DGA Monitoring – Technologies and Success Factors

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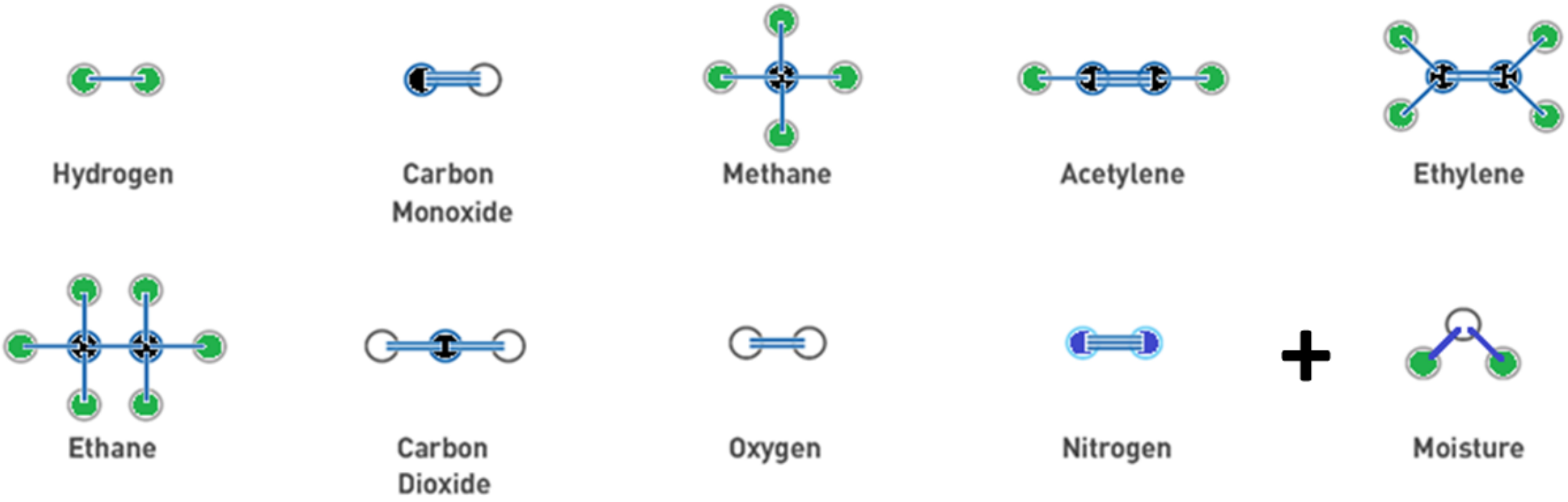
Dissolved Gas Analysis (DGA)



The most powerful tool available for understanding the health of an operating transformer

Online DGA Benefits

- Find faults earlier → reduce repair costs
- Keep gassing units in service
- Deliver peak capacity with confidence
- Oversee health of fleet in real time → prioritize maintenance

DGA Monitor Performance

Sub-systems work together to determine data quality, reliability and cost of ownership:

- Gas measurement system(s)
- Autocalibration system (if present)
- Gas extraction system
- Thermal regulation of oil and measurements
- Oil circulation
- Gas circulation
- Gas and moisture solubility coefficients

One and Two Gas Monitors

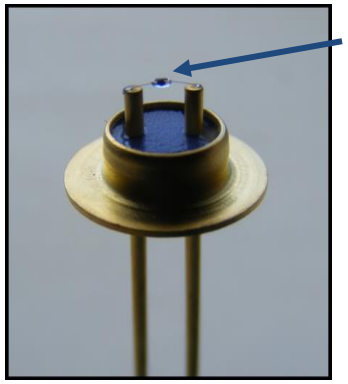
Purpose: Fault detection

- H2 for faults affecting the oil
- CO for faults affecting the cellulose

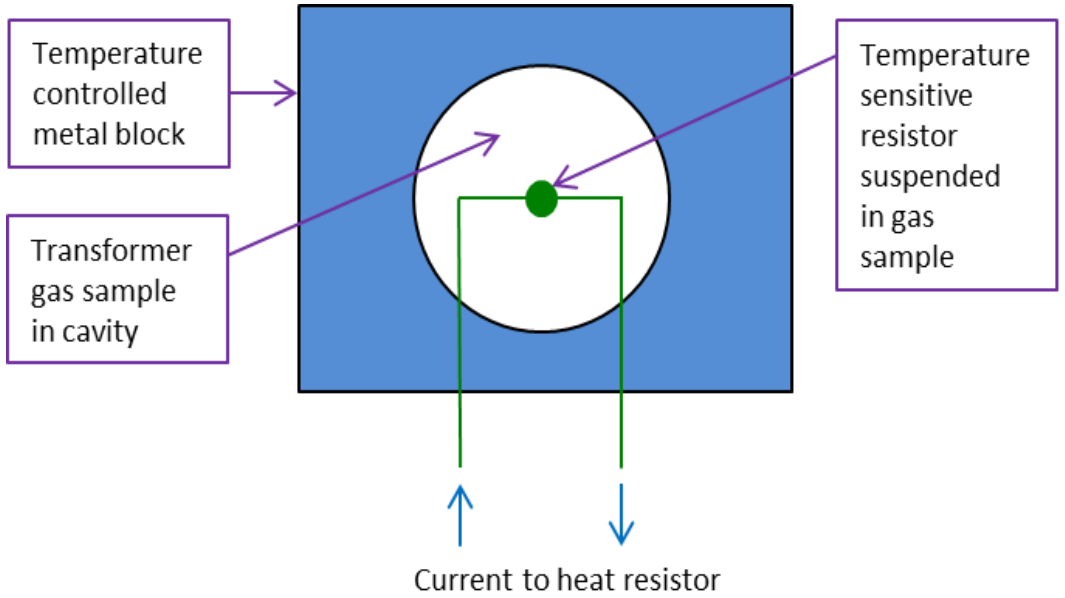
Gas measurement technologies:

- Electrochemical gel (combined gas reading H2+CO+C2H2+…)
- Tin-oxide sensor (individual gases H2, CO)
- Thermal conductivity (TCD) (individual gases H2, CO)
- H2-variable metal-film resistor (H2)

Thermal Conductivity Detector (TCD)



