Online DGA-monitoring of power transformers

Senja Leivo

Senior Industry Expert, Vaisala Finland

Member of CIGRE A2/D1.47 and D1.52 WGs

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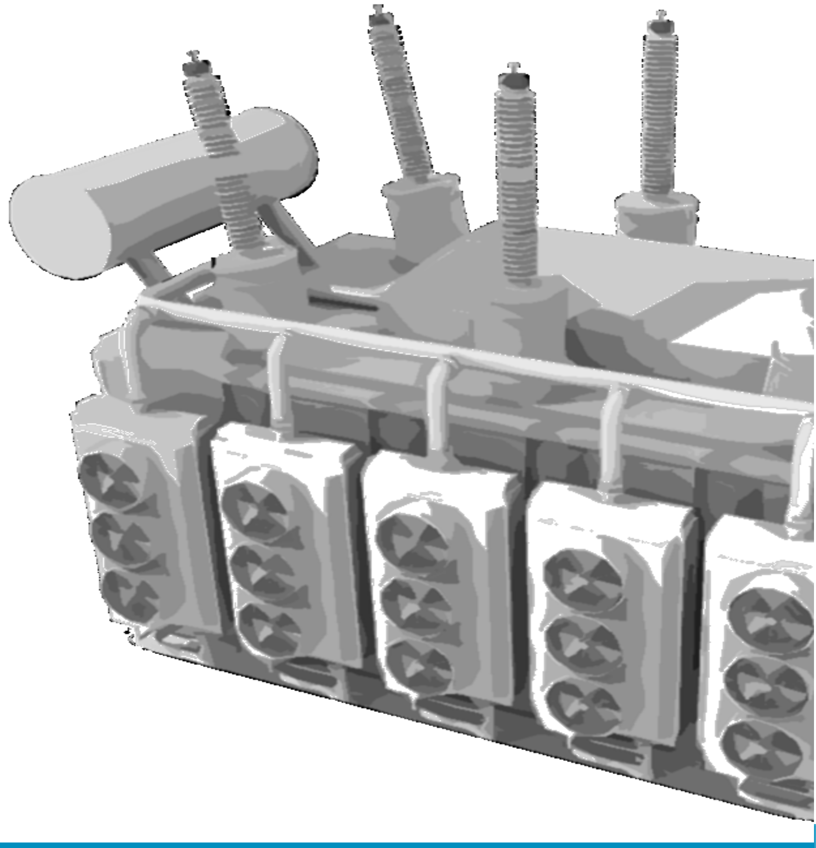
Webinar content

1. Dissolved gases – why and which gases
2. Fault types
3. Online monitoring – why
4. Things to consider when choosing a monitor
5. IR technology in online DGA – Vaisala Optimus™ DGA monitor
6. How to define limit values and interpret the data
7. How to utilize the online data – examples
8. Comparing online data to laboratory results

Dissolved Gas Analysis

- DGA is a comprehensive transformer condition assessment tool
  - It can detect multiple fault types inside a transformer.

DGA

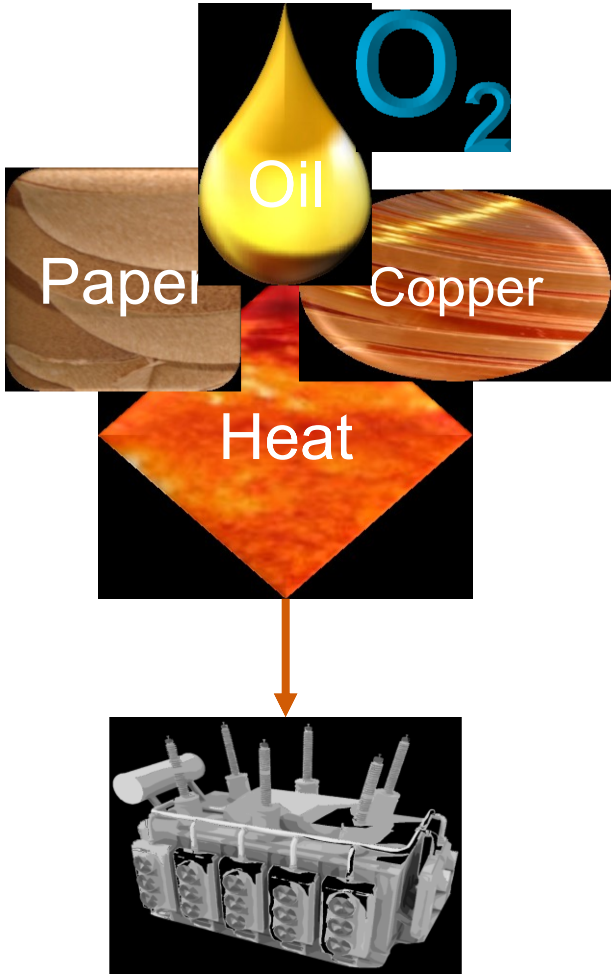


Why gases form in a transformer?

Chemical reactions happen when conditions favor them e.g. in presence of fuel, oxygen, heat and catalysts.

In case of a fault, temperature increase at fault location.

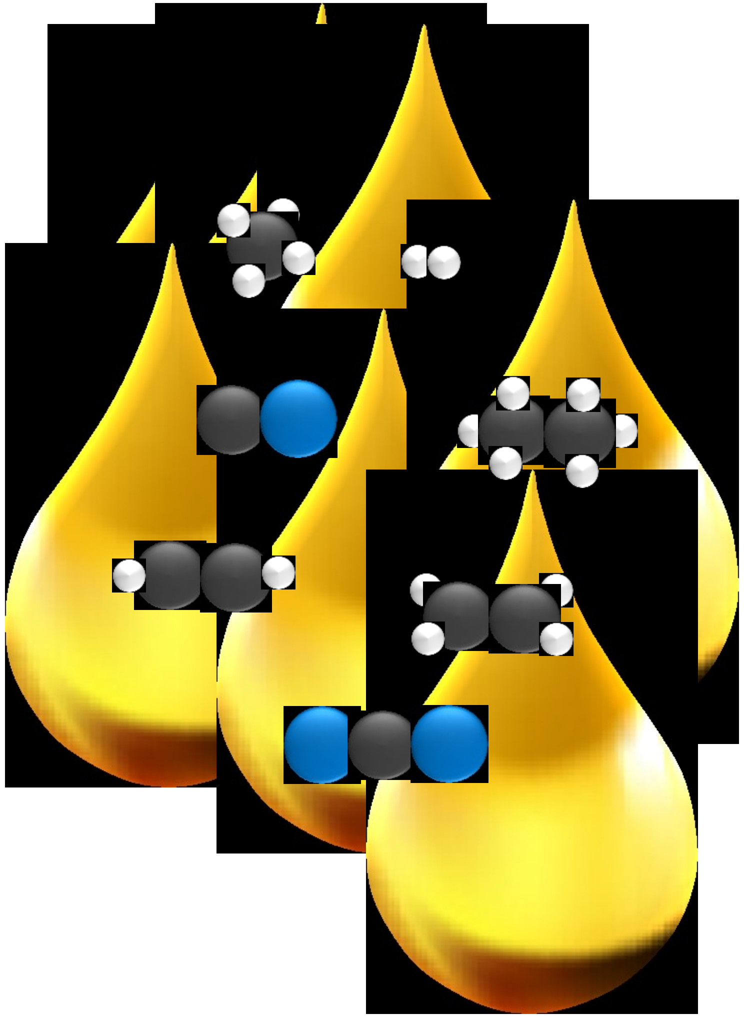
- WHY GASES: oil and/or paper decomposition due to thermal stresses → gases form
- WHICH GASES : Type and amount of gases depends on occurring fault and its energy intensity and area.
  - More intensive faults give higher gas production rate.
  - Larger fault area give higher gas production rate.



"Uncontrolled chemical reactor"

Which gases?

- 7 formed gases are commonly considered as key fault gases.
  - Mathane, ethane, ethylene, acetylene, carbon monoxide, carbon dioxide and hydrogen (CH_4, C_2H_6, C_2H_4, C_2H_2, CO, CO_2 and H_2)
- Which gases form depends on
  - temperature at fault location
  - materials in contact with the fault area



Fault types

- PD partial discharge
  T1 thermal fault <300°C
  T2 thermal fault 300-700°C
  T3 thermal fault >700°C
  D1 Low energy discharge (sparking)
  D2 High energy discharge (arching)
- S Stray gassing of oil < 200 °C
  O Overheating < 250 °C
  C Carbonization of paper > 300 °C

Most severe thermal faults when also paper is involved!

Why online monitoring

Why online DGA monitoring?

1. Online monitoring detects faults at their early phase
   → Enables corrective actions before severe transformer failure.
   → Cost reduction in maintenance and repair
   → Avoid consequential costs of catastrophic failures.
2. Enables safe use of a transformer at its end-of-life phase
3. In new transformers, reveals faults originated from manufacturing, transportation or installation
4. Majority internal faults can be detected with online DGA
   - DGA is only online method that can detect various fault types.
5. Following rate of change of gases with online monitoring is more reliable than with laboratory samples. (ref. CIGRE TB409, D1.01 TF 15)
6. Detects faults which might otherwise go unnoticed between regular oil sampling intervals.

Why online DGA monitoring?

