

Odour Assessment Task Group Final Report



Prepared by the
Odour Assessment Task Group
for the
Odour Management Team

May 2015

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Important Notice:

The content contained in this report is being provided to the Odour Management Team (OMT) for their consideration as they develop the ‘Good Practice Guide’ as well as their Final Report. The task group recognizes that the content may or may not be fully included in the final versions of these documents which will be submitted to the CASA Board of Directors for their approval.

Acknowledgements

The OMT requested that members of the Odour Assessment Task Group (OATG) also undertake the work outlined under Prevention/Mitigation, which they agreed to with the addition of a representative in land-use planning and a different representative from ESRD. The dedication of these members to complete deliverables from two task groups is acknowledged and appreciated.

The Odour Assessment Task Group would like to thank all current and past members for their hard work and commitment over the life of the group (*see Task Group Members list on page iv*).

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Executive Summary

The Odour Assessment Task Group (OATG) was formed in October 2013 to undertake the work listed under ‘Odour Assessment’ in the Odour Management Project Charter (March 2013) led by the Odour Management Team (OMT). Each deliverable of the task group was achieved through collaboration and consensus agreement of the group.

The group developed their workplan based on the vision and objectives for odour assessment: *“that effective management of existing or potential odour issues requires practical, credible and appropriate tools to assess odour. The results of an odour assessment can be used to determine the appropriate type and level of response to address a potential or existing odour issue.”*

The Charter outlines one objective for the “Odour Assessment” task group:

1. *To provide information on options, tools and recommended action for odour assessment.*

The main audience for the OATG work was determined to be both government and industry, however the deliverables were developed with the intention that it would be easily understood and useful to members of the public.

The group decided that an analysis of odour assessment tools and practices including applicability in the Alberta context was an appropriate deliverable. They agreed that the review should also assess the identified tool/practices based on when they would/would not be appropriate for use. They created a Request for Proposal (RFP) and chose a consultant to assist the group in the analysis.

The task group and consultant developed an inclusive informational report with an associated odour assessment guide that is intended for non-experts who need to understand the options available for conducting an odour assessment (see Appendix I for the *Review of Odour Assessment Tools and Practices for Alberta* consultant report.). The report and guide will be helpful to representatives of municipalities that deal with odour complaints, to industry or those wanting to change operations, to communities with odour concerns and, to provincial government agencies, and regulators that deal with odour issues.

The final work for the OATG was to develop their task group final report (*this report*) to outline their work and deliverables, discuss areas of advice for the distribution of the group’s report, and provide advice for future work areas in odour assessment. All deliverables should be considered by the OMT as they develop communication and roll-out plans for the Good Practice Guide (GPG).

The task group’s timelines were delayed due to concerns with the consultant’s report that resulted in multiple revisions. This delayed the task group’s acceptance of the final version. The task group was marginally over their allocated budget. Prior to submission to the OMT, the OATG inserted an addendum in the consultant’s report to reflect those aspects of the report where the group had a difference of opinion from the consultant. The finalization of the consultant’s report was due in large part to the in-kind hours spent by the task group and the group’s multi-stakeholder membership with its varied nature and range of odour-related

expertise and experience as well as excellent support received from the CASA Secretariat in addressing some of the challenges associated with finalizing the consultant's report.

1. Introduction

In January 2013 the Odour Management Team (OMT) was formed to undertake a project directed at advancing odour management in Alberta. The work of the OMT was divided into seven interrelated topics including, Complaints, Odour Assessment, Prevention/Mitigation, Enforcement/Role of Regulation, Health, Education /Communication /Awareness, and Continuous Improvement. The OMT prioritized three areas that first began to work on their topics; odour assessment, complaints, and health.

The Odour Assessment Task Group (OATG) was formed in October 2013 to carry out work listed under ‘Odour Assessment’ in the OMT’s Project Charter (March 2013). Each task group deliverable was achieved through the collaboration and consensus agreement of all members.

The group developed their workplan and established roles and responsibilities for each member to clearly articulate the interests of their stakeholders and to establish effective communication with decision makers in the organizations/groups they represent. Members outlined ground rules for how they would all work together; their basic rules of procedure and behaviour. All members agreed to maintain main principles throughout their work.

To meet their objectives the task group:

- Met 12 times through in-person and teleconference meetings,
- Spent over 550 in-kind hours in and between meetings developing and reviewing deliverables, and
- Came in marginally over their allocated budget from the OMT.

This task group final report outlines the work of the Odour Assessment Task Group, describes their deliverables, and provides advice to the OMT for consideration and inclusion in their project deliverables, including the Good Practice Guide (GPG) and final report.

2. Overview of tasks

2.1 Vision and Intended Audience

The Project Charter outlines a vision for odour assessment that “*effective management of existing or potential odour issues requires practical, credible and appropriate tools to assess odour. The results of an odour assessment can be used to determine the appropriate type and level of response to address an existing or potential odour issue.*”

The task group considered the main audience for their work to be both government and industry, but their deliverables were developed with the intention that it would be easily understood and useful to members of the public.

2.2 Task Group Deliverables

The Charter outlines one objective for the ‘Odour Assessment’ task group:

1. To provide information on options, tools and recommended action for odour assessment.

It also provides potential outcomes or deliverables as:

- A review of protocols and criteria for investigating and characterizing odour and how they are applicable in Alberta (e.g. based on FIDOL - Frequency, Intensity, Duration, Offensiveness, Location).
- An assessment of available and practical options for assessing (measuring, monitoring, modeling, etc.) odour and how they might be applicable in Alberta.
- An understanding of when it is appropriate/not appropriate to use each option.
- Protocols and criteria for investigating and assessing odour and its impacts.
- An understanding of the role of odour assessment in odour management.

Table 1 describes the group’s deliverables with an overview of outcomes.

Table 1: Odour Assessment Task Group Workplan Deliverables.

Task Group Deliverables	Completion Status and Details
An analysis of odour assessment tools/practices and their applicability to the Alberta context including when they are/not appropriate to use.	Complete. <ul style="list-style-type: none"> – The task group worked with a consultant to analyze odour assessment tools/practices and their applicability in the Alberta context (see Appendix I for the consultant report titled: <i>Review of Odour Assessment Tools and Practices for Alberta</i>). – The task group provided a presentation to the OMT summarizing their work.
A ‘key’ to facilitate access and use of the information in the analysis (e.g. a decision tree, roadmap).	Complete. <ul style="list-style-type: none"> – The task group created an <i>Odour Assessment Guide</i> that provides assistance in the determination of when and where odour assessment options may be most applicable (see <i>Appendix</i> of the above listed consultant report).

2.3 Scoping and Assumptions

The task group began work by considering the scope and assumptions for the odour project:

- Work should apply to all sectors, no individual sector is meant to be singled out.
- While some best practices could be sector specific, the project should focus on creating processes and identifying options (ex. for complaints, odour assessment, etc.) that provide a consistent approach to managing odour in Alberta.

- In some instances all reasonable efforts may be made to manage a source of odour, but elimination may not be feasible.

Using the overall project scope, the group compiled a list of requirements that would be applicable for their analysis:

- All deliverables must be tailored to the Alberta context.
- The tools in the consultant report will be generic and be applicable to sectors operating in Alberta (the list of sectors was developed by the group and OMT).
- The analysis will be based on source types and characteristics of the odour issue (e.g. area, point, intermittent, continuous).

The group put a considerable amount of time and work into the creation of an outline and context for the consultant report that would meet the group's objectives. In order to research and analyze an inventory of tools that assess odour, the work would include:

- A review of tools available in Alberta and other jurisdictions.
- Tools that were practical in terms of human resources and financial cost.
- Tools that could be used for assessing complaints from receptors, managing the source (e.g facilities), monitoring, etc.
- Information on when certain tools would or would not be appropriate to use.

The task group received approval of their workplan and a budget from the OMT that allowed them to hire a consultant to assist in the development of their report.

3. Methodology

3.1 Overview of Steps

The progression of work for the Odour Assessment Task Group was divided into four steps outlined below.

Step one included developing an inventory of odour assessment tools and practices with an appropriate amount of detail to conduct the next steps. The group first conducted a literature review for tools/practices. Advantage was made of existing information and compilations on odour assessment as much as possible. The review considered application of the existing tools in the Alberta context and took into account any factors that facilitated the analysis of the literature review in Step 3, to ensure the appropriate information was gathered and available (such as climatic conditions, social/economic context, landscape factors).

The second step included the OMT and outlined a list of odour issues that were determined to be relevant to Alberta. This list was used in the group's analysis of when a tool/practice was or was not applicable to Alberta and to assess how and when to use the tools/practices.

For step three, the task group prepared an analysis of the inventory of odour assessment tools/practices that address odour issues relevant to Alberta and developed specific recommendations relating to gaps that were identified as a result of the previous steps. The task group reviewed odour issues in relation to the tools/practices identified, and analyzed when,

where, and how the tools/practices would be applicable. They detailed what works/doesn't work and when and where they should/should not be used. This linked the tools/practices to specific odour issues, categories of odour issues and situations in Alberta.

In the final step four, the group developed a tool that would allow users to easily access, use and interpret the assessment report. The group discussed various considerations for what format best suited their information (ex. matrix, decision tree), and agreed to create a 'key' or 'guide' that would help users easily link an issue with appropriate odour assessment response tools/practices.

3.2 Consultant Report and Guide Development

Initially the task group determined that their work would likely have two components: an upfront 'context' piece and a 'tool' piece.

The group brainstormed high level concepts for the reports' context to provide an overall inventory of odour assessment tools and practices. They also outlined main concepts for the 'guide' that included:

- Information about when each tool is appropriate including interactions between tool categories of ambient odour monitoring (quantifying odour), emissions characterization (source identification; existing emissions inventories; emissions sampling), and dispersion modeling.
- An example of how to work through the tools using a fictitious scenario.
- Breaking the tools down further into specific monitoring tool or modelling techniques options.
- A comparison of modeling outputs to ambient odour monitoring.
- How to use the categories of tools and information from them to do an odour assessment.
- Criteria for a successful odour assessment.
- Consideration for how well tools have worked in the past.

The task group began work by developing a comprehensive table of contents for the odour assessment using their expertise and contents of other guides available that included odour management guidance from British Columbia, Scotland and New Zealand. The structure of the consultant report was based on source type (i.e. area, point, new, existing, etc.) rather than a particular odour or sector and included:

- A contextual piece about odour assessment and how the nature and character of an odour issue influences the selection and use of odour assessment tools.
- An inventory and brief description/explanation of specific odour assessment tools/practices and a brief analysis of when, where and how the tool and/or practice might be applied to the Alberta context.
 - Each tool included a short description/instrumentation summary (without going into the physics/science of it), with references for further technical information, what type(s) of information the tool yields, applicability to Alberta, basic explanation of usage, and costs and logistical considerations.
- A 'key' to the tools and practices section. This took the form of a roadmap/summary table to facilitate user's access to the information on the various tools and to help users understand which tool is appropriate to their odour assessment needs.