Glass bead thermistor

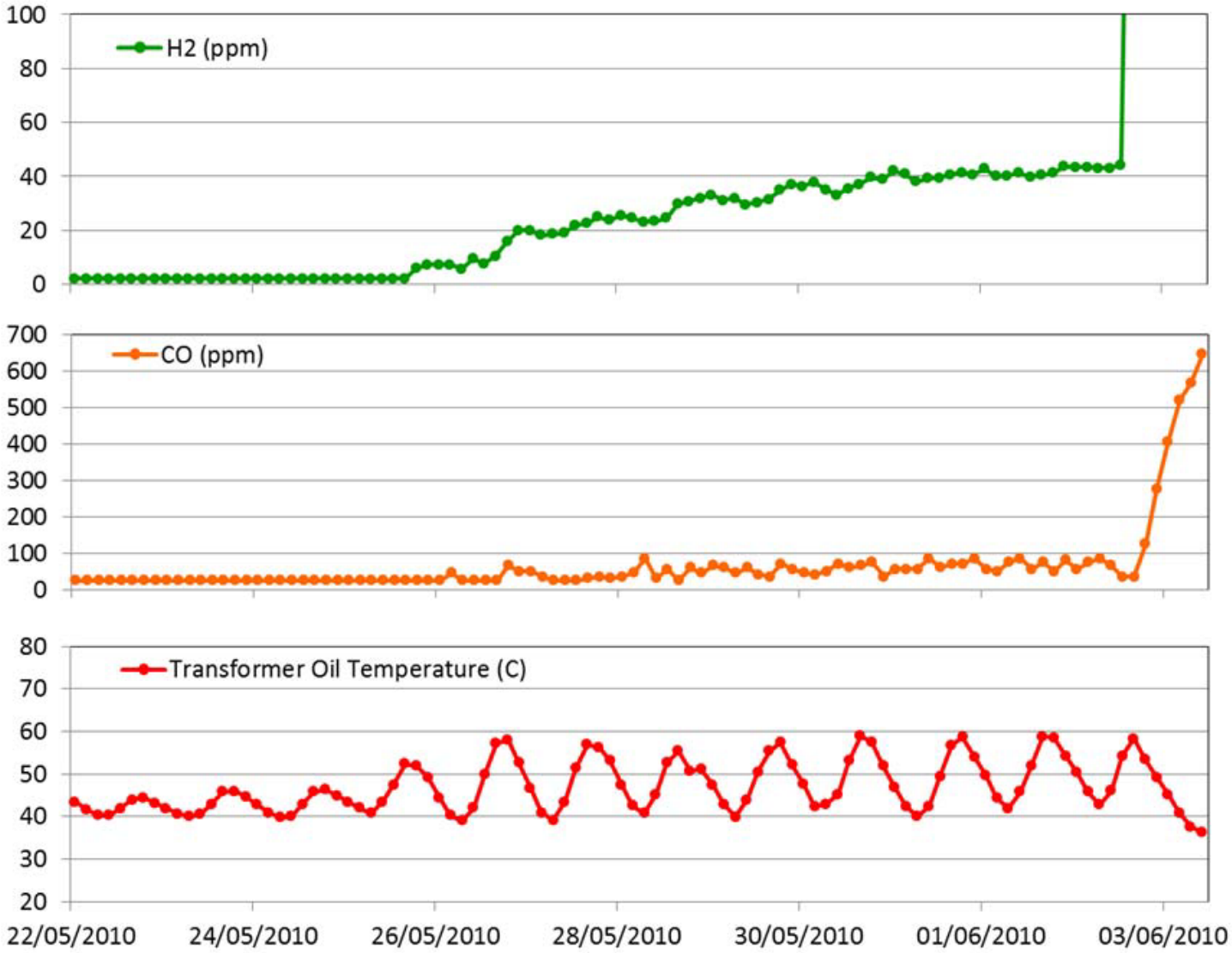


- Best performance for early fault detection
- Most sensitive:

  Limit of detection = 2 ppm H2
- Most stable: over many years
- Most accurate: ±5% H2

TCD Monitor Example

- Late May in Texas
- Daily peak load increasing
- Fault affecting oil (H2) and paper (CO)
- Alarm levels set too high (!)
- Catastrophic failure
- Best way to set gas alarm limits → based on historic gas levels in that transformer



Critical Performance Specifications

Lower Detection Limit (Sensitivity):

- Early fault detection

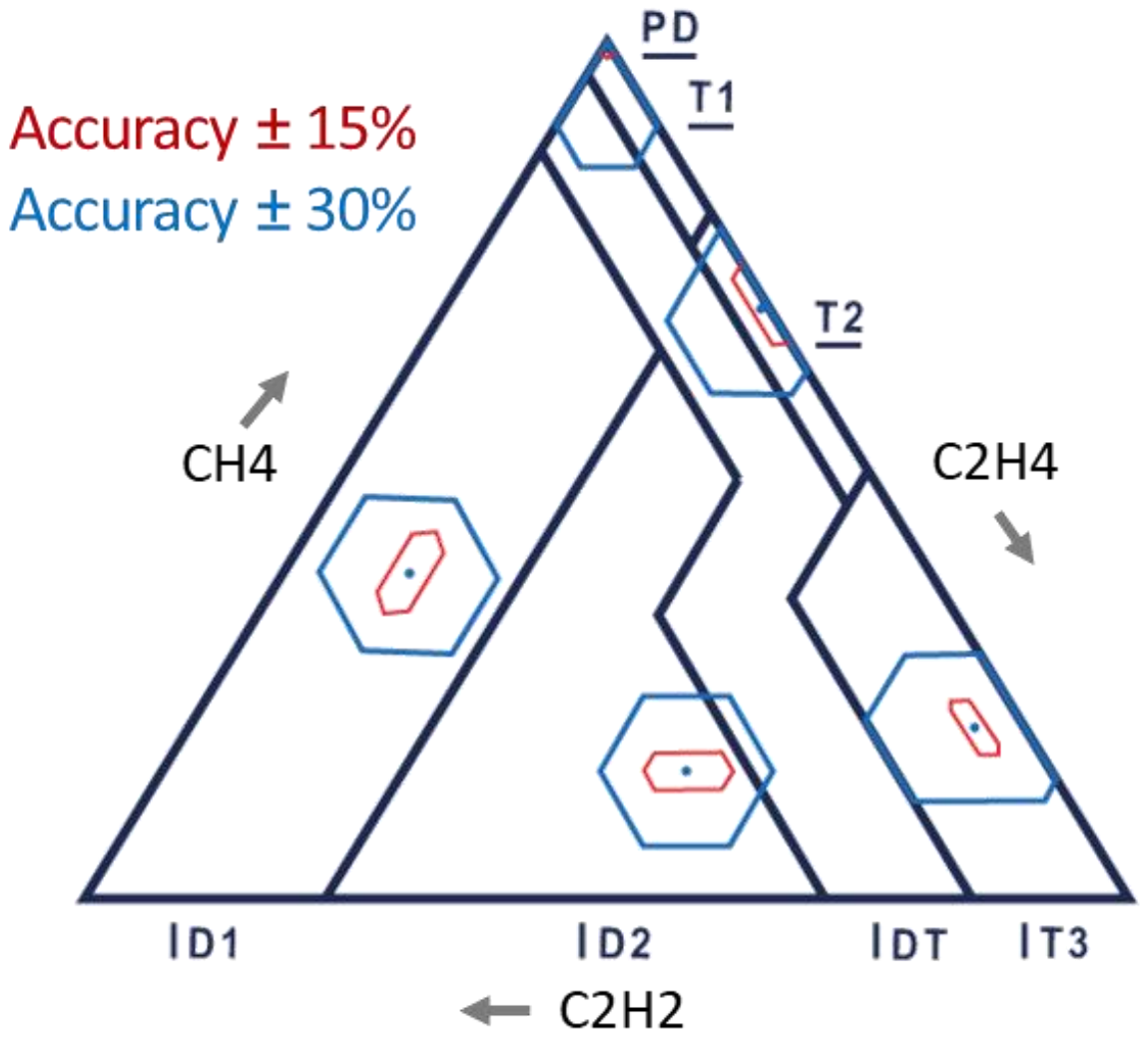
Accuracy in service:

- Agreement with a good DGA lab → understand fault type and severity
- If a monitor consistently agrees closely with the DGA lab, it will also allow early fault detection
- Avoid false alarms

Duval Triangle

When an area of uncertainty crosses several fault zones in the triangle →
Fault type and severity is unknown