- *"On-line monitors are particularly useful for* ***applications where gas formation in electrical equipment must be followed at frequent time intervals*** *(e.g., in strategic or expensive equipment, or where significant faults have already been detected).*

  / Cigre TB409 WG D1.01 (TF 15)

INTERNATIONAL COUNCIL
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Why multi-gas online monitoring

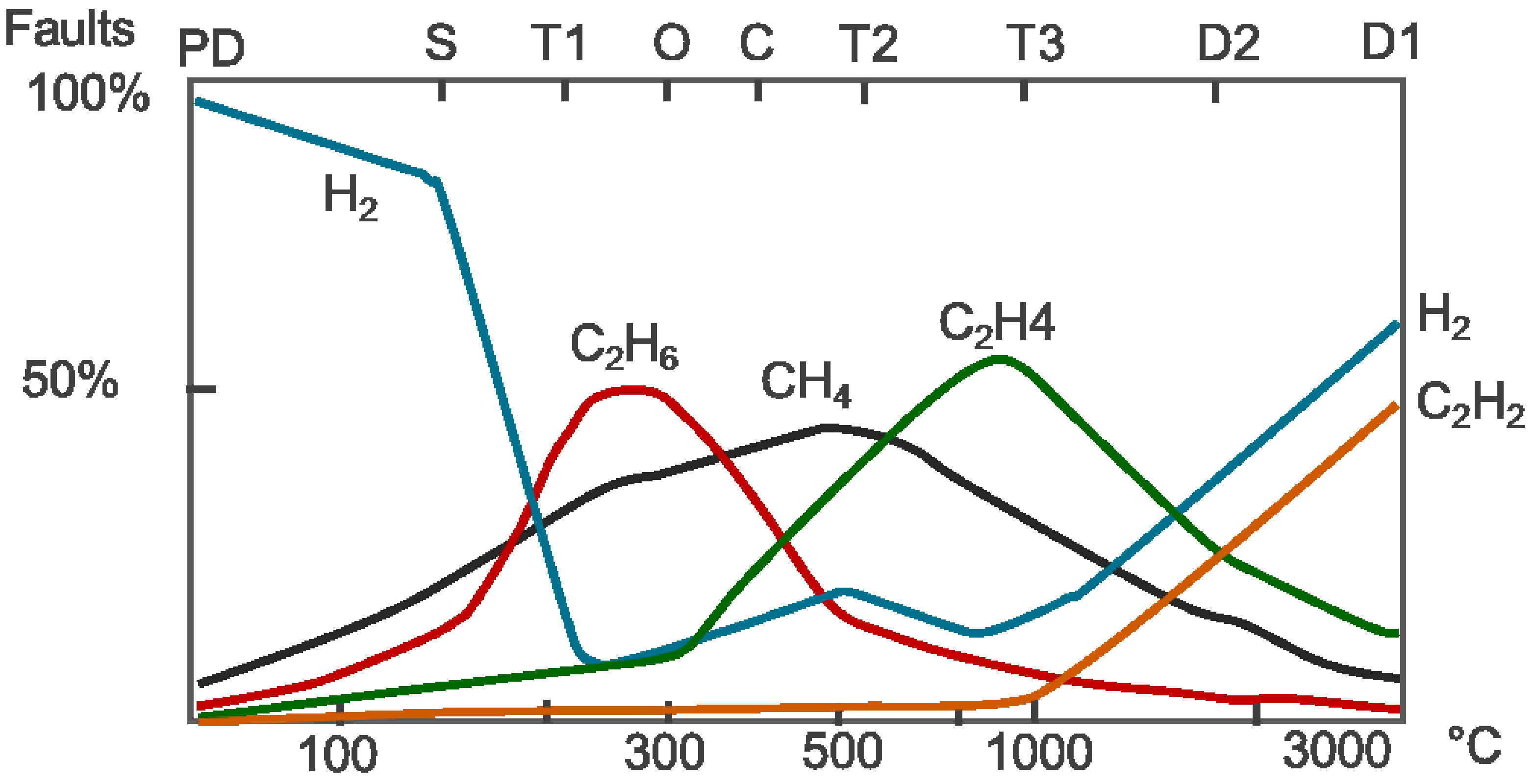
- *“Worldwide experiences using on-line DGA increasingly show that all types of faults − thermal, low-energy discharge, high-energy discharge, and partial discharge − can be identified at an early stage.
Identifying type and severity of a developing fault makes timely decisions possible for critical installations.”*
/IEEE Std C57.143™-2012

Why multi-gas online monitoring

- Often hydrogen monitors are used as early warning devices. However, not all faults produce significant amount of hydrogen.

PD partial discharge, corona type
T1 thermal fault <300°C
T2 thermal fault 300-700°C
T3 thermal fault >700°C
D1 Low energy discharge (sparking)
D2 High energy discharge (arching)

S Stray gassing of oil < 200 °C
O Overheating < 250 °C
C Carbonization of paper > 300 °C

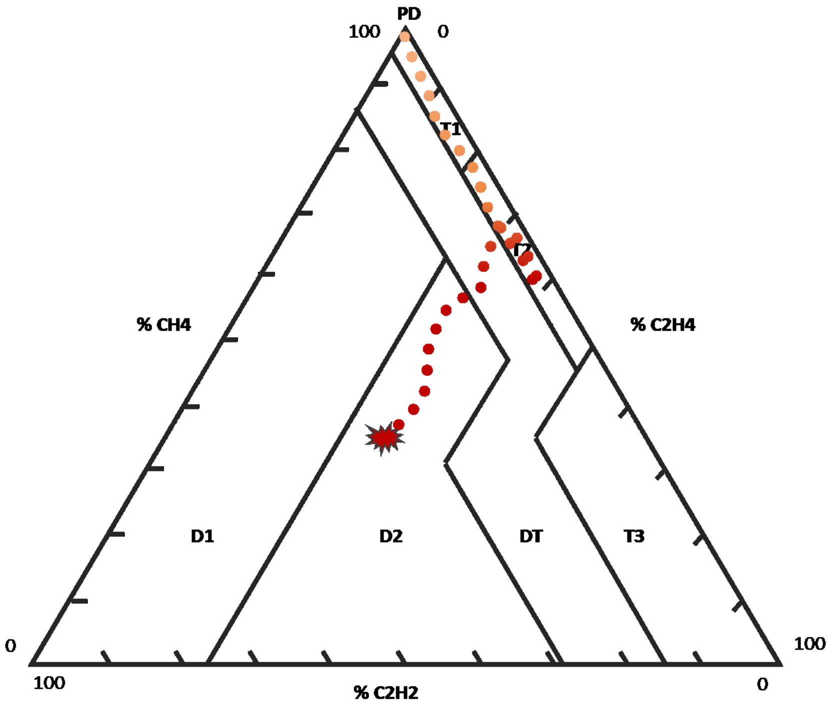


Temperature at fault location

Ref. Dr. Michel Duval

Why multi-gas online monitoring

- Continuous monitoring of key fault gases gives early and immediate notification of developing faults that may lead to transformer failure.
  - Many failures can be prevented through real-time correlation of DGA data to e.g. load and oil/winding temperature.
- Only comprehensive online DGA monitoring can provide information that enables automatic condition assessment.
  - Use of diagnostics tools for rapid warning and diagnosis of developing faults.
- Comprehensive online DGA monitoring recommended for
  - **critical and/or heavily loaded** power transformers
  - **transformers having a gassing pattern.**



Things to consider when choosing a monitor

DGA monitors - what is relevant for the user?

No monitoring of monitors!

No false alarms.

Maintenance needs.

No leaks. Robust design.

Stable long-term measurement for gas trending.

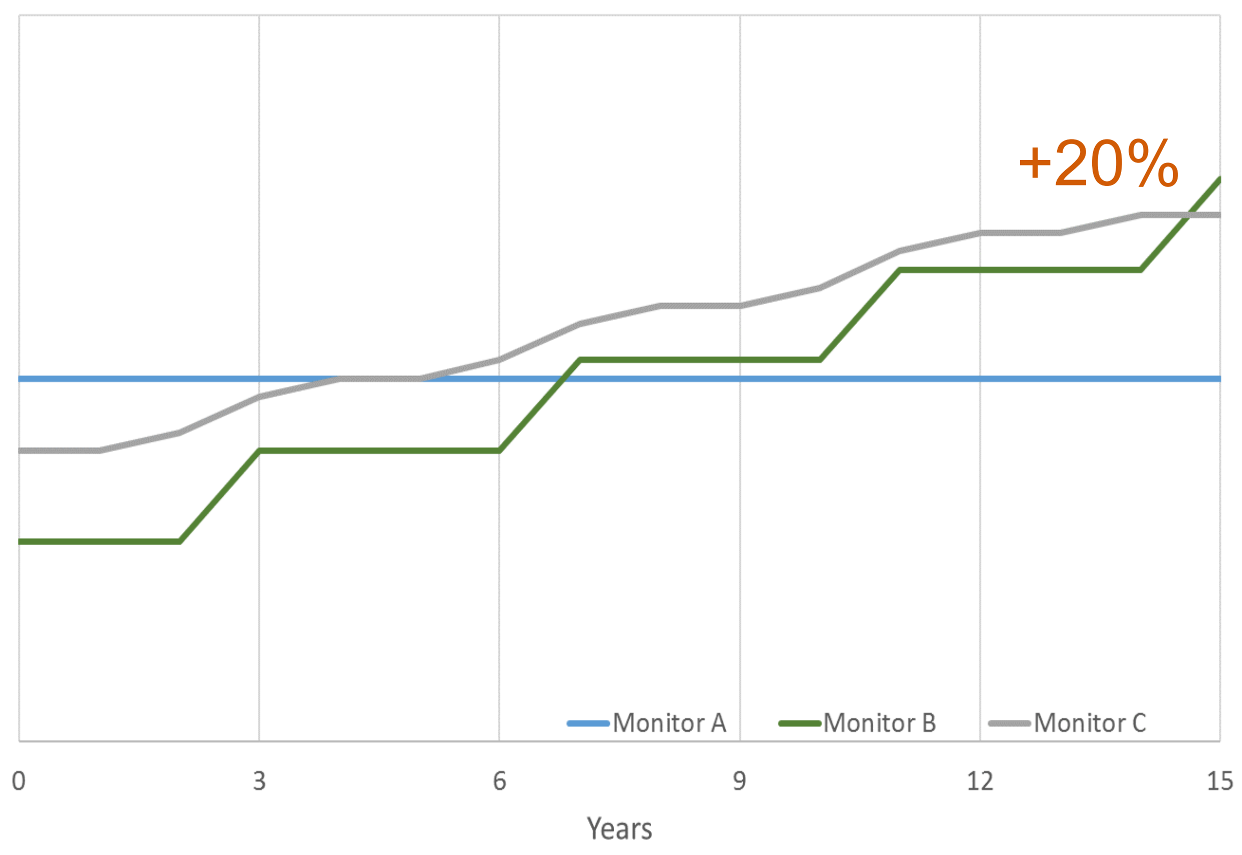
Easy to install.

