Environmental Protection Agency

Office of Environmental Enforcement (OEE)

Odour Emissions Guidance Note (Air Guidance Note AG9)

September 2019

Contents

PREFACE

One of the roles of the Environmental Protection Agency (EPA) is to contribute towards the maintenance of a high-quality environment through ensuring that large scale industrial and waste activities which are licensed by the EPA do not have an adverse impact on the environment and local community.

This Guidance Note (*AG9 – Odour Emissions Guidance Note*) aims to provide clear and robust methodologies for industrial and waste facilities in terms of odour abatement solutions that can be implemented to reduce or eliminate odour. The document sets out recommended approaches for the development of odour management plans, abatement strategies and test programmes and should allow for improved consistency and reliability in addressing odour at industrial and waste facilities. This guidance may also be useful for facilities which, although are not subject to EPA licencing, will be required to control odour. Many measures, which are straight-forward, can be implemented at no or minimal cost. For more serious odour problems, the selection of the correct abatement solution will be critical.

An Odour Management Plan (OMP) is an essential tool for preventing, addressing and controlling odour at an industrial or waste facility. The format of the OMP should provide sufficient detail to allow operators and maintenance staff to clearly understand the operational procedures for both normal and abnormal conditions at the facility. An OMP may be necessary prior to addressing requirements for abatement and control or may be developed in tandem with the required control option.

A process design approach should be applied to the abatement selection process. Of fundamental importance to selecting an odour abatement solution is that one must understand the fundamental mechanism at work at the heart of the abatement technology and the chemistry of the molecules causing the odour. This allows the licensee to select the abatement process which is most applicable to the particular characteristics of the molecules requiring removal, transformation or destruction.

Once the abatement solution is selected, the site operator must demonstrate that the solution is suitable and fit for purpose to meet the abatement targets set for the equipment. In order to demonstrate this, a test programme will be required which details how the site operator proposes to prove the abatement equipment's suitability and capability to meet the abatement targets. The test programme shall enable the site operator to assess the performance of any monitoring equipment on the abatement system. A documented maintenance and calibration programme (including a schedule), for any monitor associated with the abatement equipment, is also an essential part of the test programme.

It is hoped that this guidance will be of use to EPA and LA staff, operators and consultants in preparing appropriate and effective odour abatement solutions to ensure licence compliance.

1.0 INTRODUCTION

Uncontrolled odour from industrial and waste facilities can impact nearby communities and, often, will lead to annoyance and a risk of ongoing complaints. Indeed, odour complaints accounted for 40% of all complaints made to the EPA in 2017 (EPA, 2018). Odour is a priority for the EPA and all licensees must ensure licence compliance.

In order to help address the issues surrounding unwanted odour in the ambient environment, the EPA has produced this Guidance Note (*AG9 - Odour Emissions Guidance Note*). AG9 seeks to present a range of general principles and practical methods that may be used to assess, control and abate odour from EPA licensed industrial and waste facilities.

The guidance document is primarily aimed at the responsible individuals at industrial and waste facilities which will generally include environmental / environmental health & safety (EHS) / general managers, engineers and operators. The guidance hopes to outline practicable measures, many of which are straight-forward, which can be implemented at industrial and waste facilities, to reduce or eliminate odour problems.

Prior to the completion of an odour abatement study and test programme, as part of a licence application or review, it is recommended that the applicant discusses relevant aspects of the project with the EPA prior to proceeding with the application process. Ensuring that a robust abatement study and test programme is implemented prior to commissioning will help to ensure that the proposed aim of an abatement project, namely a substantial reduction or complete elimination of odour, is achievable.

The guidance, where necessary, has highlighted external references where more details on a particular topic can be sourced.

1.1 Descriptions Of Odour

Human beings have the ability to sense certain molecules at very low concentrations via sensory cells in the roof of the nose and then interpret specific molecules as producing a “smell” or odour. The olfactory nerve sends stimuli to the brain which then identify the smell and decide how to respond to this odour.

Where the odour is deemed to be offensive, unwanted or noxious, annoyance or frustration will often be the individual’s response to odorous chemicals. Individual responses to odour are also likely to vary depending on previous experience of the odour, the location of exposure and the coping strategies of individuals. As outlined in ***Section 1.1.2***, a range of perceived health impacts may be experienced by individuals depending on the nature of the exposure.

Various descriptions of odour can be used with odour often being described by the EPA as follows:

- ***“A response of the olfactory receptor in the nose to certain types of volatile chemicals present in the atmosphere’’,*** and
- ***“The characteristic property of a substance which makes it perceptible to the sense of smell”.***

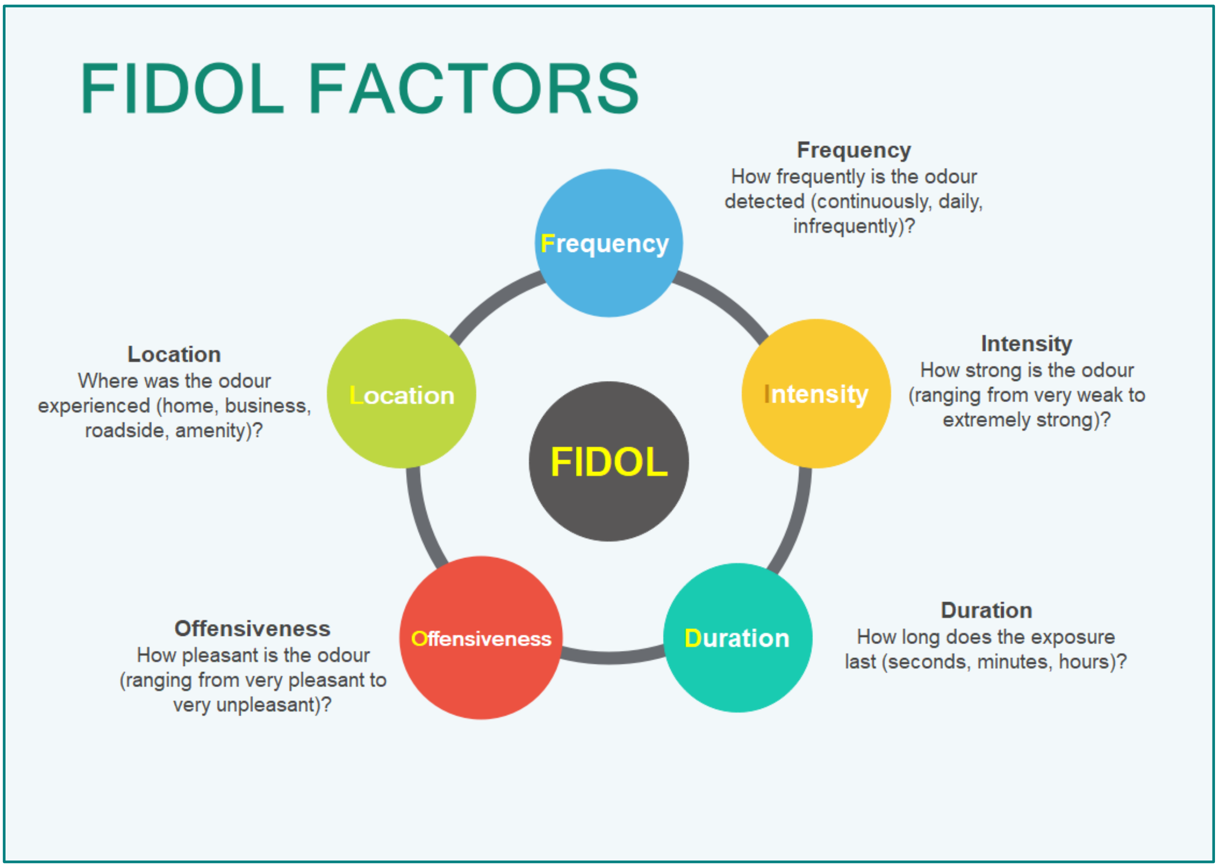
Many industrial and waste odours can be offensive or unpleasant and can lead to individuals objecting to the presence of this odour in their environment.

Typically, industrial and waste facilities will have a licence condition which specifically states that odour should not lead to “*significant impairment of, or significant interference with amenities or the environment beyond the site boundary*” or that the facility should not “*give rise to nuisance at the facility or in the immediate area of the facility*”.

Odours are the result of several properties of an odour which are experienced by a human receptor. These properties can be summarised by the acronym “FIDOL” (which equates to

Frequency, **I**ntensity, **D**uration, **O**ffensiveness and **L**ocation) as shown in ***Figure 1.1*** and described below:

Figure 1.1 FIDOL Factors Used To Determine Odour



The acronym FIDOL refers to the following factors:

- **Frequency of exposure** – how frequently is the odour detection (continuously, intermittently, daily, infrequent)? The greater the frequency with which an odour is experienced, the greater the likelihood that an odour will be deemed to be a nuisance.
- **Intensity of odour** – how strong is the odour (ranging from very faint to extremely strong)? The sense of smell, like other human senses, is logarithmic and thus reducing the concentration of an odour by a factor of two will have a much smaller perceived reduction in intensity.
- **Duration of exposure** – how long does the exposure last (seconds, minutes, hours)? Odour can be detected by the human nose over a very short period of time (a second or less) but generally the longer the exposure the greater the risk an individual will experience annoyance and frustration.
- **Offensiveness of the odour** – how pleasant is the odour (ranging from very pleasant to very unpleasant)? Certain odours, such as hydrogen sulfide (rotten eggs) and methyl mercaptan (rotten cabbage), will be objectional to almost everyone whilst other odours are interpreted by most individuals as relatively pleasant (such as acetone (fruit)) or limonene (lemon)). However, even pleasant odours, when experienced frequently, may be unwanted and lead to complaints.
- **Location** – where was the odour experienced (residential, business, roadside, amenity area)? When an offensive odour is experienced at an individual's home or garden then the risk of complaints will be greater than an odour which is detected whilst driving or walking along public roadways. The surrounding land use may also factor into the

individual's interpretation of the odour. For example, all things being equal, a meat processing facility located in a farming heartland may be more acceptable than a similar facility located in a county town.

1.1.1 Constituents Of Odour

Odour is associated with either a release to air of an individual chemical compound or, more typically, a complex mixture of chemical compounds which elicits an odour at a particular concentration (referred to as the odour detection threshold for an individual compound).

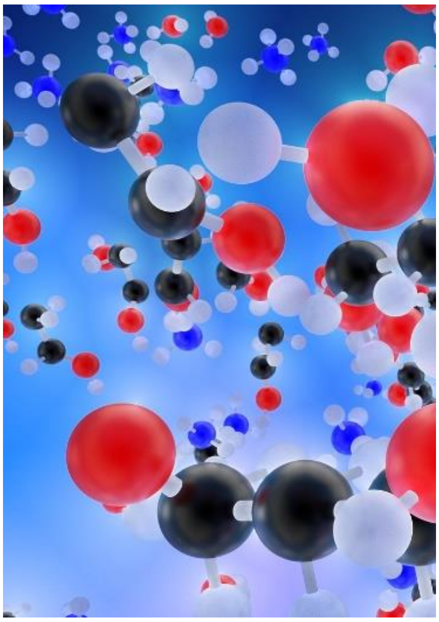
Odour detection and interpretation is a complex process due to the range of confounding factors as outlined in ***Box 1*** (taken from *Best Available Techniques (BAT) Reference Document for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector* (EC, 2016) (CWW BREF)):

Box 1 – Confounding Factors Associated With Detection & Interpretation Of Odour

- In combination with other substances, the characteristic odour of a single substance can change.
- Odour from a mixture of substances can change as the mixture becomes diluted and the concentration of each substance, in turn, falls below its odour threshold.
- Odours from a substance or a mixture can be pleasant when dilute but offensive when concentrated.

At an industrial or waste facility, odours may be generated by a significant range of chemicals, the most odorous of which include the following chemical groups with their characteristic odour described in brackets:

- **Hydrogen sulfide** (H_2S) (rotten eggs) and **Organic Sulfides** including dimethyl sulfide (decaying vegetables), dimethyl disulfide (putrid) and carbonyl sulfide;
- **Mercaptans** – including methyl mercaptan (rotten cabbage) and propyl mercaptan (unpleasant);
- **Volatile fatty acids** – including butyric acid (rancid) and valeric acid (sweat);
- **Aldehydes and ketones** – including formaldehyde (acrid) and acetone (fruit);
- **Nitrogenous compounds** – including ammonia (pungent), skatole (faecal) and indole (nauseating);
- **Amines** – including methylamine (fishy) and ethylamine (ammonia-like).



The odour associated with a compound may change when combined with other odorous compounds which may have a confounding effect on determining the general chemical structure of the odorous compounds. This may have implications for the selection of the appropriate abatement solution as the selection of the appropriate solution may vary depending on the chemical structure and properties (such as the degree of hydrophobicity) of the odorous releases.

1.1.2 *Impacts Of Odour on Health and Well-being*

Studies have investigated the possible link between odour exposure and a variety of impacts on health and wellbeing (Horton, 2009), (Schinasi, 2011), (Heaney, 2011). Research has found some evidence that odour can lead to a range of physical, psychological and social health impacts.

Physical health impacts that may be linked to odour exposure include (Heaney, 2011), (Schinasi, 2011), (Alliance, 2015):

- Nausea,
- Reduced appetite,
- Congestion,
- Sensory & respiratory irritation,
- Headaches,
- Dizziness,
- Sleep problems.

It is unclear whether the odours directly or the stress associated with exposure to these odours leads to the physical symptoms.

Psychological effects have also been linked with odour exposure in some studies. The symptoms reported include (Horton, 2009), (Heaney, 2011), (Alliance, 2015):

- Tension,
- Nervousness,
- Anger,
- Frustration,
- Depression,
- Fatigue,
- Confusion,
- General stress.

The psychological responses may be due to health worries associated with the exposure or the stress associated with the feeling that their odour concerns are not being heard. Psychological effects have also been found to lead to physical effects i.e. stress experienced by odour exposure has been linked to higher blood pressure in individuals (Alliance, 2015).

Social wellbeing has also been found to be impacted by odour. Some studies have found that odour may decrease the quality of life including (Tajik, 2008), (Alliance, 2015):

- Decreased outdoor activities,
- Keeping windows shut,
- Being forced to leave home due to odour,
- Decreased property value,
- Embarrassment leading to decreased social interaction.

1.2 Types Of EPA Licenced Facilities That Can Cause Odour

Examples of EPA licenced facilities which can potentially cause odour in the absence of the necessary odour controls and abatement measures are outlined below. This list is however not exhaustive:

- **Industrial and waste facilities with onsite Wastewater Treatment Plants (WwTPs)** – sources include primary settlement / balancing tanks and the resultant sludge treatments.
- **Anaerobic Digestion** – raw material odours and tanker transfer of digestate are potential issues.

- **Landfills** – active cell activities, leachate collection lagoons and landfill gas leakage are sources of odour.
- **Waste Transfer Stations** – facilities accepting putrescible waste will be high risk.

- **Intensive Agriculture** – poultry litter and pig manure can lead to odours.
- **Animal By-products** – all stages of the treatment of animal by-products should be viewed as high risk.
- **Composting Facilities** – potentially odorous activities include turning activities in the open air.
- **Food and drink industry** – cooking processes, wort boiling, animal feed production and fermentation.

However, any industrial and waste facility using or producing odorous material has the potential to create an odour in the absence of appropriate controls.

1.3 Sources Of Odour At These Facilities

The main sources of odour at the facility types outlined in ***Section 1.2*** include the following:

- Emission stacks;
- Ineffective abatement systems;
- Storage of animal by-products;
- Waste storage and treatment areas;
- Cooking and boiling release points;
- Transferring of materials / loading / unloading of odorous material.

- Industrial wastewater treatment plants including the following activities:
  - Primary settlement,
  - Balancing tanks,
  - Sludge holding tanks,
  - Sludge dewatering,
  - Sludge thickening / digestion;

Odour may however arise at any location where odorous material is present via fugitive releases (building leaks, seals, pressure relief valves) or operator error (leaving doors open, spills, leaks etc). As outlined in ***Section 3***, all potential odour release points should be reviewed by means of a detailed site audit and any risks that are identified should be mitigated.

In subsequent sections, this Guidance Note will focus on the following topics:

- A review of BAT Reference Documents applicable to odorous industries (Section 2);
- Guidance on preparing an Odour Management Plan (Section 3);
- A review of abatement technologies and the approach necessary to determine the most appropriate abatement solution for a facility (Section 4);
- Guidance on preparing a test programme for the proposed abatement solution (Section 5).

2.0 ODOUR GUIDANCE OUTLINED IN BAT REFERENCE DOCUMENTS

The EU has produced a range of vertical (sectoral) BAT Reference Documents (BREFs) and several horizontal (i.e. applicable across sectors / industries) BREFs over the last decade or more. The process is ongoing with many older BREFs currently undergoing revisions and additional sectors currently being drafted. A review of relevant BREFs relating to odour is discussed below and includes the following BREF documents:

Relevant BREF Documents

- BAT Reference Document for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector (EC, 2016) (CWW BREF),
- BAT Reference Document in the Food, Drink and Milk Industries (EC, 2018) (FDM BREF),
- Reference Document on Best Available Techniques in the Slaughterhouses and Animal By-products Industries (EC, 2005) (SA BREF),
- Best Available Techniques (BAT) Reference Document for Waste Treatment (EC, 2018) (WT BREF),
- Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry or Pigs (EC, 2017) (IRPP BREF).

2.1 CWW BREF

Commission Implementing Decision (EU) 2016/902 established the *BAT Conclusions for The Common Waste Water and Waste Gas Treatment Management Systems in the Chemical Sector* (EC, 2016). The Decision confirms that BAT, to prevent or where not practicable reduce odour, is to implement and regularly review an OMP as part of the facility environmental management system. The OMP should include all of the following elements:

I. *a protocol containing appropriate actions and timelines;*

II. *a protocol for conducting odour monitoring;*

III. *a protocol for response to identified odour incidents;*

IV. *an odour prevention and reduction programme designed to identify the source(s); to measure / estimate odour exposure; to characterise the contributions of the sources; and to implement prevention and / or reduction measures.*

The Decision also confirms that odour monitoring should be conducted in accordance with EN13725:2003 "*Air Quality – Determination of Odour Concentration by Dynamic Olfactometry*" with the option to complement this monitoring by measurement / estimation of odour exposure or estimation of odour impact.

The CWW BREF outlines a range of techniques considered BAT. To reduce emissions from waste water collection and treatment and from sludge treatment, one or a combination of the techniques outlined below should be used:

- Minimise the residence time of waste water and sludge in collection and storage systems, in particular, under anaerobic conditions.
- Use chemicals to destroy or to reduce the formation of odorous compounds (e.g. oxidation or precipitation of hydrogen sulfide).
- 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.

- On a case by case basis, cover or enclose facilities for collecting and treating waste water and sludge to collect the odorous waste gas for further treatment.

- End-of-pipe treatment. This can include:
  i. biological treatment;
  ii. thermal oxidation.

The *BAT Reference Document for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector* (EC, 2016) (CWW BREF) outlines specific techniques and technologies which would currently be considered BAT for reducing odour.

Some general issues identified in terms of the formation of odours include:

- The importance of controlling sulphate in the influent of WwTPs due to the potential to form hydrogen sulfide.

- Nitrogen compounds can also lead to issues at WwTPs where they breakdown into ammonia and amine.

- WwTPs should seek to optimise the aerobic treatment, e.g. by controlling the oxygen content, frequent maintenance of the aeration system, use of pure oxygen and / or removal of scum in tanks.

- Fugitive / diffuse emissions should be prevented through proper design of storage and handling facilities and through seals on pumps.

The CWW BREF includes the following recommendations in relation to biofilters:

- For biofilters, the media pH, media depth, moisture content and inlet gas temperatures will affect odour removal capacity.

- The residence time for effective abatement of odour through the biofilter should, as a rough guide, typically be a minimum of 30 – 45 seconds, with ranges of 25-60 seconds also commonly noted.

2.2 FDM BREF

The *BAT Reference Document in the Food, Drink and Milk Industries* (EC, 2018) (FDM BREF) summarizes a range of practicable measures which will help to reduce the odour impact from these facilities:

- Odour control should be based on a four-stage strategy, the extent to which each stage needs to be applied being site-specific:
  - Defining the problem – determine whether odour problems exist based on the number and frequency of odour complaints.
  - Develop an inventory of site odour emissions – the sources should be ranked in terms of the severity of their impact on the surrounding environment.

    - Undertake an odour emission monitoring survey – based on dynamic olfactometry. Air dispersion modelling may also be required to determine whether odour control is necessary.
    - Select the appropriate air emission control technique – this may involve process-integrated treatment (i.e. substance substitution, low emission systems) and / or end-of-pipe treatment (abatement system of appropriate efficiency / effectiveness).

- Segregation of animal by-products will help to reduce cross-contamination and potential odour problems whilst helping to reduce the volume of mixed by-products. This will also allow all products to be disposed of in the most appropriate way.

- The FDM BREF outlines the range of techniques which are frequently used to reduce organic / odour emissions in the Food and Drink sector:
    - Wet scrubber;
    - Plate absorber;
    - Adsorption;
    - Bio-filter;
    - Bio-scrubber;
    - Thermal oxidation;
    - Catalytic oxidation;
    - Non-thermal plasma treatment;
    - Extending the height of the discharge stack;
    - Increasing the stack discharge velocity;
    - Use of UV / ozone in absorption (emerging technique);
    - Odour Management Plan (OMP).