The task group received approval and a budget from the OMT to hire a consultant to assist the group in the development of their deliverables. A Request for Proposal (RFP) was created by the OATG. One of the objectives of the RFP was to help identify a consultant that was familiar with the Alberta context and with experience in modelling and monitoring. Each proposal was evaluated against a set of criteria developed by the task group that focused on project management, relevant experience, the consultant's understanding of the work, schedule, and budget. A consultant was selected, contracted and began working with the task group to develop the content and context of the review report and the odour assessment guide.

The consultant's work occurred in two phases:

1. Phase I: The consultant was asked to review the drafted table of contents, provide feedback, and review with the group.
2. Phase II: The consultant was asked to populate the table of contents, discuss the development of the 'guide' with the task group, and prepare final deliverables.

Over the course of several months the consultant provided draft materials to the task group, who reviewed and provided guidance and comments on the reports' development. The consultant report titled "*Review of Odour Assessment Tools and Practices for Alberta*" with the "*CASA Odour Assessment Guide*" is attached in Appendix I.

4. Advice on Education/Communication/Awareness

The task group discussed areas of advice to the OMT as it would relate to the distribution of the groups' deliverables. The following three areas were identified for the OMT to consider as they develop the communications and roll-out plan for the Good Practice Guide (GPG).

1. The task group has confidence in the odour assessment consultant report and associated guide based on the comprehensiveness of information. However they have included an addendum to the report where they document areas of non-consensus, and advise the OMT to include both components in their deliverables.
2. The task group considers their consultant report applicable to all stakeholders both technical and non-technical in nature. The OMT roll-out plan should target two main audiences for the distribution of their report (both technical (such as engineers and planners) and general audiences that are interested in odour assessment tools).
3. The task group discussed targeting applicable government departments due to the versatile nature of the report and comprehensiveness of the information. Government would have the ability to customize a communications plan (for internal staff and external clients) for odour assessment information and guidance.

5. Advice on Continuous Improvement

The task group discussed advice to the OMT about future work for odour assessment and the group's deliverables. They provide the following advice:

1. The odour assessment report should be updated regularly and kept current (a 5 year period is reasonable). This review should consider how existing practices and tools are being used and identify any new tools.

- The task group highly recommends the 5-year review follow a similar process and format used by this task group; to include a multi-stakeholder process with sufficient time to gather new information.
- 2. The *CASA Odour Assessment Guide* should be assessed to determine if it is being used.
 - The appropriateness and usefulness of the guide should be reviewed with actual users and revised based on the feedback.
- 3. The task group recommends piloting the *CASA Odour Assessment Guide* with government and industry stakeholders.
 - Task group members did informal testing with some stakeholders but were unable to conduct a true pilot given their timelines.
- 4. The task group recommends conducting a comprehensive gap analysis of odour assessment practices/tools in Alberta.
 - The group discussed the possibility of including a gap analysis in their report, but noted it would be a large undertaking. They address gaps to a lesser extent in the report and note it may also be partially covered by the work of the prevention/mitigation and enforcement/role of regulation task groups.

6. Links to Other Task Groups

The task group discussed and identified their work has a link to all other task groups. The group's work is integrated and forms the basis for all other areas of work. An odour assessment is the initial stage for odour management. Their assessment report references other task group topics in several sections. There is a notable linkage to the enforcement/role of regulation task group with regard to:

- Inclusion of Environmental Impact Assessment modelling requirements in their report. It was noted that there are no guidelines around odour assessment and that current odour regulatory requirements in Alberta are being reviewed by the Enforcement/Role of Regulation Task Group. The issue of timing relates to whether an odour regulation must be in place before the odour assessment report can be completed, so as to align with any possible new regulations.
- Identifying a variety of tools that can be used for odour assessment which includes olfactometry. Tools that apply in a regulatory sense were assumed to be reviewed by the Enforcement/Role of Regulation Task Group. Developing a regulatory framework is the purview of ESRD but the task group and OMT could provide information that would help with the process and decisions.

7. Lessons Learned and Advice

The task group discussed lessons learned for the OMT to consider in regard to their work on this topic, their task group final report, and consultant report.

- The task group wanted to express their satisfaction with the multi-stakeholder approach used by CASA and the task group, which was especially useful and beneficial in producing their deliverables. Each member provided value-added comments, advice and recommendations.

- The task group wanted to highlight to the OMT, that even though formal processes were followed for developing the RFP, checking references, following up on the proposal, and choosing a consultant with hands on experience, there were considerable challenges in the development of the consultant report. The group provided some of their considerations for future contracting.
 - There must be an understanding by the group of a balance between the technical expertise versus communications experience;
 - There must be an agreement and understanding of the complexity of working with multi-stakeholder groups;
 - There must be an understanding of the degree of task group engagement during development of any deliverable (i.e. the nature of work) and that the contract is not an independent consultant project.

8. Recommendations

The Odour Assessment task group has the following recommendations for acceptance by the OMT:

Recommendation 1: Accept the Task Group’s consultant report with qualifiers.

The task group recommends the OMT accept the consultant report with qualifiers, i.e. the task group addendum, for inclusion as the Good Practice Guide is developed.

Recommendation 2: Accept the Task Group’s final report.

The task group recommends the OMT accept their final report and the advice and recommendations within, for consideration as the OMT develops their deliverables.

Recommendation 3: Disband the Task Group, after review of the GPG.

The task group recommends they have an opportunity to review the GPG applicable sections to the groups’ topic, after which the group should be disbanded as their workplan will be complete.

9. Appendix I: Review of Odour Assessment Tools and Practices for Alberta

ERRATA and ADDENDUM

Millennium EMS Solutions Ltd. and Environmental Odour Consulting, *“Review of Odour Assessment Tools and Practices for Alberta”*, January 2015.

Compiled by the CASA Odour Assessment Task Group

The Odour Assessment Task Group has prepared this errata and addendum to reflect different perspectives on information in the above referenced consultant report.

ERRATA

1. Page 13: The sentence, *“Chinook winds in western Alberta...”* should read, *“Chinook winds in southern Alberta...”*
2. Page 18: The sentence, *“This approach which also identifies the potential for odour is currently used in the oil and gas industry in Alberta.”* should read, *“This approach which also identifies the potential for odour is currently used by the oil and gas industry in Alberta to conduct environmental impact assessments (EIAs), as an example.”*

ADDENDUM

3. Page 27, Section 4.3.2.3, Alberta Air Quality Health Index: There was no consensus between the consultant and the Task Group, nor within the task group on the contents of this section. Some task group experts are of the opinion that the discussion in this section is not an accurate and complete depiction of the purpose and use of the Air Quality Health Index (AQHI) in Alberta, and may be misleading. It is recommended the reader consult Alberta Environment and Sustainable Resource Development for clarity regarding applicability of the AQHI use as odour assessment tool in Alberta.
4. Page 31, Section 4.4.4, Olfactometry: The sentence, *“Olfactometry is considered the best available approach for measuring odours directly to objectively quantify the perception of odours.”* should read, *“Olfactometry is considered by many to be the best available approach for measuring odours directly to objectively quantify the perception of odours.”*
5. Page 34, Section 4.5.3, Short Averaging Periods: The conversion factor, p , referred to in this section can only be used to convert estimates of hourly mean concentrations to 24-hour mean concentrations. It cannot be used to estimate mean concentrations for time periods that are less than an hour.
6. Page 46, Section 6.4.4, Olfactometry: The sentence, *“Olfactometry is appropriate for use in Alberta.”* should read, *“The method is applicable within its limitations.”*



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Review of Odour Assessment Tools and Practices for Alberta

Final DRAFT

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Glossary

Adaptation (odour/olfactory): The temporary, normal inability to distinguish a particular odour after a prolonged exposure to that airborne compound.

Area Source: A surface emitting source that can be solid (compost), or liquid (ponds, tanks).

ASTM: American Society for Testing and Materials.

Continuous Monitoring: Measuring concentration data for individual compounds every few seconds and record the data as one-minute average values.

Detection to Threshold D/T: Ratio is a measure of the number of dilutions needed to make the odourous ambient air “non-detectable”.

Diffusibility: A measure of the volatility of odourants based on the ability to reach the olfactory receptors in the human nose.

Diffusibility Odour Index (OI_D): A parameter used to evaluate the diffusibility of an odour, calculated as the ratio of vapour tension of the substance (ppm) to odour threshold at 100% (ppm).

Dilution Factor: The ratio between sample flow or volume after dilution (total sample volume) and the flow or volume of the odourous gas (undiluted sample volume).

Dynamic Dilution: Dilution which is achieved by mixing two known flows of gas: odourous sample and neutral gas, respectively.

Electronic Nose: Refers to the capability of reproducing human senses using sensors.

Fatigue (odour): A decrease in sensitivity to an odour caused by a repetitive process of making and recording odour observations; not caused by adaption to an odour.

FIDOL: An odour assessment framework that considers the characteristics of frequency, intensity, duration, offensiveness, and location.

Flux Chamber: A device to isolate the surface area for collecting gaseous emissions. Nitrogen is usually used as a sweep gas.

Fugitive Emissions: Unintended emissions from any openings, such as doors, windows, trucks waiting to load or unload odourous materials, valves, phalanges, or pumps. Fugitive emissions can be parts of point, area, or volume sources.

Gaussian Model: A model in which plumes are assumed to have dimensions based on bell-shaped curves.

Hedonic Tone: A subjective measure of the pleasantness or unpleasantness of an odour.

Integrative Sampling: Also known as composite sampling, collection of samples at regular and specified time periods, each sample taken in proportion to the amount of flow at that time. Composite samples give a more representative sample of the characteristics.

Intermittent Sampling: Involve the use of adsorbent tubes or impinger solutions to collect and concentrate the compounds prior to analysis.

Japanese Odour Index (OI_J): A standardised dimensionless value that is a logarithmic function of odour concentration. See *Odour Concentration*.

Monitoring: To observe changes in concentration of odour or odourants that may occur over time, using an instrument monitor or measuring device.

Objective: Quantifiable through repeatable measurement.

Odourant: A gas that causes the sensation of odour.

Odour Concentration: A dimensionless dilution ratio that is reported as the number of Odour Units (OU) in a cubic metre of gas at standard conditions. It is the threshold concentration at which an odour can be detected.

Odour Complaint Threshold Value (OCTV): The concentration at which 50% of a population, represented by the odour panel, will complain about an odour, as determined over a short time period.

Odour Detection Threshold Value (ODTV): The concentration at which 50% of a population, represented in an olfactory experiment by an odour panel, would be expected to detect the odourant.

Odour Intensity: Perceived strength of an odour when detected by a recipient.

Odour Offensiveness Threshold Value (OFTV): The concentration at which 50% of a population, represented by the odour panel, indicates that the odour is offensive as determined over a short time period.

Odour Panel: A group of assessors who are qualified to judge samples of odourous gas using dynamic olfactometry.

Odour Persistency: A measure of how an odour's intensity decreases as the concentration of the odourant decreases (*i.e.*, as the odourant is diluted, such as downwind from an odourant source).

Odour Recognition Threshold Value (ORTV): The concentration at which 50% of a population represented by the odour panel recognizes the odour.

Odour Unit (OU): One odour unit is the amount of odour present in one cubic metre of odorous gas (under standard conditions) at the panel threshold.