Tolerates all climate conditions.

Lifetime costs

- Concerning the overall costs of a monitor, it's not only the price of the instrument to be considered, but also the costs associated with the installation and operation in service over its whole lifetime.

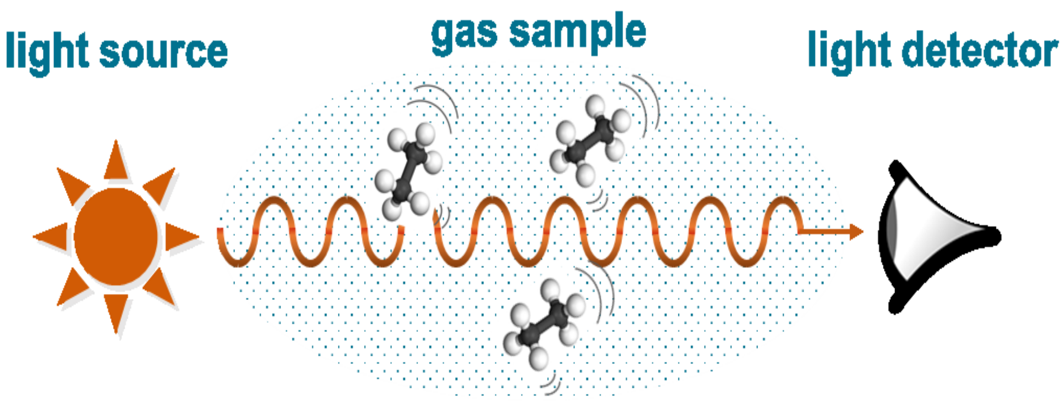
→ **Total cost of ownership**
to be considered when selecting a monitor.



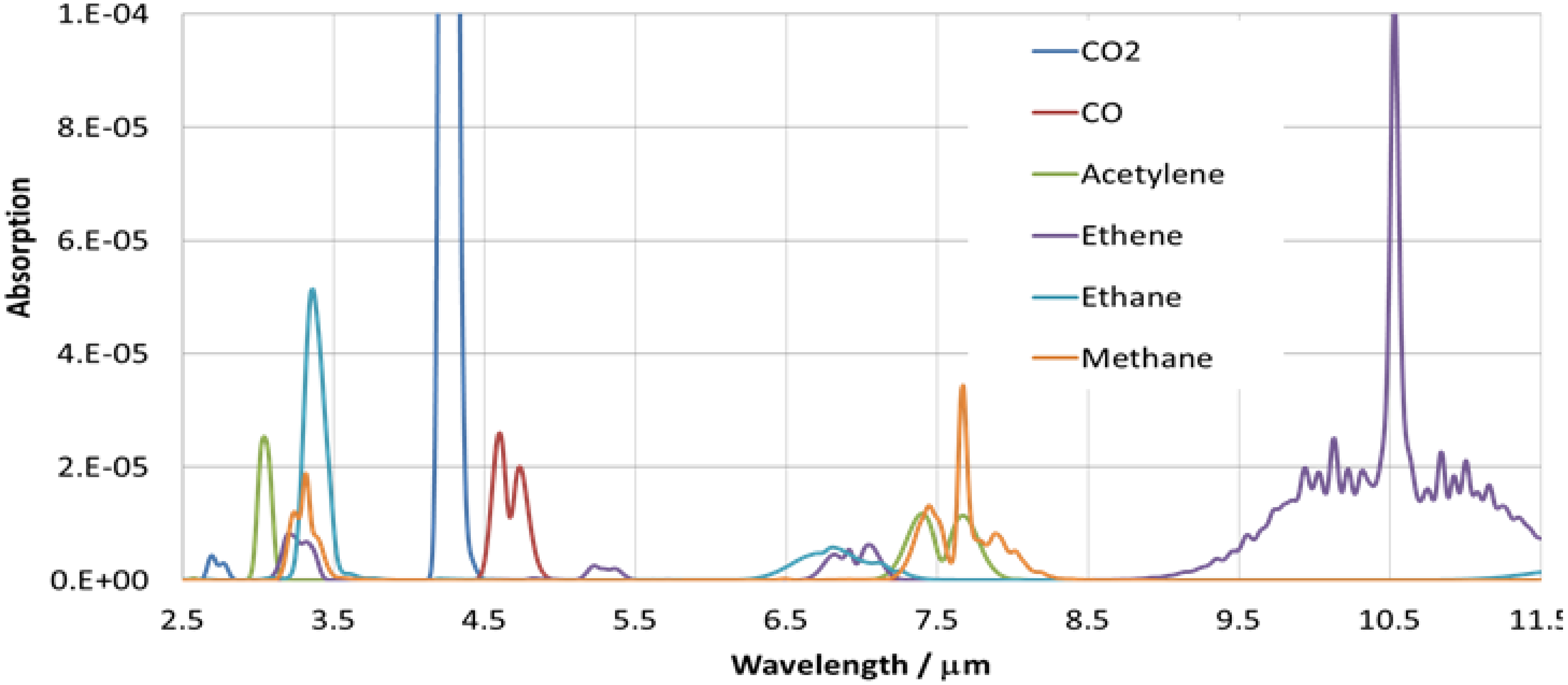
IR technology in online DGA - Vaisala Optimus™ DGA monitor

Infrared absorption (IR)

- IR is a fundamental analysis method, where light is absorbed by gas molecules.
- Gases have a unique absorption fingerprint which is used to identify gases present.
- Absorbed light intensity is proportional to number of gas molecules present in known gas volume.
- Gas specific absorption **wave length does not change over time** enabling long-term calibration free operation.