Ref: M. Duval
IEEE EI Magazine
August 2005



Multi-gas Monitor Technologies

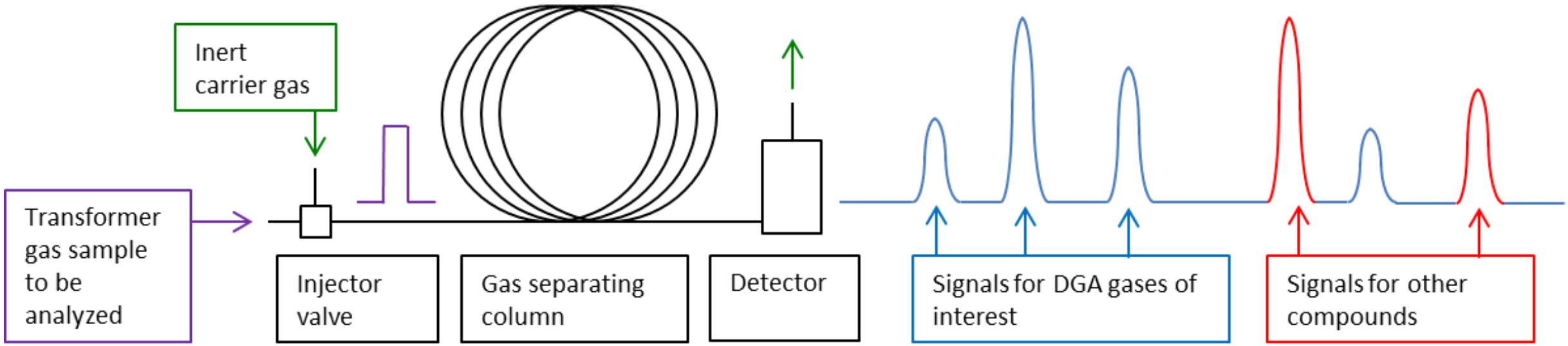
Gas chromatography (GC)

- 2 columns with thermal conductivity detectors
- 1 column with ionization detector

Infrared absorption spectroscopy (IR)

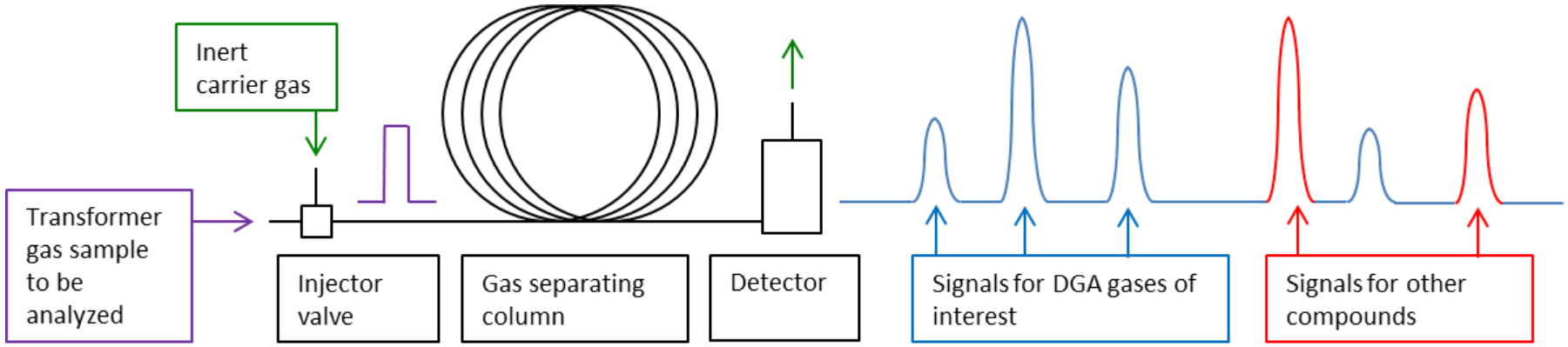
- Photo-Acoustic (PAS)
  - Resonant
  - Non-resonant
- Non-dispersive IR (NDIR)
  - Fixed filters
  - Scanning filters
- Fourier Transform (FTIR)

Gas Chromatography



- The small sample of mixed gas is propelled through a gas separating column by a carrier gas (helium)
- Each separated gas species reaches the detector at a different time
- A calibration gas run is used to identify and quantify each component gas

Gas Chromatography



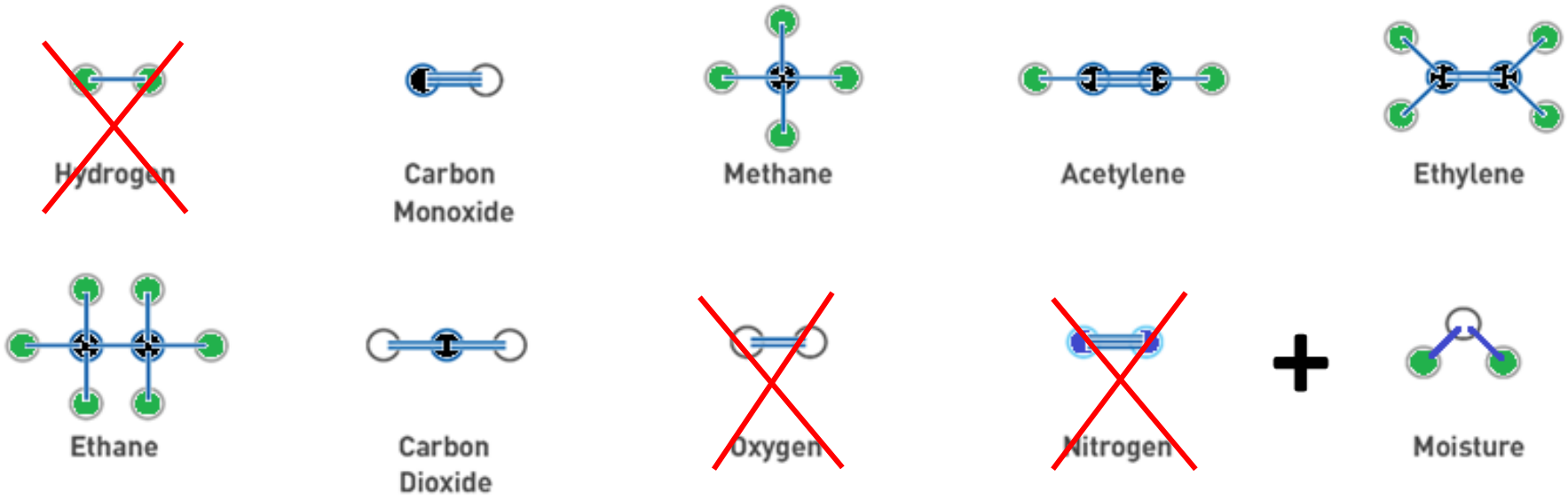
PROS

- Most sensitive
- Most accurate (like DGA lab) due to automatic calibration
- Readings not affected by interference gases