Olfactometer: Apparatus in which a sample of odorous gas is diluted with neutral gas in defined ratio and presented to panelists (assessors).

Olfactometric Analysis: The presentation to odour panel members of a sufficiently complete set of diluted samples to calculate the odour concentration for a sample.

Olfactometry: Measurement of the response of assessors to olfactory stimuli.

Passive Monitoring: Passing a fixed volume of odourant through a glass tube packed with an adsorbent material. Determination of the concentration for a specific odourant relies on the change of colour of the adsorbent material when it is exposed to the compound.

Point Source: A point of release of odour, such as a stack or vent.

Portable Olfactometer: Portable instrument capable of measuring odour concentration in the ambient air without collection of the sample and transportation to a laboratory.

Sampling: To obtain representative information on the typical characteristics of an odour source by means of the collection of a suitable volume fraction of effluent or ambient air.

Semi-Continuous Monitoring: Measuring concentrations over minutes to hours.

Sensitive Receptor: Locations such as residential houses, parks, school, hospitals, *etc.* where people may be exposed to odour released from a given source.

Static Hood: Isolates a part of the emitting surface which is directed into the hood outlet duct for the odour sample collection.

Subjective: Based on feelings of an odour observer of liking, pleasure, acceptance, and of valuation.

VOC: Volatile organic compounds are organic chemicals with high vapor pressure at room temperature.



Volatility: A fundamental parameter for assessing the capacity of a substance to create an odour.
See *Diffusibility*.

Volume Source: A source of diffuse emissions from a volume (as opposed to a surface or a point).
Examples are buildings and plant process areas.

Wind Tunnel: A device to isolate the surface area for collecting gaseous emissions with the capability to regulate the air velocity inside the device.

Acronyms

AAAQO	Alberta Ambient Air Quality Objective
AAQHI	Alberta Air Quality Health Index
ADMS3	Atmospheric Dispersion Modelling System version 3
AER	Alberta Energy Regulator
AERMOD	American Meteorological Society/Environmental Protection Agency Regulatory Model
AODM	Austrian Odour Dispersion Model
APCF	Alberta Prairie Conservation Forum
ASTM	American Society for Testing and Materials
AUSPLUME	Australian Plume
CALPOST	CALPUFF post-processing program
CALPUFF	California Puff Model
CAMx	Comprehensive Air Quality Model with Extensions
CASA	Clean Air Strategic Alliance
CEMS	Continuous Emission Monitoring System
CEN	Committee for European Normalization
CERC	Cambridge Environmental Research Consultants
CFD	Computational Fluid Dynamics
CMAQ	Community Multi-scale Air Quality Model
CO	carbon monoxide
DEFRA	Department of Environment, Food, and Urban Affairs (United Kingdom)
DEHP	Department of Environment and Heritage Protection (Queensland)
DEP	Department of Environmental Protection (Western Australia)
DREAM	Danish RIMPUFF and Eulerian Accidental Release Model
D/T	Detection to Threshold
EIONET	European Environment Information and Observation Network
EPA SA	Environmental Protection Agency of South Australia
EPA VIC	Environmental Protection Agency of Victoria (Australia)
EPEA	Environmental Protection and Enhancement Act
ESRD	Alberta Environment and Sustainable Resource Development
FEP	tetrafluoroethylene hexafluoropropylene copolymer
FIDOL	Frequency, Intensity, Duration, Offensiveness and Location
GC	Gas-chromatography
GC/MS	Gas-chromatography/mass-spectrometry
g/s/m ²	grams per second per square metre
GTOPO30	Global 30 Arc-Second Elevation

GUI	Graphical User Interface
H ₂ S	hydrogen sulphide
LES	Large Eddy Simulations
m	metre
m ³	cubic metre
m ³ /s	cubic metres per second
MM5	Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model version 5
MODIS	Moderate Resolution Imaging Spectroradiometer
MOE	Ontario Ministry of the Environment
NASA	National Aeronautics and Space Administration
NO ₂	nitrogen dioxide
NRCAN	Natural Resources Canada
NZMFE	New Zealand Ministry for the Environment
OCTV	Odour Complaint Threshold Value
ODTV	Odour Detection Threshold Value
OFTV	Odour Offensiveness Threshold Value
O _{I_D}	Diffusibility Odour Index
O _{I_J}	Japanese Odour Index
OML	Operationelle Meteorologiske Luftkvalitets-modeller
ORTV	Odour Recognition Threshold Value
OU	odour unit
PET	polyethyleneterephthalate
PM _{2.5}	particulate matter less than 2.5 micrometres in diameter
ppb	parts per billion
ppbv	parts per billion by volume
ppm	parts per million
ppmv	parts per million by volume
ppt	parts per trillion
pptv	parts per trillion by volume
PVF	polyvinylfluoride
QA/QC	quality assurance/quality check
RIMPUFF	Risø Mesoscale PUFF model
SAGD	steam-assisted gravity drainage
SA/SNZ	Standards Australia/Standards New Zealand
SCAIL	Simple Calculation of Atmospheric Impact Limits
SO ₂	sulphur dioxide
SRTM3	Shuttle Radar Topography Mission Global Coverage (3 arc-second resolution)

SRTM30	Shuttle Radar Topography Mission Global Coverage (30 arc-second resolution)
TCEQ	Texas Commission on Environmental Quality
TRC	TRC Solutions
µg/m ³	micrograms per cubic metre
U.S.	United States of America
U.S. EPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator (coordinate system)
VDI	Verein Deutscher Ingenieure
VOC	volatile organic compound
WHO	World Health Organization

1.0 PURPOSE, FORMAT, AND SCOPE OF THIS DOCUMENT

Odours can be a significant contributor to concerns regarding air pollution and, during the past few decades, many jurisdictions have incorporated control and management of odour into their environmental legislation. Offensive odours may have adverse effects on peoples' lives and well-being, and can result in conflicts between the public and the facilities generating the odours. Managing odour is complicated by the fact that the sensation caused by mixtures of odourants is very subjective and difficult to measure. The ranges of adverse effects of odour can vary significantly based on the sensitivity of the people experiencing odours. Personal sensitivity and acceptability to odours may depend on the environment where the odour is detected.

This document is a review and summary of existing national and international odour assessment tools and practices which are considered to be applicable to Alberta. It is meant to be used primarily by local authorities, regulators, and industry professionals engaged in activities related to the prevention, investigation, and management of odour issues. It is structured as a reference document, to allow stakeholders to easily identify and access information on specific topics without having to read the entire document.

This document consists of an introduction to the CASA (Clean Air Strategic Alliance) Odour Assessment Guide, including:

- An introduction to odour (Section 2);
- A discussion of odour assessment (Section 3);
- An assessment and evaluation of different odour assessment tools (Section 4);
- Reference list (Section 5);
- Tabulated summaries of the most appropriate tools applicable in Alberta (Section 6); and
- The CASA Odour Assessment Guide (Appendix A).

The recommendations provided within the sections of this report are not intended to be directly used as odour management requirements, but rather to guide the possible development of such requirements.

2.0 INTRODUCTION TO ODOUR

2.1 What is Odour

Odour can be defined as the sensation that results when olfactory receptors in the nose are stimulated by particular chemical compounds in gaseous form (called ‘odourants’) (McGinley *et al.* 2000a; St. Croix Sensory 2003).

Odour is recognized during the process of breathing. At the back of the nasal cavity there is a small patch of tissue in the olfactory epithelium, which has neurons that are olfactory receptors (Pearce 1997). When activated by a sufficient concentration (*i.e.*, threshold) of odourant molecules, the olfactory receptor neurons (10 to 25 million in total) (McGinley *et al.* 2000b), send a signal to the olfactory bulb, which is located in the brain. The olfactory bulb receives and processes olfactory information, and then sends it to other areas of the brain where it is further processed and projected through a pathway to the central nervous system (St. Croix Sensory 2003).

Odour sensation depends on the nature and concentration of the substances that interact with the olfactory receptors (McGinley *et al.* 2000a, b; DEFRA 2010). Odours generated by the food and cosmetic industries, which are generally pleasant, are often referred to as aromas or fragrances, respectively. Terms like malodour, stench, or stink refer to unpleasant odours. The average person can discriminate between possibly one trillion odours (Bushdid *et al.* 2014). A single odourant stimulus (*e.g.*, hydrogen sulphide or chlorine) is typically recognized by multiple receptors, and may be readily recognizable and easy to describe. A mixture of multiple odourants (*e.g.*, volatile organic compounds (VOCs) or the complex odour emitted from a landfill) is recognized by sets of multiple receptors in several parts of the brain, with the patterns of neuron signals helping to identify and characterise the odour. With mixtures of odourants, the olfactory system does not recognize the individual odourants comprising the overall odour (Gaillard *et al.* 2004), but rather the entire mixture, which does not necessarily correspond to the concentration of or intensity of any individual odourant within the mixture. For example, odours discharged from a paint spray operation will be composed of a few types of solvents and pigments whereas odours discharged from a landfill site will be composed of hundreds of detectable odourants, in addition to other compounds that are present in concentrations too low to be detected with current analytical methods.

Due to olfactory adaptation, some of the odours that individuals are familiar with, such as their own body odour or typical household odours are less noticeable to them than are external or infrequently encountered odours (Wolfe *et al.* 2014). Sensitivity to odour and the ability to distinguish odours weaken quickly during continuous exposure or adaptation, but recover rapidly after the stimulus is removed. However, conditions such as prolonged or frequent exposure to an odour may increase an individual’s sensitivity to that odour, and even pleasant odours such as those from baking or coffee may become offensive.

2.2 Properties of Odour

When assessing odour effects, not only the concentration of the odour but also other odour properties, such as odour intensity (strength), hedonic tone (general classification) and character (descriptors) are considered.

2.2.1 Odour Concentration

Odour Concentration refers to the number of dilutions required for an odourant sample to reach the odour detection threshold value (ODTV) or the odour recognition threshold value (ORTV) (St. Croix Sensory 2003). Odourant concentration is the most common parameter for quantifying odours and is usually expressed based on the ODTV in preference to the ORTV.

Odour Units (OU) are a unit of measurement for the overall concentration of odourant in an air sample. An OU is defined as the number of times that an odourant sample must be diluted with odour-free air so that 50% of a trained odour panel can just detect the presence of the odour (ASTM 2002; CEN 2003). For example, if it is determined that an odourous air sample needs to be diluted 620 times to be just detected, the odourant concentration is 620 OU. In North America, odourant concentrations are generally expressed as OU but sometimes as dilution to thresholds (D/T) ratios. In Europe, odourant concentrations are expressed as OU/m³, based on the odourant concentration relative to a standard concentration of n-butanol. In all cases, the numerical value of the odourant concentration is similar, but the units used to express the concentration differ.

Very low concentrations of odourants in air can be detected by olfactory receptors, at parts per billion (ppb) by volume (ppbv) or even parts per trillion (ppt) by volume (pptv) levels in air (Reed 1992; Sarrafchi 2012). These concentrations are often challenging to measure; therefore, the use of human noses is a very useful tool for measuring odour concentrations, particularly since small changes in the chemical composition of an odour can change the character of the odour.