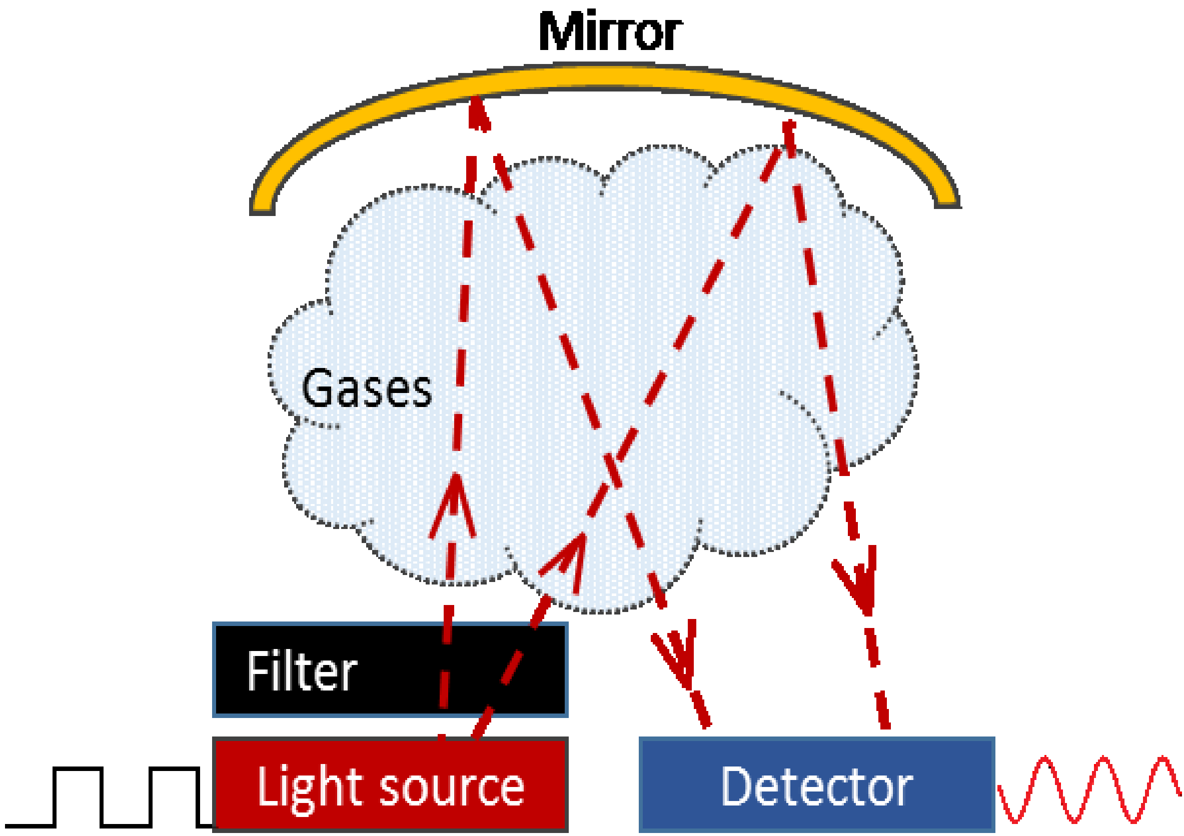


Infrared (IR) absorption by different DGA gases

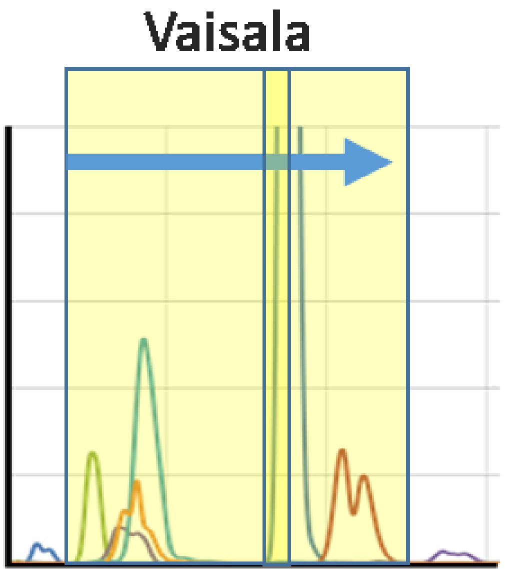


Infrared technology, operating principle

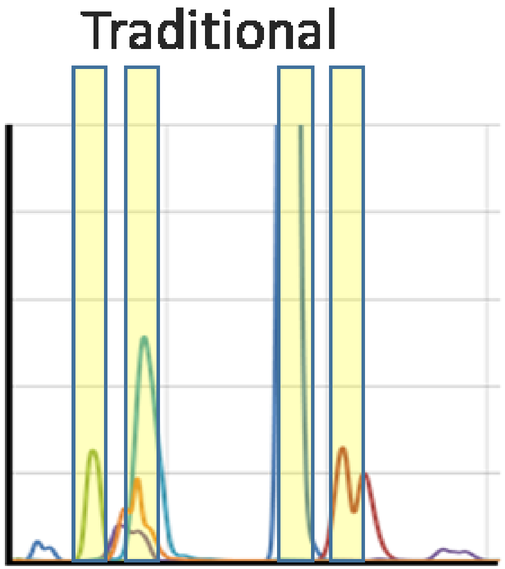
- Gas molecules absorb infrared light when exposed to it.
- More molecules in the gas volume
  → stronger absorption.
- Measured gas can be selected by changing the wavelength of the light with band-pass filters(s).
- IR cannot be used to measure gases like H_2, N_2, O_2



Difference in NDIR Technologies (NDIR = non-dispersive infra red)



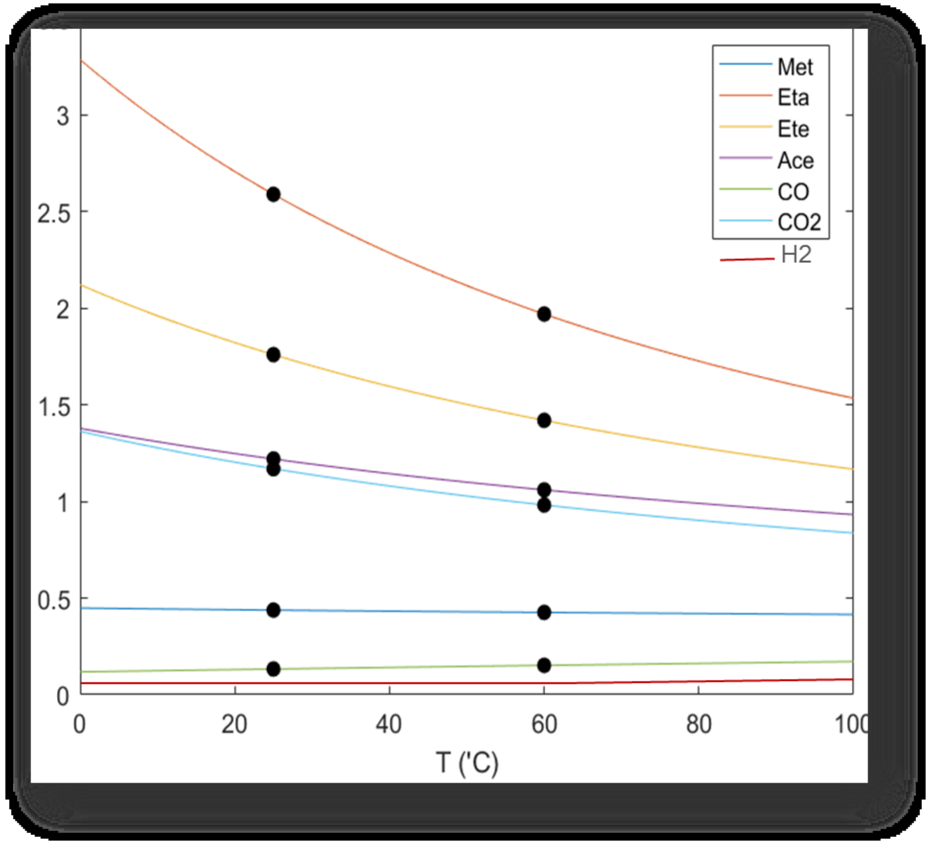
Vaisala CARBOCAP® based tunable filter
- **Wider spectrum enables better gas selectivity**



Fixed filters
- detect only part of the spectrum
- **challenges in cross sensitivity, band drift**

Gas solubility vs gas extraction

- How well a gas dissolves into oil depends on:
  - Oil type
  - Temperature
  - Total gas pressure in oil
  - Gas composition in oil
- Gas solubility in oil is defined as Ostwald.
- Higher value → more difficult to extract the gas from oil.
- Lower value → the easier gas “escapes” from oil sample.
- Affects on gas extraction efficiency.



Gas extraction methods

- Methods to extract gas from oil**
  - Toppler ~100% efficiency
  - Partial vacuum, 90-99% efficiency
  - Head space <30% efficiency
    - Varies by gas type due to Ostwald coefficients and gas to liquid volume ratio
    - Coefficients needed to calculate gas-in-oil concentrations from measured gas-in-gas concentrations
      $\mathbf{C_{oil} = K \times C_{gas}}$

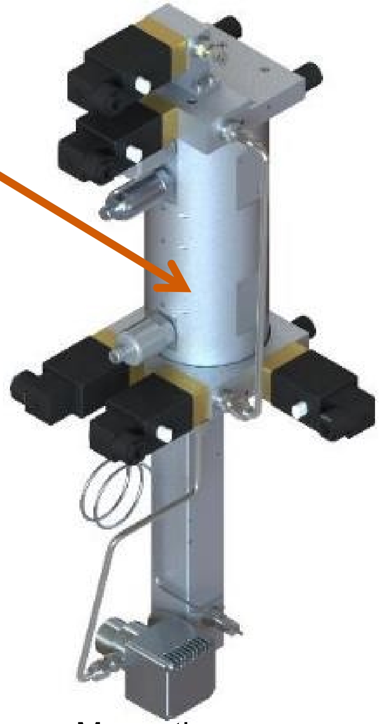
	Naphthenic	**Paraffinic**
Oil density	0.864	0.849
H2	0.074	0.036
O2	0.17	0.18
N2	0.11	0.12
CH4	0.44	0.37
CO	0.12	0.073
CO2	1.02	0.64
C2H2	0.93	0.89
C2H4	1.47	1.27
C2H6	2.09	1.73

IEC60567:2005

**New Techniques for Dissolved Gas-in-Oil Analysis,
IEEE Electrical Insulation Magazine,
March/April 2003 — Vol. 19, No. 2

Partial vacuum gas extraction

- Vaisala's monitor uses unique vacuum extraction of gases.
  - No vacuum pump used, oil column as piston.
  - Magnetic gear pump
- Can extract >95% of the gases in oil.
  - → less dependent on gas gas solubility values



Magnetic gear pump

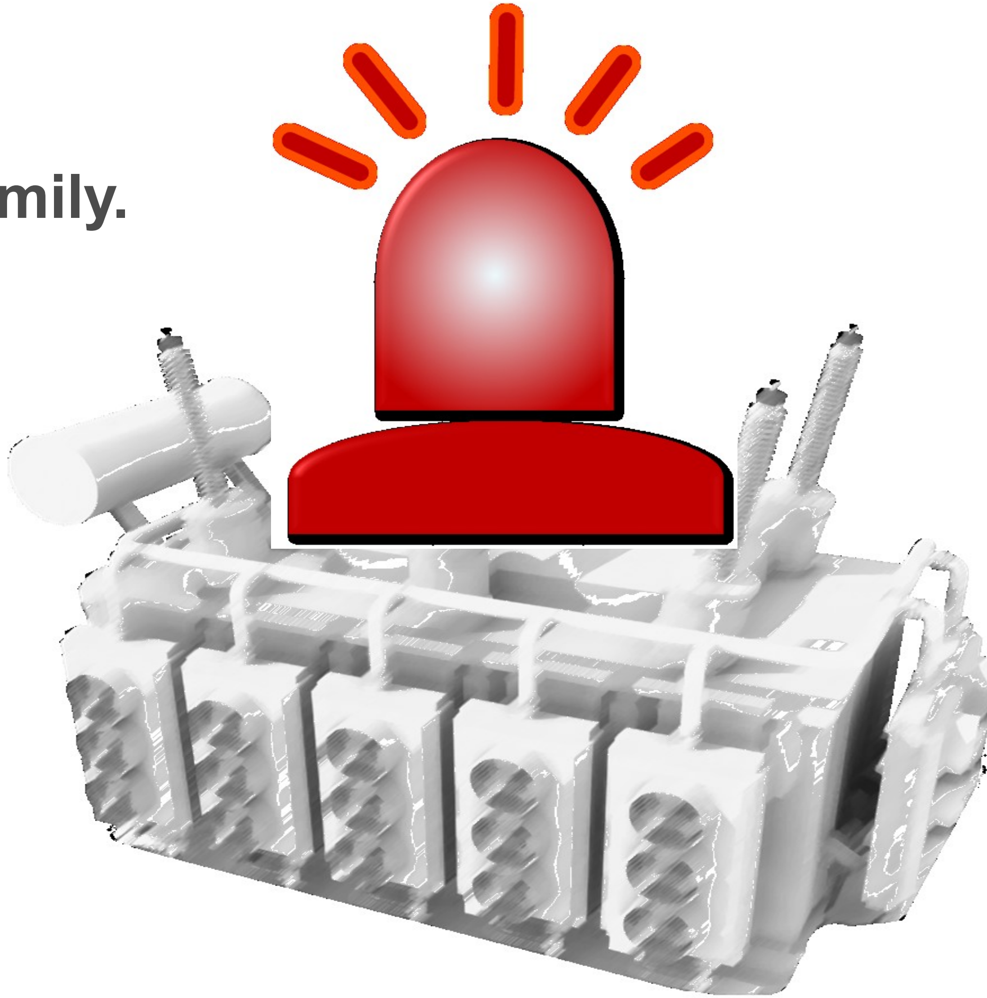
Vaisala solutions to prevent long-term drift

Drift mechanism	Vacuum IR-reference	Tunable filter	Auto-calibration	Optics vacuum clean + temperature	Hermetic Structure
Light source	V				
Filter transmission		V			
Detector	V				
Contamination	V			V	V
Cross-sensitivity		V	V		V

How to define limit values and interpret the data

How to define alarm limits?