CONS

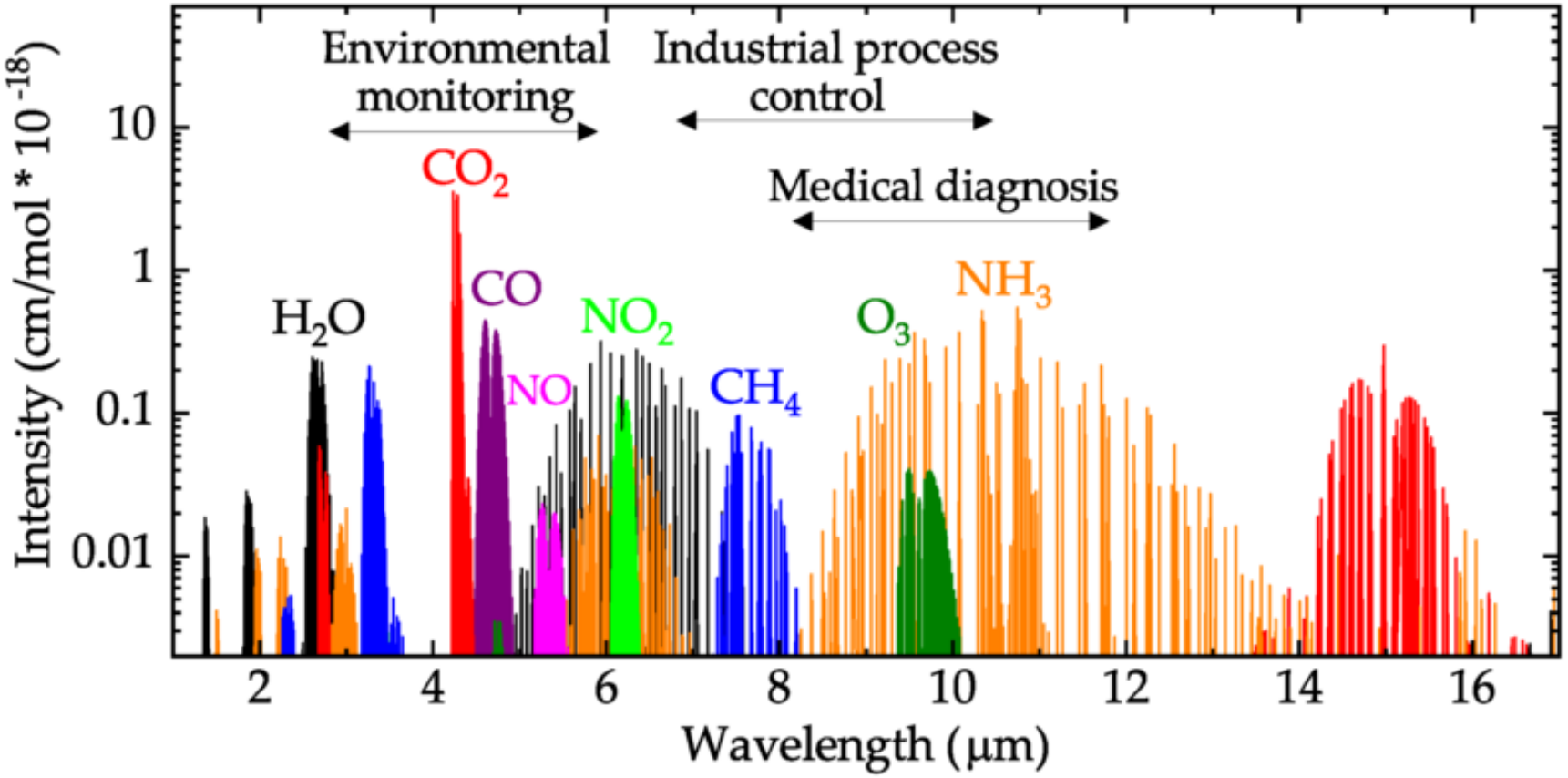
- Time and cost to replace consumables (carrier gas and calibration gas cylinders)
- Some models need major overhaul after 4-5 years

Infra-red Gas Measurements



- Each gas compound has characteristic vibrational modes
- IR light can be strongly absorbed if the frequency matches one of those vibrational modes
- Light absorption can be detected by:
  - attenuation → NDIR, FTIR
  - gas heating → PAS
- Symmetric dipole molecules (H2, O2, N2) don't significantly absorb IR light

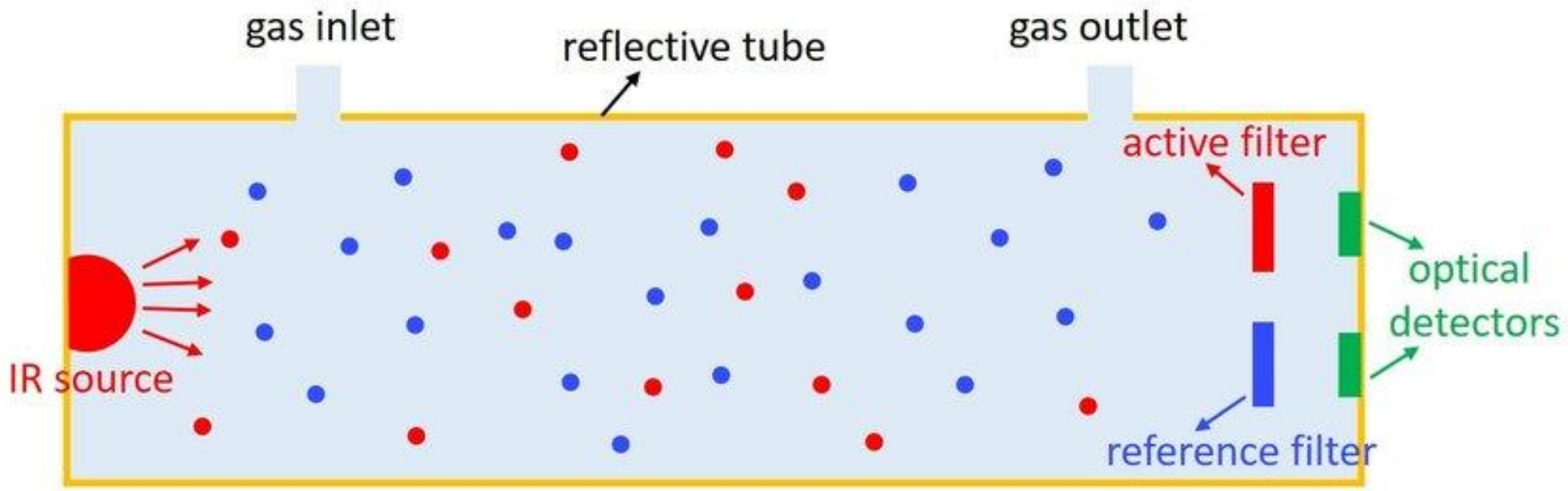
IR Absorption Spectra of Gases



Popa, Daniel; Udrea, Florin "Towards Integrated Mid-Infrared Gas Sensors". Sensors. 19 3 (9): 2076, May 2019

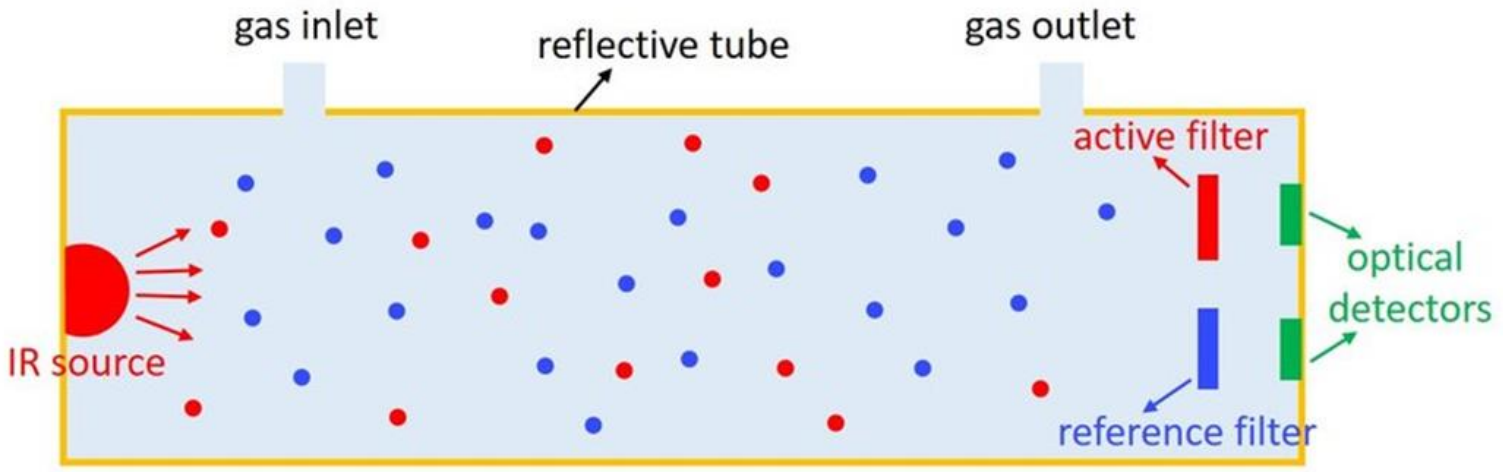
- Challenge of multi-gas IR → gas absorption spectra overlap
- Need software to untangle measurements taken at different wavelengths

