ENVIRONMENTAL SCIENCE FOR THE EUROPEAN REFINING INDUSTRY

Quantification with Optical Gas Imaging – Review of 2015/16 Test Results

Petroula Kangas

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Outline

- Test objective for Concawe
- VOC detection versus quantification
- OGI and QOGI working principle
- Tests with controlled releases
- Field tests preliminary results
- Conclusions and further work

Background and Objective

- European Refineries are required to carry out leak detection and repair (LDAR) program to control fugitive emissions of Volatile Organic Compounds (VOC)
  - LDAR programmes have been in place in most EU countries for more than a decade
  - Two methods are considered BAT in the REF BREF
    - Method 21 (commonly called sniffing), uses a hydrocarbon ionisation detector equipped with a probe to sample emissions
    - Optical Gas Imaging (OGI) uses an infra-red (IR) camera to make images of emissions
- Mass emissions are estimated using emission factors
  - Factors for Method 21 are widely accepted. They are inaccurate for individual leaks but used for a large population the errors average out
  - Factors for OGI are less widely accepted because of limited statistical support
- For this reason not all European regulators accept OGI as a standalone method for LDAR

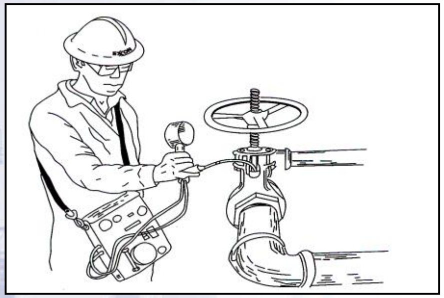
If the OGI videos could be analysed to assess the emission flux, it will lead to broader adoption of "quantitative" OGI

Detection versus Quantification

Method	Detection		Quantification		
	Established Practice	Current Challenges	Established Practice	Current Challenges	Future Opportunities
Sniffing (FID or PID)	Records a "screening value" (SV) – the VOC concentration at leak interface. Repair mandated above a given concentration.	- Time consuming - Weak correlation between VOC concentration and size of leak (false positives/negatives)	Method 21: - pegged values for SV>100,000 ppm - Correlation for lower SV	**- Use of factors leads to a conservative estimate of total mass emission - Individual component mass emission is uncertain - Accuracy improves with the size of population**	None are being pursued
Optical Gas Imaging (OGI)	Makes VOC leaks visible in a given area. All to be repaired.	- Leak detection threshold is higher than sniffing - Higher influence of environmental factors (wind, background)	Leak/no-leak factors (after determining the average detection threshold)		**Quantification of individual leaks by smart image processing (QOGI)**

Method 21 Inaccuracies

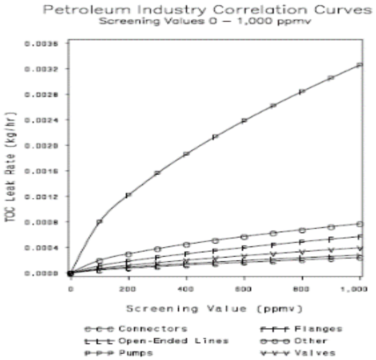
M-21 Screening Value (SV)



Uncertainty (individual component):
up to 200%

Additional errors could be introduced if SV is not corrected for compound-specific Response Factors (RF)

Correlation Eq.



Uncertainty (individual component):
-80% to +300% or higher

Based on EPA 1995 Protocol, App. C.

Emissions Rate

ER (kg/h)

High combined uncertainty

More Direct Measurement of Leak Rate has Potential for Significant Accuracy Improvement

QOGI Overview

1. **Detection**: a given area is surveyed with hand-held IR camera for potential leaking components (OGI). The components found leaking (usually a small fraction, 2% or less) are tagged for repair.

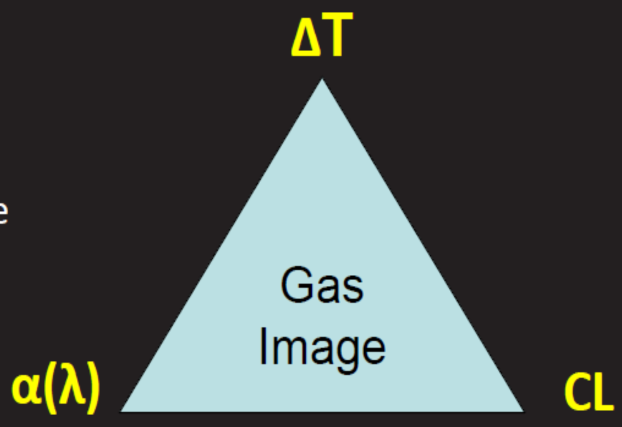
2. **Quantification**
   - Analyse the video signal
   - Quantification tablet: to be used with certain IR cameras
   - User input:
     - Ambient temperature
     - Distance from camera to leak point
     - Stream composition
   - Result: mass emission rate (e.g. in g/h)