1. Comparing to values from standards – If no other reference is available.
2. **Gas trending and gas ratios.**
3. **Using specific typical values per transformer family.**



Comparing values to standards

- Typical gas concentration values (ppm) observed in power transformers. Data collected from about 25 electrical networks worldwide and including more than 20 000 transformers (IEC60599 Ed. 2.1 2007):

	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	3 800 - 14 000
No OLTC	2 - 20						
Communicating OLTC	60 - 280						

- Typical rate of gas increase (ppm/year):

	C_2H_2	H_2	CH_4	C_2H_4	C_2H_6	CO	CO_2
All transformers		35 - 132	10 - 120	32 - 146	5 - 90	260 - 1060	1 700 - 10 000
No OLTC	0 - 4						
Communicating OLTC	21 - 37						

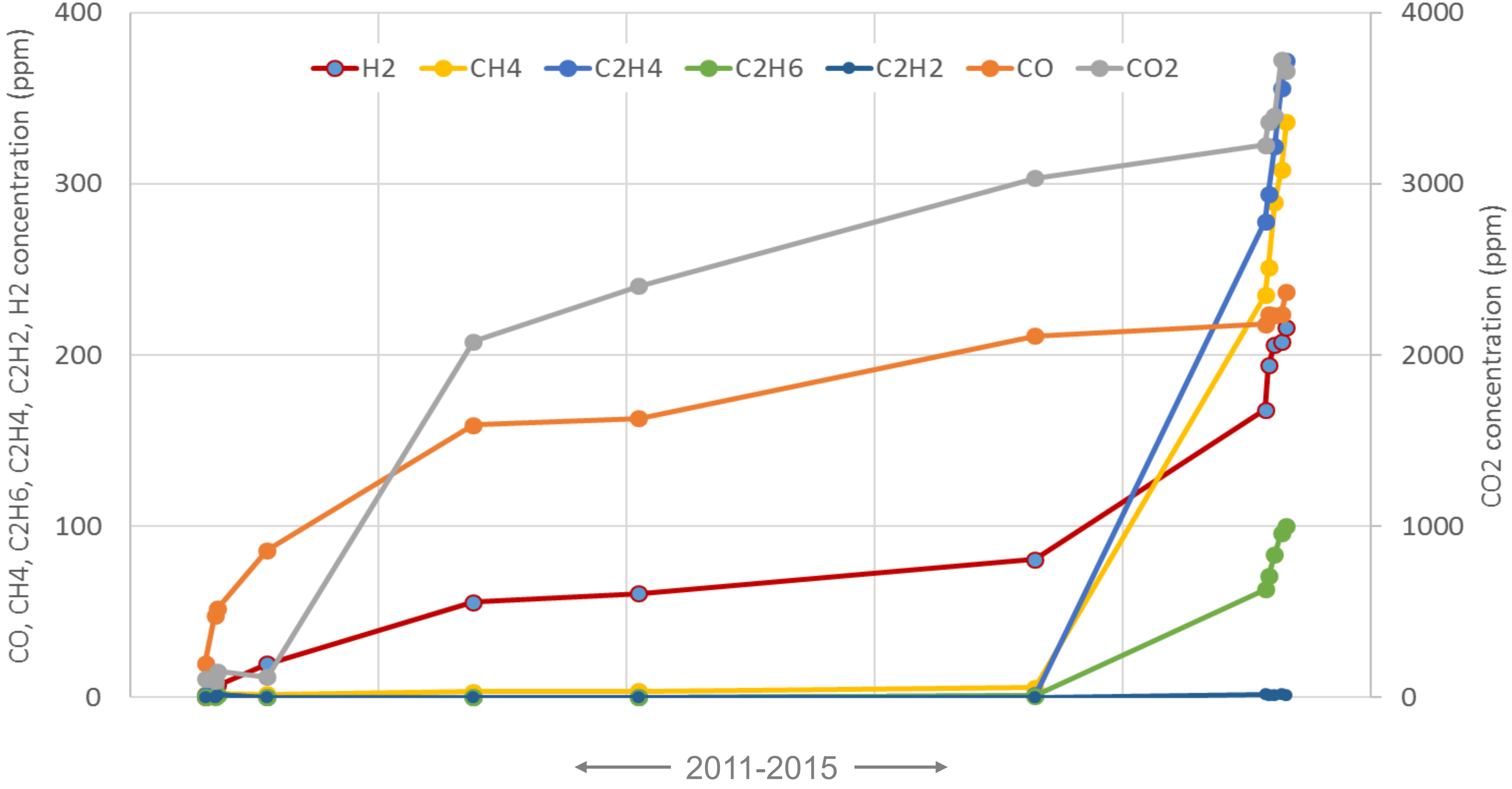
Comparing to values from standards

- Four-Condition DGA Guide (IEEE C57-104)

Status	H_2	CH_4	C_2H_2	C_2H_4
Condition 1	100	120	35	50
Condition 2	101-700	121-400	36-50	51-100
Condition 3	701-1,800	401-1,000	51-80	101-200
Condition 4	>1,800	>1,000	>80	>200

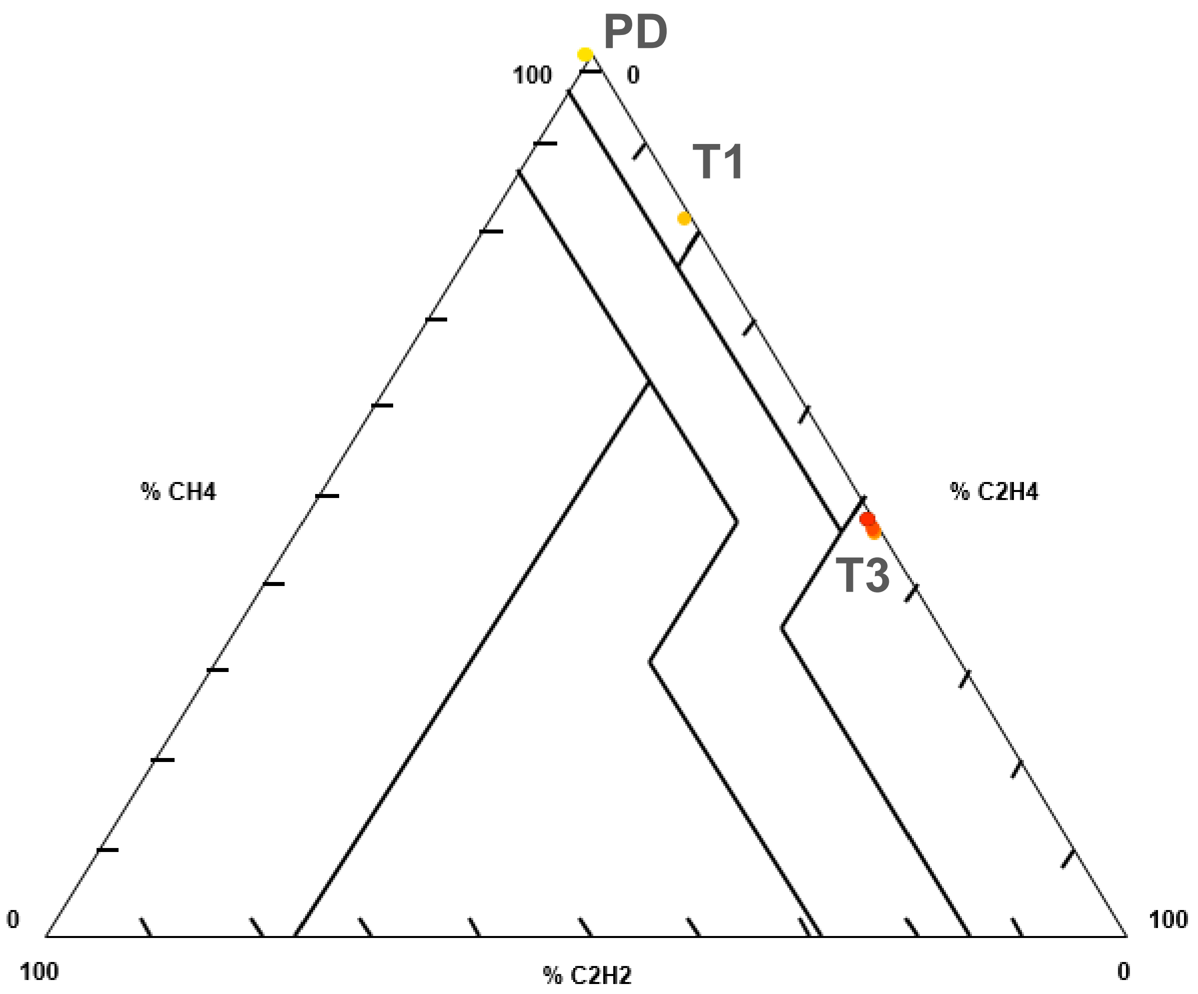
Status	C_2H_6	CO	CO_2[1]	TDCG[2]
Condition 1	65	350	2,500	720
Condition 2	66-100	351-570	2,500-4,000	721-1,920
Condition 3	101-150	571-1,400	4,001-10,000	1,921-4,630
Condition 4	>150	>1,400	>10,000	>4,630