Non-Dispersive IR Spectroscopy



- Gas absorbs IR light from the source, reducing the intensity that reaches optical detectors
- Mirrors can be used to increase the optical length between source and detectors
- IR filters used to primarily excite one gas at a time
- Scanning or fixed filters

Non-Dispersive IR Spectroscopy



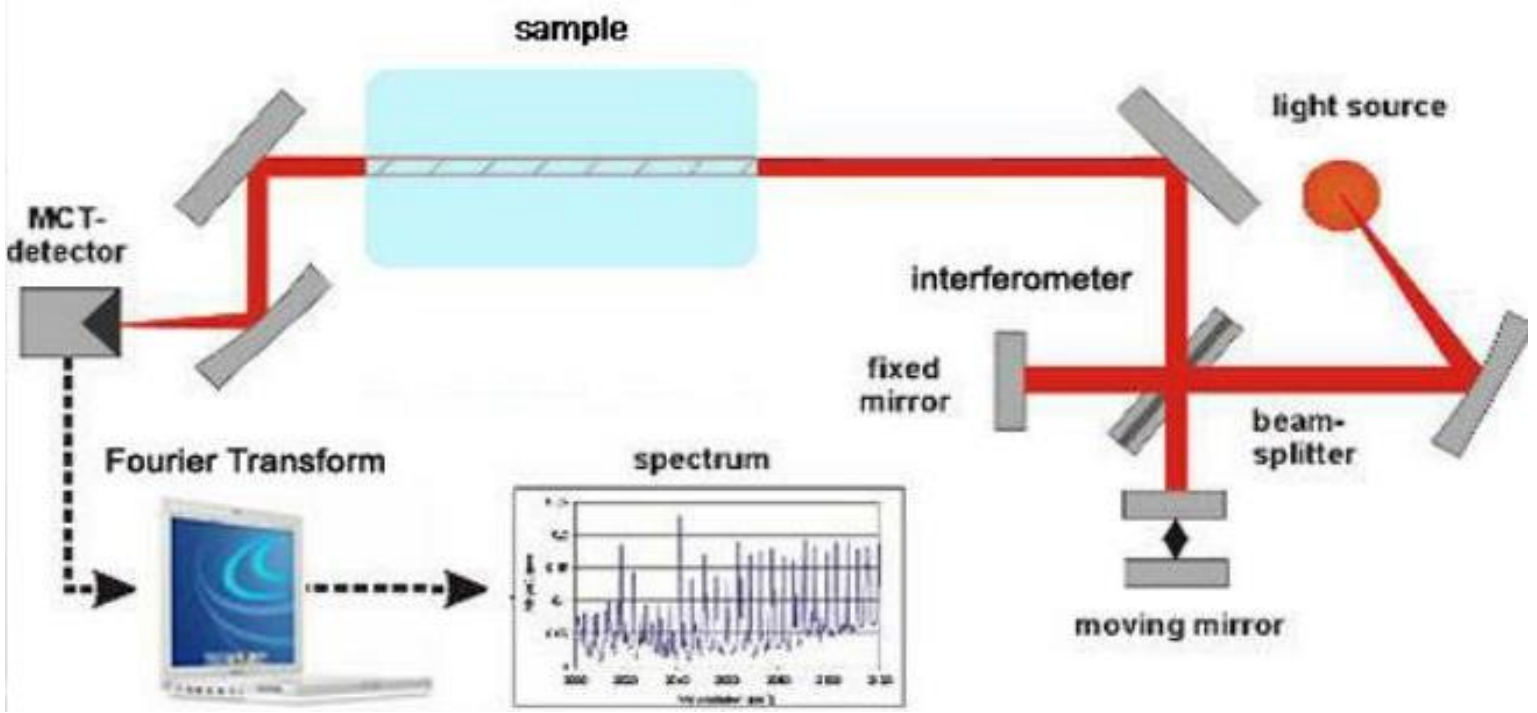
PROS

- Can be quite simple and economical

CONS

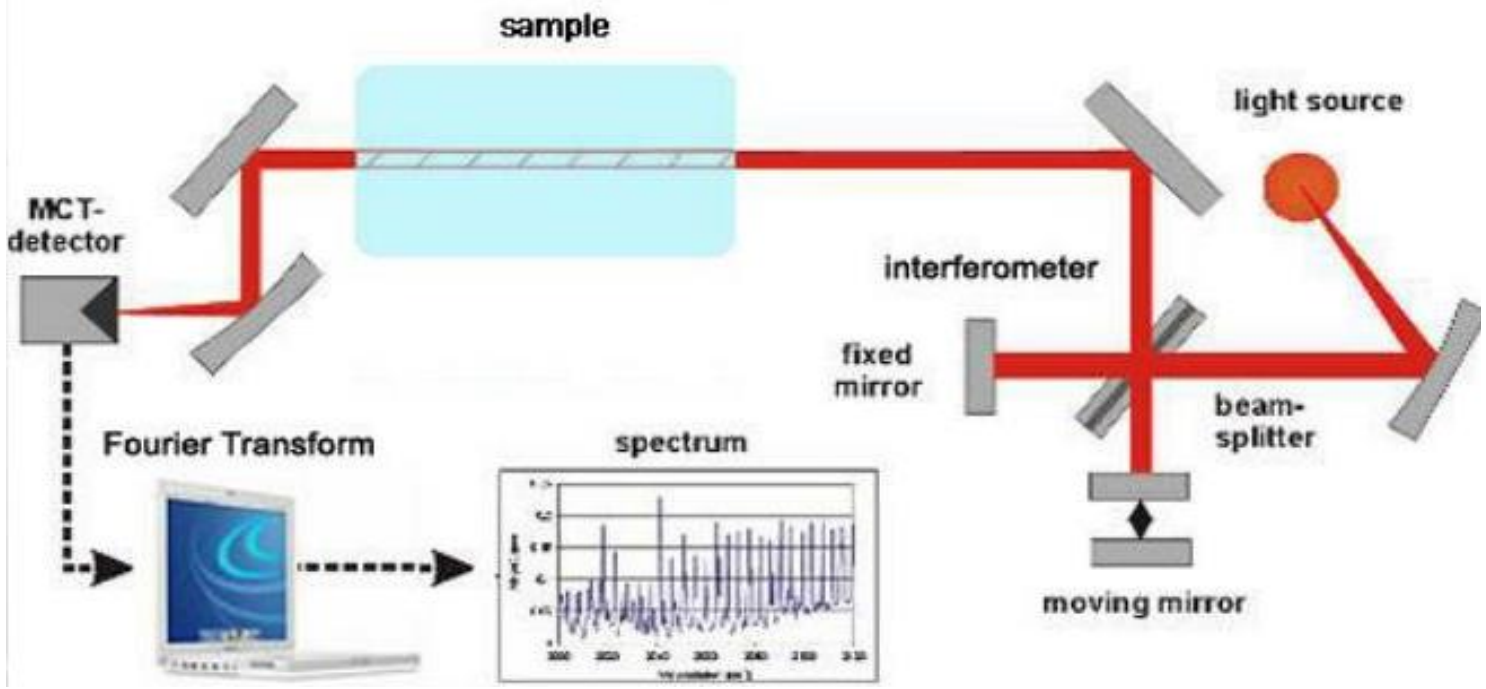
- Tends to be less sensitive
- Accuracy compromised when interfering gases are present
- Some models loose accuracy over time (drift)