The FDM BREF also notes in terms of an OMP that a review of historical odour incidents and remedies and the dissemination of odour incident knowledge should be undertaken.

2.3 SA BREF

The *Reference Document on Best Available Techniques in the Slaughterhouses and Animal By-products Industries* (EC, 2005) (SA BREF) describes a number of practicable measures, in line with BAT, which can be employed to reduce emissions as outlined in ***Box 2***:

Box 2 – Measures outlined in the Slaughterhouses and Animal By-products Industries BREF (EC, 2005) (SA BREF)

- Odour problems can be minimised by co-operation between the slaughterhouse and the animal by-products installation. If the handling and storage of by-product at the slaughterhouse is not focused on minimising odour, the animal by-product facility will likely have odour issues even if the animal by-product is treated immediately upon arrival.

- Where it is not possible to treat animal by-products before decomposition starts to cause odour problems, refrigerate them as quickly as possible and for as short a time as possible prior to processing.

- Where inherently odorous material is used or produced during the treatment of animal by-products, pass the low intensity / high volume gases though a biofilter.

- Non-condensable gases should be passed through an existing boiler with pure vapour gases treated in a thermal oxidiser.

- The segregation of by-products can reduce potential odour problems from those materials which even when fresh emit very offensive odours.

Although not a BAT requirement, odour benefits arise from the cooling of blood to below 10°C. A pilot plant investigation found that the odour concentration increased by a factor of 60 when the storage temperature was increased from 4°C to 30°C.

2.4 WT BREF

The *Best Available Techniques (BAT) Reference Document for Waste Treatment* (EC, 2018) (WT BREF) outlines a number of practicable measures which can be employed to reduce emissions as outlined in ***Box 3***:

Box 3 – Practicable Measures Outlined In The Waste Treatment BREF (EC, 2018)

- Odour criteria should be applied to reject biodegradable wastes that are already releasing or have the potential to release mercaptans or VOCs, low molecular weight amines, acrylates, or other similarly highly odorous materials that are only suitable for acceptance under special handling requirements.
- Minimise the residence time of potentially odorous waste in collection, storage and handling systems (e.g. pipes, tanks, containers), in particular, under anaerobic conditions (when relevant, adequate provisions are made for the acceptance of seasonal peak volumes of waste).
- Use chemicals to destroy or to reduce the formation of odorous compounds.
- Optimise the aerobic treatment, e.g. by controlling the oxygen content and frequent maintenance of the aeration system. In the case of aerobic treatment of water-based liquid waste, the optimisation may also include the use of pure oxygen and/or removal of scum in tanks.
- On a case by case basis, cover or enclose facilities for storing, handling, collecting and treating odorous waste (including waste water and sludge) and collect the odorous waste gas for further treatment.
- End-of-pipe treatment.
- Where the waste storage area is in an enclosed building, there should be a building ventilation system and an emission abatement system that maintains the building under a negative air pressure in order to minimise fugitive odour.

2.5 IRPP BREF

Commission Implementing Decision (EU) 2017/302 established *BAT Conclusions, Under Directive 2010/75/EU, for The Intensive Rearing of Poultry or Pigs* (EC, 2017). The Decision confirms that BAT, to prevent or where not practicable reduce odour emissions, is to implement and regularly review an OMP as part of the facility environmental management system.

The *Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry or Pigs* (EC, 2017) (IRPP BREF) document outlines good operational practice for both pig and poultry housing which will reduce odour including:

- **Cleanliness**: Pigs and poultry should be kept clean of manure whilst reducing the exposed area of manure and avoiding spilled feed will reduce odour emissions.
- **Dryness**: Keeping the lying and activity area dry will reduce odour emissions.
- **Slurry removal**: Pig manure should be removed to storage pits or subject to an appropriate treatment, including land-spreading, as quickly as practicable to avoid increased odour emissions.
- **Optimise the discharge conditions** of exhaust air from the animal house by using one or a combination of the following techniques:

- Increasing the outlet height (e.g. exhaust air above roof level, stacks, divert air exhaust through the ridge instead of through the low part of the walls);
- Increasing the vertical outlet ventilation velocity;
- Effective placement of external barriers to create turbulence in the outgoing air flow (e.g. vegetation);
- Adding deflector covers in exhaust apertures located in low parts of walls in order to divert exhaust air towards the ground;
- Dispersing the exhaust air at the housing side which faces away from the sensitive receptor;
- Aligning the ridge axis of a naturally ventilated building transversally to the prevailing wind direction.

- **Using an air cleaning system**, such as:
  - Bio-scrubber,
  - Bio-filter,
  - Two-stage or three-stage air cleaning system.

Guidance on the storage of slurry to reduce odour emissions includes, where appropriate:

- Covering of slurry or solid manure during storage;
- Take prevailing wind direction into account in locating the store and / or adopt measures to reduce the wind speed around and above the building;
- Minimise the stirring of slurry (turbulence, due to stirring, can increase emissions ten-fold compared to a still surface);
- Reducing the effective surface area relative to the volume of manure will reduce the odour emissions i.e. manure can be compacted, or a three-sided wall can be constructed.

Manure land-spreading guidance suggests that the following points should be considered prior to spreading:

- Avoid spreading when people are likely to be at home, unless it is absolutely necessary;
- Pay attention to wind direction in relation to neighbouring houses;
- Avoid spreading in warm humid conditions;
- Use spreading systems which minimise the production of dust or fine droplets;
- Cultivate land as soon as possible after land-spreading.

3.0 ODOUR MANAGEMENT PLANS

Odour management at a licenced facility should be proactively undertaken and be viewed as a necessary requirement alongside, and in addition to, the requirement to avoid causing odour. Facilities should not await complaints before implementing an odour management plan but rather should view the plan as a preventative measure which helps ensure complaints do not arise in the first place.

Odour management conditions which are currently included in licences issued by the EPA (Industrial Emissions (IE), Integrated Pollution Control (IPC) and Waste Licences) will normally include a section on implementing an odour management plan similar to the following example:

***Odour Management Plan (OMP) Requirements (Example Text)**:*

- "*The licensee shall, within one year of commencement of the Scheduled Activity, submit an odour management programme for agreement by the Agency outlining current odour reduction measures appropriate for the site. The licensee shall implement this odour management programme with the agreement of the Agency, within a specified timeframe. The odour management programme shall be reviewed annually, and amendments thereto notified to the Agency for agreement as part of the Annual Environmental Report (AER). A report on the programme shall be prepared and submitted to the Agency as part of the AER*.
- "*The licensee shall undertake, as required by the Agency, an odour assessment which shall include as a minimum the identification and quantification of all significant odour sources and an assessment of the suitability and adequacy of the odour abatement systems to deal with these emissions. Any recommendations arising from such an odour assessment shall be implemented*".

An OMP is an essential tool for preventing, addressing and controlling odour at an industrial or waste facility. The format of the OMP should provide sufficient detail to allow operators and maintenance staff to clearly understand the operational procedures for both normal and abnormal conditions at the facility. The OMP should be:

- **Non-Complex**: the plan should aim to be as straightforward as possible while still addressing all the necessary control measures and preventative actions.
- **Structured & Systematic**: there should be a clear logic to the layout of the plan which makes it easy to navigate and implement.
- **Identify Responsibility**: the plan should allow the relevant onsite personnel to know who is responsible for implementing each task outlined in the plan in a step-by-step manner.

Detailed information and examples of odour management plans have been formulated by, amongst others, legislators in the UK (DEFRA, 2010), (SEPA, 2010)), (EA, 2011), Australia (NSW, 2006), New Zealand (NZMFE, 2016) and professional bodies (IAQM, 2014). These resources have many common elements although the details vary from author to author.

Ownership of the OMP should be identified with the nominated personnel, who has overall responsibility for implementing and updating the plan on an on-going basis, outlined. The person(s) with responsibility for the OMP should keep full records of all inspections, checks, surveys, complaints and corrective actions relating to the OMP and odour issues in general.

The OMP is a living, working document which should explain and outline how the facility will manage odour generation and prevent or minimise odour. The OMP should form part of the site standard operating procedures and / or be integrated into their Environmental Management System (EMS) with regular review cycles. As such, when developing an OMP, the approach should adopt a similar approach used in the change management process such as the ISO:14001 Plan-Do-Check-Act (PDCA) Cycle as shown in ***Figure 3.1***.

Figure 3.1 Adoption and Implementation of an Odour Management Plan (OMP)

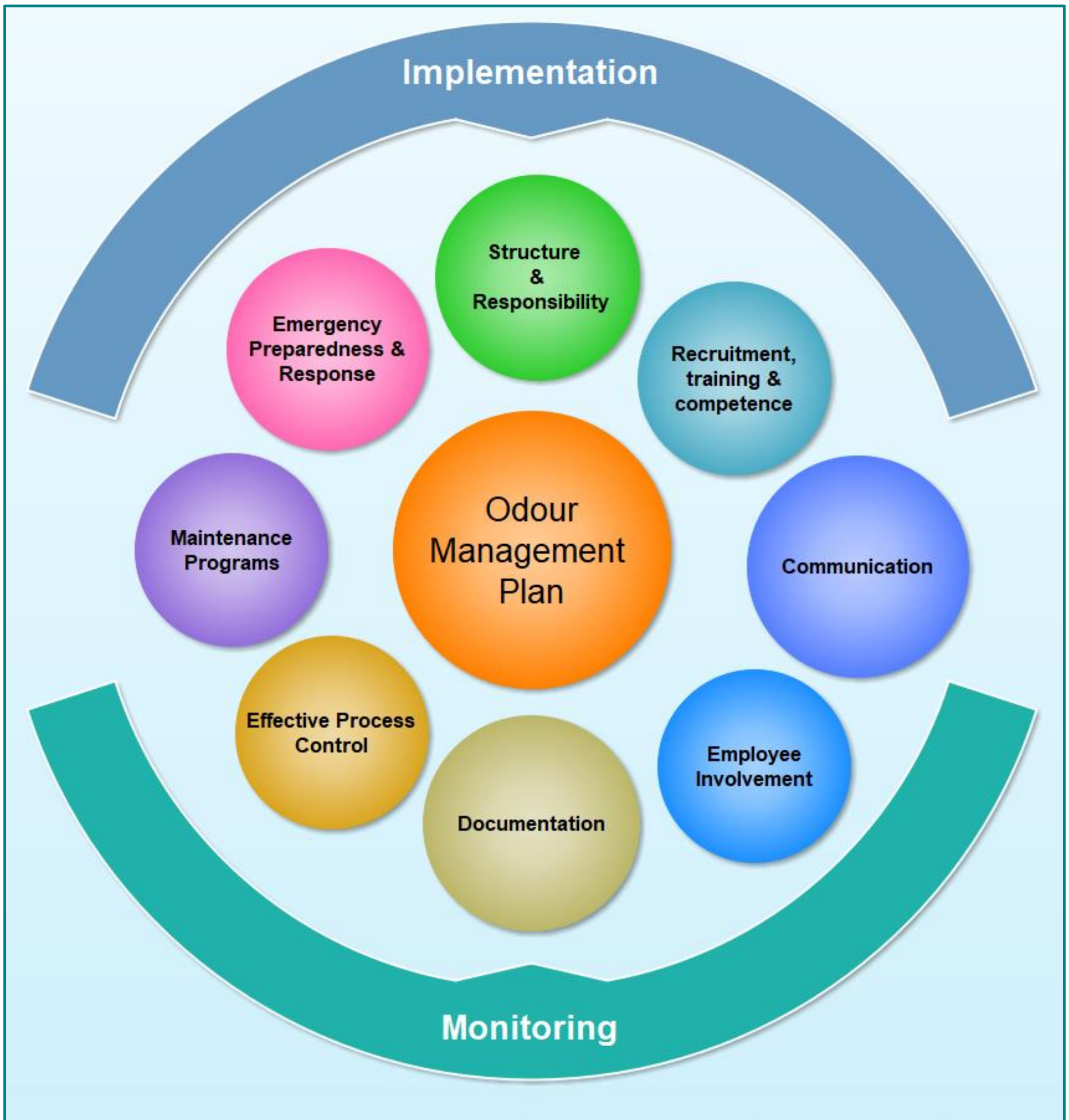
Key aspects of an odour management plan which, when incorporated into an environmental management system, would be considered BAT (adapted from the *FDM BREF (EC, 2018)*) are shown in ***Box 4*** (and shown graphically in ***Figure 3.2***):

Box 4 – Key Aspects Of An OMP (taken from FDM BREF (EC, 2018))

- Commitment of the management, including directors and senior management;
- Definition, by the management, of an odour management policy, that includes the continuous improvement of the environmental performance of the installation;
- Planning and establishing the necessary procedures, objectives and targets;
- Implementation of procedures paying particular attention to:
  - Structure and responsibility;
  - Recruitment, training, awareness and competence;
  - Communication and employee involvement;
  - Documentation;
  - Effective process control;
  - Maintenance programmes;
  - Emergency preparedness and response;
  - Safeguarding compliance with environmental legislation;
- Checking performance and taking corrective action, paying particular attention to:
  - Monitoring and measurements;
  - Corrective and preventative action;
  - Maintenance of records;
  - Auditing in order to determine whether the OMP has been properly implemented and maintained;
- Review, by senior management, of the OMP and its continuing suitability, adequacy and effectiveness.

The OMP should outline in detail how all odour sources onsite will be managed and controlled on an ongoing basis. The OMP should also identify possible abnormal operational occurrences and reasonably foreseeable accidents / incidents. The plan should then address in a step-by-step basis how these abnormal operation events will be rectified in as short a period of time as possible.

Figure 3.2 Odour Management Plan Principle (Based on FDM BREF (EC 2018))



Based on Best Available Techniques (BAT) Reference Document in the Food, Drink and Milk Industries (EC, 2018)

3.1 Odour Audit

An extensive site audit is an essential first step in determining the key odour sources at a facility and, where necessary, in controlling and abating odour to ensure no odour occurs beyond the site boundary.

The audit should ensure that the baseline conditions for a facility are known as accurately as possible. Audits also serve as an effective preventative tool which can avert odour being generated in the first place.

For example, if the odour emission rate is unknown for a range of odour sources it may be necessary to quantify the odour emission rates from these sources using dynamic olfactometry monitoring based on European Standard *EN13275:2003* "*Air Quality – Determination of Odour Concentration by Dynamic Olfactometry*". The method involves the use of the "lung" principle where odorous air is drawn into a sampling bag which has been placed within a rigid container. A vacuum pump is used to create a negative pressure within the container with the sampling bag expanding to fill the vacuum with the odorous air. Thereafter, the sample is measured based on the number of dilutions required to reach the detection threshold based on a panel of at least four people with a normal sense of smell. The number of dilutions required is called the "odour concentration" and has units of OU_E/m^3.

Shown in ***Figure 3.3*** is a brief overview of the steps which are required to undertake a successful site audit. The potential impact of odour from the sources at the facility can be determined from a review of the type, magnitude, environmental impact and frequency of operation of the process. The personnel conducting the audit should fully understand the process from receipt of raw materials, through all stages of production to off-site removal of product or disposal / recovery. A process flow diagram such as the examples shown in ***Figure 3.4*** and ***Figure 3.5*** will help to identify and isolate the key odour sources for further investigation.

The site audit should also be undertaken with an awareness of the sensitivity of the surrounding environment. The personnel undertaking the audit should be fully aware of the location of all nearby sensitive receptor locations including residential receptors, schools, commercial premises, amenity areas and hospitals. The facility should have a complaints procedure in place as part of the site odour management plan (as outlined in ***Section 3.7***). The complaints log should be investigated as part of the site audit to determine whether there have been any recent complaints and to determine if the source of these complaints has been identified or if the activities at the time of the complaint can be determined. The complaints log can be useful in directing the audit to the most high-risk areas i.e. those sources and activities which are causing annoyance in the local community.

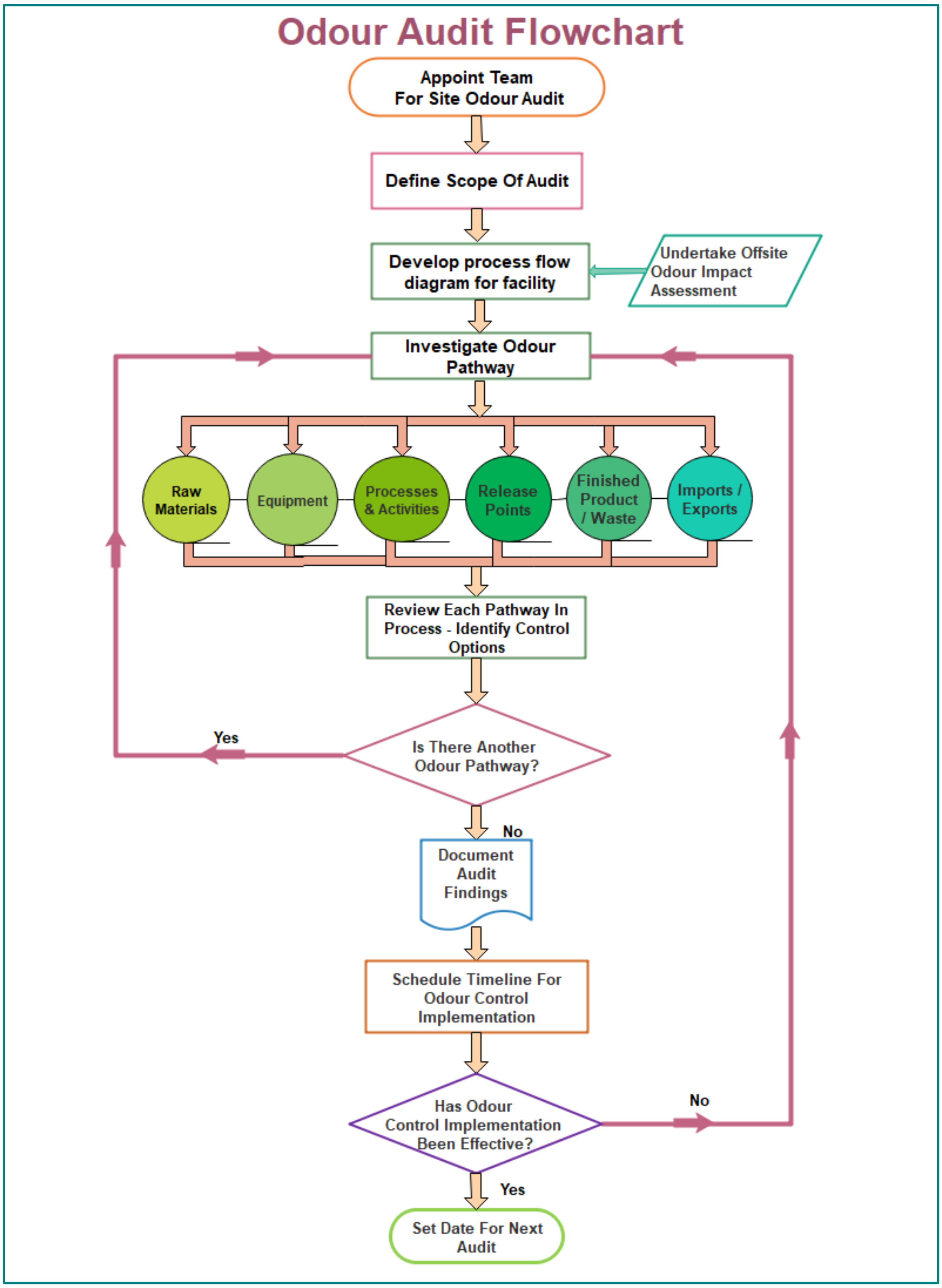
The site audit should identify all potential odour sources in terms of the following categories and attribute a risk rating to them (high, medium or low risk sources):

- **Raw Materials**: raw materials of concern from an odour perspective will generally be solids or liquids which have the potential to release odorous volatile organic compounds. Particular care should be paid to any material which is open to atmosphere or might be released from diffuse or fugitive sources. Some facilities will have high risk material that will inevitably lead to odour generation, such as the handling of organic and putrescible waste at waste transfer / composting facilities whilst other sources may be of a lower risk and may be odorous only under unfavourable conditions (primary settlement tanks at industrial WwTPs where the influent has become anaerobic, for example).

- **Equipment**: equipment, particularly where there is an interface to atmosphere such as valves, release points, openings for filling / emptying of materials, are a potential source of odour. It is likely there will be a range of odour sources which have the potential to generate odour, some of which will be of greater concern than others.

- **Processes & Activities**: the audit should review the processes and activities which are undertaken and evaluate whether any of the activities can be altered such that odour generation is minimised. For example, for a waste handling facility, the age of the waste should be minimised to avoid anaerobic conditions whilst the surface area of waste exposed to atmosphere should also be reduced to avoid odour release.

Figure 3.3 Site Odour Audit Flowchart



- **Release points**: the audit should identify all major emission points such as stacks / area sources with the potential to emit odorous material. Potential or minor emission points should also be investigated as possible odorous sources including passive vents and pressure relief valves.

- **Finished Product / Waste**: Depending on the activity, the finished product or waste may be odorous. Abattoirs will produce animal by-products which will quickly decay and cause odour issues if not controlled properly whilst industrial WwTPs will have sludge as a waste which may be odorous depending on the treatment method. Waste transfer facilities and MBT (mechanical & biological treatment) facilities may generator SRF (solid recovered fuel) or RDF (refused-derived fuel) which may be odorous if exposed to atmosphere or stored onsite for long periods.

