Selection of Emission Factors for LDAR Monitoring with Handheld Tunable Diode Laser Methane Detectors

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Abstract

Growing concern about the threats of global warming attracts attention to greenhouse gas emission control. Natural gas consists of mainly methane, a gas with strong global warming potential. The oil and gas industry implements Leak Detection and Repair (LDAR) programs to curb uncontrolled methane emissions. There is a range of tools used for LDAR monitoring. It is required that monitoring with such tools should provide “leak – no-leak” classification data for each component in the facility, which with the use of component-level average emission factors (EFs) gives the total quantity of fugitive emissions for the facility. There are EFs derived for conventional gas analyzers (“sniffers”) and for optical gas imaging (OGI) cameras, but yet there are no EFs for handheld Tunable Diode Laser Methane detectors (TDL detectors). The article presents the results of experiments conducted to fill this gap. It is found that EFs for OGI cameras can be applied to TDL detectors under some conditions, and therefore TDL detectors can be used as a standalone tool for LDAR monitoring.

Keywords: methane leaks, laser methane detector; fugitive emission quantification.

Introduction

An increasing number of oil and gas companies worldwide set objectives on reducing methane intensity in their ecological strategies: [1], [2], [3] to name a few. The basic principles and shared approaches to methane intensity reduction are claimed in Methane Guiding Principles declaration [4] by the UN Climate and Clean Air Coalition, signed by majors of the oil and gas industry. Methane goes to the atmosphere due to incomplete combustion in flares, process vents, and equipment fugitive emissions, i.e. leaks. The Methane Guiding Principles declaration states that companies should implement Leak Detection and Repair (LDAR) plans to control and reduce methane fugitive emissions.

Requirements for LDAR plans and fugitive emissions quantification methods were initially designed by the US Environment Protection Agency (EPA) Protocol [5] and then included in *Compendium* by the American Petroleum Institute (API) [6]. The corresponding standard for fugitive emissions quantification in the European Union is EN 15446:2008 [7]. EPA also published a guide [8] for companies implementing obligatory and voluntary LDAR programs. LDAR programs require building an inventory of all components being a potential leak source and then establishing periodic instrumental monitoring of components. Components are defined as any non-welded connections: flanges, valves, pump seals, open-end lines, etc. Detected leaks are subject to repair. Components inventory provides data for fugitive emissions *baseline* calculation of the asset with the average emission factors approach described in EPA Protocol [5], Section 2. Screening data collected at facility monitoring is used for calculating the actual emission volume of the facility [5]. The efficiency of the LDAR program is evaluated in terms of absolute and relative emission reduction. Reduction is the difference between the baseline fugitives' emissions volume and the actual emission volume. The quantification method, i.e. actual emission volume calculation, depends on the monitoring tool used and the screening data collected.

A classical well-known tool for LDAR monitoring is the gas analyzer ("*sniffer")*, able to measure methane concentration. The operator with a sniffer should put the sniffer probe at the leak interface of the component and measure the concentration precisely, as described in EPA Method 21 [9]. Screening values for all components are collected. Then one can use one of the approaches for fugitives emission quantification, also developed by EPA: 1) approach based on leak threshold at 10,000 ppm definition with leak/no-leak EFs ([5] section 2.3.2 p.2-18); and 2) approach based on EPA correlation equations to convert screening values in ppm to leak rates in grams per hour ([5] section 2.3.3 p.2-24). The main advantage of using a sniffer is that this is a well-known, trusted, and widely recognized method. The main disadvantage is that this method is tedious and time-consuming.

Another tool used for LDAR monitoring is Optical Gas Imaging (OGI) cameras [10]. OGI cameras are passive infrared cameras sensitive to hydrocarbon gases. A leaking component is defined as any leak observed by an OGI camera [11]. Asset fugitive emission quantification is based on using *OGI leak/no-leak EFs*, suggested by M. Lev-On et al. in 2012 [12] and included in the Oil&Gas Methane Partnership (OGMP) Reporting Framework in 2017 [13]. The main advantage of OGI is efficiency: an OGI camera operator can check ten to twenty times more components per day than an operator with a conventional sniffer [14]. The main contra is that OGI cameras are still rather expensive.