Fourier Transform IR Spectroscopy



- Light from a filament lamp is passed through an interferometer, creating an “interference beam” containing a series of wavelengths (harmonics)
- The interference beam is passed through the gas sample and focused on a cooled optical detector
- The detector signal is recorded as the interferometer is mechanically scanned to create a variety of interference beams (with different wavelength harmonics)
- A Fourier Transform calculation reconstructs the IR absorption spectrum of the gas

Fourier Transform IR Spectroscopy



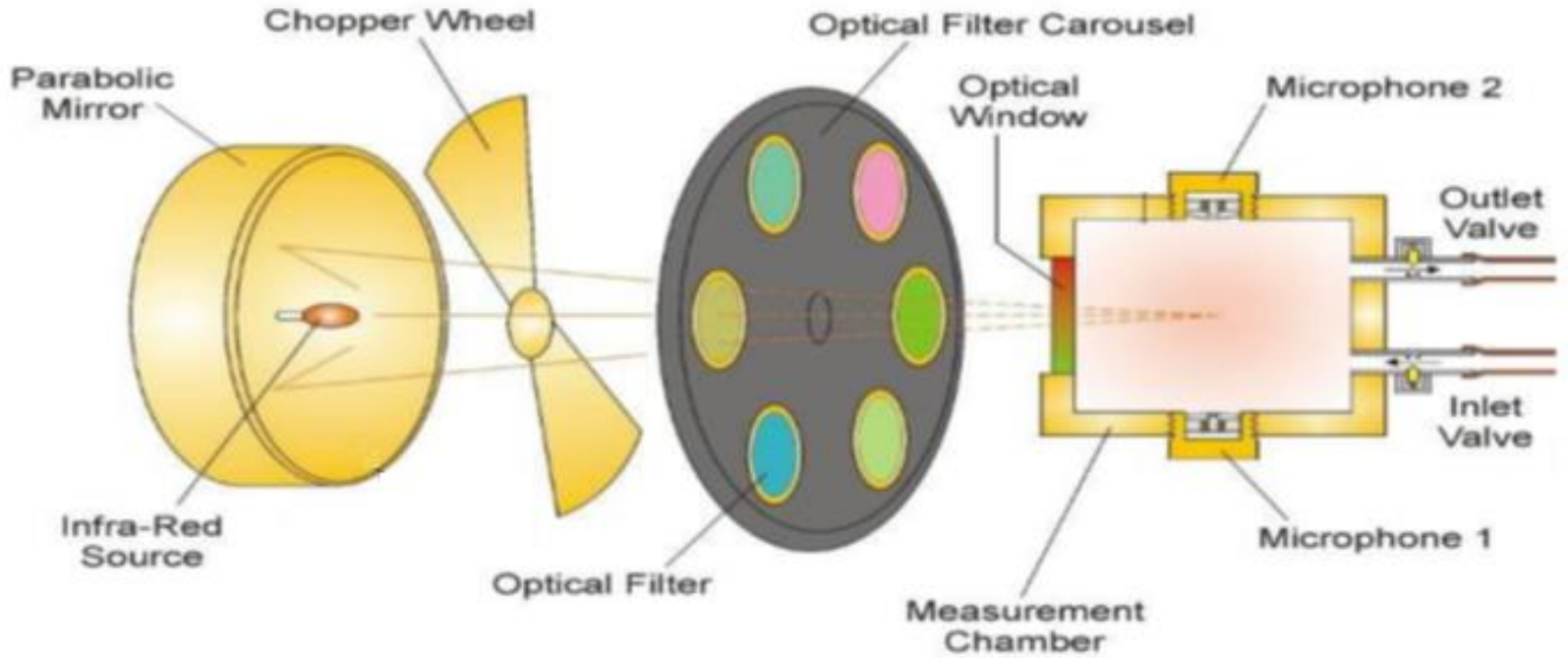
PROS

- A more complete IR absorption spectrum is obtained, which helps interpret interfering gas signals when present

CONS

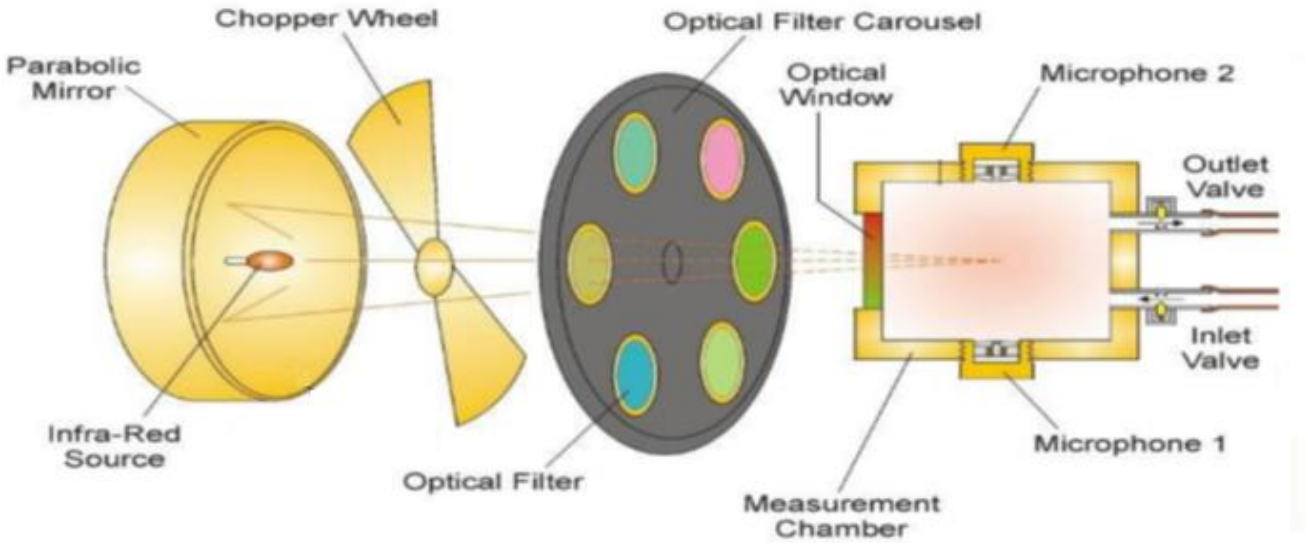
- Very complex and delicate optical system

Photo-Acoustic IR Spectroscopy



- IR filters used to primarily excite one gas at a time
- IR light is chopped at an audio frequency
- Pulsed IR light→ pulsed absorption →pulsed gas heating → pulsed expansion → sound waves → microphone signals
- Gas cell can be shaped to have an acoustic resonance at the chopping frequency (to boost microphone signal)