Concentration can be determined through olfactometry (the use of human noses), where the sample is diluted to the level where it is just detectable or recognizable by odour panelists (St. Croix Sensory 2003). The odour panel is typically comprised of six to 12 panel members (St. Croix Sensory 2003) – although the number can vary – and is intended to be representative of the population in general. A diluted odourous sample and odour-free air (as a reference) are presented separately from sniffing ports to a group of panelists, who perform the evaluations in an odour-free room. The responses of the panelists over a range of dilution settings are used to calculate the concentration of the odour (OU). The main panel calibration gas is n-butanol, which, at a concentration of 123 µg/m³ (40 ppbv), by definition in EN13725, is an odour concentration of 1 OU. The odour panelists should be screened according to the standard method described above and has an olfactory sensitivity within the range specified by the standard. For example, the European Standard EN13725 (CEN 2003) and the

Australian/New Zealand standard (SA/SNZ 2001) require that panelists detect 40 ppbv n-butanol within the range of 20 ppbv to 80 ppbv (62 to 246 $\mu\text{g}/\text{m}^3$).

2.2.2 Odour Intensity

Odour Intensity is the perceived strength of an odour when detected by a recipient. Some odourants are perceived as having high intensity odours even at low concentrations or when they are just detectable (*i.e.*, at threshold concentration) (DEFRA 2010). These odourants are common in naturally unpleasant odours (DEFRA 2010), such as hydrogen sulphide (rotten eggs) and skatole (faeces).

When odourants are mixed, the resulting odour intensity is generally not simply the sum of the intensities of the individual odourants. Therefore, the overall odour intensity of mixtures of odourants cannot be calculated with high certainty. However, in some cases (*e.g.*, for modelling assessments), summing of components may be the only feasible way to estimate total odour effects. Where possible, an odour panel evaluation should be undertaken to determine intensity and other odour properties. The panel evaluation consists of panel members rating the odour strength on the appropriate scale (*e.g.*, DEP 2002).

In Europe, the method of measuring intensity, as described in the German standard VDI 3882, Part 14 (VDI 1994), is a seven-point scale with the following interpretation:

0	No odour
1	Very weak
2	Weak
3	Distinct
4	Strong
5	Very strong
6	Intolerable

An intensity scale of five points is commonly used in the U.S. (McGinley 2000) and in Ontario, and is based on panelists' judgement of the odour strength with the following interpretation:

0	No odour
1	Slight odour
2	Moderate odour
3	Strong odour
4	Extreme odour

ASTM (1989) method E544-75, which was reapproved in 2011 and is used in only the U.S., compares the sample odour intensity to n-butanol using an odour panel. There are two sub-methods: dynamic and static. The dynamic method uses an olfactometer with a continuous flow of n-butanol. The static method uses a set of bottles with fixed dilutions of n-butanol in a water solution. In both methods, each panellist smells the odourous air sample and then determines which n-butanol sample concentration has a similar intensity. The n-butanol concentrations are correlated to an intensity scale such as those described above.

2.2.3 Odourant Concentration vs. Odour Intensity

Odour intensity increases logarithmically with odour concentration (*i.e.*, the relationship follows Steven's Power Law). The relationship between odour intensity (I) and odour concentration (C; mg/m³), where *k* is an odourant-specific constant and *n* (coefficient of odour increase) ranges from ~0.2 to 0.8, depending on the odourant, is defined as:

$$I \text{ (perceived)} = k(C)^n$$

$$\text{Log } I = \text{log } k + n \text{log } (C)$$

Odourants characterised by larger coefficients for *k* and *n* will have higher perceived odours at a given concentration than will odourants with smaller coefficients (St. Croix Sensory 2005). Also, a 10-fold increase, for example, in concentration will result in a larger perceived increase in intensity for an odourant with a higher *n* coefficient, versus an odourant with a smaller *n* coefficient. The logarithmic relationship can be important for the purposes of odour control (DEFRA 2010) for odourants characterised by a strong intensity at low concentrations.

2.2.4 Diffusibility and Odour Persistence

Diffusibility is a measure of the volatility of odourants based on the ability to reach the olfactory receptors in the human nose (Naddeo *et al.* 2013). The more readily an odourant evaporates, the more volatile it is and the more likely it is to diffuse and be able to reach olfactory receptors. A dimensionless odour index (OI_D) is used to characterise the diffusibility of odourants, and is a function of the vapour pressure of an odourant and its odour detection threshold (Naddeo *et al.* 2013).

Odour Persistence: Odour persistence is used to characterise the decrease in intensity of an odour as it is increasingly dilute with nitrogen or filtered air (Ouellette *et al.* 2006). In other words, some odourants and odours linger for much longer even after being diluted with large volumes of fresh air while other odourants or odours dissipate very quickly. For example, hydrogen sulphide and pig manure odour are more persistent than ammonia and dairy manure odour, respectively (Ouellette *et al.*, 2010).

2.2.5 Hedonic Tone

Hedonic Tone is a judgement of the pleasantness or unpleasantness of an odour, and originates from the Greek word “hedone”, meaning pleasure. The hedonic tone is subjective and independent of the odour character, and is often ranked on a nine-point scale ranging from extremely unpleasant to neutral to extremely pleasant (Pullen 2007; VDI 1994).

The hedonic tone of an odourant can be evaluated by panelists exposed to an odourant for a controlled intensity and duration. The degree of pleasantness or unpleasantness is then determined by the experience and emotional associations of the panelists to the odourants.

2.2.6 Odour Character

Odour Character uses common descriptors such as “fruity”, “chemical”, “moldy”, “soapy”, “floral”, and “sweet” to describe odour. Examples of descriptors for specific chemicals that have distinctive odours are ammonia (cleaning fluid), trim ethylamine (fishy), phenol (medicinal), skatole (fecal), toluene (solvent/hydrocarbon), and hydrogen sulphide (rotten eggs).

Odour panelists describe character using a descriptor from a standard list or in their own words. In the U.S., the common practise for describing odour is to use an odour wheel, where general categorical descriptors are at the center of the wheel and more specific descriptors are placed towards the wheel rim (see Section 4.4.3).

2.2.7 Odour Index

The *Japanese Odour Index* (OI_J) is a standardised scale for measuring odour, much like the decibel scale measures sound. $\text{Odour Index} = 10 \times \log_{10}(\text{Odour Concentration})$, where the odour concentration is based on the dilution at which the panel can no longer correctly identify an odorous bag sample. The analyzes for determining the odour concentration are performed according to the Japanese Triangular Odour Bag Method (Higuchi 2013) or olfactometry.

2.3 Odour Thresholds

Several odour threshold metrics may be used to characterise the concentration of odours. The detection threshold is the most common threshold metric; while the recognition threshold is largely limited to use in the U.S. For odourant mixtures, the odour threshold values are expressed as OU; however, odour thresholds for pure chemicals may be expressed as $\mu\text{g}/\text{m}^3$ or ppmv/ppbv. If only one odourant is dominating an odour effect and there are no synergistic effects with other chemical odourants, the odour threshold for that odourant is useful in assessing and mitigating the overall effects of odour. The following four thresholds are common odour recognition and response metrics.



Odour Detection Threshold Value (ODTV) – the concentration at which 50% of a population, based on the results from an olfactory experiment using an odour panel, would be expected to detect the odourant (VDI 1994).

Odour Recognition Threshold Value (ORTV) – the concentration at which 50% of a population, based on the results from an experimental odour panel, would be expected to recognize the odour (VDI 1994). People might describe the odour, for example, as rotten eggs or cabbage (for sulphur compounds), or fishy (for amines).

Odour Offensiveness Threshold Value (OFTV) – the concentration at which 50% of a population, based on the results from an experimental odour panel, would be expected to indicate that the odour is offensive over a short period of exposure (Bokowa 2008b). The odour might be pleasant or unpleasant, but a pleasant odour might become offensive after frequent or long exposure.

Odour Complaint Threshold Value (OCTV) – the concentration at which 50% of a population, based on the results from an experimental odour panel, would be expected to complain about an odour if exposed to the odour for a short time period (Bokowa 2008a).

Another odour threshold is the “nuisance threshold level”, which the World Health Organization (WHO)(2000) defines as the concentration at which not more than a small proportion of the population (less than 5%) experiences annoyance for a small part of the exposure time (less than 2%) to an odour. Odour issues resulting from nuisance effects may arise when:

- odour sources change with limited warning or planning;
- best management practices related to odour control are not used; and
- urban areas encroach on existing odour sources, or odour sources encroach on existing urban areas.

Published odour thresholds for single odourants vary widely, in some cases by several orders of magnitude. van Doorn *et al.* (2002) noted that odour thresholds reported more than several decades ago were not based on the level of precision of current olfactometry methods and that modern performance tests using dynamic olfactometry have improved the objectivity, sensitivity, repeatability, and reproducibility of odour threshold determinations.

Some references for odour threshold values include:

- Nagy (1991) published ODTV for 87 odourants. The work was sponsored by the Air Resources Board of the Ontario Ministry for the Environment;
- The American Industrial Hygiene Association (AIHA 1989) published ODTV for 102 odourants. The latest data in this publication are from the 1980s;



- Van Gemert (1999) compiled ODTV from 1977 data;
- American Industrial Hygiene Association (AIHA) (1989) compiled odour thresholds for chemicals with occupational health standards; and
- Bokowa and Bokawa (2014) estimated ODTVs for a selection of pure compounds.

A comprehensive set of odour thresholds has been published by Nagata (2003). Several studies comparing odour thresholds that were determined from different methods indicated that the detection thresholds obtained using the Japanese triangle method (*e.g.*, Nagata 2003,) appear to be in close agreement with those obtained using European standard methods (TCEQ 2010). The differences between the methods were considered small compared to those commonly reported for olfactometry. Thus, the variations in some of the earlier datasets listed above are substantially reduced with the use of thresholds published in the last decade.

2.4 Characteristics of Odour Episodes

Factors that affect odour episodes include odourant emission rates, odour character, meteorological conditions, terrain near the source, and the odour sensitivity of the people involved. In addition, more subjective factors such as the frequency of odour detection, air quality expectations, and the hedonic tone of the odour determine whether a person may be concerned about an odour after it has been detected.

Odour episodes are characterised by the five FIDOL parameters, which collectively provide a framework within which odour can be objectively and subjectively assessed:

- F - is the frequency of the detected odour (*e.g.*, once a week, once a month, *etc.*);
- I - is the intensity of the odour, a logarithmic function of its concentration (*e.g.*, weak, moderate, strong, *etc.*);
- D - is the duration of an odour episode - days, hours or only a few minutes;
- O - is the offensiveness. In most cases the smell in a bakery or coffee shop is considered pleasant. However, even a pleasant smell may be offensive depending on the frequency and duration; and
- L - is location where the odour is detected. Odours in the park, patio of a house, school, or church may be more annoying than those detected in or near an industrial workplace where some odour might be expected depending on the nature of the activity.