- **Deliveries / Export**: If odorous material is delivered to the facility or exported from the facility, odour may occur if materials are not fully sealed. Risks associated with this activity will be greatest for situations where there are static sources such as queuing of trucks to off-load odorous material.

The category "*Process and activities"* is generally the most critical aspect of the audit and requires the most time and resources to ensure that the audit is undertaken successfully. Each identified process or activity should be isolated, and each relevant source assessed for odour risk with a determination made as to whether there is a need for a more detailed assessment to be undertaken.

Figure 3.4 Example Process Flow Diagram Identifying Key Potential Odorous Sources

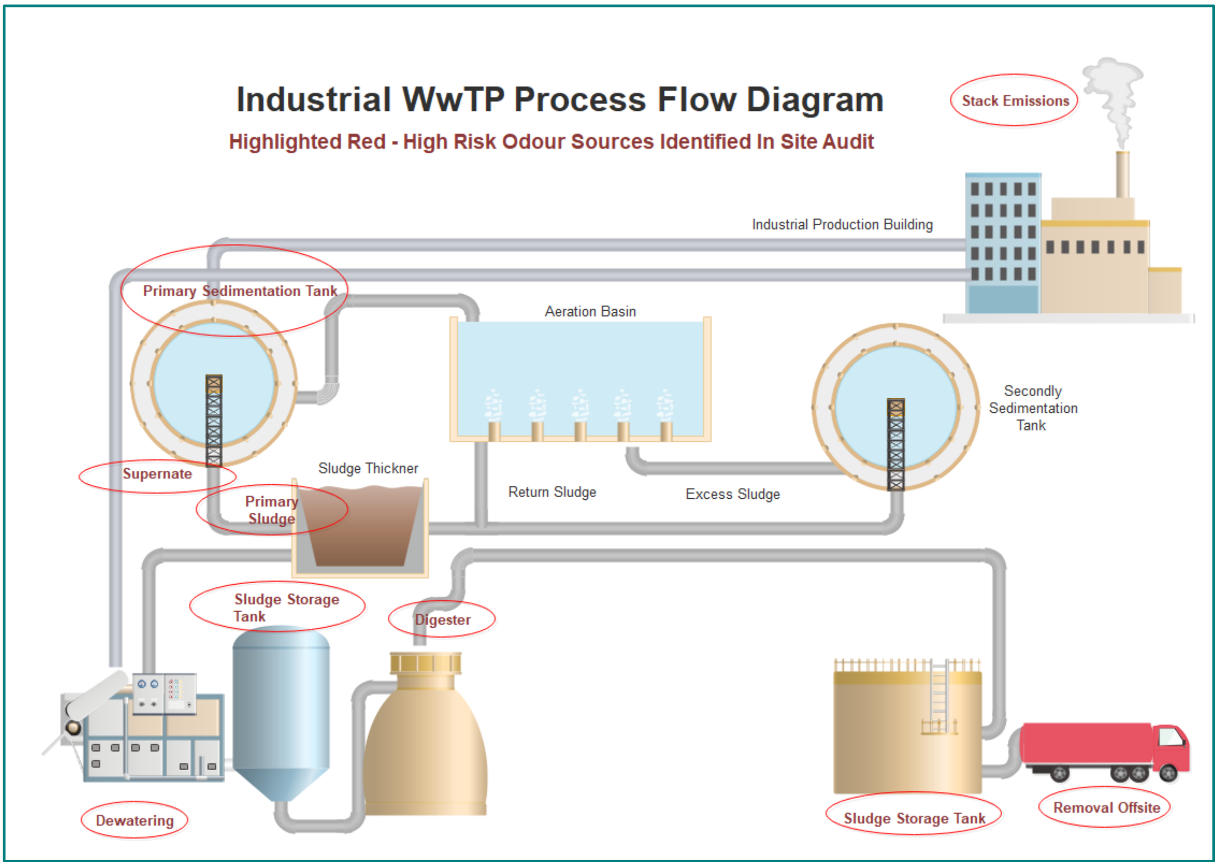
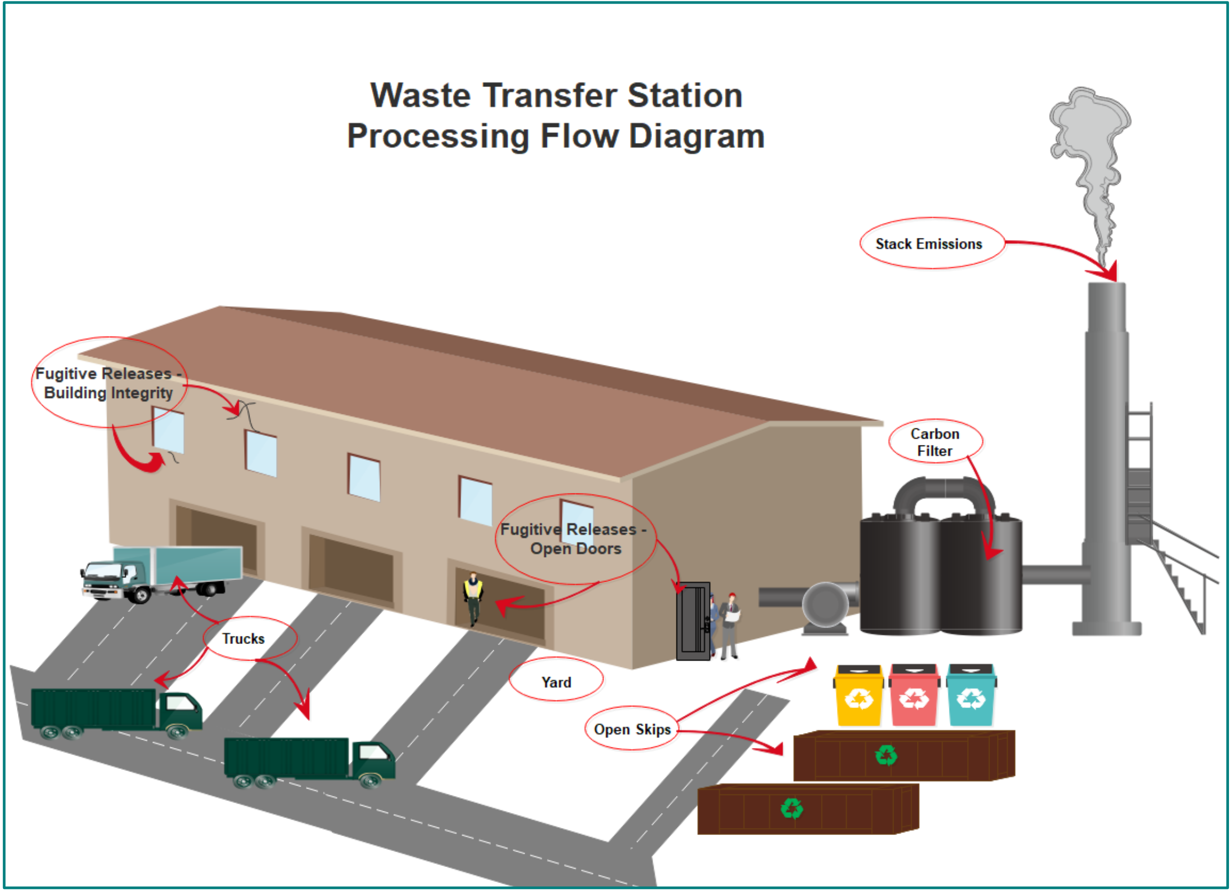


Figure 3.5 Example Process Flow Diagram – Waste Transfer Station



3.1.1 Detailed Assessment Of Odour Pathways

Based on the initial audit, high risk sources may need to be investigated in detail. There are a range of tools which can be employed to determine the significance of the identified high-risk sources. The tools which can be employed when undertaking a more detailed assessment include:

- Quantification of the odour sources onsite using dynamic olfactometry measurements in line with EN13725:2003 "*Air Quality – Determination of Odour Concentration by Dynamic Olfactometry*";
- Air dispersion modelling of the measured odour samples in the ambient environment beyond the site boundary (as outlined in ***Section 3.3***);
- A review of the frequency and geographical spread of the predicted odour concentration from each onsite source;
- Each source should be quantified (on a time-weighted basis) to determine their significance, thus allowing the audit to focus on the most significant sources.
- Where necessary, modelling of the proposed abatement / process improvement technique should be undertaken to assess whether the proposed solution will be effective; and
- Assessment of post-abatement odour levels in the environment and comparison with odour guideline levels should be conducted. A review of the odour complaints record should also be undertaken to ensure that the abatement solution has been effective.

At facilities with existing odour complaints, a multi-tool approach involving the full range of approaches outlined above may be necessary to determine the root cause of the odours. Only by identifying the root cause of the complaints will it be possible to determine the appropriate control or abatement solution required for the resolution of the problem.

3.1.2 Inventory Of Materials

The determination of odorous sources and streams should start with materials which are imported to site which may include raw materials for processing (in the case of the food and drinks industry, generic industrial facilities), waste to be treated (in the case of the waste industry, rendering) or, in some cases, living animals (intensive agriculture).

The inventory should be reviewed to determine if procedures can be implemented which will reduce odour at source such as:

- Capacity – The amount of material accepted into a facility should be no greater than the capacity of the facility to treat in a timely manner. As an example, a waste transfer station should have a policy of only accepting waste that can be treated within a defined period (for example 24 or 48 hours) to avoid the risk of anaerobic conditions developing. Thus, operators should have a knowledge of the maximum throughput that the facility can process in any one day and have a policy in place to divert waste above the capacity threshold of the facility.

- Screening – A screening policy for incoming materials will normally be conditioned as part of the Licence for the facility to ensure that the material is not contaminated with particularly odorous impurities or has deteriorated beyond an acceptable standard. Procedures should be put in place with suppliers which allows materials to be rejected when standards are breached.

- Storage – The storage of imported materials should be reviewed from the point of view of odour generation. Odour will tend to increase from materials which are:

    - exposed to the atmosphere (from evaporation of odorous compounds),
    - during periods of high ambient temperatures which increases the rate of volatilisation,
    - when it is agitated (in the open air), and
    - where the material has a large surface area exposed to atmosphere.

  Thus, reductions in odour generation can be gained by:

    - Reducing the exposure of materials to atmosphere by storing within a building or installing windbreaks / barriers where material needs to be stored outdoors;
    - Ensure materials are not in direct sunlight either by storing within buildings or in shaded areas of the facility;
    - Keeping the exposed surface area to a minimum and restricting agitation of materials to a minimum;
    - Materials should be stored under negative pressure wherever possible with the odorous air extracted for treatment if necessary;
    - Doors should be close-fitting and kept closed at all times with self-closing mechanisms installed;
    - Misting of materials can reduce temperatures and increase relative humidity thus reducing evaporation;
    - Waste being stored in accordance with the site's waste storage plan.

3.1.3 Processes And Activities

The processes and activities which are undertaken by the facility should be analysed to identify when and where in the process odour could potentially be released to atmosphere. The key considerations include:

- Temperature – Heating or cooking processes are likely to be a significant source of volatile organic compounds releases into the atmosphere including odorous compounds. High ambient temperatures will also increase chemical reactions in general which increases both the volatility of organic compounds and the risk of anaerobic conditions.

- Pressure – A positive pressure in the system will lead to the risk of fugitive releases. If possible from a process viewpoint, creating a small negative pressure differential will decrease the potential for fugitive releases.

- Building Integrity – Many odorous processes or activities are undertaken within buildings with a negative pressure system installed to reduce fugitive emissions. For negative pressure systems to work effectively the integrity of the building should be sufficient to ensure effective containment of odours. Even without a negative pressure system in place, where buildings are used to store odorous material, a system should be in place with frequent checks to ensure that there are no gaps or cracks in the structure of the building. A smoke test (based on ASTM standards E1186 / E741) may be required in order to identify any leakages prior to remedial action. An air lock system may be necessary where highly odorous sources are exposed within a building.

- Ventilation – Many processes or activities at industrial and waste facilities may require a ventilation system be installed on health and safety grounds (rather than purely for odour abatement considerations). However, where this occurs it can also have a positive impact on odour. Where there is a ventilation system under negative pressure, the air stream can be extracted and directed to a stack for dispersion in the surrounding environment. Depending on the initial odour concentration and the volume of air exchanged, odours may be sufficiently diluted by this method alone and require no further treatment. Alternatively, the odour may be of sufficient magnitude to require an abatement system prior to release from the stack. Air dispersion modelling is normally required to confirm whether additional abatement is necessary in these circumstances.

3.1.4 Equipment

Equipment may release odour intentionally, via specific emission sources (pressure release valves, passive venting), or unintentionally via leaks due to fugitive releases from valves, seals, flanges etc particularly where the system is under positive pressure. Where necessary, a fugitive emission study of the facility should be undertaken using ISO EN 15446:2008 "*Fugitive and Diffuse Emissions of Common Concern to Industry Sectors – Measurement of Fugitive Emission of Vapours Generating from Equipment and Piping Leak*" with a corrective action plan implemented promptly. Passive vents and pressure relief valves may be important depending on the frequency of operation and the associated odour emission rate of these sources. Where it is found that these sources are contributing to off-site odour complaints, corrective engineering solutions should be investigated.

3.1.5 Release Points

A release point may be an emission point such as a stack or a less contained source such as an area or volume source (aeration basin, tank, weir). When releasing an odour through a stack it is important that the exit conditions are sufficient to escape the building wake and to avoid the risk of plume recirculation in the cavity zone adjacent to the building on which the stack is located. Generally, it is desirable to achieve an exit velocity of greater than 10 - 15 m/s based on a vertically positioned stack and with no obstacles (such as rain caps) to interrupt the mechanical and / or buoyancy driven plume rise.

Where it is found that existing stacks are creating an odour offsite, it may be necessary to increase the stack height by means of a stack height optimisation study using air dispersion modelling. Alternatively, abatement may be required to reduce the odour emission rate sufficiently to avoid odour detection offsite. It is also possible that a combination of a stack height increase, and a less efficient (but cheaper / more practicable) odour abatement solution may be preferred to achieve the same optimised solution.

Area and volume sources will generally benefit from restricting evaporation of the liquid / solid surface. Thus, measures which reduce evaporation will be beneficial such as restricting turbulence, covering of sources to reduce wind flow over the surface and maintaining a low temperature will all be beneficial from an odour release perspective.

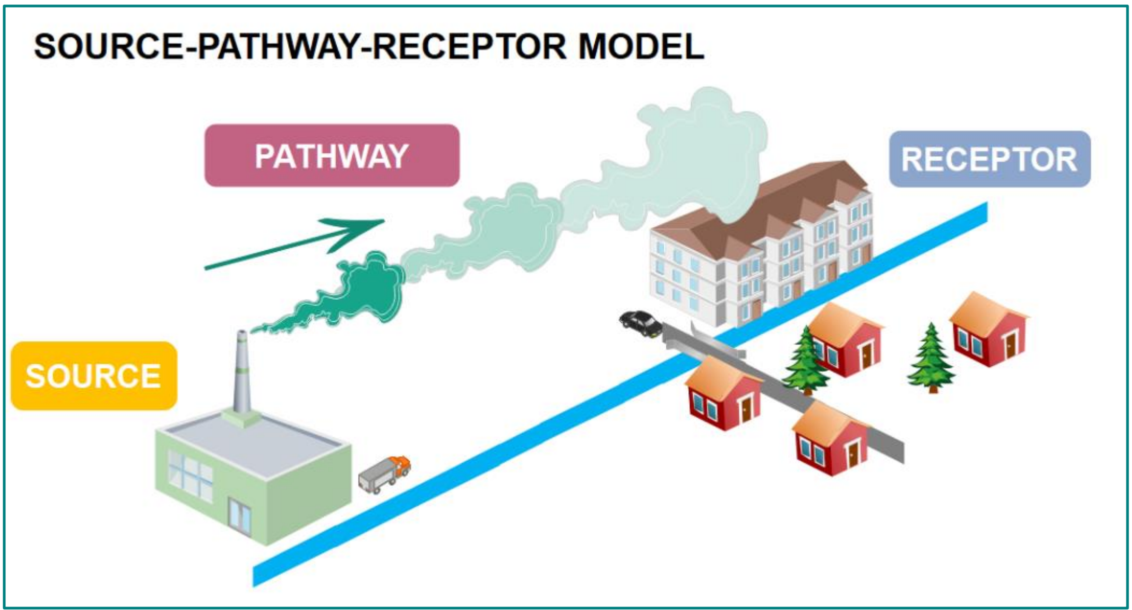
3.1.6 Staff Training Requirements

In order for site audits and odour management plans to be undertaken and implemented effectively, there will be a requirement for all staff members to be adequately trained. The training should be adapted to suit the tasks and responsibilities of the relevant personnel and the odour risk profile of the facility including the sensitivity of the surrounding environment.

Training requirements should include the following:

- How and why odour is controlled and the importance of the control measures which are in place in ensuring that odour impacts are prevented or, at least, minimised should be explained to relevant personnel.
- General good housekeeping practices should be covered in the training programmes including site maintenance, record keeping, inventory and product storage.
- Staff should be trained in the odour management procedures to be implemented under circumstances where abnormal operation / emergencies onsite occur.
- All environmental incidents with the potential for odour release such as spills, leaks and failure of equipment should be documented and recorded in the OMP file. A follow-up note should address the root cause of the incident and include a discussion of the measures introduced to prevent a reoccurrence.
- Relevant staff members should be aware of the procedure to deal with odour complaints.
- Staff should be trained to undertake site odour impact assessment in line with EPA publication AG5 "*Odour Impact Assessment Guidance for EPA Licensed Sites (AG5)*" (EPA, 2019).
- Staff should be trained in the "***Source-Pathway-Receptor***" concept and thus understand how the release of odour onsite can lead to an odour at nearby receptors (***Figure 3.6***).

Figure 3.6 Odour Source-Pathway-Receptor Concept



Particular attention should be paid to the following issues affecting the source of the odour:

- Facilities with highly odorous compounds with very low odour detection thresholds (e.g. mercaptans) are at a greater risk of odour.
- Operators of processes with a large volume of unpleasant odours (e.g. rendering) will need to be keenly aware of any potential release points.
- The larger the facility in terms of tonnage of material, the greater the risk to the immediate environment.
- Facilities with external odour sources and an absence of abatement will require a higher degree of active controls to ensure odour release is minimised.

- The factors affecting the pathway include:
  - The distance from each source to each receptor with extra vigilance required for high sensitivity receptors such as residential receptors.
  - The meteorological conditions in particular the frequency of wind blowing towards receptors and the occurrence of low wind speeds.
  - The topography between the sources and receptors (e.g. a downwards sloping valley between source and receptor may intensify the impact).
  - The selection of stack height, exit velocity, and temperature of release for odours released from stacks.

- The factors affecting receptor sensitivity include:
  - High sensitivity receptors include residential homes, hospitals, nursing homes, creches, businesses (retail/commercial), industry and schools within the area of the observation point. Facilities with the potential for odorous emissions located close to these receptors will generally require a high degree of odour control.
  - Moderate sensitivity locations will have housing, commercial/industrial or public areas within 100m of the observation point.
  - Low sensitivity locations will have housing, commercial/industrial or public areas between 100m – 500m of the observation point.
  - Remote sensitivity locations will have no housing, commercial/industrial or public areas within 500m of the observation point.

3.2 Odour Impact Assessment In Accordance With AG5

The assessment of odour from the facility should be undertaken using the procedures and guidelines outlined in EPA publication AG5 "*Odour Impact Assessment Guidance for EPA Licensed Sites (AG5)*" (EPA, 2019) and described below in ***Box 5***. The assesment involves the use of an odour impact assessment at suitable locations in the vicinity of a facility. Odour impact assessment is the use of the human nose to assess odour and is the most common form of odour monitoring in the field. The procedure requires that the odour impact assessment is applied in a consistent and systematic way, the details of which are outlined in *AG5*. When properly undertaken on a regular basis, the results of odour impact assessments can be used to support, or otherwise, the evidence of complaints by members of the public.

Box 5 – Odour Impact Assessment Protocol

An offsite odour impact assessment at nearby sensitive receptors should form part of the odour audit. The odour impact assessment should take the following factors into account:

- Staff should only undertake the odour impact assessment prior to coming to work as staff are likely to be desensitised to the odour generated onsite, termed odour adaptation, and thus might be unable to objectively assess odour in the surrounding environment.

- Prior to the test, the wind conditions must be confirmed, and an initial odour impact assessment taken upwind of the facility prior to moving to downwind locations.

- The survey should be undertaken using the *"Assessment of Odour Impact Field Record Sheet (Annex A)"* which is an annex to *AG5* (EPA, 2019). The survey should record both the intensity of the odour and its persistence at each location assessed using the terminology outlined in ***Figure 3.7***.

