Concawe
Environmental Science for European Refining

Report

Report no. 1/23

Guidance for diffuse VOC emission determination following EN 17628:2022

ISBN 978-2-87567-168-4

Guidance for diffuse VOC emission determination following EN 17628:2022

G. Valastro (Concawe Science Executive)

This report was prepared by: Peter Roberts (Consultant)

Under the supervision of: T. Megaritis (Concawe Science Associate)

At the request of:

Concawe Special Task Force on Emissions Determination and Reporting (STF-69)

Thanks for their contribution to:

Members of STF-69: O. Duclaux, A. Jimenez, D. Leventos, B. Smithers, D. Steinert

Members of AQMG: D. Leventos, D. Steinert

Pety Kangas (ex-STF-69 chair)

ABSTRACT

This document addresses the periodic determination of diffuse emissions of non-methane volatile hydrocarbon compounds from refineries by means of remote sensing. A recent European standard, EN 17628:2022, addresses the proper conduct of such a survey and the techniques that might be chosen to be applied.

This document is aimed primarily at oil refinery sites with no prior experience of remote sensing surveys. It covers the planning, preparation for and execution of a measurement campaign and the assessment of results.

Unlike measurements on channelled emission sources, diffuse emission measurement locations change during the day according to wind-direction and survey progress. Timely access to operations data is needed in order to distinguish between on-going, intermittent, maintenance, and possibly unknown emission sources. Questions may be unfamiliar and detailed. Communications channels may have to be prepared to enable this information exchange and not add burden to normal working.

Although preliminary results will be available at the end of the measurement period, full analysis and interpretation of survey results make take some time. It is important to ensure that all necessary complementary data was gathered because it may be difficult/impossible to recover after some weeks have passed. A process of continuous review and information exchange is recommended in order that uncertainties and data dependencies are explained to refinery staff and needed information promptly identified.

The results of a survey apply only to the duration of the survey. Results cannot be extrapolated to give annual emissions. However, a survey that confirms that the refinery inventory of emission sources is complete and that the refinery can explain and quantify the observed emissions will strengthen the refinery position on reporting.

KEYWORDS

Diffuse emissions, VOC, DIAL, SOF, TC, OGI, RDM, emission determination, emission survey, emissions source, source localisation, refinery, remote measurement, remote sensing, reverse modelling, wind, meteorology, gas sampling, speciation.

INTERNET

This report is available as an Adobe pdf file on the Concawe website (www.concawe.org).

CONTENTS

EXECUTIVE SUMMARY

This document discusses the application of some methods described in a new standard EN 17628:2022 “Fugitive and diffuse emissions of common concern to industry sectors — Standard method to determine diffuse emissions of volatile organic compounds into the atmosphere” [1]. EN 17628:2022 was developed from a 2012 request of the European Commission to the European Standardisation Institute [2] to develop a standard protocol for the detection and assessment of diffuse volatile organic compounds (VOC) on a refinery-wide basis and under normal operating conditions.

This document addresses diffuse VOC emissions from mineral oil refineries specifically but is generally applicable. It complements, but does not replace, EN 15446:2008 “Fugitive and diffuse emissions of common concern to industry sectors – Measurement of fugitive emission of vapours generating from equipment and piping leaks” [3]. That standard addresses point-by-point detection, and assessment by use of industry factors, of fugitive emissions from equipment with contents under pressure (e.g. flanges, fittings, seals, valves, etc.). Fugitive emissions account for part of refinery diffuse emissions.

There are several definitions of VOC. In the context of this document, and in the standard, VOC excludes methane. Although the techniques described here can be used to assess methane emissions, the performance requirements of the standard are not applicable. Work started in 2022 to develop a technical specification which may lead to a methane specific standard.

The standard provides specific protocols (operating procedures) for the conduct of the following five named emission determination techniques:

- Optical Gas Imaging (OGI) – used for emission detection.
- Differential Infrared Absorption Lidar (DIAL) – used for emission detection and quantification.
- Solar Occultation Flux (SOF) – used for emission detection and quantification.
- Tracer Correlation (TC) - used for quantification. Although the associated gas measurement process can be used for detection it is not described as such by the standard.
- Reverse Dispersion Modelling (RDM) – used for quantification. Although the associated gas measurement process can be used for detection it is not described as such by the standard.

The first four of these techniques have been described previously by Concawe [4].

This guidance assumes a refinery is conducting a diffuse VOC emissions survey for the first time. It assumes that the survey is conducted according to EN 17628.

The main points this guide seeks to make are:

- Assessing diffuse emissions by survey is not a straightforward task. Complexity comes from identifying sources & determine whether these emissions result from normal operation or not.
- Assessing diffuse emission rates requires skills and judgement but it is not a step-by-step procedure leading to a guaranteed result as many variables (e.g., weather conditions) may influence the results.

- Measurement objectives and scope (e.g., refinery units, VOC components) need to be clearly defined beforehand for a successful campaign.
- During a survey it is crucial to provide the following data/information quickly:
  - The nature of the emission (equipment, composition and state of streams, known continuous or discontinuous sources, how these are accounted in refinery emissions management)
  - Activities taking place (maintenance, sampling, cleaning, loading, operational changes)
  - Not normal condition due to known problem (management in place, emission assessment on record)
  - Not normal condition due to unknown problem (strategy in place to assess and manage, etc.)
- Emission assessments involve compromise:
  - Detection improves if concentration measurements are made close to a source.
  - Quantification needs concentration measurements to be made relatively far from a source in order to avoid regions of wind disturbance.
  - Concentration measurement locations are physically constrained.
  - The influence of other sources must be eliminated.

There are many sources of uncertainty in emissions assessment and these need to be fully explained and quantified. Sources of uncertainty arise from compromises in concentration measurement, e.g. the way account is taken of variation in wind speed and direction across the site, natural variability (random errors), weather conditions during the survey period, etc.

After a survey is concluded, the refinery will receive a report, framed by the measurement objectives, on the emissions observed. This information will usually be offered first as a preliminary report of first impressions, contemporary with the end of the survey. A draft report, comprising a more detailed assessment and uncertainty analysis will follow. The timing of this report is best agreed as part of the survey contract discussions. The refinery review of the draft report is important because corrective actions may result and, depending on jurisdiction, the final report may become of public record.

Points of review should include:

- Contractual requirements such as whether the measurement objectives were met, uncertainty was addressed adequately, completeness of the report and ancillary information such as spreadsheets.
- Relevant environmental information such as the description of refinery operation, processes and streams as well as description of meteorology.
- Qualitative assessment of the survey results compared with the refinery own view of emission sources, both intermittent and continuous, under normal operating conditions.
- Treatment of any other sources found, specifically unknown sources.

- Potential for assessing quantitative information from the survey that may provide useful verification information or illuminate inconsistencies in the survey approach.
- Correction for third party emissions should the refinery be neighboured by other sites that handle VOCs.

To reduce the potential for surveys to discover “unknown” emission sources, refineries might consider incorporating the OGI technique into maintenance inspections.

Survey results are valid for only the short term of the investigation and should not be generalised to the longer term. In some limited cases it may be possible to simulate short term emissions. If the gap between survey results and the refinery own view of emissions for these periods is significant then it does not necessarily mean that survey results are correct. The preliminary report should flag potential for disagreement in certain areas and allow the refinery to prepare for detailed discussion of the draft report.

1. INTRODUCTION

Refineries store, handle and process volatile hydrocarbons, a small proportion of which may escape to air. The several pathways include venting, co-emission as products of incomplete combustion (including from flares), working losses linked to product movement/handling, leaks from pressurised equipment, spills, losses from drains, water treatment, product loading, etc.

Emissions are characterised as either channelled emissions or diffuse emissions. Channelled emissions are those emissions that can be monitored from within their source (e.g., a vent, a flue or a stack). The emission rate may be calculated directly, or estimated from derived values of flow rate and VOC composition and concentration. The uncertainty is able to be quantified.

Diffuse emissions account for the balance of VOC emission. They are difficult to assess because the sources and source conditions are not precisely known. Broadly speaking they are consequential to operations and arise from the imperfect function of emission barriers. Assessment is largely based on the use of emission factors and activity data or calculation by models of the processes involved.

Those diffuse emissions from loss of tightness on flanges and fittings, wear on valve and rotating equipment seals, etc., are widely known as fugitive emissions. The terminology can lead to confusion. Fugitive emissions contribute to diffuse emissions and are examples of diffuse emission.

A second source of possible confusion is the definition of VOC. For the purpose of the standard, and of this guide, VOC means any organic compound having a vapour pressure of 0.01kPa or more at 193.15 K or corresponding volatility under conditions of use. Methane is excluded, and the abbreviation should be taken to be synonymous with non-methane VOC (NMVOC) as used in Europe. The reason the standard does not address methane is an accident of timing. Interest in diffuse methane assessment is more recent. A companion and methane specific standard is planned which will redress this and include additional and methane-specific techniques.

Total VOC emission, as well as emissions of other substances, has to be identified and reported on an annual basis from each refinery site. The information is gathered and made public under the European Pollutant Release and Transfer Register (E-PRTR) regulation [5]. The regulation has formalised the gathering of this and other emission information since 2007 building on earlier work starting in 2001.

The main methodology used to derive refinery emissions, including VOC, is a combination of measurement and calculation based on activity data and emission factors. Concawe publishes a regular update of emission factors and calculation methodology references to assist emissions reporting where measurements are not available [6].

There is no explicit way to measure the annual diffuse VOC emission total and validate the calculation based on activity and emission factors. However, some advanced techniques allow an informed calculation to be made of emissions taking place over a short period of time. The methods are not new and the significant ones were described by Concawe in 2008 [4].

The techniques combine air concentration measurements and a model of the wind field to calculate emission mass flux. Such determinations are not straightforward to make, require technical skill and have complex uncertainty. Particularly important is that their applicability is weather dependent. Under favourable conditions they can inform on diffuse emissions that take place during the measurement period. For the results to be understood, much needs to be known about refinery activity during this period. EN 17628 was developed to systemise use of these methods.

This report is a guide to the detection and assessment of diffuse emissions of Volatile Organic Compounds (VOCs) from a refinery site using methodology described in EN 17628 “Fugitive and diffuse emissions of common concern to industry sectors — Standard method to determine diffuse emissions of volatile organic compounds into the atmosphere” [1].

The report covers planning, practical preparation for and the conduct of a measurement campaign, and assessment of the results taking into account refinery activity during the measurement period. It is assumed that the refinery is conducting the diffuse VOC survey for the first time, possibly as a requirement stemming from BAT 6 of the Refinery BAT Reference Guide [7].

2. BACKGROUND

EN 17628 was developed from mandate M/514 (2012) [2] of the European Commission to the European standardisation bodies. This mandate anticipated that conclusions on Best Available Technique (BAT) for the refining [8] and for the chemical sectors [9], under revision at that time, would address quantification of diffuse VOC emissions. It is a requirement that those BAT conclusions that require measurement to be made do so with reference to an EN standard method or international standard.

Explicit measurement of diffuse emission rates is not generally possible. An exception is where emissions from some individual sources, in subcategory fugitive emissions, can be physically collected.

However, under favourable conditions, emissions can be assessed using spatially distributed measurements of concentration together with measurements of wind speed and direction. With appropriate assumptions, these measurements can be combined by calculation to give a horizontal flux passing through a vertical plane. This flux is then equated with the gross upstream diffuse emission rate after correction for known channelled emissions.

For the Mineral Oil and Gas refinery sector [8] the relevant text (2014) is BAT 6, which states:

BAT is to monitor diffuse VOC emissions to air from the entire site by using all of the techniques:

i. *Sniffing methods associated with correlation curves for key equipment*

ii. *Optical gas imaging techniques*

iii. *Calculations of chronic emissions based on emission factors periodically (e.g. once every two years) validated by measurements.*

Screening and quantification of site emissions by periodic campaigns with optical absorption-based techniques such as differential absorption light detection and ranging (DIAL) or solar occultation flux (SOF) is a useful complementary technique.

Similar text is used in the BAT Reference Document for Common Waste Water and Waste Gas Treatment/Management in the Chemical Sector [9] (BAT 5) and the BAT Reference Document for Common Waste Gas Management in the Chemical Sector [10] (BAT 22). This latter references EN 17628.

BAT 6 point i), the conduct of “sniffing methods” and assessment of emissions via the use of correlation factors is common practice and is addressed by EN 15446: “Fugitive and diffuse emissions of common concern to industry sectors – Measurement of fugitive emission of vapours generating from equipment and piping leaks”. Note that the particular diffuse emissions covered in EN 15446 are known as fugitive emissions. EN 17628 is complementary to, and does not replace, that standard.

BAT 6 point ii), the use of optical gas imaging (OGI) is directly addressed by EN 17628 and is important for cost-effective leak detection.

BAT 6 complementary text on the potential usefulness of periodic campaigns using the techniques DIAL and SOF is directly addressed by EN 17628. They are not new techniques but previously their deployment was not regularised. Two other techniques, tracer correlation (TC) and reverse dispersion modelling (RDM), are also covered by the standard.

BAT 6 point iii) is less straightforward to interpret.

The calculation of chronic [VOC] emissions based on emission factors [and activity] is a long-standing practice. For those emissions covered by EN 15446 calculation is required and emission factors provided. Validation of the chronic emission calculations by measurement is, strictly speaking, not possible because there is no continuous measurement method to account for cumulative emissions on the required annual basis.

The periodic measurement methodology covered by EN 17628 may usefully complement calculation based assessment provided that it is realised that:

- Emission determinations apply only to the measurement period.
- Uncertainty in the determination of emissions is a variable quantity depending on local conditions and on favourable meteorology.
- Estimating short term (< 1hr duration) emissions by means of correlation/calculation may be challenging.

One clear test can be made using detection (e.g. Bat 6 (ii) for OGI) to verify the inventory of emission sources used in emission calculations and, in doing so, verify that there are no unknown or "missing" sources. The proposition that refineries have unknown emission sources was a major driver for the development of remote sensing methods in the 1980s. It remains a reason for using DIAL and SOF to monitor emissions.

EN 17628 addresses both the determination of emission sources (detection) and emission strength (calculation) using measured concentrations of VOC in air and wind data. Concentration and reference wind measurements are made using a campaign of short period, typically 2-3 weeks in total if a large refinery is to be covered. In this period, individual sources or source groups may be studied for less than 1 hour.

EN 17628 does not, and cannot, address the scaling up of diffuse emissions observed in the short term to annual emissions. Diffuse emissions are inherently variable and, even if a consequence of normal operating conditions the emission rate depends on environmental, operating and process conditions. Therefore, survey results only apply to the period of measurement. However, if the refinery has methods to as variable emissions these can be tested against survey results. Such comparisons can support the methods used to build a "bottom up" inventory.

EN 17628 is intended to be a "toolkit" approach whereby methods can be used individually or in combination to achieve a certain task. It sets generic performance criteria. The toolkit is populated with five techniques.

- Optical Gas Imaging (OGI) – used for emission detection.
- Differential Infrared Absorption Lidar (DIAL) – used for emission detection and quantification.
- Solar Occultation Flux (SOF) – used for emission detection and quantification.

- Tracer Correlation (TC) - used for quantification. Although the associated gas measurement process can be used for detection it is not described as such by the standard.
- Reverse Dispersion Modelling (RDM) – used for quantification. Although the associated gas measurement process can be used for detection it is not described as such by the standard.

The first four of these techniques have been described previously by Concawe [4].

Other techniques may be used if their procedures and performance requirements are defined with rigour as exemplified by the standard.

3. SCOPE

This report describes the basic steps that a refinery might take to plan, commission, execute and interpret the results of a campaign to detect and assess diffuse VOC emissions conducted according to EN 17628.

The techniques that might be applied are described in **Appendix A**.

It is assumed that, because all techniques other than OGI are proprietary, contractors will do the work and are responsible for their work to be compliant with the standard. The refinery needs to understand the work process, demands for information and key difficulties that might be met and points to check in reviewing and accepting the work.

It is assumed that this is the first survey the refinery has conducted. Several refineries have had experience of remote sensing surveys which have been used, particularly in Sweden, since the late 1980's. The changes these refineries should see with use of the standard are greater clarity of approach, greater transparency in reporting, and improved uncertainty assessment.

EN 17628 covers the detection and location of diffuse emission sources and assessment of the size of these sources (emission rate) in aggregate or, in the case of large sources, individually.

For emissions detection, Optical Gas Imaging (OGI) is a technique covered by the standard which refineries can, with suitable staff training, use themselves.

For emissions assessment the guidance is focussed on the main techniques DIAL and SOF. These techniques are not available to the refinery staff to use and contractors will need to be employed.

The main items covered by this guidance are:

- Preparation and planning
- Commissioning, including the selection of techniques
- Execution
- Interpretation of results

A survey aimed at emission characterisation can provide much useful information. If a survey is required then it is effective for the refinery to have specific information objectives ahead of time so that the survey can be tailored appropriately. This guidance therefore examines the application of EN 17628 techniques to the typical refinery locations of diffuse VOC emission:

- Storage tanks
- Process Areas
- Water Treatment
- Loading areas
- Flares

4. PREPARATION AND PLANNING

4.1. PREPARATION

A diffuse VOC emissions survey, whether focussed on the whole refinery or on a refinery section, requires extensive preparation on behalf of the refinery if it is to obtain useful results in a timely manner. Preparation involves management, as well as technical, actions which may need to be taken well before any practical consideration is given to the detailed planning of a survey.

In EN 17628 the basic approach to quantitative emissions assessment is to take the difference between the mass-flux of VOC in ambient air entering the refinery (or refinery section) airspace and the mass-flux of VOC leaving the refinery (or refinery section) airspace. This difference is the mass rate of emission from the refinery (or the refinery section).

