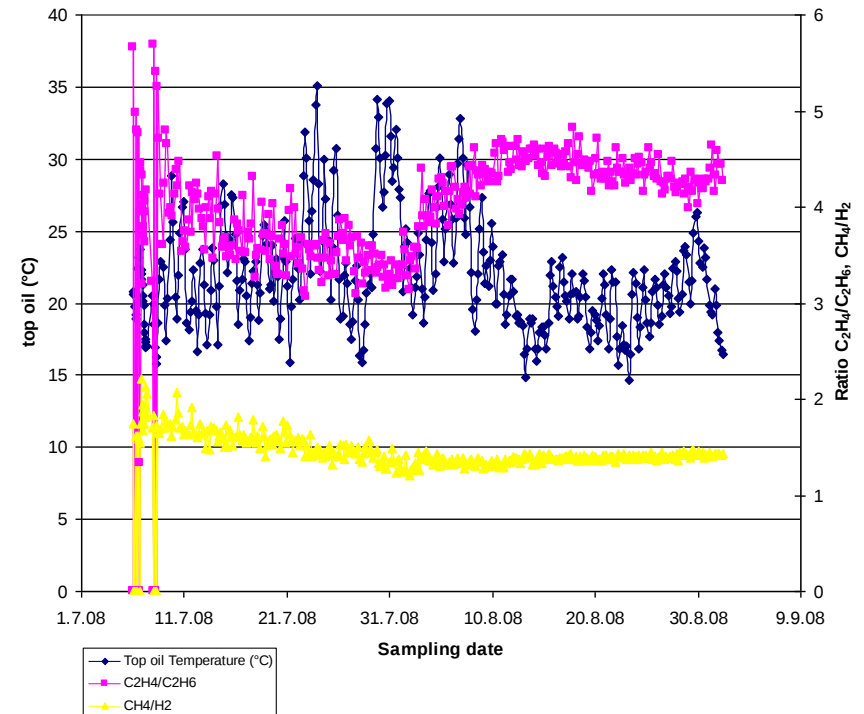
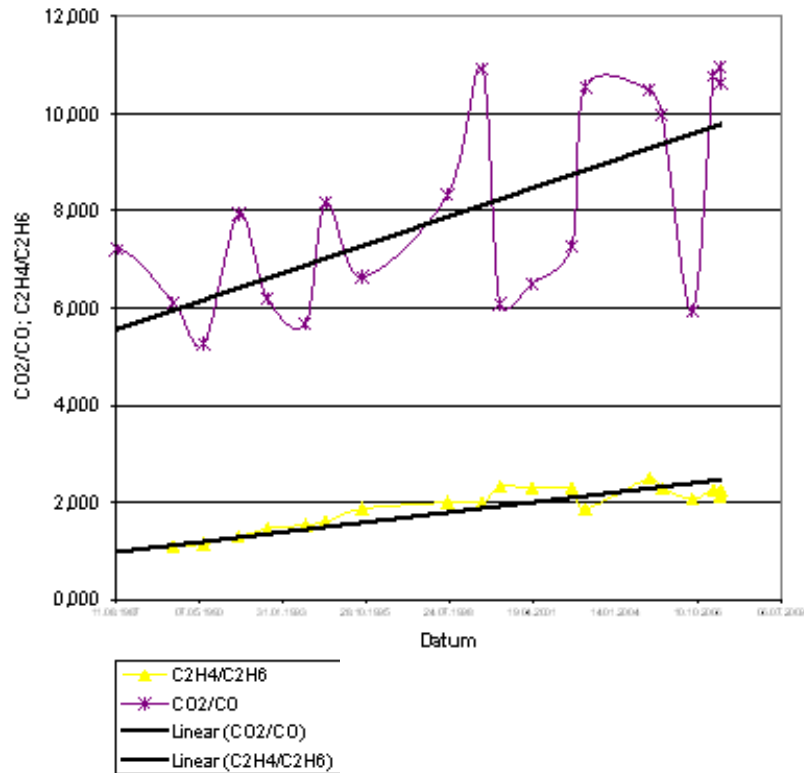
Gas increase rates are temperature and volume dependent

Trend Analysis

Development of the Fault Gases After Two Months of On-Line Monitoring



Trend Analysis



► Trendanalysis is important not only with absolute values, but also with the ratios.

On-Line Monitoring

- ▶ Early failure recognition
- ▶ Diagnosis is only possible with the sophisticated types – where IEC ratios can be built

Cigre TF 15 DGA did a comparison between On-Line monitoring systems and Off-Line analyses. The brochure is on the way.

