Abating fugitive VOC emissions more efficiently

Comparing best available techniques for detecting refinery fugitive emissions

This article summarizes the Concawe study, 'Techniques for detecting and quantifying fugitive emissions—results of comparative field studies', that compares the two BAT (best available techniques) detection methods[1] for refinery fugitive emissions (leaks) of non-methane volatile organic compounds (NMVOC): 'sniffing' and 'optical gas imaging' (OGI). The main finding is that the OGI technology is faster and can effectively detect the main leaks. By repairing those leaks, a reduction comparable to that achieved using the sniffing method is achieved, contributing to the total site NMVOC emission reduction.

The petroleum refinery industry has successfully reduced NMVOC emissions—one of the precursors to surface level ozone formation—through leak detection and repair (LDAR) programmes, and technology advances (e.g. improved valve packing). To go further with this reduction, the industry is now focusing its efforts on the control of fugitive emissions which can contribute up to one third of the total site NMVOC emissions. Fugitive emissions are generated at plant components which are supposed to be leak-tight (e.g. pump or compressor seals, valve packings, flanges, sample points, etc.). While a typical site would have more than 50,000 such components, only a few of these contribute to the bulk of fugitive emissions. Identifying these leaks for repair is difficult and time consuming, as they will be spread out over the entire site, and in locations which are difficult to access.

Two methodologies are currently available to detect leaking equipment in LDAR programmes:

1. 'Method 21' (or 'sniffing'), developed by the US-EPA, involves the use of a hydrocarbon ionisation detector; it was historically the first approach and is a widely accepted method.
2. Optical gas imaging, using an infra-red camera, is a newer technique which is gaining increasing acceptance.

Both methods are effective, and each has advantages and limitations (outlined below). However, as they are based on different technologies and applied in the field in different ways, a comparison is not straightforward. The two methods had not previously been compared in large simultaneous, independent field trials in Europe. Such trials were the objective of a project managed by the Concawe OGI Group, and the results obtained are summarized in this article.

Background

Initial methodology: 'Method 21' or 'sniffing'

The monitoring and emissions estimating methodology is described in EPA-453/R95-017 (US) and in EN 15446:2008 (EU) (CEN, 2008), and is commonly referred to as 'sniffing'.

A hand-held hydrocarbon detector (either a flame ionisation detector (FID) or photo ionisation detector (PID)) is used to 'screen' all potential leak points one by one and record, for each of them, the highest hydrocarbon concentration measured (screening value). Above a given concentration threshold (e.g. 10,000 ppmv), the equipment is identified as leaking and must be repaired. A maximum of around 500 components (most of which will not be leaking) can be screened effectively per work day by one person. In EN 15446, factors are provided per equipment type and service, to permit the estimation of NMVOC mass emissions based on the screening value. Those factors were derived by the EPA from a statistical analysis of a significant number of leaks from various components, which were simultaneously both screened and 'bagged' (i.e. the leak flow is captured in an impermeable bag and its concentration and composition are analysed, allowing its emitted mass to be calculated). These data showed a very large spread, e.g. for the same hydrocarbon concentration, the mass emission could vary by as much as four orders of magnitude.

For the lower concentrations, correlations were developed on a log/log scale but can only be statistically representative if applied to a very large number of components. For the higher concentrations (above 50,000 ppmv methane) the FID and PID detectors do

[1] The 'sniffing' method and the optical gas imaging technique are part of BAT6: monitoring of diffuse VOC emissions to air.

not give a linear response. Therefore, the methodology assigns 'pegged values'—fixed mass emission values—to the high concentration readings (e.g. >10,000 ppmv and > 100,000 ppmv).

Newer technology: optical gas imaging (OGI)

In OGI technology, passive mid-wave infrared cameras are equipped with a filter to selectively detect radiation at the specific C-H absorption band (3.2–3.4 μm). The commercial OGI cameras are easy to use and show the hydrocarbon leak as a plume coming from the emitting source. OGI can detect any leak whereas sniffing cannot survey components which are not accessible. A major advantage of OGI is the monitoring speed. The OGI technology provides a qualitative assessment of the size of the leak. The main limitation of OGI is its higher minimum detection limit, i.e. 1–10 g/h, depending on the hydrocarbon, compared to about 0.01 g/h for sniffing.

OGI has proven to be very useful in safety and maintenance applications, and is now commonly used after a unit start-up to verify equipment tightness.

The latest camera models on the market are the FLIR GF320 and the OPGAL EyeCGas. Based on the feedback from several contractors performing OGI surveys, they give comparable results in the field.