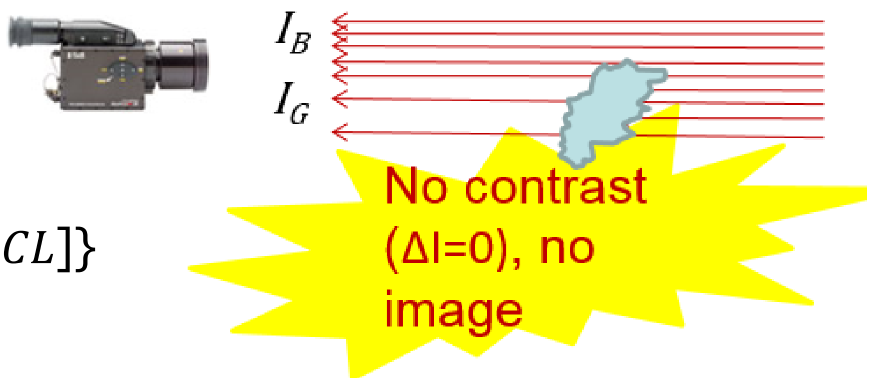
Courtesy Providence Photonics

OGI Principle

OGI Triangle

1. α(λ): The gas has IR absorption peak that overlaps with the spectral window of the OGI camera
2. ΔT: There is sufficient temperature differential between the gas plume and the background
3. CL: There is sufficient concentration-pathlength





$$\Delta I = I_B - I_G$$
$$= [B(T_B, \lambda) - B(T_G, \lambda)]\ \{1 - exp[-\alpha(\lambda) CL]\}$$

Courtesy Providence Photonics

Quantification with QOGI

- Methodology:
  - User input: Ambient temperature, distance from camera to leak point and stream composition
  - Algorithm calculates ΔT and infra-red response factor
  - For a given ΔT, calibration curves have been established for a reference gas (propane) linking the aggregated pixel intensity of the gas plume image to the concentration path-length
- Challenges:
  - ΔT required for quantification is higher than for detection
  - Concentration path-length required for quantification is higher than for detection
  - The signal is dependent on:
    - Weather conditions - wind speed, wind direction, sunlight, cloud, rain, etc.
    - Background complexity and plume geometry

Concawe QOGI Program

- 2015 - First comparison between QOGI and Method 21
  - Controlled releases (known release rate)
  - Test conditions simulated releases from different equipment types
  - At VITO LDAR training facility (i.e., not refinery)
- 2016 - Application of QOGI under field conditions
  - At an operating refinery
  - Complementing an LDAR survey
  - Comparing QOGI, Method 21 and bagging

Initial Tests Using Controlled Releases

- Objectives:
  - Assess QOGI mass prediction accuracy (versus known release rate)
  - Compare mass estimation by QOGI and by Sniffing/Method 21
  - Assess QOGI applicability range: distances from leak, various gas compositions, different backgrounds, different leaking components
  - Research site set-up to mimic field conditions
- Test matrix:

Key Parameters	**Types / Ranges**
Background scene	brick wall, concrete, metal, sky
Leaking component	flange, valve, open-ended pipe
Volatile organic gas	methane, propane, propylene, a mixture of the three (~33% each)
Leak rate	1.7 – 1000 g/h
Camera distance from leak source (meters)	2, 3, 5 and 10

The results presented in the next two pages were published in Concawe report 2/17: ***An evaluation of an optical gas imaging system for the quantification of fugitive hydrocarbon emissions***

Results of Controlled Tests

Date test	Quantifiable + reason	Number of scenarios	background	Flow (g/h)	Distance (m)	Component	Stream
May 4-5, 2015	No, ΔT < 5C	15	Brick wall in shadow	2, 10,17, 50, 200	3, 5, 10	Open end, Flange, Valve	Propane, methane, mixture
		3	Concrete (ground)	10	2	Flange	propane
		12	Metal door	30, 50, 150	2, 3, 5, 9	Open end, Flange, Valve	Propane, methane, mixture
	Yes, ΔT > 5C	7	Concrete (ground)	10, 17, 50, 200	3	Flange, Valve	Propane, propylene
June 15-16, 2015	Yes, ΔT > 5C	6	Brick wall in the sun	50, 200	3, 5	Open end, Valve	Propane
		11	Concrete (ground)	16, 50, 200, 1000	3	Flange	Propane, propylene, methane, mixture
		1	Sky	50	3	Open end	Propane
	Yes, with enhanced background*	5	Cooled towel	50	2, 3, 5, 8	Valve, Flange	Propane, propylene