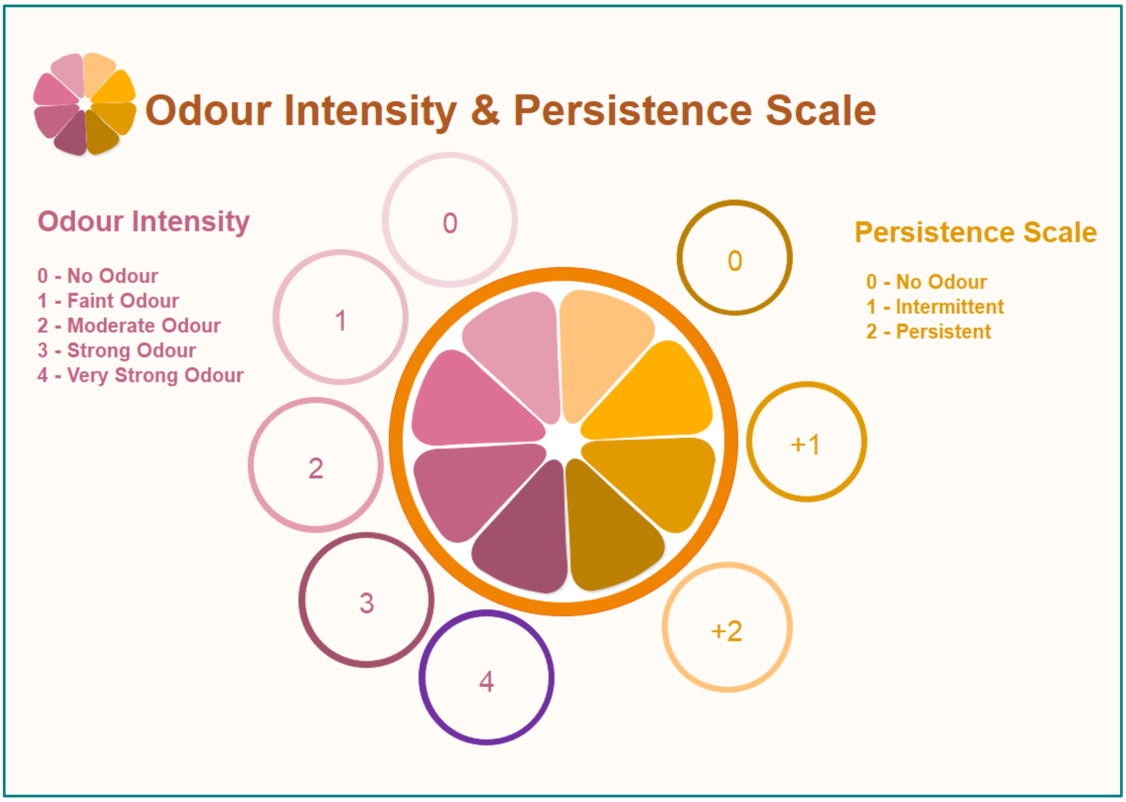
- The personnel undertaking the survey should not smoke, chew gum, drink coffee / tea nor be experiencing a medical condition (such as a cold / flu) which could interfere with the test.

- Surveys should be conducted on at least several occasions over varying days of the week. The time of day when odour complaints are made and the wind direction which leads to most complaints should be considered also.

- The surveys should also be ideally undertaken at different times of the day and under a range of weather conditions.

- Where an odour is detected, an inspection of the facility must be carried out directly by the odour investigator, to determine whether any observed odour can be linked to the site and to evaluate any potential odour producing activities or locations. Understanding the actual process conditions onsite at the time of the complaint will help to locate the issue and isolate the problem.

Figure 3.7 Odour Intensity & Offensiveness Scale Terminology



3.3 Modelling Of Odorous Emissions

The air dispersion modelling of odour from a facility should be undertaken using the procedures and guidelines outlined in EPA publication AG4 "*Air Dispersion Modelling from Industrial Installations Guidance Note (AG4)*" (EPA, 2010). A short summary of the pertinent issues is outlined below.

Firstly, there are two general approaches to assessing odour emission rates from industrial installations. One approach is to assess the emissions from the installation in terms of Odour Units (OU or OU_E/m^3). A second approach is to use a chemical marker which it is assumed will correlate with the odour detected at the boundary or the nearest residential receptor.

For existing facilities, direct measurement of odour using dynamic olfactometry (*EN 13725:2003*) is recommended for determining odour emission rates. The measurement from each stack or other sources (basins, tanks, surfaces etc) should be conducted in triplicate, in order to reduce uncertainty and to enable the identification of outliers. Sampling and analysis for a specific chemical can only be undertaken adequately where the release is a single compound although even in this case finding accurate odour detection thresholds can be problematic. Where more than one compound is present, dynamic olfactometry is the preferred approach for determining odour emission rates due to the synergistic and non-linear effects of multiple odorous compounds. Chemical characterization can however be usefully employed to determine the correct design for an abatement solution as outlined in ***Section 4*.**

For proposed installations or the expansion of existing operations, the modeller should ensure that the emission rates used are fully justified in the report. Sources of data may include libraries of data from similar existing installations in Ireland (preferably), data from similar existing installations in other jurisdictions or, if available, emission factor databases.

3.3.1 Relevant Odour Standards

The exposure of the population to a particular odour consists of two factors; the concentration and the length of time that the population may perceive the odour. By definition, 1 OU_E/m^3 is the detection threshold of 50% of a qualified panel of observers working in an odour-free laboratory using odour-free air as the zero reference.

Currently there is no general statutory odour standard in Ireland relating to industrial installations. The EPA (EPA, 2001) has issued guidance specific to intensive agriculture which has outlined the following standards:

- Target value for new pig-production units of 1.5 OU_E/m^3 as a 98^{th}%ile of one hour averaging periods,
- Limit value for new pig-production units of 3.0 OU_E/m^3 as a 98^{th}%ile of one hour averaging periods,
- Limit value for existing pig-production units of 6.0 OU_E/m^3 as a 98^{th}%ile of one hour averaging periods.

Guidance from the UK (EA, 2011), and adapted for Irish EPA use, recommends that odour standards should vary from 1.5 – 6.0 OU_E/m^3 as a 98^{th}%ile of one hour averaging periods at the worst-case sensitive receptor based on the offensiveness of the odour and with adjustments for local factors such as population density. A summary of the indicative criterion is given below in ***Table 3.1*** (taken from (EA, 2011) and adapted for Irish EPA use):

Table 3.1 **Indicative Odour Standards Based On Offensiveness Of Odour Taken From** (EA, 2011) **And Adapted For Irish EPA Use**

Industrial Sectors	Relative Offensiveness of Odour	Indicative Criterion Note 1
• Processes involving decaying animal or fish remains. • Processes involving septic effluent or sludge • Waste sites including landfills, waste transfer stations and non-green waste composting facilities.	Most Offensive	1.5 OU_E/m^3 as a 98^{th}%ile of hourly averages at the worst-case sensitive receptor
• Intensive Livestock Rearing • Fat Frying / Meat Cooking (Food Processing) • Animal Feed • Sugar Beet Processing • Well aerated green waste composting Most odours from regulated processes fall into this category i.e. any industrial sector which does not obviously fall within the "most offensive" or "less offensive" categories.	Moderately Offensive	3.0 OU_E/m^3 as a 98^{th}%ile of hourly averages at the worst-case sensitive receptor
• Brewery / Grain / Oats Production • Coffee Roasting • Bakery • Confectionery	Less Offensive	6.0 OU_E/m^3 as a 98^{th}%ile of hourly averages at the worst-case sensitive receptor

Note 1 Professional judgement should be applied in the determination of where the worst-case sensitive receptor is located.

3.3.2 *Modelling Procedure*

Odour modelling is generally undertaken using either of the two most commonly used air dispersion models, ADMS or AERMOD, using the same principals as are used when modelling the release of any other pollutant. Both models have the capability of accepting emission rates in terms of OU_E/sec and producing ground level concentrations in terms of OU_E/m^3. The same principals in relation to meteorology, terrain and building downwash will also apply to odour modelling as per other air emissions as outlined in AG4. When modelling odour, the measurement of ambient levels of odour and the incorporation of these levels into the modelling results is not a valid approach as odours are not generally additive due to synergistic and non-linear effects of multiple odorous compounds in the ambient environment. Secondly, an ambient odour level from an odour source will typically be masked by existing background odour level which have been recorded as high as 100 – 200 OU_E/m^3 (Yang, 2000) whilst residual odour in sampling bags can range from 20 – 50 OU_E/m^3 (Laor, 2014).

When undertaking the modelling of odour from a facility the following points should be kept in mind:

- The frequency of operation of each source at a facility should be assessed to determine a suitable time-weighted odour emission rate for each source. Whilst this time-weighted approach should be the scenario assessed for compliance, it is also appropriate to consider a scenario with the odour source emitting continuously so that an assessment of short-term impacts may be considered.

- The additional odour releases during transfer and agitation / shredding of materials should be considered as odour source concentrations may vary considerably on a daily / weekly / seasonal basis depending on the specific operation / activity being undertaken.

- An appropriate odour guideline value should be selected depending on the offensiveness of the odour. However, good professional judgement should be applied in selecting an appropriate odour assessment criterion for any particular case and that justification should be provided for that selection.

- For example, if a facility of medium sensitivity has a history of odour complaints it may be prudent to impose an odour assessment criterion used for high sensitivity facilities. Likewise, a facility which ducts all emissions through biofilters, thereby changing the offensiveness (hedonic tone) of the odour, might reasonably have a less stringent odour impact criterion applied in this case.

- Compliance with the indicative odour standard, confirmed through modelling, does not reduce the licensee’s requirement to ensure that the activity does not cause nuisance. Odour management at a licenced facility should be proactive, and may require additional measures to ensure that the activity is in compliance with their licence.

3.4 Appropriate Abatement Technologies

The elimination, or reduction to acceptable levels, of odour in the Industrial Emissions Directive (IED) is based on the principle of Best Available Techniques (BAT). However, the IED allows flexibility in the selection of the appropriate abatement measures to comply with the regulations. Thus, the selection of the right abatement solution should be based on detailed site-specific engineering considerations rather than adhering to a specific pre-determined technology.

The *CWW BREF Note* (EC, 2016) outlines the range of considerations which may need to be taken into account when selecting the most appropriate abatement solution:

- The flow rate of the odorous emissions;
- The concentration of the odorous pollutants(s);
- The physical and chemical properties of the odorous molecules;
- The efficiency of the techniques to abate the targeted odorous pollutants and the variability over time of this abatement efficiency;
- 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 concentrations, moisture content);
- The space requirements of the techniques;
- The operation and maintenance requirements of the techniques; and
- The cost of the techniques.

A graphical representation of the range of considerations which will need to be considered is outlined in ***Figure 3.8***.

The odour efficiency of the various abatement solutions varies both between technologies and between differing processes using the same technologies as shown in ***Table 3.2*** (taken from (Schenk, 2009)). Where there is uncertainty surrounding abatement efficiency, it is recommended that a test programme be undertaken on a pilot basis to determine the site-specific abatement efficiency (as outlined in ***Section 5***). In many cases, there will be sufficient data sets available to demonstrate abatement efficiency and pilot testing will not be required, but where such data sets are not available, pilot testing should be undertaken. Detailed information on the various odour abatement techniques is given in ***Section 4***.

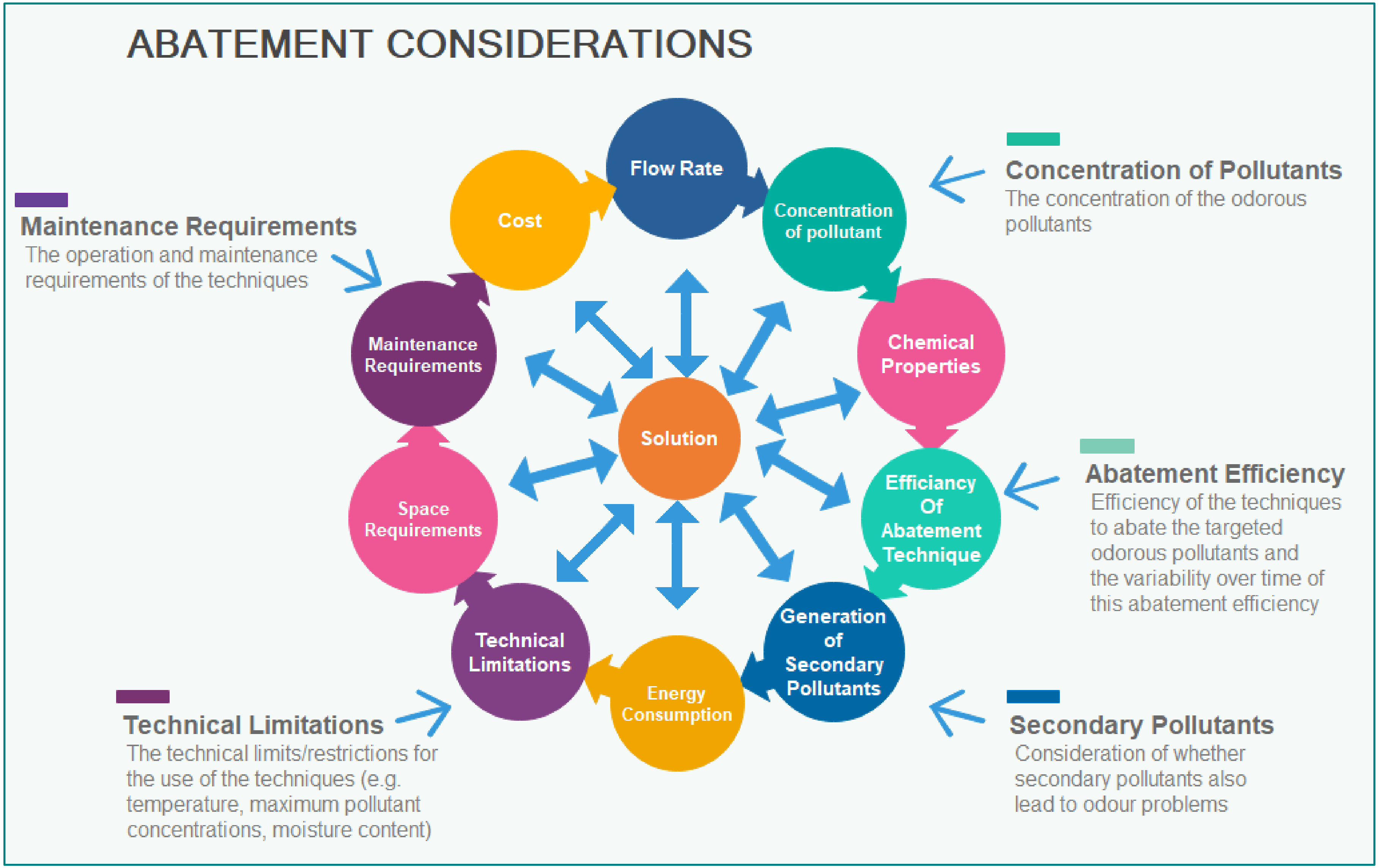
Table 3.2 Odour Abatement Efficiencies And Relative Costs Across Various Techniques

Technique	Odour Abatement Efficiency (%)	Examples of Industry Using Technique Note 1	Odour Compound Removed Most Efficiently	Relative Cost
Activated Carbon	70 - 99	Waste, Anaerobic Digestion	VOCs / some H_2S	Medium
Wet Scrubber	60 - 85	Chemical, Composting	Soluble VOCs / H_2S / NH_3	Medium
Thermal Oxidation	98 - 99.9	Manufacturing, Pharmaceutical, Rendering	VOCs / H_2S / Inorganic compounds	High
Bio-filtration	70 - 99	WWTP, Composting, Anaerobic Digestion, Rendering, Animal Feed	Soluble VOCs / H_2S / NH_3	Low
Bio-scrubbing	70 - 80	WWTP	Soluble VOCs / H_2S / NH_3	Medium
UV / Ozone / Cold-plasma	< 50 - 98	Food & Drink, WWTP, Animal Feed	VOCs	Medium

Note 1 The various techniques could apply a greater range of industries than that outlined in this table.

Source: Adapted from Schenk et al. (2009)

Figure 3.8 Range of Abatement Considerations (based on CWW BREF (EC, 2016)).



3.5 Methods Of Eliminating Odour (Including Fugitive Odour)

There are a range of methods which may be employed to reduce odour (including fugitive odour) depending on the specific circumstances of the facility in question:

Box 7- Methods Of Eliminating Odour (Including Fugitive Odour)

- At the planning stage of a facility or when undertaking an upgrade, consideration should be given to locating the more odorous operations furthest from any nearby residential / sensitive receptors. Consideration should also be given to the prevailing wind and thus to avoid locating particularly odorous activities immediately upwind of sensitive receptors.

- Truck deliveries of odorous materials should be sealed or enclosed. Truck staging areas should also be situated away from the nearby receptors. Locating truck staging areas near buildings will help to provide a wind break.

- The facility should operate a “just in time” management approach for odorous material. Waste disposal should also be undertaken as soon as feasible particularly if there is a risk of anaerobic conditions occurring. Storage of odorous material should also be based on “first in, first out” (FIFO) policy.

- The OMP should outline a preventative maintenance (PM) schedule for the facility including preparing relevant standard operating procedures (SOPs) for key odour control equipment / activities. Maintenance should be proactive rather than reactive.

- Mitigation measures for the storage and handling of odorous materials located outdoors include constructing 3-sided enclosures and relocating activities indoors.

- Good housekeeping of all outdoor areas should be implemented particularly during periods of unfavourable meteorological conditions (for example, decomposition of organic material will accelerate during warmer periods).

- All spills, overflows and leaks should be cleaned up promptly with all operators aware and trained in the relevant SOP for this procedure.

- Chemicals which are potentially odorous or can lead to odorous by-products should be reviewed as to the potential for product substitution. For example, the use of sulfuric acid may lead to odorous sulfur-forming chemicals downstream. It may be possible to replace sulfuric acid with an equally effective alternative.

- A local fume hood collection system with flexible hoses may be useful for capturing and extracting fugitive odours from sources with odour potential. Localised containment will reduce the volume of air to be extracted and, if necessary, treated.

- For the transfer or delivery of odorous liquids, vapour recovery or a closed-loop system should be used.

- Extraction of air through a negative pressure system to a point source will reduce fugitive emissions associated with passive sources such as general ventilation exhausts, louvers, windows or doors.

- A building integrity test is recommended for any building where odorous material is stored. Ideally, the building should have a negative pressure system installed with the extracted air ducted to a vertically pointed stack (and possibly with an abatement system prior to release where the need arises). Self-closing doors and trigger alarms on roller doors should also be installed.

- A waste storage plan should be developed.

3.6 Minimisation Of Odours That Cannot Be Abated

Odours which cannot be abated can be minimised by implementing the following practices:

Box 8 - Minimisation Of Odours That Cannot Be Abated

- In certain instances, odour can be effectively minimised by process design and operation. Odorous emissions from intensive agriculture can be minimised through animal nutrition for example (reduction of protein in feed).
- The facility should have a high level of cleanliness with outdoor surfaces washed down regularly with any remaining stagnant water removed. Cleaning of waste and storage bins, trucks carrying odorous materials and holding vessels should be undertaken regularly with an increased frequency in summer months.
- A closed-door policy should be strictly enforced where there is the potential for odorous releases through open doors.
- Keeping the temperature as low as possible will reduce evaporation and thus odorous material should be kept out of direct sunlight and refrigerated if possible.
- Increasing the humidity and reducing airflow over the surface of the odorous liquid will reduce the rate of evaporation (the rate of evaporation is directly proportional to the speed of air flow over the liquid surface).
- Reducing the exposed surface area of liquid storage tanks by using floating covers will reduce the rate of evaporation and subsequent release to atmosphere.
- Activities such as agitation, shredding and mixing (turbulence) in liquids and solids will increase the odour emission rate significantly. These activities should be undertaken with appropriate mitigation measures in place.
- Adjustment to pH can increase the solubility of certain odorous compounds in water. For example, acidic conditions will suppress the evaporation of ammonia and similar alkaline compounds. Likewise, increasing alkalinity will help suppress H_2S release to atmosphere.
- Odour neutralisers may be useful in certain limited circumstances where intermittent odours occur although these are generally not a long-term solution.
- The addition of surfactants to aqueous solutions will help to shift the air-water equilibrium of volatile organic compounds leading to decreased rates of evaporation.
- Stack design to ensure that extracted air is dispersed adequately is important. The exhausted air should have sufficient stack exit velocity and an appropriate stack diameter to avoid stack-tip downwash (typically greater than 10 - 15 m/s required). The stack height should be sufficient to avoid significant building downwash and be directed in a vertical direction without rain caps on top of the stacks.
- Fugitive emissions such as valves, pump seals, flanges and leaks should be investigated using appropriate methods (for example photoionisation detection (PID)) and followed up with a corrective action programme.