Frequency and duration, both of which depend on wind direction and the layout of the odour source, need to be considered together when assessing an odour issue. Odour sources may be continuous, (*e.g.*, from agricultural, municipal and industrial facilities), intermittent (*e.g.*, spreading of waste on

land), or a single event (*e.g.*, due to an accident, a process upset, or a disruption in normal operations; bacterial growth in water bodies; animal decomposition on land).

An odour episode typically has to be annoying before concern is expressed in the form of a complaint. Annoyance resulting from odour episodes is most likely to occur in residential areas where annoying odours are not expected. While the reason for an odour complaint may simply be annoyance at the unpleasantness of the odour, other issues may also contribute to responses such as nausea and aversion to and/or interruption of normal activities (such as avoidance of certain areas).

2.5 Types of Odour Sources

Which odour sampling method is used to determine the properties of an odour is dependent on the type of odour source. The following sections briefly identify the types of sources, provide examples of these sources relevant to Alberta, and provide references to other locations in this document that describe appropriate sampling methods for each source type.

2.5.1 Point Sources

A *Point Source* is a localised source of air pollutant or odourant emission, such as stacks or flares. Point sources may occur at ground-level or be elevated. The source parameters normally required to quantify point sources include the UTM or grid coordinates, emission release height (*i.e.*, stack height), exit velocity, stack diameter, exit temperature, and mass emission rates of the substance of concern (ESRD 2013a).

Common examples of point sources in Alberta include:

- electricity generation sources such as stacks associated with coal-fired power plants, biomass generation, gas-fired generation, and co-generation;
- major stack and vent sources at refineries, oil sands processing and upgrading facilities, SAGD facilities, and gas plants. These sources include steam generators, flares, furnaces, *etc.*;
- major sources at forest products facilities including oriented strand board (OSB) plants, sawmills, and pulp and paper mills;
- incineration at municipal waste management facilities; and
- major stack sources at chemical plants.

Most major point sources in Alberta are approved under the *Environmental Protection and Enhancement Act* (EPEA) and approvals granted under EPEA and have limits on emissions of certain pollutants that may also be odourants.

Techniques for sampling point sources are identified in Section 4.1.1. Additional details are provided in Section 6.1.1.

2.5.2 Fugitive Emissions

Fugitive emissions are unintended emissions from a variety of source types. Examples of sources of fugitive emissions include:

- small oil and gas facilities, well sites, and transloading facilities;
- rail car or truck loading and unloading activities;
- doors and windows in enclosed operations;
- recycling or composting facilities; and
- piping flanges, valves, pumps, and other equipment at various heights within industrial facilities such as oil refineries, gas plants, and petrochemical plants.

Fugitive emissions can be considered as point, line, area, or volume sources and may be monitored or modelled in different ways.

2.5.2.1 Line Sources

Line sources occur where emissions are linear in form, such as roads and rail lines (ESRD 2013a). Line source emissions are measured using techniques associated with volume sources or with ambient sampling, and modelled using techniques associated with area or volume sources, as described in Sections 4.1 and 6.1. Parameters normally required to quantify line sources include the dimensions of the line and mass emission rates of the substance of concern. Other examples of line sources are emissions from rooftop vents.

2.5.2.2 Area Sources

Area Sources are clusters of point or line sources (*e.g.*, fugitive emissions from industrial processes having numerous vents) (ESRD 2013a). Parameters normally required for quantifying area sources include the coordinates of the area perimeter, the emission release height, and the mass emission flux rate of the substance of concern (*i.e.*, mass emission rate per unit of area, $g/s/m^2$). Emission rates associated with area sources are typically not easily measured since the emissions from the surface area are diffuse, likely intermittent, and not uniform across the source. Area source sampling techniques are described in Sections 4.1.2 and 6.1.2.

Examples of area sources in Alberta include:

- Sewage ponds and landfill sites associated with municipal waste management;
- Tailings ponds at mine sites; and
- Most agricultural sources, including land applications (*e.g.*, manure), herbicides, and pesticides, as well as composting piles and confined feeding operations.

2.5.2.3 Volume Sources

Volume Sources are three-dimensional sources of diffuse air pollutant or odourant emissions, such as area sources distributed with a vertical (height) depth (ESRD 2013a). As with area sources, emission rates associated with volume sources are not easily measured since the emissions from volume sources are diffuse, likely intermittent, and not uniform across the source. Parameters normally required for quantifying volume sources include the coordinates of the volume dimensions and the mass emission rates of the substance of concern. Volume source sampling methods are discussed in Sections 4.1.3 and 6.1.3.

Common examples of volume sources in Alberta include:

- emissions from small businesses such as retail outlets, dry cleaning facilities, and garages;
- agricultural storage; and
- secondary agricultural processing including slaughter, canola, sugar beets, biofuel production, food processing, rendering plants, pet food, and grain alcohol.

Many odour sources can be considered either area or volume sources depending on the distance of the source from a location of interest. For example, an assessment of emissions from a refinery or chemical plant may classify the collection of emissions from a variety of small sources such as vents, short stacks, and equipment leaks as a volume source if the assessment was concerned with a location across the street from the source. However, the source could also be considered an area source if the assessment was concerned with a location several kilometres from the facility, where the height of the facility sources would be small relative to the distance separating the source and the receptor.

2.5.2.4 Multi-Source

A multi-source air pollutant or odour emission is comprised of a collection of potential sources (*e.g.*, from within a facility or within an area with multiple sources). Multi-source odour emissions can be investigated using approaches applicable to volume sources, which could involve the use of ambient sampling techniques (Sections 4.2 and 6.2).

Cumulative emissions can occur simultaneously from several point, line, area, and volume sources located in close proximity to each other. Cumulative emissions from multiple sources can be treated as emissions from a single area or volume source.

2.6 Factors Affecting Odour Emissions

2.6.1 Terrain

Landscape characteristics influence the dispersion of odour emissions and the effect of odour emissions on potential receptors (*e.g.*, people). Dispersion of odour emissions is inhibited if the

emission source is located in a valley or a depression, but enhanced if the emission source is located on high ground or the emission point is located well above the ground. Due to the physical barriers they create, valleys can channel winds, and with that they may also channel emissions, which may result in high concentrations of an odour emission being channeled for a long linear distance, rather than dispersing in multiple directions. Odourant flow can also be directed around obstacles that are high relative to plume height.

Tree cover can reduce odour concentration by enhancing dispersion (reducing odour concentration) and providing surfaces for deposition of odourants.

2.6.2 Meteorology

Meteorology can influence odour episodes in two ways: it can affect the thermodynamic nature (*e.g.*, volatility) of odour emissions generated by a source, and it affects the atmospheric transport, dilution, and dispersion of odour emissions when they leave their source.

2.6.2.1 Temperature & Humidity

Factors such as ambient temperature and humidity affect the perception of odour. Higher temperatures and humidity increase the likelihood of detection. During precipitation, the actual concentration of odour is generally reduced. The volatility of odourants increases during warm weather, and odour emissions from open tanks and storage piles will increase during summer months, leading to increased odour potential during this season. Odour emissions from other sources such as industrial processes may also increase if the process is affected by warm weather. Other reasons for increased odour detection in summer include the opening of windows and doors at facilities and an increase in the number of people outdoors.

2.6.2.2 Wind Velocity

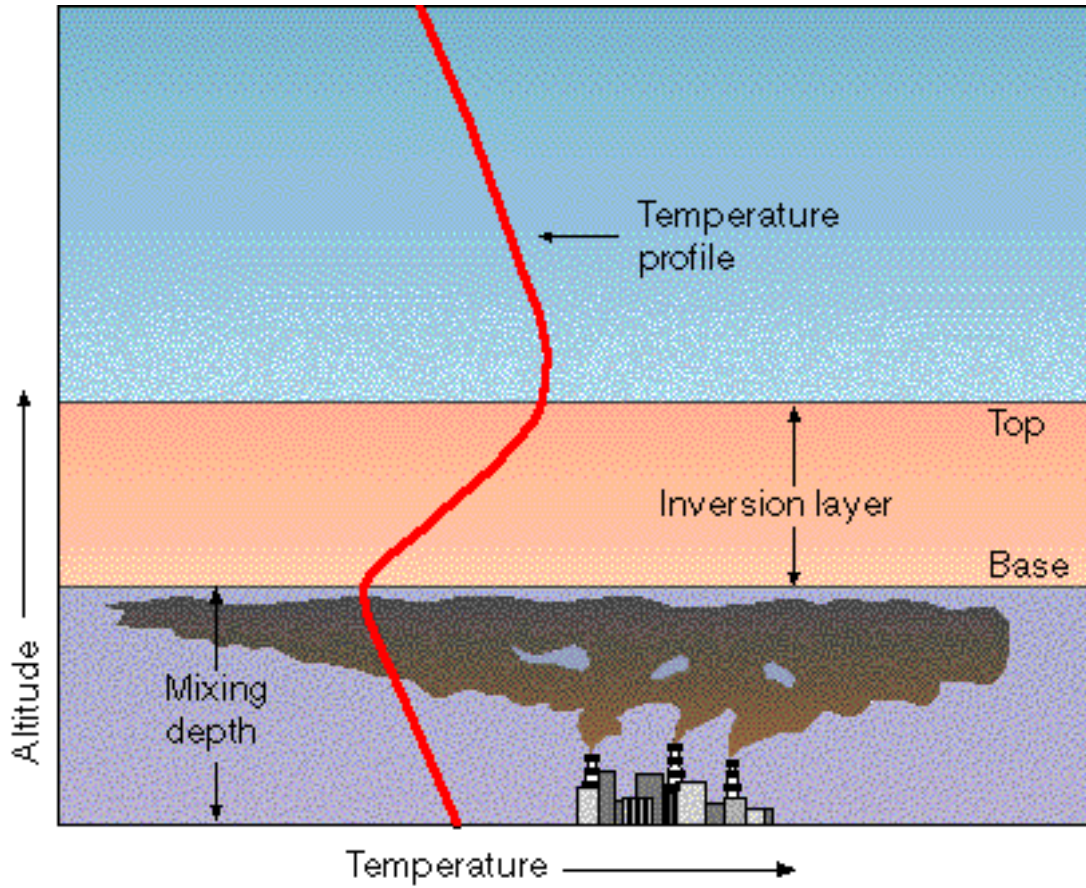
To detect odour, the odour source must be located upwind; therefore, wind direction is a key factor in odour potential. Odour emissions from open tanks and storage piles may be increased by higher wind velocities but this effect is somewhat balanced by increased dilution and, in some cases, improved atmospheric dispersion under windy conditions.

2.6.2.3 Mixing Height

Mixing height (mixing depth), inversions, and atmospheric stability are concepts that affect dispersion of odourous emissions (Figure 2.6-1). Mixing depth is the lower atmospheric layer characterised by relatively constant potential temperature, with an increase in temperature above this layer (the inversion). The inversion acts like a lid limiting the depth through which an odourant plume is mixed. Tall stacks emitting odourants above the mixing height result in reduced ground level odour.