Photo-Acoustic IR Spectroscopy



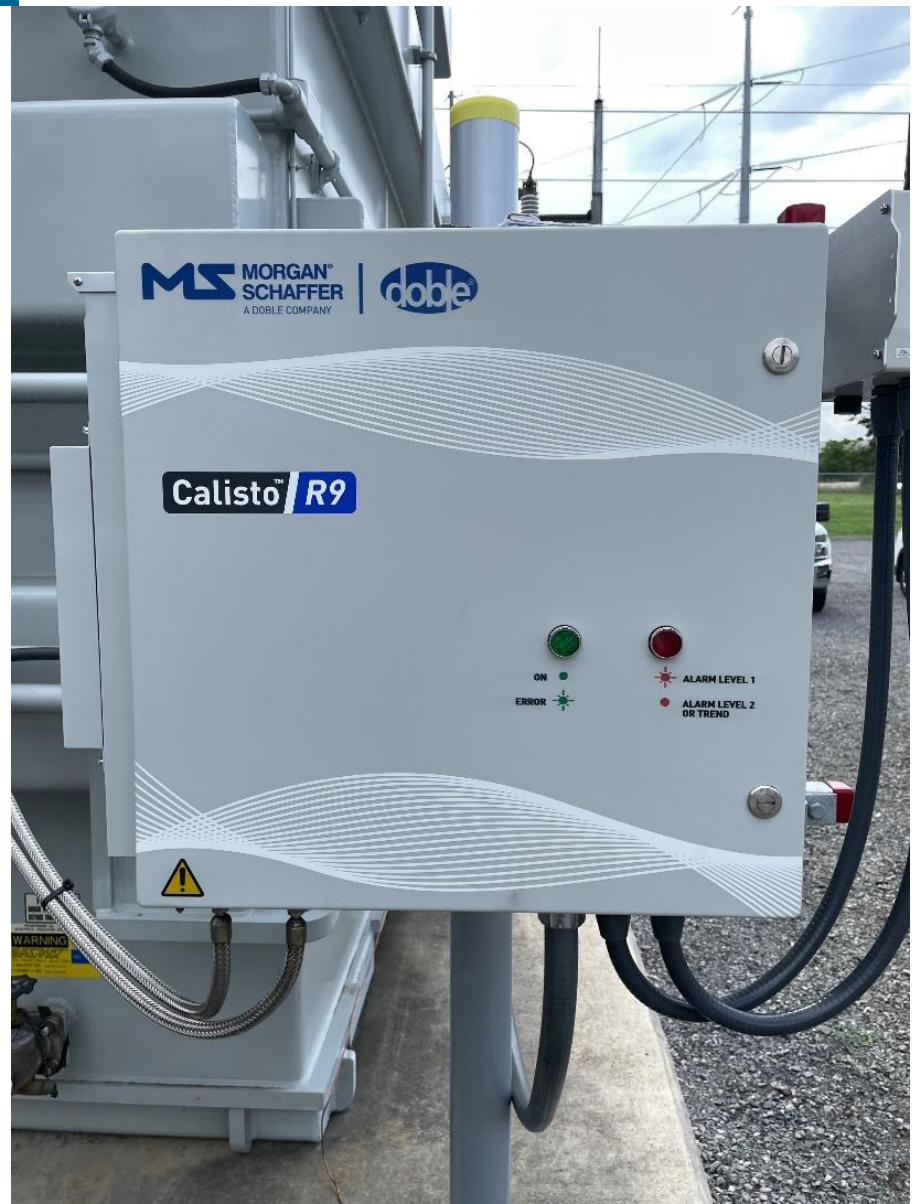
CONS

- Some models accuracy can be compromised when interfering gases are present
- Some models loose accuracy over time (drift)
- Some models need major service after about 3-4 years

PROS

- Most sensitive IR method for a given absorption length
- NEW! One model has autocalibration using water vapor

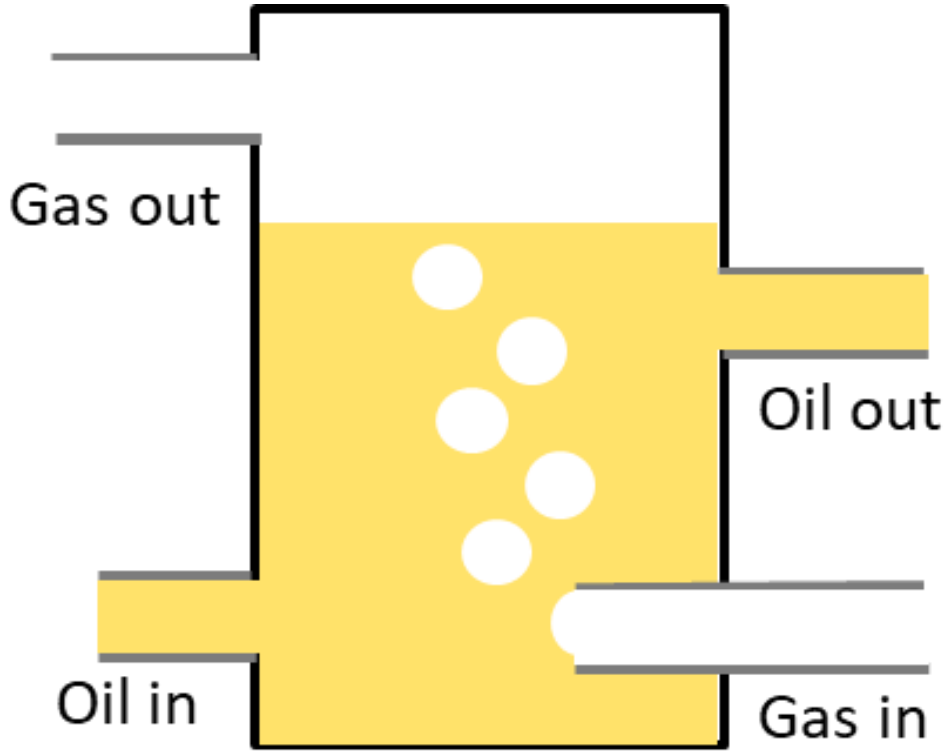
Introducing: Calisto R9



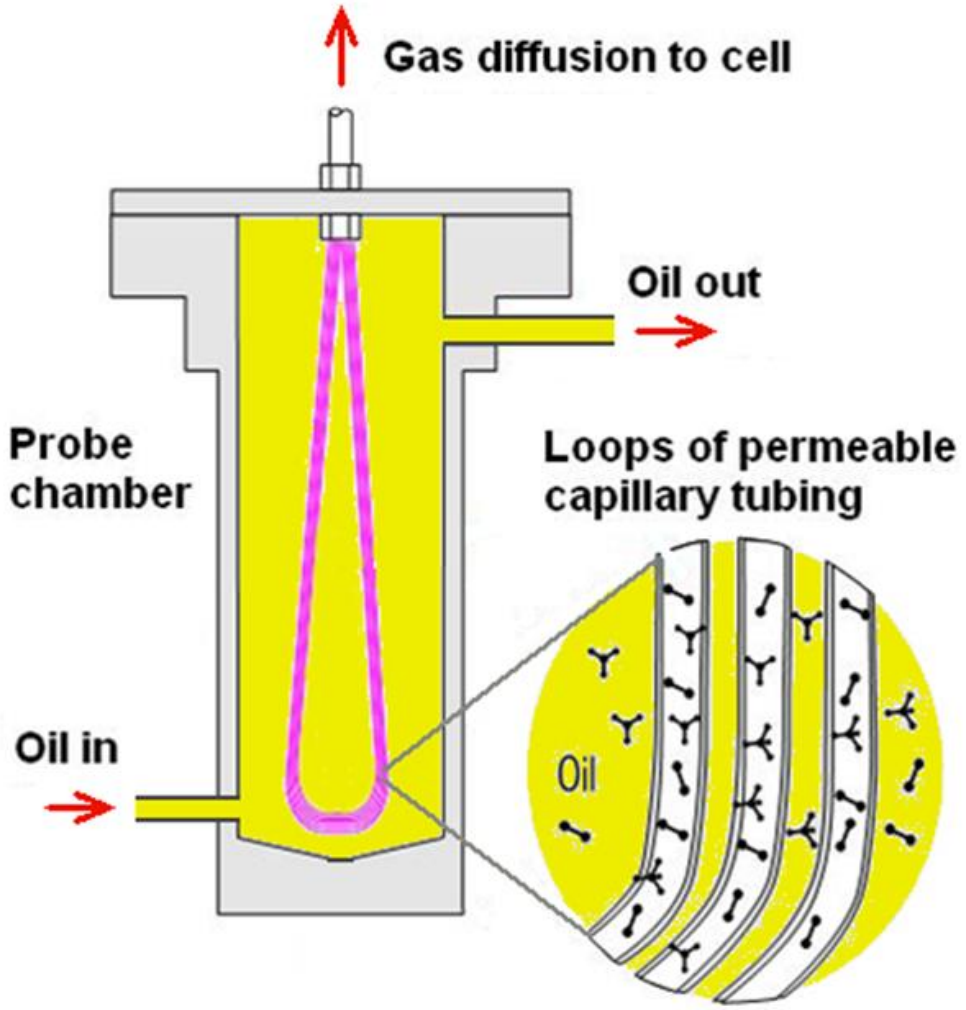
- Best of both worlds:
  - Like other IR monitors → easy to install and operate (no gas cylinders)
  - Like GC monitors → calibrates itself to stay accurate throughout its lifetime
- Leading sensitivity and accuracy among IR
- 3 different US patents
- All new electronics and software
- 20+ years of Calisto® experience built-in
- Extensive field trials and compliance testing
- Local support in 90+ countries

