Detection Limits for Optical Gas Imaging

PROVIDENCE PHOTONICS

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Why This Topic?

- Optical Gas Imaging (OGI) has been widely used for detection of hydrocarbon leaks from process equipment
- OGI has been used without a comprehensive understanding of detection limits! What other detection device is used without a well understood detection limit?
- There is a persistent tendency to compare the sensitivity of OGI to the sensitivity of Flame Ionization Detector (FID) commonly used in EPA Method 21, and to compare the OGI detection results to the leak definition in the Leak Detection And Repair (LDAR) programs (e.g., 10,000 ppm, 2,000 ppm, 500 ppm, etc.).

Why This Topic?

- New OGI technologies and vendors, how do we compare detection limits between technologies?



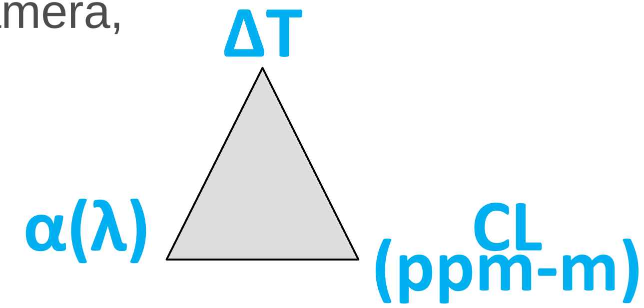
OGI Detection Limits

- OGI Detection Limit (DL) can be developed and expressed in the following four forms:
  - ✓ Concentration-pathlength, commonly expressed as ppm-m.
  - ✓ Gas volume (e.g., liters, standard cubic feet)
  - ✓ Gas mass (e.g., grams, pounds)
  - ✓ Leak rate either in volumetric flow rate (e.g., sccm, scfm) or mass flow rate (e.g., g/hr, lb/hr, tpy)
- This presentation will cover the ppm-m based DL only

OGI DL in ppm-m – Methodology

- Gas plume is detectable when the gas plume pixels in the OGI camera display have sufficient contrast against a background, e.g., contrast > 1% *
- Pixel contrast can be predicted by a model based on Radiative Transfer Theory. For a given OGI camera,

$$\text{Contrast} = f\ \{\alpha(\lambda),\ \Delta T,\ \text{ppm-m}\}$$

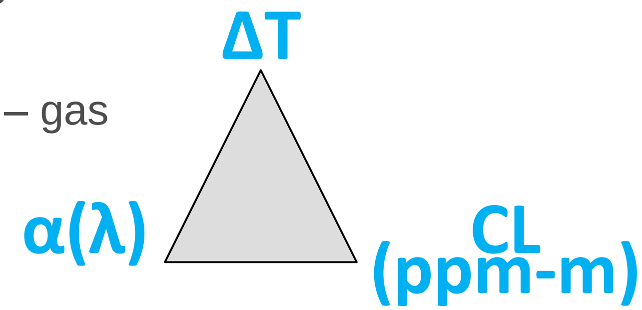


OGI Triangle

* In the standard 8-bit OGI camera display, this 1% contrast is equivalent to 2-3 grey scales out of the 256 possible grey scale values