Mixing heights vary by season and are generally lower in winter. Chinook winds in western Alberta frequently create inversions that trap emissions near the surface. Ground-level emissions (*e.g.*, from area sources) cannot easily penetrate to the layers above mixing heights. The most intense odours typically occur in stable conditions with light winds that inhibit the mixing of odour plumes. The more unstable is the atmosphere, the higher the mixing height is. Usually higher wind speed causes an increase of the mixing height due to mechanical turbulence. However, mixing height is dominated by surface heat flux and in cold temperatures the mixing height may be relatively low (Figure 2.6-2).



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Figure 2.6-1 Inversion Layer - Mixing Depth Concept
(http://apollo.lsc.vsc.edu/classes/met130/notes/chapter18/dispersion_intro.html)

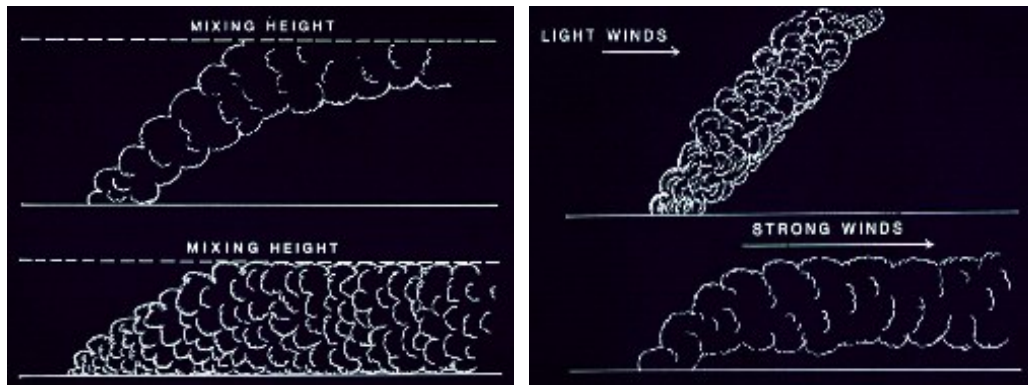


Figure 2.6-2 Inversion Layer and Wind Speed Effect
(http://www.auburn.edu/academic/forestry_wildlife/fire/smoke_guide/smoke_dispersion.htm)

3.0 ODOUR ASSESSMENT

3.1 Purpose of Odour Assessments

Odour assessments are generally performed to:

- verify and investigate odour complaints;
- comply with conditions outlined in operating/industrial permits, including the verification of emissions;
- determine compliance with odour legislation;
- assess long term odour exposure levels in an area;
- rank potential odour sources for mitigation purposes;
- determine background odour concentrations before building a new facility;
- determine the off-site odour impact from existing operations; or
- determine the expected changes in off-site odours resulting from new facilities, expansions of existing facilities, or other operational changes.

An assessment could be focused on specific emission sources, either existing or planned in order to provide the current or predicted odour emissions along with the expected impact of these emissions. The most common methods of odour assessments for odour emission sources include odour emission measurements (although for a pre-development assessment, measurements are not currently common in Alberta), with dispersion modelling used to predict the off-site odour or odourant concentrations associated with these emissions. For both existing and planned developments, the assessment may include odour emission estimates based on similar developments or calculated odour emission estimates using sources or odour threshold values for pure compounds and the estimated emissions of these compounds. Background odour may be added to the assessment.

- An odour assessment could involve source or ambient measurement of odour or odourants, or modelling of the predicted change in odour from a change in activities. An assessment may also consider possible mitigation measures or avoidance opportunities that could be applied at the odour source, at odour receptors, or at a location between the source and its receptors (NSW 2006).
- Conversely, an assessment may focus on the communities or areas in which odour associated with emissions may be detected in the ambient air. Ambient air assessment may include community/resident odour surveys, observations, questionnaires for residents, odour complaint reports, and ambient odour sampling or monitoring.
- In Alberta, odour assessments are often performed to determine off-site odour impacts from proposed or expanded industrial facilities. A change in operating procedures in existing facilities may change emissions of odourants. An odour baseline (see Section 3.4) provides a

means of establishing current conditions such that the impact of any changes can be identified and quantified.

3.2 Types of Odour Assessments

As indicated in Section 3.1 above, the particulars of how an odour assessment is performed will depend on its purpose. For instance, if the purpose is compliance with an industrial permit then a measurement of source emissions might be required. On the other hand, if the purpose is to investigate odour complaints or to verify compliance with an existing ambient air quality standard, then the assessment may require ambient air monitoring. Other considerations are assessment associated with existing, proposed, modified, or expanding facilities or operations. In some cases, odour assessments may combine a number of different approaches (*i.e.*, ambient air assessment, source emission assessment, dispersion modelling, *etc.*).

3.2.1 Overview of Types of Odour Assessments

There is no standard method for odour assessments; however, there are a number of components to an assessment (*e.g.*, source odour measurements, dispersion modelling, ambient air testing and monitoring) and an odour assessment will generally include a combination of these components.

Odour assessments may vary in their detail. DEFRA (2010) states “the degree of detail provided in such assessments should be proportionate to the risk of odour impact, taking account of factors including the proximity of receptors, the scale of the proposed activity and the nature of the proposed development.” Screening assessments typically involve simple, low-cost approaches designed to identify some general characteristics of an odour issue. Examples include non-analytical methods such as odour wheels, ambient measurements such as some types of integrative monitors, or screening dispersion models. Detailed assessments are designed to provide more data and a more rigorous understanding of the problem, and could involve olfactometry, continuous emission measurements, or advanced dispersion models. Screening and detailed assessments are identified in Section 4.

The following approaches may be used for conducting odour assessments:

- **Ambient odour assessment** involving off-site odour monitoring techniques such as real time ambient odour monitoring, community odour surveys, electronic noses, continuous or semi continuous monitoring for specific compounds or groups of compounds (*e.g.* total reduced sulphur compounds) odour mapping or investigation of community responses to surveys or subjective odour event diaries. Ambient techniques are summarised in Section 4, with advantages and disadvantages of each technique discussed.

- **Source odour assessment** which includes odour and/or specific odourant measurement/estimation at potential odour sources at the facility and determination of odour emissions rates for each source. The emission rates are then used to predict off-site odour concentrations generally using dispersion modelling assessment. The odour sources can be a point source such as a stack or vent, an area source such as a lagoon, or a fugitive source such as an open door or truck containing odorous material. The odour emission rates determined for the potential sources at the facility can be used in dispersion modelling to predict off-site odour, or specific compound (such as sulphur and volatile organic compounds) concentrations at residences or other sensitive receptors such as schools, parks and community centres.
- **Inventory assessment** of facility materials and odour emission sources. Nominal odorous emissions can be assigned to typical sources, based on published measurements at similar facilities and the scale of operations. This approach can be undertaken where odour emissions cannot be directly measured.

Assessments can be made for existing or new facility activities or changes in activities.

For existing activities, an assessment would include documentation of community recordings or odour complaints (if any), a determination of sources and potential causes of odour releases, a ranking of potential odour sources to aid in odour management, prediction or monitoring of ambient odour levels, and a review of odour management and control strategies.

Assessments of new activities could include comparison of ambient odour or odour emissions at a similar existing facility to determine a predicted odour impact. In addition, the odour background in the area selected for the new operations could be assessed. Assessment of odour potential at new facilities in Alberta typically involves a dispersion modelling assessment, with emissions often based on engineering estimates or standard sources such as the U.S. EPA AP42 website.

Assessments for modified facilities, which include expansion or process alterations, could begin with the assessment of the existing odour emissions to provide baseline information. The predicted new emissions from the process changes can be determined based on the baseline information and using estimated odour emission changes through the emission inventory approach and a dispersion modelling approach.

3.2.2 Assessments Based on Ambient Monitoring

Ambient monitoring approaches to odour can be considered as objective or subjective.

In an objective assessment, odour is typically established by ambient measurement techniques that use analytical methods (*e.g.*, those in Section 4.3) that are repeatable.

In a subjective assessment, the feelings of an odour observer of liking, pleasure, acceptance, and of valuation are expressed. Because subjective assessments usually involve expressions of pleasure (or displeasure), they are often called hedonic (EPA SA 2007). The non-analytical assessment methods in Section 4.4 are typically subjective, although comparisons can be made to scales.

3.2.2.1 Objective Techniques

Ambient air odours can be assessed using a variety of objective methods such as:

- Ambient odour sampling at specific locations, usually downwind of a potential odour source, followed by odour panel evaluation on the collected samples to determine the odour concentrations at these locations;
- Ambient monitoring using portable olfactometers such as the Nasal Ranger (St. Croix Sensory 2012) or other sensory-based monitoring devices;
- Ambient odour intensity measurements expressed in concentration units (OU);
- Ambient sampling or monitoring for specific odourants such as hydrogen sulphide, reduced sulphur compounds, ammonia, volatile hydrocarbons, and amines with comparison of measurements to odour thresholds; and
- Continuous monitoring either for specific odourants or for odour (examples: electronic nose or OdaLog (Thermo Fisher Scientific 2011)).

Measurements of methane or total hydrocarbon can be used to detect the presence of the plumes that may contain odourants to verify the potential presence of the odour. Dispersion modelling can also be done using dominant components (*e.g.* hydrocarbon). This approach which also identifies the potential for odour is currently used in the oil and gas industry in Alberta.

3.2.2.2 Subjective Odour Investigations

Subjective odour investigations are often conducted by residents in the vicinity of odour sources, but can also be conducted by regulators, operators, or consultants. Subjective measurements are typically part of complaint data collection procedures. For example, the Alberta Energy Regulator (AER) notes that the starting points for odour investigations begin with identifying or summarizing odour complaints (typically subjective), followed by the use of human senses including smell, and then followed by objective measurements if needed (AER 2014).

Subjective investigations include:

- Community odour surveys/observations performed in the vicinity of (particularly downwind from) potential odour sources using experienced and trained community members and not trained field inspectors (McGinley 1995; Brancher and de Melo Lisboa 2014);



- Odour diaries compiled by facilities or residents. Diaries provide a means to record short term odour episodes, and to show changes and trends in odour impacts (ATSDR 2014; EPA VIC 2014a). They may also be useful in distinguishing between two or more sources of odour, if the reporter keeps good records of the nature or characteristics of the odours. Similarly, simple local wind or weather records used in conjunction with odour diary records can also help identify or confirm the source of recorded odours. Diaries can incorporate a standard format which enables air quality information to be captured in a consistent manner on a daily or weekly basis with a particular emphasis on odour episodes. The diary could detail of the observer/recorder perception of the odour and any effects that the odour has on behaviour or health; and
- Sensory observations, where one or more trained individuals observe odour at locations that are not necessarily downwind from potential odour sources. This method provides direct data on the frequency of “odour hours” at receptor points and odour exposure levels over the long-term. A standardised method for this type of observational monitoring is outlined in VDI/DIN3940:200648 (VDI 2006).

3.2.3 Assessments Based on Source Sampling

To estimate odour emissions from sources, representative odour samples are collected from potentially significant sources. These sources may be selected based on the experiences of facility personnel, information about the facility operations or the expected performance of odour control equipment. Samples are evaluated in the laboratory by an odour panel for the odour concentrations, which are later used together with measured or estimated source volumetric flow rates to estimate the odour emission rates.