Where a refinery is sited in an industrial area there may be VOC emission sources outside of the refinery fence. For certain wind directions the VOCs from these sources will pass over the refinery and appear to add to the refinery emission. Emissions from neighbours may therefore need to be accounted for and excluded from the refinery assessment. If neighbouring emissions are large, and often from upwind, it may be difficult to separate the refinery emission.

The relationship between the refinery and its neighbours has therefore to be managed, particularly:

- The refinery survey will generate information on emissions from neighbours.
- Understanding the accuracy/credibility of this information will generally require discussion with those neighbours.
- The ability to account for the refinery's own emissions may depend on those from neighbours. This is particularly the case if emissions vary in time or come from sources near to the refinery boundary. An example would be a refinery neighboured by a third party terminal/tank farm.
- Refinery own emissions pass across neighbour boundaries. Reputational aspects need to be considered.

One argument used to promote the use of surveys is to discover “unknown” refinery emissions. It is therefore important that the refinery review their inventory of emission sources, both continuous and discontinuous, including emission potential from their maintenance inspection program and activities such as tank cleaning.

The refinery should review the methods it uses to estimate or calculate emissions from these sources, ensure that they are documented and that the methods are understood and robust. Thus, if an emissions calculation spreadsheet is used the formulae encoded should be documented. If complex software is used to estimate emissions, for example, from storage tanks and water treatment, the key skill holders should be identified.

The inventory of refinery reported emission sources, and refinery assessed emissions for the survey periods, provide the main reference point for evaluating the survey results. Where refinery methods are bottom up, i.e. calculating annual emissions from the sum of short term emissions, the comparison will be particularly relevant.

EN 17628 is particularly directed to assessment of emissions under normal refinery operating conditions. Not-normal conditions do occur in practice and the review of refinery emission assessment methods should include intermittent events such as emissions during tank-cleaning. If not-normal conditions do occur during a survey then the emission contribution should be clearly identified.

To distinguish between normal emissions and those arising from intermittent events, or other than normal conditions, requires prompt access to operational data. The refinery should have procedures in place to allow such information to be retrieved and rapidly shared between operators, control room and environmental staff. Preparation in this area will minimise disruption during a survey. It is important to have accurate information to hand in order to avoid misinterpretation of results and to prevent incorrect conclusions being drawn.

Typical actions to identify "what happened" may include:

- Requests to identify activities associated with short-duration emissions such as arise from maintenance tasks, cleaning, drain emptying, sample taking etc. Movement of a vacuum truck in its daily duty is a classic case.
- Requests about operational and process activities such as tank movements, pressure relief valve operation, mobile equipment start-up/shutdown, temporary venting, loading, etc.
- Questions on composition: e.g., composition of tank contents, process streams, etc.
- Questions on state: phase, temperature, pressure of process fluids.

It is recommended that the refinery considers proactive screening to identify potential sources of emissions. This should be guided by review of:

- The latest process area LDAR report, with attention to components identified for repair.
- Forthcoming maintenance items, especially scheduled age-related replacements.
- Activities able to generate short term VOC emissions that might take place on areas subject to survey.

This review can be supported by in-house inspection. The OGI technique, for example, can be used to assist routine visual inspection of external floating roof tank seals, not readily accessible pipework, cold vent openings, etc. which may fall outside the scope of an on-going LDAR or other maintenance inspection programme. If OGI is not already in use staff will require training in the technique, as set out in EN 17628.

4.2. PLANNING OVERVIEW

There are three main stages to the survey process:

- Commissioning: The refinery has to set objectives for the investigation, initiate a procurement process, assist potential contractors to prepare work proposals by providing necessary information including HSSE requirements. The refinery has to prepare acceptance criteria for key deliverables and determine how the work should be reported. The work should be contracted with agreed time-scales.

- Execution: The refinery has to facilitate the survey work, provide necessary support and information, collate operational data and reconcile contractor's observations with that data and known emissions or accept that unknown emission sources have been found.
- Delivery: The contractors will prepare a report of their findings. The refinery has to prepare to accept this report. Reporting will usually comprise a preliminary post survey account of findings and then a draft report with interpretation, analysis and uncertainty estimates. The refinery will need to work with the contractors to ensure timely delivery and assist the interpretation of the results. The survey outcome can take one of three forms, assuming contractual obligation are fulfilled:
  - Results are in-line with the refinery's own view of emission sources and magnitude of emissions from these during the survey period;
  - Results differ from the refinery's own view but these differences can be reconciled with operations and events occurring during the survey period;
  - Results differ from the refinery's own view and there is disagreement over findings requiring challenge to solve.

The refinery has also to consider the implications of the survey findings. For example, whether remedial measures need to be taken on emission sources, whether refinery emission assessment methods need to be refined etc. and whether there are consequences for reported emissions.

4.3. SUMMARY DESCRIPTION OF A SURVEY

To put the planning requirements in a context it is useful to consider the course of a survey as considered in EN 17628. The description below is for a survey of the whole refinery operating under normal conditions. However, it could be that scope is limited to sections of especial interest to the refinery or excludes sections where non-normal operations are taking place such as construction.

Either of the techniques SOF or DIAL can be used to perform this task. Assume the work has been contracted so that measurement objectives, the technique(s) to be deployed and the work deliverables have been agreed. For completeness and brevity, the description below makes reference to all the techniques named in EN 17628. However, not all techniques need to be used, either singly or in combination, excepting OGI for source localisation.

The survey start date will have been chosen to recognise that:

- Remote emissions assessment techniques depend on weather conditions being favourable. As part of the work proposal statistical climatic analysis will have been carried out by the contractor to determine suitable times of year to do the work. The SOF technique requires sunlight and the sun to be above a minimum elevation, therefore working opportunities may be limited in winter in higher latitudes.
- The refinery will have time windows that avoid other than normal operating conditions (e.g. shutdown/start-up of units, major projects, tank cleaning, etc.). This may extend to activities on neighbouring sites.
- Contractors and their equipment have to be available.

The contractors will come on site bringing their equipment after fulfilling the refinery safety induction and instruction on site work rule and permitting procedures.

Agreement will have been reached beforehand for storing equipment on-site overnight, power requirements, arrangements for the supply/handling of consumables such as liquid nitrogen, etc.

Contractors will install fixed (for the survey period) meteorological measuring equipment at one or more locations. These will provide reference wind direction and wind speed data. The locations will have been identified and agreed as part of the work proposal and reviewed during a pre-survey site visit. These will be in remoter areas of the refinery, away from equipment and roads. Masts will be erected to support equipment. Telemetry is used for data communication. Where possible the station upwind of the refinery at a particular time will provide the reference. The refinery weather station is not used unless it is suitably located and meets performance requirements. EN 17628 also imposes requirements on how the wind speed and direction data are averaged to smooth out fluctuations. Refinery weather station data processing may not be consistent with this.

Contractors should work daily with a nominated member of the refinery, who will be referred to as their “buddy” in the rest of this document.

Because the methods used depend on the weather, particularly on wind speed and direction, an adaptive approach has to be used. It is usual to formulate an advance plan for the day’s work taking account of the weather and the measurement objectives. This allows working areas to be predefined and work-permits issued where necessary. The location of the contractors needs to be known for safety and security reasons. The plan will contain some flexibility in case the weather changes or if the monitoring team(s) spend longer than intended in an area e.g. to respond to a detected emission source.

Potential parking locations will have been identified for the DIAL instrument before the contractors come on site. It is a large vehicle and must be parked so that it presents no obstruction to refinery roads and has a clear line of sight for the measurement path. Combinations of refinery plot-plan and satellite imagery of the refinery assist in this preselection. During the pre-survey site visit the contractor will check that the locations are suitable, e.g. adequate hard-standing for the vehicle, potential lines of sight are not obstructed, etc.

Similarly, possible routes will have been identified for the SOF vehicle. The vehicle is generally limited to surfaced refinery roads in order to reduce vibration and pitching during movement. The SOF instrument needs sight of the sun. The height and extent of refinery equipment bounding the roads therefore needs to be considered. The consideration takes into account the effect of time of day and season on solar elevation. The vehicle location is recorded using a global positioning system (GPS). This will be mapped to a refinery plot-plan by reference to a standard projection (e.g. WGS 84 or equivalent). The contractor will note how close significant structures are to the road. These structures disturb the wind. If they are too close to the road this has to be accounted for when analysing results.

Wind direction determines where concentration measurements can be made using DIAL and where concentration measurements (confined to roads) can be used when using SOF. Concentration measurements will be made upwind and downwind of the target section to account for possible upwind sources.

In planning the work the contractors will have obtained information on the composition of material handled within the section. This is to assist the measurement process which needs information on the target species. During the course of work the contractors will take air samples for chemical analysis to verify the composition of VOC in air. The location at which samples would be taken, and approximate timing, will be entered in the daily plan.

If using DIAL the measurements will be supported by extra wind measurements using a mobile anemometer. This is to check that the intended DIAL scanning plane is not too close to the section structures for emissions to be calculated. These local wind measurements will be compared with data from the reference measurement station(s) and evaluated for too low wind speed and changed wind direction caused by flow around the structure(s).

If using SOF (which is a mobile technique that measures continuously as it changes position) it is not possible to verify wind conditions as the vehicle moves. Expert judgement is used to identify which measurements can be used for flux estimation and whether wind speed and/or direction need to be corrected.

To perform the survey the contracted teams will move into the area targeted for the day, following site rules on access/authorisation. The control room and operators are aware of the measurement activity and prepared to record/make note of emissions relevant activity such as sampling, product movement, etc., taking place inside or near the surveyed area.

The survey process is dynamic. If the measurement team detect a “hotspot”, i.e. a region of elevated VOC concentration, they will investigate by making further measurements. The refinery buddy will contact the control room and ask if there is operations activity in (or upwind of) the section that could release VOC. Such inquiries may be “live” or next day.

At the end of the measurement day a meeting with refinery staff is held to discuss the findings of the day, identify follow up actions and plan the next day activity, taking account of forecast weather.

If a source is suspected, i.e. observations cannot be reconciled against refinery information, a follow up action may be to localise the source. The primary method is using OGI. If a source is confirmed then the technique TC, and possibly RDM, might be used for quantification if their use is covered by the scope of work.

The survey evolves through a series of working day contributions to the overall goal. The daily discussion with refinery staff provides contextual and supporting information to assist interpretation of the data.

On completion a summary description of work done should be provided. This will include information on localised emission sources and a provisional value for their emission rate, as well as the aggregated emissions for refinery sections and for the refinery.

Evidence for emission sources not previously known to the refinery will require a refinery response, e.g. inclusion in maintenance or repair schedules.

The detailed analysis of results and uncertainty assessment will take place later. These will be presented in a draft report for refinery review. It is not unusual for the final VOC emission rate calculations to differ from the provisional figures.

4.4. PLANNING: COMMISSIONING

4.4.1. Setting Objectives

As with every project, refinery objectives will determine the scope of work, the choice of contractor(s) and the techniques to be used and influence job timing.

A survey may have one or more purposes e.g.

- Source Detection: To investigate if there are unaccounted emission sources on the refinery and assess their size. Concern over "unknown" emissions was a major driver for including remote sensing methods in the BAT reference guides (BREFs). Before the development of OGI methods, remote sensing was the main candidate for source detection. The ability to assess the size of the emission was advantageous but the benefit comes from finding and repairing such sources.
- Emission Determination: If there are uncertainties about VOC emissions from particular refinery sections and emissions are chronic then emissions assessments by remote sensing may assist. A challenging example is emissions from waste water treatment.
- Project Justification: Investment in diffuse emissions abatement is expensive. A VOC survey may usefully inform on the need for a significant maintenance project. Examples might include the refurbishment or upgrading of external floating roof tank seals or replacement of pressure relief valve assemblies as they near the end of their statistical service life.
- Project Assurance: A VOC emissions survey can support an emissions reduction project. For example, a VOC survey before a leak detection and repair program on a process unit. The survey can give a snapshot of total emissions from leaks which, with some caveats, might be compared with the calculated emissions derived from correlations. This application comes closest in spirit to BAT 6 part iii).

This guidance assumes that the refinery wishes:

- To identify refinery diffuse emission sources so that they can be compared with the refinery emission source inventory; specifically, to establish whether the refinery inventory is complete or missing "unknown" sources.
- To locate and quantify any "unknown" sources so that a response plan can be developed.
- To provide a snapshot of refinery section emissions in such a way that these can be evaluated in part or in whole.
- To understand the uncertainty inherent in this short-term emission rate assessment.

The refinery should consider, as an internal objective, how it might respond to the conduct of the survey and assessment of the results. There are two basic approaches:

- "Show me". The refinery chooses to engage fully at all preliminary and formal project review stages. The refinery requires the contractor to demonstrate and explain method and results of each day's work. This entails open and full reporting by the contractor of intermediate data, assumptions made, calculation procedures and results including sensitivity analysis to investigate uncertainty. The refinery will need to dedicate resources to this review. The contractor will have to devote time to providing additional information and explanation.

- "Tell me". The refinery chooses a hands off approach. The refinery will focus on the delivery of results against targets and be prepared to accept results as they are reported. This requires less information on method from the contractor and less review input from the refinery. This would be the usual approach to a contracted environmental measurement.

Whichever approach is taken the refinery still needs to be an active participant in providing contextual and operating information to assist the contractor interpret their measurements and so assess and attribute diffuse VOC emissions.

This guidance assumes that for a first experience of a survey the refinery chooses a "show me" approach in order to better understand what has been determined.

The "tell me" approach may be appropriate for refineries who have had past experience with diffuse emissions surveys and are confident of the outcome.

The refinery should include information transfer/reporting requirements as a topic for discussion.

4.4.2. Information needed for discussion

With objectives set the refinery can seek expressions of interest from contractors. The contractors will need certain information to engage in proposal discussions. These will include:

- Identification of the site.
- Refinery objectives for the work, including reporting/information transfer.
- Desired timing.
- Refinery plot plan.
- Description of the refinery operations at a basic level including the processes used, storage, loading, flare, etc. so that they can be located on the plot plan.
- Description of relevant non-refinery operations in the instance that the site has multiple uses (e.g. petrochemical) or is divided or is neighboured by sites that may also emit VOC.

The above will enable the contractor to develop some outline proposals. The principle ones being:

- How the refinery might be divided into study sections.
- Which methods might be used.
- Which refinery sections are able to be studied separately and which may have to be aggregated.
- How fence-line conditions will be established and how external emissions sources be addressed.
- Whether site topography influences the wind-flow.
- Potential locations for the reference meteorological stations.

- Suggested time frame based on climatic conditions. To confirm this the contractor will carry out a desk-top study to determine principal wind directions, wind speeds, rainfall, insolation, etc. by season. Refinery own data may be useful but is often not suitable.

4.4.3. Take away from discussion

Following the discussions, the contractor should have sufficient information to produce an outline proposal for the work. This will include key objectives, the measurement techniques to be used, the length of campaign needed, and the projected uncertainty in assessed emissions. The length of campaign is linked to the need to make sufficient measurements to draw conclusions robust enough to meet the EN 17628 quality requirements.

To assist the assessment of the outline proposal, **Appendix A** provides a summary of the techniques named in EN 17628. **Appendix B** considers how the techniques might be applied to different sections of the refinery. **Appendix C** considers areas of uncertainty in emissions assessment.

The outline proposal should cover reporting and information transfer.

The techniques proposed will depend on the contractor because, apart from OGI, they are proprietary.

The outline proposal should be clear on how refinery objectives will be met with clarity on:

- What can be detected and what can be measured.
- The methodology to be used and why. The required input data.
- Procedure for detection and localisation.
- Procedure for emission rate assessment.
- How emission rate assessments will be presented, e.g. per isolatable section.
- How the results of the study will be reported.
- How uncertainty will be addressed.

It is important that the survey report shows how each emission rate is derived from measurements, the assumptions used and the choices that can be made. Discussions should encourage openness about the methodology throughout the assessment. Without this information it will be difficult to challenge the robustness of the assessment. This will be important if the study reports higher emissions than the refinery expects.

As a historical note, before the development of EN 17628, the working information needed to understand survey results was often (usually) absent from final reports. The standard report would comprise a narrative description of method followed by statement of the assessed emissions and their uncertainty but not how these values were derived.

EN 17628 does not encourage such a “black box” approach but neither does it require full disclosure. To ensure that communication of results tends toward “show me” rather than “tell me” the detail required in reporting should be considered as part of the work contract.

The standard requires contractors to retain their records. An electronic data report containing necessary data and working spreadsheets (with worked examples) should be part of the deliverable.

Appendix C on uncertainty addresses the questions the report should be able to answer: in particular the data report should include (in usable form, not just as graphics):

- Concentration profiles measured.
- Wind data used to calculate flux from these concentrations.
- Spatial information to show where concentrations used in flux calculations were measured in relation to site structures taking account of wind direction.
- The time-series of flux calculations in chronological order on a linear scale.
- These time-series to include both upwind and downwind flux determinations (individual values).
- Method for assigning weights to individual values, with especial attention to values obtained in low wind speed.
- Statistical values (mean, median) and measurement uncertainty.
- Sensitivity calculations used to assess systematic uncertainty arising from choices in inputs.

4.4.4. Final proposal

If the draft proposal based on discussions is satisfactory the contractor will make a site visit to obtain final information and to survey areas for the installation of meteorological equipment and siting of other equipment specific to the selected techniques.

Timing can be agreed taking account of logistics, meteorology and availability (of site and of contractor).