Effectiveness of LDAR programmes

Over the years, LDAR programmes based on sniffing have helped to reduce fugitive emissions. Data now available indicate that OGI-based programmes would most likely have achieved similar reductions faster and cheaper, considering that only the largest leakers (less than 2% of the total equipment population) are responsible for more than 90% of the fugitive mass emissions (API, 1997).

Europe promoting the use of OGI-based LDAR

The latest BAT Reference document (BREF) for refining of mineral oil and gas (REF BREF) considers both sniffing and OGI as BAT. In 2013, the Netherlands Standardization Institute (NEN) developed guidelines for performing OGI surveys, aimed at providing a common methodology (National Technical Agreement 8399:2013) (NEN, 2013).

Concawe study objective

In 2012–2013, Concawe carried out several parallel LDAR campaigns. Both OGI and sniffing (EN 15446:2008) were applied by two independent teams. The objective was to compare the NMVOC mass emissions detected by each method. The mass emissions were independently estimated for all detected leaks by 'bagging'[2], when possible. The bagging technique applied uses a combination of two instruments: the High Flow® Sampler (a device developed by manufacturer Bacharach for estimating natural gas leaks) and the 'TVA-B'—a FID/PID detector commonly used in sniffing surveys. The High Flow® Sampler was used to estimate the volumetric flow rate of the leak. The TVA-B was used at the outlet of the High Flow® Sampler to estimate the VOC concentration of the leak. The combination of these two techniques, which is much faster than the original methodologies described in EPA-453/R95-017, will be referred to as 'HFS' throughout this article.

HFS was validated in a controlled experiment and compared to the EPA 'vacuum bagging' method in the field (20 leaks were bagged by both methods). The limit of the validation resulting from the controlled experiment was 200 g/h and this was used as a maximum HFS rate when analysing the results of the field campaign. This approach is similar to the 'pegged values' in Method 21 (see above). For the leak rates between 20–200 g/h, HFS was found to give a larger leak rate by a factor 2 to 5 than vacuum bagging. However, as this results in a conservative estimation of the NMVOC emissions, the HFS results were used for leaks between 20–200 g/h in this study. For the lowest leak rates (1–20 g/h) HFS accuracy was comparable to vacuum bagging.

[2] Bagging techniques are not applicable for regular LDAR surveys as only a maximum of 20 leaks per day can be bagged.

Parallel sniffing and OGI surveys

Units handling gas and light hydrocarbons were surveyed by both methods at two European refineries. Site 1 is a newer facility (built in the 1980s) where LDAR was applied for the first time during this survey. Site 2 is an older facility with an LDAR programme in place for 10 years. A single campaign was done at Site 1 (November 2012) while three consecutive campaigns were done at Site 2 (between June and November 2013). In the first campaign at Site 2 several units were surveyed, totalling 25,000 LDAR points. In the subsequent campaigns, only sub-unit 1 was surveyed (selected as previous surveys had shown this to have a relatively high number of leakers). Site 1 and Site 2 sub-unit 1 have approximately 4500 LDAR points each. The leak definition threshold was 10,000 ppm for Site 1 and 5000 ppm for Site 2 (based on the site permit). Experience with sniffing has shown that the number of components classified as 'leakers' does not increase significantly when the leak threshold definition drops from 10,000 ppm to 5000 ppm, and the two sites can still be compared.

To improve the comparison for site 1 the bagged leaks that were below the Site 1 leak definition but were above or close to the Site 2 leak definition are added to the analysis. In this Concawe work, a leak is defined as either a visible OGI image or a screening value above site leak definition.

The OGI surveys were performed according to the Dutch guideline (NEN, 2013). The FLIR GF320 camera was used and the equipment was surveyed at no more than two metres distance from multiple angles (for the accessible components). The pace of the survey was 2000 components per person per work day. The sniffing surveys were performed according to EN 15446:2008.

The analyses for comparing the VOC mass emissions estimated by the various methodologies were only done for the bagged accessible leaks. This approach was selected to make the comparison meaningful. Method 21 correlations are only statistically meaningful if applied to a very large number of leaks. The accuracy of the Method 21 estimations for the number of leaks detected in these partial surveys, therefore, is not as high as when full site surveys are undertaken.

The main four observations made during the field LDAR surveys are illustrated and discussed below.

1. The emissions estimated by the EN 15446 factors and correlations are conservative for a facility where no leaks above 200 g/h are present.