Typical sources contain a mixture of compounds and it is very rare that only one or a few compounds are responsible for odour detection or complaints. Therefore, the characterization of odourant emission sources based on odour units that can be used in modelling input is generally the most appropriate method for odour assessment.

For all types of sources, samples collected for total odour analysis should be evaluated for ODTV, OFTV, OCTV, or ORTV using dynamic olfactometry with an odour panel. ODTV (in units of OU) and measured flow rates (m^3/s) are used to calculate the odour emission rates, which can be used in dispersion modeling analysis to predict off site odour concentrations.

Source sampling may also be used for sampling specific compounds such as ammonia and hydrogen sulphide. Samples are analyzed by analytical methods. Once measured, emission rates can be used by dispersion models. Predicted off-site concentrations of the specific odourant may be compared with the limits or correlated with the ODTV for that compound to estimate the total odour

concentration expressed in units of OU. The use of ODTV values based on current and reproducible methodologies, with the application of a safety factor, is prudent in this case.

3.2.4 Inventory Assessment

Where emission measurements are not available, and are difficult or impossible to directly measure, alternative means of estimating emissions and assessing odour can be used. Two examples of this approach are the use of emission factors for specific sources from established publications (such as the U.S. EPA 2014a) or emission estimates for entire facilities that can be scaled based on production. This approach should be used with caution and when there is confidence that the emission factors and/or scaling approaches are applicable to the odour issue being assessed.

An example of this kind of assessment is for facility amendments due to changes to operations. In this case, amended emissions and sources can be compared to original emissions and sources. If emissions and sources are not significantly different, it could be established that a potential for increased odours is unlikely and that there is no need for additional assessment using measurement or modelling. In another example, if emissions increase, scaling can be used to assess the potential for increased odours based on current ambient odour levels.

3.2.5 Assessments Based on Dispersion Modelling

A common approach for facility odour assessment in Alberta is source sampling with dispersion modeling analysis to predict off-site odour concentrations or concentrations of odourants at selected sensitive receptors. This method is used because it addresses all meteorological conditions and provides more spatial information than ambient air monitoring alone. Odour source sampling is the estimation of odour emissions from potential odour sources at the facility (Section 3.2.3).

Three basic approaches can be used to model odourants from multiple sources:

- exposure to individual chemicals;
- aggregate exposure – using total odour emissions in odour units per second (OU/s); and
- aggregate exposure – modelling individual chemicals and summing their odour potential.

In the individual chemical approach, each odourant is modelled separately, and comparisons are made to individual odour thresholds and assessments of odour potential are made on this basis. In terms of the odour assessment, the use of a single-odourant-by-single-odourant approach can underestimate the frequency of odour detection (Cometto-Muniz *et al.* 2004).

Odourants predicted at lower concentrations (even at or below threshold levels) when aggregated may generate observed odour (Kim and Park 2008). In the odour unit (aggregate) approach, odours

are calculated as emissions (OU/s), modelled directly and then processed as a single compound (total odour).

In the third approach, the predicted concentrations of odourants are divided by their respective odour thresholds, and the resultants in OU are summed over all odourants modelled. Generally, the second approach (aggregate odour unit), is expected to be more conservative as it accounts for all odourants in the mixture. Nonetheless, for industrial processes, knowledge of the contribution to odour of individual odourants can be important to the management and reduction of odour.

Predicted odour concentrations derived from dispersion modelling are used to assess odour potential by comparing with ambient air quality odour criteria. For example, an acceptability criterion may be a predicted three-minute average odour concentration of 7 OU for no more than 0.5% of the time (the 99.5th percentile) such as established for sensitive land uses near existing poultry farms by the Government of Western Australia (2002). The Ontario standard is that 1 OU may not be exceeded more than 2% of the time (Ontario MOE 2010).

Units of odour measurement and modelling can be confusing. Odour measurements (*e.g.* using an odour panel or a Nasal Ranger) assume odour concentrations in OU or D/T, respectively. Dispersion models use OU/s units as a “mass” emission rate which is obtained by multiplying OU by the volumetric flow rate of the source expressed in m³/s (method ON-6 in Ontario MOE 2010) as noted for example in Section 4.10 and 4.11 of NZMFE (2003) or the CALPUFF User Guide (TRC 2011).

3.3 Odour Baseline

An odour baseline establishes odour concentrations prior to development or activity changes that may result in changed odour emissions. For example, before a new facility is built, an odour baseline may be completed, particularly if odour sources already exist in the area. The odour baseline can be based on ambient odour measurements/monitoring or community odour surveys. It can also be based on emission factors for existing sources of odour.

An odour baseline should also survey the locations of sensitive individuals in the area such as residences, schools, and recreational facilities.

The typical use of an odour baseline is to add to it estimates of odour resulting from emissions expected from a new or expanded facility or activity. This can be accomplished with dispersion modelling to predict odour concentrations throughout the area and particularly at the location of sensitive individuals. As such, results from the odour baseline, in conjunction with the changed emission profile of the facility or activity, may affect the design of the facility or nature of the activity with respect to process conditions, odour control equipment, or emission siting and timing.

4.0 ODOUR ASSESSMENT TOOLS AND PRACTICES

4.1 Source Sampling and Measurement

Potential odour sources may be sampled for total odours and/or specific odourants such as ammonia, hydrogen sulphide, amines, ketones, and aldehydes. Sampling methods vary based on the nature of the odourants being sampled, the sample analysis method and purpose, and the source type (*e.g.*, point, area, or volume) being sampled.

Sampling methods vary by jurisdiction. In Europe most countries use the methods outlined by VDI 3880:2011 (VDI 2011) and/or European Standard EN: 13725:2003 (CEN 2003). The EN13725 standard is designed for odour analysis rather than sampling. Sampling in Australia and New Zealand follows methods outlined by the SA/SNZ (2001). Compliance sampling for odour in Ontario follows the Ministry of Environment (MOE) Method ON-6 (Ontario MOE 2010). The sampling approach in Quebec is similar to Ontario's. There is no specified federal U.S. sampling methodology for odour. In most states, a simple grab sample is common using the lung method, which collects an undiluted/grab sample from a point source. This method is not acceptable in Ontario, especially for moist, high-temperature sources, when there is a potential for condensation, chemical reaction, or oxidation and, therefore, a significant loss of odour. The loss might be as high as sixteen-fold (Bokowa and Beukes 2012). High-flow Differential Absorption Light Detection and Ranging (DIAL) has been used in Alberta for locating and measuring fugitive emissions from upstream oil and gas facilities (ARC 2006; Chambers *et al.* 2006), although not specifically for odour measurement.

Source sampling involves collection of gaseous samples, using specialized sampling procedures, and evaluation of the samples to determine either the odour detection threshold values (for odour) or the concentrations of odourants. These methods are used, in conjunction with volumetric flow rates, to calculate odour or specific odourant emission rates.

Sampling of fugitive odour emissions from area, volume, line, or multi-sources is challenging because these types of emissions are diffuse, may not be spatially well-defined (*e.g.*, leaks within a plant process area), may last briefly, and be influenced by meteorological conditions. A further difficulty is determining the emission rate after sampling and analysis are completed, which involves estimation of the area or volume of the fugitive emission sources and the "exit" velocity of the emissions, which may be wind-speed dependent. It may be possible in some cases to capture fugitive emissions in a temporary enclosure for sampling and analysis purposes (SA/SNZ 2001).

Sections 4.1.1 and 4.1.2 describe two approaches to collecting whole-air samples for subsequent analysis. Sections 4.1.3 to 4.1.5 describe approaches to collecting whole-air samples from area sources into containers that can be subsequently analyzed. Section 4.1.6 describes approaches to collect whole-air samples for analysis and remote sensing measurement approaches from volume sources. These tools are discussed in more detail in Section 6.1.

4.1.1 Point Source Methods

Point source methods are further explained in Section 6.1.1.

4.1.1.1 Lung Sampling Method

Lung sampling methods involve collection of the sample in a sample container (like a Tedlar bag), which is subsequently analyzed. This method is less common and less accurate for sources with high odourant or moisture concentrations. Special precautions should be taken to avoid condensation and adsorption during sampling, including storage of the samples at a temperature sufficient to prevent condensation and timely analysis.

The sampling time depends on the jurisdiction and the nature of the emission source. The lung sampling method is appropriate for collecting samples from sources with the following characteristics:

- The odour concentration in the sample is low so that if pre-dilution was used, the odour concentration after pre-dilution would be too low for the diluted sample to be reliably evaluated by an odour panel;
- Water or other compounds in the undiluted sample do not condense during the period between sample collection and odour panel evaluation if there are changes to the temperature or pressure of the sample; and
- There is no obvious sign of condensed material in the sample as it is collected.

More information is found in Section 6.1.1.

4.1.1.2 Dilution Sampling Method

The dilution sampling method is used to collect samples with high odour concentrations that exceed the upper operating limit of the olfactometer, or if condensation of either moisture or odourants could occur in the sampling bag during the time between sample collection and evaluation.

There are two methods of dilution sampling using bags:

- The Dynamic Dilution method involves direct collection of a sample from a source, using a dynamic sampler. A dynamic sampler has the capability to dilute samples on site with nitrogen to prevent condensation, oxidation, or chemical reaction within the sample prior to odour panel evaluation.
- With the Static Dilution method, the gas is collected directly to a sample container that contains a known volume of nitrogen.

More information is found in Section 6.1.1.

4.1.2 Area Source Methods

In the three area source sampling methods included in this section and Section 6.1.2, air containing odour or odourants is drawn from a surface and collected in a container. The odour or odourant concentration is determined by analysis and the emission rate is estimated on the basis of the sample collection characteristics (flow rates). The methods described here are ways to direct samples from the surface to a collection device.

4.1.2.1 Flux Chamber Sampling Method

The flux chamber is used to collect odour samples from area sources such as the surface of solid or liquid material (U.S. EPA 1986; Zarra *et al.* 2012). In this method, a small domed chamber is placed over a selected part of the surface and then sealed. Valves on the upper surface of the dome allow sweep gas to enter the dome and odour sample to exit the dome into a sample collector (Tedlar bag, canister, impinger, *etc.*). The collected sample is then analyzed.

4.1.2.2 Wind Tunnel Sampling Method

The wind tunnel sampling method (Wang *et al.*, 2001) is similar to the flux chamber sampling method and is used to collect odour samples from solid or liquid surfaces. Instead of a domed chamber, a wind tunnel with an elongated box shape is employed.

4.1.2.3 Static Hood Sampling Method

This method is commonly used for active surface sources such as biofilters and aeration tanks (VDI 2011). In this technique, a sample over a surface is drawn up a small stack. The stack is fitted with a sampling port and the sample is drawn up the stack for subsequent analysis using point source sampling methods (*i.e.*, lung or dilution methods – see Sections 4.1.1 and 6.1.1).

4.1.3 Volume Source Sampling

Quantifying odour emissions from volume sources such as valves, pump flanges, doors, windows, process areas, and transport trucks, is challenging. The sources are typically not well defined (such as those from truck unloading). There can be numerous fugitive emissions within a facility (*e.g.*, valves, flanges, and fittings). In some cases, emitted substances can be trapped within cavities associated with air flow near buildings or structures.