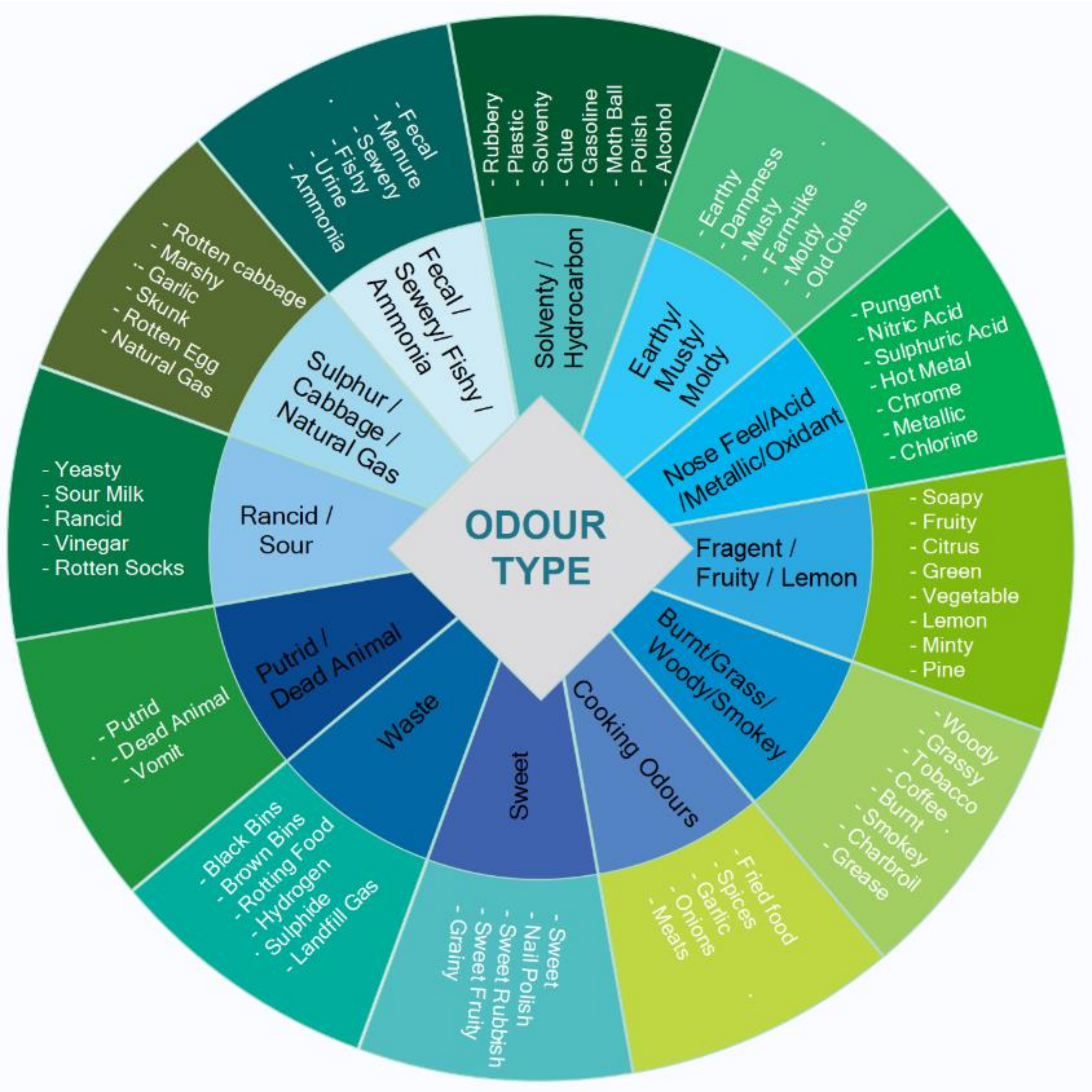
3.7 Odour Complaint & Investigation Procedure

The OMP should formalise the procedures for dealing with any odour complaints. A recommended odour complaint procedure is outlined below in ***Box 9*** with a template for the Odour Complaint Report Form shown in ***Appendix A***. A detailed odour wheel in ***Figure 3.9*** shows the characteristic odours associated with major odorous sources.

Box 9 - Odour Complaint Procedure

- The facility is required to have a notice board with contact details as part of the Licence. These contact details should be used for logging odour complaints with experienced personnel available to answer calls during normal working hours.
- A phone number should be available outside of normal working hours with a follow-up call made as soon as possible to the caller by an appointed person.
- The staff personnel taking the call should request the information as outlined in ***Appendix A*** of this guidance including details on:
  - Time, date and where the odour was detected,
  - Duration of the odour,
  - How strong is the odour?
  - Describe the odour (suggested odour types are outlined in ***Figure 3.9***).
- The staff personnel should record any other relevant aspects of the call including the responses made to the complainant.
- The staff personnel should immediately arrange for a company representative to undertake an odour impact assessment in line with AG5. The survey should commence upwind from the facility with a visit to the location of the detected odour also undertaken to verify the nature of the odour.
- If the nature of the odour can be linked to the facility, the company should undertake a site audit to identify the source of the odour.
- Once identified, the odour source should be investigated to determine whether there has been an operational failure or a failure of an abatement system with steps implemented to rectify the problem.
- In the event that the odour source cannot be serviced / rectified immediately, it may be necessary to cease operations until the issue is resolved.
- Where no odour is detected by the company representative at the location of the complainant, the complaint should not be dismissed out of hand. Odour detection can be transitory whilst the company representative may have a higher odour threshold compared to the complainant.
- A site audit should be undertaken in any case to confirm or otherwise the source of odour release. Once the odour investigation is completed, the company should follow-up to brief the complainant as to the outcome of the investigation.

Figure 3.9 Characteristic Odour Wheel Based On Major Odour Sources



Adapted from the odour wheel described in (Suffet, 2009)

3.8 Odour Management Plan Template

The odour management plan should be based on a standardised and consistent methodology. A suitable template for undertaking a OMP is outlined below with a detailed checklist outlined in ***Appendix B***. In order to be effective, the OMP should be fully integrated into the site EMS and adjusted as circumstances change onsite.

Introduction – This should outline the purpose of the odour management plan and include a policy commitment from the company signed by senior management / directors.

Facility Details – This section should cover the setting of the facility in the local environment with details on nearby sensitive receptors. A figure of the facility showing the receptors should be provided with a windrose included to identity the prevailing wind direction.

Legal Framework - The licencing regime under which the facility operates should be delineated in addition to any relevant odour conditions which are specified in the licence. The type of processes and activities undertaken at the facility should also be discussed in this section with a clear description of how the process could give rise to odour pollution. The OMP should also demonstrate that the licensee has the competence and knowledge to manage that risk effectively.

Structure / Designation of Responsibility – The management structure of the organisation should be outlined from Senior Management, through General Manager and Environmental Manager down to the relevant operators of the process control equipment detailing responsibilities of the key personnel. Responsibilities for each control measure and each aspect of routine maintenance should be highlighted in detail for each task with back-up personnel nominated in case of absence of the duty personnel.

Critical Paths of Potential Odour Sources – The OMP should identify the potentially odorous activities and materials used onsite. A process flow diagram of the operations onsite (such as ***Figure 3.4*** and ***Figure 3.5***) will help to identify high risk sources for odour release, such as transfer points, high temperature processes, material open to atmosphere, loading / unloading etc. Any odorous release points should be documented by way of a detailed odour audit of the facility.

The critical paths for relevant release points should be identified on a map to aid the interpretation of the cause of the odour complaint (Source-Pathway-Receptor concept). The potential release route(s) should be considered under normal and abnormal operations.

Routine Methods / Control Measures – The routine methods and control measures which are implemented onsite to minimise odour should be described in detail. This should cover measures which are undertaken under normal operation such as:

- deliveries of materials / inventory,
- inspection and storage of materials,
- correct use of plant and processes,
- checks on plant performance,
- planned maintenance and repair schedule,
- containment measures,
- treatment of odorous materials,
- abatement of odorous emissions and
- export offsite of materials.

The frequency and scheduling of each action should be recorded with the person responsible for undertaking the action identified. The planned inspection, maintenance and repair schedule for odour critical equipment should be outlined with responsibility assigned to relevant personnel.

Monitoring – The plan should identify a series of planned onsite checks, inspections and measurements to ensure that all process parameters (such as pH, oxygen level, pressure, temperature, moisture level) are within design parameters on either a daily, weekly or other defined frequency as required. This may change on a seasonal basis due to meteorological conditions or increases in capacity at certain times of the year.

Where parameters are outside of the design range, the measures which will be employed to address the non-compliance should be addressed and itemised. For example, if the pH level in a settlement tank is too low, the solution to the problem (dosing with sodium hypochlorite for example) should be written into the plan. Also, where stack monitoring determines that the odour emission rate is greater than the abatement system design level the abatement system should be scheduled for servicing / repair.

Odour impact assessments (possibly daily depending on the risk factors) should also be formalised in the OMP with a log of who is responsible for undertaking the survey, the time of day, meteorological conditions and the results recorded in line with *AG5* (EPA, 2019).

Emergency / Abnormal Operation – The facility should undertake an odour risk analysis to determine the risk of a failure of an odour control measure or abatement system. The review should identify the likelihood, severity and consequences of each scenario / risk. The review should also include an assessment of the odour impact area of the relevant odour sources.

Risk factors for abnormal operation should be identified such as ambient conditions (high temperature, low rainfall, calm weather), onsite equipment failures (abatement system malfunction, power failure, loss of negative pressure etc) and human error (spillages, doors left open, uncovered trucks). The risk factors should be itemised with the likely consequences of each scenario documented. Abatement equipment spare parts which are essential for the operation of the facility should be purchased and stored onsite to minimise downtime to the abatement system and possibly production downtime.

Corrective Measures – For each item identified in the risk analysis, there should be a discussion as to the additional measures, and an action plan, which will be employed to address and minimise the likely consequences.

For example, during periods of high ambient temperature, the acceptance of waste at a transfer station may need to be reduced with any additional waste diverted to lower sensitivity locations. Similarly, when abatement systems fail it may be necessary to cease or significantly reduce operations until the problem is rectified.

Community Liaison – The OMP should formalise the procedures for liaising with the local community. This should focus on building a positive relationship with the neighbouring community, include mechanisms for communicating with those individuals / local resident groups / organisations seeking information on the odour control measures employed at the facility, the frequency of complaints and improvements / changes onsite. A log of all communications should be kept as part of the OMP file.

Review Process – The OMP is a dynamic document which will require reviewing and possibly updating on an annual basis, as a minimum. Where a facility is subject to odour complaints, the OMP may need to be reviewed more frequently with the corrective action required to deal with the complaints incorporated into the OMP. The OMP will also need to be updated to take account of changes to operations, infrastructure or due to changes to the efficiency of the mitigation measures.

4.0 SUMMARY OF ABATEMENT TECHNOLOGIES

Odour abatement technology must achieve the destruction, transformation or removal of odorous compounds from an exhaust stream, prior to this exhaust being discharged to the outside environment. Correctly selecting the abatement technique which best destroys, transforms or removes the odorous compounds in the most efficient manner is key to successful odour control.

An understanding of odour chemistry is critical to the selection of the most appropriate odour abatement technology. Many odour abatement projects have failed to deliver the required odour destruction efficiency due to a failure to understand the chemistry of the odour molecules causing the odour impact.

Odour abatement technologies need to be selected by following a systematic approach – technologies can often be selected based on incorrect assumptions, a lack of appreciation of odour chemistry or a failure to understand variations in loading rates, therefore a systematic approach will be presented in this guidance. This approach begins with the characterisation of the odorous compounds, which can be achieved by a combination of olfactory techniques (smelling the odour and deciding that it smells like rotten eggs for example, which indicates the presence of hydrogen sulfide or mercaptans) and chemical analysis, which can be used to determine whether the odorous compounds are mercaptans or hydrogen sulfide.

A process design approach should be applied to the selection process. Design is the development of a plan to accomplish a goal. In this case the goal might be to meet an emission limit value at a stack emission point or to achieve no offsite odour. Defining that goal and stating it at the start of the process will ensure the best project outcome.

The definition of the inputs to the abatement technology is critical, data should be collected to define the following:

- Composition of the exhaust stream (chemical composition, water vapour, dust concentration, odour unit concentration),
- Flow rate,
- Hours of operation,
- Air stream temperature and pressure,
- Variation in operating parameters.

The primary reliance to define each of the above must be on competent practitioners using independently certified equipment, to ensure the best possible foundation for the selection of the equipment. It is often found that abatement equipment fails to perform due to assumptions made on input parameters, whereas measurement may have defined different values for input parameters.

The environmental footprint of odour abatement technology is also an important consideration – many odour abatement technologies consume significant energy, produce wastewater, wastes or by-products or consume significant quantities of chemicals which in turn have associated environmental risks. The environmental footprint should therefore be factored into odour abatement technology selection.

It is important that a systematic approach is also adopted to abatement technology specification – often incorrect specification of odour abatement technology occurs which in turn leads to a failure of the installed unit to achieve the required odour removal rates. This guidance sets out, in the following paragraphs, a standard approach to specification that includes the range and nature of odours, air flows, temperatures and pressures, to enable a standardised and sufficiently robust approach to specification.

When considering an odour abatement requirement, three important factors should be considered:

- What compounds are likely to be causing the odour?
- What are the options for removing them from the air stream? Can the compounds be removed by absorption, adsorption or scrubbing, or can the compounds be in some way denatured or removed using oxidation or other chemical reactions?
- When the technologies that are shortlisted for abatement are considered, which has the lowest capital, operational and environmental cost (where environmental cost focuses on the environmental impact of the technology, both direct impacts such as the combustion of fuel onsite, the generation of wastewater or spent filter media, and indirect impacts such as electricity consumption).

The following matrix in ***Table 4.1*** is a useful guidance tool for determining which odour abatement technology may be appropriate for a given situation:

Table 4.1 Matrix of Odour Abatement Technologies

System	Appropriate For	Not Appropriate For	Pros / Cons
Activated Carbon	Removal of all organic odorous compounds.	Dust	Requires pre-treatment dust removal system, operating costs are high due to regular requirements for filter and carbon change out. Dust removal can be achieved but dust will block the carbon filter and therefore pre-treatment is required.
Thermal Oxidation	Removal of all odorous compounds.	Dust	Requires pre-treatment dust removal system, high capital and operating cost, risk of dust explosion or fire if dust abatement system fails.
Biofilter	Removal of all odour compounds, efficiencies greater than 90% reported.	Dust	Needs dust pre-treatment system, which requires bag filter or similar, dust removal can be achieved but dust will block the biofilter and therefore pre-treatment is required.
Bio-scrubber	Removal of dust and will reduce odorous compounds (including less soluble compounds) by at least 50% (likely range 50-60%).	Some residual odour	No pre-treatment system needed, but system does produce effluent to sewer.
UV / Ozone / Cold-plasma	Removal of Organic compounds.	Ammonia, H_2S, dust	Only removes some compounds, requires pre-treatment to remove dust.
Wet Scrubber And Biofilter Combination	Removal of dust and will reduce odorous compounds by at least 90%.	Very low residual odour	Achieves much higher odour removal rate but costs and complexity are greater.

There are three key headings to consider when deciding on the selection of odour abatement equipment which are outlined in ***Box 10***:

***Box 10* - Engineering, Environmental and Economic Considerations**

Engineering

- Chemical and physical characteristics of the emissions,
- Dust or particulate loading,
- Design and performance characteristics of the proposed abatement unit,
- Contaminant destruction or removal ability,
- Reliability,
- Dependability,
- Ability to consistently meet targets,
- Turn-down capability, and
- Ability to deal with fluctuations, temperature limitations, maintenance requirements.

Environmental

- Equipment location,
- Available space,
- Ambient conditions,
- Availability of utilities and waste disposal systems,
- Emission limits,
- Visual impact (e.g. steam or vapour plume),
- Impact on wastewater infrastructure,
- Impact on local noise environment.

Economic

- Capital Cost:
  - equipment,
  - installation,
  - civils,
  - structural,
  - engineering design.

- Operating cost:
  - utilities,
  - chemicals,
  - maintenance.

- Equipment lifetime.

4.1 Appropriate Abatement Technologies

Of fundamental importance to selecting an odour abatement solution is that one must understand the fundamental mechanism at work at the heart of the abatement technology and the chemistry of the molecules causing the odour. This allows one to select the abatement process which is most suitable to the characteristics of the molecules requiring removal or destruction.

4.1.1 Activated Carbon

Activated carbon technology is based on the physical adsorption of odorous compounds on an activated carbon bed by intermolecular forces of adsorption (it is important to clarify an often-repeated error – ***Adsorption*** is the removal of molecules from a gas stream by attachment to a solid, ***Absorption*** is the removal of molecules from a gas stream by transfer into a liquid medium). The key processes involved in this technique are outlined below:

- The molecules being removed from the air stream are known as the adsorbate, the solid doing the adsorbing is known as the adsorbent. The attractive forces that hold the molecules to the surface of the solid are the same that cause vapours to condense (van der Waals forces).
- All gas / solid interfaces exhibit this type of attraction, some more than others, so all adsorption systems use materials to which the molecules to be removed are strongly attracted.
- The molecules removed are merely stored on the surface of the adsorbent, and over time the adsorbent becomes saturated with the adsorbate and must be disposed of or regenerated.
- Adsorption can also occur by a chemical process, where the target molecules react with the adsorbent, forming a chemical bond by exchange of electrons. This process is not easily reversible and is less commonly used in odour abatement. An example where it may be of use in odour abatement is the use of iron oxide chips to remove hydrogen sulfide from an exhaust stream.
- In an adsorption process such as activated carbon where the adsorbed odorants are stable and poorly reactive, they will remain trapped in the solid adsorbent. If the odorants are reactive, they may chemically react with other compounds adsorbed.
- For instance, reduced sulfur compounds are oxidized in the presence of atmospheric oxygen when adsorbed in activated carbon.
- Adsorption processes usually take place in packed carbon beds in cylindrical tower units at gas residence times ranging from 1.5 – 10 secs.
- At the end of the carbon packing lifespan or when no regeneration of the activated carbon is possible, one of the towers will be in operation while the packing material of its counterpart is substituted.
- Activated carbons are usually obtained by activation at high temperature of organic materials such as wood or coconut fibre (coir). This process is not part of the abatement system onsite, instead it is conducted at an offsite location which could be owned and operated by the activated carbon supplier.
- It should be noted that in many cases the activated carbon supplier does not offer a regeneration service, in which case the activated carbon must be disposed of as a waste material.
- Activation involves firstly heating the substrate (such as wood, coconut fibre) to 600ºC to drive off all volatile material, essentially leaving only carbon behind. This material is then exposed to air, steam or carbon dioxide at higher temperatures. This process attacks the carbon surface and increases the pore numbers and surface area of the carbon.
- Manufacturers vary the process temperatures, times and substances to produce carbons which are more suitable for different applications. This is important to note for the selection of activated carbon systems for odour control.
- It should be made clear to the supplier of the carbon what the target compounds and application is, so that the most appropriate grade of carbon can be provided.
- Adsorption does not require the transfer of odorants to an aqueous phase, and the high affinity of the adsorbent for hydrophobic compounds (compounds which are poorly water soluble) supports the highest abatement efficiencies for these odorants (up to 99.9%). However, the removal efficiencies for hydrophilic VOCs are lower, generally ranging from 80 to 90%.

Overall, activated carbon adsorption typically has higher removal efficiencies compared to biofiltration and chemical (wet) scrubbing. The adsorption capacity of a carbon bed depends on a number of factors such as:

- the nature of the material,
- the odorant concentration in the gaseous stream,
- the operation temperature and humidity, and
- the mixture of odorants present in the emission.

In some specific scenarios, a high humidity in the malodorous stream or its fluctuations can hinder the design and operation of adsorption systems. For example, water molecules compete with odorant compounds for the active sites of the carbon.

Activated carbon has a strongly non-polar surface and therefore will attract solvents, other VOCs, organic odour compounds and some toxic gases. A typical capacity value of 0.1 g adsorbed compounds/g activated carbon is often considered for design purposes. The bulk density of an activated carbon bed varies from 0.3 to 0.5 g/cm^3 depending on the grade of carbon being used. Typically activated carbon used for odour control will have an internal porosity in the range of 55 to 70% of carbon volume and a surface area of a quite extraordinary 600 to 1600 m^2/gram.

Mean pore diameter is in the range of 150 to 200 nanometres (nm) with most gaseous air pollutant molecules in the range of 40 - 90 nm. Carbon with pore diameters of less than 40 nm will not be effective in air pollutant removal, hence the need to carefully select the carbon grade required.

Activated carbon adsorption presents a low environmental impact when the sustainability analysis is only performed on the odour removal process. It is a low resource usage method when applied at relatively low odorous compound concentrations. In addition, the low residence times applied in this technique reduce the land needs, supporting high removal rates in compact systems.

In terms of investment costs, adsorption systems also benefit from the small required gas contact time and the wide application and accumulated experience.

The robustness of activated carbon filtration ranks this technology as the most practicable odour abatement method applied nowadays. The relative simplicity of the technology (no water or chemicals needed, and no process control involved) implies that common issues in odour abatement scenarios such as fluctuations of inlet odorant concentrations, foul air interruptions or air temperature fluctuations will result in minor or marginal effects on the odour abatement efficiency. However, it must be noted that duplicate or backup systems are often needed to guarantee a consistent odour removal during packing material replacement or regeneration. The high odour removal efficiencies supported by activated carbon adsorption systems provide the highest benefits to the nearby population and to the health and welfare of employees.

Activated carbon units are less suitable for dusty conditions often found in the waste industry, where air is extracted from waste handling and storage sheds, without the use of a pre-filtration system to remove dust. This leads to the requirement for a unit fitted with cartridge filters which remove dust from the air stream, which adds to cost and maintenance requirements. Monitoring of the pressure drop across a carbon bed and across the ducting feeding the carbon bed should be undertaken to check if the ducting or bed is starting to block from an accumulation of dust. Differential pressure across the carbon bed should be checked on a regular basis to ensure it remains within the range specified by the equipment supplier.

An important consideration as noted above is also to avoid moisture entering the carbon system as this reduces the efficiency of the carbon considerably. Where warm moist air is being fed to a carbon system (such as from composting) the incoming air should be cooled to condense the water vapour (this has the added advantage of removing water soluble compounds which reduces odour loading). It is also important to ensure that the carbon bed can be accessed via a manway access cover at the base of the unit, so that in the event of a requirement to replace the carbon bed, the manway can be used to access the bed and enable the bed to be dug out, it is much more difficult to dig out a carbon bed by accessing from the top of the vessel.

A carbon bed can become saturated by the compounds removed from the air stream being treated, leading to an event known as breakthrough, where the carbon bed becomes saturated, (meaning there are no sites remaining to achieve adsorption). To ensure the carbon bed is replaced before saturation occurs, reference should be made to the manufacturer's calculations for intervals between bed change out, and periodic monitoring for indicator species should be conducted using on-site monitoring equipment.