Evaluated are:

- Precision
- Longterm stability
- Repeatability

In case of

- Routine concentrations, d.h. $5 * \text{Detection Limit}$
- Low Concentrations, d. h. $2-5 * \text{Detection Limit}$

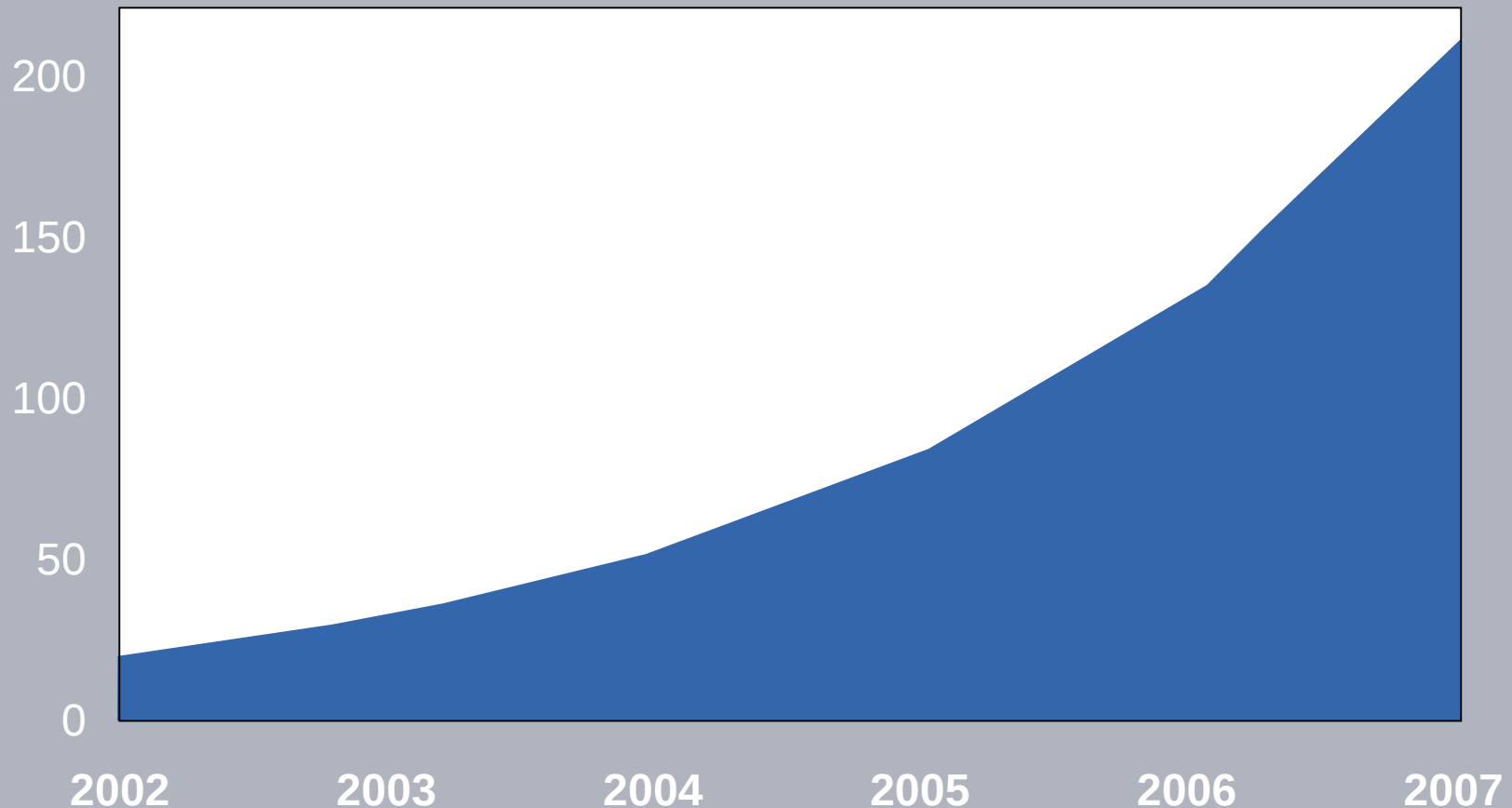
- ▶ **Necessary in case a problem has been identified**
- ▶ **Often, however, difficult to maintain**
- ▶ **Interfaces can lead to problems**
- ▶ **Able to deliver important information in a short time**
- ▶ **Does not automatically lead to higher reliability**

What can be measured on-line:

- ▶ **Temperature**
- ▶ **Current, Voltage**
- ▶ **OLTC**
- ▶ **Oil level**
- ▶ **Gas-in-Öl Analysis**
- ▶ **Humidity in oil**
- ▶ **Bushings**
- ▶ **Acoustic Signals**
- ▶ **Magnetic Circuit**
- ▶ **Coolers**

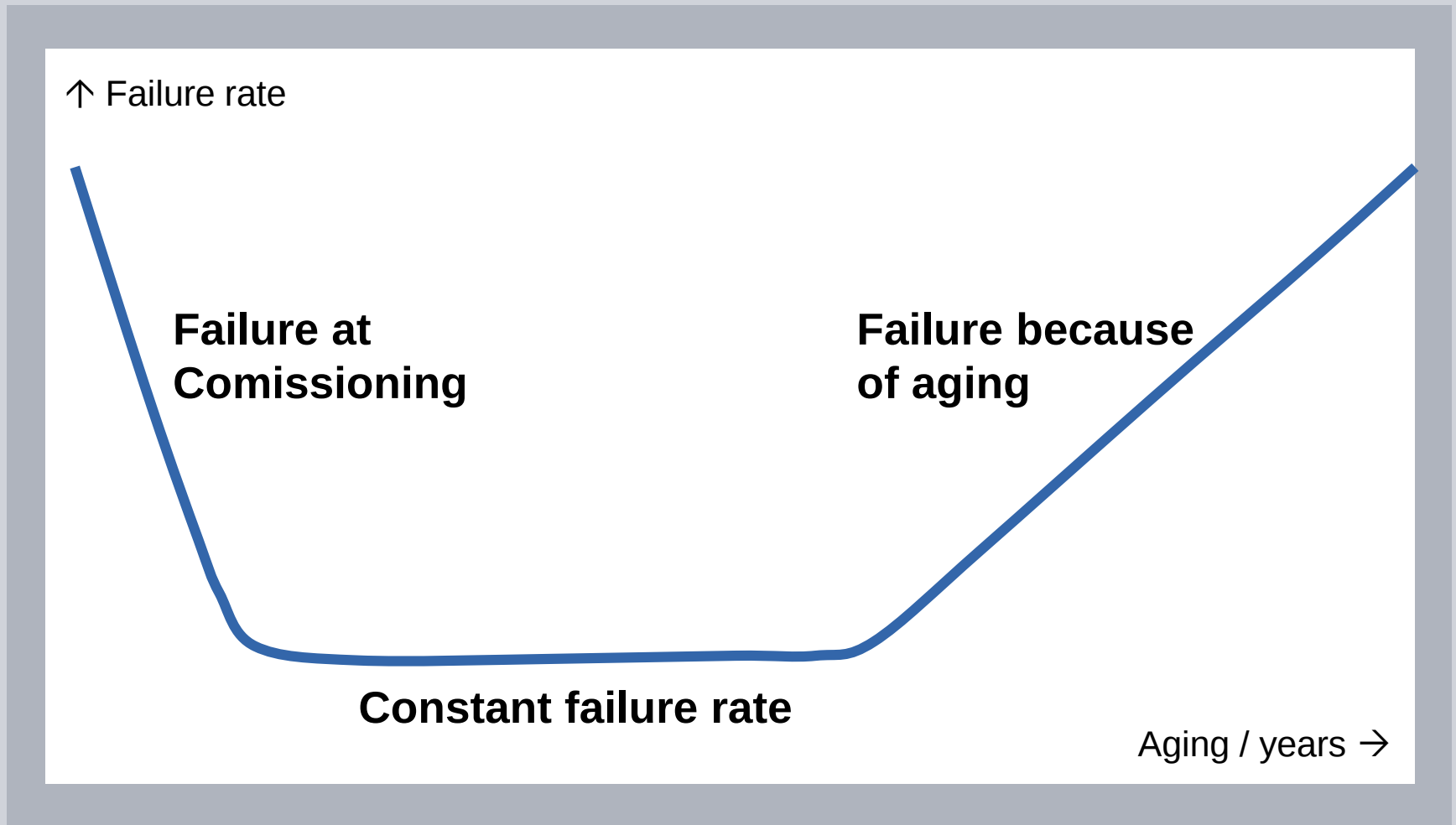
More Data does not mean automatically more Information

Data Explosion¹⁾ (Total Exabytes)



1) Exa = 10^{16} = 10 Mil of Billions

Transformer Failure Rate



Future Developments

- ▶ **Further development of the On-Line analysis with decision criteria**
- ▶ **Gas-in-oil analysis in OLTC**
- ▶ **Gas-in-oil analysis in alternative insulation fluids and high temperature insulating materials**

**Thank you
for your attention!**