There is unlikely, in the short-term after publication of EN 17628, to be much choice of contractor. The assessment techniques, other than OGI, are proprietary. There is a very big technical and knowledge barrier to new entrants providing DIAL services. There is less of a technical barrier to the TC and SOF techniques developed by FluxSense AB in terms of equipment used. Data analysis and interpretation is greatly dependent on experience. New entrants face a steep learning curve and need to prove their competence. Application of the RDM technique to diffuse VOC emissions has been demonstrated by a single supplier. Again, new entrants face a steep learning curve and need to prove their competence.

4.5. PLANNING: EXECUTION

4.5.1. Preparation

The contractor will carry out a preliminary site visit to agree suitable locations for meteorological equipment. The contractor will seek locations where the wind from the prevailing wind direction is free from disturbance by buildings. Mounting a meteorological mast can involve driving anchors into the ground. Power may be needed.

The site visit will provide opportunity for introduction to those refinery staff who will be involved in the survey. Importantly a refinery focal point needs to be appointed as a "buddy" who will handle the daily interface between contractors, operations staff and technical staff. Environmental staff, especially those involved in monitoring and emissions reporting, should be involved with the survey. The visit can serve to establish how lines of communication will work and what kind of information is likely to be requested. Also, the structure of the survey working day can be gone through so that expectations are established and necessary actions known.

If the survey is to have special focus on a refinery section and results be compared in detail with the refinery own assessment then the refinery should define its own needs so as to be prepared to mirror the upcoming work.

The visit will establish what resources the contractors will need including supplies, storage of equipment, power requirements, etc., especially if equipment has to run overnight unattended.

When the survey starts the contractors will come on site and follow the site-specific induction procedures covering safety and environment, site rules and working procedures.

The contractors will bring and set up the meteorological monitoring stations.

The contractors will have to set up and test their measuring equipment.

The site has to provide a location for a daily review and planning meeting. This meeting is key to determining the work plan, usually for the following day.

The nature of the survey means that the contractors will be moving around site. Their movements on a particular day will depend on the wind direction. There may be non-working days if the weather is unsuitable. The contractor expected locations in time and activities to be undertaken will be communicated to the control room where necessary at the start of the working day. The contractors also need to be informed of movement restrictions, etc.

The refinery buddy will facilitate such communications.

4.5.2. Conduct and Daily Review

The survey process involves measurement of air concentrations. When a higher than expected concentration is detected, this triggers a "detection process" to identify the specific source of the upwind emission. Otherwise, air concentrations will be taken as indicative of cumulative trace emissions, the flux also to be assessed after correction for background.

The identification of events where concentrations are higher than expected can be in general terms, e.g. "an emission appears to be coming from within a unit", or an item of equipment may be indicated. It will be decided (see below) whether or not to initiate a search for the point of release. The standard terms this search "localisation". The main method used for localisation is OGI.

Detection will be followed by an assessment process to estimate the mass-flux associated with the measured concentrations. Detection and assessment may be conducted in parallel or as a 2-stage process of screening followed by more detailed measurements. SOF lends itself to a 2-stage approach and DIAL to a parallel approach as described below.

The SOF technique involves driving a mobile sensor around the refinery looking for concentration “hot spots”. The van will pass a source in several (< 20) seconds. The record of the concentration against time is converted to concentration against position using GPS. Inspection of the concentration record indicates the location of the “hot spot” which will be revisited for confirmation. Further concentration measurements will be made at different times and wind conditions to gather data for flux assessment.

DIAL operates from a fixed position which takes some time to set up. It is efficient to continue to observe the passage of gas and collect concentration data for the flux calculation. The DIAL scan pattern is optimised to capture the cross-section of VOC crossing the beam. These preliminary scans indicate the nature of the emission i.e. whether there is a “hot spot” or otherwise. Concentration measurements will typically be made for 20-30 mins comprising 4-6 complete DIAL scans unless more scans are needed to reduce uncertainty.

Progress will be assessed each day and discussed with refinery staff. The environmental team must be involved. It is to be expected that preliminary results presented, especially if they involve initial flux estimates, will be subject to revision and correction.

The meeting will cover:

- Progress against overall objectives (units covered etc.).
- Day results.
- Follow up actions.
- Next day priorities for both follow up and completion of the overall objective.
- Outline plan for next day work.

Particular interest will be paid to areas of elevated concentration found. It has to be decided whether these are naturally arising or represent an unknown source to be localised.

The most basic information coming from concentration measurements is that their source is “somewhere upwind” of the measurement location[1]. The contractor should show the location of the “hotspot” on a plot plan of the refinery, or an aerial view of the refinery as obtained from, for example Google Earth™. A line can then be drawn on this plan indicating the reference wind direction. The physical extent of the “hotspot” and the magnitude of the concentration observed will also indicate if the source is close by.

Refinery staff will be asked for contextual information to help identify the source of emission. For example whether there are known emissions (continuous or

[1] Note that a source may not lie directly upwind of the “hotspot” as indicated by the reference wind-direction. The wind follows a path of least resistance between the refinery structures and in some places may be very different to the reference direction. Uncertainty in wind direction is a major source of uncertainty in emissions assessment. The local wind direction can be assessed from the plot plan, hotspot location and source location when identified.

variable), potential for emissions due to maintenance or operations, signature composition based on process or stored material.

The refinery staff will therefore need to reference:

- The refinery source emissions database, recognising that channelled as well as diffuse emissions will be detected.
- Operations data for sources with time-varying emissions.
- On-the ground activities that may have caused temporary emissions.
- Composition and state data on material handled in upwind plant.

If no explanation for the emission can be found then the contractors will propose to locate the source.

Location steps may include further screening concentration measurements to confirm that the "hotspot" persists and provide input data for emissions assessment, followed by use of optical gas imaging (OGI). OGI usually has a working distance of < 30 m but this depends on the size of the source. If the source is considered likely to lie within a process section, the OGI operator will need to enter the section. This may require authorisation.

When the source is located the contractor may plan further concentration measurements to assess the emission rate because measurement locations that favour detection may not be optimal for emissions assessment. The contractors should discuss suitable measurement positions. It may be necessary to wait for appropriate wind conditions to occur.

As the survey progresses, preliminary estimates of emission rate from located sources and from targeted refinery sections will also be discussed in the daily meeting. Sufficiency and quality of data is very important. The contractor has to decide when enough data have been gathered to assess the emission flux and to quantify uncertainty. Full data analysis will take place after the survey completes and working estimates may later be revised. It is important to note what concentration measurements have been made, whether they are consistent or show change, indicate a steady, time varying or intermittent emission flux. Note should also be made of prevailing conditions and whether they were favourable or otherwise.

It is important that a record of the daily meeting is kept. It will be useful to the refinery when reviewing the contractor's draft report.

- The identification of emission sources in the final report should concur with the findings of the daily meetings and the information given to the contractors by the refinery.
- The assessment of emission rates for refinery sections or sources will combine results from several days of measurement. The daily review narrative may be very useful in understanding the uncertainty in the overall assessment.

Items of the daily review discussion that will be important to record for review of the draft report are:

- Refinery supplied information on operations/process conditions, etc.
- How emission sources were located.

- Evidence of wind deviation e.g. “hot spots” or greatest concentrations do not appear exactly downwind of the source when using the reference wind direction.
- Identification of any concentration measurements as unsuitable for use in emissions assessment, e.g. made too close to a structure/building, made at an oblique angle to the wind direction, insufficient data points.
- Availability of upwind concentration measurements to establish background.
- Availability of air composition samples.
- Problems encountered.
- Appropriateness of meteorology conditions (windy, calm, changeable, cloudy, raining).
- Confidence in the day’s work.

If contractually agreed the discussions following source localisation would also include the use of TC or RDM techniques for emission assessment.

TC is only applicable to suitable localised sources. If it is to be deployed then permits to work within the section and to release tracer, taking account of relevant safety and engineering considerations for placing of tracer equipment, will need to be prepared.

Daily review will take the same form as for other techniques. Additional points of discussion will be:

- The adequacy of tracing, whether tracer can be released from the emission source.
- Tracer release quality (constancy and amount of release).
- Concentration measurement adequacy (coverage of emissions).
- Correction for background.

RDM is unlikely to be applied to a newly discovered source because the technique requires extensive preparatory work. The models needed to simulate dispersion from the source need to be developed and validated. RDM is best suited to custom deployment.

Daily review will take the same form as for other techniques. Additional points of discussion will be:

- Concentration measurement adequacy (coverage of emissions).
- Correction for background.

At the end of the survey period there should be a summing up of the work and an indication of how the survey report will express its findings. There may be several questions left open for investigation.

4.6. ACCEPTANCE

The survey has been completed. Intermediate results have been discussed with refinery staff on a daily basis. The refinery has been alerted to any sources of emission not included in the refinery emissions management plan and launched appropriate investigation/mitigation actions.

The contractors have reported preliminary results.

The contractors will now consolidate the information they have to present a draft report.

For detection the report should duplicate the results communicated through the daily exchanges and summarised at the end of the survey period.

For assessment the report will reflect a deeper analysis. This should take account, for each refinery unit or discrete source, of measurements taken across several days in a sufficiency that exceeds the minimum requirements set in EN 17628 for the method.

The deeper analysis will include:

- Correction for background (upwind) emissions.
- Uncertainty due to random variations associated with the measurements.
- Uncertainty due to systematic errors e.g. wind speed or direction, modelling assumptions.

Unless a source is known to vary in time, and has been monitored on this basis, emission rate will be assumed constant.

Assessed emission rates apply only to the periods of time for which the sources were observed.

The refinery has methods of assessing emissions. If these can be applied to the short periods of time of the survey, then a comparison can be made between method predictions and survey results. If these disagree then the survey results may need to be queried.

The points of report review therefore cover:

- Fulfilment of objectives.
- Clarity of narrative, regarding what was done in a procedural sense.
- Description of sources/refinery units.
- Description of method.
- Description of meteorology during the study period. Conformance with EN 17628 imposes some conditions on the processing of meteorological data and identification of periods of time when measurements can be made and periods when they cannot.
- Description of emission rate assessment and calculation method by source together with results.
- Assessment of uncertainty for each source assessment.
- Statement of compliance with EN 17628 and evidence for such. If there are exceptions such as uncertainty not meeting target values, then explanation for the same.
- Conclusions and recommendations.

The draft final report will take some time to prepare. It will be generally difficult for the refinery to answer if the authors later realise they missed critical contextual information.

It is possible that the refinery disagrees with the findings of the report regarding assessed emission rates. The ability of the refinery to seek clarification depends upon:

- Availability of working files showing measured data and calculation method (including uncertainty assessment) and completeness of these files.
- Daily record of results discussions where these data were presented and discussed on a disaggregated basis.
- Willingness of the refinery to engage in challenge.
- Cooperation of the contractor.

The biggest areas of systematic uncertainty (e.g. leading to bias in assessed emissions) are:

- Deviation of wind properties from the reference values (speed, direction) in the locale where concentrations are measured.
- Incorrect assumptions about gas composition.
- Incorrect correction for wind speed based on a vertical profile of wind speed and height of dispersing VOC.
- Insufficiency of data from which to draw statistically robust conclusions.

Pointers are given in **Appendix C**.

5. CONCLUSIONS

This document has led through the steps of preparation and execution of a survey to assess diffuse VOC emissions (in context of the standard this excludes methane) and some steps that can be taken to assess whether the methods used in the survey have been applied rigorously.

It is strongly advised that the assessment of diffuse emissions is not treated as a "black box" process. The refinery should encourage the contractor to expose and explain measurement data as they are acquired. If the results are unexpected there must be sufficient exposure of data, assumptions and calculations available for verification purposes.

Remote sensing methods were first designed to seek out unknown emission sources. The proposition that refineries have unknown, and hence uncounted, emissions has become established as a concern. This concern underpins the current requirements, expressed through BAT, to investigate and assess diffuse emissions.

Refineries can work to eliminate unknown sources by proactive emission screening, particularly on equipment ordinarily out of scope of LDAR programs. The development of the optical gas imaging camera provides an effective means to do this. OGI is a powerful investigative tool able, as part of an inspection and maintenance program, to detect emission sources likely to be detected by survey.

Note the emphasis is on eliminating the "unknown". A source identified by the refinery and accounted for in the emissions management system is a known source, even an unintentional one scheduled for mitigation.

A survey is potentially disruptive. During its course, information will be sought to explain often transient sources of emission. These can come from normal refinery operations. This guidance report urges that the refinery review how information on operations and operating conditions can be quickly passed between site personnel without disrupting the normal course of work.

A survey should be purposed. A survey can provide valuable information about how the refinery assesses emissions and how effective its methods are. It is important to set productive measurement objectives. Equally important are requirements placed on deliverables. An open approach should be encouraged. Here the survey contractor shows collected data, explains how they are used, the assumptions made and calculation used to assess emissions. Deliverables can formally require that these data and intermediate working steps are reported. This guidance suggests this is done as an electronic (e.g. spreadsheet based) data report. The capability to examine the basis for reported emission values will assist the refinery in accepting the work done.

The assessment of emission rate is not a precise process. There are many sources of uncertainty. Uncertainty has two components, random uncertainty and bias. EN 17628 focusses on random uncertainty. For example, estimates of emission rate should have an indicative uncertainty smaller than 30% of value at the 95% confidence level. This condition can be met even if results are a factor of 2 too high (or low) because of bias.

Bias in a technique cannot be detected without an independent verification method. The greatest potential for bias in emissions assessment is incorrect use of wind parameters in calculating emissions and incorrect gas composition data. The potential scale of a bias effect can be tested using sensitivity calculations. This is why this report recommends intermediate results and calculations be reported in a useable form.

Diffuse emissions from storage should be assessed reliably if the guidelines on downstream separation between the storage unit and concentration measurement location are observed. Interpretation of results involves understanding the stored products, product movement and environmental factors affecting tank breathing.

Diffuse emissions from process areas should be assessed reliably if guidelines on downstream separation between the unit and concentration measurement location are observed. Uncertainty will be highest at low wind speed conditions where waste heat from the unit may cause convection. Vertical convective flow can also be caused by mechanical means e.g. air-coolers. Assessment methods all assume horizontal flow.

Diffuse emissions from wastewater treatment areas may not be assessed accurately or able to be assessed at all. Success will be critically dependent on the site configuration and favourable meteorology. The wastewater facilities can be included in the site survey but results should be regarded as indicative rather than absolute.

A diffuse emissions survey informs only on emissions observed. It does not reflect annual emissions and results from the survey cannot be annualised. The survey can, applied to specific refinery sections, be used to assess refinery bottom up inventory methods where these take account of how changing operational and environmental parameters affect the variation in emissions with time.

APPENDIX A: SUMMARY OF TECHNIQUES

The techniques in EN 17628 are summarised below. The main techniques have also been described by Concawe [4,11] and in the informational chapters of the Refinery [7], Common Waste Water [9] and Common Waste Gas [10] BREFs.

A.1 OPTICAL GAS IMAGING (OGI).

OGI is the method of choice for localising single sources of emissions. An operator uses an infra-red sensitive camera to visualise emissions. OGI has been mainly used to inspect potential emission sources for leaks in the context of leak detection and repair and supporting traditional “sniffing” methods using aspirated wands to make a point-by-point inspection. However, OGI operates from a distance of a few (< 30 m) metres and can be used to inspect a variety of sources. A very practical one, proven in work to support the standard, is inspection of external floating roof tank seals. OGI was developed to inspect for alkanes but there are camera adaptions for other VOCs. The technique is not yet quantitative but a trained operator can readily assess sources as small/medium/big. There are developments to make the next generation OGI technique semi-quantitative but this capability is not explicitly recognised by EN 17628.

OGI is so practically useful that it will always be used as part of a VOC campaign to localise sources where these are identified remotely by other techniques. Although OGI has been criticised in the LDAR context for not detecting very small leaks compared to sniffing, these individual leaks are not the target of a diffuse VOC survey.

OGI is a non-proprietary technique and cameras are commercially available. The technique is in use in refineries, by refinery staff, and also by a number of environmental contractors specialising in LDAR. If used proactively by a refinery as part of regular maintenance inspection it should reduce the probability of a remote VOC survey finding unknown emission sources.

A.2 DIFFERENTIAL INFRARED ABSORPTION LIDAR (DIAL)

DIAL has been the reference method for determining diffuse VOC emission rates using remote sensing for more than 30 years. Operating in the infra-red it is optimised for the measurement of alkanes but can be used for many other VOCs that absorb light at the instrument frequency, generally with a higher uncertainty. DIAL provides a range-resolved concentration measurement across a vertical plane. This is achieved by scanning with a pulsed laser beam and measuring the properties of the laser-light reflected from the atmospheric aerosol. One wave-length is absorbed by the VOC and the other acts as a reference. The difference is proportional to the mass of VOC in the light path segment (~ 3 m). The measurement range can extend to a few hundred metres and the scanned area is large enough to cover one or more large storage tanks or a process-unit.

A DIAL system is large. It comprises a mobile laboratory mounted on a standard articulated trailer. There are access limitations but once in place the system is very flexible. DIAL orients the direction of the laser beam so that it is normal to the wind direction. It then scans, in a vertical plane, across an open area downwind of the target. It builds a 2-D concentration map over a period of order 5-10 minutes. The map is interpolated from polar co-ordinates to a cartesian grid with resolution of ~ 3 m in the horizontal and vertical. The concentration cross-section informs on the nature of the source. A wide cross-section of low concentration characterises the cumulative emission of multiple diffuse emissions from, for example, a process unit. A narrower cross-section with higher concentration indicates a possible discrete emission source which can then be located using OGI. The height of the source can be judged from the concentration profile. This is important in estimating the correct wind speed to use in estimating emission flux. A measurement can be rejected as incorrect if the concentration profile is not consistent with assumptions used in the emissions flux calculation.

Because DIAL operates from a fixed location for an extended time, supporting meteorological measurements can be made to verify the direction of the wind and to ensure that the unit being surveyed is not interfering with wind speed or direction. Such measurements are usually made at 2 m height. Reference wind conditions will be measured at 10 m in one or more refinery locations that are free from aerodynamic interference.