OGI DL in ppm-m – Methodology

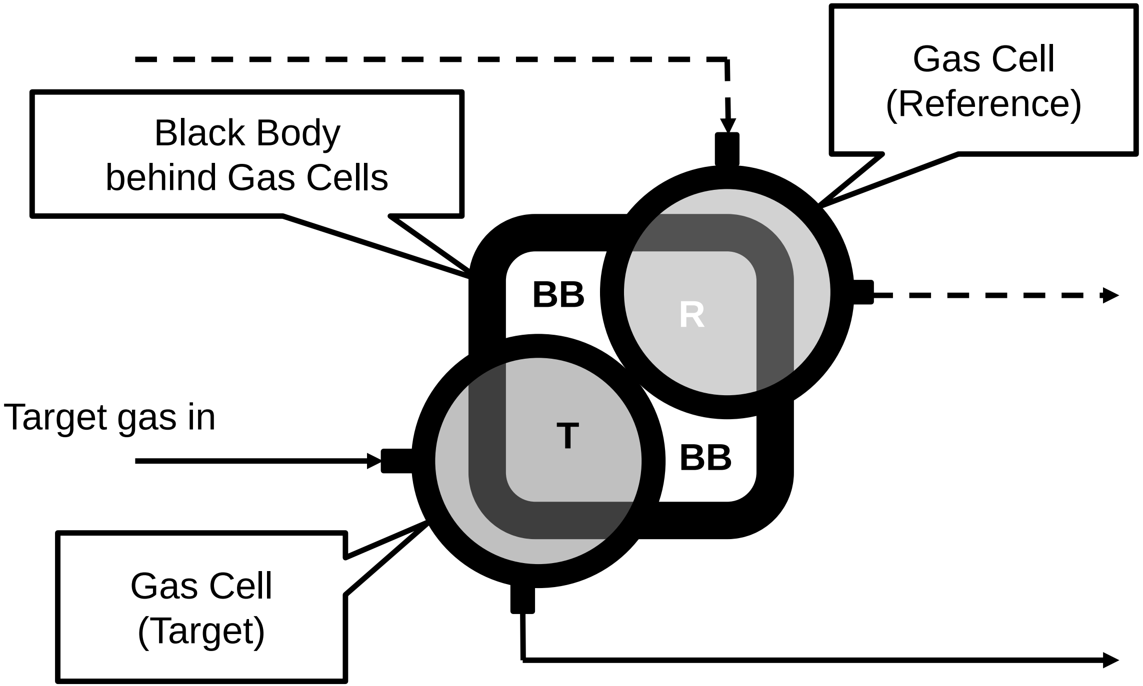
- Once the model is established, a detection limit in ppm-m can be predicted if
  - ✓ A contrast threshold for plume recognition can be established, e.g., “contrast > 1%” is needed to make a plume visible in the OGI camera.
  - ✓ The target gas is given and the IR spectrum of the gas is available (e.g., from PNNL IR Library)
  - ✓ ΔT is given (ΔT=Background apparent temperature – gas temperature)

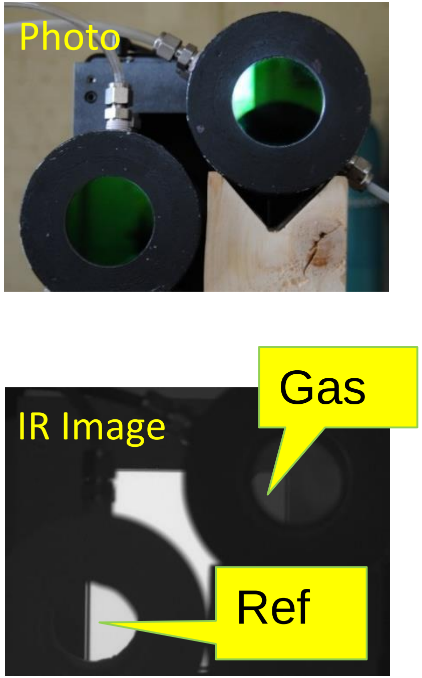


OGI Triangle

Model Verification

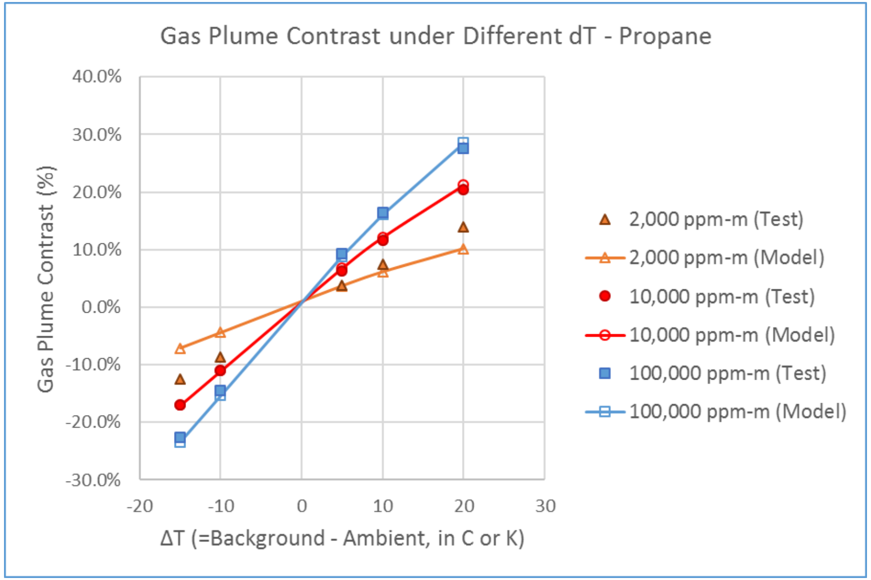
- Experiment set up for model verification:

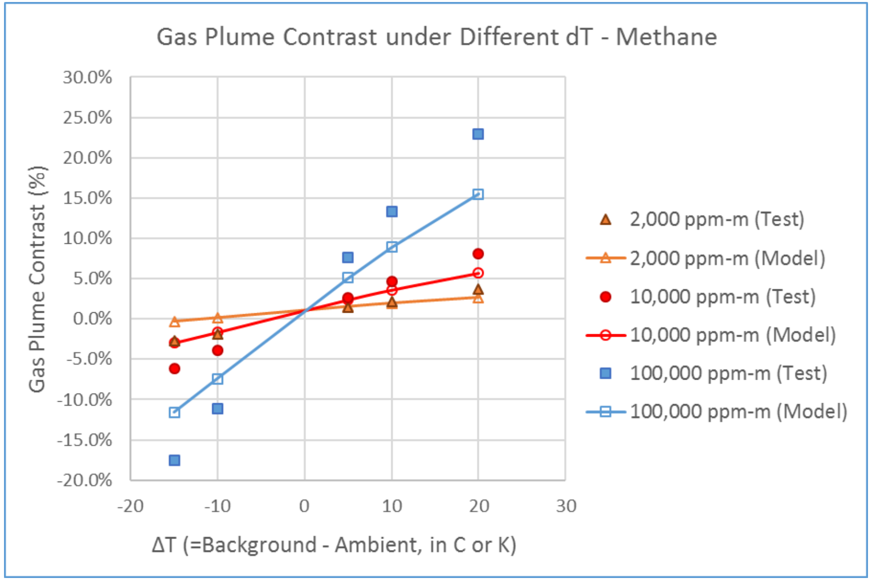




Model Verification

- FLIR GF300/320 camera was used in the experiment
- Results of model verification:



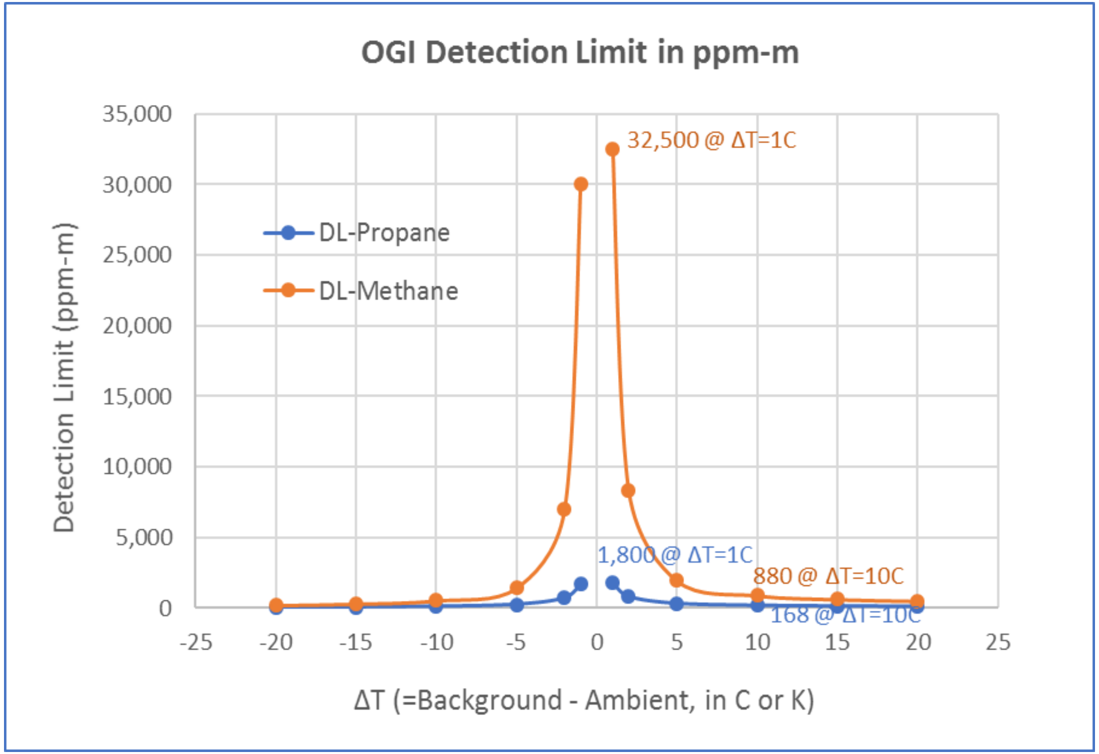


Model Verification

- With a given gas [i.e., given $\alpha(\lambda)$] and a given ΔT, the model can reasonably predict the relationship between contrast and ppm-m. The model matches experimental results quite well in the low contrast range, which is the most relevant to determination of DL
- Next step: find DL in ppm-m at a contrast of 1% under different ΔT for different gases. Propane and methane are evaluated in this study, but any gas can be evaluated for DL as long as its quantitative IR spectrum data is available.

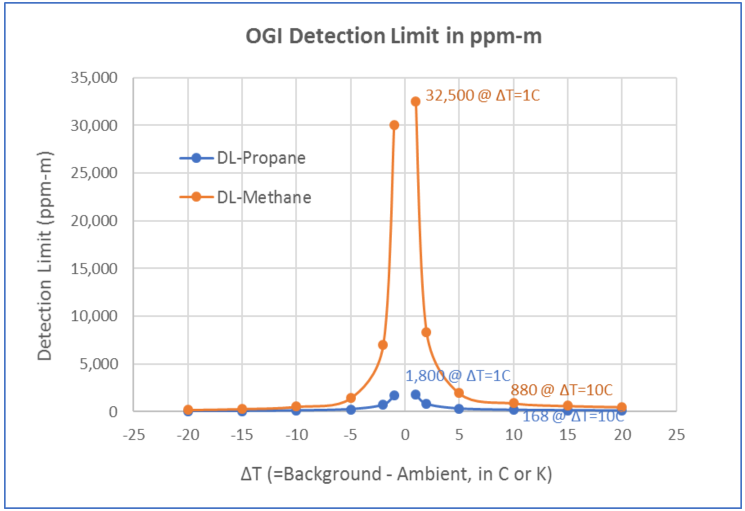
OGI DL (ppm-m) for Propane and Methane

- For the same camera design and the same gas, OGI DL (ppm-m) can be 1-2 orders of magnitude different depending on ΔT
- The DL vs. ΔT curves change sharply as ΔT approaches zero from either positive or negative side of the chart. They are relatively flat when |ΔT|>~5 ^{O}C.



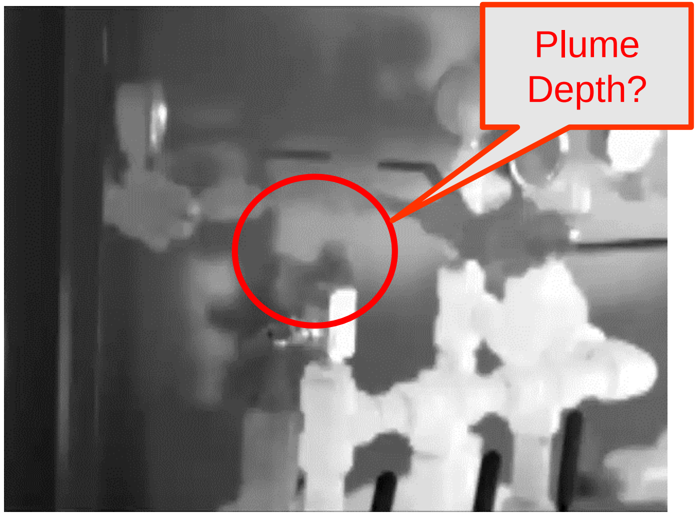
OGI DL (ppm-m) for Propane and Methane

- Propane is much easier to detect (lower DL) than methane
  - 5.2 times easier at ΔT=10 °C (880 ppm-m/168 ppm-m = 5.2)
  - 18.1 times easier at ΔT=1 °C (32,500 ppm-m/1,800 ppm-m = 18.1)
- For propane, the DL is 10.7 times higher (more difficult to detect) at ΔT=1 °C than ΔT=10 °C (1,800 ppm-m/168 ppm-m = 10.7)
- For methane, the DL is 36.9 times higher (more difficult to detect) at ΔT=1 °C than ΔT=10 °C (32,500 ppm-m/880 ppm-m = 36.9)