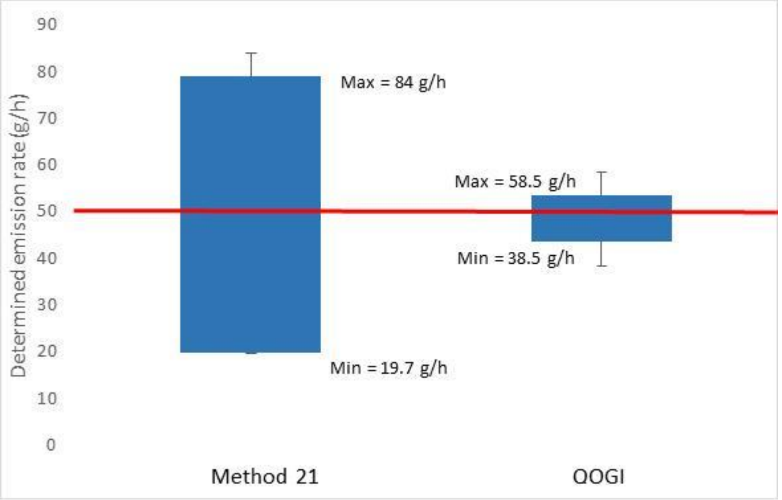
* An "enhanced background" is an artificial background, either cold or hot, providing a higher contrast with the plume in comparison to the "naturally occurring" background

Results of Controlled Tests (cont'd)

- Available ΔT with the selected background was found to be important for quantification
  - No quantification if ΔT too small
- For the 30 quantifiable scenarios, QOGI accuracy was comparable to earlier tests (Ref. 1, 2) and better than Method 21 (for single leaks)

QOGI vs. Method 21 – Comparison of differences between calculated emissions and known release rates		
Difference [1]	QOGI	Method 21
Minimum	-23%	-92%
Average	6%	31%
Standard deviation	22%	155%
Median	2%	-4%
Maximum	69%	667%

Table note 1: Difference = (calculated emission rate – release rate) / release rate (%)



Comparison box whisker plot for Method 21 and QOGI at a generated leak rate of approximately 50 g/h

Ref 1: Concawe Symposium, Brussels, Feb. 2015; New Optical Gas Imaging Technology for Quantifying Fugitive Emission Rates, ExxonMobil & Providence Photonics

Ref 2: PEFTEC, Antwerp, Nov. 2015: Quantitative Optical Gas Imaging (QOGI) Device QL100, ExxonMobil & Providence Photonics

Field Test Objective and Set-up

- Controlled tests may not be representative of field conditions
- Field tests also provide information on:
  - Practicability: time to apply, user-friendliness
  - Adaptability to broad and varying conditions (in terms of background, surrounding equipment, interference from e.g. steam, etc.)
  - Applicability to different types of leak
- Test used a selection of leaks identified in a preceding LDAR campaign
  - All leaks had a screening value > 10,000 ppm with a majority of pegged values
- For each leak the following were determined:
  - Mass flow rate using high flow sampler/bagging*
  - Gas composition using GC/MS
  - Estimated release rate using sniffing/Method 21
  - Mass release rate calculated by QOGI

** This method was validated in the controlled release experiments*

Videos: Good vs. Difficult Quantification

Good quantification

Difficult quantification

Field Tests: Preliminary Results

- **Observations:**
  - Some leaks could not be quantified. Most of these were only visible with the High Sensitivity Mode*
  - **Steam plumes** posed a problem: steam plume image pixels were interfering with leak plume image pixels
    - It was not always possible to select a different viewing angle, without steam in the background
  - **Insufficient "Delta T"** between the plume and the background was <u>not</u> a problem
    - Either the sky or equipment in operation provided enough contrast
  - **Capturing the entire plume** was not always possible (large plumes in congested areas)
  - **Background contrast changes** (e.g. due to glint) interfered with plume image pixels

* The High Sensitivity Mode is an enhanced viewing mode that makes it easier to see the plume

Conclusions

- The tests carried out so-far have proven that estimating leak rates by analyzing IR video images is a sound technique
  - When the plume is captured correctly QOGI gives a reasonable mass estimate
  - For releases where Method 21 would use a pegged value, QOGI offers an opportunity for more realistic release rates
- Measurements under field conditions have revealed:
  - Water vapour from steam leaks can interfere with the VOC signal
  - A better way to reduce this interference may be to use multiple IR wavelengths which will need a multi spectral camera
  - Positioning the camera for an ideal view of the plume is limited by:
    - The field environment
    - Current system constraints
  - There was less of a problem with ΔT than expected.
- This is a rapidly developing field - more evaluation is needed as technology improves. Priorities are:
  - Reducing interference (e.g., steam)
  - Dealing with partially obscured plumes
  - Extending testing to smaller releases than used here

Back-up