DIAL can operate at night and for extended periods of time from one location. Depending on the particular circumstances DIAL may be able to switch scans between measuring upwind and downwind of the unit without physically moving the laboratory and thus be able to separate net emissions from the target. More generally the unit would have to be moved.

DIAL measurements are relatively easy to explain and to understand. The measurement is consistent with the emission flux calculation model assumptions. The time-averaged plume measurement lends itself to traditional analysis of uncertainty and emission estimates are given with a 95% confidence interval.

The composition of the VOC being detected has to be known because DIAL uses a simple correction technique. If the VOC mixture contains only small proportions of absorbing VOC species then the DIAL correction becomes large and uncertainty greater than when detecting alkanes. The normal approach is for the refinery to provide information on the composition of refinery streams, or stored material, in the section under investigation. Samples of ambient air will be taken, usually within 2 m of the ground, and analysed to confirm that background concentrations are representative of the stream composition.

Note: there is a presumption that the “typical” composition of VOC in refinery air near ground level is representative of what might be detected and assessed as an emission. Thus, there is a vulnerability if VOC composition changes with height. In practical terms this can be a problem if unsuspected material is present at height. If DIAL is not sensitive to that material, or if an incorrect composition weighting factor is used then errors may occur. A check should be carried out to see whether material being handled in units upwind of a measuring location is significantly different to what is expected to be measured locally.

Composition adjustments are applied to DIAL results in post processing. It is important to be sure that sufficient composition data is gathered during the survey, especially if large adjustments to calculate mass-flux are likely to be needed.

Care must be taken when separating emissions from neighbouring units if the correction factor is very different for emissions from different units.

DIAL has an indicative wind speed window of 2-10 m/s. The lower end is limited by increasing variability in wind conditions as wind speed decreases. This compromises the flux calculation accuracy. The upper end is a concentration limit as dispersion is more effective at higher wind speeds.

At the time of writing the only known operator of DIAL is the UK National Physical Laboratory (NPL).

A.3 SOLAR OCCULTATION FLUX (SOF)

SOF is good for emissions detection and is more flexible than DIAL for surveying a refinery for potential emission sources. The SOF technique uses the sun as a light source. It measures light absorption at several, rather than a single, wavelengths. Given a target gas composition, the observed absorption spectrum can be used to calculate the mass of VOC in the light path.

Refinery air samples must be taken and analysed to establish a target gas composition. It is assumed that VOCs present in refinery air near the ground are representative of emissions. If the measured gas absorption spectrum is a poor fit to the calculated target gas spectrum this should be detected. SOF therefore has some protection against systematic error arising from incorrect VOC composition assumptions.

SOF provides a path-integrated concentration. This is the total amount of target gas inside the measurement path. It is assumed that this material is in the lower atmosphere above the refinery. Reference measurements away from sources should provide a background. This should be clearly reported.

SOF provides no spatial information along the line of sight. The spatial extent of the gas has to be estimated and a height above ground assigned. From this height a wind speed for use in the flux calculation is estimated. Wind speed increases with height. This is a potential source of error (bias). Too large a wind speed will give too large a flux.

The SOF instrument is mounted inside a vehicle and driven around refinery roads. Roads should be paved so that the vehicle moves smoothly and avoids vibration and pitching. The measuring instrument uses a solar tracker so that it always orients toward the sun, irrespective of the vehicle trajectory. Measurements cannot be made if the line of sight to the sun is blocked.

In typical use, a measurement is reported approximately every 10 m of travel. This reflects the speed of the vehicle and the time taken to measure the absorption spectrum and perform the deconvolution to target species and to sum. The measurement reflects the average path-integrated concentration over the travel segment.

As the vehicle passes through VOC it records an elevated reading. Because the technique is highly mobile, and sensitive to VOC, it is very good for detecting those concentration “hot spots” that occur on refinery roads.

The vehicle position is continuously recorded using a GPS system. Concentration profiles can be transferred to a map of the refinery road. Using a plot plan the neighbouring equipment can be identified. Satellite imagery (as from the Google Earth™ application) can also be used. Information on the reference wind direction can be added to identify the expected direction of VOC flow.

Where a source is detected, it can then be localised using OGI if not identified as coming from a known source.

SOF does not, as a method, use supporting meteorological measurements. Judgement has to be used to assess if reference wind conditions apply and whether to make adjustments. Properly a sensitivity analysis should be made to test how the calculated flux depends on wind parameters.

Interpretation of SOF emission flux assessments is difficult compared to DIAL and subject to greater uncertainty. This is discussed in **Appendix C**. SOF assessments may suffer positive bias but by how much is not known.

Each SOF flux determination is obtained as an integral along the driven path of the SOF concentration measurement multiplied by a wind speed and corrected for wind direction. The wind speed depends both on the reference wind and an assumption about vertical wind profile and height of VOC above the ground. The accuracy of the numerical integration depends on the number of measurements and their separation.

Each derived flux value constitutes a "snapshot" of duration given by the drive-by time. Snapshots cannot be combined to give a conventional time average. They are taken at different times, with differing wind conditions, with possibly different solar elevation and azimuth. Emissions may also change. The variability of snapshot values is often high.

Results are presented statistically. The source emission rate is identified as the median value of the distribution of flux snapshot values.

Reporting requirements under EN 17628 are insufficient to assess uncertainty in a rigorous way. In particular the assessment of net emissions (the mass flux downwind of the target minus the mass-flux from upwind of the target) is not clear.

SOF relies on the availability of sunlight. The sun must have a minimum elevation. Cloud cover and the number of useable daylight hours affect applicability. SOF has a similar wind speed window to DIAL. Flux determinations at low wind speeds (≤ 3 m/s) are likely to be adversely affected by convection and have a high uncertainty.

At the time of writing the only known provider of SOF services is FluxSense AB. They operate in Europe, USA and China.

A.4 TRACER CORRELATION (TC)

The TC method set out in the standard is a variation on traditional tracer methods that has been developed by FluxSense AB.

TC cannot be used for detection. It is used for emission assessment when the source of emissions is precisely known. A tracer gas is released at the point of VOC emission at a known rate. The concentration of tracer and VOC are measured at points downwind. Provided that the tracer and VOC are intimately mixed the VOC emission rate is proportional to the tracer release rate, in the ratio of their concentrations.

The TC technique is easy to understand. Accuracy depends on correct positioning of the tracer and correction for upwind or other interfering VOC sources. The concentration measurements are most readily made near to ground level. The technique is less useful for elevated emission sources because the gases must mix to the ground to be measured. An omission in EN 17628 is that the method is not required to establish that the footprint of the tracer in the measurement plane matches that of the VOC from the traced source.

The choice of tracer gas, and the release of tracer may be restricted on refineries. A safety assessment will have to be carried out.

At the time of writing the only known provider of TC services as described in EN 17628 is FluxSense AB. They operate in Europe, USA and China

Use of tracers (in a slightly different way to TC) is a well-established emissions assessment technique that fell out of use when SF_6 was banned for tracer gas use. Of the assessment techniques named in EN 17628 TC could be implemented by an independent contractor.

Although TC as described cannot be used for detection, the concentration measurement system used by FluxSense is mounted in a vehicle. This vehicle can be driven around the refinery to map ground level concentrations. Such mapping can indicate the presence of sources in the same way as SOF, provided that the sources are not so high above ground that the emissions do not mix to the measuring height. Similar mobile measurement systems have been widely used for urban pollution monitoring.

A.5 REVERSE DISPERSION MODELLING (RDM)

RDM is an advanced technique that in essence simulates the TC technique by using a computer model to mimic the dispersion of the tracer. It can be used to model sources that cannot be physically simulated with a tracer release, such as area-sources. Emissions from water treatment would be an example of an area source.

RDM cannot be used for detection.

RDM is not suited to assessing emissions from a whole refinery. It is suited to specific cases.

RDM demands a high level of skill, and very significant investment in time and effort, to set up the necessary flow and dispersion models. Once configured and tested the method can be used multiple times for the specific facility. It is unique to that facility.

As described in EN 17628 the technique uses near ground measurements of concentration to infer emission rates and as such is applicable to where the emission plume reaches the ground.

At the time of writing the specific RDM described in EN 17628 is not offered commercially by the developer Total. It would be within the competence of some university departments and technical consultancies specialising in computational fluid dynamics to implement the necessary flow and dispersion models. The algorithm to calculate the emission rate would have to be developed, tested .and shown to meet the required performance standards.

Although the specific RDM implementation described in the standard is not intended for detection, the concentration measurement system could be used to generate a map of ground level concentrations. The detector system is hand-held so is restricted to measurements local to a suspected source.

APPENDIX B: EXAMPLE SECTION SURVEYS

B.1 INTRODUCTION

This section provides a narrative on emission sources and how survey techniques might be applied to certain refinery sections in order to assess these emissions.

This section is intended to provide background information that may be useful in the review of the contractor's proposal for work, the daily review of work in progress and the possibly the formal review of the contractor's draft report.

Contractors working to EN 17628 should be aware of the issues that affect how measurements and calculations are made.

These mainly relate to where concentrations are made and how wind data are treated in assessing emissions when an emissions flux is calculated

Unless specific reference to a necessary refinery action is made any instructions herein reflect expected contractor actions.

B.1.1 A note on wind

Emission assessments obtained by combining concentration measurements and wind-data are very reliant on wind properties. Wind measurements are made at one or more reference positions to advise the survey process. A detailed discussion on wind is provided in **Appendix C**, while the section below highlights the main points for attention.

EN 17628 recognises several things about wind properties.

- Only periods of steady wind can be used for assessing emissions.
- A steady wind is defined as one having a reasonably constant direction for at least 10 minutes. All measured wind speed and wind direction values are averaged over the preceding 10 minutes. A steady wind is described as persistent. A numerical criterion for persistence is used. This is a single parameter that combines variability in both wind speed and wind direction. If persistence is too low, then the wind is too variable for flux calculations to be reliable.
- Wind speed increases with height. The change with height depends on atmospheric stability. Reference stations measure wind speed at 2 heights. Contractors should report the assumptions they make about the vertical wind speed profile. This includes goodness of fit to the reference measurements. There are expected forms for the atmospheric wind profile that develops over long stretches of flat land.
- Wind direction changes with height are ignored. This is a practical consideration. For emissions at tall stack (> 250 m) height, and rising with buoyancy, the wind direction can be very different to that near the ground. Diffuse emissions generally disperse much below 100 m. For certain tall sources such as flares the wind direction can be visually confirmed from the direction of the flame. Vapour emissions from stacks also inform on whether wind direction change with height is present on a measurement day.

- Calm periods have to be excluded. Assessment methods must specify a minimum wind speed. The persistence criteria exclude low-wind speed periods because the wind direction during these is very variable.
- High wind speed periods have to be excluded. Assessment methods must specify a maximum wind speed. The value is linked to their ability to measure low concentrations because dispersion increases with wind speed.
- Wind interacts with obstacles. This is a very complicated subject but essential.
- Wind goes around refinery objects which changes wind direction and wind speed.
  - Low wind speed and highly turbulent regions occur behind obstacles. Concentration measurements made here cannot be used for flux calculations.
  - It takes some distance for the flow around the obstacle to recover its initial state therefore flux measurements using upwind (reference) wind conditions must take account of wake effects.
  - EN 17528 adopts the principles of VDI 3786 guidance for the siting of meteorological instruments and provides some criteria for judging separation from upwind structures.
- Wind is affected by the refinery. Reference wind measurements, made upwind, show the properties of the wind as it arrives at the refinery. The wind will follow the path of least resistance through refinery and may deviate considerably from its upwind values. More than one reference wind station may be installed so as to provide upwind data for more than one wind direction.

From a refinery view it is important that contractors openly address the use of wind data in their studies and communications. They should demonstrate the impact of uncertainties in wind speed and direction on calculated fluxes by means of sensitivity calculations. Errors in wind speed and direction contribute to bias (systematic error) in flux calculations.

B.2 STORAGE TANKS

Storage facilities are a potential source of emissions.

- Tank emissions are generally split between standing losses (breathing losses) and working losses. Standing losses occur over the course of the day and are unlikely to be captured by a short term measurement (< 1 hour): the values will fall within the measurement accuracy level. Working losses occur during tank filling (fixed roof tanks) or during tank emptying (floating roof tanks) and will be captured if such movements take place during the survey. For interpretation of the survey results in tank farms, tank movements should be tracked.
- Floating roof tanks (both external and internal types) will emit while the tank liquid-level is decreasing due to the small amount of fluid retained at the tank wall. The main sources of emissions are vapour loss from roof fittings and the peripheral seals. Increased emissions can arise from the latter due to gaps or damage to the seals. Other emissions can occur due to poor operating practice such as allowing the roof to rest on the supporting legs at low liquid level. Ambient conditions such as temperature/insolation, wind speed, wind gusting and the associated pressure fluctuations influence product vapour pressure and consequential tank breathing losses respectively.

- Fixed roof tanks used for the storage of low volatility liquids are less likely to be sources of significant diffuse emissions but may be sources of emissions if pressure relief/breaker valves vent to air directly, or are collected and vented
- Fixed roof tanks used for the storage of more volatile liquids may be connected to other vessels for vapour exchange, or be connected to a vapour recovery unit, during product movement. Emissions from pressure relief/breaker values are more likely to be routed to vapour recovery or destruction units.
- Open tanks for storing process water are rarely used but any contaminating hydrocarbon may evaporate. Open tanks used for storm water are not expected to be significant VOC sources
- Tanks of very different capacities may be sited together, and in many cases tanks are grouped within bunded areas to contain liquid in the event of a tank failure. The size and arrangement of tanks, including the bund geometry, affects the wind flow around them and the dispersion of any released VOC.

Concawe has investigated remote sensing of diffuse emissions from tanks:

- An extended (90 hour) study use of DIAL to examine emissions from a floating roof tank engaged in loading operations showed that it was vital to have information on tank movements if emission flux measurements are to be interpreted [12]. The study also supported use of the EPA Tanks model which uses the API 2517 method of estimating emissions. A wind tunnel was used to simulate the effect of emissions from seal leaks. The dispersion of emissions from single tanks and groups of tanks, in the absence or presence of bunds, was simulated. Physical modelling in controlled conditions allowed precise measurement of concentrations and an accurate mass-balance, between calculated flux and release rate, to be made. The studies confirmed that the wind speed behind a tank, or arrangement of tanks, is reduced. If the emission flux is calculated using a reference upwind wind speed then the flux can be significantly overestimated. The report can be obtained on request from Concawe [13]
- Field experiments with DIAL were carried out to further investigate emissions from tanks [11]. Controlled releases from an open topped tank were measured by DIAL. The release simulated emissions from a floating roof tank with the roof at a low level. The study found that measurements made with a DIAL scanning plane between 3 and 5 tank-heights downwind could yield accurate emission estimates providing due account of wind-profiles was taken. Otherwise, emissions would be over-estimated. Between 5 and 10 tank heights downwind there was some under-estimation. This was attributed to some VOC passing below the scan pattern.

B.2.1 DIAL

To survey tanks with DIAL, the instrument should be located to allow a clear line of sight behind the target tanks. The scan line should pass as close to normal to the wind direction as possible. Ideally, it should pass no closer than 5 tank heights behind the closest tank. This is a guidance given in EN 17628 and consistent with Concawe studies [11].

The DIAL protocol requires local measurements of wind speed and direction to be taken. These are compared to the reference wind data. They check that the scan-line is outside of the shelter zone behind the tanks and establish the local wind speed and direction. If the wind direction differs from the reference wind direction the scan path can be adjusted.

The local wind measurements should be taken for the duration of the DIAL measurement and be analysed in the same way as the reference wind data as set out in EN 17628 to give running 10 minute average values of wind speed, wind direction and wind persistence. Concentration measurements can be used for flux assessment if values of these parameters are within acceptable limits.

DIAL measurements have to be conducted upwind as well as downwind of the tanks to eliminate external emissions. There is no specific requirement in EN17628 on the spacing between the DIAL plane and the upwind edge of tanks but there will be modification of the wind-field as it approaches the tank array. The separation should be reported and potential for interference discussed. Accompanying portable wind speed and direction measurements should confirm that it is negligible. In the absence of measurements, a separation of 5 tank heights is recommended.

If upwind emissions are found to be significant and variable then it may be difficult to determine the tank contribution separately.

Note that measurements may not be possible for some wind directions, depending on the layout of the refinery.

DIAL provides a concentration cross-section of the VOC plume crossing the DIAL scan plane. The data is converted from the measurement polar co-ordinates to a cartesian grid in preparation for the flux calculation. It is a useful visual guide if this gridded data is plotted as a 2-D chart with concentration isopleths. This information should be made available and discussed with the refinery.

The shape and value of the concentration isopleths indicate the nature of the emission. For example, the vertical and horizontal extent of the plume; a compact plume will indicate a nearby source and a diffuse plume a more distant or multiple sources. The completeness of plume capture can be assessed. In particular it can be decided whether it is appropriate to extend the concentration profile to the ground if it appears that some emissions might pass under the scan path.

The centroid height can be calculated and, together with the wind profile, used to calculate the wind velocity to be used to calculate flux. If the scan-plane is not normal to the wind direction then a correction will be made.

Much of the above flux analysis will take place after data capture. It is important to ensure that relevant data are captured and that the capture is verified at the measurement time.

The interpretation of emissions will only be possible if tank movements, fill level and liquid composition are known for the measurement period and for all tanks (e.g. those upwind) of the DIAL scan.

B.2.2 SOF

To survey tanks with SOF the instrument is driven along on refinery roads bordering the tanks. Multiple passes are made at intervals of several minutes and on both upwind and downwind sides of the tank. Wind direction informs the driving pattern.

