Report

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Odour management guidance for refineries

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Odour management guidance for refineries

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ABSTRACT

This document aims to help refineries, in conjunction with any existing national guidance, to develop methods to prevent odour nuisance and how to manage a complaint should an odour event arise on site.

It describes some of the main aspects relating to odour emissions at refineries that should be considered. These include methods of measuring and investigating odour, the key regulatory instruments, odour management and control methods, contents of an odour management plan (OMP) and implementation of an odour complaint handling system.

KEYWORDS

Odour, refinery, odour management plan, complaint handling

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1. SUMMARY

The objective of this document is to help refinery operators, in conjunction with existing national guidance, in the discussions related to odour events with stakeholders and regulators. The document is designed to give an understanding of the basics of odour management and to provide information on aspects which are fundamental to it. This document is not designed as a specific step-by-step guide due to the complexity and variability of the processes and mitigation techniques used in the sector. It does, however, provide information on ways to manage odours at a refinery.

The document covers:

- *Generic aspects of odour*

Odour is subjective and the assessment of odour is complex, often difficult to quantify and has the potential to cause public concern.

To understand the generic aspects related to odour and odour nuisance, this document provides the basics of odour including a definition of odour, how it is perceived by human receptors, including the subjective experience, and what needs to be considered when conducting odour assessments.

- *Sources of odour at refineries*

Refineries work with feedstock and processes that have the ability to emit odours. A variety of abatement techniques can be used to minimise the impact of odours from refineries in the surrounding areas.

A brief overview of odour at refineries is presented to help identify possible odour sources. Additionally, techniques are described that may be considered for the abatement of odorous emissions in a refinery.

- *Odour characterisation and assessment methodologies*

The effects of odour emissions can be assessed for a variety of reasons such as part of a complaint investigation or to enhance the refinery's own environmental awareness. The amount of measurements, the type of measurement and type of information required depends on the circumstances of the odour emission and the reason for undertaking the assessment. Usually the aim of the investigation is to establish whether the odour is offensive and objectionable and therefore causing problems in the local environment.

Various characterisation methodologies (qualitative and (semi-)quantitative) are described to present an overview of how odours can be assessed. The level of complexity of an odour assessment depends on the character of the odour, frequency of complaints, as well as the layout and location of the site.

- *Overview of policy and legislation*

Review of national and international policy and regulation indicates that there are a number of different approaches taken in existing regulatory frameworks for controlling and managing odour issues. Most odour related policy and legislation are generic, focussing on offensiveness, sensitive receptors and/or are related to type

of activities such as industry, agriculture or waste treatment. No legislation has been identified focussing specifically on refineries.

The policy and legislation section provides a description of the types of regulatory instruments applied internationally, e.g. on an ambient or environment basis, emission basis and management basis. The goal of this section is to enable environmental managers to recognise the policy and regulatory instruments used in their area. In addition, the legislative frameworks of two countries are provided as an example. These show the different approaches taken at national and local level.

- *Guidance on creating an odour management system*

An odour management plan (OMP) is a systematic approach to odour control. It addresses each area of concern in a proactive and effective way. The creation of an odour management plan follows a generic procedure which is not specific to refineries. The information provided in the other chapters of this document can be used to assist in the creation of an OMP.

The section related to odour management strategy (OMS) focusses on determining objectives and goals, content (and possible variations) of the odour management plan and the procedure to create such a plan. A fugitive emissions management plan is an important element of an odour management system for refineries.

- *Odour complaint handling system*

Odour complaints are the primary mechanism for the reporting of odour nuisance events in the local environment. Receiving, understanding and effectively addressing odour complaints is an important part of odour management and is a key part of both public engagement and odour investigations. Reported odour nuisance events can be an operational trigger for odour emission investigations and maintenance activities.

This section describes the necessity to have an odour complaint handling system in place and what it consists of. Besides the complaints through direct contact from the public or through the authorities, the management of complaints through social media is also covered.

The document as a whole, therefore, should provide refinery environmental managers with the basic knowledge of how to make an inventory of odour emissions, control odour emissions, measure odour emissions, prevent odour nuisance and respond to complaints.

2. INTRODUCTION

Odour and the assessment of odour is complex, often difficult to quantify and has the potential to cause public concern. Odour is frequently the most commonly reported public complaint regarding the operation of licensed or environmentally permitted facilities, including refineries.

For licensed facilities to operate in harmony with their neighbours, odour management principles are an essential part of day-to-day operations in order to minimise impacts wherever possible.

Oil and gas refineries work with materials that have the potential to cause odour impacts. This is further complicated by the fact that some compounds can be detected at very low concentrations. The assessment of the degree of odour nuisance is difficult. Individual reaction to odour is highly subjective and threshold concentrations at which odours can be detected vary from person to person by a factor of as much as one hundred. The quality of odour management guidance varies across national and regional boundaries. National guidance ranges from well-established guidance documents with procedures that are integrated into the licensing or environmental permitting process to an absence of formal guidance in some countries.

The objective of this document is to help refinery operators, in conjunction with national guidance, in the discussions related to odour events with stakeholders and regulators. The document is designed to give an understanding of the basics of odour management and to provide information on aspects which are fundamental to it. It is not designed as a specific step-by-step guide due to the complexity and variability of the processes and mitigation techniques used in the sector. The document does however provide information on the following:

1. Odour characterisation and quantification: How to measure concentration and determine offensiveness;
2. Odour assessment techniques: Provides a description of odour analysis methodologies ranging from a simple screening method to a detailed assessment;
3. Policy and legislation overview;
4. Odour management plans: Provides an understanding of what an effective odour management plan (OMP) contains;
5. Odour complaint handling: Suggests Odour Management System (OMS) processes that allow effective odour management and complaint handling.

3. ODOUR

To evaluate odour impacts effectively, it is important to understand the definition of odour, how it is perceived by human receptors[1] and the properties which need to be considered when conducting assessments. This section gives a brief introduction to aspects which are important in odour management.

3.1. What is an odour impact

An odour is perceived in response to the presence of one or more compounds in the air by the sense of olfaction: a physiological reaction which forms the sense of smell. Odorous compounds are generally detected at concentrations far below thresholds set for the protection of human health.

When ambient concentrations are below health based thresholds, the human response is typically a level of annoyance, often defined by the tolerance of the individual.

An odour impact can only occur when a source and a human receptor are connected by a pathway. The 'pathway' is most commonly defined by the specific short- or medium-term meteorological conditions, which are predominantly wind speed and wind direction. All three aspects are required in order to create an odour response as shown in **Figure 3-1** below:

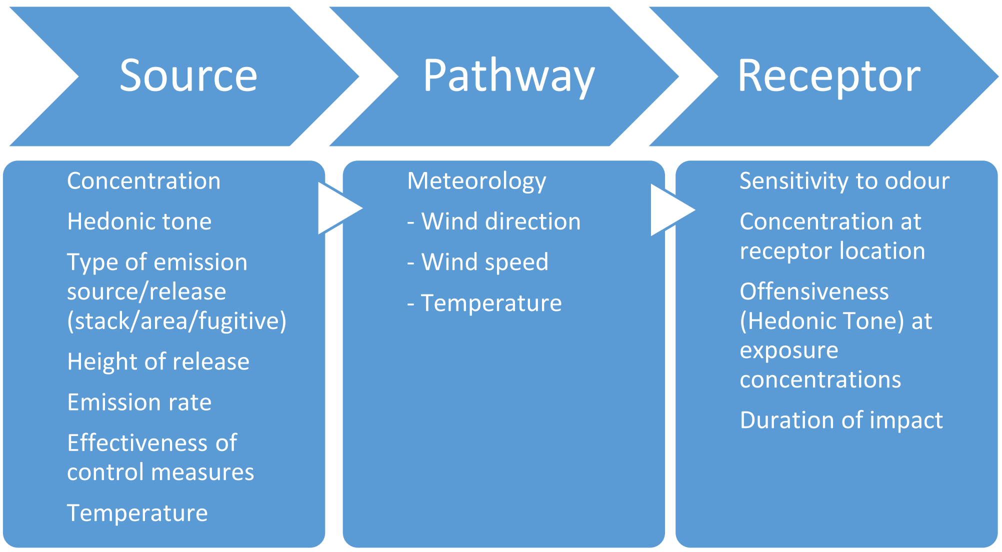

Figure 3-1 Factors which affect an odour response

The impact of meteorology determines for a large part how odour is distributed. The role of wind direction and wind speed are easily understood. Less obvious is the impact of temperature on the distribution of the emission. Depending on the relation between the plume temperature and the temperature gradient above ground, the emission plume either sinks at a short distance from the emission point or rises in the air.

[1] Receptor could be interpreted as either the human sense of smell (i.e. receptors within the nose) or a sensitive location within the surrounding environment (e.g. residence, school or hospital).

3.2. Perception of odour

A person's reaction to odour and the extent and persistence of an odour nuisance is highly variable and subjective. An individual's response to an odour is based on the sensitivity of the individual, the frequency of the detection, the frequency of release, the frequency that odour causes a nuisance effect, tolerance, psychological aspects and the person's background and previous experience, including being familiar with the facility or other facilities producing the odour. Sensitivity to odour and the ability to distinguish one odorous compound from another can become more difficult after a continuous or prolonged exposure, which is known as olfactory fatigue, but odour sensitivity soon recovers shortly after the stimulus is removed.

The way in which the nose and brain combine to respond to odour exposure is not precisely understood. As a result, the science of odour perception has not progressed in a similar way to dose-response relationships associated with pollutants that have the potential to cause human health effects. It is therefore difficult to quantify precisely an exact level of odour in the environment that would be acceptable to all members of the public.

3.3. Odour characteristics

A concentration of odour in isolation cannot be used to determine the level of impact. A measured odour concentration takes no specific account of intensity or offensiveness. Odours considered to be pleasant or unpleasant may be attributed to the same odour concentration but the population response to the odour will be different. Odour concentrations are expressed as odour units per cubic metre (ou_E/m^3), where the odour unit is clearly defined under European Standards. However, an assessment of the full range of odour properties is required to understand the physiological and psychological response by an individual or population.

The factors in **Table 3-1** need to be considered when assessing odour impacts.

Table 3-1 Qualitative and quantitative factors used to describe an odour

Property	Description
Concentration	The ambient odour concentration determines whether odour can be detected and is a quantification of its strength compared to other similar odours. **Note:** Concentration does not take into account intensity or offensiveness.
Offensiveness	Most commonly a subjective measure related to relative aversion of an individual to a specific odour at a fixed concentration. Offensiveness can be measured quantitatively by assessing the hedonic tone, under laboratory conditions. Hedonic tone presents a result on a -4 (very unpleasant) to +4 (very pleasant) scale with a result of zero being described as neither pleasant nor unpleasant (i.e. neutral). **Note:** The offensiveness of an odour depends on the concentration of the odour. As odour concentrations decrease, the relative offensiveness also tends to decrease but not at a linear rate.
Intensity	Often a composite property to describe how strong the odour is when concentration and offensiveness parameters are combined. **Note:** Odour intensity is not often quantifiable. Alternatively intensity can be assessed on a seven-point intensity scale from no odour (0) to extremely strong odour (6). While this is subjective (different people will perceive odours as different intensities), it still provides a useful quantitative tool for estimating odour intensity. The scale is derived from German Standard VDI 3882 (Part 1) [1].
Persistence	A measure of duration of exposure. This typically involves a description of the total duration and intermittency of exposure. Intermittency can be described on a short-term basis (e.g. detected for a few seconds or minutes over an hour) or a long-term basis (e.g. odour was present for a certain number of days in a month or year).
Character	A qualitative description of the odour. Subjective description based on either a set of provided examples or on an individual's experience. Character may only be well described at higher concentrations. For example, butyl acetate has a sweet odour at low concentrations, but smells like banana at higher concentrations.

4. ODOUR AT REFINERIES AND METHODS OF ABATEMENT

This chapter discusses the main sources of odour at refineries and gives a brief overview of the most commonly used end-of-pipe abatement techniques. There are many intermediate technical measures that can be implemented to reduce odour emissions in addition to these end-of-pipe techniques. Because the applicability of these intermediate techniques depends highly on the overall design of the facility, these techniques are not discussed in detail in this chapter. For more detailed information on emission abatement technique options, the reader is referred to the relevant sections in the BREF Documents '*Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas*' (abbreviated to REF BREF) [2] and '*Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector*' (abbreviated to CWW BREF) [3].

4.1. Refinery specific odour compounds and potential sources

Odours in a petroleum refinery are mainly created by:

- Sulphur compounds, including hydrogen sulphide (H_2S), mercaptans, sulphides and disulphides;
- Nitrogen compounds, including ammonia (NH_3) and amines;
- Hydrocarbons, including Volatile Organic Compounds (VOCs), ketones, aldehydes, organic acids, phenols and aromatics.

The main sources of odour at refineries include:

- Storage (e.g. sour crudes);
- Bitumen production;
- Water desalters;
- Sewers, oil/water separators, uncovered Dissolved Air Flotation (DAF) units and bio-treatment units;
- Flaring of gas (e.g. products of incomplete combustion);
- Loading operations.

The different sources can be divided into two major types of emissions: *channelled* and *diffuse* emissions [4]. Channelled emissions are emissions into the environment through any kind of pipe, regardless of the shape of its cross-section. Diffuse emissions are simply all emissions that are not considered as channelled. A sub-set of diffuse emissions are *fugitive* emissions; these are defined as diffuse emissions from point sources.

Table 4-1 gives a general overview of the processes where odorous emissions can occur. It provides options which may be considered for reducing these emissions. Many of these techniques are described in the Chapters on "Techniques to consider in the determination of BAT" in the REF [2] and CWW [3] BREF documents, but are subsequently not specified as BAT. Moreover, it should be noted that there are no techniques considered BAT specifically for odour control in the REF BREF.

Table 4-1 Refinery processes, odour sources and techniques to consider for odour reduction

Refinery Process	Possible odour source	Odour reduction - operational and prevention measurements	Odour reduction - control/treatment techniques (end-of-pipe)
Alkylation	• Fumes can originate in the neutralising basins • Acid-soluble oil may be released from process shutdown ponds during maintenance work, particularly the descaling of pipes conveying hydrogen fluoride.	• Neutralising basins can be tightly covered • Special care taken during maintenance and cleaning of the plant not to release odours from the drainage system and/or ponds	• Neutralising basins can be equipped with a gas scrubber to remove any offensive agents. (see **Appendix 4**)
Storage (e.g. sour crudes, bitumen materials, land oil)	• Sulphur compounds • VOCs	• Spill prevention by good housekeeping • Tank maintenance procedures • Double seals on floating roofs	• Gases can be treated in an incinerator (see **Appendix 4**: incineration) • Gas treatment with a granular reactant (see **Appendix 4**: adsorption) • Absorption/washing with a cleaning fluid containing terpenes (see **Appendix 4**: absorption) • Vapour destruction through decomposition of VOCs by biofiltration (see **Appendix 4**: biofiltration)
Flaring	• Sulphur compounds • VOCs	• Prevention or reduction in gas flow to flare. • Improved flare combustion efficiency.	-

Refinery Process	Possible odour source	Odour reduction - operational and prevention measurements	Odour reduction - control/treatment techniques (end-of-pipe)
Sour water from bitumen production	• Hydrogen sulphide, aromatics, ketones, aldehydes and fatty acids		Oxidiser overhead waste water accumulated in the overhead condensate collection drum can be sent to a sour water stripper (SWS) prior to sending it to the effluent water treatment facilities. In some particular schemes, water from the oxidiser is not suitable for the SWS and is sent directly to the wastewater treatment plant (WWTP)
Bitumen production (refining crude oil)	• Hydrogen sulphide, complex aldehydes, organic acids and phenolic components	Oxidiser overhead slop oil can be treated in the sludge processing or recycled in a refinery slop oil system, thus reducing odorous emissions during the collection of slop oil as solid waste.	• Prior to incineration, the oxidiser overheads can be routed to a scrubber, rather than direct water quenching. The off-gases are condensed in a scrubber, where most of the hydrocarbons are eliminated. The water vapour (sometimes after full condensation) is left in the airstream to incinerate at a temperature of approximately 800 °C to ensure complete destruction (see **Appendix 4**: scrubbing) • Both incondensable products and condensates from the separator, hydrocarbon and aqueous unit can be burnt in a purpose-designed incinerator, using support fuel as necessary or in process heaters. (see **Appendix 4**: incineration) • Waste gas treatment with a granular reactant (see **Appendix 4**: adsorption) • Vapour destruction through decomposition of VOCs by biofiltration (see **Appendix 4**: biofiltration)
Air vented from sweetening processes	• Sulphur compounds		Off-gases, especially odorous spent air from sweetening units, should be appropriately disposed of by routing them to destruction, e.g. by incineration (see **Appendix 4**: incineration)

Refinery Process	Possible odour source	Odour reduction - operational and prevention measurements	Odour reduction - control/treatment techniques (end-of-pipe)
Dewaxing to produce lubricating oil	• Sulphur compounds		Catalytic dewaxing processes, based on selective molecular sieve-based catalyst, typically produce less foul odours and sulphur content, compared to solvent dewaxing (see **Appendix 4**: adsorption)
Septic water areas (e.g. storage tanks, water buffer tanks, sewage systems, oil/water separators and Dissolved Air Flotation (DAF)) and waste water sludge treatment	• Sulphur compounds • Nitrogen compounds • Hydrogen sulphide	• Maintaining the smallest possible surface area of oil and water in contact with air e.g. using a fixed roof tank or a floating roof tank • Nitrate-based products can be used in order to replace bacteria feedstock and to favour the development of denitrifying bacteria, which will both reduce added nitrates in nitrogen and existing hydrogen sulphide in sulphates • Part of WWTP can be covered with closed sealed covers • Source reduction and spill prevention by good housekeeping • Use chemicals to destroy or to reduce the formation of odorous compounds (e.g. oxidation or precipitation of hydrogen sulphide). • Minimise residence time • Optimise aerobic treatment. This can include: I. controlling the oxygen content; II. frequent maintenance of the aeration system; III. use of pure oxygen IV. removal of scum in tanks.	• Some refineries employ a hydrogen sulphide oxidation tank prior to DAF and bio-treatment. • Waste gas treatment with a granular reactant (see **Appendix 4**: adsorption) • Treatment of off gases in incinerator (see **Appendix 4**: incineration) • Biofiltration (see **Appendix 4**: biofiltration) With alkaline oxidative gas scrubbing the organic odorous components are oxidised in an alkaline environment. (see **Appendix 4**: alkaline oxidative scrubbing)

Refinery Process	Possible odour source	Odour reduction - operational and prevention measurements	Odour reduction - control/treatment techniques (end-of-pipe)
Management of spent caustics used to absorb and remove hydrogen sulphide, mercaptans and phenol contaminants from intermediate and final product streams	• Hydrocarbons • Mercaptans • Hydrogen sulphide	• Neutralisation and stripping. • Handling and disposal • Recycling, reusing and/or regeneration of caustics within the refinery or outside the refinery • Physical separation of phenols by reducing pH to precipitate phenols	If recycling of caustics within the refinery or outside the refinery is not feasible, destruction is necessary using an incinerator (see **Appendix 4:** incineration)

4.2. Reducing odorous emissions using end-of-pipe techniques

There are many parameters to consider when selecting techniques to reduce odour emissions:

- the volumetric flow rate of the odorous gas emission;
- the concentration of the odorous pollutant(s);
- the physical and chemical properties of the odorous compounds, such as solubility, acidity, basicity, polarity, adsorbability and biodegradability;
- the efficiency of the techniques to abate the targeted odorous compounds and the variability over time of this abatement method (especially when catalysts are used);
- the generation of secondary pollutants;
- the energy consumption of the techniques;
- the technical limits/restrictions for the use of the techniques (e.g. temperature, maximum pollutant concentration and moisture content);
- the space requirements of the techniques;
- the operation and maintenance requirements of the techniques;
- the costs of the techniques.