Two similar process units were surveyed in two different European refineries (Site 1 and Site 2 sub-unit 1). Figure 1 shows the number of leaks detected by sniffing, and how many of those leaks had a screening value

Figure 1 Total number of leaks found by sniffing (Site 1 and Site 2 sub-unit 1, campaign 3)

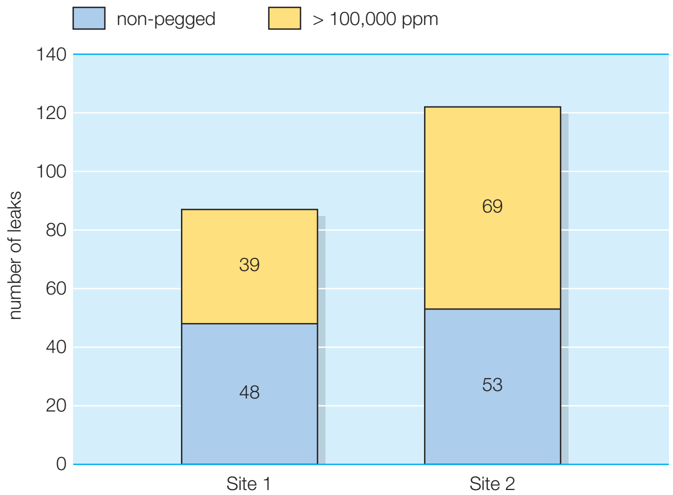
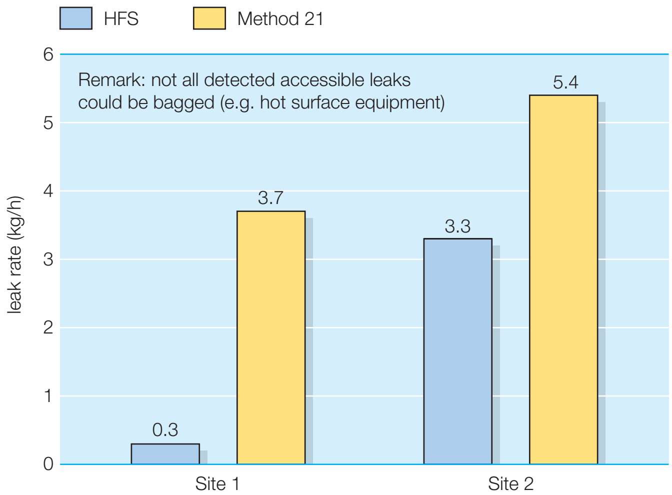


Figure 2 Leak rates estimated by two methods (Site 1: 74 leaks; Site 2: 97 leaks)



above 100,000 ppm (pegged leak) and how many were below 100,000 (non-pegged leak).

In the two facilities, the fraction of 'pegged leaks' was comparable (45% in Site 1 and 57% in Site 2 sub-unit 1).

Figure 2 shows the mass of these leaks estimated with Method 21 and with HFS.

While the number of 'pegged leaks' is comparable, as shown in Figure 1, Site 1 has fewer leaks in total and no single large leak (≥ 200 g/h) based on the bagging results (HFS). Site 2 sub-unit 1 has more leaks in total (but a lower leak threshold) and 8 large leaks.

For Site 2 sub-unit 1, the emissions estimated with Method 21 are close to those estimated with HFS (a factor of 1.6 difference). For Site 1, the emissions estimated with Method 21 are much higher than the HFS estimation (a factor of 12 difference). A possible explanation is that the Method 21 factors and correlations were established many years ago, when the occurrence of large leaks was statistically more frequent. This method has not been revised in 20 years and could misrepresent the current situation, where LDAR programmes and technology advances (e.g. improved valve packing) have resulted in reduced fugitive emissions relative to 20 years ago.

2. OGI and sniffing may not find the exact same leaks. However, the 'common leaks' found represent the largest portion of the total VOC mass emissions.

Figures 3 and 4 show, for Site 1 and Site 2 sub-unit 1, the number of leaks detected by the two methods and the mass of these leaks (calculated with the HFS method). As illustrated above, Site 1 and Site 2 sub-unit 1 are very different in terms of total NMVOC mass leak rate.

In Site 1 (Figure 3), the number of leaks only identified by sniffing was significant (70 out of 104), but the mass of these leaks (0.15 kg/h) is smaller than the mass of the common leaks (0.18 kg/h). One could argue that OGI 'missed' 0.15 kg/h of NMVOC mass on accessible components, but the three 'OGI-only' leaks which could not be quantified (non-accessible) are likely to generate an equivalent mass emission to the 'Method 21-only' leaks.