Refinery roads may pass very close to the tanks. This is an advantage for detection and a disadvantage for assessment.

For detection, VOC can be retained in the shelter zone behind the tank. If the road passes close enough to this zone, and the sun is in a suitable position, the SOF path-integrated concentration can be enhanced. As a result, SOF has the potential to quickly flag “hot spots” within a tank farm. The horizontal extent of the shelter zone is at least 3 tank heights and may be as much as 5 tank heights on the downwind side.

VOC concentrations measured inside or near the shelter zone cannot be used for assessment because the methodology will give a large overestimate of emission flux.

For assessment the SOF instrument should be driven on roads downwind from the tanks and across the wind direction. The separation from the tank should preferably be more than 3 tank heights, increasing to 5 tank heights if the SOF column passes over the tank due to the sun’s position.

Unlike DIAL the SOF measurement path cannot be trimmed to lie normal to the wind direction. Also, the local wind direction is not known because supporting wind measurements are not made. From a practical point of view, therefore, it is not possible to arrange each individual measurement contributing to tank emission assessment.

Instead, SOF measurements are made continuously. The results are then reviewed. A selection is made of those results most suitable for analysis. This can be done by marking the path-integrated concentrations on a refinery plot plan. There will be a data point approximately every 10 m distance along the roads. The reference wind direction can be marked. Those lengths of road that pass too close to tanks can be marked and their data are excluded.

The remaining data can then be assessed:

- Do they lie approximately normal to the reference wind direction?
- Do they capture a VOC plume?
- Does the centroid of the cross-section lie directly downwind of the known (localised) source?
- If not, assess the effective wind direction by drawing a line between the source and the centroid of the measured concentration profile.
- Use this effective wind direction when calculating the emission flux.

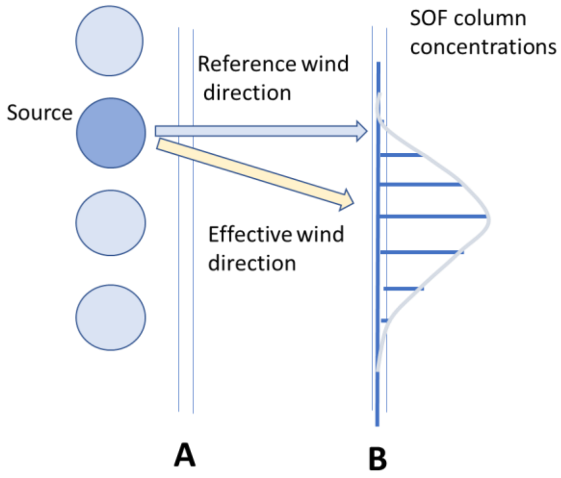

Figure 1 Measurements on road A are too close to the tanks to be used for assessment. Measurements on road B show increase to maximum and decrease suggesting the presence of an emissions source and that the dispersing VOC is captured. The source would be located using OGI. In this case the source as shown is not on the tank that would be expected taking the reference wind direction and the location of the maximum SOF column concentration into account. Once the source has been found a local wind direction can be inferred, assuming the centroid of the column concentration distribution marks the plume centreline.

This analysis can be carried out for each traverse and the measurements assessed. Results have a large variability because:

- SOF traverses are quite rapid (tens of seconds) and dispersing VOC is not homogenously mixed.
- Traverses are repeated at intervals that can be far apart, from several minutes to days.
- Each traverse is conducted under different atmospheric conditions.
- Different roads may be used as wind direction is changed.
- Source emission rate may change in time.

The source assessment is based on the distribution of fluxes calculated from traverse profiles that consistently show a VOC plume. A large number of profiles may need to be considered. The protocol requires more than 12 valid traverses in sets of at least 4 passes on each of 3 days.

The results are expressed as a statistical distribution. The distribution is often not symmetric about the mean value and the median value is taken to indicate the emission flux. Variability is assessed as a 95% confidence limit.

The process involves judgement and data selection. It is important that intermediate results, such as column-concentration distributions are retained and reported. An electronic spreadsheet format is recommended.

B.2.3 TC

Subject to safety considerations on the use of tracer, TC can be used to assess emissions from, for example, a failed seal on an external floating roof (EFR) tank provided that the source can be simulated directly, i.e. the tracer must be released from the location of the emission source.

The Concawe wind-tunnel study showed that releases from different positions within an EFR tank gave rise to very different dispersion patterns. It is not sufficient to release tracer from a point on the tank roof access walkway and assume that it disperses in a similar manner to a release on a lowered tank roof.

Differences in ground level concentration from different release points do diminish with distance. Measurements more than 20 tank heights downwind are preferred to lose sensitivity to source position [13]. However, the demand for tracer may be high, especially if the tank roof is low and the tank is large, if tracer is to be measured at this distance.

B.2.4 RDM

The RDM implementation described in the standard has not been tested for emissions from tanks within the verification scope of EN 17628. In principle the method could be applied provided that a suitable flow and dispersion model(s) are developed and shown to fulfil the performance requirements of the standard. Accompanying guidance on the distance downwind of the tank(s) beyond which the concentration measurements should be made must also be provided.

B.2.5 General considerations for emission assessments with DIAL, SOF and TC

It is important to assess the preliminary findings of a storage section survey to prepare for detailed discussion of the draft formal report on emissions found during the survey. This draft will need to be approved and may arrive several weeks after the survey is completed. There is no assurance that preliminary emissions estimates and final emission estimates will be the same.

A primary concern is whether initial results suggest there may be leaks. For example, if emission estimates exceed, say, 10 kg/h, of emission not explained by operations then an inspection should take place, for example using OGI to localise a mechanical failure. Such localisation activity might be agreed to be carried out in the scope of the survey or done independently.

If an emission source is found then there is an implication for the site reporting of annual emissions. Efforts should be made to establish when the emission may have started, and maintenance scheduled to determine when the additional emission will be stopped.

It will be generally useful to evaluate whether surveyed emissions are coherent with the expected emissions from the tank(s) using site inventory methods if these can be used for the short period of the survey and calculated before the draft report is presented for acceptance.

If a significant difference (higher or lower) is found between site expectation and the survey results then this is an important point for the acceptance review. Availability of intermediate data and calculation assumptions will be important inputs to the resolution. In such a comparison the refinery methods are also open to challenge, with potential consequences for reporting.

There are multiple reasons for operational emissions that may be captured in the survey and which are short term. It is therefore important to record all operational events that occurred. In preparing for the review the site should consider, inter alia,

- Were all the tanks static or was any tank moving during the survey?
  - Note: fixed roof tanks may emit VOC when they are filling; floating roof tanks may emit VOC when emptying;
- Was there any special tank activity taking place: maintenance; tank cleaning; roof landing?
- Was there any tank equipment malfunctioning: tank seal integrity; nitrogen blanketing control system operating per design?
- Were atmospheric conditions likely to cause noticeable tank breathing activity?
- If important up-wind sources were identified, have they been constant during the measurement of the (total) down-wind emissions?

For further investigation the following approaches can be used:

- Using the API 2517 equations, calculate the expected “losses” for the measurement duration using the actual data (i.e. those at the time of measurement): feedstock composition and temperature, ambient temperature and insolation, throughput if the tank was not static.
- Reconsider the current feedstock characterisation: is the correct vapour pressure used? Heavy intermediate product stored in heated fixed roof tanks might have varying levels of light cracked material.
- Evaluate tank level variations in periods where the tank was static and with comparable temperature data (both liquid tank temperature and ambient temperature). For large tanks (e.g. 30 meters diameter) a static period of > 1 week is needed for any abnormal level variation to be visible.

B.3 PROCESS AREAS

For safety and environmental purposes, process areas are subject to leak detection and repair programmes (LDAR). These address emissions arising from loss of tightness of fittings and from wear on moving parts such as pump seals. Emission estimates are made using a statistical method. This weights the distribution of sources found with emission factors representative of the various source types.

The detailed conduct of LDAR programs is covered by EN 15446 and is not discussed here.

It is expected that calculated emissions decrease from the time of an LDAR survey as sources scheduled for repair are tightened or components replaced. The methodology is robust for large units with a great number of potential sources.

The prime objective when applying EN 17628 to process areas is to quantify emissions for the unit as a whole and not the pursuit of individual sources.

However, LDAR programs are limited in scope to accessible equipment and fittings. Fittings behind insulation or out of reach may not be inspected. Should preliminary measurements by SOF or DIAL indicate the presence of a large source or higher than expected emissions overall for the unit (e.g. > 2 times higher than the historical LDAR emissions from the area) then this should be investigated with OGI to rule out that a single (or small number) of sources are responsible

Although not subject to as much time variation in emissions as storage facilities there still remains the possibility of maintenance work, sample taking, cleaning, etc., giving rise to temporary emissions that might be detected. Accurate tracking of these activities is needed.

Process areas vary widely in size and function. They are associated with waste heat release (heat losses from pipework). They may have embedded process heaters connected to a stack. Process temperatures may be controlled using fin-fan heat exchangers, often installed in banks. Process units will shape the airflow around themselves and, for large units even the airflow around the refinery, due to their size and the aerodynamic blockage they present to the wind.

Concawe carried out assessments of how wind can be diverted by the presence of process units and other structures [14]. Similar behaviour was observed in validation studies carried out by CEN in the development of EN 17628 [15].

Wind speed and direction in the vicinity of a process unit may differ significantly from the reference wind measurements advising the campaign. This applies to the wind-field both upwind and downwind of the unit. The extent of the change is site specific.

A unit is usually characterised by one or more process vessels or reactors surrounded by pipework. In many ways it behaves aerodynamically as a building with the following characteristics:

- Immediately downwind there is sheltered zone in which air recirculates.
- Downwind of the recirculation zone is a near wake region in which the flow diverted around the unit reconverges.
- Further downwind the wind slowly adjusts to recover upwind values of speed, direction and vertical profile. This is called the far-wake.

Generally, the wind will impact at an angle on the longer face of the unit. The wake will extend from an extent around the trailing corner of the unit and wind may divert to follow the longer sides of the unit as indicated in **Figure 2**.

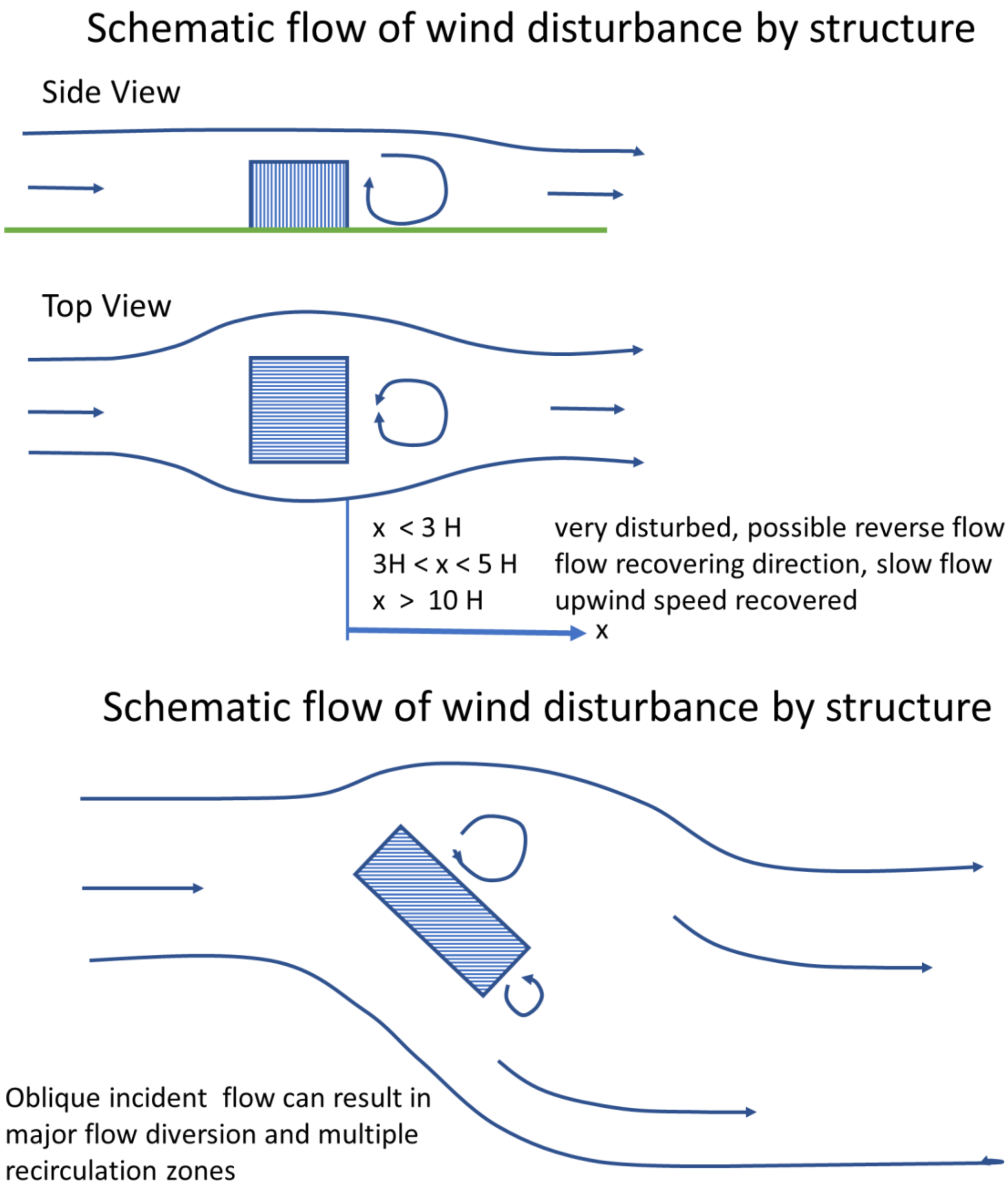

Figure 2 Schematic of flow around structures. Unless the building is very wide (as seen by the wind) and shallow the wind will divert around the sides if it can. Behind the building is a region of low pressure into which air will flow from above as well as from the sides. In this region air can recirculate giving reverse flow on average nearer the ground. The volume circulation rate can be much larger than the rate of volume exchanged with the surrounding flow. The extent of severely disturbed flow can reach to 3 or 5 building heights, H, downwind. If the building is angled to the wind then the disturbance can be greater with significant changes in direction and an increase in the downwind distance to recover the upwind conditions, generally > 10 H.

Less densely occupied units may act as if they are porous buildings with some flow passing through the unit. Unless the structure is very open this does not change the character of the flow described above substantially. The zone of recirculation behind the unit may be displaced downwind compared to a solid building and the whole wake extended [16]

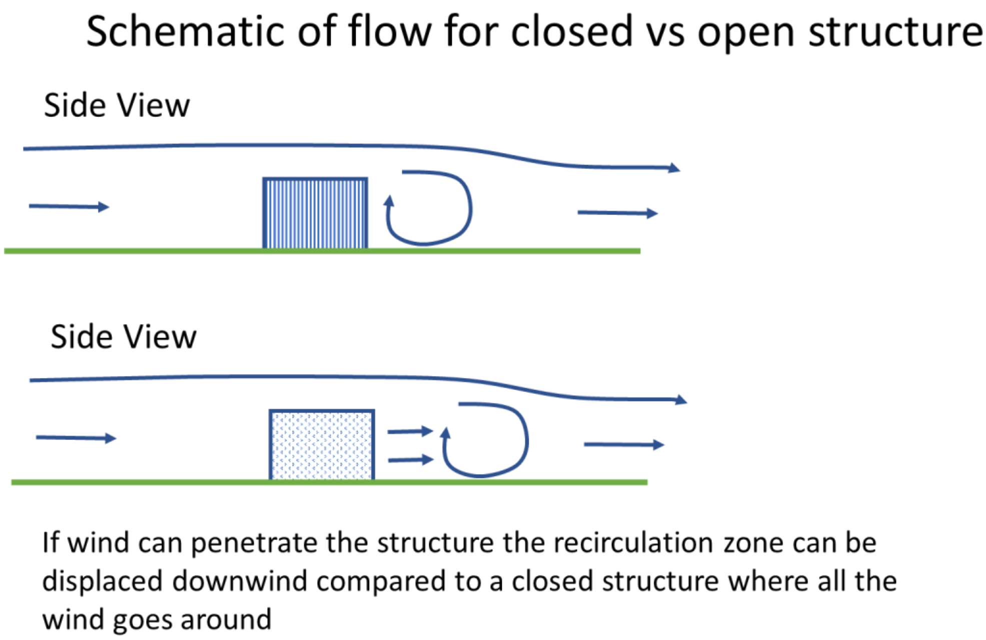

Figure 3 The gross aerodynamic influence of a structure on wind flow is not substantially changed if the wind can penetrate the structure. For example a process unit surrounded by pipework is not impervious to wind but presents much resistance to flow. The recirculation zone that would form behind an impervious structure is not as strongly attached and can displace downwind. The magnitude of the displacement is of order 1-2 H. This makes advice, such as avoid using measurements within 3H for flux measurements, difficult to turn into hard rules. Local wind measurement is advised.

Because of the effect of the structure on wind speed and wind direction, care has to be taken when locating measurements. The principles are the same as those for investigating storage emissions:

- No concentration measurements taken inside a recirculation zone should be used for flux assessment.
- Measurements should be taken in the far-wake when flow has been re-established.
- Account has to be taken of the deviation of the wind flowing around the structure.

B.3.1 DIAL

The DIAL protocol requires that local wind measurements are made. These are used to verify that the measurement plane does not lie in the recirculation region or near wake zone. The wind direction can be verified and the measurement plane adjusted to lie appropriately across the wind direction.