As discussed in the general description of adsorption, activated carbons can exhibit a wide range of H_2S capacities, depending upon the type of carbon used. An industry standard test, ASTM D-6646, was adopted many years ago to provide a common measuring stick for activated carbon H_2S capacities. This test yields a H_2S capacity measured in grams of H_2S removed per cubic centimetre of carbon utilized. The following table allows for a simple comparison of the carbons discussed:

Carbon Type	H_2S Capacity
Standard Carbon	0.01 – 0.03 g/cc
Impregnated Carbon	0.12 – 0.14 g/cc
Blended Carbon	0.14 – 0.27 g/cc
Catalytic Carbon	0.09 – 0.63 g/cc

What this means for designers is that standard carbon should only be used to treat low levels (1 to 2 ppm) of H_2S, while impregnated, blended, and catalytic carbon can be economically used to treat H_2S levels as high as 20 to 30 ppm.

Image courtesy of ERG (Air Pollution Control) Ltd. www.ergapc.co.uk

4.1.1.1 Organic Sulfur Compounds

This class of compounds is the most prevalent in waste odour control after hydrogen sulfide. Typical compounds include methyl mercaptan, dimethyl disulfide, and carbonyl sulfide. In all cases, these compounds will be removed by activated carbon via physical adsorption.

Caustically impregnated carbons and blended medias do not provide added capacity for these compounds and in fact, the presence of the metal oxides in or on the carbon decreases the physical adsorptive capacity of the carbons. As these compounds are removed via physical adsorption, there is no way to regenerate the carbon in situ. Carbon can economically treat organic sulfur compounds up to the low ppm (1 - 5 ppm) concentration level. Higher concentrations than these will typically exhaust the carbon so frequently that carbon exchanges will represent an unreasonable expense and operator headache.

4.1.1.2 Amines

Activated carbon can provide useful capacity for most amine compounds found in municipal wastewater. However, as with the organic sulfur compounds, carbon has a finite capacity for such compounds and cannot be regenerated in situ and so tends to be quickly exhausted.

4.1.1.3 Ammonia

Most activated carbons are ineffective for ammonia removal. The ammonia molecule adsorbs very poorly on carbon and breakthrough occurs rapidly. Carbon is not typically recommended for ammonia removal. One exception involves the use of acid-impregnated carbon. However, this is usually not as cost effective as other means of ammonia reduction.

The positives and negatives of activated carbon are shown in ***Box 11***:

***Box 11* – Positives & Negatives of Activated Carbon**

Pro's

- Widely used well established technology,
- Can achieve high removal efficiencies (90 – 98%),
- Suitable for a wide range of gas flow rates (100 to 100,000 Nm^3/hour),
- Able to handle a wide range of VOC loading rates (from 20 to 5,000 ppm),
- Suitable for varying flow rates and loading rates provided the unit is sized to deal with variable loadings.

Con's

- Carbon bed fires are a risk – the adsorption of high concentrations of some compounds such as mercaptans onto the carbon bed can lead to localised hotspots (due to the heat released by the adsorption process) which can ignite flammable gases or dust,
- Bed performance declines with time due to carbon attrition where small quantities of VOCs gradually bond to the carbon and block the active sites,
- Efficiency of removal decreases significantly above 50% relative humidity (RH) meaning that moisture laden odours from facilities such as composting plant will be difficult to treat in an activated carbon system,
- Dust blockages are a risk – as noted above mean pore size on the carbon is in the range of 100 – 200 nm (0.1 to 0.2 μm), with most dust particles being orders of magnitude greater than 0.1 to 0.2 μm. Therefore, for dusty applications, such as waste transfer stations, pre-filtration will be required in the form of cartridge filter systems which are expensive and require frequent replacement (for some sites replacement is required every 2-3 weeks),
- Not considered cost effective above 5,000 Nm^3/hour, at which point wet scrubbing / bioscrubbing (or biofilter if the space is available) is considered more cost effective.
- Channelling within the carbon bed (where channels are formed over time through which exhaust air can flow, with minimal contact with the carbon) is an issue which can lead to a decrease in odour removal efficiency. Monitoring of pressure drop across the carbon bed, which will show a reduction in pressure drop if channelling occurs, is an effective method for detecting channelling.

4.1.2 Thermal Oxidiser

Thermal oxidation of the air exhaust is undertaken at temperatures between 800 and 1100ºC. At these temperatures, hydrocarbon compounds are oxidised to produce carbon dioxide, water vapour and compounds such as sulfur dioxide (if sulfate is present) and HCl (if chlorine or chlorides are present). Thermal oxidation systems are relatively simple pieces of equipment capable of achieving very high removal efficiencies of target compounds. However, it would be very unusual to select thermal oxidation for odour removal as a majority of odorous air streams in industry (food industry, waste industry, wastewater plants) are at ambient or room temperatures.

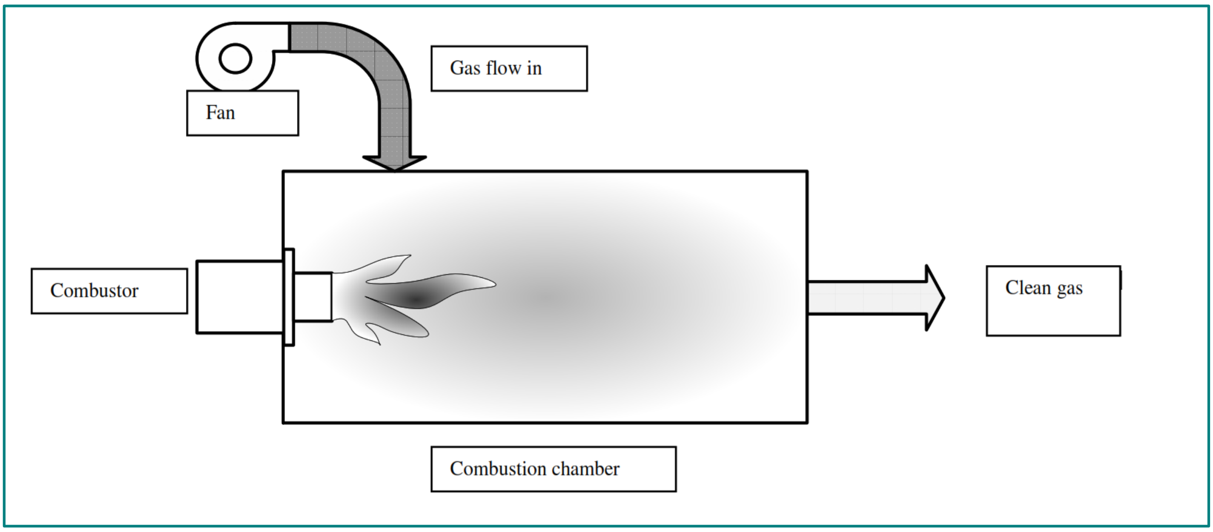
A Regenerative Thermal Oxidiser (RTO) may reduce fuel usage significantly depending on the air temperature and components of the air stream, but these operating costs are simply uneconomical for the abatement of most odorous air streams.

It should be noted that incomplete combustion of organic compounds which can occur could lead to the formation of aldehydes or organic acids, which can create air pollution issues, or combustion of halogens can lead to the creation of hazardous substances such as sulfur dioxide, hydrochloric acid, free chlorine, phosgene or hydrofluoric acid, which require further treatment systems for their removal and which create waste streams requiring disposal.
Thermal oxidisers can be either:

4.1.2.1 Direct Fired (DF)

A direct fired oxidiser is the most energy inefficient type of thermal oxidation, as it does not allow for heat recovery in a standard direct fired oxidiser configuration, as shown in ***Figure 4.1***.

Figure 4.1 Direct Fired Oxidiser

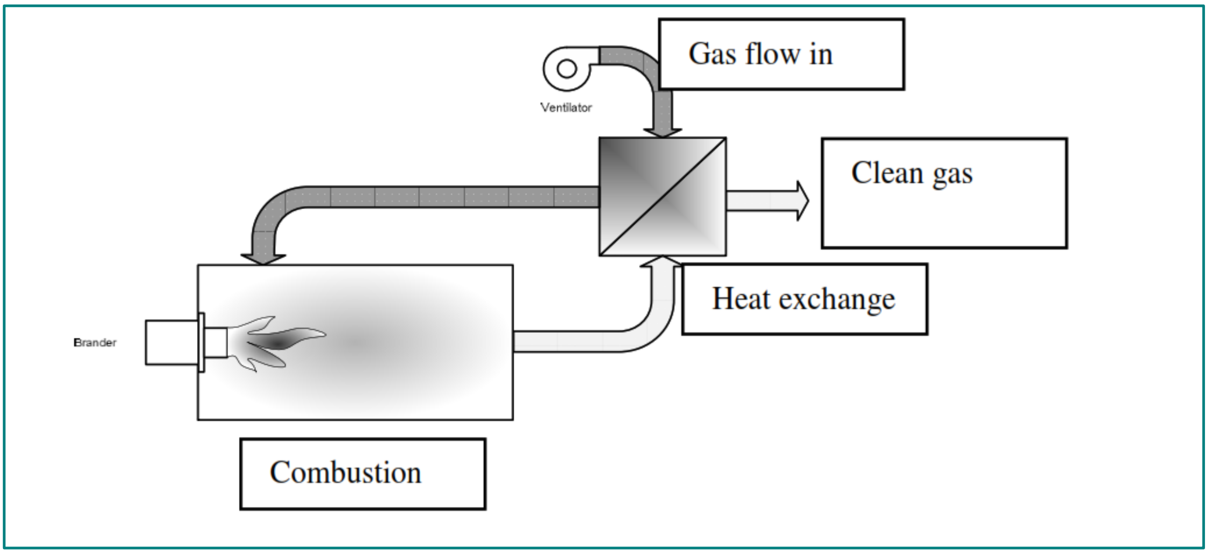


This type of abatement is not normally used for odour abatement. It is usually only applied where the incoming air has a component such as fluoride, which would be oxidised to produce HF (hydrogen fluoride gas) which is extremely corrosive and attacks the majority of metals and ceramic media used in RTO units (see below). For this reason, direct fired oxidisers are brick lined to prevent corrosive gases corroding the metal from which the unit is manufactured. Therefore, it would not be expected that DF (direct fired) oxidisers would be used for odour abatement. In addition, it should be noted that DF oxidisers are highly energy inefficient, with each m^3 of incoming air being heated from ambient temperature (circa 10 - 20ºC) to 850 - 1100ºC with this energy being discharged to the environment as waste heat. DF oxidisers can be fitted with heat recovery systems in the form of a heat exchanger on the exhaust system. However, most applications lead to the formation of corrosive gases by the combustion process. Thus, the heat exchanger must use very expensive metals such as Hastelloy (a nickel-based steel alloy), and even then corrosion may occur, making heat recovery not an option for most applications.

4.1.2.2 Recuperative Thermal Oxidiser

A recuperative thermal oxidiser is similar to a direct fired unit except that a heat exchanger is installed downstream of the oxidation unit as shown in ***Figure 4.2***. This allows for partial energy recovery with the recovered energy being available to heat incoming air or to be used as a process heat supply.

Figure 4.2 Recuperative Thermal Oxidiser



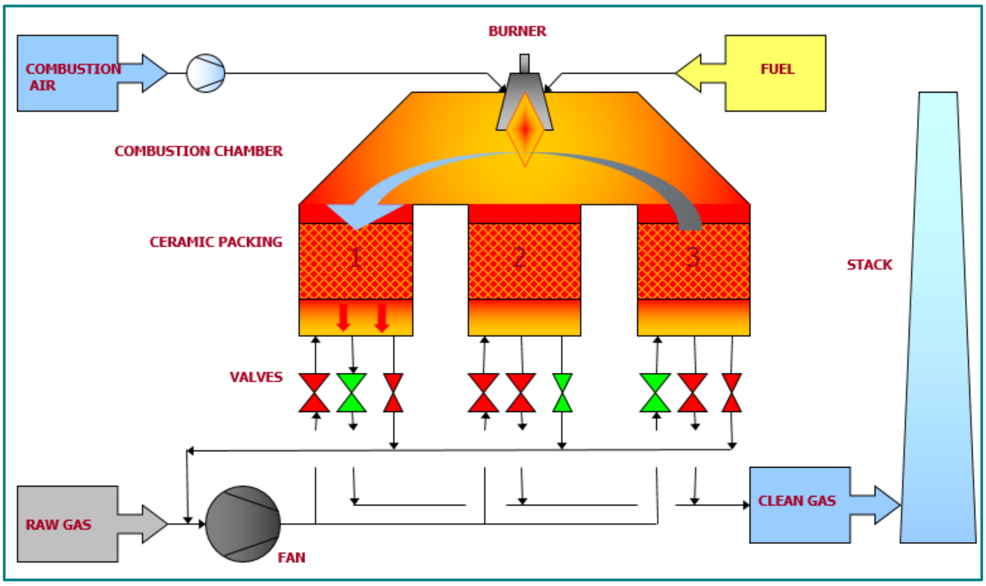
This kind of energy recovery is only suitable for gas streams that do not contain precursors of corrosive substances. If corrosive substances are formed as a result of oxidation of the exhaust gas, corrosion problems are likely to occur in the heat exchanger, making this kind of technology unsuitable for such gases. Recuperative Thermal Oxidisers are rarely used as the RTO unit (described below) is considered much more energy efficient.

Both direct fired and recuperative thermal oxidisers are generally not considered appropriate for abatement of odorous compounds due to high capital and operational costs.

4.1.2.3 RTO (Regenerative Thermal Oxidiser)

The RTO is the most energy efficient form of thermal oxidation and may in some cases be considered appropriate odour abatement technology where odorous compounds are not susceptible to treatment by other abatement options. These systems contain a ceramic honeycomb media where the oxidation process takes place. A burner fuelled by natural gas, oil or an electrical heat source raises the incoming air temperature to the required temperature with the ceramic honeycomb medium ensuring that this heat is recovered and used to minimise the amount of fuel or energy required.

Figure 4.3 Schematic of how RTO operates



Images provided courtesy of Brofind SPA

An example of a RTO unit is shown in ***Figure 4.4*** below.

Figure 4.4 An Example Of An Operating RTO Unit

Image courtesy of Dürr Systems AG

As shown in ***Figure 4.3***, incoming air (the red exhaust stream) enters the first oxidation chamber where it is oxidised. The valve arrangement for the unit then vents this cleaned air to the second chamber, where the heat from this air is absorbed by the ceramic media, resulting in the exhaust gas exiting the oxidiser at a temperature in the region of 110 - 130°C.

The next portion of incoming exhaust air is then directed by the valving arrangement to the second chamber which is now at its operational temperature of 850°C, and oxidation occurs in this chamber. The hot gas from this chamber then exits and is directed to the 3rd chamber where it raises the chamber temperature to the operational temperature required, and the incoming gas is diverted to this chamber. In this manner the RTO continues to cycle efficiently, achieving destruction of odorous compounds while minimising energy usage. RTO units can achieve up to 97% energy efficiency.

Thermal oxidation units are best suited to odour abatement where the odorous compounds are solvent fumes, paint fumes or other such VOC derived odours, which are present in relatively high concentrations and which oxidise exothermically to generate heat which contributes to the temperature of the oxidiser unit.

The positives and negatives of thermal oxidation are shown in ***Box 12***:

***Box 12* – Positives & Negatives of Regenerative Thermal Oxidation**

Pro’s

- RTO is a highly energy efficient technology,
- Stable robust technology,
- Once the unit is at operational temperature there is minimal risk of emissions short-circuiting or channelling or failing to be abated,
- Destruction efficiencies of >99.9% are readily achievable,
- Energy contained in incoming compounds is used in the process to provide thermal input.

Con’s

- Capital and operational costs are relatively high,
- These units are poor at coping with variable flow rates and loading rates,
- Corrosive gases are formed if compounds such as sulfur, fluorine or chlorine are present in the incoming gas stream,
- Not cost effective at low incoming gas concentrations with low VOC load,
- Valve seat (the valve seat is the component against which the valve closes to ensure a seal) wear and subsequent leakage across the valve units into the exhaust stream leading to emission limit breaches,
- Burner issues can be experienced where condensation forms on burner units, stopping the unit from firing after being off-line for a period. This needs to be mitigated by either trace heating the burner unit or thermally isolating it from the external environment.

4.1.2.4 Management and Monitoring of Thermal Oxidation Systems

Thermal oxidation systems require relatively low operator input although the combustion chamber operating temperature should be clearly displayed at all times for viewing by the operator and should also be recorded. The operating temperature within the unit is monitored by at least two thermocouple units within the oxidiser bed combustion zone, which in turn signal to the PLC controlling the unit to adjust fuel flow to maintain operating temperature. Operating pressure is also monitored within the oxidiser bed to ensure that any pressure rise due to blockages is detected before it becomes an issue.

Operator input is usually limited to periodic checks on operating temperature (which is also alarmed). Consequently, in the event of a drop in operating temperature, operators are alerted. More sophisticated monitoring is available in the form of on-line CEMS (Continuous Emissions Monitoring Systems) which provides real-time data on combustion products and enables more sophisticated control of the oxidation systems.

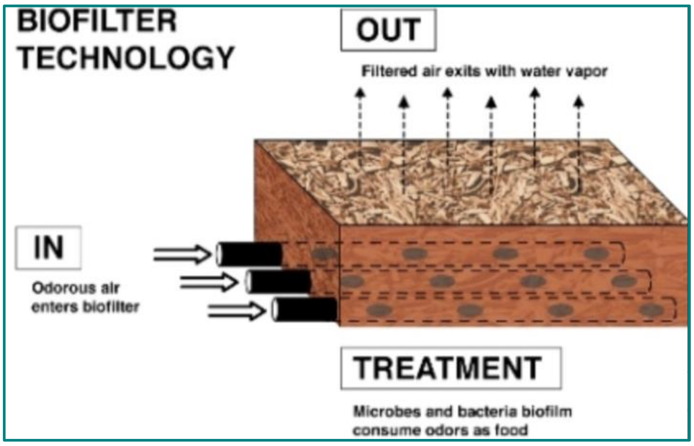
Reference oxygen concentration should be established for a thermal oxidiser. It should be noted that in most cases the reference oxygen will be very close to that of ambient air, unlike a boiler where the majority of the air used is consumed in the combustion process, leading to a low oxygen content exhaust. A thermal oxidiser raises air to the required operating temperature to enable the oxidation of target compounds with very little of the exhaust oxygen consumed in the process.

4.1.3 Biofilter

A biofilter consists of a bed of soil, sea-shells, wood chips, heather or compost, underneath of which is a network of perforated pipework.

Odorous air is blown through the pipework and up into the bed where micro-organisms remove odorous compounds. Crucial to the operation of a biofilter is a stable environment where micro-organisms will thrive. The organic substrate provides salts and trace elements for the bacteria and volatile organic compounds within the air provide the food source for the bacteria. The key component parts of a biofilter are shown below in ***Figure 4.5***. It will be seen that the design is relatively simple, meaning construction costs are relatively low but land requirements are relatively larger than technologies such as scrubbing.

Figure 4.5 Biofilter Technology Design



Biofiltration is a well-established technology, with 30 – 40 years of operational history. It is effective at dealing with VOC loading rates up to 1000 ppm (as C) and offers a low cost, low maintenance solution although as noted above there is a significant land take associated with biofilters. Reported odorous compound removal rates are in the region of 95 - 99% with removal rate variables being media type, operating temperature, bed pH and residence time.

Odorous organic compounds are metabolised by bacteria in the bed into carbon dioxide and water and other oxidised compounds such as sulfur dioxide. Hydrogen sulfide, ketones, thiols, amines, esters and organic acids are all readily degradable in biofilters. Generally, incoming air to a biofilter may need to be humidified with water to saturate the air stream, which enhances biodegradation of odorous substances.

Biofilters range in depth from 0.5m to 2.5m, depending on required residence time and media type, with most biofilters being about 1m deep. A number of media types (listed above) all have common characteristics required for a biofilter which are, a neutral pH, pore volumes of 80% or greater and organic carbon content of 55% or greater.

The micro-organism population in a biofilter can be divided into 3 broad categories, fungi, bacteria and actinomycetes (which are organisms that resemble both bacteria and fungi). For optimum performance the micro-organisms require an aerobic environment, adequate moisture (damp but not saturated), neutral pH and ambient temperatures. The start-up of a biofilter typically requires about two weeks for the micro-organisms to become accustomed to the specific compounds in the exhaust stream.

Biofilters can be suitable for applications where odours may be generated on a campaign basis, whereby a composting or other such process may only discharge air at intermittent periods, and indeed biofilters can be maintained in a standby arrangement for up to 2 months once moisture, nutrient and air supplies are maintained.

Typically, a Carbon/Nitrogen/Phosphorous ratio of 100:5:1 in the media is required to provide adequate conditions for micro-organism growth. Water content of the media should be in the range of 20-60% by weight. pH should remain in the range of 7-8, biofilters with high hydrogen sulfide loading can experience reduced pH as hydrogen sulfide converts to sulfuric acid. This needs to be adjusted by the addition of lime or the use of a higher pH medium such as sea-shells.

Biofilters are sized based on retention time (a minimum retention time of 30 seconds is required) and on loading rate, within the range of 0.3 -1.6 m^3/min-m^2. For a small to medium sized waste transfer station, which would typically generate in the region of 10,000 Nm^3/hr of exhaust air from waste storage buildings, assuming a median loading rate of 1 m^3/min-m^2 this would equate to a 166 m^2 biofilter. This would be in the region of 18m x 9 m (length by width) and not every site will have this space availability, considering that additional area will be required for fans, humidification unit and control panel.