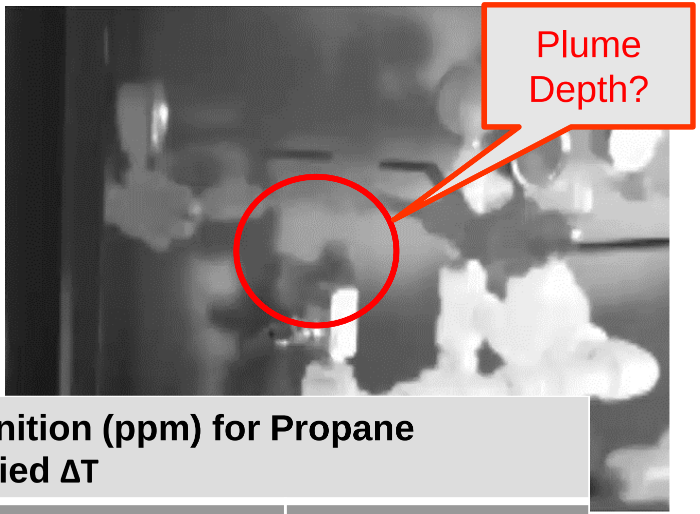
OGI DL (ppm-m) and LDAR Leak Definition

- Concentration (ppm) measured by Method 21 in LDAR program only represents one point in space, and is not representative of the leak
- For the sake of comparison, OGI ppm-m based DL can be related to Method 21 if a plume depth can be estimated. In some cases the plume depth is well defined and can be estimated, e.g., gas released from certain shapes of vent at some exit velocity.



OGI DL (ppm-m) and LDAR Leak Definition

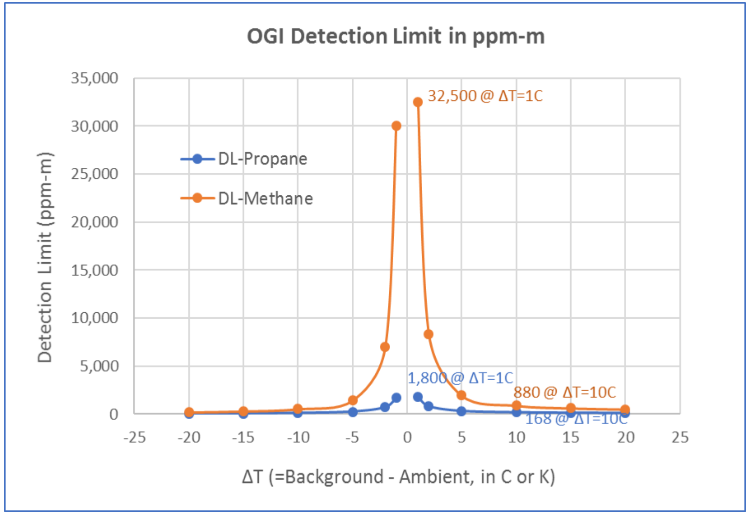
- OGI can be more or less sensitive than Method 21 depending on ΔT



Plume Depth (inch)	Equivalent LDAR Leak Definition (ppm) for Propane at Specified ΔT			
	ΔT=2 ^{o}C	ΔT=10 ^{o}C	ΔT=20 ^{o}C	ΔT=-30 ^{o}C
1	31,496	7,008	4,370	512
6	5,249	1,168	728	85
12	2,625	584	364	43

Summary

- Sensitivity of OGI, expressed as a detection limit, can vary up to 2 orders of magnitude due to differential temperature (ΔT) alone.
- OGI detection limit expressed as ppm-m can be predicted using a model.



- OGI can be as sensitive as Method 21 if ΔT is sufficiently high (e.g., 20 ^{O}C). However, when ΔT approaches 1-2 ^{O}C, OGI's sensitivity is very low (high DL)
- The methodology presented here can be used to objectively evaluate sensitivity of different OGI camera models or OGI cameras made by different vendors

OGI Detection Limits in other Forms

- OGI DL in the forms of gas volume, mass, and leak rate have been evaluated by using the ppm-m based DL and adding other variables such as number of pixels needed for plume recognition, camera design, distance, and wind conditions. Those forms of DL, particularly leak rate, are more meaningful to OGI practitioners.
- Other forms of DL are beyond the scope of this presentation and will be published elsewhere.