The plane will need to be further away from a process structure than for a storage tank. The separation expected is more than 5 times the unit height (i.e. the average height of structures within the process unit) and closer to 10 times the height if space allows.

The concentration profile should be extracted and examined to determine if it is consistent with the assumptions of the flux calculation method. Specifically:

- Does the concentration cross-section suggest that emissions are being lifted by heat release or mechanical driven flow?
- Does the concentration profile show that the emissions are being adequately captured?

A concentration profile that is symmetric, wider in the horizontal than in the vertical extent, is clearly above the detection limit for a large part of its extent, has a centroid below the height of the unit, and has substantial content above the lowest scan line would indicate these conditions are met.

It is preferable to avoid the lowest wind speed range of the method when investigating process units. At low wind speeds it is more likely that thermal/mechanical effects will influence the dispersion of emissions. The flux calculation method assumes horizontal flow driven by the wind.

B.3.2 SOF

SOF measurements are confined to refinery roads and refinery roads are likely to pass very close to process units. SOF transits used for assessment are therefore best made on roads that are further from the unit than those transits used for emissions detection. If more than one road is suitable then measurements at two distances should be taken.

There is little scope to adjust the measurement path according to wind direction in order to achieve a transect that crosses the wind near right angles. It will take time to consider the implications for possible wind modification on calculated fluxes. Provisional flux estimates are likely to be amended.

For example, consider emissions from a process unit with the wind approaching from the North West. The footprint of dispersing VOC is not known because of the effect of the unit on the wind-field. The SOF vehicle will drive around the refinery roads measuring VOC concentrations.

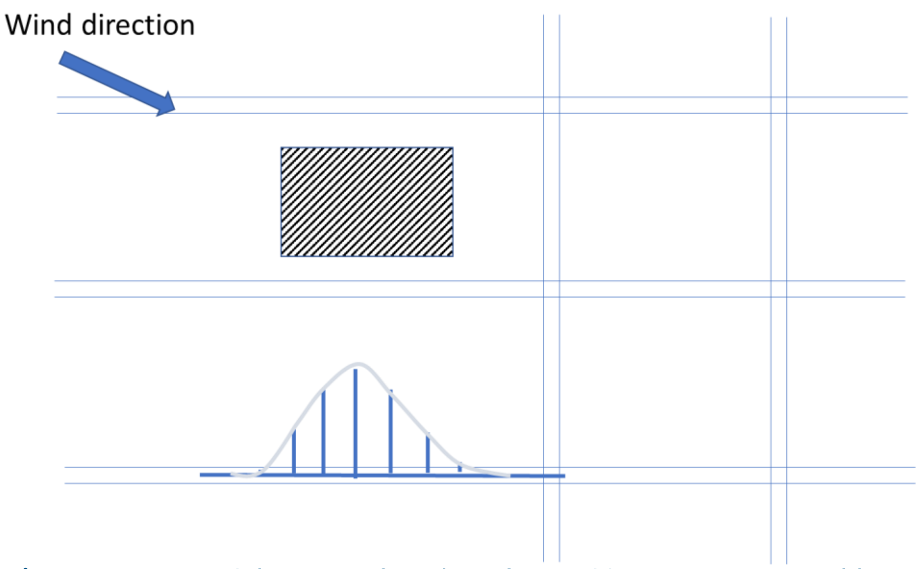

Figure 4 Schematic of readings from a SOF traverse (vertical bars, with a profile fitted, flux is proportional the area under the profile) past a process structure.

If the SOF measurement indicates a credible plume crossing, such as shown in **Figure 4**, and there are no obvious other candidates then a significant change in wind direction is indicated and the reference wind should not be used for flux estimation.

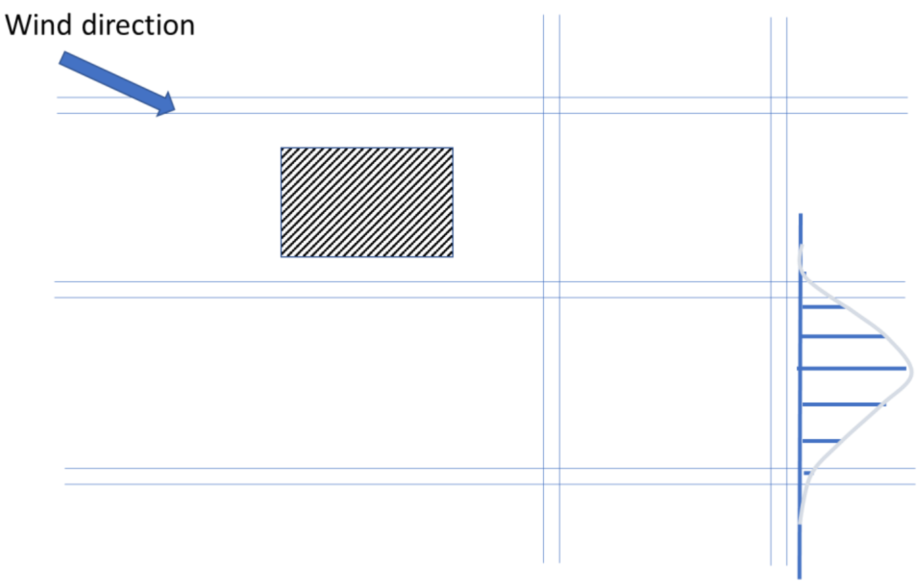

Figure 5 Schematic of readings from a SOF traverse made across the reference wind direction.

The second example, **Figure 5**, shows the results of a traverse that also indicates a credible plume crossing. It is distanced from the unit and is more or less consistent with the reference wind direction which, if there are no obvious other source candidates, can be used to assess flux.

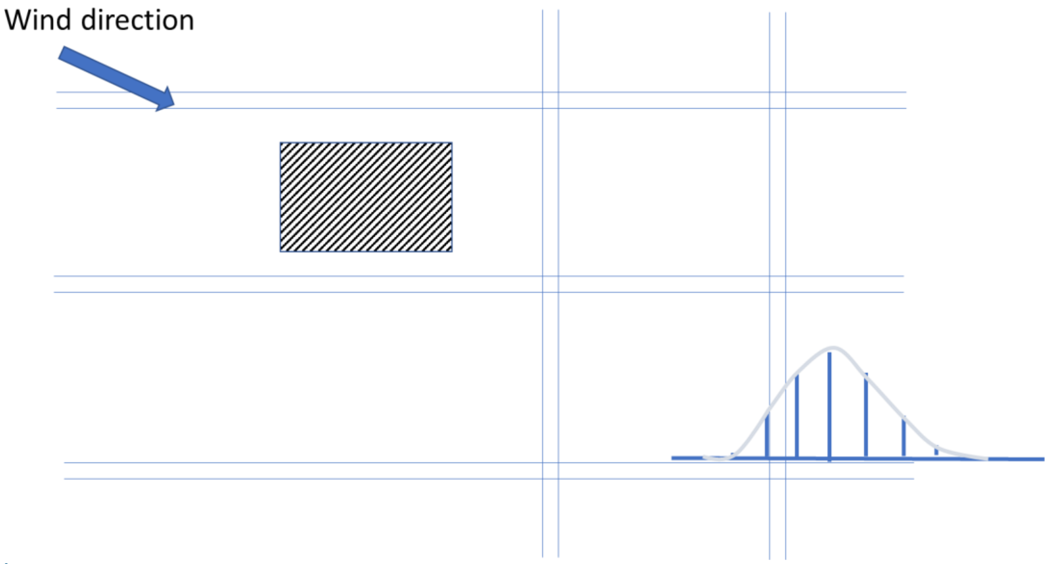

Figure 6 Schematic of reading from a SOF traverse made oblique to the reference wind direction.

The third example, **Figure 6**, is more uncertain. The traverse appears to be a credible plume crossing but if it is oblique to the wind then the assessed flux becomes more uncertain. The last example makes this clearer.

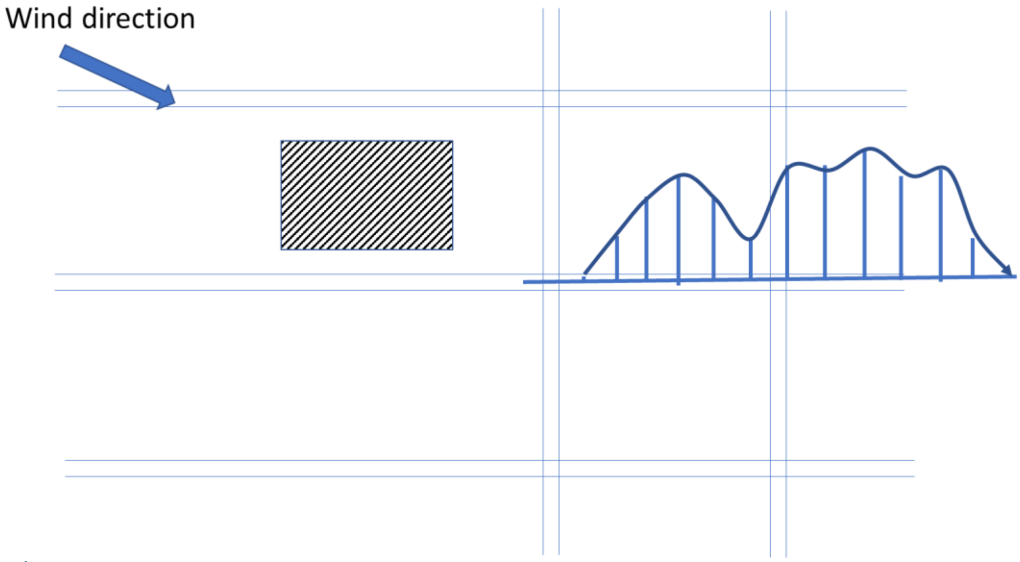

Figure 7 Schematic of reading from a SOF traverse made oblique to the reference wind direction. The vehicle is running in line with the plume and not across it.

Figure 7 shows the trace as the vehicle moves along the parallel road to that shown in **Figure 6**. The measured signal is high and the trace extended. This is the vehicle following the plume. The wind direction may have diverted lightly but the measurements cannot be used for flux assessment which requires the traverse to cross the VOC plume in a close to normal direction.

These considerations are complex. The concentrations measured along the refinery paths will have contributions from other sources. The further the path from the unit the more difficult is the decision to assign concentrations along a segment to a particular source. Further, SOF traverses are made according to a driving schedule and wind conditions may change between repeat traverses. The protocol also demands that traverses are made at different times across several (at least 3) days.

Such deliberations will generally take place during final data analysis and reporting and hence after the survey is completed. It is therefore important to ensure that all the path-integrated concentration measurements are recorded against time and position, together with reference wind direction and site layout, including information on unit size and geometry. For this reason it is recommended that these data be reported so that there is clarity on how judgment and sensitivity analysis is used to determine uncertainty in the final flux calculations.

SOF does not give information on the height of the dispersing VOCs as they cross the transect. There is no specific means to test whether the method assumption of horizontal dispersion is met. SOF measurements made under strong insolation conditions and low (< 3 m/s @ 10 m height) reference wind speed conditions should be carefully assessed, especially when surveying process units with strong heat release and/or mechanical ventilation. The possibility of convection is a real one and this can adversely affect SOF measurements. Poor repeatability of concentration profiles along the line of travel would be an indication, as would a large spread of individual transect flux determinations.

B.3.3 TC and RDM

TC and RDM are not techniques suitable for assessing emissions from a process unit. The reference measurements would have to be made at a sufficient distance for the unit to appear as a point source of emissions. The distance involved and the amount of ambient air that would need to be mixed with the VOC would render concentrations very low and the influence of other sources would be very difficult to correct for.

B.3.4 General Considerations

Assessing emissions from process units may be difficult because of the need for sufficient distance to avoid disturbance of the wind. Their location in the interior of the site makes them difficult to isolate and to compensate for emissions from other sources.

Under normal operating conditions diffuse emissions should not change too much with time. Operational emissions associated with, for example, maintenance, cleaning, the emptying of process drains, etc. may give a temporary increase in emissions. Emissions from drains and sewers may be affected by rainfall and events on other units.

It is therefore necessary to have activity data for events that could lead to a source of emission during a remote survey.

For assessing emissions, DIAL is the preferred method because the measurement can be configured to take account of the local wind and can provide information on the dispersing VOCs, particularly whether material is being lifted by convection. Flux methods covered by EN 17628 do not take account of dispersion with a vertical flow component.

Assessment using SOF involves consideration and the exercise of judgment. An analysis of uncertainty is required.

Detection of sources using SOF is enhanced by proximity and so is less affected by uncertainty in the wind interaction with the unit.

B.4 WATER TREATMENT

The water treatment plant is a complex source of diffuse VOC emissions. Different areas of the plant have the potential to release VOCs at different rates and of different composition. Emissions vary with time and environmental conditions. For example, rain-fall affects the flow into and through the system, temperature affects vapour pressure and wind speed influences convective mass transfer. Periodic discharges into the system, such as from vacuum trucks, also take place.

Assessment of diffuse VOC emissions using the techniques in this guidance is technically challenging. Interpretation of the assessment equally so, particularly within an emissions survey which takes a short view. There is no practical method to validate an assessment using, for example, a tracer method, as might be done for a point source. This is due to the large surface area of the various plant components and their potential to produce emissions at different rates and composition.

The current benchmark for assessing VOC emissions is calculation using correlations or advanced models, for example the US EPA Refinery Wastewater Emission Tool. These need extensive input data including composition sampling. An emission calculation for the period of the diffuse VOC survey will give a point of comparison with survey results. Evaluation of this comparison will need uncertainty, in both the calculation and the survey assessment, to be well understood.

The degree to which water treatment plant VOC emissions can be separated from other emissions during a survey will be site dependent. Much depends on the physical layout of the unit with respect to other units and access for remote measurement.

VOCs emitted from water treatment are characteristically complex and of greater molecular weight than the VOCs emitted in the other refinery areas. Where correction factors for the measuring instrument response are large, this further complicates the separation of VOC contributions.

For all methods considered, it is important to ensure that gas sampling and analysis of refinery air provides a clear picture of VOC composition for both waste water area and upwind sources.

B.4.1 SOF

SOF is oriented to measure emissions dispersing at height and does not inform on the vertical distribution of VOC concentration. Many water treatment plant VOC emissions (e.g. from oil-water separators, mixing chambers, sluices, etc.) originate at, or below, ground level.

If the water treatment plant is free of surrounding buildings/structures then SOF traverses have to be made at sufficient downwind distance from the water treatment plant for VOCs to mix vertically into the measurement plane. The proportion of VOC flux passing below the plane has to be estimated. Appropriate separations might be estimated using a Gaussian dispersion model and using refinery calculated emissions.

If the water treatment plant is neighboured by buildings/structures (up-wind, downwind or both) then the additional turbulent mixing due to wind-flow around these structures may raise a greater proportion of VOC into the SOF measurement plane, albeit at lower concentration. SOF traverses have to be made sufficiently downwind of the plant for the external wind-field to re-establish.

It is important that the assumptions made are explained and the uncertainties associated with the flux assessment made clear. Uncertainty will be high close to the unit because the concentration profile is unknown and, in the presence of buildings, the wind-field uncertain. Uncertainty will be high far from the unit because concentrations are lower and correction for upwind and neighbouring sources larger.

B.4.2 DIAL

DIAL is oriented to measure emissions dispersing at height and does inform on the vertical distribution of VOC concentration. Additionally, it is possible to orient the DIAL scan plane toward the ground. However, the extent to which this is possible is very much dependent on access and the detailed layout of the water treatment plant.

If the water treatment plant is free of surrounding buildings/structures and appropriate lines of sight are available then DIAL can indicate if it is detecting VOC and the proportion of the VOC plume passing under the scan plane estimated, e.g. by extrapolating the concentration profile to the ground. Local measurements used by the technique provide information on the local wind.

If the water treatment plant is neighboured by buildings/structures (up-wind, downwind or both) then the additional turbulent mixing due to wind-flow around these structures may raise a greater proportion of VOC into the DIAL measurement plane, albeit at lower concentration. This can be observed directly. Local wind measurements advise on placement of the measurement plane.

DIAL measurements give a relatively clear indication of whether quantification of the VOC flux is possible, or not possible, given the circumstances of the survey and shape of the concentration profile observed.

For gas composition reasons the DIAL measured fluxes are likely to use large correction factors. Correction for upwind sources, if any are present, will be an important factor in uncertainty.

B.4.3 TC

Not applicable to area sources.

B.4.4 RDM

RDM is a custom method. For application to water treatment plant an emission distribution model that apportions the distribution of emissions between the different parts of the plant is needed in addition to the wind-field and dispersion models.

Validating RDM for a water-treatment plant by means of a tracer method, which is a possibility for other applications, is not possible.

If the water treatment plant is free of surrounding buildings/structures then the wind-field model component is relatively straightforward to implement. The RDM uses near ground concentration measurements and the largest concentrations might be expected to be near the ground. Local wind measurements support the model.

If the water treatment plant is neighboured by buildings/structures (up-wind, downwind or both) then modelling the additional turbulent mixing due to wind-flow around these structures and the effect on dispersion VOC becomes very difficult.

RDM uses a total VOC measurement method and correction factors. As for the other techniques correcting for upwind and neighbouring source contributions becomes more difficult the further downwind measurements have to be made and the lower the concentrations measured.

B.4.5 General Discussion

Diffuse VOC emissions from waste water treatment areas are the most difficult to assess of any area of the refinery and by any means. Concawe has investigated waste-water treatment plant emissions on two sites using DIAL (Concawe report 5/14) [17]. That work illustrated some of the difficulties in deployment and interpretation

Within the scope of a diffuse VOC survey the techniques SOF or DIAL may provide some useful information, provided uncertainty is quantified by the contractor.