A summary of the most commonly used end-of-pipe odour emission treatment techniques, including typical ranges of odour reduction, is given in **Table 4-2** [3]. These should be regarded as general ranges. More details of each technique are given in **Appendix 4**.

Table 4-2 General overview of end-of-pipe odour treatment techniques

Technique	Typical odour abatement efficiency [%]
Adsorption	80 – 99
Wet scrubbing (absorption)	60 – 85
Alkaline oxidative scrubbing	80 – 90
Thermal oxidation	98 – 99.9
Bio-filtration	70 – 99

It should be also noted that before extracting air for treatment in an odour control facility, vapour capture and containment systems (e.g., fitting lids and sealed covers) will be required.

5. ASSESSMENT OF ODOUR

A fundamental part of odour management is to understand and quantify emissions from actual and potential odour sources. Understanding the amount of odour emitted will allow a suitable and appropriate response to be developed. However, in the absence of data, a qualitative assessment of odours can also be a helpful starting point.

Odour monitoring can be required for varying reasons, including national legislative requirements, contractual or licensing obligations or voluntary use as a proportional response to odour events or complaints. Therefore, an odour monitoring survey needs to be based on the circumstances of the odour discharge. It should be designed to provide the information required to satisfy the specific assessments requested by regulatory authorities, or the desired need of the facility operator.

Fundamentally, odour monitoring is conducted to determine either the magnitude of the emitted odour from the source or the magnitude of impact at a receptor location. To achieve this, there is a range of available odour monitoring methods. The selection of the most appropriate method for a particular site is a judgement call and is based on the specific objective of the assessment and the limitations of the different monitoring methodologies. The various methods are described in the following sections, with a clear distinction between qualitative and (semi-)quantitative assessments.

5.1. What type of assessment is needed?

Odour assessments range from a simple assessment of the complaint information to a full detailed assessment. It is important to select an assessment type that is proportional to the actual or potential odour impact and that can provide sufficient information to meet the requirements of regulators, stakeholders and/or members of the public.

This document does not provide detailed guidance as to which assessment is required in each situation; rather it aims to raise awareness of the potential options and choices that are available.

As a general guideline, if the odour risk is minor, has no historical background, and involves only a few isolated complaints, a simple assessment would be appropriate. If the odour assessment is required in response to multiple complaints from many individual complainants or has been instigated in response to a request by a regulatory authority, a more detailed assessment including remedial measures could be required. In general, consultation with the regulatory authority is useful to both develop and agree on a proposed assessment methodology prior to starting the assessment. Some of the assessment options are shown in **Figure 5-1**.

As an alternative, a risk-based screening assessment could be a prudent first step to gauge the need for a more detailed assessment. However, when there is a clearly established odour impact, or history of repeated odour events, it is normally more effective to proceed directly to a detailed assessment.

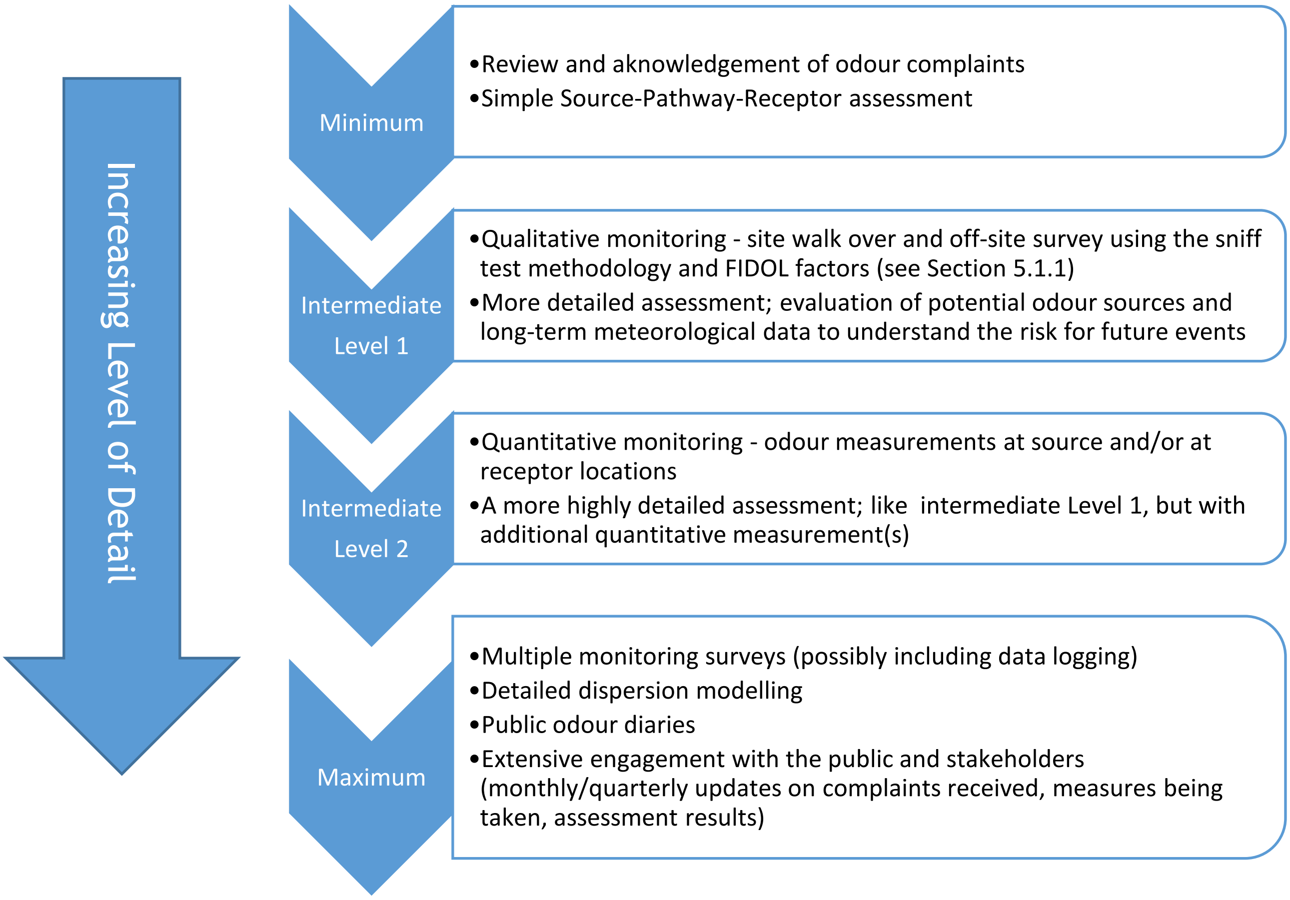

Figure 5-1 Possible assessment options proportionate to the level of public/regulator concern

5.1.1. Qualitative assessment

Qualitative assessment methodologies often incorporate the properties of odour with the source-pathway-receptor (S-P-R) environmental assessment method. The basic S-P-R methodology is used in odour assessments to consider a range of factors often defined as the FIDOL (or FIDOR) factors. This qualitative methodology incorporates the following factors to describe the potential for an odour impact:

1. Frequency - How often does an individual or individuals detect odour?

2. Intensity - What is the perceived strength of the odour experienced (see also **Table 3-1**)?

3. Duration - How long does each event last?

4. Offensiveness - What is the relative pleasantness or unpleasantness of the odour on either a subjective or quantitative scale[2] (see also **Table 3-1**)?

5. Location (also described as Receptor) - Factors associated with the receptor, e.g. sensitivity and tolerance of impact.

The FIDOL factors can be used as a basic means to make a qualitative judgement about the effect of an odour occurrence. Because of this, the FIDOL factors are generally used in assessing field odour investigations, in population annoyance surveys and/or complaint forms (see Section 8). Examples of possible field investigation outcomes and the corresponding FIDOL assessments are given in the table below [5].

Table 5-1 Examples of possible outcomes of field investigations

Possible field investigation outcomes	Assessment*	Overall qualification
I did not detect any odour	F I D O L	Not objectionable
I did detect odour, but do not consider it would be objectionable in this location for any frequency or duration	F I D O L	Not objectionable
I did detect odour, and consider that it would be objectionable if it would have been stronger and more frequent	F I D O L	Objectionable
I did detect odour, and consider that it would be objectionable if it became continuous	F I D O L	Objectionable
I did detect odour, and consider it to be objectionable even for periods of short duration	F I D O L	Objectionable

* Green: the individual factor is assessed as not objectionable, red: the individual factor is assessed as objectionable, blue: the individual factor cannot be assessed or is a variable parameter.

All FIDOL factors should be combined in assessing the effects of an odour occurrence in order to determine whether such an occurrence had an adverse or objectionable impact. The factors contribute differently to the overall judgement. For example, offensiveness is assessed under the FIDOL process however, an odour does not need to be offensive to cause an impact. In addition, an intense odour that

[2] Often measured by hedonic tone, description provided in **Figure 3-1**.

occurs frequently in short bursts ('acute' odour) may be assessed as being similar to a weaker odour, occurring over longer, less-frequent periods ('chronic' odour). There is no guidance as to how to attribute the factors into a combined impact magnitude, but it is emphasised that all FIDOL factors should be taken into account.

5.1.2. Quantitative assessment: Measurement of odour

Due to the way the brain responds to odours, it is not often possible to quantitatively assess the combined impact of multiple odour sources or a complex mixture of compounds. This is because the response is not generally additive [6] in the same way as decibels for noise or specific air quality pollutant concentrations. The brain has a tendency to screen out odours which are always present but those that are out of place or intermittent may noticeably stand out.

An assessment of individual compounds can lead to the misrepresentation of total odour impacts due to the potential screening or synergistic effects as detected by the human nose. As a consequence, odour quantification is commonly performed with human sensors.

There are limitations in the use of human responses to quantify odour largely associated with the accuracy of measurements which varies between individual assessors. As such, alternative and more precise chemical and electrical measurements have been developed which seek to improve quantification. Divergence by measuring a physical property rather than the human response can cause issues.

A basic classification of the available methodologies for the measurement of odour is as follows:

- Quantitative, *Olfactometry* – The total odour concentration within a gas sample is determined using a standard methodology by human response (see Section 5.2.1);
- Quantitative, *Chemical concentration measurement* – The quantity of the odorous compound is directly measured as a concentration (rather than a human response);
- Semi-quantitative: *Sensory* – A judgement of the magnitude of odour is made by a human assessor.
- Semi-quantitative: *Surrogate* or *Marker compound* – A known compound is used as a surrogate for total odour.

There is a range of monitoring options each with specific intended uses, benefits, limitations and practical application considerations. It is therefore considered appropriate to seek suitable advice from a regulatory authority or suitably experienced professional before a specific method is chosen, since it is important that the selected odour measurement technique relates to how the regulatory authority defines success. For example, measuring the odour removal efficiency of a control measure may show that the mitigation is effective, but it does not provide any information on the risk of an off-site impact. Alternatively, a sniff test that does not detect an odour on one particular day or time, does not prove that an odour impact did not occur when it was reported. Any chosen method therefore, should be selected to provide a sufficient level of information proportionate to the impact.

Commonly used odour measurement methods are briefly described in Section 5.2.

5.2. Odour measurement methods

Common measurement methods, suitable for use in the Oil and Gas sector, are summarised in **Table 5.2**. All of the suggested measures will provide some information on the magnitude of odour either at the emission source or in the environment. A non-limitative overview of when the various techniques could possibly be used in different odour issue scenarios is provided in **Table 5.3**.

Table 5-2 Common odour measurement methods suitable for use in refineries

Type	Approach	Common use
Quantitative - Olfactometry analysis	Determination of odour concentration (ou_E/m^3) through olfactometry (see 5.3.1). Conducted by an objective odour panel, applying the EN 13725 [7] methodology , i.e. an external (accredited[3]) laboratory or otherwise unbiased panel.	Quantification of odour source emission rates. Measurement of odour in the environment.
Quantitative - Chemical concentration measurement	Determination of concentration of a specific odorous compound (ppm or mg/m^3). GC-MS. PID, FID, etc.	Quantification of emission of a single emitted compound. Concentrations compared to the odour detection threshold for that compound.
Semi-quantitative - Sensory	“Sniff” tests / field odour investigation. Community Surveys/ Odour Diaries. Field Olfactometer (see 5.3.3) used by trained operator.	Used to assess odour impacts off-site or at the site boundary.
Semi-quantitative - Surrogate/Marker compound	Determination of concentration of a single surrogate or marker chemical compound (ppm or mg/m^3), or Pre-calibrated measurement of total odour using electronic nose.	Result used to infer total odour using established relationship between single or multiple marker compound concentrations and total odour emitted.

[3] External accreditation by country specific accreditation organisation, if applicable

Table 5-3 Overview of how the various measurements techniques could possibly be used in different odour issue scenarios

Typical odour scenario	Method(s) which can be used	Other considerations
Odour impact assessment during (re)permitting or for new project	Quantitative measures should be used once the sources are identified: - Olfactometry - Chemical concentration - Air dispersion modelling	In some countries, a prescribed methodology should be followed
Identification of the main odour sources in a facility (self-initiative). Sources can be continuous or discontinuous	A semi-quantitative approach (like making an assessment using FIDOL factors) is a good starting point, if local regulations are not more prescriptive	This is often a consequence of complaints (internal or external)
Response to 3rd party complaint	Semi-quantitative approach: - Sensory (FIDOL) - Electronic nose Note: *Electronic noses can only be used if "calibrated" beforehand for site-specific odours*	Process (and level of assessment) is described in the odour management plan
Odour mitigation during special activities (e.g. turnarounds)	Before the event: identification of odour scenarios (should be part of odour management plan) During the event: semi-quantitative methods	Preventative approach if earlier events caused (multiple) complaints
Purchase of new chemicals		Screening of new chemicals for odour should be part of the site environmental management system
Equipment or process modification (Change Management). Example: sulfiding hydrofining catalyst in-situ instead of purchasing presulfided catalyst		Evaluation of potential odour issues should be part of the site Change Management system
Consequence of an upset in the facility	Measurements are often not possible after the event.	Odour observed outside the fence. Response is described in the odour management plan. Response (to complainants and/or to Regulators) should explain the scenario and lay-down actions to prevent reoccurrence

5.2.1. Olfactometry and the odour unit

Olfactometry is a common method used to quantify the concentration of odour. Prior to the adoption of a standardised olfactometry method (EN 13725 [7]), national protocols determined how olfactometry should be conducted within individual European countries. Some adopted a, so called, 'Dutch standard' due to its use in early studies to quantify the dose-response relationship of odour exposure and population impacts.

A different method (the 'mass equivalent standard') was generally adopted in European studies, to replace the national protocols. However, a standardised way to quantify odour concentrations was adopted across Europe in 2003 by through the publication of the EN 13725:2003, *Determination of odour concentration by dynamic olfactometry* [7]. The procedure is described in **Appendix 1**.

It should be noted that there are also Australian and American standards which are different in approach to the European standard as they are based on dilution alone. These other standards are used in some studies which can cause confusion within the scientific and regulatory community, as the definition of an odour unit is different depending on the methodology adopted.

In summary, olfactometry relies on the response of a panel of trained observers when presented with differing dilutions of a sample of odorous air in laboratory conditions. In its simplest form, panellists are presented with two 'funnels', one which contains the odour to be assessed and the other which contains odour-free air. Panellists are asked whether they can detect the odour and which of the two funnels it is presented through.

The number of dilutions of the presented odour is altered until the panel response is equivalent to that of exposure to a reference compound (123 µg/m^3 of n-butanol evaporated in a cubic metre of odour free air), known as the equivalent European Reference Odour Mass (EROM). This reference response is equivalent to the concentration of 1 European Odour Unit (ou_E/m^3) and represents a position where 50% of the population is expected to be able to detect the presented odour.

The European Odour Unit (ou_E) is the commonly adopted unit for studies in Europe. The Australian or American odour unit is defined as 'OU', however, this unit is not recommended in Europe as it may cause confusion. The obsolete 'Dutch odour unit' ('*geureenheid*'), 'ge', was defined in standard NVN2820:1994 [8], the predecessor of the current EN 13725:2003 [7] standard. This now obsolete unit translates to ou_E as: 1 ou_E = 2 ge. Usage of this old unit is strongly discouraged now, but it is not uncommon to come across this unit in older odour studies.

Table 5-4 Various notations for 'odour unit'

Notation	Usage	Remark
ou_E	European Odour unit	Preferred notation for use in Europe
OU	Odour Unit (USA and Australia)	Not preferred for use in Europe
ge	'Geureenheid' (Dutch)	Obsolete

5.2.2. Chemical concentration measurement

As described in the previous section, during olfactometry analysis the entire air sample is assessed by the odour panel, resulting in an overall odour concentration (expressed in ou_E/m^3). This technique is especially useful for air samples with an intricate mixture of odorous compounds (for example, odours from bitumen production). For example, it can be used to determine information about an individual compound within a complex mixture which is not possible using olfactometry. In some cases, the constituents of an air sample are already known, or are less complex, (for example odours from oil/water treatment facilities) and a different analysis method can be selected to quantify the odour concentration. Using gas chromatography with a flame ionization detector (GC/FID) or gas chromatography with mass spectrometry techniques (GC/MS), individual chemical concentrations can be determined, expressed in mg/m^3 or $\mu g/m^3$. Experience has shown that the use of GC/MS is preferable for analysing complex mixtures.

Determining the concentration of an individual compound or set of compounds is not enough to determine the human response to an odour. A specific odorous compound is only perceivable by the human body above a certain concentration. This so-called Odour Detection Threshold (ODT) value is usually determined for each compound using empirical studies.

Using the ODT value, the concentration of the compound can be normalised, resulting in a parameter called the Odour Activity Value (OAV). It is defined as the ratio between the odour concentration and the ODT:

$$OAV_i = \frac{C_i}{ODT_i}$$

For a gas mixture of various odorous compounds, the individual Odour Activity Values are added to result in an Odour Concentration (OC) for the total gas mixture.

$$OC = \sum_{i=1}^{n} OAV_i$$

A list of odour detection thresholds of substances typical for the refining sector can be found in **Appendix 2**.