Open Headspace Gas Extraction

- Accelerate gas extraction by stirring or bubbling or partial vacuum
- Accurate extraction requires careful control of
  - gas volume
  - liquid volume
  - temperature
- CON: Oil and oil-vapor contamination of the gas measurement system

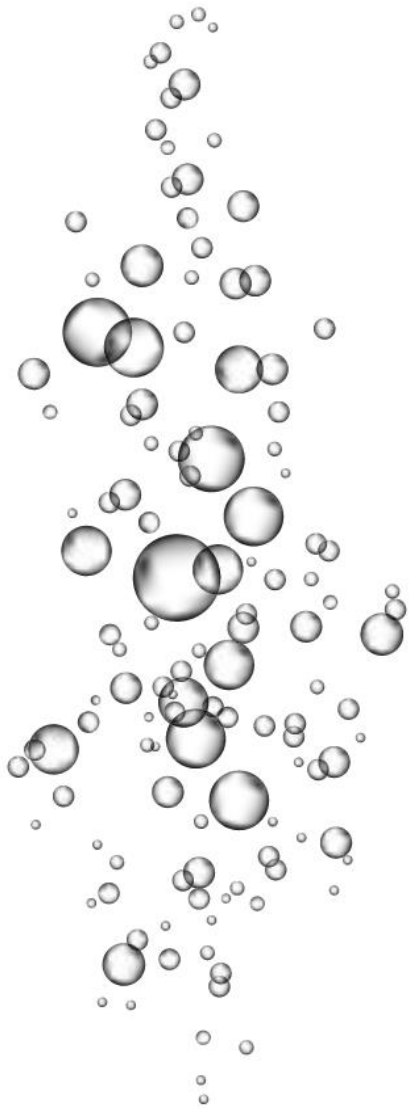


Membrane Gas Extraction



- Membrane = Gas-permeable Teflon® capillary tubing
- No moving parts → reliable
- Fixed liquid and gas volumes → very reproducible extraction
- Vacuum tolerant for transformer dry-out
- PRO: Oil and oil vapors cannot enter the gas analyser → Long-term accuracy and reliability

Other Important Monitor Features



- Thermal regulation of gas extractor and gas analyser → accuracy and reproducibility
- Oil-flow monitoring → representative oil sampling → accuracy
- Bubble trap → Easy installation, protect the transformer

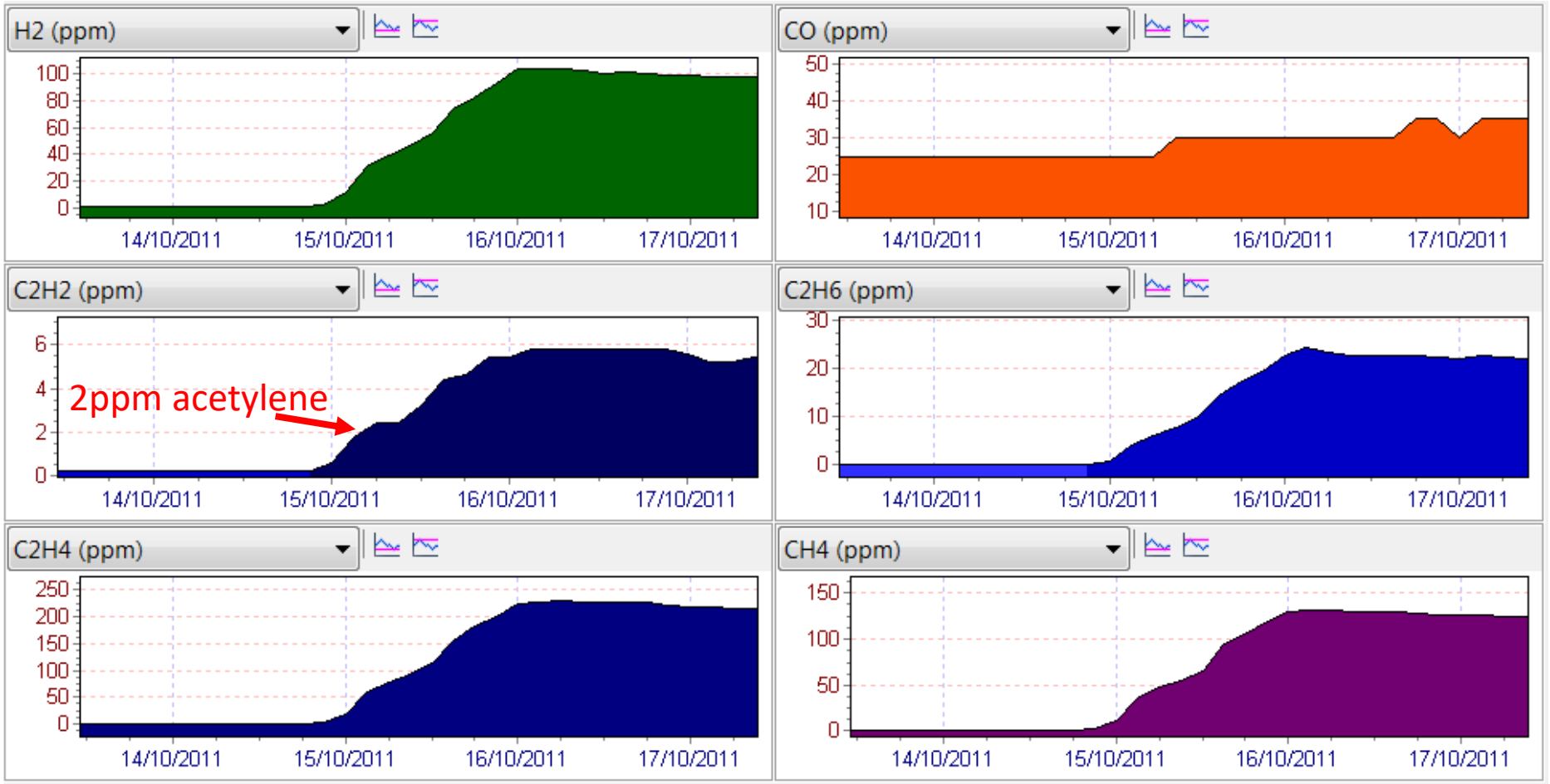
Important but not on the Datasheet

- Real-life accuracy
- Reliability
- Real-life maintenance requirements
- Vendor responsiveness for support
- Long-term relationship with vendor

<u>How to know?</u>

- Field testing
- Talk to others!

Multi-gas Save of 900 MVA Unit



- GC monitor alarmed on arcing fault 6 hours after first energizing unit on site
- Transformer was returned to manufacturer under warranty

Return On Investment

- Set gas alarm levels based on history of each transformer
- Connect comms to the monitor!
- Practice action plans for gas alarms
- Fault-detection monitors are a very good way to monitor more transformers within a budget
- Reliable multi-gas monitors for critical transformers
- Follow maintenance guidelines
- Partner with vendor

Thank you

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