In Site 2 sub-unit 1 (Figure 4), both the number and the mass of common leaks are the most important. The mass of 'OGI-only' leaks is comparable to the mass of 'Method 21-only' leaks.

Figure 3 Site 1, leaks identified by detection method and mass of bagged leaks (estimated with HFS)

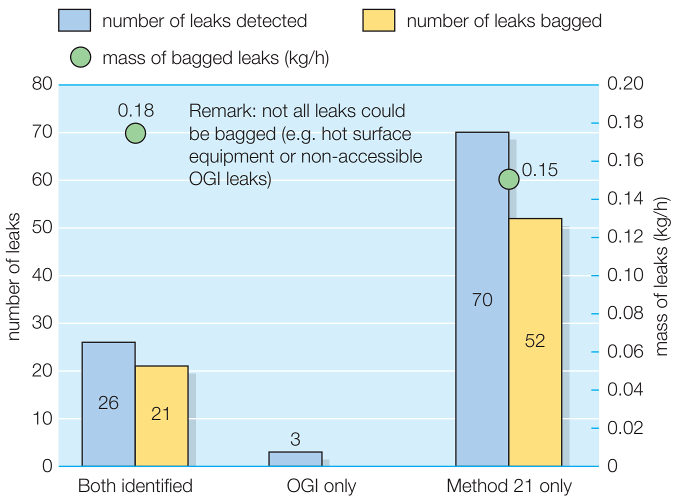
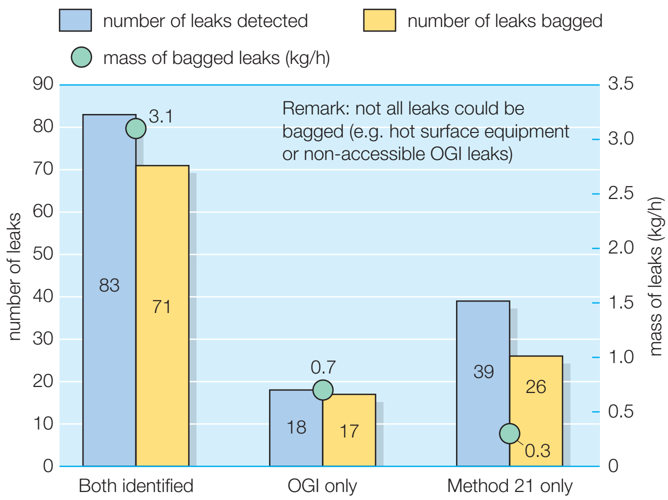


Figure 4 Site 2, sub-unit 1: leaks identified by detection method and mass of bagged leaks (estimated with HFS)

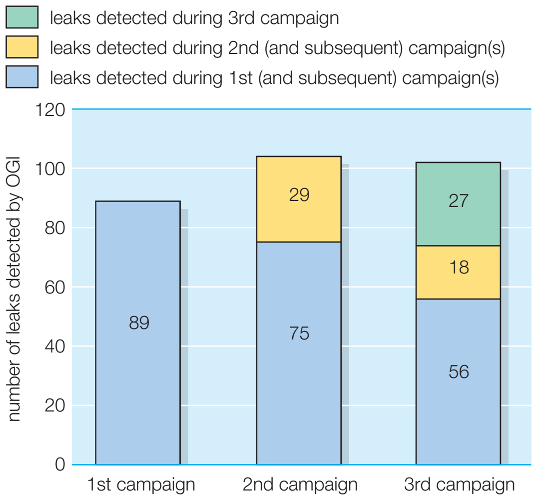


3. OGI was able to detect up to 90% of the total NMVOC mass of accessible leaks in a single campaign. This is comparable to sniffing, where some leaks are missed (e.g. where equipment is not accessible or is missing from the LDAR database).

Figure 3 shows that, for Site 1, the mass of OGI leaks quantified is 55% of the total mass of accessible leaks. Figure 4 shows that, for Site 2 sub-unit 1, the mass of OGI leaks is 90% of the total mass, which is in line with an analysis done in 1997 (Lev-On *et al.,* 2007) by the American Petroleum Institute (API). OGI effectiveness is highest when the fugitive emissions from a facility are relatively high: total NMVOC mass emission in Site 2 sub-unit 1 is 11 times higher than in Site 1 (3.3 kg/h versus 0.3 kg/h for a comparable process and size, as shown in Figure 2 on page 5). When the facility has relatively low fugitive emissions, e.g. Site 1, the effectiveness of OGI is lower but comparable to Method 21.