The key determinant is the layout of the unit and the degree to which it can be isolated from neighbouring plant with regard to both emissions and disruption of the wind-field.

If access for a DIAL scan plane extending to the ground, and outside the range of wind disturbance by building is possible then DIAL may be better able to quantify uncertainty than SOF. This does not mean that the uncertainty is necessarily less, only better known.

An important part of the uncertainty assessment will be correction of assessed emission fluxes for upwind, or neighbouring sources. Particularly where large composition corrections have to be made to account for the molecular weight of VOCs.

Prevailing weather conditions will be important if suitable access only exists for certain wind directions.

The work carried out to prepare the proposal for a VOC survey, especially the site visit, should inform on how applicable the considered technique is likely to be.

RDM is a custom technique. It is not likely to be invoked as a choice for use in a VOC survey. Rather, implementation would be a strategic decision by a site to set up a modelling system to examine water treatment plant emissions. The practical difficulty and outlook for success is again configuration dependent.

The variable nature of diffuse emissions from water treatment plant places another assessment difficulty. That of interpreting short term diffuse VOC emission results. To understand the potential for emissions the practical way forward is to conduct emission modelling. This can be via correlation or detailed modelling, both of which require detailed and timely measurement of oil-in-water inputs, concentrations and compositions through-out the survey.

Validation of assessed emissions, or components in the calculation such as wind (assumed or predicted), is not feasible. Tracer methods cannot be used.

B.5 LOADING AREAS

SOF, DIAL or TC can be used for quantifying short term emissions from road or rail car loading areas. Applications to barge or ship loading have not been tested.

RDM has not been applied.

Emissions in such areas are highly variable and should not be extrapolated outside the measurement period. For EU refineries a distinction should be made between:

- Truck and railcar loading, which are most of the time equipped with Vapour Recovery Units (VRU) or other equivalent VOC reduction technique.
- Barge or sea-going vessel loading, for which the installation of a VOC reduction equipment could be conditioned to the annual throughput [7].

Where no VOC reduction technique is installed, VOC emissions during loading could be important, but such emissions may only occur a few hours per week (e.g. for barges) and the annual amount could be small compared to other sources. Where a VOC reduction technique is installed, the VOC emissions during loading should be minimal, as such units usually achieve > 98% abatement. If the measured emissions are high while all loading taking place is connected to a vapour abatement device, the following should be checked:

- Is there any abnormal operation in the area (e.g. not linked to loading)?
- Is the vapour abatement device well connected and fully operational?
- If important up-wind sources were identified, have they been constant during the measurement of the (total) down-wind emissions?
- In industrial harbours, loading piers from various operators are often in close proximity. Could there be a vessel loading at a 3rd party pier during downwind measurements but not during upwind scans?

B.6 FLARES

EN 17628 is not the target methodology to measure VOC emissions from flare, which are highly variable in time. However, during a total site measurement campaign, some of the techniques listed will provide an estimation of VOC emissions from flares.

Flare emissions can be measured together with the emissions from a given area (SOF) or measured separately due to a different VOC plume elevation (DIAL). RDM and TC cannot be used for the assessment of flare VOC emissions.

It is important to make measurements at higher wind speeds than for other emission sources because the measurement methodologies do not account for plume rise. Flare waste gases are highly buoyant and possessed of vertical momentum.

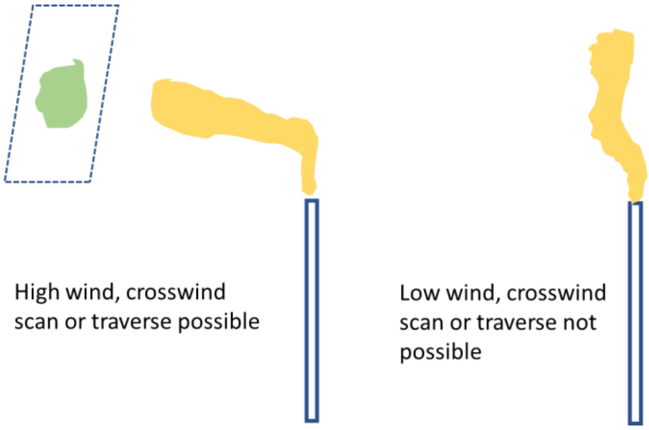

Figure 8 Assessing VOC measurements from flares requires sufficient wind to ensure that the waste gas plume can be scanned or traversed in cross-wind direction where the rate of plume rise is small and the flow is not far from horizontal.

Flare VOC emissions could be high for two reasons:

- During a safety event (usually short term) a high amount of hydrocarbons are sent to the flare, and the very low % of uncombusted VOC can still be a significant short term source. Such case is easy to confirm by visual observation. The VOC emitted can also be calculated using process data (e.g. unit volume, flow measurement) and compared to the number provided by the diffuse monitoring technique.
- In low flare conditions, there could be an excess of inert gases (steam, nitrogen) sent to the flare relative to the combustible fraction, resulting in low combustion, and hence higher VOC emissions. If such case was not already known by the operator, the survey information can be used to reduce VOC emissions.

APPENDIX C: UNCERTAINTY IN EMISSIONS ASSESSMENT

EN 17628 requires that uncertainty in emission flux measurements is quantified and expressed as a 95% confidence interval. The principles followed are those given in the Guide to Uncertainty Management [18].

There is also potential for systematic uncertainty or bias, arising not from an uncertainty in measurement but in the application of assumptions when calculating results.

There are several potential contributions to uncertainty. DIAL and SOF rely on measurement of concentration (strictly path-integrated concentration, although for DIAL this is over short ~ 3 m paths) and calculation of flux using a simple model and measurements of wind speed and direction.

Uncertainty can come from the concentration measurements, the wind speed measurements, the appropriateness of the model and the calculation procedure.

All parameters have their own natural variability. Concern for emissions assessment is two-fold. Firstly, the uncertainty about the determined value, e.g. the range of values within the confidence limits, and secondly a systematic bias which would lead to the determined value being consistently too large or too small compared to the genuine flux.

Formal analysis of uncertainty provides confidence limits on the determined value. Unfortunately, the only means of detecting systematic uncertainty (also known as bias) in a method is through calibration which cannot be done. In its place some confidence can be gained by reviewing assumptions and inputs to the emissions assessment. Appropriate sensitivity calculations can inform on how the potential magnitude of systematic uncertainty.

For example:

The model used by both DIAL and SOF is that the dispersing VOC is well mixed and forms a horizontal plume that disperses in the wind direction. With this assumption the flux, Q, crossing a vertical plane, normal to the wind direction is given by the product:

$$Q = C.U.A$$

Where C is the average concentration, U is the wind speed and A is the cross-sectional area of the VOC. This is a conventional view of dispersion, most often encountered as the Gaussian Plume model.

Under steady conditions and in the absence of background concentration Q is equal to the source emission rate.

The uncertainty in Q thus depends on the determination of:

- C, or the spatial distribution of concentration from which C can be calculated.
- U which is the wind speed at the plume centroid height. This is the height of the centre of the plume if the concentration profile is symmetric and the vertical wind speed gradient is small.

- A, which in practical terms represents how well the entirety of the plume crossing the plane is captured by the measurement. A is not determined explicitly. A DIAL scan or SOF traverse effectively determines a combined measure C.A.

Uncertainty in Q further depends on:

- How steady (independent of time) these quantities are.
- Deviation of the measurement plane to the vertical and to the normal to the wind direction.

The assumptions are shown schematically in **Figure 9**.

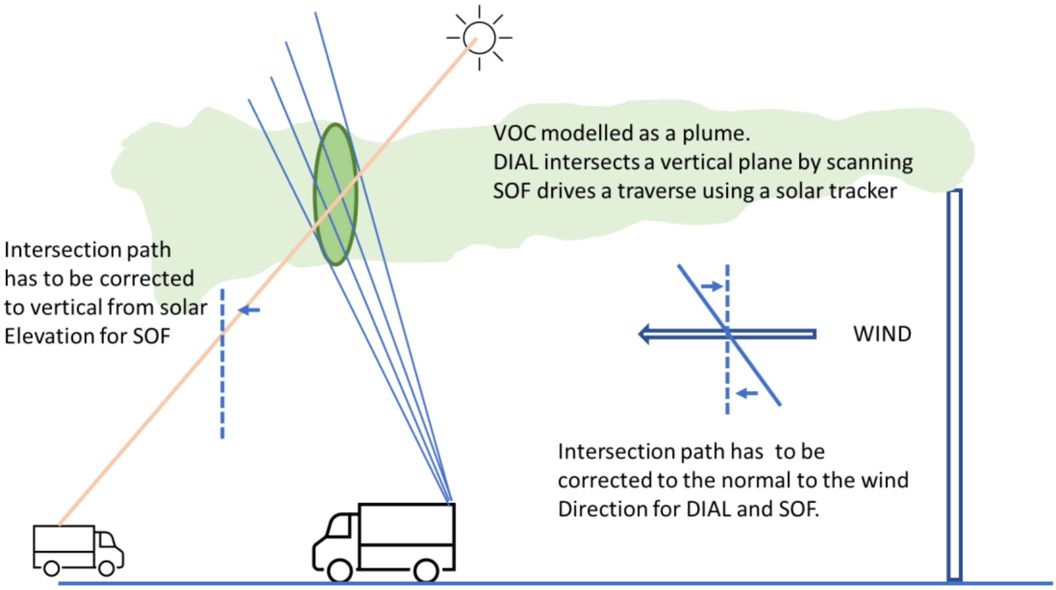

Figure 9 Schematic of basic straight line plume model used by DIAL and by SOF. The plume is assumed horizontal and VOC to be transported at the wind speed. The intersections with the plume have to be corrected for deviations from the vertical (SOF, correction depends on solar elevation) and horizontal deviation from the normal to wind direction (SOF and DIAL). DIAL normally chooses to use a vertical scan pattern, though other angles are possible.

C.1 CONCENTRATION

The determination of concentration is reasonably robust.

C.1.1 DIAL

DIAL, in essence, counts the number of C-H bonds in each of multiple gas columns. The individual gas columns are approximately 3 m in length, and together constitute a scan line. Because the columns are small and of known length the result is treated as an average point concentration at the column centre. Multiple consecutive measurements are combined to give a time average.

For alkanes the number of C-H bonds is a surrogate for mass concentration. For other VOC, or a mixture of VOC, the composition needs to be known. A correction factor is then derived and applied to the basic measurement to calculate mass concentration. This correction factor can be large if the sensitivity of the DIAL to the target species is small.

VOC composition is obtained from air-samples. These are taken and analysed. Sampling is manual at a convenient working height. They represent near-ground composition.

The refinery will provide information about the composition of stored liquids, process streams, etc. in the vicinity of the measurement area.

If the air sample composition is consistent with the make-up of VOC handled in the vicinity then the composition will generally be taken as known. This check should be made before measurements are acquired.

Background (i.e. upwind) compositions should also be checked both by air-sampling and review of potential components from upwind sources. This information will be needed to quantify the background flux of VOC.

Correction for background flux is not covered explicitly in EN 17628. It is most likely to be problematic when quantifying emissions of a hard-to-detect VOC against a background of easy to detect VOC. Specific measures such as restricting measurements to a narrow range of wind directions to minimise the upwind interference may be necessary.

High background flux of similar VOC is less an issue. The total flux can be determined even if the local and distant contributions cannot easily be separated. Note that upwind and downwind concentration measurements are necessarily made at different times. Differencing the two to give a net flux for a unit involves the assumptions that the upwind source is unchanged.

The determination of gas composition used to develop correction factors for each measurement location should be documented.

Methodology for correcting for background and corrections made should be documented.

C.1.2 SOF

SOF uses a spectral method for determining gas concentration. The gas column is examined for light absorption at several wavelengths. The detail is not described but it is thought to take several seconds to complete the absorption spectrum.

A specimen absorption spectrum is calculated from library values to match the gas composition determined from ambient air samples and guided by refinery information on the composition of stored liquids, process streams, etc. in the vicinity of the measurement area.

The amount of VOC present in the column is derived by matching the observed and target spectra. In principle this approach could be used to speciate the VOC. In practice it is possible to identify inconsistency between observed and target spectra, review assumptions and correct. SOF therefore has some robustness to uncertainty in VOC composition.

VOC composition, especially changes in composition or differences from air samples should be recorded.

SOF column measurements are obtained while driving. It is assumed that VOC composition is unchanged along the swept path. The same assumption is made for DIAL.

EN 17628 does not address the spectral analysis. It is a widely used technique. Uncertainty is not addressed and concentration results taken “as given”.

The SOF column extends from the measuring instrument to the sun. It is assumed that VOCs under investigation are in the lower atmosphere. No information as to their actual height above ground comes from the measurement. Reference background measurements correct for distant VOC.

The correction for background should be reported.

C.1.3 TC

TC also uses a spectral method on gas samples drawn into a chamber. Samples of ambient air will be taken in the vicinity of the measurement location. VOC composition and tracer composition can be considered well known.

The correction for background should be reported.

C.1.4 RDM

RDM uses a point sensor of the flame or photo-ionisation type. Samples of ambient air will be taken in the vicinity of the measurement location. VOC composition can be considered well known.

The correction for background should be reported.

C.2 WIND

Wind speed and wind direction are key parameters for calculating emission flux. Wind speed is parameterised by the value at 10 m height and by a vertical profile.

Wind properties outside of the refinery are determined using one or more dedicated meteorological stations located in remote areas. Their placement should allow the wind arriving at the refinery (the incident wind) to be measured. Climatic analysis will identify the wind directions most likely to be expected during the course of a survey.

Wind is shaped by both natural and built topography. It must go around each refinery structure. The way that structures are grouped together, in rows or arrays, also shapes the flow through the refinery. As a result, wind speed and wind direction vary across the refinery and, point by point, can be very different to the reference values determined at the remote refinery areas.

Where there is more than one reference station they will also show significant differences in wind properties for different incident wind directions. This was observed during the field work undertaken in developing EN 17628 [15] and in a separate investigation by Concawe [14].

Wind is continuously variable and it is essential to have a definition of wind speed and direction at the reference station(s) and for use in flux calculations.

A measuring station outputs instantaneous values of wind speed and wind direction. These must be averaged. The averaging time used in EN 17628 is 10 minutes. This value is long enough to average out the effects of small scale turbulence and short enough to be responsive to significant changes in wind direction. The averaging is applied as a running average.

Instantaneous wind speed and wind direction values are averaged to compute the wind vector ($\bar{u}, \bar{v}$) where u and v are orthogonal wind speed components, and the scalar wind speed which is the average of the instantaneous wind speed values. From which are obtained:

- The vector wind speed (the average wind speed in the average wind direction).
- The average wind direction.
- The persistence (P) (the ratio of the vector wind speed to the scalar wind speed).

P is chosen as an indicator of steady conditions. If P is close to 1 in value then the wind direction has not been variable in the preceding 10 minutes.

P was chosen as an indicator because the alternative, the standard deviation of wind direction fluctuation about the mean, is difficult to calculate and to understand.

The model used for flux assessment fails in calm conditions. For this reason the measurement protocols have minimum wind speed criteria with a 2 m/s cut-off. EN 17628 allows some discretion if the value of P is near one. It is possible, if unlikely, for steady, low wind speed conditions to occur.

By default, the reference wind conditions will be used to compute flux.

From what is known about the disturbance to flow by single structures and groups of structures EN 17628 provides some advice:

- Measurements taken "too close" to structures should not be used for flux calculations. The calculated fluxes may be several times too great. EN 17628 allows some discretion in deciding what constitutes "too close". Strict criteria for avoiding wake effects entirely would exclude almost all measurements on an industrial site. As a guide < 5 H downwind of a structure, such as a tank (where H is the tank height) is undesirable and < 3 H very undesirable. For buildings and process structures a greater separation may be needed.
- Away from structures account should be taken of possible changes in wind speed and direction. In practical terms this means testing the robustness of the flux calculation to a change in wind direction. There is no systematic basis to propose wind speed changes. Potential for wind direction changes can be assessed using common sense, recognizing:
    - Wind goes around, rather than over, a structure and will change direction as it approaches in the upwind and as it recovers in the downwind direction.
    - Wind will take the path of least resistance through arrays of structures. It will tend to divert along "streets" between structures if it can before returning to its original direction.

- Reference wind-profiles should be used. This is a practical consideration. There is no ready means of establishing wind profiles locally. Uncertainty in wind profile affects the wind speed used in the calculation. Flux is proportional to wind speed.

Uncertainty can be reduced my making local wind speed and direction measurements.

C.2.1 DIAL

DIAL measurement is done from a static position and the scanning path can be directed. A portable anemometer is used to investigate the wind speed and direction at the ground and delimit areas of low wind speed, and/or reversed wind direction, due to wake effects. The measurement plane can then be oriented to be normal to the wind direction.

Local wind data should follow standard processing to give (vector) wind speed, directions and persistence on a running 10 minute average basis.

Note: for practical reasons measurements at refinery locations and at the reference wind station(s) use a common clock. The ten-minute averaging time mitigates time-of-flight effects and the persistence criteria will signal any significant change in wind conditions in time.

The measurement gives a VOC concentration cross-section. This is built up as a time-average. The shape, across repeated measurements, informs on the consistency of what is being measured. The height of the VOC above ground is shown and, with assumptions on the vertical wind profile the appropriate wind speed can be calculated.

Uncertainty in flux calculations should be assessed using the observed differences between local and reference methods.

C.2.2 SOF

Local wind speed and direction measurements are not practical for the SOF technique which is mobile. Therefore, the general guidance in EN 17628 should be applied particularly because SOF is constrained to refinery roads which may pass close to some structures.

Use of reference wind speed and reference wind direction therefore has the potential to create systematic error.