Gas trending

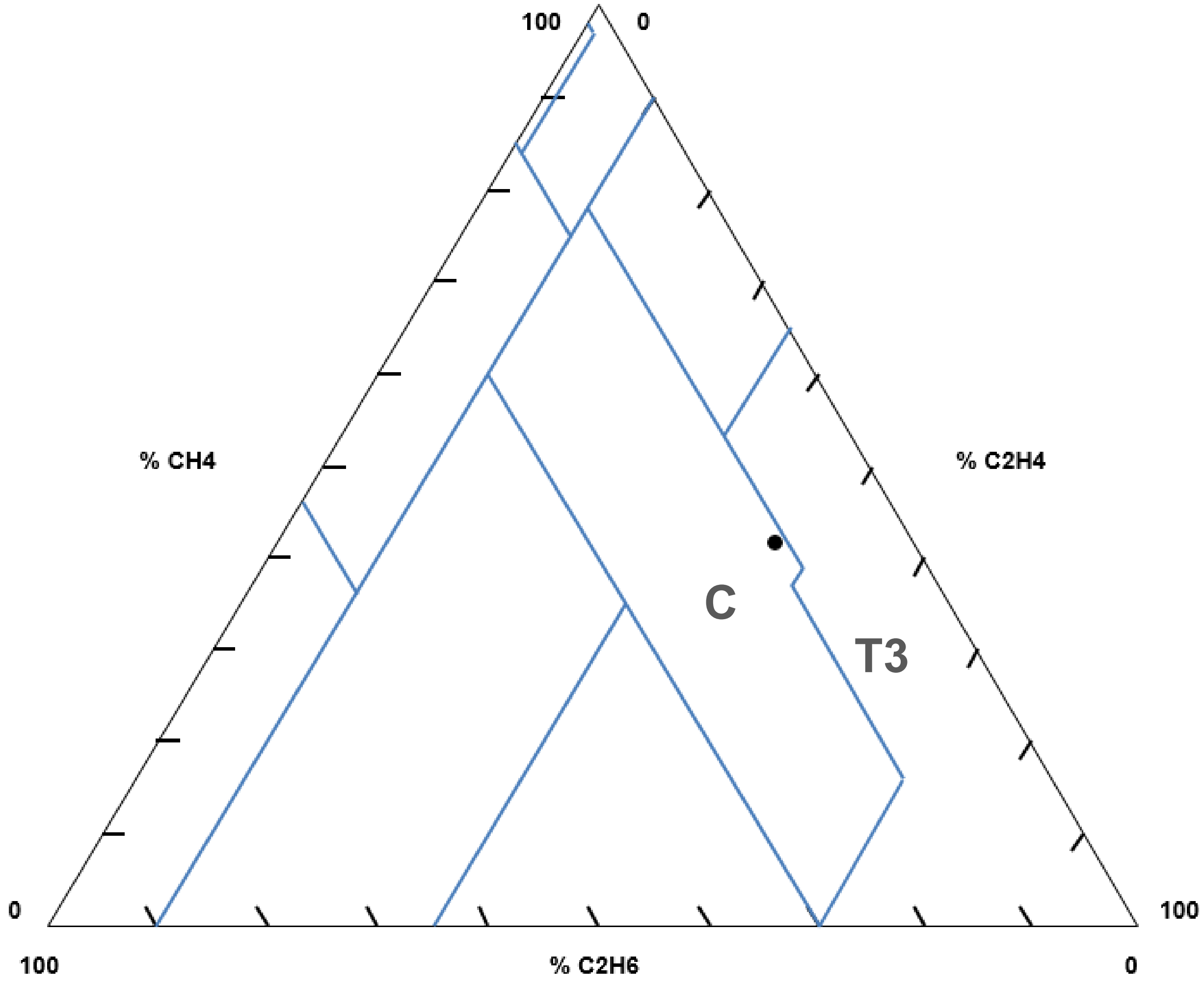


Duval triangles

H2	CO	CO2	CH4	C2H4	C2H6	C2H2
216	237	3657	336	372	100	1.5



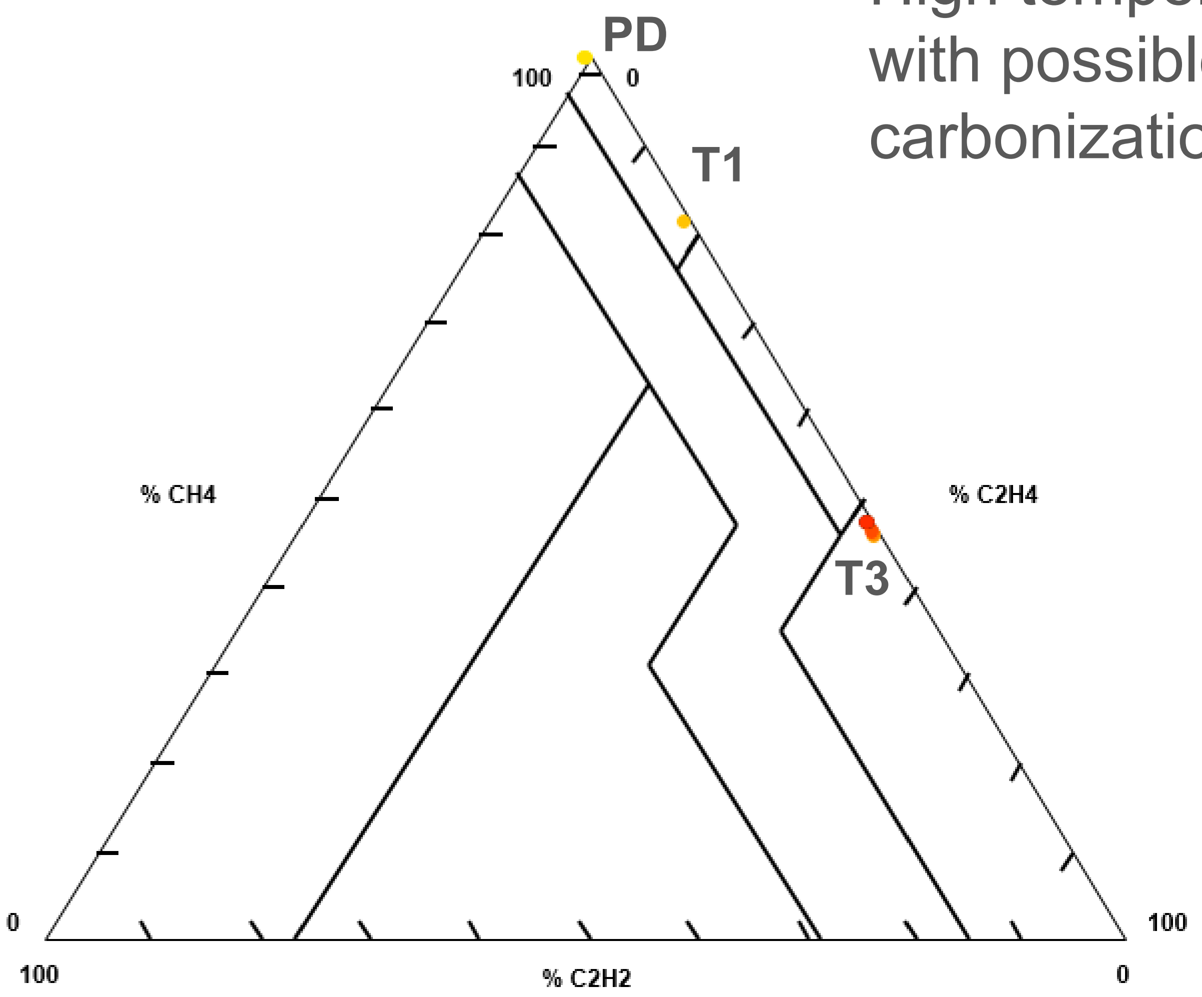
Triangle 1



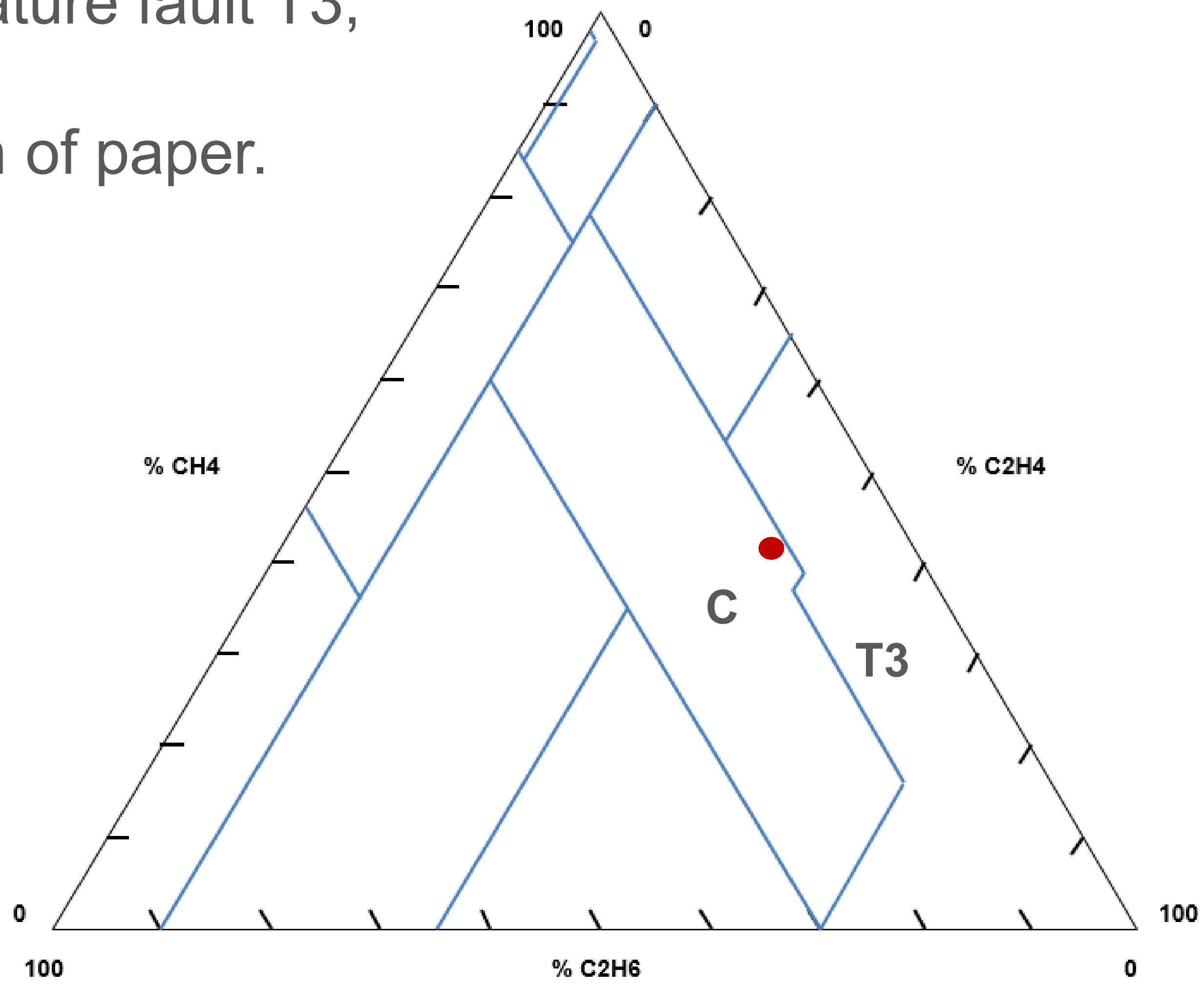
Triangle 5

Duval triangles

High temperature fault T3, with possible carbonization of paper.



Triangle 1



Triangle 5

Ideal prospect for online monitoring!

Using typical values per transformer family

- Using typical values per transformer family/design of utility's own fleet.
  - Comparing gas levels and gas RoC of those transformers.