Handheld and aerial laser methane detectors, also known as Tunable Diode Laser (TDL) detectors, are used for remote methane detection along with OGI cameras [15]. TDL detector measures the intensity of the reflected laser beam and calculates the amount of methane in the beam path. TDL detector returns screening value in ppm×m units. Handheld TDL detectors are simple to use and efficient for methane detection. The operator with TDL detector points a laser beam at the component and reads the ppm×m value; if it is over a certain threshold, the operator gets an alert. The operator can check methane remotely at distances up to dozens of meters, keeping himself safe from potential hazards. The main advantage of TDL detectors is its simplicity and ability to detect methane remotely. They main disadvantage of TDL detectors is that they not as efficient as OGI cameras in the leak source localization when a leak is detected.

The question is why handheld TDL detectors cannot be used as a standalone tool for ground LDAR monitoring. This would give a wider choice and flexibility to LDAR programme operators and potentially increase efficiency of LDAR implementation. The obstacle seems to be that there are no publicly adopted leak/no-leak EFs for LDAR monitoring with TDL detectors, as there are for conventional sniffers and OGI cameras. The authors of this article aim to address this gap.

The idea of the solution is straight and simple. As mentioned above, there are EFs published for OGI cameras [13] as shown in Table 1. The leak definition here depends on the ability of the LDAR tool to detect leaks over certain threshold: 3, 6, 30 or 60 grams per hour. These EFs was derived theoretically [12] over series of Monte-Carlo simulations for an abstract LDAR tool able to detect leaks over a given threshold. Therefore, existing leak\no-leak EFs for OGI can also be applied for LDAR monitoring with TDL detectors, whenever TDL detector ability to detect leaks over a given threshold is assured experimentally under known conditions.

Table 1. Leak/No-leak Emission Factors for OGI technologies[1].

Component Type	**Emission Factor Type**	**Emission Factor (g/h/component) for Specified Leak Definition (g/h)**			
		3 g/h	**6 g/h**	**30 g/h**	**60 g/h**
Valves	No leak	0.019	0.043	0.17	0.27
	Leak	55	73	140	200
Pumps, compressors	No leak	0.096	0.13	0.59	0.75
	Leak	140	160	310	350
Flanges	No leak	0.0026	0.0041	0.01	0.014
	Leak	29	45	88	120
Other components	No leak	0.007	0.014	0.051	0.081
	Leak	56	75	150	210

[1] Source: OGMP TGD-2 [13], Table 2.7

In this paper we share experimental data collected at a range of distances by handheld TDL detector when observing a controlled leak from a sources imitating a valve and a flange. We conclude that at reasonable distances TDL detector can be considered as LDAR tool with leak definition threshold 30 g/h and over, so the corresponding EFs derived for OGI (Table 1) could be applied for the mass emission quantification.

Test Design and Results

The Goal of the Experiment

The goal of the experiment is to answer the following questions:

1. How sensitive to leaks is TDL detector at the range of its working distances? In other words, what is the leak definition threshold in grams per hour (g/h), for which operator with TDL detector can reliably distinguish a leak (emission over the leak definition threshold) from a no-leak (emission lower the leak definition threshold or zero emission).
2. What is the TDL detector readings threshold in ppm×m, corresponding to this leak definition threshold in g/h?

Equipment and Materials Used

The test stand photo is shown in Figure 1. The test stand scheme is shown in Figure 2.