Figure 5 shows, for Site 2 sub-unit 1, three successive OGI campaigns performed over six months. A very small number of leaks were repaired between the campaigns (only those with a potential safety issue). Successive campaigns show that some additional leaks were found and some previous leaks were not detected again. An unexpected shut-down took place between campaigns 2 and 3; the opening of some equipment could explain the higher number of new leaks in campaign 3.

Figure 5 Site 2, sub-unit 1: leak trend by campaign for OGI leaks



In the same way, successive sniffing campaigns also point out differences in the leak screening values. But as OGI surveys are faster, it is possible to increase campaign frequency at similar cost and improve leak detection effectiveness.

4. In real conditions, the OGI detection limit cannot be defined by one single number. For the Concawe survey (Site 2 sub-unit 1, Campaign 3), OGI detected all leaks above 43 g/h and 80% of the leaks above 1 g/h (out of all leaks bagged with HFS).

Figure 6 on page 8 shows all the third campaign bagged leaks in the Concawe survey on a log/log scale. The x-axis is the sniffing concentration while the y-axis is the NMVOC mass flow, estimated using HFS. Two horizontal lines can be drawn dividing the data into three zones: all the leaks in the top section were detected by OGI (> 43 g/h); most of the leaks in the middle section were also detected by OGI (between 1 and 43 g/h); leaks in the bottom section (below 1 g/h) were difficult, but not impossible under ideal conditions, to detect with OGI.

In the middle section of Figure 6 (referred to as the 'partial OGI leak detection zone'), there were 90 leaks bagged, with an average emission rate of 13.6 g/h. Twenty-four leaks were missed by OGI and 11 leaks were missed by sniffing.

Estimation of NMVOC mass emissions when using OGI

For OGI, the plume image only gives qualitative information of the leak size. In 2004, the API published leak/no-leak factors to be used in OGI campaigns to report NMVOC mass emissions (see Table 1 on page 8). These factors are based on a model refinery with a statistically relevant leak population, surveyed by OGI. For modelling the leak behaviour, the same bagging data were used as in Method 21. The factors were developed for four different lower detection limits of OGI cameras in the field.

Based on the observed 'average' field detection limit for the new camera model FLIR GF320, when applied according to the Dutch protocol (regarding distance and survey speed), the leak/no-leak factors for 6 g/h (leak definition, Table 1) were chosen for use in the analysis of the field measurement data.

Figure 6 Site 2, sub-unit 1: OGI detection sensitivity

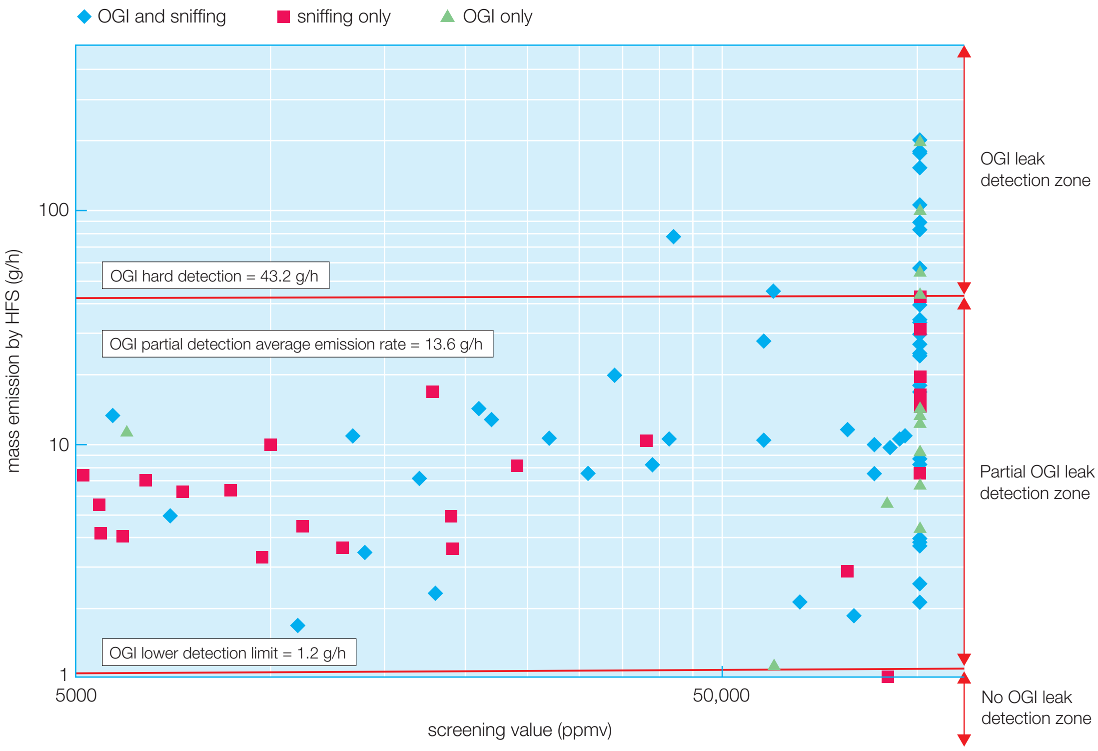
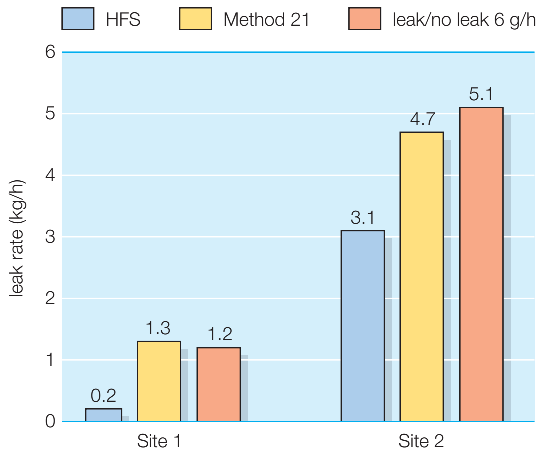