The positives and negatives of biofilters are shown in ***Box 13***:

***Box 13* – Positives & Negatives of Biofilters**

Pro's

- Relatively low cost, low technology units.
- Ability to treat large gas volumes with dilute concentrations of odorous compounds,
- Allow the biotransformation of pollutants (i.e. they are broken down into other non-odorous compounds).

Con's

- Not suitable for high concentration odour streams,
- Requires regular checking and monitoring to ensure bed pH and moisture content remains within required limits,
- Large land-take required relative to other technologies,
- Performance decreases in cold weather due to effect of ambient temperature on bacterial kinetics. The rate of bacterial reaction doubles for every 10 ˚C rise in temperature but the opposite is also true for a fall in temperature.
- Sensitive to shock loading – in cases where the odour loading increases sharply in a very short time period the biofilter bacterial population could be negatively affected. This can lead to reduced odour removal performance – biofilters are therefore more suitable to stable odour loading rates.

4.1.4 Wet Scrubber and Bio-scrubber

Wet scrubber systems have been used for over one hundred years in air pollution control in industries such as chemical manufacturing and waste management. A wet scrubber consists of a number of component parts, namely a vessel which contains media, across which water is sprayed via recirculation pump, and a fan and ducting system which blows exhaust air in from the base of the scrubber.

The counter-current mixing of water and air, together with the thin film of water across the surface of the packing, provides for mass transfer of contaminants from the air into the water, thereby cleaning the exhaust gas. The wastewater from the scrubber is discharged to sewer or to a treatment plant and the exhaust air is discharged to atmosphere via a stack.

The key phrase when scrubber operation is referred to is "***mass transfer***", this is the transfer of substances from the gas phase (exhaust stream into the scrubber) to the liquid phase (the scrubber liquid).

The rate of mass transfer is governed by a series of variables, the most significant being:

- concentration in the exhaust stream into the scrubber,
- surface area of the liquid available,
- contact time between exhaust and liquid,
- temperature of the liquid, and
- concentration of contaminants in the scrubber liquid.

It can readily be seen that these variables explain many of the problems that arise in scrubber operation, for example:

- poor removal rates of contaminants can be due to insufficient contact time (scrubber too small),
- insufficient surface area available (wrong type of packing or insufficient packing material available), and
- insufficient scrubber blowdown (blowdown settings incorrect) leading to build up in concentration of contaminants in the scrubber liquid (blowdown is water which is removed from the scrubber unit to keep dissolved solids below setpoint upper limits).

Bio-scrubbers have the same component parts with the addition of biomass in the water, so not alone does the scrubber remove pollutants from the air, the biomass (composed of micro-organisms) degrades these pollutants, ensuring their destruction.

Wet scrubbers remove particulates and dissolved gases from an air stream and are therefore particularly suitable for use where dusty and odorous exhaust streams are present, such as those at waste transfer stations. Particulates are removed by a process called "impaction", the particles of dust or other substances are accelerated in the exhaust stream and impact onto the water surface on the packing or onto a droplet.

In addition to particulate removal, scrubbers achieve removal of gaseous compounds in the exhaust stream via absorption of the compounds into the scrubber liquid.

The aim of any scrubber design should be to provide the greatest surface area of liquid available in a given volume of a scrubber vessel. This surface area is achieved by a combination of scrubber spray-ball orifice dimensions (which govern droplet site) and Packing Factor, which indicate the ability of a given type of packing material to provide a given surface area. Both of these variables must be optimised. If the droplet size is too small relative to the gas velocity, droplets will tend to get carried out of the discharge from the scrubber, rather than descending down onto and through the packing. If packing units are too small the scrubber is likely to block, especially a bio-scrubber.

Inlet velocities to a scrubber unit should be in the range of 10 – 30 m/sec, with water velocities in the region of 0.5 to 2 m/sec.

All wet scrubber designs incorporate mist eliminators or entrainment separators to remove entrained droplets. The process of contacting the gas and liquid streams results in entrained droplets, which contain the contaminants or particulate matter. The most common mist eliminators are chevrons, mesh pads, and cyclones:

- Chevrons are simply zig-zag baffles that cause the gas stream to turn several times as it passes through the mist eliminator. The liquid droplets are collected on the blades of the chevron and drain back into the scrubber.

- Mesh pads are made from interlaced fibres that serve as the collection area.

- A cyclone is typically used for the small droplets generated in a venturi scrubber (a venturi scrubber utilises the energy from the inlet gas stream to atomise scrubber liquid which increases scrubbing efficiency). The gas stream exiting the venturi enters the bottom of a vertical cylinder tangentially. The droplets are removed by centrifugal force as the gas stream spirals upward to the outlet.

Wet scrubbing systems are susceptible to several operating problems. The most common of these include:

- inadequate liquid flow,

- liquid re-entrainment,

- poor gas-liquid contact,

- corrosion, and

- plugged nozzles, beds, or mist eliminators.

4.1.4.1 Bio-scrubber

A bio-scrubber unit combines a wet scrubbing unit with a biological reactor, which provides micro-organisms to biodegrade pollutants in the air exhaust. Bio-scrubbers are used in industries such as chemical processing, meat or dairy processing, where high concentrations of amines and ammonia may be present – thus it is suited to treatment of air where odorous compounds are both soluble and biodegradable. Degrees of conversion of over 90% can be reached in a bio-scrubber for compounds such as ammonia, amines, hydrogen sulfide, mercaptans, VOC's and other odorous compounds.

A picture of a typical bio-scrubber is shown in ***Figure 4.6*** below.

Figure 4.6 An Example Of An Operating Bio-scrubber Unit

Image courtesy of MEHS Ltd.

A high mass transfer rate can be achieved in the scrubber compartment by the high absorption capacity of the water (i.e. low COD, nitrogen, etc.). In this way both the reactor and the energy consumption can be reduced. The substrate concentration in the organic phase may be 100 to 1000 times higher than those in the aqueous phase. Thus, in the regeneration compartment the compounds, which have mainly been absorbed in the organic phase, are transferred to the aqueous phase where the microbial degradation takes place.

Biological scrubbing of gases to remove odour involve either absorption in a suitable solvent or chemical treatment with a suitable reagent. It is important that hot, moist streams are cooled before they contact scrubbing solutions. If this is not done the scrubbing solution will be heated and become less efficient and the scrubbing medium will become diluted from condensation of water vapour (temperature of less than 35^{o}C).

Biological scrubbing or absorption systems can be either venturi system or packed tower system. The high-density spray also provides reasonable mass transfer to the absorption of gaseous contaminants. Bio-scrubber are typically counter current scrubbers that utilize high surface area media as a contact zone for the gas stream with suitable scrubbing liquor.

The contaminated gas is diffused in the bio-scrubber with the recirculation water and the bacterial mass and adsorbed onto the biofilm within the packing. This gives microorganisms the opportunity to degrade the pollutants and to produce energy and metabolic by-products in the form of CO_2 and H_2O.

This biological degradation process occurs by oxidation, and can be written as follows:

$$\textbf{Organic Pollutant} + O_2 \quad \rightarrow \quad CO_2 + H_2O + \textbf{Heat} + \textbf{Biomass}$$

A bio-scrubber consists of two reactors: (a scrubber, and a bioreactor), and also a settling chamber. In the scrubber, contaminated inlet gas flows through a fine spray of water or water plus dispersed microbes. The water-soluble contaminants are absorbed out of the gas into the water or activated-sludge mixture. This contaminant laden water is pumped into the bioreactor. The cleaned gas is exhausted from the scrubber.

In the bioreactor or activated sludge aeration tank the pollutants are degraded, and the water is regenerated. Some of the bioreactor liquid is recycled back into the sprayer. Some is sent to a settling chamber where biomass is settled out. The biomass is returned to the bioreactor and excess water is sent to a drain. A schematic for the system is shown below in ***Figure 4.7***:

Figure 4.7 Schematic of a bio-scrubber

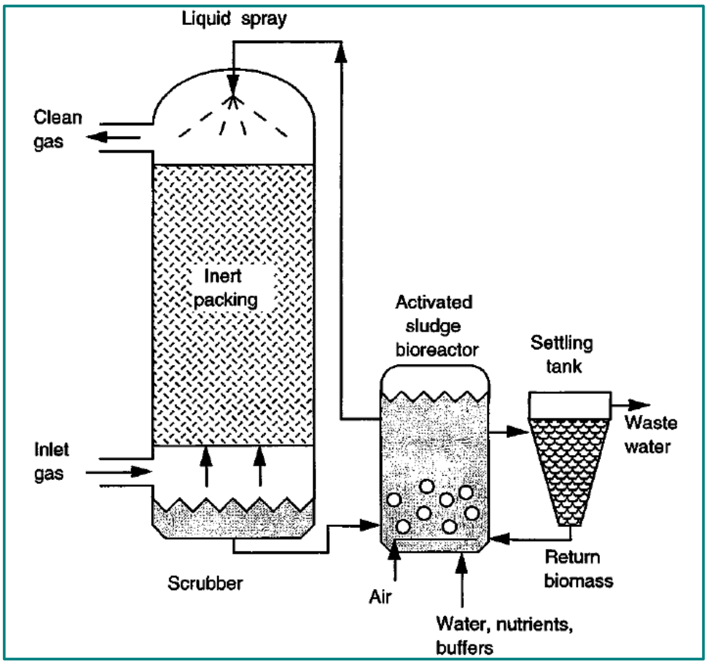


Image courtesy of MEHS Ltd.

Of the various biofiltration systems, bio-scrubbers have the least space requirements, the highest operational stability and process-control, and greatest permeability to gas flow. Experience has shown that typically, removal rates of 60 - 70% are achievable whereas a biofilter system can achieve up to 90% removal.

4.1.4.2 Typical Bio-scrubber Design Criteria are as follows:

Air flow rate dependent on loading rate:

- Flow rate, 5000 to 30000 m^3/hr
- Loadings 40 – 140 m^3/m^2 (dependent on contaminant concentrations)
- Contact time 4 - 10 seconds
- Amines removal efficiency 85 – 90%
- Ammonia removal efficiency 85 – 90%
- H_2S removal efficiency 85 – 90%
- VOC removal efficiency 60 – 80%.

4.1.4.3 Major Design Considerations:

A. Irrigation
The media must be kept moist, but if irrigation is too frequent, the biomass may be deprived of oxygen. If irrigation is too infrequent, the media can dry out and reduce effectiveness. A programmable timer may be used to properly time irrigation cycles. The temperature of the process air is required to be measured during commissioning to establish the cycle.

B. Media
Media should possess high surface area to volume ratios, good adsorption characteristics, low pressure drop, and good sloughing characteristics. For nitrogen and organic compounds treatment, media impregnated is seeded with bacteria prior to commissioning.

C. Nutrients
Nutrients must be kept fresh to maintain healthy biomass. Appropriate nutrients essential to the various bacteria in the bio-scrubber need to be identified. This will be determined prior to commissioning by sampling and running lab scale tests on samples of the leachate. A dosing pump is required to allow dosing of nutrients and bacteria selected for particulate odorous compounds.

D. Construction materials

Corrosion-resistant materials such as high-density polyethylene (HDPE) are required.

E. Air distribution

Uniform air distribution through the media bed is important for efficient operation. Perforated fibreglass reinforced plastic (FRP) distribution plates have been used effectively to support the media bed and distribute the air flow uniformly.

The positives and negatives of scrubbers and bio-scrubbers are shown in ***Box 14***:

***Box 14* – Positives & Negatives of Wet Scrubbers & Bio-scrubbers**

Wet Scrubber

Pro's

- Good particulate removal rates,
- Efficient at removing soluble VOCs and other odorous compounds.

Con's

- Wastewater disposal required,
- Not good at coping with variable loadings.

Bio-scrubber

Pro's

- Additional removal over and above that of wet scrubber as the biomass provides a surface onto which some sparingly soluble compounds will more easily adsorb,
- Biodegradation of compounds leading to lower strength wastewater,
- Ability to cope with variable loadings as biomass provides extra buffering capacity.

Con's

- Requires daily checks for biomass concentration and COD to determine scrubber health,
- This requires training for operators onsite and operator time,
- Wastewater disposal required,
- Sludge also generated which requires disposal.
- While the risk of overloading or shock-loading of the biomass due to a sudden sharp increase in compounds which the biomass is degrading, is low, it is still a risk associated with bio-scrubber operation, and regular checks on biomass (using bacterial counts for example) should be conducted. If a shock-loading or overloading event occurs which leads to biomass die-off, it may take a number of weeks to re-seed the bio-reactor and bring the bio-scrubber back on-line.

4.1.5 UV / Ozone / Cold-plasma

In recent years a number of systems for oxidation of odorous compounds within a gas stream have become available on the market. It is difficult to formulate a single heading for this type of equipment. At the entry level are ozone generators, which use a high strength electrical current applied across a narrow gap between graphite electrodes to chemically split the oxygen molecule in air and generate ozone gas (O_3). Oxygen (O_2) is a stable gas which provides us with a stable atmosphere to breath and which supports life on earth, ozone is a corrosive toxic gas which is unstable, and which tends to degrade to O_2 and O^- radicals. The O^- radicals are aggressive atoms which attack organic compounds and oxidise them to non-odorous components.

The effectiveness of ozone against odorous compounds present in odorous air streams depends on several factors including:

- the amount of ozone applied,
- the residual ozone in the air,
- the chemistry of the compounds,
- the concentration of particles present, and whether the odour attaches to particles or not,
- the smoke content of the emission, and
- various environmental factors such as medium pH, temperature, relative humidity, additives and the amount of organic matter in the air.

Volatile fatty acids and ammonia concentrations are not affected by ozonation to any great degree.

The next most sophisticated version of these types of equipment uses high voltage UV lamp arrays to generate a "cold plasma", which contains ozone and free radicals, but which has a more comprehensive impact on degrading odorous compounds. These cold plasma units are used in a range of industries from food processing to chemical manufacturing. Not all odorous organic compounds are degraded by these systems and a trial is recommended using an onsite pilot plant, as part of any technology selection process.

The "cold plasma units" have a unique feature whereby the exhaust gas does not pass through the units. Instead, the units draw in fresh air, which is then "radicalised" and blown into the exhaust duct where the odorous air is present, and it is here that the oxidation reaction takes place. This is an advantage for air streams which may contain aerosols of liquid that could block carbon systems or coat the surface of abatement equipment.

These systems typically only achieve 50 – 60% odour reduction and are ineffective for some odours such as smoke from cooking or manufacturing processes but are efficient are degrading small and more complex organic molecules.

The units tend to be small and compact with a unit the size of a domestic "American fridge" being sufficient to treat an exhaust stream of 3000 Nm^3/hour and would have a power consumption of 30 – 40 kW. A typical unit is shown below in ***Figure 4.8***. The control panel and transformer unit used to generate the high voltage for ozone/cold plasma generation is labelled on Figure 4.8 below, as is the unit which houses filters that remove any dust particles prior to the plasma generation unit and the fan which draws in clean air and pushes it through the unit out to the duct where treatment is occurring.

Figure 4.8 Example Of A Cold Plasma Unit

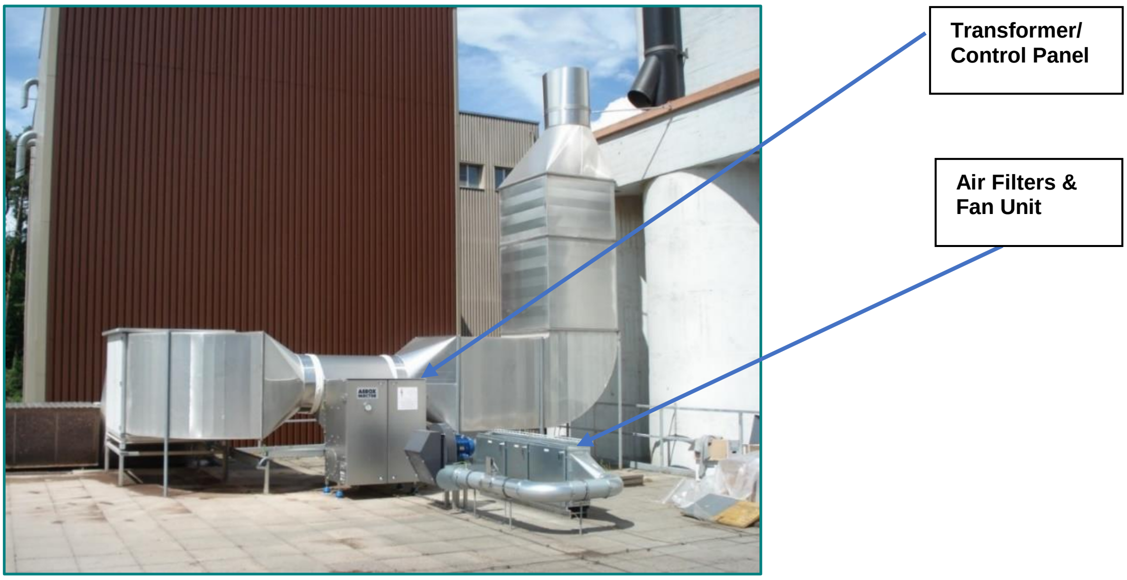


Image courtesy of Aerox B.V.

The positives and negatives of Cold Plasma Units are shown in ***Box 15***:

Box 15 – Positives & Negatives of Cold Plasma Units

Pro's

- Small, compact units,
- Relatively low operating cost and low operator input.

Con's

- Destruction rate can be in the region of 50 - 60%,
- Not suitable for all odours – requires pilot plant testing,
- Air streams with dust concentrations tend to soak up the ozone / air mixture (as it reacts with the dust particles) without much impact on odorous compounds.

4.2 Management Of Abatement Systems

Irrespective of the abatement option chosen, it is important to have in place a system for the management of the abatement equipment. It is often noted that when abatement systems experience problems, at the root cause can be a lack of a structured approach to the management of the system. A person should be appointed to manage the abatement system on-site and the cost of this person receiving appropriate training on the management of the system should be included in the manufacturers cost of the installation and commissioning of the abatement equipment. Training should also be given to a second operative, who can cover for the first operative if they are not available, this training should be provided by the equipment supplier also. A management procedure should be prepared which must include:

- The daily, weekly or monthly tasks required by the operative during normal and abnormal operation for abatement plant control and successful operation.
- The defined ranges for equipment operating parameters and specific procedures for what the operative should do if one of the equipment parameters deviates from defined ranges.

- Includes a form for recording deviations from normal operating parameters, which should record the duration, nature and impact on emissions, the root cause of the deviation identified and the steps which were taken to eliminate the deviation.

- Assurance that the equipment is included in the equipment register for the site.

- Linkage to the Management of Change (MoC) procedure for the site which ensures that any change in the process generating the odours is reviewed for its impact on the abatement plant and upgrades or changes to the abatement plant are made prior to the change being made (a MoC procedure is used on a site when there are proposed changes to site operations, so that the effect of any change on emissions can be considered and mitigated prior to the change being made).

- A reference to the maintenance regime for the system (see below for more detail on maintenance) including ensuring the equipment is placed on the Preventative Maintenance Schedule for the site and that all necessary maintenance documentation is available.

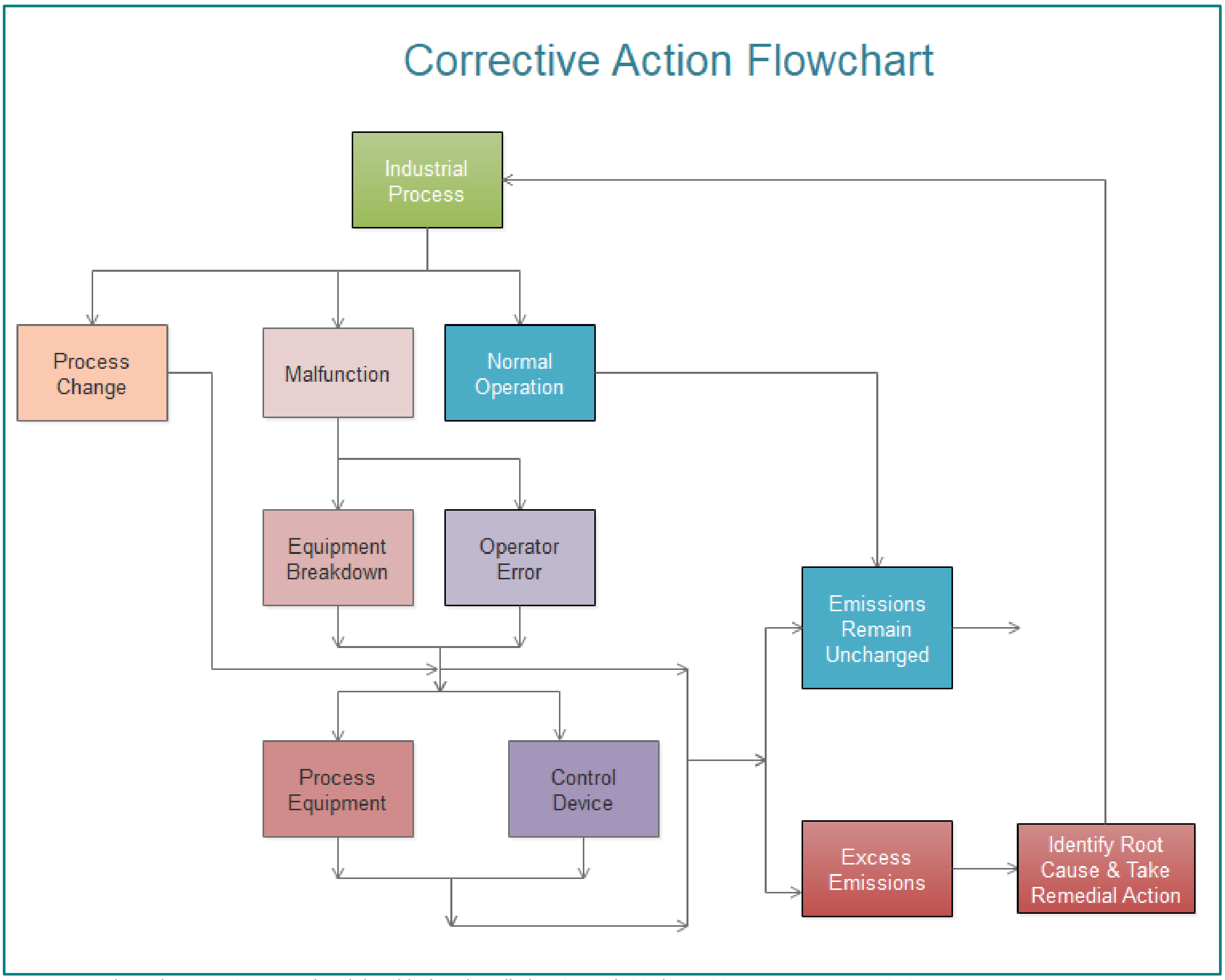
- A copy of the Operation and Maintenance Manual for the equipment, as provided by the supplier. It is very important that the supplier is instructed as part of the contract to provide an equipment-specific and site-specific O&M manual. It is noted that all too often much of the O&M manual is generic for a range of plant and it is often not clear which plant it refers to.