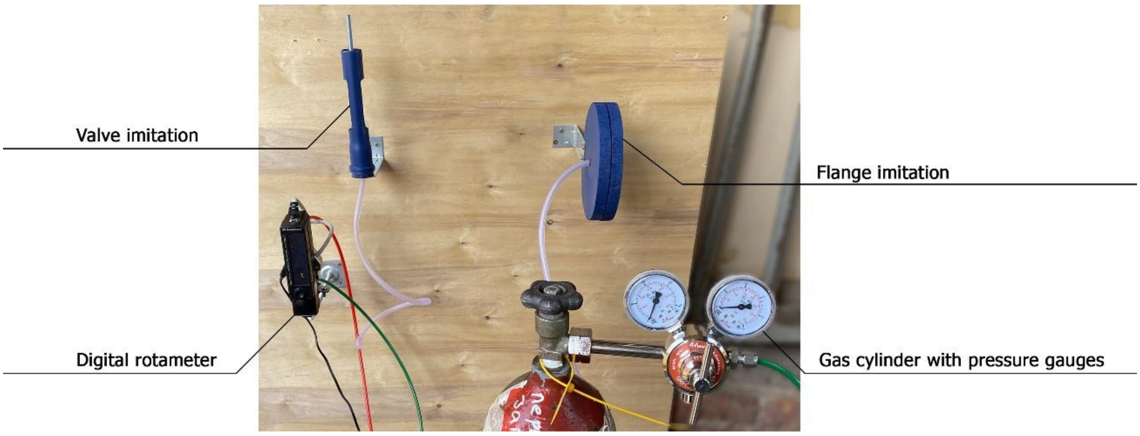

Figure 1. Test stand photo.

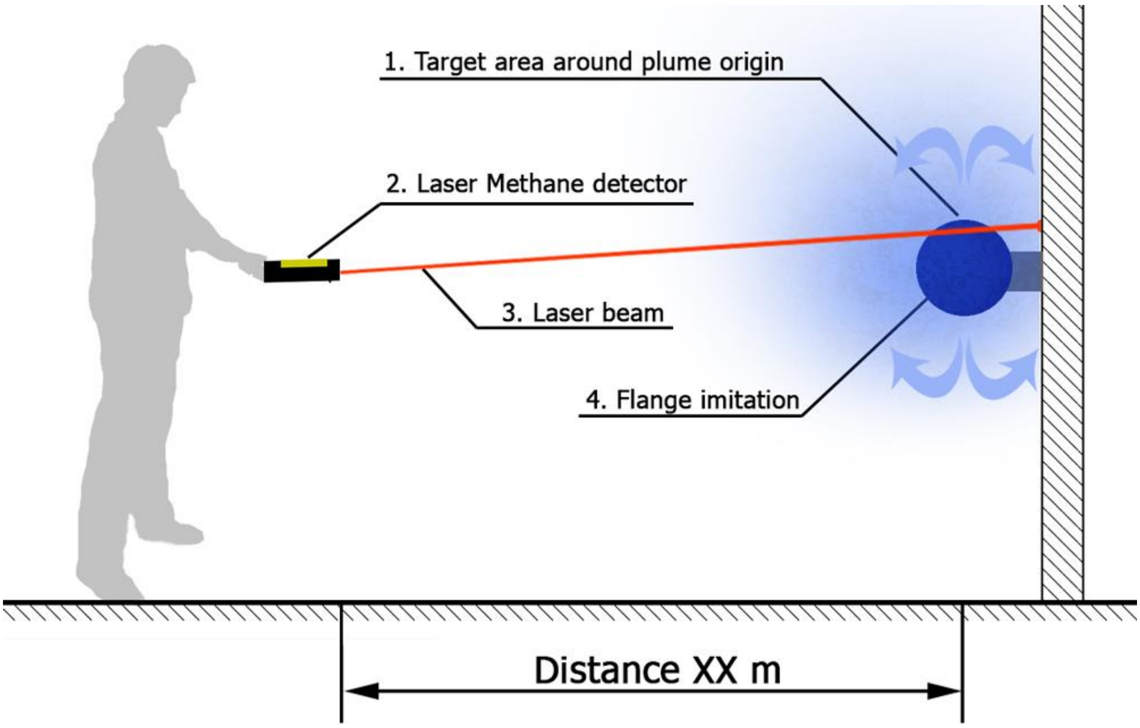

Figure 2. Test stand scheme.

Stand elements:

1. A Gas cylinder with 98% methane equipped with a valve and reducer.
2. Gas mass flow rate meter MV-302.

3. Handheld TDL detector *LaserMethane mini* by Tokyo Gas Engineering Solutions. Measurements interval: 1 – 50 000 ppm×m; graduation interval: 1 ppm×m; readings frequency: 2 readings per second.
4. Laboratory equipment: a portable table for equipment, measuring tape, wiring, gas cylinder support, a smartphone for recording TDL detector screening data.