5.2.3. Semi-quantitative measurements – Sensory

Observational evidence can be used as a method of odour quantification. This relies upon the human sense of smell alone to provide descriptions of intensity and offensiveness to quantify environmental odours. Sensory techniques differ from olfactometry, since the latter is a quantitative method (because of the diluting of the odorous sample). Sensory methods depend on actual sniffing at the location, therefore making it a semi-quantitative method.

At its most basic, sensory monitoring can involve a field odour assessor recording observations in the event of an odour complaint or issue. During this assessment, the previously described FIDOL factors (see Section 5.1.1) are taken into account as much as possible. This is, however, subjective and dependent on the individual assessor's sense of smell and previous experiences. Therefore, it is recommended to require the assessor to have regular 'nose calibrations' (by an odour laboratory).

Methodologies which try to more precisely quantify sensory methods have been developed. These include use of standardised methodologies and practices to achieve better alignment between field odour investigation and use of mechanical aids.

A commonly used approach is to use a pre-defined observational 'sniff test' procedure. This involves following a common approach with standardised sampling durations and numerical intensity descriptors. Often these approaches also include a way to assess intermittency and pervasiveness by requiring results to be taken at regular intervals (common practice is every 10 seconds over a 5 minute duration, to provide 30 samples). There are no uniformly accepted methodologies across Europe and it is expected that there are differences between national practice guidance documents. A good example is the UK's Institute for Air Quality Management (IAQM) Guidance on the Assessment of Odour for Planning [6] which is in part based on the German VDI 3940 [9]. The latter and EN 16841 [10] (see also **Appendix 1**) can be used for odour mapping.

Other sensory measurements involve equipment which allows the operator to quantify the concentration in the air more precisely (field olfactometers). This includes equipment which allows pre-dilution of ambient air by presenting a proportion of clean air using an in-built activated carbon filter. These field aids can allow the user to gain an approximation of the number of dilutions that are required for the odour to be just detectable. Although not comparable to olfactometry analysis in accordance with EN 13725 [7] an approximate odour concentration can be achieved using this method.

5.2.4. Semi-quantitative measurements – Use of surrogate/marker compound

The analysis methods mentioned above are mostly laboratory based techniques using stationary sampling of the odorous gases. For quicker and more mobile odour analyses (e.g. 'in the field') a range of electronic devices are available. These so called 'electronic noses' (commonly known as 'eNoses' or 'e-noses', although these are actually commercial brand names for specific devices) are low-cost and compact devices that play an increasingly important role in odour monitoring in both industrial and densely populated areas. They can be used as standalone or handheld devices or imbedded in a monitoring network.

An electronic nose is a compact instrument, comprising a sensor array that responds to small variations in reactive gas concentrations in ambient air. Like the olfactometry technique described in Section 5.2.1, it uses a holistic analysis, considering the gas mixture as a whole instead of identifying every component separately (in contrast to the GC/MS technique described in Section 5.2.3).

Electronic noses can be connected to an online remote computer system that interprets the data in real-time. The software interpreting the data features two functions. Firstly, it detects anomalies in the air composition. If any anomalies are present, the software then compares the composition pattern with a database of reference patterns. It does this through a least-squares classification method, such as a Linear Discriminant Analysis (LDA). This method aims to identify an unknown data sample within a reference database.

The applied type of gas sensor in electronic noses may differ depending on the anticipated composition of the gas mixture. The most frequently utilised sensors include semiconductor, electrochemical and photo-ionisation detector (PID) types. Such sensors are now increasingly used. Applications in industry range from detection of odorous compounds to hazardous compounds that may form a threat for human or environmental health and safety.

5.2.5. Benefits and limitations of odour measurement methods

A number of methods for odour measurement have been outlined above but none are without drawbacks.

The choice of a method over all the others should be made in line with practicalities, cost and the objective of the assessment. **Table 5-5** highlights some of the benefits and limitations of commonly used odour measurement techniques.

Table 5-5 Benefits and limitations of commonly used measurement techniques

Type	
Quantitative - Olfactometry analysis	**Benefits** Quantifies human response to a specific odorant rather than a substitute or model compound. The measured odour concentration is based upon the air presented to the assessors and as such represents a combined odour response to the specific mixture. **Limitations** Measurements have a relatively low accuracy. This is reduced by analysis of repeat samples, but not comparable to measurement of physical parameters. This is due to responses varying between individuals. In addition, an individual's response to odour can vary on a day-to-day basis due to health, psychological and external environmental factors. The limit of detection is dependent on the individual's response but is typically in the range of 20-50 ou_E/m^3. This precludes the use of the method for studies at or beyond the site boundary, where odour levels can be below this level. Offers only a snapshot of the odour during the time of the collected sample. The temporal variation of the odour cannot be quantified. Logistics can be an issue due to the requirement to analyse collected samples within 30 hours, in accordance with EN 13725 [7]. Large scale sampling campaigns can be expensive.
Quantitative - Chemical concentration measurement	**Benefits** Often very precise accuracy of measurement of the concentration of the target compound in air. Equipment can offer real-time results and data logging. **Limitations** Measures concentration of the target compound rather than odour. The relationship between pollutant concentration and odour response may not be well understood. Use of a literature based odour detection threshold (ODT) decreases reliability due to the reliance on human response studies.
Semi-quantitative - Sensory	**Benefits** Surveys can have a large geographical and temporal spread. Surveys can be commissioned in direct response to a reported odour event (e.g. complaint).

	Relies on human sense of smell, allowing understanding of source apportionment in the environment, although within a complex structure, such as refinery process plant, this can be difficult. **Limitations** Requires regular assessor (nose) calibration. Sniff tests are field based and can require significant training and experience for the assessor to achieve high accuracy. It can be challenging to train an individual to be an effective assessor. Requires experience for the surveys to be undertaken reliably. Suitability for inexperienced persons (e.g. members of the public) is arguable, but should not be readily dismissed. For instance, asking neighbours to write down their experiences for a certain period can be of added value to the overall odour assessment.
Semi-quantitative - Surrogate/Marker compound	**Benefits** Provides an accurately measurable emission rate, often at a much better resolution than olfactometry. **Limitations** Requires a precise understanding of the make-up of other compounds emitted alongside the marker compound. Requires a study into the relationship of the chemical compound and the 'total odour' as determined by olfactometry. May underestimate or overstate total odour if the relationship between the marker concentration and total odour is not well established or understood.

5.3. Estimation of emissions – fugitive releases

Fugitive odorous emissions, from equipment leaks for example, are difficult to quantify and hence are normally estimated. The US EPA Protocol for Equipment Leak Emission Estimates [11] is a commonly used method which has been adopted as a suitable approach in European countries [12]. The method uses emission factors for different component types (e.g. flanges, valves, open ends and pumps, etc.), the number of such components, the type of transported material (light or heavy liquid, or gas) and the composition (e.g. a specific odorous compound as a proportion of the total VOCs in the liquid or gas).

It must be noted that the US EPA emission rates are from measurements undertaken at operational sites in the 1990s and the reported emission factors are likely to be conservatively high for newly built facilities using modern components and best practice containment measures.

These methodologies provide an estimation of the VOCs released, to which an odour detection threshold can be applied to calculate the equivalent odour release.

5.4. Atmospheric dispersion modelling

Advanced dispersion models are commonly used for regulatory and assessment purposes. Typical examples include the US EPA AERMOD [13] and the UK ADMS models [14]. Atmospheric dispersion is determined by input data (stack and pollutant release parameters, land use and terrain characteristics, meteorological data and building dimensions) to calculate ground-level odour concentrations (immission concentrations) across a selected receptor grid and discrete receptor points. The following input data are typically required.

- Hourly meteorological conditions – wind speed, wind direction, temperature, relative humidity, cloud cover and precipitation. Used to determine how odorous compounds disperse in the atmosphere.
- Source emission rate (ou_E/s) – a product of the odour emission concentration (ou_E/m^3) and volumetric flow rate (m^3/s) of the release. Note that this requires the emission concentration at source and not derived from ambient air measurements.
- Source parameters – location and release height of the emission source.
- Source type – point, flare, capped, area or volume source. Used to determine the initial size and type of the dispersed plume. Accompanied by exit velocity (or volumetric flow rate) and exit temperature for stack emission sources.
- Terrain influences – typically included when local topography includes significant features or a gradient of more than 10% is observed in the study area.
- Building influences – large buildings or structures may influence dispersion as either an obstruction or indirect impact, e.g building downwash (or building wake) effects.

The dispersion modelling is an effective way of calculating the odour concentration at a certain location. The calculation is however depending on a variety of assumptions which vary depending on the model type and the level of complexity, and the outcome of the modelling can be of reduced accuracy. It is therefore recommended that outcomes of modelling are checked by simple measures such as sniff testing, for example. In this way the assumptions related to the input are checked and adjusted to experience and means that the outcome becomes more trustworthy. Another way of testing is to use e-noses to provide data for certain locations.

6. POLICY AND LEGISLATION

Both national and international regulatory frameworks try to find the best options for controlling and managing odour issues. Due to both the local and subjective aspects of odour, many authorities have multiple approaches when considering and managing odour. Although the approaches vary across Europe, environmental policies and regulations are designed to minimise both short- and long-term effects on the public.

Odour policy and legislation are generic and focus either on the type of activity or industry, such as waste treatment or agriculture, or on the offensiveness of the odour. It is not typical for odour policy or legislation to focus specifically on refineries, however some jurisdictions include odour-specific requirements in environmental operating permits.

As much of the legislation related to odour management is determined by local authorities, it is difficult to provide an overview of national legislation which relates to refineries. To understand the basis of local legislation related to odour, this section will provide a general overview of regulatory instruments and regulatory frameworks in place to control odour emissions.

6.1. Description of possible regulatory instruments

A review of legislation in different countries, with an understanding that odour is difficult to quantify, shows that the legislative instruments and assessment standards are typically divided into the following categories:

1. Ambient or environment-based;

2. Emission-based; and

3. Management-based.

To understand the legislative instruments and relate them to the local situation, these categories are described in general terms in the following sections.

6.1.1. Ambient or environment-based instruments

Ambient or environment-based instruments are dealing with the impact of odour within the local surroundings. There are a variety of ambient-based instruments related to impact management which vary in their degree of complexity, as shown in the following sub-sections.

I. Avoidance of nuisance law

This type of law essentially provides a general statement that odour from a facility will not result in a “nuisance”.

Depending on the local situation, the term “nuisance” can be defined differently. For example, on one hand odour is classified as a private nuisance if it “interferes with the reasonable and comfortable use of a person’s property”. On the other hand, public nuisance “means a condition that is or might become injurious or dangerous to the public health, or that might hinder in any manner the prevention or suppression of disease.”

The exact definition of nuisance is generally not included in the national law. However, examples may be found in case law, i.e. court rulings that provide an interpretation of the legislation, and certain criteria to determine when a nuisance has occurred and when appropriate remedial actions should be taken.

II. Ambient concentration criteria for individual chemicals

Most European countries have concentration limit values for individual chemicals that are odorous. The basis of the limit values is normally related to acute and chronic human health impacts. Odour detection thresholds applied to odour concentrations are not typically defined by national guidance. The use of ambient concentration limit values is, therefore, generally not useful in odour assessments, unless they are specifically based on odour.

III. Ambient concentration criteria for odour or maximum impact standard

Few countries have a defined specific limit value for odour. It is often up to the legislation/enforcer to justify the odour standard used.

Typically an odour concentration between 1 and 10 odour units per cubic metre of air ($ou_{E/}m^3$) predicted at a receptor equivalent to the 98 to 99.9th percentile is used as an odour annoyance standard. It is most common to use an assessment standard of 3 to 5 ou_E/m^3 at the 98th percentile of hourly averaged data (3 ouE/m^3 at 98th percentile of hourly averaged data, means that an odour concentration of 3 Odour Units per cubic meter or higher is experienced 2% of the time, or 175 hours per year).but this can be modified due to source-based (e.g. a particularly offensive odour) or receptor-based (e.g. a highly sensitive receptor) factors [15] [16].

This type of regulatory instrument works closely together with immission or effect calculations. Based on a quantitative assessment (or a prediction) of the potential odour emissions, source parameters and meteorological data, the effect in the surrounding community (using atmospheric dispersion modelling) is calculated and expressed as the concentration related to the percentile.

The ambient concentration criteria for odour are based on hourly average concentrations. In other words, short-term (sub-hourly) peaks in odour, which may trigger an actual odour response, could be averaged out over the hour by the dispersion model, resulting in concentrations that are predicted by the dispersion model to be below the odour assessment criterion.

IV. Episode duration-frequency

The episode duration-frequency system considers not only the intensity of an odour, but also its duration and frequency. It considers field measurements and the result is expressed in “odour hours”. This methodology ensures that short odour peaks constitute the same amount of “odour hours” as broader peaks over a longer time period. The thought behind it is that short but recurring odour peaks can be more annoying than broader peaks.

A test is used which registers every 10 seconds in a 10 minute period if an odour is experienced. When, during a 10 minute measurement, the quantity of odour experiences is equal or exceeds 10% of the total experiences, the measurement results in 1 odour hour. Repeating this measurement provides a certain percentage of odour hours.

The percentage of odour hours registered is a measure of the exposure at the location. Legislation will specify a maximum of odour hours.

The standard EN 16841-1:2016 [10] describes this methodology further (see also **Appendix 1**).

V. Minimum separation distances

This type of legislation defines minimum separation distances to act as a buffer between source and receptor.

VI. Odour intensity scales

This is a semi-quantitative approach where a few words are used to describe the odour intensity applicable to each level.

The odour experience can be classified in numbers, where each number represents an intensity. An example is presented in **Table 6-1**, which is a similar but easier to use methodology described in VDI 3883 (see chapter 3) [17].

Table 6-1 Annoyance Categories

Score	Description
1	Not Annoying
2	A Little Annoying
3	Annoying
4	Very Annoying
5	Extremely Annoying

VII. Complaint criteria

Complaint criteria are expressed in terms of a minimum number of complaints required before an investigation is launched, or an odour is considered a nuisance. Some jurisdictions have regulations or guidelines on how the regulator will respond to complaints.

6.1.2. Emission based instruments

An emission-based instrument limits the odour emissions. It does not focus on the impact, although there is a relation between emissions and impact. There are two types of emission based instruments:

I. Quantitative emission criteria

This is expressed either in units of odour/compound concentration (i.e. ou_E/m^3) or as an emission limit value which incorporates the volumetric flow rate of the odour discharge (i.e. odour units per second (ou_E/s)).

II. Technology criteria

This describes technologies required to minimise odour emissions (including odorous compounds), usually as a percentage removal efficiency.

6.1.3. Management-based instruments

Management-based instruments focus on procedures to limit either odour emission, immission or effect. A good example is the Odour Management Plan (OMP). This requires the operator to describe how potential odour problems are dealt with to reduce the potential for adverse effects.

As an OMP is a commonly used instrument, it is described in more detail in Section 7.

6.2. Legislative frameworks within EU

To provide insight into how regulatory instruments may work together, some examples of legislative frameworks are provided.

6.2.1. EU

There is no EU legislation specifically concerning the subject of odour.

6.2.2. Basis for European national legislation

A review of national odour legislation in the EU shows that there is no uniform approach.

The following table shows the leading principles in several EU countries for odour management in general. Note that the approaches in the table do not necessarily relate to any one particular activity e.g. industrial sector, agriculture, waste treatment, etc. It is also possible that a specific situation may require the use of one or a combination of approaches.

Table 6-2 Leading principles related to odour legislation in several EU countries [16]

Country	Approach
UK	National guidance.
	Maximum impact standard, differentiated by offensiveness.
	Technology criteria such as description of Best Available Technology.
Germany	National legislation and technical instructions.
	Maximum exposure standard, differentiated by land-use; Cumulative approach (existing odour exposure plus new contribution) odour-hour concept.
	Technology criteria.
	Separation distance standard.
Austria	There are no national limits, but for some areas targets based on maximum impact standards including differentiating by offensiveness.
	Separation distance standard.
France	National level: emission standard.
	Maximum impact standard (only when exceeding a certain emission).
	Technology criteria.

Netherlands	National level: avoidance of nuisance law. Regional and sectorial odour policy regulating nuisance. Maximum impact standard based on type of activity, hedonic value, type of receptor. Technology criteria.
Denmark	National guidance documents. Maximum impact standard, monthly percentile values. Maximum emission standard. Maximum immission limits for chemical substances.
Belgium	Regulated at state level (Flanders, Wallonia and Brussels). Maximum impact standard. Minimum separation distances.
Italy	No national approaches, regions have autonomy to regulate on air quality. Variety of interpretations by administrative regions of maximum impact standards. One region related the maximum impact standard to the number of people it can effect. Another relates it to land use and the presence of potentially sensitive receptors. Regulations provide guidance and standards for odour impact studies.
Ireland	No general statutory odour standard. There are guidance documents defining maximum impact standards differentiating by target value and between new and existing developments.
Norway	General description that permits are required for activities that can cause pollution. No legal limits, but guideline is developed. Guideline sets framework for risk assessment/operating and action, OMP/communication. Through the risk assessment, maximum impact criteria are taken into account (differentiated by land-use).
Spain	No national approaches - based on municipal ordinances and activity licences. Draft local legislation with maximum impact standards in residential area. Maxima depend on offensiveness (under development).
Hungary	No legal limits, only suggestions.

6.2.3. Examples of odour legislation

Two examples are presented of legislative requirements (as pertaining at the time of writing) from European countries with established odour guidance, i.e. the Netherlands and UK (specifically England and Wales).

The complexity of the national framework is explained for these two examples.

The Netherlands

The Dutch odour policy is included in article 2.7a of the Activities Decree and in the 'Manual for odour: determining the acceptable nuisance level of industry and companies (non-livestock farms)'.

A process that is aimed at determining the acceptable level of nuisance is central. The national legislation allows local authorities to determine the acceptable level of nuisance per situation in a customised regulation. The law describes that a local authority should consider the following:

a) the existing frameworks, including local odour policy;

b) the odour load at the location of odour-sensitive objects ;

c) the nature, quantity and appreciation of the odour that is released at the facility in question;

d) the history of the facility concerned and the complaints pattern with regard to odour nuisance;

e) the existing and expected odour nuisance of the facility concerned, and

f) the costs and benefits of technical provisions and rules of conduct in the establishment.

Many local authorities have prepared their own local policies to define the nuisance level. Some include hedonic tone values, others differentiate between type of receptors (e.g. between industrial, residential or recreational area, office buildings or nature etc.), and some do both.

Many of the Dutch refineries are within the Rotterdam Area. The province of South Holland is the local authority and policies for the whole province apply, including a special focus on the port (Rijnmond area) but not specifically for refineries.