- Reference to a Testing and Verification Regime to ensure the plant is operating correctly and achieving its desired abatement goals before the final equipment handover.

- For older abatement equipment which is already in place to treat odour from a facility, for which a Testing and Verification Regime may previously not have been developed, a testing regime should be developed to ensure the performance of the abatement equipment can be periodically tested against defined limit values. In most cases this may already be in place as a requirement of the site EPA Licence, but if such a regime is not in place, one should be developed.

The following flow chart in ***Figure 4.9*** is a useful tool for analysing and documenting a deviation from normal operating parameters of an abatement plant:

Figure 4.9 Industrial Process Corrective Action Process Flowchart



Source: Adapted From US EPA Industrial Guide for Air Pollution Control, 625/6-78-004, US EPA, June 1978

4.3 Monitoring Of Abatement Systems

Monitoring of the abatement system will be part of the site's EPA licence requirements. The key variables which provide the most reactive and up to date information on an abatement system should be identified and used to monitor the performance of the abatement system. The variables used to monitor equipment performance should be listed and the key variables identified. This should be done in conjunction with the supplier of the equipment, in order to ensure the correct outcome.

The key variables should be:

- Easy to measure (special training or equipment should not be required),
- Cost effective to measure - it should be cheap to measure without needing to hire equipment),
- Readily obtainable – a result should be obtainable in real-time,
- Able to be read from a digital display,
- Recordable by data-logger or chart, if not, should be recorded in a log book.

Key variables will vary with the equipment chosen. For example, the bed or chamber temperature and pressure are key parameters for monitoring a thermal oxidiser unit. If these parameters are within the required range values the plant should achieve the target reduction rate.

For scrubber units the key parameters are pressure difference and static pressure measurements, for the fan, mist eliminator and scrubber unit. The measurement locations should be out of the liquid and designed to minimise the risk of scaling or blocking. The pressure lines should have 3-way valve fittings which would allow compressed air to be purged through the lines to clear any blockages. For bio-scrubbers, COD and MLSS (Mixed Liquor Suspended Solids) in the biomass reservoir are important parameters.

With regard to biofilters, pressure drop across the bed and liquid pH are important parameters and hand-held Draeger units can be used onsite to check for ammonia, hydrogen sulfide and amines in the treated exhaust. For ozone/cold plasma units, voltage and current flow through the electrodes or lamps are the critical parameters for determining system status.

If a site BMS (Building Management System) or PCS (Process Control System) is in place, the key on-line parameters and alarms should be connected to this system, so a deviation can be immediately notified to personnel. Where a site is unmanned, this may require the BMS or PCS to send a text or call to a mobile phone, to notify an operator of a deviation.

4.4 Maintenance Requirements Of Abatement Systems

Maintenance can be either Reactive Maintenance (RM) which is a reaction in the event of a breakdown or malfunction, or Preventative Maintenance (PM) which ensures all equipment is in the correct condition for operation.

Abatement systems should be placed on the Equipment Register for the site and the PM requirements including any training required should be determined and agreed as part of equipment handover prior to final sign off.

The PM regime for the site should have a line item which includes the abatement equipment, and which lists in an attachment the PM requirements for the equipment. The PM requirements should be entered onto the site PM regime with the intervals at which each is required. This should be cross checked and included in final equipment sign off as part of the handover process before final payment for the equipment.

A site may find that operatives or contractors at the site may not be familiar with the abatement equipment provided and may require specialist maintenance skills, for both PM and RM. PM regimes will vary with the type of equipment chosen, as will RM requirements.

It is advisable that a PM / RM contract be signed with the equipment operator for a minimum 12-month period from equipment handover, thus ensuring site operatives are familiar with PM and RM and are adequately trained in both. The specific tasks which comprise a PM regime will vary with the type of abatement equipment, but should as a minimum include the following as shown in ***Box 16***:

***Box 16* – Specific Tasks Of A Preventative Maintenance Regime**

- Taking the unit off-line once per year,
- Visually inspect the unit daily; to include all flanges, joints and external units such as fans,
- Note any signs of corrosion, warpage or cracking,
- Liquid level (where appropriate) and pressure drop should be checked to determine if they are within range,
- The outlet should be checked for odour in accordance with manufacturer's instructions,
- The outer shell of the unit should be inspected for signs of deterioration,
- Critical parameters (which may be temperature, pH, pressure drop – depending on the equipment) should be checked and recorded and compared to manufacturers specifications,
- On-line monitoring systems should be reviewed to check unit performance over the previous 24 hours,
- Any signs of leaks which may have occurred overnight (staining within bunds for example) should be recorded and investigated,
- Electrical power being drawn by the unit,
- All alarms should be checked visually,
- Valve positions should be checked to ensure none have been changed.

Weekly checks should include:

- Monitoring probes should be checked and recalibrated if required,
- Spray bars within scrubber units should be checked for blockages,
- Pipes and manifolds should be checked for blockages,
- Pressure gauges should be checked for accuracy,
- Alarms should be tested to ensure they are electrically energised.

Annual checks will vary with the unit but will generally include taking the unit off-line and replacing consumables such as seals and filters. Valve seats and other more complex equipment components may also be checked and replaced, and carbon, scrubber media or ceramic media may be replaced or cleaned.

It is important that the Annual Check is planned well in advance to ensure all spares, equipment, tools and personnel are present and available onsite to minimise the down-time for the site while the abatement system is off-line.

4.5 Staff Training Requirements

Staff training should be provided by the equipment supplier. At least one staff member should be trained on the operation, troubleshooting and basic maintenance of the unit, by hands-on training with the commissioning engineer. A training manual should also be prepared for this operative which describes their tasks and explains how the system works, some of the faults which commonly occur and how they can be rectified. This operative should also train at least one other staff member. Records of training undergone should be kept in the OMP file.

Site maintenance personnel should also be trained by the commissioning engineer, and it is recommended that the first 12 months maintenance is undertaken by the equipment supplier, whose team can further train the site maintenance team over that period. The training should focus on the PM and RM tasks required, how each component of the unit can be maintained and repaired if required, and how standard lubrication and greasing should be undertaken.

5.0 TEST PROGRAMMES FOR ODOUR ABATEMENT EQUIPMENT

Where abatement is required, a test programme may be obligated as outlined in the example below from a current IE Licence (for a waste facility):

***Test Programme Requirements (Example Text)**:*

- "*The licensee shall prepare, to the satisfaction of the Agency, a test programme for (a) abatement equipment installed to control odour / dust emissions from the Waste Recovery Buildings and (b) the biodiesel production equipment. Each test programme shall be submitted to the Agency, prior to implementation.*

- *Each programme, following agreement with the Agency, shall be completed within three months of commencement of operation of the equipment*

- *The criteria for the operation of the odour / dust abatement equipment and biodiesel production equipment as determined by the respective test programmes, shall be incorporated into the standard operating procedures as approved by the Agency.*

- *Each test programme, referred to above, shall as a minimum: -*
  - *Establish all criteria for operation, control and management of the equipment to ensure compliance with the requirements of this licence and*
  - *Assess the performance of any monitors on the abatement system/s and establish a maintenance and calibration programme for each monitor.*

A report on each test programme shall be submitted to the Agency within one month of completion".

5.1 Monitoring Of Odour Abatement Effectiveness

Once abatement equipment is newly installed on an existing site or if a site is newly licensed and already has pre-installed abatement equipment on it, the site operator must demonstrate that equipment is suitable and capable for use to meet the abatement targets set for the equipment. In order to demonstrate this, a test programme should be developed which explains how the site operator proposes to prove the abatement equipment's suitability and capability to meet the abatement targets.

The test programme should also ensure that the site operator can assess the performance of any monitoring equipment used on the abatement system and establish a maintenance and calibration programme for each equipment item. Additionally, the test programme should also assess the performance of any monitors on the abatement system/s and establish a maintenance and calibration programme for each monitor. The test programme for any piece of abatement equipment is not just limited to how that item operates in isolation; rather its impact on other plant and equipment must also be assessed.

The equipment items which are part of the abatement system will have the following functions:

- ***Controlling,***
- ***Measuring,***
- ***Monitoring.***

Each of these equipment items will have to be examined as part of the test programme and be deemed fit for purpose. Any monitor (for example thermocouple, flow meter, flue gas analyser) should also be capable of operating across the performance range in which the abatement equipment is being tested.

As a consequence of the manner in which these related items perform during the test programme, a test programme must ensure that the equipment is maintained and calibrated so that changes in the abatement equipment do not have an adverse or an unknown impact on the relevant monitors.

A documented maintenance and calibration programme (including a schedule), for any monitor associated with the abatement equipment is an essential part of the test programme.

The criteria for the operation of the abatement equipment as determined by the test programme, should be incorporated into the standard operating procedures (SOPs) by the site operator once the abatement system is commissioned and fully operational.

The findings of the completed test programme should be recorded and implemented. All relevant SOPs should, following the completion of the test programme, be updated to account for the knowledge gained from assessing the results obtained from the test programme.

5.2 Template For A Test Programme

The template for a test programme is provided in ***Appendix C*** of this document. The test programme shall as a minimum establish all criteria for operation, control and management of the abatement equipment to ensure compliance. A successfully completed test programme should provide the operator with the knowledge of how best to operate, control and manage the relevant abatement equipment in order to comply with the requirements of the abatement targets.

The programme should include reference to the Manufacturers requirements for maintenance, operational procedures and training requirements and describes how the Operator will ensure compliance with these requirements.

5.2.1 Acceptance of Test Programme Output

The test programme should define the criteria for determining when system performance will be deemed to be acceptable, for example it should include the statement:

"Abatement system performance will be deemed to be acceptable if over the two-month period:

- *All emission limit values (ELVs) defined for the abatement equipment are met on each monitoring occasion and if a CEMS unit is installed, for the CEMS Unit for those parameters measured:*
  - *Concentration limit values,*
  - *Volumetric flow rate.*

  There are no emission limit values for the following parameters, but it is important to measure these parameters and compare with design criteria:
  - *Velocity,*
  - *Pressure,*
  - *Temperature,*
  - *Oxygen content (where relevant),*
  - *Water content (where relevant).*

And (for the following continuously recorded parameters):

- *System design temperature in the combustion chamber (for thermal oxidisers),*
- *System design retention time shall be met at all times,*
- *Pressure drop across bed or abatement system,*
- *Voltage or current across electrodes,*
- *Scrubber conductivity (where relevant) shall remain within set point values at all times."*

For thermal oxidisers the test programme should also include defining reference oxygen concentration. Testing before and after the abatement equipment should be undertaken to check if the abatement unit is experiencing the loadings for which it was designed and to determine if the removal efficiency is as per the design criteria.

5.3 Maintenance, Operation and Training to be Documented in Test Programme

The supplier of the abatement equipment must ensure that site personnel receive appropriate training on the maintenance and operation of the system prior to the two-month test programme commencing.

The supplier must ensure that at the end of the training programme sufficient personnel have been trained in how to maintain and operate the Abatement System such that criteria defined for the abatement system can be met.

5.3.1 CEMS System

This should include training in how to operate and maintain the CEMS system and the associated Data Acquisition and Handling System – it is accepted that a specialist maintenance external contractor may maintain and test the CEMS unit. The air emissions monitoring undertaken should also focus on verification that the CEMS unit is operating correctly.

5.3.2 Alarms

CEMS unit alarm, temperature and flow alarms are set to trigger at 75% of the relevant ELV (Emission Limit Value) and when 90% is reached a signal is sent to production to begin shut-down of the manufacturing process. Alarms need to be visual and audible, the CEMS system should link to the site SCADA (Supervisory Control And Data Acquisition) system. Alarms could include text or email alerts to key personnel if 24-hour supervision is unavailable onsite.

5.3.3 Calibration

Calibration should be carried out as per the instrument list issued by the equipment supplier. Calibration certificates and labels should be produced for each instrument calibrated. Calibration gases (calibration gases are marked with a date after which they should not be used – the gases used should be within date) and calibration certificates for each calibration gas should also be provided.

Training in Preventative Maintenance should include:

- Replace consumables where necessary (usually filter elements where cleaning will not suffice).
- Test the operation of individual items in each of the systems, such as the chiller, sample pumps, moisture switch, flow switch.
- Ensure all alarms operate correctly and are indicated where applicable.
- Complete a visual inspection for loose fittings, ingress of moisture and general wear and tear.

The following should also be completed as part of maintenance:

- Back-ups to be made of all data files.
- Back-ups to be made of the system software every six months.
- Reports system to be tested.
- General software and hardware maintenance.

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APPENDIX A – Odour Complaint Report Form

ODOUR COMPLAINT REPORT FORM	
Name & Address:	Phone Number:
Time / Date of Complaint:	Time / Date of Odour:

Location of Odour:					
Weather Conditions:	Dry	Rained Recently	Drizzle	Raining	Foggy

Temperature:	Cold	Cool	Warm	Hot

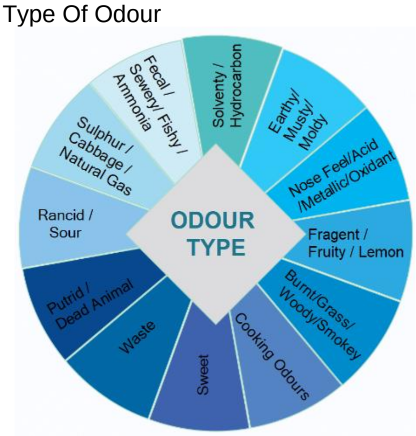
Wind Strength:	Calm	Light Air	Light Breeze	Gentle Breeze	Moderate Breeze	Fresh Breeze	Strong Breeze	Near Gale	Gale	Strong Gale

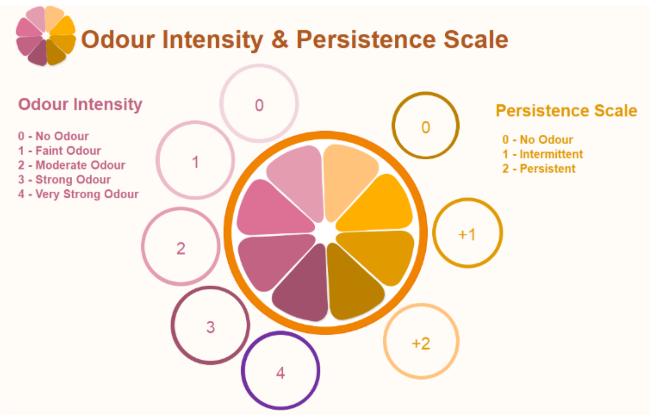
Type of Odour (see below):	
Odour Intensity (see below):	
Persistence Scale (see below):	
Duration of Odour (time):	

Nature of Exposure:	No Odour	Intermittent	Persistent

Any Comments / Additional Information:	

Type Of Odour





APPENDIX B – Odour Management Plan Checklist

Odour Management Plan Checklist	
Name of Activity:	**Date:**
Process Description / Potential Odorous Activities:	**Approved By:**

	Checklist (√ - on completion)	Comments
Details of Sensitivity of Local Environment:		
Map of Site & Local Receptors / Meteorological Factors (Source-Pathway-Receptors Concept):		
Legal Framework / Licence Conditions:		
Management Structure:		
Designation of Responsibility for Compiling Odour Management Plan:		
Process Flow Diagram Detailing Odour Sources / Release Points:		

Odour Sources / Pathways	Raw Materials / Inventory	Equipment	Processes & Activities	Release Points	Finished Products	Wastes	Imports / Exports
Routine Methods / Control Measures:							
Assigned To:							
Planned Maintenance & Repair Schedule:							
Assigned To:							
Emergency Incidents / Accidents Measures:							
Assigned To:							

	Checklist (√ - on completion)	Comments
Odour Impact Assessment **Survey Protocol:**		
Odour Complaint Log Protocol:		
Community Liaison Protocol:		
Review Process / Audit Timetable:		
Record Keeping:		
Comments:		

APPENDIX C – Test Programme Checklist

Test Programme Checklist	
Name of Activity:	**Date:**
Odour Abatement Process Description (attach a Process Flow Diagram with explanatory text of the odorous processes including key characteristics of odorous exhaust and abatement design):	**Approved By:**

	Checklist (√ - on completion)	Comments
Emissions monitoring conducted on 3 occasions over the duration of the test programme?		
System retention time met at all times?		
Combustion temperature achieved at all times (if relevant)?		
Pressure drop across system within range at all times?		
Voltage/current within range at all times? (if relevant)		
Conductivity in scrubber within range at all times (if relevant)		
Velocity and flow rate through unit measured?		
Oxygen content of exhaust measured? (if relevant)		
Water content of exhaust measured? (if relevant)		
Did any deviations from standard operating parameters occur during the test programme period? (If so please describe on a separate sheet and explain how they were investigated, what was the outcome and how were they rectified).		
Describe the criteria the unit has to meet to pass the Test Programme and have these been achieved? (Provide evidence on a separate sheet and attach).		
Comments:		

The duration of the Test Programme should be agreed with the EPA in advance of the implementation of the test programme from the date of completion of commissioning by the equipment supplier. The Abatement System should be subject to the loads normally seen from the manufacturing process, over the test programme period. Emissions monitoring upstream of the abatement unit and downstream of the abatement unit should be conducted by an ISO 17025 accredited Air Emissions Monitoring Team, on three occasions over the testing period with a comparison undertaken with the target values defined for the abatement equipment.

Any deviations from these target values noted during this testing programme should be investigated and subject to Root Cause Analysis. The fault shall be identified and remedied and the testing re-done once the fault is remedied. The monitoring should be undertaken following Irish EPA Guidance *(AG2 - Emissions Monitoring Guidance Note)* (EPA, 2018) and other appropriate guidance as agreed with the EPA.

APPENDIX D – Glossary of Terms

Adaptation	Temporary modification of the sensitivity of the human nose due to continued and/or repeated stimulation
Aerobic Processes	Biological processes that occur in the presence of oxygen
Anaerobic Processes	Biological processes that occur in the absence of any common electron acceptor such as nitrate, sulfate or oxygen
Anoxic Processes	Biological processes that occur in the presence of electron acceptors such as nitrate or sulfate, while oxygen is absent
Advanced models:	Dispersion models that are based on modern scientific theories and complex mathematical formulations. They can assess multiple sources, complex terrain and detailed meteorological conditions.
Biodegradability	Extent to which an organic substance can be degraded by microorganisms under specified conditions. Biodegradability is usually expressed as a percentage of the substance degraded.
Dynamic Dilution Olfactometry	A technique which determines the odour concentration based on the number of dilutions with neutral air that are necessary to bring the odorous sample to its odour detection threshold concentration.
Detection Threshold	The concentration at which an odorous chemical or mixture can be just detected.
EHS	Environmental, Health & Safety
End-of-pipe technique	A technique that reduces the final emission level, but which does not change the fundamental operation of the core process.
Intensity	An assessment of odour strength, based on a logarithmic scale, ranging from no odour to extremely strong odour.
Odour Concentration	The concentration of an odorant mixture is defined as the dilution factor to be applied to an effluent in order to be no longer perceived as odorant by 50% of people in a sample of the population. The odour concentration at the limit of detection is by definition 1 OU_E/m^3.
Odour Intensity	Value of the perception for a stimulus above the corresponding detection threshold. The odour intensity is determined by a sample of persons by comparing the odour perception level in the effluent with samples of an odorant reference (n-butanol at different levels of dilution).
Odour Threshold	The limiting concentration of a substance in air below which its odour is not perceptible
Olfactory Fatigue	Associated only with H_2S. At concentration of greater than about 100ppm, H_2S causes paralysis of nerves in the nose leading to complete but temporary loss of smell.
Recognition Threshold	The concentration at which the specific odour can be recognised, typically 3-5 times the odour detection threshold.