Test Design

All measurements are taken at open air to eliminate background methane concentration bias. Measurements were taken during 3 days with mild weather at day 1 and day 2 (temperature 25C, wind from 0 to 3 m/s), and windy weather on the day 3 (temperature 12C, wind up to 6 m/s).

1. Measurements are taken with the following parameter space:
    a. Leak rates are set according to the leak definitions at Table 1: 3, 6, 30, 60 g/h, extended with zero leak 0 g/h and a 'big leak' at 100 g/h.
    b. Observation distances: ½, 2, 4, 6, 8, 10, 12, 15, 20, 25, 30 m.
    c. Controlled leaks are observed at sources imitating a valve and a flange.
2. Each observation is conducted in the following way:
    a. Ensure that gas cylinder connected to the controlled leak source through reducer and mass flow meter;
    b. Open gas cylinder valve and set gas flow rate; then wait 5-10 seconds to let the gas flow stabilize.
    c. Record actual mass flow meter readings.
    d. Start taking readings of TDL detector. Readings are collected for 60 seconds until ~120 data points are collected. Collect data thoroughly as recommended by Method 21 [9].

e. Close gas cylinder valve;

f. Change experiment parameters (distance, leak rate, target source).

g. Repeat for a new observation with new parameters.

Test Results Dataset Description and Data Clean-up

Raw data dataset contains 11,570 readings collected over 95 observations.

As recommended by Method 21 [9], the readings are taken thoroughly and then the maximal screening value should be taken. Observations might have outliers (see sample at Figure 1). To exclude these outliers data is smoothed over sliding window before taking the maximum. The width of the window is empirically set to 4 consequent readings, i.e. approximately 2 seconds. For each observation, a smoothed maximum *ppmm is* calculated as a maximum of sliding window mean values.

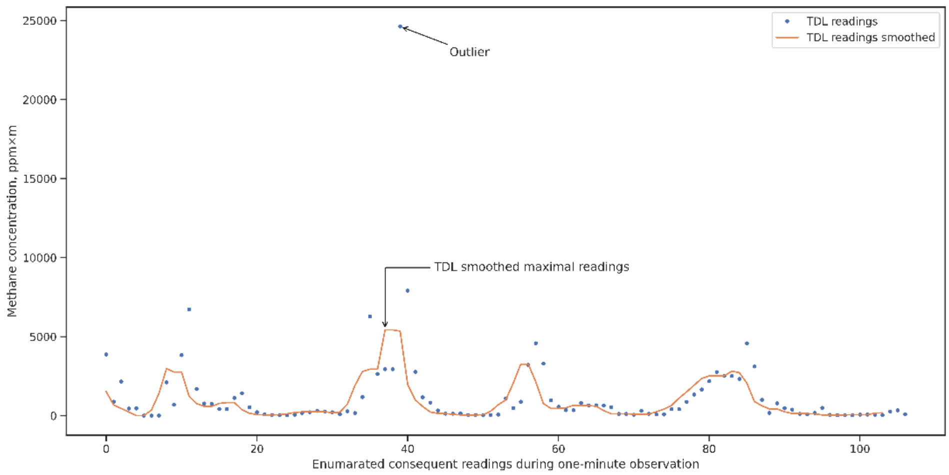

Figure 3. Excluding outliers from TDL detector readings data with sliding window smoothing method. On the figure is shown data from observation #27.

The cleaned-up dataset has one record for each observation, with the following columns (Table 2).

Table 2. Cleaned-up dataset columns description.

#	Column	Description	Type	Comments
1	Num	Observation number	Ordinal	95 observations
2	Source	Leak source type	String	“Valve” or “Flange”
3	Distance	Distance from the leak source to operator with TDL detector, m	Real	From 0,5m to 30m
4	LR	Leak rate, grams per hour	Real	Leak definition thresholds out of Table 1.
5	ppmm	TDL smoothed maximal readings, ppm×m	Integer	Calculated feature. Maximal per observation TDL readings with outliers excluded.
6	ppmm_raw	TDL raw readings, ppm×m	Integer	Approx. 120 readings per one-minute observation.