The odour policy in the Rijnmond area can be summarised as follows:

The aim of the odour approach is that "outside the site boundary no odour from the installations may be observable". To achieve this a duty of care principle is included in every permit. The duty of care principle expects every company to continuously work to minimise odour emissions from their site. Alternatively, a condition is included in the permit that the local authority can demand additional requirements relating to odour management and control.

The basis for the regulation is that technologies recommended as BAT within The Netherlands are used. However there are situations where a company, even with all BAT technology in place, cannot prevent odour emissions occurring on their site. The local authority is then allowed to take other criteria into consideration besides the previous mentioned criteria of no odour emissions from site.

In such a case the authority can define three levels of requirement:

- Measure level I: "No odour from the refinery may be detectable outside the site boundary"

  The target value is 0.5 ou_E/m^3 at the 99.99th percentile on boundary of the site.

  (The value is calculated with disperion modelling taking into account hourly mean values).

- Measure level II: "At the location of an odour-sensitive location, no odour from the refinery can be detected."

  The target value is 0.5 ou_E/m^3 at the 99.99th percentile on pre-defined odour sensitive locations.

- Measure level III: "At an odour sensitive location, there is no odour nuisance".

  The target value is 0.5 ou_E/m^3 at the 98th percentile on pre-defined odour sensitive locations.

The goal is to achieve the best protection (measure level I). It is up to the site to propose measures to achieve this. If the activity causes odour off-site, the company must prove that additional measures are technically not possible or not cost-effective and also take social, economic and local aspects into account. If measure level III is not achievable, a new activity would not get a permit. In the case of an existing facility, an odour management plan (OMP) is required to manage and minimise odour emissions from the site.

The proposed measures will be included in the permit along with a “safety net” that allows the local authority to request additional measures.

England and Wales

Emissions from a wide range of activities are regulated through a framework currently set out in the Environmental Permitting (England and Wales) Regulations (EPR) 2016, as amended in 2018. Scotland and Northern Ireland have devolved separate processes. However they closely mirror or have formally adopted the Department for Environment, Food & Rural Affairs (Defra) documents adopted formally in England and Wales.

The EPR provide a consolidated system of environmental permitting and transpose the provisions of the Industrial Emissions Directive regulating emissions to air, water and soil, waste management and management of specific substances, including odour.

The Environmental Permitting regime requires operators to prevent or minimise emissions in accordance with their Environmental Permit. The aim of the regime is to:

- protect the environment and human health;
- manage permitting and compliance effectively and efficiently in a way that provides increased clarity and minimises the administrative burden on both the regulator and the operators of facilities;
- encourage regulators to promote best practices in the operation of regulated facilities; and
- continue to fully implement European legislation.

Sector-specific guidance is provided by the Defra and the Environment Agency (EA) on how to apply for and comply with an Environmental Permit. This guidance includes the H4 Odour Management Guidance [18] for the assessment and management of odour impacts. It is a general purpose document which does not focus specifically on refineries.

Facilities regulated under EPR are required to operate under specific conditions in accordance with an issued Environmental Permit. Potential odour impacts are normally managed by inclusion of odour conditions which require that the site activities should not cause adverse effects associated with odour emissions beyond the process boundary. These conditions can either be in line with standard rules, i.e. a commitment to provide sufficient control to avoid any nuisance odours outside the site boundary, or conditions specifying an odour emission limit value, odour removal performance limits or alternative odour criteria where enhanced environmental protection is required.

The overarching principles of what is considered BAT for odour within the UK are set out in the Environment Agency H4 Odour Management guidance document [18], which provides generic management and control techniques for odour emissions. The guidance describes odour control measures, odour monitoring and reporting requirements, dispersion modelling approaches and best practice odour management, and the need for the preparation of an odour management plan (OMP), where required. The guidance also provides suggested odour assessment threshold criteria for predictive assessments using a benchmark-based odour offensiveness classification of the source.

The H4 Odour Management technical guidance document states that dispersion modelling assessments should compare predicted dispersion model outputs to ‘benchmark levels’ based on the relative offensiveness of the odour source. These benchmarks, assessed at the 98^{th} percentile of hourly averages, are as follows:

- 1.5 odour units (ou_E/m^3) for "most offensive" odours;
- 3 odour units (ou_E/m^3) for "moderately offensive" odours; and
- 6 odour units (ou_E/m^3) for "less offensive" odours.

From the examples of the offensiveness classification provided in the H4 guidance, it is considered that the majority of industrial sources fall into the "moderately offensive" classification. It is expected that refineries fall into the category of "most offensive" odours with a 98th percentile value of 1.5 odour unit/m^3, although that may not be applicable for refineries with robust odour management systems. Under the requirements of an Environmental Permit, the sources with the highest potential for off-site odours will be abated using odour control systems designed to minimise impacts. There is, as well, an Institute for Air Quality Management (IAQM) guidance document called 'Guidance on the assessment of odour for planning' [6].

7. ODOUR MANAGEMENT FRAMEWORK

An effective odour management framework can form part of a wider reaching Environmental Management System (EMS) or can be a standalone item.

Odour management is complex and it is therefore important to have a structured approach to assessing and managing odours. The structure applies to all odour emitting activities and is not specific to refineries.

An odour management framework can be divided into two parts: a mid- to long-term strategy and an execution plan describing the short-term actions. See also **Figure 7-1** below.

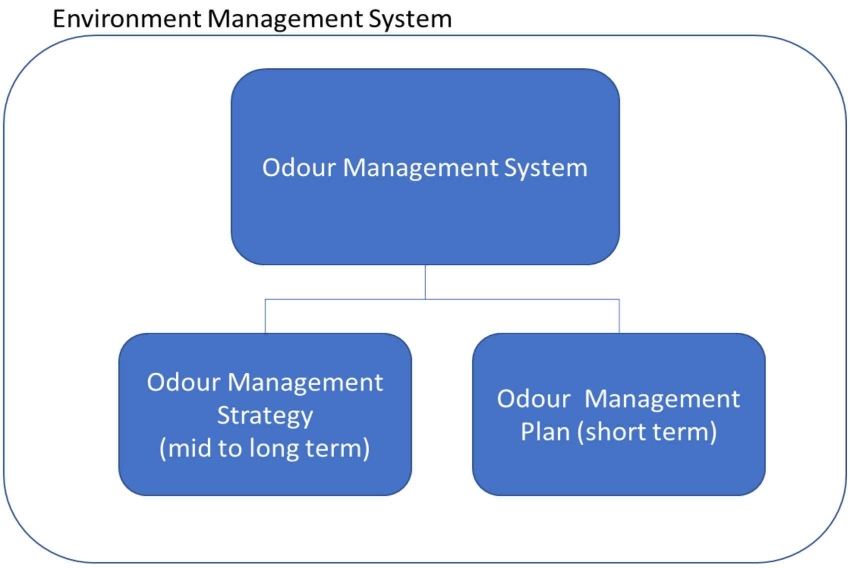

Figure 7-1 Break-down of the Odour Management System

The purpose of this chapter is to introduce the basics of an effective odour management framework. It will briefly describe the content of the strategy and provide guidance on preparation of an odour management plan (OMP), including the execution plan required to achieve the strategy.

7.1. Odour Management Strategy

An Odour Management Strategy (OMS) defines the direction and goals and provides clarity on decisions, which need to be made on the road to achieving the goals.

The OMS describes what an organisation wants to achieve, for who they are doing it and the actions needed to achieve those goals, including a division of responsibilities. The document provides clear directions as to what extent odour management should take place. The directions and goals of an OMS can vary. The first goal to achieve is to be in line with legislation. The direction and goals could also be worded differently such as no or limited odour complaints or no odour emissions that result in an adverse effect (offensive or objectionable effect) at or beyond the site boundary. These alternatives could be in line with legislation, instead of legislation or on top of legislative requirements.

The strategy of a company is not something that can be decided through the consensus of a single management meeting. It requires an interactive process involving several managers and experts who discuss and agree on various critical strategic questions. After finalising the strategy, a shared commitment is reached.

7.2. Odour Management Plan

An OMS typically requires an odour management plan (OMP) to be prepared. The OMP contains procedures to minimise odour emissions, and the impacts associated with emissions from sources located at the facility. This can be through correct operation, mitigation measures and/or general good practices on a day-to-day basis. The aim of an OMP is to achieve the odour management strategy.

Generally, an OMP should be a live, working document that formalises and describes how odour issues will be managed on site. It should cover normal operations (continuous and intermittent) as well as anticipate and plan for abnormal events and foreseeable accidents and incidents. It should contain possible mitigation and control measures. The overall aim is to achieve the odour management strategy.

Details for developing an OMP are provided in **Appendix 5**. In addition, information from a few case studies taken as examples of how refineries have dealt with odour events that have occurred in their vicinity, is provided in **Appendix 6**.

7.2.1. Minimum content of an OMP

In general, an OMP should follow the basic management system principles of “Plan”, “Do”, “Check” and “Act” as follows:

- *Plan* – identify odour emission sources from processes and site operations, identify potential sources of odour (continuous, intermittent, or occasional discharge of odour) and the manner of discharge (point or area source, fugitive, etc.).

  Detail odour prevention, control and mitigation strategies specific to the facility and site operations based on material and waste handling, production systems, ancillary services, preventative maintenance and general site operations.

- *Do* – identify measures to be implemented, establish odour complaint response protocols, implement administrative controls such as staff training, develop standard operating procedures, create preventative maintenance schedules and recordkeeping.

- *Check* - verify that the measures are working well (odour monitoring and inspection protocols, recordkeeping, accountability and management oversight).
- *Act* – review and revise to keep the OMP effective.

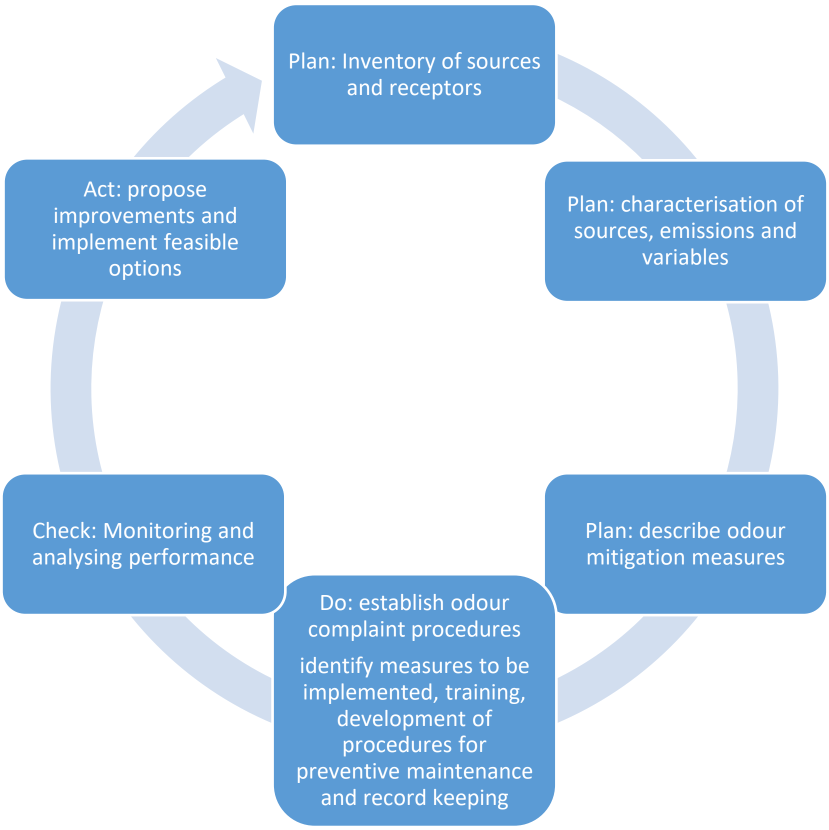

Figure 7-2 Process for creating and revising management processes relating to odour

Taking this into account the OMP content is broadly separated into four sections following an Introduction. The latter would outline the requirements and the important legal or company policies and objectives within the OMP. The elements of planning in the OMS would also be covered along with the need to define responsibility, authority and communication within the company.

1. *Plan*: Description of situation regarding odours

Three major components are included in this part of the OMP document, all related to the current situation.

A. *Identification, description and characterisation of odour emission sources:* presents an inventory of odour emission sources at the facility, and describes the characteristics of each emission source (type of odorous compounds, volumetric flow rate, emission release height, odour emission rate and concentration, and temperature of the emissions, etc.).

Sources could be identified using e.g. process flow diagrams, site plans, etc., to establish if these emit odorous emissions. *Special attention should be paid to fugitive emissions (reducing fugitive emissions– see* **Appendix 4***).*

Sources are related to process, maintenance, utility services, transport, storage, spillage, cleaning, rainwater run-off, oily-water treatment, etc.

B. *An assessment of the sensitivity of the surrounding environment*[4] *and potential impact on sensitive receptors*: presents information regarding sensitive receptors, including their location, the distance from the odour source and their position with respect to the prevailing wind directions and an estimate of the impact of the odour emissions on the identified receptors. This assessment focuses on:

- Impact calculations (dispersion modelling predictions) for normal operating conditions, showing isopleth contour plots;

- An estimation of the odour effects under abnormal circumstances: from extreme weather conditions, seasonal activities, certain critical process steps and operations (e.g. receipt of odorous materials or compounds for storage on site, etc.), accidents (due to human error, failure or equipment breakdown), and cleaning or maintenance operations, etc.

This assessment framework can include target and limit values specified in national legislation or an operating license to describe suitable criteria for what would constitute a nuisance or an adverse effect.

C. *An overview of the mitigating measures.*

In the case where an odour nuisance is expected as a result of the project or facility, measures should be investigated which would allow the risks to be minimised.

Possible aspects to consider related to reducing odour emissions are:

- Replacing materials with less odorous materials or components;

- Improve inspection and monitoring to identify potential odour emission at an early stage;

[4] Receptor: in this context relates to sensitive receptors. These could be employees, hospitalised people, residents, students, and the elderly, etc.

- Installation of abatement techniques or other measures than can reduce odour impact;
- Improved operational procedures;
- New or improved maintenance procedures;
- Taking weather conditions into account when planning to undertake certain activities;
- Preventative actions such as monitoring process parameters to ensure the optimal operations;
- Good housekeeping including prevention of spills, spill clean-up, etc.

2. ***Do*: Operate**

Implement administrative controls such as staff training, development of Standard Operating Procedures (SOPs), preventative maintenance schedules and recordkeeping.

3. ***Check*: System review and reporting procedures**

This section contains the requirements for assessing and re-assessing the situation regarding odours. It should contain regular monitoring procedures in line with public or regulator expectations. In addition, it should include procedures and frequency for internal audits. The focus for monitoring should be both on-site and off-site. The latter could be by sniff-testing, odour diary surveys, etc. A procedure for record keeping should be included.

4. ***Act*: Improvement**

Depending on the findings, a procedure should be included to improve the OMP. This should include a regular review (at least once per year) of the effectiveness of odour controls - including the OMP itself – considering complaints, monitoring results, inspections, surveys and other information and feedback received. The interval between reviews should be shorter if there have been complaints or relevant changes to site operations or infrastructure. All actions should have clear deadlines.

Details on the development of an OMP, including a general content list, are provided in **Appendix 5**.

7.2.2. Variations to basic OMP contents

The previous paragraphs summarised the basic content of an OMP. There are, however, possible variations.

A simpler version of an OMP could be an odour audit, which contains an analysis of the activities, products, processes and general cleanliness of the facility (e.g. frequency/size of spills, leaks, etc.), with consequences for odour emissions. The audit focuses on environmental, organisational, and in particular, management aspects. The implementation of an odour audit should lead to a company internal code of good practice, with recommendations.

More detailed versions of an OMP exist as well. These OMPs contain one or more of the following aspects:

1. Risk assessment approach;

   This is a review of the foreseeable situations that may compromise the operator's ability to prevent and/or minimise odorous releases from the process and the actions to be taken to minimise the impact. A risk assessment:

   - identifies the conditions under which abnormal operational conditions might arise or when the operational limits of the site may be reached;
   - describes what these conditions are;
   - summarises the potential impacts from the identified abnormal/failure situations and assesses the degree of those impacts; and
   - describes how these conditions could be prevented and/or mitigated and controlled.

2. Communication procedure;

   Typical content: Engaging with the nearest neighbours and surrounding community and communicating with relevant interested parties (e.g. local community and local authority) to provide the necessary information to minimise their concerns and complaints, including methods, content and frequency of communication;

3. Complaint handling;

   Typical content: Monitoring, or responding on receipt of complaints e.g. carrying out investigations and taking appropriate remedial action to prevent recurrence, and reporting back to the complainant. (see Section 8)

4. Training requirements;

   Typical content: The roles and responsibilities of personnel on site (e.g. organisational chart) and the training and competence of staff in odour-critical roles. Examples of courses are odour surveys, odour complaint handling, community engagement, community odour surveys, site inspection and general awareness

8. ODOUR COMPLAINT HANDLING

Odour complaints are the primary mechanism for the reporting of odour nuisance events in the local environment. Receiving, understanding and effectively addressing odour complaints is an important part of odour management and is a key part of both public engagement and odour investigations. Reported odour nuisance events can be an operational trigger for odour emission investigations and maintenance activities.

The specific complaint response procedure may vary depending on local and national guidelines, and specific facility obligations. However, they generally fall into the following groups:

- Complaints are reported directly to the operator of the site suspected of causing the odour;
- Complaints are reported to a local government representative;
- Complaints are collated by a community group and submitted to either the regulator or operator, or both;
- Complaints are reported via the company corporate website;
- Complaints are reported on social media.

Regardless of how the complaints are received, there are several best practice procedures that need to be considered in developing an internal complaint handling procedure.

The following sections provide a best practice framework that would be applicable in most cases where the site can communicate with the complainant. As social media is an increasing platform for complaining, the last section provides specifics related to complaints received where it is not possible for the company to interact with the person submitting the complaint.

8.1. Implementing a complaint handling system

A refinery should consider odour complaints as a useful and effective way of monitoring environmental or social impacts. Complaints should not be seen as a burden but an opportunity to engage and respond to a community's specific concerns in a direct manner.

Implementation of an effective odour complaint handling process has several advantages:

- Potential to identify opportunities for improvement;
- Can be used as an early warning system for fault detection and targeted maintenance or investment;
- Allows prompt investigation, avoiding escalations;

- Effective communication on the odour management process has the ability to preserve the reputation of the company and the relationship with the community and regulator.

An effective odour complaint handling system consists of two parts: the external interface for receiving complaints and communicating results and an internal complaint investigation and response procedure.

The first part of the odour complaint handling system should focus on the reception of complaints. Members of the public should be encouraged to raise concerns when appropriate, understand when and where to complain and what to expect from their complaints. Decisions to be made include whom to approach, the strategy on how to approach them, and which communication channels to use to receive complaints (in writing, in person, by telephone, by email, online, comment box, etc.). It is also important to manage the expectations of complainants, when they will receive feedback on their complaint and what responses can be expected. The procedure should be short, informative, and easy to use, and should have an encouraging effect on the complainants. Local staff should be trained to handle complaints or refer them to someone who has been suitably trained.