Table 1 Leak/no-leak factors for OGI surveys (API, 2004)

Component type	**Emission factors (g/h) for specified leak definitions**				
Leak definition—instrument detection limit (g/h)		**3**	**6**	**30**	**60**
Valves	No leak	0.019	0.043	0.17	0.27
	Leak	55	73	140	200
Pumps	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
All components	No leak	0.007	0.014	0.051	0.081
	Leak	56	75	150	210

Figure 7 shows, for Site 1 and Site 2 sub-unit 1, a comparison of the NMVOC mass emission (from bagged leaks only) based on the different methodologies: Method 21, HFS and leak/no-leak factors (6 g/h detection limit). The leak/no-leak factors give an overestimate of the emissions for Site 1, as does Method 21. They give a reasonable estimate for Site 2. Knowing that the fugitive NMVOC emissions for Site 1 and Site 2 sub-unit 1 are very different, illustrating the variability that can occur between facilities, the choice of the API leak/no-leak factors for a 6 g/h leak definition seems reasonable.

Figure 7 Comparison of the VOC mass emission based on the different methodologies



Looking ahead

An attempt to improve the existing OGI quantification factors based on new leak bagging and statistical analysis is not justified because the assumptions needed to derive statistical correlations will at best represent an 'average' site situation. The methods for estimating actual NMVOC emissions, e.g. by bagging, are time consuming and/or subject to inaccuracies. Moreover, one should bear in mind that the main objective of LDAR surveys is to reduce fugitive emissions (by identifying leaking components for repair). Only a technology step-out, e.g. an improved OGI camera allowing direct and fast leak mass quantification, has the potential to substantially improve the estimation of fugitive NMVOC emissions in the future.

Conclusion

The Concawe parallel surveys, based on four large field trials, confirmed that sniffing and OGI are equally able to detect fugitive NMVOC emissions. OGI provides a better identification of the leaks with a high mass emission. The OGI detection limit has improved in the past few years: the new camera models are now able to detect leaks of a few g/h with a high probability. The leaks from accessible components not detected by OGI are all small in size and represent a small fraction of the total NMVOC mass emissions. OGI has the advantage over sniffing of being able to detect any leak above the detection limit present in the surveyed area, and not only the leaks from accessible components listed in the site database. OGI surveys also have the advantage of being much faster, allowing more frequent surveys than sniffing at comparable cost. For the OGI surveys using the new camera models at the surveyed refinery sites, the API leak/no-leak factors for a 6 g/h leak definition provided a reasonable, although conservatively high, estimate of the VOC mass emissions.

In a forthcoming Concawe report detailing this study, an LDAR survey protocol will be proposed using OGI as a standalone technique, comprising both detection and quantification (estimation). This protocol will have a detection efficiency of fugitive emissions similar to the sniffing programmes currently practiced in Europe.

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