Dataset Exploration and TDL detector threshold suggestion

An overview look on the data collected on multiple plots is shown on Figure 4.

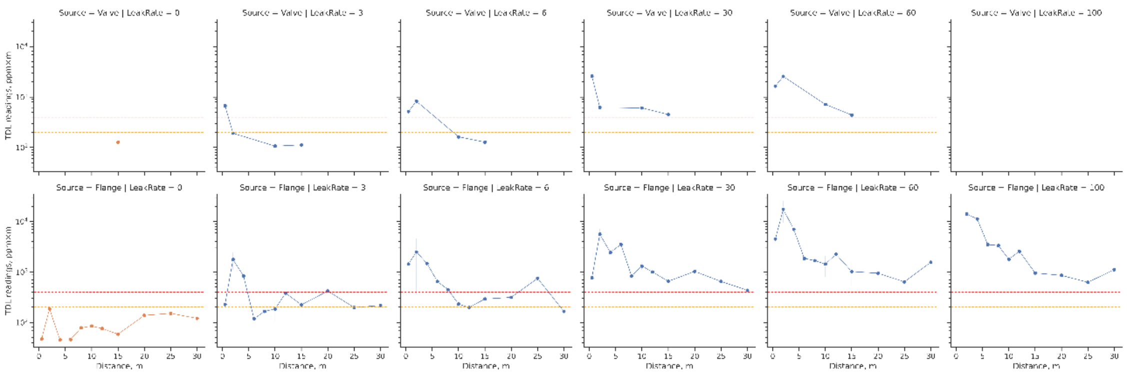

Figure 4. Dataset overview. In the rows - leak source types: either valve or flange. In columns – leak rates: 0, 3, 6, 30, 60 and 100 g/h. Each plot shows dependence between TDL smoothed maximal readings on log-scale y-axis and observations distance on x-axis at the fixed leak rate for a given leak source. Reference lines are drawn at 400 and 200 ppm×m.

Note that TDL detector even for non-leaking sources returns non-zero readings with magnitude from 50 ppm×m up to nearly 200 ppm×m. This could be explained by the ambient methane in the air detected by this high-sensitive tool.

For the leak rates 3 g/h and 6 g/h, TDL readings at distance 5m and more could be less than 200 ppm×m, overlapping with TDL readings for non-leaking sources. That means that small leaks cannot be reliably distinguished from zero-leaks when the operator with TDL detector stands far enough from the source.

For leak rates 30 g/h and 60 g/h TDL detector returns readings over 400 ppm×m at all working distances. That means that these big enough leaks can be reliably detected by TDL operator, when TDL readings threshold is set to 400 ppm×m.