The main advantage of a facility managing its incoming complaints is that they can contact the complainant directly. Complaints via social media, however, are not directly addressed to the site and are anonymous.

The second part deals with the internal organisation of complaint handling. There should be a section in the complaint response procedures defining roles and responsibilities related to complaint handling, a section describing the steps for handling complaints including provision of feedback and a section related to documentation of complaints. Furthermore, it should contain a mechanism for learning and improving. The procedure should also contain details regarding the analysis of any data, trend identification, management reporting, and proactive identification of problems.

In a way, a complaint management system works in the same way as any other quality management system. Designing a suitable complaint handling procedure is not enough for effective management of complaints, but it is a first step. The procedure should be implemented, used, and continuously improved.

8.2. Managing odour complaints

It is expected that the following odour management procedures are prepared as part of a wider environmental management system:

- A defined procedure for managing odour complaints, including the definition of roles and responsibilities for odour management and control;

- An odour event or complaint log, either as a hard copy but preferably an electronic database or spreadsheet;

- An odour complaint pro-forma detailing the information required from the complainant to adequately investigate a reported odour event; and

- A system to log the results of any odour investigations and follow-up actions, including responding to the complainant.

The level of detail and requirements of the above are discussed in sections 8.3 to 8.8.

8.3. Receiving an odour complaint call

It is normally the case that odour complaints are made to the front-line staff at the facility, and as such, a procedure should be in place to collect sufficient information for the complaint to be dealt with in an appropriate manner and for the information to be sent to the appropriate and responsible member of staff for assessment.

As part of the training for front-line staff, the site operator should describe the correct procedures for re-directing odour complaints made by phone, emails or post. The general response procedure should be checked to ensure that sufficient information is collected to allow, as minimum, the environmental manager to make a follow-up phone call or email response.

In certain circumstances the site may be required to provide a contact phone number or online public reporting system specifically for odour complaints. Whilst this is uncommon, it may be needed to comply with site specific conditions set by a local or national regulator as part of the site's operational environmental obligations.

8.4. Responding to an odour complaint via social media

As social media is now such a public and open platform, it is important for a refinery that every complaint is investigated and resolved as soon as possible.

The difficulty with social media is that messages are not directly addressed to the refinery. Therefore, relevant messages could be identified by social listening. To identify the complaints via social media a search system could be used whereby specific websites are monitored for specific words which would trigger an alert. Examples of such websites are Meltwater.com or Google alerts (www.google.com/alerts).

When odour complaints are received via social media there should be a procedure in place to manage the complaint. As this is still a relatively new method of receiving odour complaints, the content of the procedure is still under development. Most websites discussing the appropriate response procedure focus on the following:

- The importance of displaying empathy, thanking the complainant for their feedback, and apologising for whatever problem they have had;

- Letting the complainant know that their complaint is being investigated and respond to the issue publicly, where appropriate. If possible, explain how the problem will be remedied and correct any misinformation, where appropriate.

- Only replying a limited number of times on social media; and

- Taking the conversation private when appropriate.

All information sources investigated regarding this aspect are uniform about the response time. A fast response is vital as it demonstrates to the local community that the facility cares about people and any complaints they may have made. Today, nearly 40% of all social media complainants who expect a response, expect that response to arrive within 60 minutes [19].

It is therefore important to have a social listening and detecting system, and an internal communication procedure in place to prepare an investigation and response, and any remedial action, as fast as possible.

By taking the conversation private, often more structured information can be collected to provide a response to the complainant.

8.5. The initial response to an odour complaint

The initial response by the environmental manager or responsible member of staff should be to record the details of the complaint in the odour complaint logging system. In addition, an assessment should be made as to whether sufficient information has been collected to allow an investigation into the reported odour nuisance. As a minimum, the following information is required.

- Complainant location at the time of the odour nuisance – this may be different to the complainant’s home address.

- Date and time and duration of the reported odour nuisance – the complaint may not be reported at the time/date of the reported odour nuisance.

- Characterisation of the odour – including intensity, offensiveness, and character of the odour.

- Weather conditions – general description of temperature, cloud cover, wind speed and direction and precipitation.

If sufficient information is not provided, a follow-up must be arranged to collect the missing data.

It is an important part of the initial response to state that the reported odour nuisance will be logged and investigated. Responsibility for the reported odour nuisance cannot be provided in the initial response as this will be determined in the subsequent investigation.

8.6. Investigation of reported odour nuisance

Once sufficient odour nuisance data have been collected from the complainant, a qualitative assessment can be conducted principally to establish the source of the odour and to establish where it is coming from. It is recommended that any odour investigation follows the principles of the Source – Pathway – Receptor environmental assessment model.

The complaint data alone, however, do not provide sufficient information to adequately investigate an alleged odour nuisance.

In order to investigate the potential source of the alleged odour, the environmental manager of the refinery and the operational staff will need to discuss the site activities that were taking place at the time of the alleged odour nuisance. This discussion should be undertaken to better understand the potential activities that could cause a release of odorous emissions into the atmosphere, either as part of planned operations or due to equipment failure. The latter would include details of any spills or leaks caused by plant failure, emergency situations or maintenance activities.

A specific operational explanation for a higher than normal odour emission rate (or a high intensity odour release) may be useful to determine the cause of the odour nuisance. Fugitive (or uncontrolled) odour emission sources, however, may be continuous, but the emission rate and intensity of these sources can be highly variable both in space and time, depending on the nature and type of the source.

As part of the investigation of the alleged odour source, the character of the odour must also be considered. This can be done by matching the described odour character to the actual and potential releases on the site. The source can be considered incompatible where the character described is clearly of a different nature to the process. Oil and gas facilities are often typified by a solvent or chemical smell associated with the processing and storage of hydrocarbon products. Care, however, should be taken against discounting a source on this basis as the odour character of releases may be different at lower concentrations and members of the public may inaccurately describe the character using descriptions based on their previous experiences.

The potential exposure 'pathway' is determined by evaluating the meteorological data during the period of the reported odour nuisance. If the environmental manager has access to a site weather station, data can be evaluated to determine the wind direction and wind speed during the reported nuisance. If the receptor is located generally upwind of the site during the reported odour event, it can be inferred that the odour source is unlikely to be the site. Alternatively, if the receptor is located downwind of the site during the reported time of the odour complaint, an effective pathway between the site and the receptor may have occurred.

In situations where there is an odour emission source, a potential pathway and a reported impact at a receptor (complainant), it is possible that the source of the odour was located on the alleged site.

However, a field odour investigation or sniff test will be required to identify the source and to corroborate or contradict the complaint, along with analysis of the wind speed and direction data at the time of the complaint. Only then can it be confirmed with certainty that the source is on-site.

8.7. Sample odour complaint and investigation form

An example odour complaint and investigation form is provided in **Appendix 3**. The example is that provided by the Environment Agency (England and Wales) within their H4 Odour Management (2011) guidance document [18].

The Environment Agency complaint investigation form is considered to be a good example of the initial information required to conduct an odour investigation. The example is not sector specific and was designed to cover all environmentally permitted facilities in England and Wales. It could be expanded or amended to take account of specific aspects of a facility.

8.8. Odour investigation response

The odour investigation provides an assessment of the likely source and the magnitude of impact. If the assessment identifies that the refinery is the likely source, the level of internal and external response needs to be determined.

In some situations, the odour investigation responses may be pre-determined within licensing or environmental permitting conditions. These would need to be followed as part of operational obligations and can include a defined notification system to report odour nuisance and response to the regulator or local community or a set internal operational response for site mitigation.

It is normally the responsibility of the environmental manager to decide on a proportional response to a specific complaint. This is often made based on their perception of the significance of the nuisance and whether it has occurred in isolation or is a frequent event. It is often good practice to respond to complaints (internally and externally); however, it may be impractical if a refinery receives multiple complaints over a sustained period. In these situations, a combined odour response looking at general odour management principles across the site could be a more effective way of formulating an effective response.

8.8.1. Odour investigation response - Internal

If the odour investigation suggests that the refinery is a possible source, an internal response is required to ensure that potential impacts are minimised. An internal response could be based on the following framework starting that a specific process or activity is identified as the odour source.

Table 8-1 Internal Response Process

Step	Question	Response
Step 1	Insignificant source, no complaint history, and/or "best practice" odour control installed	If Yes – No further assessment of odour required. Necessary or desirable conditions developed, including prescribed odour outcome If No – proceed to Step 2
Step 2	Is process operated as usual and are installations in good condition?	If Yes – proceed to step 3 If No – proceed to step 6
Step 3	Are there intermittent processes?	If Yes – proceed to step 6 If No – proceed to step 4
Step 4	Are there malfunctions in process or supply?	If Yes – proceed to step 6 If No – proceed to step 5
Step 5	At the time of the event were mitigation measures operating correctly?	Can the following (where installed) be demonstrated? • Containment is effective; • Odour extraction systems are functioning correctly; • Odour removal technologies are operating; and/or • Evaporative losses from tanks and leaks from processes are minimised. **If Yes** All measures can be considered to be normal process **If No** Proceed to Step 6
Step 6	Improvement plan	Prepare an improvement plan which is designed to rectify any process issues or failures. This could include: • Corrective maintenance to repair identified faults; • Consideration of additional containment or treatment processes; If no actions can be implemented to minimise losses, a proportional response is required to understand whether odour generating activities can be avoided, remedied or mitigated.

After the investigation is completed, the cause of the odour should be identified and immediate action should be taken, where necessary, to rectify the situation and remedy or mitigate the odour emissions. If odour emissions cannot be stopped immediately, steps should be taken to control the odour emissions as soon as practical. Odour problems may result from the plant design and/or the proximity of new neighbours.

Regardless of the investigation's outcome, the complainant should be notified of the findings, even if no definitive cause to the odour nuisance is identified.

In situations where odour is not related to the plant or process, further analysis of the complaints record and meteorological data may reveal the potential emission source. By researching patterns, causes may also be identified.

8.8.2. Odour investigation response – External

Depending on the complaint history of the site and the severity and frequency of the complaints, an external response to relevant stakeholders should be considered.

Engagement with the regulator

The reporting obligations to the regulator are likely to be pre-determined as part of the licensing conditions or they are based on the relationship between the two parties. It is suggested that the minimum measures to demonstrate a sufficient level of regulator engagement could be as follows:

1. Make the odour complaint and investigation log available to the regulator upon request;
2. Report on the number of complaints received on a periodic basis, normally on a monthly or quarterly basis;
3. In some cases, if public complaints are received directly to the facility, these may have to be passed on to the regulator within a set time period.

The level of engagement should be discussed with the regulator in order to understand their requirements. It is however expected that a closer relationship would become established in situations where there is a perceived odour nuisance issue. In contrast, where few odour complaints are received, it is likely that engagement with the regulator would be less frequent.

Engagement with the public

A site operator has the option to extend external engagement to the public through a number of channels. The benefit of presenting feedback can be rewarding from a public relations perspective.

External feedback provides confirmation to a complainant that reported issues are being taken seriously and that there is a process in place to ensure that odours are minimised wherever possible. Without external feedback, there is a tendency for a loss of trust in the operator which can exacerbate ill feeling. Odour complaints are a marker of alleged odour nuisances; however, they may also, on occasion, represent a certain level of acceptance of an operator, which can erode community morale and lead to a deteriorating relationship with neighbours.

The level of detail provided in a response to an odour complaint should be tailored to the specific situation. However, the released information should be designed so not to cause undue concern or accept responsibility until a full investigation has been completed.

It is recommended that a decision on providing feedback should be made at the following key time periods, see **Table 8-2**.

Table 8-2 Public Response Process

Stage	Aim	Comments
Initial Report	Provide acknowledgement that the complaint has been received and logged. A brief description of the investigation process can be provided either verbally or as a pre-prepared written information release.	No acceptance of blame should be provided at this stage. At this point the operator cannot determine the source or the magnitude as a detailed investigation has not been completed.
After completion of the odour investigation	Provide the high-level results of the odour investigation. This would include a summary of the likely source, whether the nuisance is due to a mitigation or process failure and any remedial actions taken.	Consider the level of detail that is needed to satisfy the complainant. In effect the complainant wants to know whether the operator accepts the blame for the incident and to understand why it occurred. Comfort will be provided, if possible, by knowledge that the event is not a health concern and that it is an infrequent nuisance.

A decision must also be made as to the way feedback is provided. Some form of direct response is likely to achieve the best results but the response should be proportional to the perception of odour problems at the site. Common responses, ordered in terms of their level of engagement and detail, are provided in **Figure 8-1**.

Figure 8-1 Level of engagement

Care should be taken to ensure that any response given to the public is proportionate and practicably achievable. If the level of public concern about odours increases it is expected that a greater level of engagement will be required. It must however be noted that if odour issues are on a larger scale, the practicality of a direct response, either by email, telephone or face-to-face will become impractical. In these situations, a wide focused response method (e.g. information website) may be a worthwhile investment to reduce staff time.

The proposed method of external public engagement should also be discussed with the regulator to understand their expectations. Regulators often appreciate a role within public engagement as it shows that all stakeholders are involved and are taking odour complaints seriously.

9. GLOSSARY

Acceptable nuisance: Nuisance level that is considered acceptable by the competent authority (e.g. licensing authority). This concept is similar to the terms "Normal neighbourly burden" and "normally acceptable limits", originally from civil law. In doing so, the competent authority makes a weighing-up of which factors such as socio-economic business impact, technical feasibility, social damage, context and planning can be taken into account in addition to the odour load. Acceptable nuisance can be expressed in a maximum permitted percentage of odour nuisances (either related to individual activities or related to actual local odour), or in a maximum permitted odour concentration in combination with a percentile value.

Acidity: The strength of an aqueous acid solution, measured by pH. Acids typically have a pH of <7. The lower the pH (minimum is pH 1), the stronger the acid.

Adsorbability: A measure of the degree to which a material is capable of adsorption. Adsorption is the adhesion of atoms, or molecules to a certain surface. Not to be confused with 'absorption' (the phenomenon in which atoms or molecules enter some liquid or solid bulk phase).

Aromagram: A chromatogram representative for the odour activity of a sample (e.g., GC-olfactometry).

Basicity: The strength of an aqueous basic solution, measured by pH. Bases typically have a pH of >7. The higher the pH (maximum is pH 14), the stronger the base.

Biodegradability: The ability of specific organic matter to be broken down into simpler substances by enzymes or microorganisms, such as bacteria and fungi.

Channelled emission: Emission of pollutants into the environment through any kind of pipe, regardless of the shape of its cross-section.

Denitrification: A waste water treatment process where nitrogen oxides (NO_x) are reduced to nitrogen (N_2). This process is usually performed by denitrifying bacteria.

Diffuse emissions: Non-channelled (VOC) emissions that are not released via specific emission points such as stacks. They can result from "area" sources (e.g. tanks) or "point" sources (e.g. pipe flanges).

Electronic or e-nose: A technique to replicate the processes of human olfaction electronically. The e-nose uses a sensor array which reacts to volatile compounds to calculate an inferred odour concentration. Typically the e-nose response requires calibration to the olfactometry result of a reference odorous compound.

Emission: The release into the atmosphere; air pollution originating from an installation.

FID: Flame Ionisation Detector. Analytical instrument typically used for the determination of the amount of total hydrocarbons (THC) in a gas stream. Comparable with the PID, but a hydrogen fuelled flame is used for the ionisation of the hydrocarbons.

Field Olfactometer: A sensory measurement aid which allows some quantification of odour. The hand held device allows for dilutions of the sampled air to be provided to the user. This can be used to infer concentration by adjusting the dilution level to the point of operator detection. Requires a trained operator who has an odour sensitivity equal to the calibrated panellists used for olfactometry testing. Results are not comparable to analysis conducted in accordance with EN 13725 [7] but can give a better understanding of relative concentration than achievable from sniff tests alone.

Immission: Any air pollution effects on the environment which affect human beings, animals and plants, soil, water, the atmosphere as well as cultural objects and other material goods.

Linear discriminant analysis: A statistical method in pattern recognition and machine learning, commonly used to identify a linear combination of features that characterise or separate two or more classes of objects or events.

Odour activity value: The ratio of the concentration of a volatile organic compound (in $\mu g/m^3$) to the odour threshold of that same volatile organic compound (also in $\mu g/m^3$) as known from the literature. This value does not take into account the presence of other compounds in the ambient air and any associated effects. The odour activity value is abbreviated as OAV (odour activity value).

Odour concentration: Number of scent units or snifter units per volume unit (ou_E/m^3). The numerical value of the odour concentration is the number of times that the odorous air must be diluted with odour-free air to reach the odour threshold.

Odour load: The presence of fragrances in the ambient air in such a high concentration that this leads to odour perception. In addition to concentration, the frequency and duration are also decisive for the odour load. The odour load is usually expressed as a concentration in combination with an underspent frequency (percentile value, usually the 98th percentile).

Odour threshold: The concentration of an odorous substance, expressed in $\mu g/m^3$ or mg/m^3. Because the odour threshold differs from individual to individual, panel thresholds are mentioned in the literature, so that the individual differences are averaged out. The panel threshold is the concentration that can be distinguished from pure air by 50% of a panel. The odour threshold mentioned in the context of sniffing measurements is based on the recognition of smell, and not on perception. After all, it concerns the ability to distinguish between an odour and background odours in the field.

Odour threshold distance: When observations are performed in the field, a maximum odour threshold and odour plume can be determined. The odour threshold distance is the maximum distance, along the axis of the fragrance plume, to which the smell considered by 50% of a panel (usually consisting of 2 persons, cf. European standard EN 16841 – part 1 [10] and 2) [20] of observers is noted. This distance is determined by interpolation. The odour threshold distance varies depending on the source characteristics, nature of the pollutants, pollutant load, wind direction, wind speed, atmospheric stability, presence of obstacles, etc. The average maximum odour threshold is the average value obtained from different observations (sniffing team measurement campaign).

Odour unit: The European odour unit (ou_E) is the amount of a substance that, when evaporated in 1 m^3 neutral gas at standard conditions, elicits the same physiological response in a panel of observers as if 1 "European Reference Odour Mass "in 1 m^3 neutral gas at standard conditions is offered to this same panel. A European Reference Odour Mass is a generally accepted reference value, and is the equivalent of 123 micrograms of n-butanol. When this amount is evaporated in 1 m^3 neutral gas, it produces a concentration of 0.040 µmol/mol (40 ppb).

Odour emission: Amount of odour per time unit ($ou_{E/}s$). This is the product of the volume flow rate of a source in m^3/hour and the odour concentration, divided by 3600. The odour emission is preferably expressed per second as a unit of time.