- Useful especially when transformers of same design have similar loading pattern.
- This is recommended when sufficiently large transformer fleet is available.

Transformer	H2	CO	CO2	CH4	C2H4	C2H6	C2H2
GSU1	23.9	260	1752	16.5	1.8	4.2	0
GSU2	23.3	301	1854	165.5	228.8	97.1	0
GSU3	16.1	357	2316	21.9	8.7	6.1	0
GSU4	28.2	238	1636	18.7	2.5	5.7	0
GSU5	27	499	2845	18.4	2.5	6.1	0
GSU6	42.3	739	3431	19	2.5	4.7	0

Using typical values per transformer family

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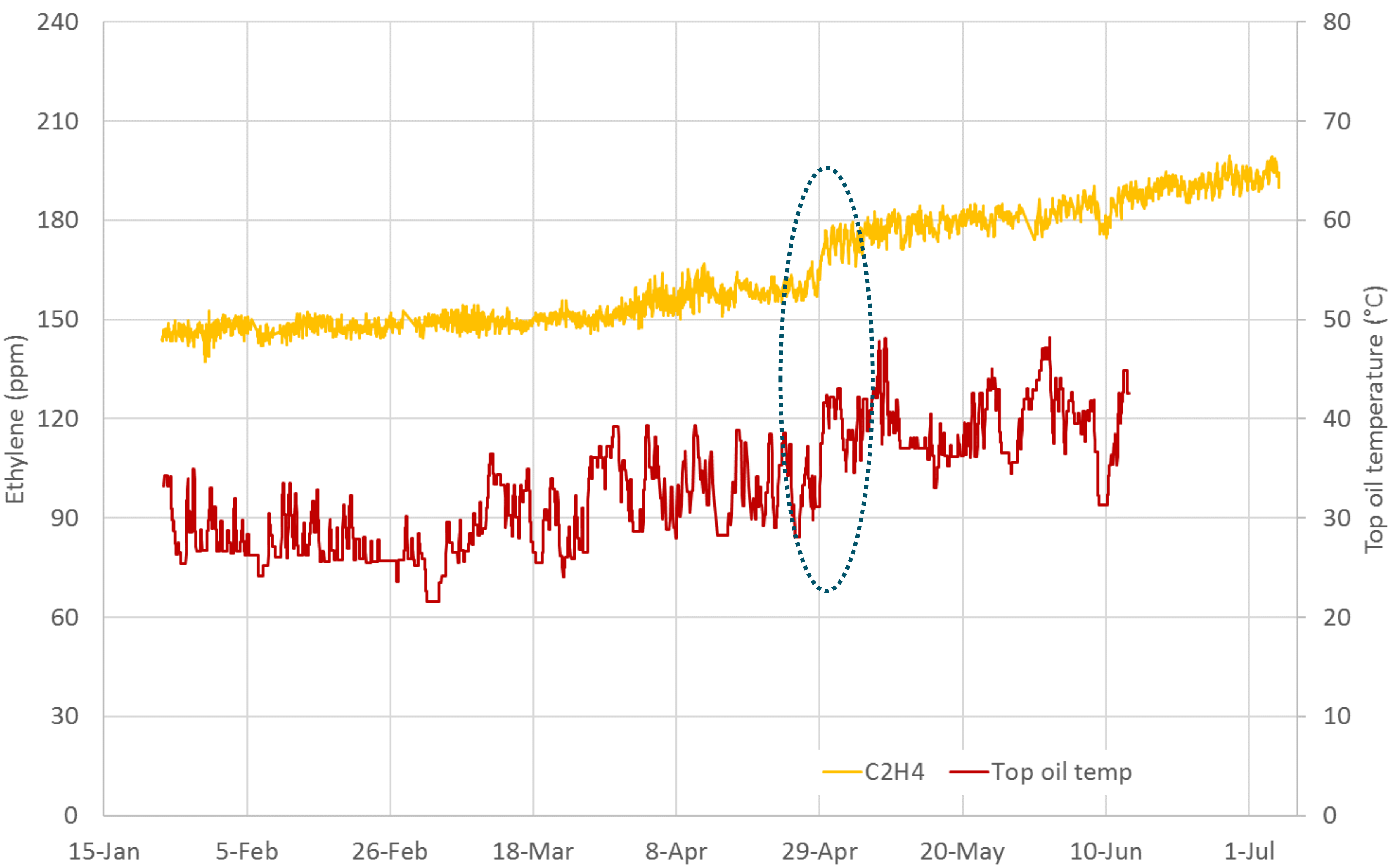
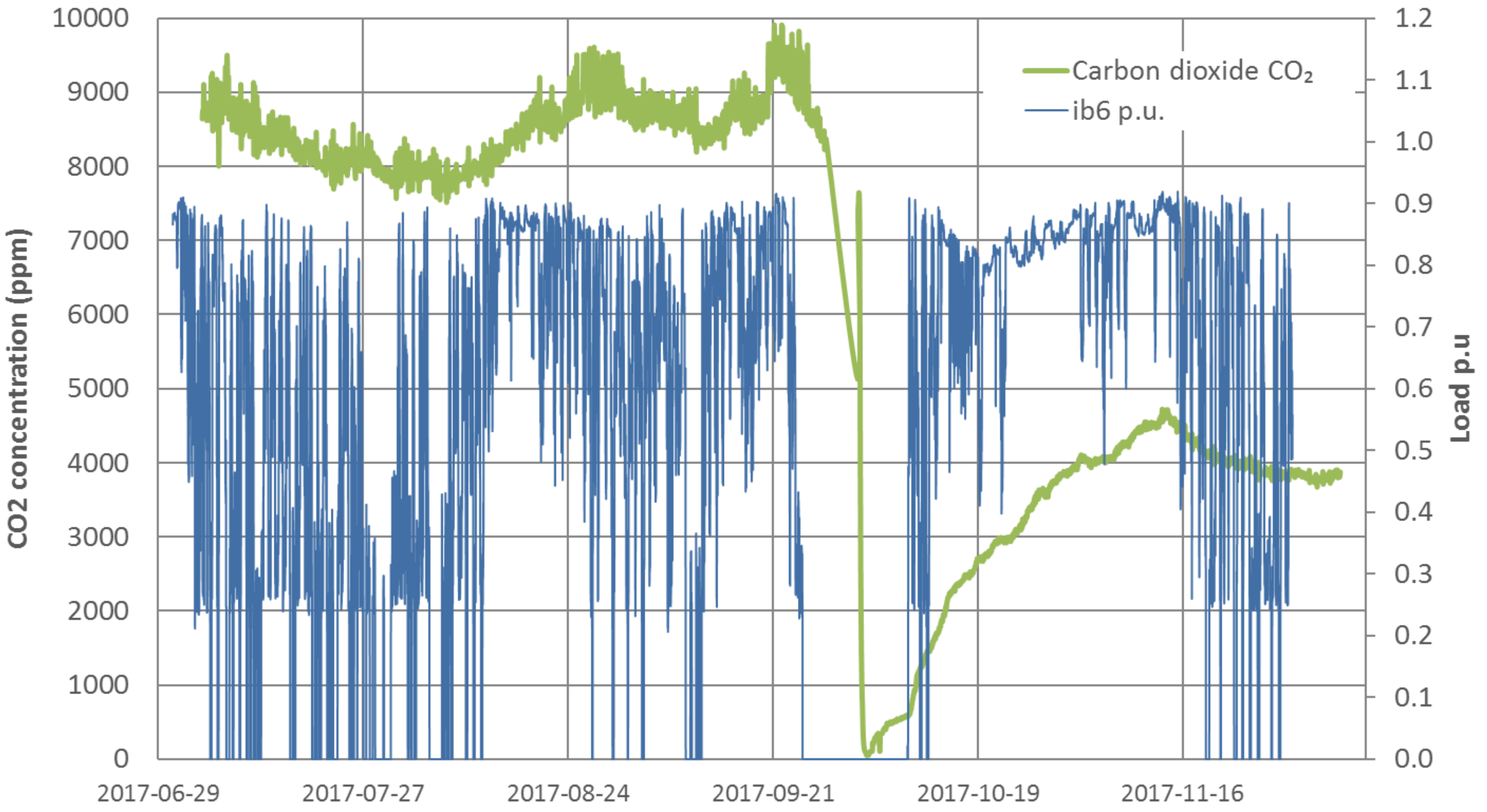
Ideal prospect for online monitoring!