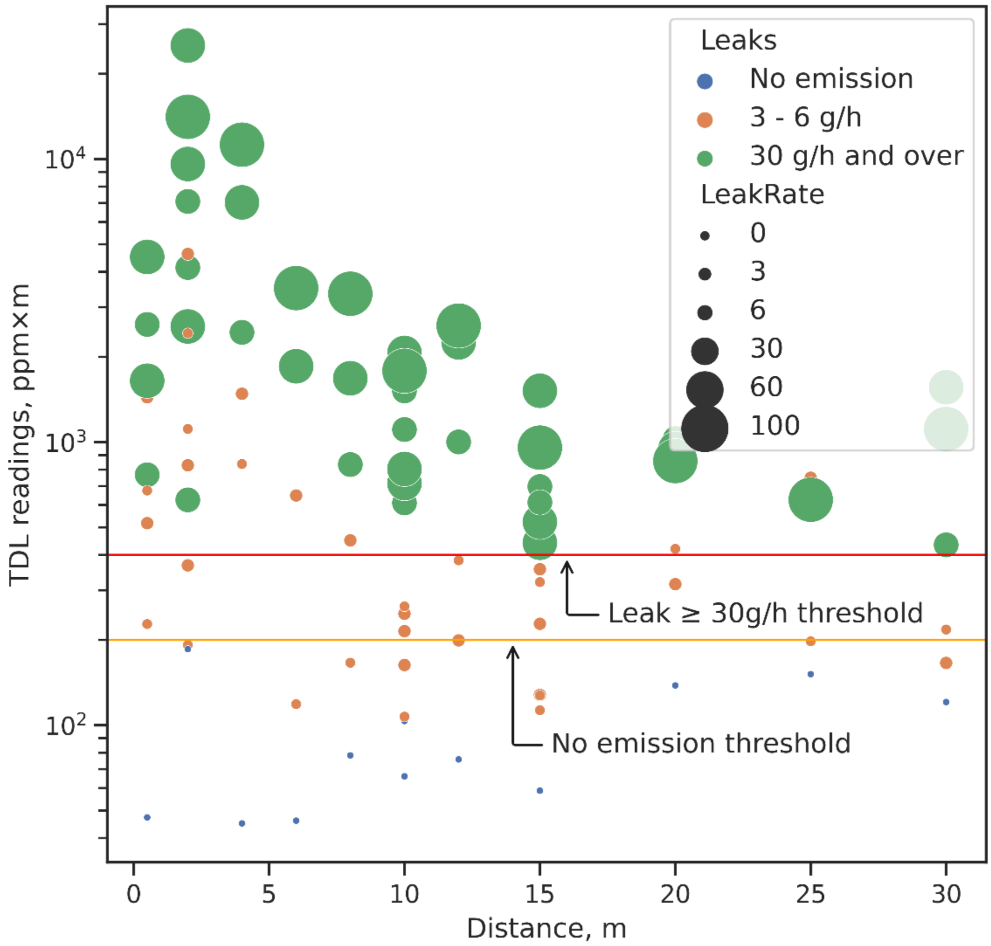

Figure 5. All observations of the dataset on one scatter plot. Each point is one observation. As on Figure 5, TDL smoothed maximal readings on log-scale y-axis and observations distance on x-axis. Point size corresponds to the leak rate. Threshold lines are drawn at 400 and 200 ppm×m.

The TDL readings threshold line (red line in Figure 4 and Figure 5) makes a binary classifier for the leak\no-leak binary classification task. The quality of a binary classifier is defined in terms *Precision* and *Recall* [16]. The best quality with *Precision = 0.77* and *Recall = 1.0* is achieved for the leak rate threshold 30 g/h and over at TDL readings threshold 400 ppm×m for all operating distances up to 30m. Note that it is possible to decrease leak threshold to 6 g/h by decreasing operation distance to 5m, which is not suitable for all facilities.

Conclusion

Handheld TDL gas methane detectors could be suggested as a standalone tool for methane LDAR monitoring. It is possible to operate at distances up to 30 meters, but it is recommended to take the most of the observations at working distance up to 10-15 m, since the TDL detector ability to detect leaks degrades with the distance.

The TDL detector readings threshold, averaged over 2s window time, should be set at 400 ppm×m level. For this threshold leaks with mass rate 30 g/h and over are reliably detected. Some leaks with mass leak rate less than 30 g/h could be missed, especially at long distances.

For the leak emission mass quantification purposes it is recommended to take EFs for leak definition thresholds 30 g/h or 60 g/h from the Table 1. The selection is shown at Table 3. It is suggested that the result, validated experimentally for sources imitating valves and flanges, is valid for all component types.

Table 3. Leak/No-leak Emission Factors for TDL detectors.

Component Type	Emission Factor Type	Emission Factor (g/h/component) for Specified Leak Definition (g/h)	
		30 g/h	**60 g/h**
Valves	No leak	0.17	0.27
	Leak	140	200
Pumps, compressors	No leak	0.59	0.75
	Leak	310	350
Flanges	No leak	0.01	0.014
	Leak	88	120
Other components	No leak	0.051	0.081
	Leak	150	210

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No potential competing interest was reported by the authors.

Data Availability Statement

The data that support the findings of this study are openly available in the *Codeocean* repository with DOI 10.24433/CO.0240582.v1.

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