Odour nuisance: The World Health Organization (WHO) defines nuisance as "a feeling of displeasure associated with any agent or condition known". The WHO also states that nuisance can be considered a health effect, because "Health is a state of complete physical, mental and social well-being and not just the absence of disease". In dose-effect relationships that form the basis of the zero effect levels, derived from policy preparation studies, odour nuisance is the perception that respondents have of a situation with which they were confronted during the past 12 months. This concerns the cumulative result of a (repeated) odour disturbance during the past year.

Odour plume: The zone in which a smell can be observed and recognised by a sniffing team. This zone is delineated by interpolation from source, transition points and maximum odour threshold distance. See also EN 16841 part 1 [10] and 2 [20].

Pervasiveness of odour: A semi-quantitative indication of how widespread an odour is.

PID: Photo-ionisation Detector. Analytical instrument typically used for the determination of the amount of total hydrocarbons (THC) in a gas stream. Comparable with the FID, but ionisation of the hydrocarbons occurs through high-energy photons.

Polarity: Physical property of a substance which relates other physical properties, such as melting and boiling points, solubility, and intermolecular interactions between molecules. Generally speaking, there is a direct correlation between the polarity of a molecule and the number and type of the polar/non-polar bonds within the molecule. However, in some molecules the arrangement of these bonds within the molecule determines the final polarity of the substance.

Receptor: Either the human sense of smell (i.e. receptors within the nose) or more generally the location of sensitive receptors within the surrounding environment (e.g. residences, schools and hospitals).

Limit value: Upper value; may not be exceeded, except in case of force majeure. This value corresponds to the level above which odour complaints become established, i.e. the level above which serious odour nuisance can be expected.

Hedonic tone/value: Indicates to what extent an odour perception is perceived as pleasant on a scale of extremely pleasant (+4) to extremely unpleasant (-4). The nature, intensity and context in which the observation takes place play a role here.

Neutral Effect Level: Given concentration above which interference from a source can be expected. Is equal to the background nuisance level or the nuisance level in a control group (outside the sphere of influence of a source of odour). Expressed in ou_E/m^3 in combination with a percentile value (usually 98^{th} percentile). In other words, it corresponds to the level below which no negative effects can be expected.

Olfactometry: Measurement method for the determination of odour concentrations (in ou_E/m^3) in lab conditions in accordance with methodology EN 13725 [7].

Percentile value: The value of a group of data when a known proportion of the highest results are discounted. Used as a time metric in odour assessments as a duration of impact is required to cause an impact. As an example, the commonly used '98^{th} percentile of hourly averages' indicates the 175^{th} highest result from all hourly predictions in a non-leap year.

Solubility: Chemical property referring to the ability for a given substance, the solute, to dissolve in a solvent.

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APPENDIX 1: DESCRIPTION OF ODOUR STANDARDS

EN 13725:2003 Air quality. Determination of odour concentration by dynamic olfactometry [7]

This standard specifies a method for the objective determination of the odour concentration of a gaseous sample using dynamic olfactometry with human assessors. Measurement results are expressed in European odour units per cubic meter (ou_E/m^3). The standard includes the methodology for the determination of emission rates from point sources and surface sources with or without outward flow.

Two types of sampling can be carried out: dynamic sampling for direct olfactometry, where the sample is ducted directly to the olfactometer and, more commonly, sampling for delayed olfactometry, where a sample is collected and transferred to a sample container for analysis by delayed olfactometry.

The advantage of dynamic sampling is the short time period between sampling and measurement, which reduces the risk of a sample modification over time. The disadvantage is that it requires the use of ventilated rooms in order to isolate the panel members from the usually odorous ambient environment. This is difficult to implement and often requires very long sampling lines which may affect the sample (e.g. by condensation, adsorption or ingress of air). In contrast, delayed olfactometry reduces the measurement uncertainty by placing the panel in the best possible conditions.

In the case of delayed olfactometry, the sampling is similar to that of other periodic air pollutant measurements, and comprises, for example, a recommended sampling duration of 30 minutes and at least three consecutive measurements. The most common sampling system follows the 'lung principle', where the sample bag is placed in a rigid container. Subsequently, the air is removed from the container using a vacuum pump. The under-pressure in the container then causes the bag to fill with a volume of sample equal to that which has been removed from the container. By doing so, the contact of the sample with any pump is eliminated.

Maintaining the sample integrity during handling, storage and transport is of crucial importance. This includes:

- use of odourless materials when they come into contact with the sample;
- if necessary, sample pre-dilution with nitrogen to avoid condensation, adsorption and/or chemical transformations;
- sample bag conditioning by filling them with sample gas and emptying them again.

EN 13725:2003 sets a maximum storage time of 30 hours. In practice, it is advisable to carry out the olfactometric measurement as soon as possible. In Germany, for example, proof is to be provided that the odour concentration in the samples has not changed, if the storage time exceeds six hours

For the actual measurement, an olfactometer is used to dilute the sample with neutral gas in a defined ratio and to present the diluted gas stream to a panel consisting of at least four selected and trained panel members. The odour concentration is measured by determining the dilution factor required to reach the panel response equivalent to that of exposure to a reference compound (123 $\mu g/m^3$

of n-butanol evaporated in a cubic metre of odour free air), known as the equivalent European Reference Odour Mass (EROM). The odour concentration of the sample is thus expressed as a multiple of 1 ou_E/m^3 at standard conditions. In contrast to other periodic measurements, the standard conditions for olfactometry refer to room temperature (293.15 K), normal atmospheric pressure (101.3 kPa) on a wet basis. This applies to the olfactometric measurements as well as to the volume flow rates of emissions. The conditions were chosen by convention, to reflect typical conditions for odour perception.

In addition to sampling and measurement, EN 13725:2003 also defines requirements for data recording, calculation, reporting, and quality assurance.

EN 16841-1:2016 Ambient air - Determination of odour in ambient air by using field inspection - Part 1: Grid method [10]

This describes the grid method for the determination of the level of odour exposure in ambient air within a defined assessment area. The method relies on qualified human panel members to determine the distribution of the frequency of odour exposure over a sufficiently long period (6 or 12 months) to be representative of the meteorological conditions of that location. The sources of the odorant under study may be located within or outside the assessment area.

The parameter measured by the human panel members is the 'odour hour frequency' which is the ratio of positive test results (number of odour hours) to the total number of test results for an assessment square (or in special cases for a measurement point). The odour hour frequency is an odour exposure indicator, and can be used to assess the exposure to recognisable odour originating from one or many specific odour source(s) emitting in a particular area of study, independent of whether the odour emissions are channelled or diffuse.

If the odour types are recorded separately, the identification of the source among several installations with different odour types is feasible. However, if several installations emit the same odour type, identifying the emitter can be significantly more difficult and will require analysis of wind measurements.

EN 16841-2:2016 Ambient air - Determination of odour in ambient air by using field inspection - Part 2: Plume method [20]

This describes the plume method for determining the extent of recognisable odours from a specific source using direct observations in the field by human panel members under specific meteorological conditions (i.e. specific wind direction, wind speed and boundary layer turbulence).

The odour plume extent is described by points where a transition occurs from absence to presence of the recognisable odour under investigation. The shape of the plume is delineated by a smooth interpolation polyline through the transition points, the source location and the location determined by the maximum plume reach estimate.

The results are typically used to determine a plausible extent of potential exposure to recognisable odours, or to estimate the total emission rate using reverse dispersion modelling. The plume extent measurement is particularly useful as a starting point for estimating emission rates for diffuse odour sources where sampling at source is impracticable.

APPENDIX 2: ODOUR DETECTION THRESHOLD VALUES

The table below presents a list of some odour detection thresholds of substances typical to the refining sector from CWW BREF [3].

Table A2-1 Odour thresholds of some substances and compounds typical of refining activities

Substances or compounds		Odour detection thresholds	
		Reported ranges [ppm weight]	Typical [mg/m3]
Methylmercaptan	CH_3SH	0.00007 – 0.004	0.0021
Ethylmercaptan	C_2H_5SH	0.0000087 – 0.002	0.00277
Hydrogen sulphide	H_2S	0.00041 – 0.002	0.0253
Dimethylsulphide	$(CH_3)_2S$	0.0022 – 0.3	0.0058
Diethylsulphide	$(C_2H_5)_2S$	0.002 – 0.4	0.00146
Dimethylamine	$(CH_3)_2NH$	0.033	0.153
Diethylamine	$(C_2H_5)_2NH$	0.048	0.567
Benzene	C_6H_6	1.5 – 4.7	11.8
Ethylbenzene	$C_6H_5(C_2H_5)$	0.17 – 2.3	7.3
Toluene	$C_6H_6(CH_3)$	0.33 – 50	5.95
o-, m-, p-xylene	$C_6H_6(CH_3)_2$	0.08 – 3.7	1.43 – 3.77
Lighter alkenes (from C_2H_6 to C_4H_{10})		> 50	> 500
Mid-range alkenes (from C_5H_{12} to C_8H_{18})		> 2	> 30
Heavier alkenes (from C_9H_{20})		< 2	< 6

APPENDIX 3: SAMPLE ODOUR COMPLAINT REPORT FORM

ODOUR Complaint Report Form	
Time and date of complaint:	Name and address of complainant:
Telephone number of complainant:	

INFORMATION REQUESTED FROM COMPLAINANT		
Date of odour:		
Time of odour:		
Location of odour, if not at above address:		
Weather conditions (i.e., dry, rain, fog, snow):		
Temperature (very warm, warm, mild, cold or degrees if known):		
Wind strength (none, light, steady, strong, gusting):		
Wind direction (eg from NE):		
Complainant's description of odour: o What does it smell like?		
o Intensity (see below):		
o Duration (time):		
o Constant or intermittent in this period:		
o Does the complainant have any other comments about the odour?		
INFORMATION FROM MANAGER		
Are there any other complaints relating to the installation, or to that location? (either previously or relating to the same exposure):		
Any other relevant information?		
Do you accept that odour likely to be from your activities?		
What was happening on site at the time the odour occurred?		
Operating conditions at time the odour occurred (eg flow rate, pressure at inlet and pressure at outlet):		
Actions taken:		
Form completed by:	Date	Signed

Intensity : 0 No odour , 1 Very faint odour , 2 Faint odour, 3 Distinct odour , 4 Strong odour , 5 Very strong odour, 6 Extremely strong odour

APPENDIX 4: TECHNIQUES FOR REDUCING ODOUR EMISSIONS

This Appendix provides details of the most commonly used end-of-pipe odour emission abatement techniques. It should be noted that the following sections focus on the abatement of odour, but the emission of other, non-odorous compounds should also be taken into account when selecting an emission reducing technique.

Note: for further (detailed) information the reader is referred to the REF BREF [2] *and the CWW BREF* [3].

ADSORPTION

General description

Adsorption is a heterogeneous reaction in which gas molecules are retained on a solid or liquid surface (adsorbent is also referred to as a molecular sieve). Specific compounds are targeted and removed from the gas stream. When the surface has adsorbed as much as it can, the adsorbed content is regenerated which allows the contaminants, usually at a higher concentration to be either recovered or disposed of.

Major types of adsorption systems are:

- *Fixed-bed adsorption;*
- *Fluidised-bed adsorption;*
- *Continuous moving-bed adsorption;*
- *Pressure swing adsorption (PSA).*

For odour abatement, *fixed-bed adsorption* and *pressure swing adsorption* are the more commonly used types.

Typical adsorbents include:

- granular activated carbon (GAC): the most common adsorbent with a wide efficiency range and not restricted to polar or non-polar compounds;
- zeolites, properties depending on their manufacturing, working either as mere molecular sieves, selective ion exchangers or hydrophobic VOC adsorbers.

Other adsorbent types are available, but the highest abatement efficiencies (specifically for odour) are achieved with GAC and zeolites.

Applicable refinery areas
Bitumen production, storage (facilities), septic water areas, dewaxing process and product loading.

Odour abatement efficiency
Depending on the specific configuration, operational conditions and adsorbent, an efficiency range of 80 – 95% is documented for general odour abatement (both GAC and zeolites, based upon half-hourly averages). Specifically, for hydrogen sulphide (H_2S), higher efficiency rates are achievable:

- >95% using GAC, >10 ppmv of H_2S in raw gas mixture;
- >99% using GAC, <10 ppmv of H_2S in raw gas mixture.

Cross-media effects

Regeneration of adsorbent can be done automatically within some systems or the saturated adsorbent can be sent to an external company for treatment. When this is not feasible, the adsorbent has to be disposed of, i.e. normally transferred to incineration.

Small amounts of waste water from the demister are generated when using activated carbon to abate H_2S.

Advantages and disadvantages

Table A4-1 Advantages and disadvantages of the adsorption technique

Advantages	Disadvantages
General • High efficiency for VOC removal (and recovery) • Simple and robust technology • High saturation level of the adsorbent • Simple installation • Relatively simple maintenance • Suitable for discontinuous processes	**General** • Particulates in the waste gas stream can cause problems (i.e. clogging) • Mixtures can cause a fast bleeding (a form of deterioration) of the bed • Heavier VOCs can be difficult to desorb resulting in loss of bed capacity
GAC • Wide efficiency range • Not restricted to polar or non-polar compounds	**GAC** • Usually only suitable for low VOC concentrations although designs are available for very much higher concentrations from e.g. gasoline loading applications • Not suitable for wet gases (not as critical with impregnated activated carbon) • Risk of bed fires • Potential for polymerisation of unsaturated organic compounds on GAC
Zeolites • Very suitable for low VOC concentrations • Not as sensitive to fluids/humidity as GAC	**Zeolites** • Not suitable for wet gas streams • Risk of bed fires

WET SCRUBBING (ABSORPTION)

General description

Wet scrubbing (or absorption) is a mass transfer between a soluble gas and a solvent (often water) in contact with each other. In general, the gas stream passes through an absorbing liquid, where the polluting compound is dissolved, and involved in a reversible chemical reaction, which potentially enables the recovery of the gaseous compound. The technique is particularly useful for highly soluble compounds, such as hydrogen halides, SO_2, ammonia, H_2S and VOCs, which makes it applicable for the abatement of odorous gases.

Depending on the odorous pollutant(s) to be removed, several aqueous scrubbing liquids (solvents) are used including *water* (removal of ammonia and hydrogen halides), *alkaline solutions* (removal of acidic compounds, such as hydrogen halides, phenols, H_2S, SO_2, chlorine), *alkaline oxidative solutions* (see below) or *acidic solutions* (removal of ammonia, amines and esters).

Applicable refinery areas
Alkylation, bitumen production, storage (facilities) and loading.

Odour abatement efficiency
A relatively low odour abatement efficiency range is achieved if only water is used, depending on the solubility of the compound (at 20 – 45%), whereas an increased efficiency range of 60 – 85% can be reached using alkaline and water scrubbing.

Cross-media effects
Scrubbing generates waste water, which will need to be treated if the scrubbing liquid (with its solutes) is not otherwise used (in some cases it can be evaporated and processed for the recovery of products). Acid scrubbing water is partially drained to control the pH. The drained scrubbing water needs to be treated before it is discharged..

Advantages and disadvantages

Table A4-2 Advantages and disadvantages of wet scrubbing

Advantages	Disadvantages
• Wide range of uses • Very high abatement efficiency can be achieved • Compact installation thanks to a favourable ratio between capacity and device volume • Simple and robust technology • Simple maintenance • Only few wear-sensitive components • Can handle flammable and explosive gases/dusts with little risk • Can also cool hot gas streams (quencher) • Can handle mists • Corrosive gases and dusts can be neutralised • Can be constructed in modules	• Water or diluted chemicals are required for the replacement of the purged water and the evaporation losses • Waste water due to replacement of scrubbing liquid needs treatment • Conditioning agents (e.g. acids, bases, oxidants, softeners) are required for many applications • Heavy equipment; for roof fitting, support structures are needed • Sensitive to corrosion. For outdoor fitting, frost protection is needed (depending on climate) • Off-gas may require reheating to avoid visible (steam) plume • For treating odour problems, pilot-scale tests are required to evaluate the abatement potential of the system • Recirculation of scrubbing liquid may cause an increase in odour emissions

ALKALINE OXIDATIVE SCRUBBING

General description
Alkaline oxidative gas scrubbing is a variant of wet gas scrubbing (see above) which is mostly applied for odour control. The organic odorous compounds are oxidised in the alkaline environment at pH 7 – 10. Sodium hypochlorite (NaOCl), potassium permanganate ($KMnO_4$) or hydrogen peroxide (H_2O_2) are used as strong oxidants. For odour removal, it is recommended to test the technique on a smaller scale first to determine the specific removal efficiency.

Applicable refinery areas
Septic water areas.

Odour abatement efficiency

Efficiency depends on the specific plant configuration, operational conditions and reagents used, but an efficiency of 80 – 90% is achievable (based upon half-hourly averages). Comparative research for odour abatement efficiencies between scrubbers and biofilters (see below) show that biofilters achieve higher efficiencies.

Cross-media effects

When using an alkaline oxidative scrubber with NaOCl, toxic chlorine fumes might be formed at low pH values. An alkaline scrubber might then be placed in series to the alkaline oxidative scrubber to remove these chlorine fumes.

Advantages and disadvantages

Table A4-3 Advantages and disadvantages of wet alkaline oxidative scrubber

Advantages	Disadvantages
• Relatively high abatement efficiency can be reached for aromatic substances	• Use of strong oxidants requires some safety precautions and a special design of the installation • Depending on the selected oxidant, additional installations and/or handling is required to minimise cross-media effects

THERMAL OXIDATION

General description

Thermal oxidation is also often referred to as '*incineration*', '*thermal incineration*' or '*oxidative combustion*'. The thermal oxidation process involves heating a mixture of combustible gases and odorants in a waste gas stream with air or oxygen above their auto-ignition point in a combustion chamber. The combustion process is maintained at a high temperature for sufficient time with the aim of obtaining complete combustion to carbon dioxide and water.

After thermal oxidation, the main constituents of the treated waste gas are water vapour, nitrogen, carbon dioxide and oxygen. Depending on the composition of the raw gas mixture being incinerated and the operating conditions of the thermal oxidiser, other pollutants may be present in the treated waste gas such as carbon monoxide (CO), hydrogen chloride (HCl), hydrogen fluoride (HF), hydrogen bromide (HBr), hydrogen iodide (HI), nitrogen oxide (NO_x), sulphur dioxide (SO_2), volatile organic compounds (VOCs), dioxin/furan compounds (PCDDs/PCDFs), polychlorinated biphenyl compounds (PCBs), and heavy metal compounds (among others).

Several types of thermal oxidisers are available: the *straight thermal oxidisers*; the *regenerative thermal oxidisers* ; the *recuperative thermal oxidisers* , and the *gas engines and/or steam boilers*. More information can be found in the CWW-BREF (Section: 3.5.1.3.5). Burning gas in engines or steam boilers is not common for odour abatement and will not be discussed further in this document.

Applicable refinery areas

Bitumen production, storage (facilities), product treatment areas and sweetening process.