Utilizing online DGA data - examples

Review data against transformer temperature



Review data against transformer loading



Use of information

- If transformer generates gases only during loading peaks or exceptionally high temperature, this information can be used in local loading guidance or as input to more efficient cooling.
- If gas formation does not indicate severe fault, maintenance actions can be scheduled further.
- If gases indicate critical fault (e.g. acetylene) more immediate actions may be needed to avoid catastrophic failure.

How to compare online data and laboratory results

Accuracy considerations

- *"For all methods operating on the* ***headspace principle****, a good knowledge of* ***Ostwald or solubility coefficients K is required at all temperatures of gas extraction****, in order to calculate gas concentrations in oil (monitor readings) from gas concentrations in the gas phase (actually measured by the monitor)"**.

  - ➢ **Vacuum extraction significantly less dependent on K values**.

When comparing gas monitor readings to laboratory results, it should be noted that laboratories may have significant uncertainties as well

- For example the accuracy for a sample with 100 ppm H_2 varied between -29% and +22% within the 16 participating laboratories.*

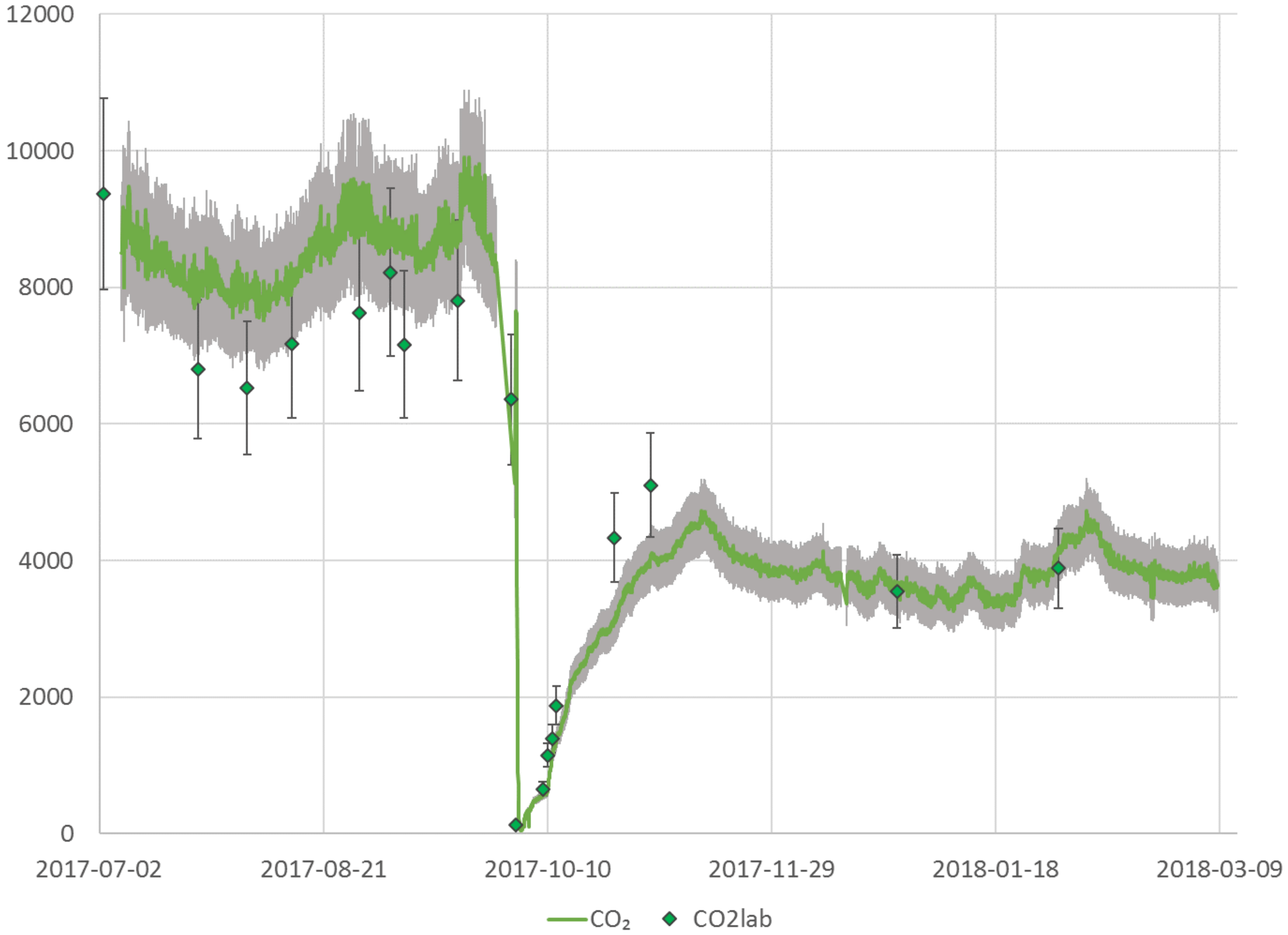
* Cigre TB409, WG D1.01 (TF 15)

Laboratory accuracy, in percentage of the nominal value

Extraction procedure	Medium concentration	Low concentration
Toepler	13	35
Partial degassing	13	30
Stripping	18	23
Headspace	18	37
Mercury-free Toepler	15*	14*
Mercury-free partial degassing	11*	
Shake test	15	44
* Based on a limited number of analyses.		

Ref. IEC 60567 Ed 4.0 2011

- Laboratory points with ±15% uncertainty bars.
- Vaisala OPT100 graph ±10%.
- Laboratory:
  - Located at power plant.
  - Oil analysis within hours.
  - Lab technician takes oil samples.



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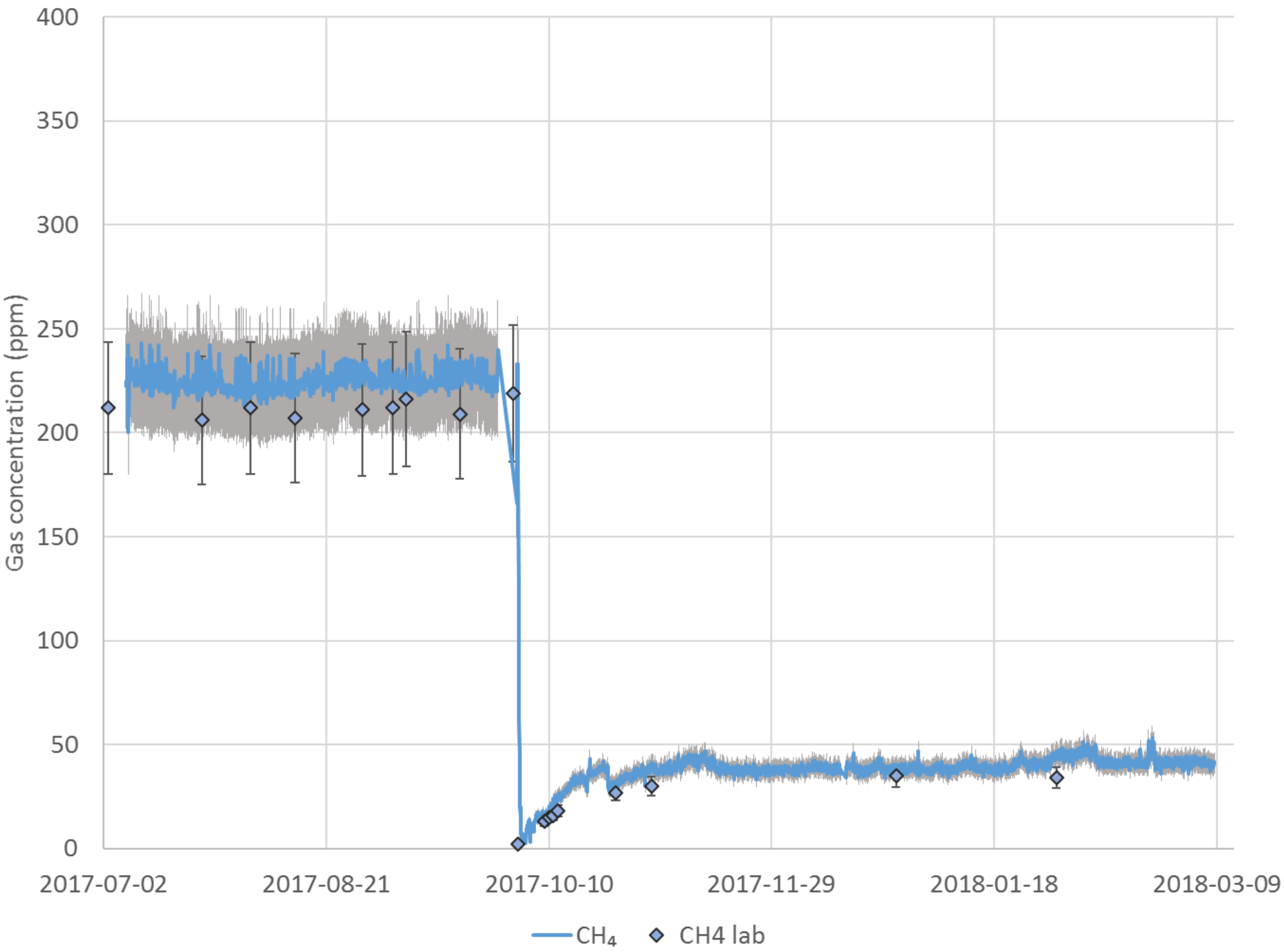

Thank you for joining the webinar.