The means to assess this is via sensitivity analysis. Sensitivity to wind speed is straightforward because flux is proportional to wind speed. Sensitivity to wind direction may be more complex.

Because SOF is confined to refinery roads the potential to make the scan path normal to the wind direction is constrained. The greater the deviation from normal the greater the uncertainty in the flux calculation. If the wind direction is unknown this can compromise the interpretation of measurements and, if the scan fails to complete a cross-section of the VOC plume, the measurement itself.

There is information in the SOF measurement record that can give useful information on local wind direction if the source of emissions is clearly identified and measurements not too confused by other VOC sources.

An example for tanks was shown in **Figure 1** but is shown again here for convenience. In this example the flux calculated assuming the reference wind direction would be too high by an amount cos(θ) where θ is the angular difference between the actual and reference winds.

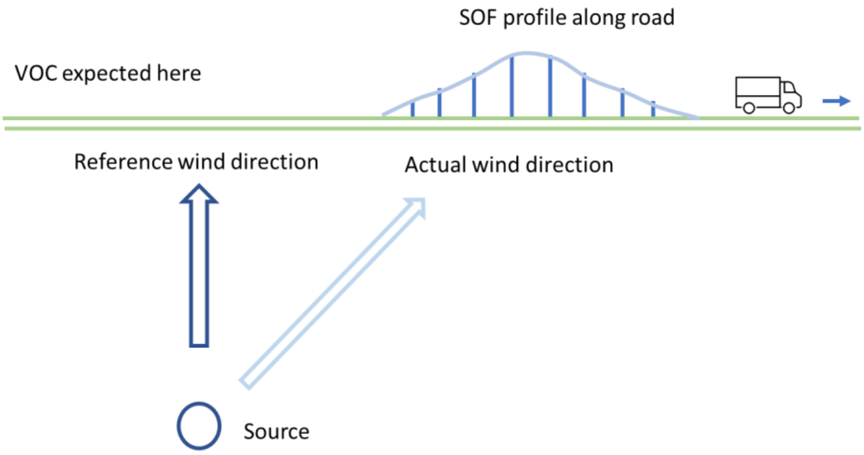

Figure 10 Schematic showing how SOF concentration profile information may inform on wind direction in some circumstances.

C.2.3 TC

Local wind measurements are made for the TC technique. The footprint of the tracer plume is also determined and the location of the tracer source known. Wind data are not used explicitly in the flux calculation because this is derived as a ratio of the tracer release rate.

Uncertainty due to wind inputs is low

C.2.4 RDM

RDM relies on accurate model prediction of wind flow and dispersion. Local measurements of wind are made using a portable analyser.

Uncertainty to wind inputs has to be well discussed in the presentation of results as they constitute verification of the method.

C.3 REPEATABILITY

This section applies only to DIAL and SOF.

Uncertainty estimates in a measurement are usually made by repeating the measurement and measuring the spread of results. These are then expressed as a standard error at 95% confidence. Where a measurement depends on several inputs, each subject to variation, then the uncertainties can be summed. Procedures are set out in the Guide to Modelling Uncertainty (GUM) ([18]) which EN 17628 adheres to.

The model used to calculate emission flux implicitly assumes that the emission is effectively constant and that the flux is also constant of the measurement period.

This is not strictly true. Wind varies continuously in time as does the dispersion process that takes place between source and measurement plane. The source also may vary in time depending upon its nature.

The flux can be written:

$$Q + q' = (C.A + (c.a)')(U + u')$$

Where the prime indicates variation from the average value. C.A is taken together because the DIAL and SOF measurements capture a concentration cross-section.

If this is averaged to eliminate the flux variability q' then

$$Q = C.A.U \ + \overline{(c.a)'.u'}$$

Where the extra term represents the contribution to flux from the correlation between variations in concentration cross-section and wind speed.

It is not possible to measure this correlation. The guidance on wind and on measurement position is aimed at promoting measurements where this contribution to flux can be expected to be small:

- Avoiding mixing zones behind structures, where the correlation is large and negative.
- Avoiding shelter zones within which the wind speed is low and, with increasing distance from the structure, increasing toward its freestream value.
- Promoting measurements under steady wind conditions.

The averaging of cross-section measurements to derive CA and it's variability (ca)' is expected to be presented by proxy as the variation in determined flux. It should be made clear whether this is flux as measured or flux after the correction for upwind sources.

EN 17628 and the field program conducted in its development is not clear on how correction for upwind sources is done or accounted for in uncertainty. Upwind and downwind measurements are made at different times, both have variability, and a procedure has not been defined.

There has been a general presumption that the flux contribution from upwind sources to a measurement downwind of a target area is minor. Should this not be the case the contractor should clearly describe how the upwind and downwind data were gathered and how averages (with confidence intervals in their values) were formed. This is because the downwind flux is conditional upon, and not independent of, the upwind flux. This complicates interpretation of the measurement sample distributions, particularly when the sample numbers are small.

C.3.1 DIAL

DIAL builds up a concentration profile by constructing consecutive measurements in a continuous time series. The scan profile comprises a number of rays (lines) subtending the plume as it passes the scanning plane.

DIAL has two scanning options. It can scan along one line and acquire data in time and then move to the next line. Or it can scan one line, move to the next, repeat the pattern. In either case the total scanning period is several minutes. The objective is to obtain a stable averaged scan where the addition of more data does not alter the pattern seen. This is effectively a time-averaging method.

The effect of the two scanning patterns was investigated as part of work for Concawe [11] which investigated controlled releases from an open tank. The two modes of scanning were found equivalent. The data assimilation time should be at least 5 minutes. Under steady wind conditions no advantage was found in extending beyond 30 minutes. On a refinery survey the measurements are usually between 10 and 20 minutes.

The DIAL measurement is repeated at least four times. The approach is consistent with the processing of meteorological data.

For each instance, the concentration distribution along each ray (polar coordinate) is mapped to cartesian plane. Wind speed is applied using a vertical profile and the whole integrated to give the flux. A VOC species factor is applied.

Results may be post-processed to account for adjustments for wind speed and direction (plane of intersection) but these are usually small for this technique.

Repeatability is assessed from the variation between these measurements. The source may be revisited, e.g. under different wind conditions, but consistency between visits depends on the source emission being the same on each visit.

C.3.2 SOF

SOF makes measurements of path-integrated concentration as the instrument is driven along a refinery road. Each crossing of a plume creates an instance of CA comprising a discrete set of path-integrated concentration values approximately 10 m apart and a path length. CA is the integral of this profile along the path. The flux is obtained multiplying CA by the reference wind speed, adjusted for a vertical profile with an assumption about the height of the VOC plume.

Geometric correction factors are applied. In the horizontal to account for the angle of intersection of the driven path with the wind direction. In the vertical to account for the fact that the scanned plane is not vertical but aligned to the solar elevation.

In this way SOF acquires a set of discrete estimates of flux, each based on a short duration pass through the plume. This exposes the method to fluctuations in emission flux arising from VOC concentration fluctuations.

This set of results are presented as a statistical distribution.

If the rate of emission was constant, all environmental parameters that affect dispersion from the source of equal quality, plume crossings made near normal to the wind direction and solar elevation near maximum, than there is a sound statistical basis for considering of set of spot measurements to be a random sample of the emission flux.

In which case the average flux is given by the sample mean. A confidence interval can be constructed in the normal way.

In practice individual observations are unlikely to be of equal quality. The spread of values observed is often skew with few large values and a higher frequency of low values. The method proposes to use the median of this skew distribution to indicate the emission flux, in effect putting a lower level of confidence in the higher values.

EN 17628 requires a minimum of 12 flux value determinations, comprising 4 determinations daily taken on 3 different days. This is a small sample and a greater number are likely to be needed to demonstrate the target uncertainty (say, 30%) with 95% confidence.

Certain checks can be carried out on SOF measurements to assess their individual quality. These checks require intermediate working data.

- A plot of the path integrated concentrations along the measurement path(s) superposed on a refinery plan can show:
  - Does the profile resemble a plume cross-section and is the profile complete?
  - Does the location of the peak/centre of the profile correspond to the wind direction being used for the flux calculation? Has a correction to wind direction been made?
  - Is the angle of intersection of the driven path more than 20° from the normal to the wind direction used in the flux calculation?
  - Does any part of the profile come close to a structure or region where wind properties may be affected? Particularly if the indicated path-integrated concentration at this position is large compared to other values.

The individual measurements can be inspected to see if they appear to be a random sample or whether there is a trend with any key parameter corrected for in the derivation of flux.

- Relationships with:
  - Wind speed
  - Persistence
  - Solar elevation
  - Angle of plume intersection

Finally, the flux estimates should be plotted on a time line to see if there is a trend, for example, high or low values being grouped, particularly if systematic differences occur between different days. This should be done for both upwind and downwind flux instances to examine whether downwind values are consistently higher than upwind values.

These data quality checks should be able to be done on an ongoing basis as part of the data review. The main purpose is to identify if there are sufficient robust upwind and downwind flux instance values to assess the strength of each source.

C.4 VERTICAL FLOWS

The DIAL and SOF methods for calculating emission flux assume horizontal flow and do not apply directly to diffuse VOC emissions dispersing with significant plume rise.

Vertical flow can be source driven, and emission fluxes in this case can be determined under certain conditions associated with source driven plume rise.

Vertical flow can be naturally occurring, e.g. convection in unstable atmospheric conditions. Under these circumstances vertical or inclined emission fluxes cannot be calculated.

C.4.1 Source driven plume rise

There are few diffuse emission sources possessed of vertical momentum and buoyancy. Examples are flares and fugitive emissions from pipework cooled by means of air coolers

The dispersion considerations apply equally to channelled emissions released from stacks. While these are not the subject of a diffuse emissions survey they may be included in the assessment deliberately or by necessity and if so have to be accounted.

These sources entrain air and in doing so, gain horizontal momentum, the greater the dilution the smaller the gradient of plume rise and the smaller the excess of velocity. Measured well downwind of the source and in moderate wind speed the plume path is nearly horizontal and the plume moves with the ambient wind speed at the plume height.

An appropriate dispersion model can help the contractor to assess the plume trajectory.

The general requirements are that the atmospheric stability is neutral or stable and the wind speed at 10 m height is moderate or high (> 5 m/s). These conditions are often synonymous.

Measurements should be conducted at two downstream stations to check invariance of the calculated flux. The relevant wind speed should be calculated from the wind speed profile or using the dispersion model. DIAL measurements will locate the height of the plume. SOF will have to use dispersion model to assess height and wind speed.

Where the source is from an air-cooler the VOC plume is likely to stay closer to the ground due to aerodynamic effects (downwash) as the wind blows through the process area.

C.4.2 Convection

Instances of vertical flow can occur naturally. The circumstances required are low wind speed and sufficient insolation to render the atmosphere strongly unstable.

The criteria for minimum wind speed and for persistence of wind direction should mark such conditions as unsuitable for emission assessment. However, conditions at the reference measurement stations may be substantially different to those within the refinery and close to process units. Should a refinery source of waste heat trigger an instability then a vertical flow could result.

Should an emission be carried upward by a convection current:

- DIAL may not detect a lofted emission if the rise is very steep and the measurement plane location is chosen on the assumption of horizontal flow.
- SOF may see the emission because the measurement path, oriented toward the sun, is raised and all VOC falling within the measurement column is recorded

whatever the VOC height. The relative position of the sun and wind direction will be important. As shown in **Figure 11**, if the SOF path crosses a plume rising away from the sun (right hand van) it will record a very much smaller value than if it follows the path of a plume rising toward the sun (left-hand van). Analysis always assumes that the plume trajectory is horizontal.

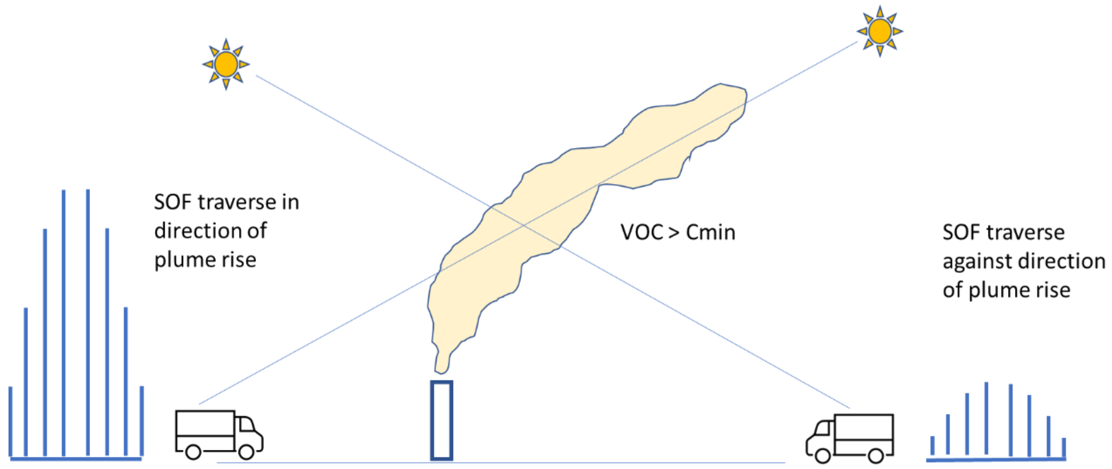

Figure 11 Schematic of potential impact of unrecognised plume rise. The SOF direction of travel is out of the board. A greatly enhanced concentration is seen if the traverse follows the line of plume rise compared to if the traverse is against the direction of plume rise. The relative position of the sun should be noted when evaluating sources. Particularly if measurements show very large variation in magnitude between instances.

Caution should therefore be taken when screening SOF data for hotspots at the bottom of the operating wind speed window, particularly if there are large changes in magnitude of concentrations (and hence computed flux) between traverses.

C.5 UNCERTAINTY SUMMARY

EN 17628 contains sufficient guidance for users to address uncertainty in the form of random measurement error. This is also coherent with the Guide to Uncertainty Management [18].

Some care must be taken to scrutinise remote sensing data flux calculations for sources of possible systematic error. Systematic errors can only be truly resolved by measuring against known emission fluxes and in effect establishing a calibration. This cannot, in practice, be generally undertaken but there are several causes of systematic error that can be avoided.

In particular:

- Are measurements used for flux calculations and indicating “hotspots” made too close to structures? If so they should be excluded.
- Are wind values used for flux calculations steered by local measurements or based on reference values?
- Is there reason to suppose that the presence of structures might influence wind direction and wind speed for each measurement set?

- Are reference wind conditions within bounds and steady?
- Are concentration profiles provided?
- Are individual flux determinations presented in a time-series?
- Do measurements made under low wind speed conditions show extreme variability? e.g. max/min > 5 for the same source.
- Have measurements been repeated on different days and are they consistent?
- Is the determination of upwind fluxes clear and is the process of correcting for upwind concentrations explicitly described?

Reports should be required to include sufficient information to answer these questions.

6. REFERENCES

1. EN 17628:2022 “Fugitive and diffuse emissions of common concern to industry sectors — Standard method to determine diffuse emissions of volatile organic compounds into the atmosphere”

2. M514 EN: Standardisation Mandate to CEN, CENELEC and ETSI under Directive 2010/75/EU for a European Standard Method to determine fugitive and diffuse emissions of volatile organic compounds (VOC) from certain industrial sources to the atmosphere (2012)

3. EN 15446:2008 “Fugitive and diffuse emissions of common concern to industry sectors – Measurement of fugitive emission of vapours generating from equipment and piping leaks”

4. Concawe Report 6/08 Optical methods for remote measurement of diffuse VOCs: their role in the quantification of annual refinery emissions

5. Regulation (EC) No 166/2006 of the European Parliament and of the Council of 18 January 2006 concerning the establishment of a European Pollutant Release and Transfer Register and amending Council Directives 91/689/EEC and 96/61/EC.

6. Concawe Report 4/19 Air pollutant emission estimation methods for E-PRTR reporting by refineries

7. Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas (2015)

8. Commission Implementing Decision of 9 October 2014 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions, for the refining of mineral oil and gas

9. Best Available Techniques (BAT) Reference Document for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector (2016)

10. Best Available Techniques (BAT) Reference Document for Common Waste Gas Management and Treatment Systems in the Chemical Sector (Final Draft March 2022)

11. Concawe Report 12/14. Towards the establishment of a protocol for the quantification of VOC diffuse emissions using open-path remote monitoring techniques: DIAL monitoring of a VOC source of known emission flux

12. Concawe Report 95/52 VOC emissions from external floating roof tanks: comparison of remote measurements by laser with calculation methods

13. The dispersion of diffuse emissions from storage tanks. University of Surrey EnFlo Report 2011-01 for Concawe

14. Concawe Report 12/19 A study of wind flow around a refinery

15. Final Report concerning the Standardisation Mandate to CEN, CENELEC and ETSI under Directive 2010/75/EU for a European Standard Method to Determine Fugitive and Diffuse Emissions of Volatile Organic Compounds (VOC) from Certain Industrial

Sources to the Atmosphere. VDI/DIN-Commission on Air Pollution Prevention (KRdL) | VDI

16. Speirs LJ, Dispersion on Process Plant: Enhancing VOC emission control, EngD Thesis, University of Surrey, 1998

17. Concawe Report 5/14 Methods for estimating VOC emissions from primary oil-water separator systems in refineries

18. Evaluation of measurement data - Guide to the expression of uncertainty in measurement, JCGM 100:2008 (GUM 1995 with minor corrections)

Concawe
Environmental Science for European Refining

Concawe
Boulevard du Souverain 165
B-1160 Brussels
Belgium

Tel: +32-2-566 91 60
Fax: +32-2-566 91 81
e-mail: info@concawe.eu
http://www.concawe.eu

ISBN 978-2-87567-168-4
9 782875 671684 >