Odour abatement efficiency
Efficiency depends on the specific plant configuration, operational conditions, and oxidiser design. For the three main thermal oxidiser types an odour abatement efficiency of 98 – 99.9% is achievable (based upon half-hourly averages.

Cross-media effects
Besides the emissions of CO_2, there are traces of combustion products, e.g. CO, NO_x and other (non-odorous) compounds, that discharge to air, depending on the raw gas mixture composition and the operation conditions of the thermal oxidiser. Possible treatment techniques of the effluent gas can be summarised as follows:

CO:
Application of an appropriate catalyst.

NO_x:
Further treatment of the exhaust gas may be necessary (e.g., SNCR; not provided in this document[5]).

Sulphur and halogens:
May require further gas treatment, e.g.:
- *Water or alkaline scrubbing* to absorb hydrogen halides;
- *Lime injection* to absorb sulphur dioxide;
- *GAC adsorption* to abate dioxins,.

Organo-silicon compounds:
The presence of organo-silicon compounds can cause highly dispersed amorphous silicon dioxide which needs abatement by suitable filter techniques.

It should be kept in mind that additional gas treatment techniques can have different cross-media effects themselves, which should be handled accordingly.

Advantages and disadvantages

Table A4-4 **Advantages and disadvantages of thermal oxidation**

Advantages	Disadvantages
• Good and constant performance • Simple principle • Reliable in operation • Recuperative and regenerative oxidation have a high thermal efficiency, with the effect of lowering extra fuel consumption and hence lowering carbon dioxide emission • Process integration of waste heat is possible	• Emission of carbon monoxide and nitrogen oxides • Risk of dioxin formation, when chlorinated compounds are incinerated • Flue-gas treatment necessary for VOCs which contain sulphur and/or halogens • Additional fuel needed, at least for start-up operations, and VOC concentration below auto-ignition point (not cost-effective with low concentrations and high flow)

BIOFILTRATION

General description
The gas stream is passed through a bed of organic material (such as peat, heather, compost, root wood, tree bark, peat, compost, softwood and different kinds of combinations) or some inert material (such as activated carbon and polyurethane),

[5] For more information, see BREF-document 'Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector' section 3.5.1.5.3

where it is biologically oxidised by naturally occurring micro-organisms into carbon dioxide, water, inorganic salts and biomass.

Biofilters can be divided into *open biofilters* and *enclosed biofilters:*

The majority of biofilters in operation are open-bed filters, which are less costly than enclosed biofilters but also less efficient. Hence enclosed filter systems might be preferred. For both types, parameters such as biofilter media pH, moisture content (relative gas moisture of about 95% and more is required) and inlet gas temperatures affect odour removal capacity.

More information on biofilters can be found in the CWW-BREF (Section: 3.5.1.3.1).

Applicable refinery areas
Bitumen production, storage (facilities) and septic water areas.

Odour abatement efficiency
Efficiency depends on the specific plant configuration and operational conditions. Under normal operating conditions an odour abatement efficiency of 70 – 99% is achievable (based upon half-hourly averages). For specific odorous components (e.g. mercaptans and H_2S) a minimum efficiency of 75% is known. Comparative research for odour abatement efficiencies between scrubbers and biofilters show that biofilters can achieve higher efficiencies.

Cross-media effects
Percolate water (leachate) from the biofilter is polluted with decomposition products (e.g. nitrate, sulphate) and organic materials. This waste water needs to be treated. Periodically, the filter bed material should be replaced and disposed of (e.g. composted or incinerated).

Since not all VOCs that pass through a biofilter are biodegradable, it is possible that the filter may contain hazardous contaminants which will need to be disposed of as waste (e.g. by incineration). The percolate water that is released from the filter material may contain organic residues and should be disposed of. Enclosed biofilters usually recirculate the leachate.

Advantages and disadvantages

Table A4-5 Advantages and disadvantages of bio-filtration

Advantages	Disadvantages
• Low investment and operating costs • Simple construction • In combination with adsorption and absorption, also suitable for barely soluble compounds • Specifically, high efficiency for odorous substances • Low amount of waste water (percolate water) and waste material	• Dried-out peat and compost filter beds are difficult to rehydrate • Relatively bulky design • Poisoning and acidification of the biomass must be prevented • Fluctuations in the gas stream conditions have a significant impact on performance • Packing is sensitive to dust clogging • Limited control (including pH) • High energy consumption where cooling of the incoming gas is necessary

REDUCING FUGITIVE EMISSIONS

An important part of understanding odour emissions at refineries involves considering fugitive emission sources.

Refineries have numerous points of potential fugitive emissions, such as flanges, valves, pumps and sampling connections, etc. Fugitive emissions of VOCs from these locations may be odorous, depending on the composition of the source fluid.

Reducing these fugitive emissions starts with the detection of the leak location and subsequent repairing or replacement of the leaking components.

AVO inspection rounds
Leaks can be detected by undertaking a routine Audio/Visual/Olfactory (AVO) inspection during a walk-around both inside and outside of process units, and along aboveground piping. AVO inspections should check for:

- frosting or sweating of valves and pressure-relief devices connected to vent lines;
- visible vapour from components;
- normally closed valves connected to vents or open-ended lines that are not fully closed during normal operations;
- odours downwind of piping, process equipment, and storage tanks;
- sounds indicative of a leak; and
- reasonable indications of a leak.

In general, AVO inspection rounds are suitable for detecting relatively large leaks. Smaller leaks are usually better identified using an LDAR program.

LDAR program
A more structured approach is commonly known as a '*Leak detection and repair*' (LDAR) programme. An LDAR programme generally consists of the following steps:

Step 1: Leak detection

Two methods are currently available for the identification of leaks, and each method has its individual strengths and weaknesses. It is therefore necessary to decide upon the purpose behind a measurement exercise when selecting the method.

<u>Sniffing method (EN 15446):</u>
Leaking components are identified by measuring the concentration of hydrocarbon vapours in the direct vicinity, using a flexible tube, connected to an FID (flame ionisation detector), a semiconducting detector or a PID (photo-ionisation detector). With a well calibrated device the method is quantitative, but very time- and cost-intensive.

<u>Optical gas imaging (OGI):</u>
This method involves the detection of leaks with advanced hand-held infrared cameras that are specially developed for this purpose. There is currently no reference protocol for this semi-quantitative method, so detection limits and representativeness might differ from one user to the next.

Step 2: Leak repair

A staged approach is often applied to the repair of leaks, involving:

1. An initial intervention such as tightening bolts to eliminate leaks from valve stems or flanges, installing tight caps on open ends. Such an intervention needs to be performed by skilled operators taking due recognition of necessary safety precautions;
2. Repairing equipment with leaks that cannot be stopped by minor interventions. This may involve changing gaskets or packing, and may therefore require the equipment to be taken out of service;
3. When no effective repair can be performed, the replacement of the equipment needs to be considered.

The LDAR programmes based on sniffing typically do not include tanks and difficult-to-access plant areas. OGI can identify problem areas that cannot be monitored by sniffing and allow them to be addressed. In many instances, they allow for more efficient allocation of maintenance efforts, by targeting the sources with the highest emissions first.

APPENDIX 5: CREATION OF AN ODOUR MANAGEMENT PLAN

This appendix is based on an example of national guidance [21] for industrial sources. Although still providing much generic guidance it has been adapted to be more specific for oil refineries.

1. Introduction

An effective odour management plan (OMP) integrates odour management activities into the daily routine of site staff to ensure practices and procedures for the management and mitigation of potential odour issues become routine.

An OMP consists of practices and procedures that are intended to prevent or minimise odorous effects. These practices and procedures are general in nature and applicable to a wide range of facilities and intend to help reduce odorous releases from process operations or activities at an individual site. The practices are more easily implemented and effective when they are incorporated into standard operating procedures and training programmes and workers are assigned responsibility and accountability.

In general, an OMP does not involve additional engineering, significant process modifications, or the installation of additional pollution control equipment.

The OMP should identify and address all potential sources within the facility that could cause odour effects at off-site receptors. This identification should then result in the application of appropriate actions to effectively manage, minimise or mitigate the odours from each source and the subsequent effects at odour receptors. An odour receptor generally refers to a location where human activities may regularly occur, (e.g., residences, schools, day-care centres, hospitals, sports fields, etc.)

1.1. Development of an OMP

To create an effective and efficient OMP, the development and implementation process should include the following four stages:

- Plan
- Do
- Check
- Act

These four basic management system principles are described in Section 7.2.1. The guidance provided in this Annex will support preparation of an OMP and an odour management programme that incorporates all four stages.

A sample Table of Contents is provided in the main report, Section 7.

2. Requirements of a OMP

Having an OMP for a facility or site operations is a key tool in any effective odour management system and will minimise the potential impact a site can have on the community.

The elements of an OMP assist in identifying potential odour sources and best practices to prevent or minimise potential odour emissions. The following sections provide a list of suggested content and requirements.

3. Identification of Potential Sources of Odour

The identification of potential odour sources requires an understanding of all processes and activities that are considered normal or typical for the facility, as well as sources that may be or become odorous. Upset conditions, ineffective pollution control equipment, and spills are examples of potential causes of odours that are not a normal operation or activity.

The steps involved in identifying potential sources of odour include process mapping, understanding where discharges to the air may occur, and identifying when these discharges are potentially odorous. Odours may be associated with gas phase emissions, liquids, aerosols, or particulate matter (fumes). The physical state of the odour carrier determines the controls and management practices that may be required to prevent or minimise the discharge of odour.

3.1. Process Mapping – Source Identification

3.1.1. Process Flow Diagram:

To assist in identifying all aspects of the process that may result in odour emissions, a simple process flow diagram may be used. This can indicate specific equipment or activities that have the potential to generate odours.

Once the potential emission sources are identified, a further detailed review can then be undertaken to determine the odour potential associated with each source.

3.1.2. Site Plan:

The general site plan or layout can also effectively present all aspects of the sites activities and not focus solely on the process emissions. The site plan should include all buildings, storage, trucking routes, waste management and any other activities undertaken on site.

The site plan or layout should indicate the following, where applicable:

- Roadways and trucking routes;
- Receiving areas for incoming materials;
- Storage tanks;
- Buildings;
- Process plants and vents;
- Flares and incinerators;
- Water treatment areas and/or discharge points;
- Waste storage facilities;

- Material handling and storage for off-site transfers; and
- Loading and off-loading facilities

The sources as identified in the main report should be included.

3.2. Identifying Air Emissions Sources

A complete inventory of potential air emission sources should be prepared that includes, but is not necessarily limited to:

- sources venting normal process activities;
- flares and incinerators;
- fugitives from equipment components installed on process plant, pipework and storage;
- fugitives from buildings or enclosed process plant e.g. from forced ventilation exhausts, openings for natural ventilation such as louvers, etc.;
- material transport, handling, and storage;
- waste handling and storage;
- wastewater handling and treatment;
- storm-water and storm-water retention ponds;
- facility cleaning and sanitation practices;
- miscellaneous activities and equipment, if applicable;
- start-up or shutdown activities; and,
- upset conditions (spills, equipment malfunctions).

There may be sources at an individual facility that do not fall into one of these categories. They should also be included in the OMP if significant.

3.3. Identifying Odorous Air Emissions Sources

Not all air emissions sources at a facility have the potential to generate odours or result in odorous emissions.

If a complete inventory of air emissions sources has been prepared, it is necessary to identify which of these sources should be classified as a potential odour source. The completion of a semi-quantitative odour survey (e.g. a site walk-through trying to detect odours) may be useful in this process; however, facilities should ensure that odour surveys are conducted by individuals who have not become desensitised to the odours. Scheduling a survey first thing in the morning, after several days of absence, testing the sensitivity to odours prior to the survey, use of a carbon-filtering mask between odour sources, or retaining a third party, are examples of ways in which facilities can avoid desensitisation affecting the outcome of the survey.

The main sources of odours at refineries are given in Section 4.1.of the main report. It must be emphasised that the identification of odorous air emission sources is very specific to each facility.

The odour source inventory developed as part of an OMP should also consider sources that may become odorous under upset or unexpected conditions.

It is also helpful at this stage to rank the sources in terms of their potential to cause off-site odour impacts and prioritise the measures accordingly. The ranking could be done on the basis of potential odour emissions (strength of odour), offensiveness of odour, frequency of occurrence and/or source configuration/location. Facilities may also consider odour testing, a comprehensive odour assessment, and/or odour dispersion modelling to quantify potential off-site odour effects.

4. General Facility Measures and Considerations

4.1. Site Features and Weather Influences

There are ways to incorporate site features into odour management, such as strategic site layout to have maximum separation between potentially odorous sources and off-site odour receptors, or incorporation of physical barriers such as buildings and structures or natural elements such as berms or trees.

Local weather conditions can also affect the potential for odorous emissions from a site in several ways. Wind direction may result in specific receptors being downwind of potentially odorous sources, and subsequently more frequent off-site odour effects can be expected. Wind speed, precipitation, temperature, and relative humidity may affect odour dispersion or the potential for outdoor activities to generate odours. For example, spillages may vaporise more rapidly under hot, dry conditions.

The amount of precipitation can also influence the potential for odour sources to move off-site as entrained in storm-water or wastewater discharges.

Measures that can help to offset adverse weather effects may include incorporating weather forecasts into scheduling, where feasible, to limit odorous activities to times when wind direction and speed are favourable, or to allow for preventative measures to be implemented prior to severe weather conditions such as heavy precipitation, cold or heat, if applicable.

4.2. Source Reduction

Odorous materials should be reviewed to identify whether a specific component is the root cause of an odour, or whether the manner in which it is used or processed contributes to the odour. Implementing material-specific mitigation or controls at intermediate process stages may be more cost-effective than larger scale vapour capture and control.

Examples of measures that pertain to materials used:

- Reviewing the manner in which materials are used, including type of storage, processing, or application to reduce losses;
- Product substitution or reformulation to incorporate less odorous ingredients or reduce the concentration of odorous constituents; and

- Adjusting operational parameters such as temperature, mixing, or sequencing of operations.

4.3. Housekeeping, Spill Response, and Facility Cleaning

Efforts to control odours from process and fugitive sources may be offset by unexpected odours associated with on-site spills that are not promptly cleaned up and are allowed to vaporise.

Good housekeeping practices should be applied to both indoor and outdoor areas at a facility and may include any or all of the following, as well as other site-specific practices:

- Maintenance of spill clean-up kits at identified locations throughout the facility, complete with routine inspection, and operator training on clean-up practices;
- Prompt waste disposal;
- Inspection of storm water and water retention areas to ensure organic material trapped in those systems do not decompose and create odours.

The OMP should detail site-specific housekeeping procedures. The following are example odour measures that pertain to cleaning and sanitation

- Detailed cleaning practices outlined in standard operating procedures (SOPs) to address potential odour emissions from dust, aerosols, acid mists, VOCs, or other materials or products;
- The use of mitigation systems, e.g. water sprays where potentially odorous dust is generated;
- The substitution of sterilisation instead of sanitation where odour issues are significant and where the equipment or systems being cleaned can be feasibly sterilised.

4.4. Preventative Maintenance (PM)

Preventative Maintenance refers to a system of periodic inspection, maintenance, and testing of equipment in order to prevent malfunctions or, in the case of pollution control equipment, to ensure optimal control efficiencies are maintained. PM activities should consist of an inventory of equipment and assets, SOPs, and scheduling of PM tasks.

All inspections, testing, and maintenance activities must be carried out by competent employees that have been adequately trained. Records of maintenance activities should be maintained. Equipment or process specific checklists or forms are effective in ensuring comprehensive PM.

Preventive Maintenance for significant emission sources may already be a condition of the facility’s permit. If so, the OMP should make reference to these procedures and, if required, indicate how these procedures manage odour emissions.

4.4.1. Equipment Manuals and SOPs

It is recommended that the facility document preventative maintenance activities and prepare written SOPs and equipment manuals. Maintenance should be carried out in accordance with manufacturer's specifications, at minimum. The manuals should identify items subject to routine wear and replacement parts that may be required. Facilities may consider maintaining stock of these items, where reasonable to do so, to limit downtime of key odour control equipment or equipment that could result in odorous emissions.

4.4.2. Scheduling Preventive Maintenance (PM) Activities

Preventative Maintenance activities may themselves be an odour source. In that case, the activity should be reviewed, controlled, or scheduled, with consideration of the potential for odour effects.

PM activities that involve odour control, mitigation or abatement systems should be scheduled appropriately in case the PM requires unit shut-down. If there is a planned major maintenance project that has the potential to impact the community or will result in significant odour for a short duration and possibly the local community as well, communication to community is essential to help to avoid nuisance odour complaints and lessen community concern.

5. Potential Sources of Odour and OMPs

A site-specific list of potential odour sources and the corresponding measures employed to eliminate or minimise odour effects associated with each source should be prepared as part of the OMP.

The examples provided in this section are not comprehensive, and each facility should ensure that their OMP is inclusive of all potential odour sources at their facility.

5.1. Sources Venting During Normal Process Activities

These sources are typically referred to as point sources; however they may include passive vents or pressure relief valves that may not be identified in a typical emission summary of point sources. These sources may be directed to pollution control equipment to reduce the emission rate of odorous contaminants. Often the equipment is designed to control specific pollutants in the gas, liquid, or solid phase, but may also be effective in mitigating odour. Equipment that serves the dual purpose of controlling other emissions as well as odour should be clearly identified.

The OMP should consider ventilation type, stack parameters, and maintenance of any add-on controls as potential measures to reduce the generation of off-site effects of odours. Some specific examples and further detail on these measures are provided.

5.1.1. Ventilation Type and Stack Design

The type of ventilation can impact the direction, intensity or atmospheric dispersion of the exhaust gases and odours. Ventilation can be:

- Forced or fan-driven ventilation, which has the characteristics of flow and direction and are generally point sources that may be directed vertically or horizontally. Odour dispersion from well-designed forced ventilation is generally better than from passive ventilation.

- Passive ventilation, which includes process or tank vents, or other discharge points that have no fan or blower. Odours vented passively may not disperse well and can result in off-site odour.

- Pressure Relief Valves, which may be considered a sub-group of passive. These may have significant potential for odour effects when associated with process vessels or storage tanks containing odorous materials.

Air dispersion of odours can be optimised by designing stacks that are directed vertically, extended in height to avoid building downwash effects, increasing stack velocity with higher flowrate or smaller diameter (or cone), and redesigning rain caps to remove flow impediments. Stacks that discharge horizontally or have rain caps or other flow impediments reduce effective dispersion and may result in odour effects on nearby odour receptors.

The key design parameters for exhausts are direction (vertical or horizontal), velocity, temperature, moisture content, and flow impediments. Altering the exhaust characteristics or connecting passive sources to active exhausts can effectively improve the dispersion of odour.

These changes, if applicable, should be done using appropriate design and engineering, possibly with supporting dispersion modelling studies where considered appropriate, to avoid potential issues such as increased noise, air balancing problems, or other issues.

5.1.2. Pollution Control Equipment Maintenance

Pollution control equipment should be maintained in accordance with the manufacturer's specifications, at a minimum. Key parameters that may influence the ability of the equipment to control odour emissions should be monitored, documented and periodically reviewed for trends indicating the need for corrective action as part of site records.

5.2. Process Fugitives

Refineries have numerous points of potential fugitive emissions, such as flanges, valves, pumps and sampling connections, etc. Reducing these fugitive emissions starts with the detection of the leak locations and subsequent repairing or replacement, as appropriate, of the leaking components. Techniques are described in **Appendix 4**.

5.3. General Ventilation Exhausts and Building Fugitive Emissions

Generally, buildings where odorous materials are used or stored or enclosed process units have forced or natural ventilation exhausts.

An odour survey should include consideration of these potential sources.

Particularly odorous buildings may want to investigate capture efficiencies on process areas, providing better separation within the building to prevent internal odour migration, or potentially redesigning forced building ventilation to maintain negative pressure and direct building air through strategic roof exhausts that are effectively dispersed.

5.4. Material Transport, Handling and Storage

The manner in which materials are handled and stored on-site may result in the discharge of odours and must be considered as an odour source for the purposes of the OMP.

5.4.1. Transfer of Materials

The transfer of materials could include activities such as deliveries to tanks, pumping through process pipework, loading, etc. Depending on the nature of the material and the method of handling, there may be a potential for odorous emissions. Several measures are effective in reducing the potential for the release of odours, for example:

- Good housekeeping practices, the availability of spill response materials and trained responders, and preventative maintenance that encompasses the piping and storage systems;
- For liquid deliveries into fixed roof tanks, vapour recovery or closed-loop systems to prevent odour releases;
- Vapour capture (e.g. carbon adsorption filters) or destruction, if permitted;
- Tank filling preferentially using a submerged line at the lowest level possible to avoid splashing or agitation; and,
- Preventing spills from tank overfilling.

5.4.2. Storage of Materials

Outdoor and indoor material storage can be sources of odour, depending upon the nature of the material and the design of the storage area., The following examples of measures may be appropriate for odorous materials:

- Indoor storage or sealed containment drums or tanks;
- Changing the frequency of deliveries to avoid lengthy storage periods or large volumes, but ensuring odour releases associated with delivery are minimised;
- Maintaining good housekeeping and spill clean-up procedures;

5.4.3. On-Site Vehicles

There may be odour sources associated with the transportation of materials on and off site, such as uncontrolled tanker vents.

Example measures which may be considered if the transportation systems are identified as potential odour sources are:

- Preferentially using sealed containers for shipments that may be odorous;
- Strategically siting filling areas to prevent nuisance effects;.
- Considering potential odour effects or releases to on-site storm-water collection systems of spillage from vehicles;

- Requiring documentation of appropriate training for truck operators if they are involved in loading or off-loading of odorous materials; and,

- Control of passive emissions from on-site trucks that contain odorous material, especially if they remain on-site for extended periods.

5.5. Waste Management

The method of handling, storage and transfer of waste material at a facility and its site operations can impact the potential for odour emissions. Understanding the content and source of each waste generated at the facility or site operations can assist in developing the best approach to odour management.

If waste materials are considered as a potential on-site odour source, measures specific to waste management should be developed, such as:

- Waste minimization and segregation programs to reduce the volumes of wastes that can generate odours;

- Maintenance of an enclosed system for the collection, compaction, and storage of solid waste;

- Collection of waste materials at a high frequency;

- Scheduling frequent removals by waste service provider to limit the quantity of odorous waste materials or the length of time wastes remain on-site; and,

- Siting of waste storage areas distant from odour receptors;

Several of the measures noted for solid wastes may be applicable to liquid wastes, with special consideration given to the rapid degradation of liquids in holding or containment vessels. Preferential use of sealed containers and frequent pick-ups may be considered for liquids.

5.6. Wastewater

Primary, secondary or tertiary wastewater treatment prior to discharge may involve multiple processes and stages that may be potential odour sources, with settling, aeration, digestion, clarification, and filtering as examples. The wastewater collection and conveyance may also be a source of odours, particularly if there are sumps or open draining channels.

When wastewater is discharged to a sanitary sewer, interceptors and manhole covers may be sources of odour if the discharge itself is odorous. Warm discharges may also increase the potential for odours from sanitary sewer discharges. Aside from implementing measures for odour, facilities should ensure that they comply with all municipal requirements for the discharge.

If wastewater is found to be a potential source of odour, some examples of measures that may be applicable to wastewater systems include:

- Preventative maintenance of wastewater collection systems and sumps;

- Monitoring of systems to ensure optimal performance.

Measures that are described for waste management in Section 5.4 of this Appendix would also apply to off-site transfer of wastewater or waste created by treatment systems.

5.7. Storm-water and Storm-water Retention Ponds

The potential for odour emissions associated with storm-water management are generally associated with the storage of the storm-water if there is contamination of the water run-off. Good housekeeping practices, adequate spill clean-up, and sufficient containment measures are means to prevent odorous materials from being collected with storm-water run-off.

Storm-water retention ponds may also be an odour source if there is stagnant water for lengthy periods of time. If these ponds are identified as potential sources at the site, this may not be solvable with measures alone, and the installation of an aeration system or change to a dry pond that does not have a permanent pool of water may be considered.

5.8. Miscellaneous Activities and Equipment

There may be sources of odour at individual facilities that do not fit into any of the previous categories but should still be detailed in the OMP.

In addition to the standard measures, developing standard operating procedures, preventative maintenance, and good housekeeping, the facility may consider specific measures for miscellaneous activities or equipment.

5.9. Start-up, Upset and Other Conditions

Examples of these conditions may include control equipment malfunctions, odours from VOC breakthrough of an activated carbon adsorption bed, the start-up of biological wastewater treatment, or seal leaks or failures on organic storage tanks or containers.

Some upset conditions are, however, difficult to identify by site odour survey. Input from site engineers or emergency planners may allow for some potential upset conditions to be considered as potential odour sources. The OMP should also be maintained as a 'living document' to which details of such odour episodes are added, including triggers that indicate an upset condition or when abnormal odours may be released, and measures developed as preventative or responsive measures. When upset conditions occur, the cause(s) should be investigated and standard operating procedures (SOPs) developed to prevent the re-occurrence or mitigate the effects.

If there is a potential for odour emissions to occur during these conditions, measures should be developed for foreseeable scenarios, such as those of equipment scheduled maintenance, start-up and shutdown. Specific consideration should be given to manufacturer specifications.

6. Documentation and Recordkeeping

Maintaining records of site conditions can assist in identifying the potential for odour emissions as well as provide details of operations should an odour complaint be received. The following are typical operating procedures and inspection reports to be considered in developing an odour management strategy.

6.1. Standard Operating Procedures (SOPs)

There are many substantial benefits from establishing written SOPs. Effective written procedures provide a means to communicate and apply consistent standards and practices. These SOPs ensure that worker training is comprehensive, avoid errors or oversights, help to develop routines, allow all activities to be incorporated into a facility's management system, and ensure quality control.

The development of SOPs should incorporate manufacturer's recommendations and maintenance procedures for equipment, and involve consultation with site engineers or operators. They should also build on lessons learned from previous incidents, if any.

The SOPs provide the detailed specific directions to ensure that the components of the odour measures are implemented and maintained. Written SOPs should be retained and reviewed on a routine basis.

6.2. Records Pertaining to Odours and the Measure

These records may include odour surveys or assessment reports, community surveys, odour or other environmental complaint records, routine site inspections and specific parameters associated with odour abatement measures that can be measured and tracked e.g. flowrates and pressure differentials of a liquid scrubber system.

6.3. Equipment or Operation Specific Documentation

These may include SOPs for the management of specific aspects of equipment or processes, equipment maintenance and inspection records, and logs of process or equipment operating parameters that may affect air emissions.

6.4. Inspection Reports

Written records of inspections and findings should be provided to management in order to initiate any required actions. The reports should also contain details of any follow-up actions in response to deficiencies or findings.

6.5. Training

Employee training records should be maintained to allow for tracking and scheduling of refresher training as required.

7. Complaint Response Protocol

Having an established methodology for handling an odour complaint prepares staff and provides a professional approach to the individual complainant. Section 8 of this report provides detailed guidance.

8. Training

The OMP, and the measures identified within, require appropriate training for employees to ensure success.

The training program should include training of both new employees, and existing employees with new responsibilities. Refresher training is recommended at an appropriate frequency, to ensure changes to requirements or SOPs are communicated.

Where applicable, the key systems for which appropriate staff should have enhanced or specific training are:

- Potential sources of odour at the facility;
- Best practices outlined in the facility's OMP;
- Standard Operating Procedures for Activities and Equipment;
- Site Inspection Protocols, Reporting of Findings, and Recordkeeping;
- Odour surveys;
- Odour complaint response procedures;
- Community engagement and outreach; and,
- Conducting of community odour surveys.

All training should ensure that the appropriate employee is aware of the importance of the requirements as it relates to his or her job and preventing nuisance odour effects.

The employee handling the Community Response could benefit from training specific to media relations and managing difficult situations in accordance with company policy.

9. Site Inspections and Monitoring

Routine site inspections will, in many cases, allow for site personnel to identify odours and initiate responsive actions to prevent the odours from having off-site effects. These inspections are independent of the Preventative Maintenance program. It is recommended that a site-specific checklist be developed that can be completed by the trained individual, and retained on file as record of the inspection. All findings should be communicated to the environmental manager, or designate, and subsequent investigation and response initiated.

The site inspections will, in effect, be odour surveys. All areas in and around the facility should be included, with emphasis on the odour sources identified in Section 5 of this Appendix. The surveys will assess the effectiveness of existing measures, and may identify new sources of odour that should be added to the OMP. Visual inspection of physical odour control measures or pollution control equipment and parameters should be included as part of the site inspection.

Any notable odours should be documented, the intensity estimated according to an established scale (e.g. from detectable to very strong), and the character of the odour noted. The findings of the odour survey should be reviewed by management and the OMP revised if it is determined that some odour sources are not yet adequately controlled and could cause off-site impacts. A key part of the survey would be to determine if the odours noticed on-site are also present at the site boundary or off-site. In cases where there are ongoing substantial odours or elevated point sources of odour such as stacks, off-site odour surveys could also be considered.

Odour surveys should be conducted after any major installations or process changes that could affect odour sources or the ventilation system, as previous findings may change significantly. For example, if a new vapour capture and control system is installed to reduce odorous emissions, new sources of odour may be identified during the survey that were previously masked or undetectable due to other more intense or offensive odours.

Facilities may consider odour testing, a comprehensive odour assessment, and/or odour dispersion modelling to quantify potential odour effects.

10. Sample Table of Contents for OMP

1. Facility Description
   - 1.1. Legal name of Company and Site
   - 1.2. Legal Name of Each Owner
   - 1.3. Legal Name of Operator
   - 1.4. Site Address
2. Requirements (if applicable)
3. Process Description and Process Flow
4. Facility / Process Mapping
5. Identification of Potential Sources of Odour
   - 5.1. Method used to identify sources and screening for potential odour effects
   - 5.2. Details of odour sources, odorous emissions and intensity under normal operating conditions
   - 5.3. Details of potential odorous emissions from sources under upset or other conditions or on an intermittent /occasional frequency
6. Current Facility Measures Associated with each Source/Potential Source of Odour
7. New Measures and Implementation Schedule for Measures
8. Inspection, Maintenance, and Monitoring Procedures
9. Recordkeeping Practices
10. Procedures for Handling Complaints
11. Training Practices
12. Measure Review Procedures and Schedule
13. Statement and Signature of Facility Representative,

APPENDIX 6: ODOUR CASE STUDIES

Odour Case Study 1

Background

During a permit revision, the local regulators asked the site to perform an odour mapping based on the German norm VDI 3940 [9] and to propose odour reduction measures. The site had a history of several complaints for odour from the neighbouring communities. Focus was given on low height odour sources (flare and stacks were excluded)

Study and results

The site engaged a specialised contractor to help with the study. The main activity was an odour survey by a team of trained people and took place over a 10 day period.

The preparation required by the site included:

- Listing odorous products used/produced at the site, with associated Material Safety Data Sheet (MSDS).
- Listing units/locations where these products are used/produced.
- Selecting the survey team and agreeing the different monitoring areas/points for the duration of the campaign.

First study step:

- From the ~500 site products, the odorous products were grouped in 11 “recognisable” odours. The groupings were: naphtha; gasoline; n-methyl pyrolidone (NMP, lubes additive); slop; H_2S; olefin; sulphide; asphalt; MEK; lubricant oil; gasoil.
- Typical samples were prepared in the refinery laboratory for training the survey team. The members were selected based on:
  - their olfactory sensitivity, measured with the European odour reference substance (n - butanol), such that they were not out of the average (reference in VDI norm).
  - their ability to recognize the odours produced by the plant.
- The refinery site was divided into 28 “squares” and 42 “measurement points”, based on the VDI norm recommendation. The measurement plan specified how many times/days each point would be “sniffed” for 5 minutes by a person of the team. A total of 270 measurements were collected.
- For each measurement, the odour recordings were noted in a log sheet. Data captured in the log sheet were: a) the detected odour (out of the list of 11) or no odour; b) the odour intensity (4 ratings); c) the wind speed and wind direction; d) the day/time/duration of the measurement; e) any particular observation.
- The results were presented in graphical form: each of the 28 squares was attributed an odour intensity per odour type, based on the average of the

observations at the corners. The map was compared to the known sources for the odour.

Second study step:

- The refinery area identified as the highest odour source was the API separator (at the wastewater treatment plant). Three gas samples from this area were collected for more detailed analysis.

  - Gas chromatography-olfactometry (GC-O) was used to identify the odorous components in the headspace of the collected samples. In this method, a classical GC-MS spectrum is superimposed on to an aromagram. The aromagram is obtained by injecting in a GC column different dilutions of the samples, while the sample is sniffed when every compound is eluted by the GC column.

  - The odorous components identified in the samples were all containing sulphur. Besides H_2S, mercaptans (thiols) and linear, cyclic thioethers were the main sulphur odorants in the samples. Mercaptans gave the strongest contribution to the whole odour, and were also perceived at lower level concentrations.

Recommendations for odour reduction

- Source control (no oil to sewer) can help to reduce the concentration of these components in the water.

- H_2S and sulphide scavengers can be injected into the API separator to oxidize these components and reduce the odour.

- If the steps above are not sufficient, covering the API separator can be considered.

Odour Case Study 2

Background:

A regional odour management and monitoring approach is applied in an area where odours have been considered as the major concern for the public based on a perception survey that has been conducted annually for over 25 years. Under the authority of a public independent Air Quality Association, a network has been created where people from the refineries and other companies located in the region, as well as volunteers from the public, are trained to conduct olfactory investigations in the case of odour events and to perform surveys.

The network uses a methodology developed by a researcher, which establishes a common language to describe any odour event, and can be understood by all the participants in the network. For each odour type, the so called “human noses” are able to identify the type of odours using a list of a minimum 24 odour references (depending upon the level of training of the participant) and describe its intensity based on a scale from 1-9 (low – high).

In general, public complaints regarding odour events are made through the Association’s web page. However, there are cases where the companies receive complaints directly from the public, but the network would register all complaints. In the case of an odour event, whenever possible an odour characterisation is conducted by the “human noses” who can use a mobile phone application to provide any relevant information regarding the odour event (odour description, location). The Association has then to inform the companies which may be responsible for the odour event.

The odour cases below refer to two refineries located in the area where the regional approach described above is used:

Case Study 2a

Event and Investigation Overview:

During an odour event in the past, the Association informed the refinery that several complaints were received in a very short period of time from a specific area more than 50 kilometres from the site. One of the complainants, who was a “human nose” mentioned specifically thiomentone. This is a dedicated reference of one grade of lubricants additive. A site investigation was then immediately conducted on the unit by one of the refinery trained noses. No modelling simulations or measurements were conducted during the investigation process. The refinery “human nose” investigated the areas which were likely to have caused this odour event, and found that a pump in a storage tank which was out of order was responsible. The refinery repaired the pump and started it up again to mitigate the odour. The event duration was only 2 hours.

During another odour event that happened at the refinery, the refinery initially linked the odour with a possible leak that might have occurred in a specific location in the unit. After several hours of investigation, however, the source could not be identified. The refinery operators then asked a colleague who participated in the network of “human noses” to do an investigation. He concluded that the odour event was not related with any leak in the area initially examined but with a tank cleaning operation 3 km away.

Post-Event Actions:

In the past, the Air Quality Association conducted a campaign based on the data received from the volunteer “human noses”. In addition, they used modelling to assess the characterisation and the intensity of the odours present in the area and how these could eventually be attributed to the companies located in the area in order to make an odour “picture” for each of them. A similar campaign was conducted 5 years after, and the results have shown that the frequency of odour events attributed to the refinery has reduced by 50%, proving that the dedicated investments made to address odour concerns were successful.

Case Study 2b

Event and Investigation Overview:

During an odour event in the past that lasted for a few days, the refinery used an internal protocol that requires a site investigation from their own team, comprising of at least two members. During this site investigation, the team used the information from the odour description as provided from the network and the investigation focussed on areas which were likely to have caused the odour event. No modelling simulations or measurements were conducted during the investigation process. The investigation found that an API basin tank, which was undergoing maintenance, was responsible for the odour and upon discussions with the refinery operators, they concluded that the reason for this event was the water purge of a fuel tank. The type of fuel used during the event was sulphur-rich. The refinery normally takes precautions with the way this type of fuel is stored and used in order to mitigate the odour.

Post-Event Actions:

A third party company is responsible for collecting the results of the investigations conducted, combining them and making conclusions that are discussed once every month in regular meetings of the network participants. However, this company is not authorised to provide recommendations for measures to mitigate an odour event.

Odour Case Study 3

Background:

In this location, complaints regarding odours are typically made by the public directly to the local authorities. Direct complaints from the public to the refinery are not likely to happen, having occurred only a few times in the past. In general, the authorities initially conduct their own investigation on the event before contacting the companies in the surrounding area where the odour event has happened. The refinery has also reported that complaints only arise whenever there is an upset in some parts of their installations and that they have not received any odour complaints under normal operating conditions.

Event and Investigation Overview:

During one particular odour event in the past, the local authorities had received complaints from the public, and after their investigation, they concluded that the source of the odour was from the refinery's flaring system.

The refinery completed their own investigation, which involved commissioning a specialised contractor who used modelling to assess the relationship between the air composition records from an air quality monitoring system installed in the surrounding area, generally known as an e-nose system, and the weather conditions to identify whether the flare system was in fact the source of the odour event. Their analysis concluded that the odour originated from a different source (a malfunctioning combustion unit), which was located a few hundred meters away from the flaring system.

Additional Information:

The assessment of odour concentrations is most often done using modelling at this refinery, however there have been cases where measurements have been conducted in order to evaluate whether the model predictions are valid.

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