The usual approach for sources of this nature is to use lung techniques coupled with a quantitative analysis technique to determine the odour or odourant concentration near the source, and then use dispersion modelling to estimate emission rates from the source of fugitive emissions. Another approach is to cover the fugitive source and treat it as a point source. As a further alternative, remote sensing can be used to measure the concentration *in situ*. When coupled with knowledge of the flow

characteristics in the area of measurement, the emission rate can be determined. As above, dispersion models can be used in reverse to estimate emission rates from the remotely sensed measurement.

Further information is available in Section 6.1.3.

4.2 Ambient Odour Monitoring

Ambient odour monitoring for measuring odour levels (*e.g.*, in OU), is usually carried out downwind of odour sources but may also be conducted upwind to confirm the contribution of background sources. There are several methods of ambient odour monitoring described in this section. The methods summarised in this section are further explained in Section 6.2. Ambient measurements can also be made using analytical approaches, which are described in Sections 4.3 and 6.3.

4.2.1 Ambient Sampling

Ambient sampling (see Section 6.2.1) for odour assessment is typically conducted using lung sampling techniques (with the sample collection done in ambient air rather than within a source such as a stack). Typically, lung sampling techniques are used to collect samples that are subsequently analyzed using analytical (Section 6.3) or non-analytical (Section 6.4) assessment methods.

In conjunction with dynamic olfactometry, ambient sampling is one of the most common and appropriate methods to assess odour, provided the odour concentration is sufficient to give panelist responses at the lowest dilution levels of the olfactometer. If the odour concentration is too low for a sample to be evaluated by olfactometry, then the odour panelists can evaluate the sample directly in the sample bag without the need for further dilution that is the basis for dynamic olfactometry.

The lung sampling procedures for ambient odour monitoring are similar to those described in Sections 4.1 and 6.1. Typically, the sampling probe is located about 1.5 m above ground level but specific heights may be selected based on the nature of the monitoring program. Sampling periods depend on the jurisdiction (*e.g.*, 10 minutes in Ontario) but can vary depending on the nature of the upwind source and the meteorology.

4.2.2 Portable or Field Olfactometry

A portable olfactometer (see Section 6.2.2), such as Nasal Ranger or Scentroid; directly determines the odour concentration in the ambient air without having to collect a sample in a container.

The portable olfactometer, which is used one person at a time, draws ambient air into a portable olfactometer, which is basically a portable dilution device. The diluted sample is presented to the odour observer via a face mask and the observer indicates whether an odour can be detected at each dilution. The results are used to calculate the detection threshold, which is the number of dilutions needed to make the odour in ambient air non-detectable.

All portable olfactometers (Nasal Ranger and Scentometer) are based on individual readings for one minute, whereas ambient sampling for laboratory olfactometry generally occurs for a longer time. Portable olfactometry is considered to be a screening tool only, because the method is expected to be less accurate than ambient sampling combined with the dynamic olfactometry. The portable olfactometer has limited dilution levels and therefore is less accurate than the lung sampling method, but is useful for screening purposes (Bokowa 2008c). One observer operates the instrument; therefore, results depend on operator sensitivity. In addition, the observer likely breathes odourant before using the portable olfactometer, increasing the opportunity for odour fatigue.

A description of portable olfactometers is provided in Sections 6.4.5 (Field Olfactometry).

4.2.3 Community Surveys

A community odour survey (see Section 6.2.3) consists of the evaluation of odour by experienced and trained community observers (not trained field inspectors) in a structured observation session, in which the odours are rated using a standard intensity scale at prescribed locations. Training is conducted by odour measurement specialists.

The community odour survey can be an effective alternative or supplement to source testing for odour, particularly in cases where there are a number of potential odour sources that can affect a community, where sources are difficult to sample, or when sources are expected to vary with meteorological conditions. Usually, observations are made periodically over an extended time frame.

The survey can result in a large database of odour observations, which can provide a reliable indication of the impact of odours in the area.

4.3 Analytical

4.3.1 Electronic Nose

The electronic nose (see Section 6.3.1), through electronic sensing and a pattern-recognition mechanism, identifies the chemical constituents of an odour to identify that odour (Rök *et al.* 2008; Wang and Liu 2011). The sensing system consists of an array of sensors that will undergo a physical change (*e.g.*, temperature change, mass change, resistance changes) when their surface makes contact with a volatile compound. This response of the sensor to the compound is recorded in digital value. Through pattern-recognition statistical models, the compounds are identified, much like the brain will process the information transmitting from the olfactory receptors in the human nose.

4.3.2 Continuous Monitoring

Continuous monitors are described in Section 6.3.2.

4.3.2.1 Emissions

Continuous source monitors are frequently installed at facilities, particularly at combustion facilities, to monitor emissions of individual compounds, including odourants.

Odourants may be monitored as individual compounds (*e.g.*, hydrogen sulphide) or as groups (*e.g.*, total hydrocarbons). Data on combustion gas concentrations (primarily oxygen, carbon monoxide and carbon dioxide), together with the gas temperature, may be included as input to combustion process optimization and odour emission minimization. Continuous source monitors can be installed on stacks to monitor emissions immediately before they are discharged to the environment.

Continuous monitors typically measure concentration data for individual compounds every few seconds and record the data as one-minute average values. There are no intermediate steps and the gas sample is analyzed directly by the continuous emission monitor.

4.3.2.2 Ambient

Technology that is similar to continuous emission monitoring is used to continuously measure concentrations of specific gases in ambient air, typically in Alberta communities or outside the fence lines of industrial facilities. Continuous monitors form the backbone of air quality monitoring networks in Alberta (CASA 2006).

Continuous monitors can provide automated operation, fast instrument response, and store many measured values. In these aspects they are ideal for measuring some characteristics of odour. Typically, each monitor measures a unique odourant and this is a limitation for odours resulting from mixtures of gases.

4.3.2.3 Alberta Air Quality Health Index

The Alberta Air Quality Health Index (AAQHI) is an example of an ambient monitoring program (fine particulate matter, ozone, nitrogen dioxide, sulphur dioxide, carbon monoxide, hydrogen sulphide, and total reduced sulphur) set up to relay health-related information to the public (ESRD 2014a). Comparisons of individual hourly pollutant concentrations are compared to the Alberta Ambient Air Quality Objectives (AAAQOs) and, based on a compilation of comparisons, the AAQHI is calculated.

The AAQHI was designed to be an air quality index, not an odour index. The concept of the AAQHI has been the basis for a preliminary odour index whose further development is under review (personal communication from Richard Sharkey, ESRD).

4.3.3 Semi-Continuous Monitoring

Semi-continuous monitors measure concentrations over many minutes to hours compared to continuous monitors, which typically measure concentrations over seconds. Semi-continuous monitoring involves subsequent steps such as the separation of odourants by a gas chromatograph and detection by a suitable detector. The time required to obtain successive measurements is dependent on the time required to separate the odourants by the gas chromatograph.

Semi-continuous methods are described in Section 6.3.3.

4.3.4 Intermittent/Integrated Monitoring

Intermittent monitoring refers to the timeframe in which sample collection is completed, and usually involves collection for a finite period of time that can range from a few minutes to hours depending on the application.

Most methods for determining concentrations of odourants in a gas stream at source, on an intermittent or integrated basis, involve the use of adsorbent tubes or impinger solutions to collect and concentrate the compounds prior to analysis. In gas streams, sampling times of one hour are typical but this can vary depending on the requirement of the standard method, expected duration of the odour episode, or the desired detection limit.

The monitoring methods can be used for whole-air samples for olfactometry or for specific odourants.

Recovery methods for adsorbent tubes include thermal desorption and extraction with a suitable solvent. Analytical methods for the extracted odourants include gas chromatography (GS) with a flame ionization detector or a mass spectrometer detector, although some groups of specific odourants require other types of analytical methods. An example is the analysis of reduced sulphur compound species which requires a chemiluminescence or a flame ionization detector (Luong *et al.* 2013).

Draeger Tubes are a special form of integrated sampling for odour, carried out by passing a fixed volume of odourant through a glass tube packed with an adsorbent material. Determination of the concentration for a specific odourant relies on the change of colour of the adsorbent material, which is proportional to odourant concentration. These monitors provide a fast, inexpensive method for determining compound concentrations but the results are less accurate than those obtained by standard methods for sampling and analysis. Other disadvantages are the high detection limits and

the effect of interference from other compounds. Therefore, Draeger tubes have limited potential for measuring odour near detection thresholds.

Evacuated cylinders made of stainless steel, or coated stainless, can also be used for sample collection (Ayers, 2002). “Grab” sampling refers to collection of periods ranging from seconds to a few minutes which is typical of the time associated with whole-air sampling for odour evaluation. Longer duration samples require a flow controller. Canister sampling is one of several approaches currently used in response to odour complaints is the Rural Municipality of Wood Buffalo (WBEA 2014).

Intermittent and integrated samplers are discussed in Section 6.3.4.

4.3.5 Passive Monitoring

Passive or diffusive sampling relies on the unassisted molecular diffusion of gases through a diffusive surface onto an adsorbent. Unlike active (pumped) sampling, passive samplers require no electricity (for pumps), have no moving parts, and are simple to use (no pump operation or calibration). After sampling, the adsorbed gases are desorbed off the adsorbent by solvent or thermal desorption.

Most commercially available passive/diffusive samplers offer lower sampling rates and limited sampling capacity. As a result, sensitivity can suffer during the short-term sampling required for odour assessments (due to low diffusion rates). Some improvement in sampling rates can be had by improving the geometry of the diffusive surface.

Passive samplers augment air quality sampling networks in Alberta, especially for H₂S, SO₂, and NO₂. However, exposure periods to accumulate sufficient sample within the sampler adsorbent are too long to be useful for odour assessments, even as a screening tool (Section 6.3.5).

4.4 Non - Analytical

4.4.1 Triangular Odour Bag Method

The Odour Index is commonly used in Japan to quantify the odour intensity of odours, and is defined as:

$$\text{Odour Index} = 10 \times \log (\text{Odour Concentration}).$$

In Japan, odour concentration is determined using the Triangular Odour Bag Method (JME 2006). The panelists identify the one bag with odour (two more bags have blanks), and the odourant is gradually diluted until it becomes impossible to identify the sample bag. The odour index is based on this final dilution. See Section 6.4.1 for more information.

4.4.2 Odour Descriptor Wheel

Numerous standard odour descriptor lists are available to use as referencing vocabulary. For example eight recognized odour descriptor categories are illustrated as an “odour wheel”: Vegetable, Fruity, Floral, Medicinal, Chemical, Fishy, Offensive, and Earthy. General categorical descriptors are at the center of the wheel and more specific descriptors are placed towards the wheel rim. A large number of “standard descriptor lists” are available and can be tailored for specific industries or industry mixes.

The odour wheel is commonly used only in the U.S. An example of the odour wheel is provided below in Figure 4.4-1 (from Rosenfeld *et al.* 2007). Some Canadian provinces follow the European approach and use a descriptor list with 20 user-defined adjectives. Further information is provided in Section 6.4.2.

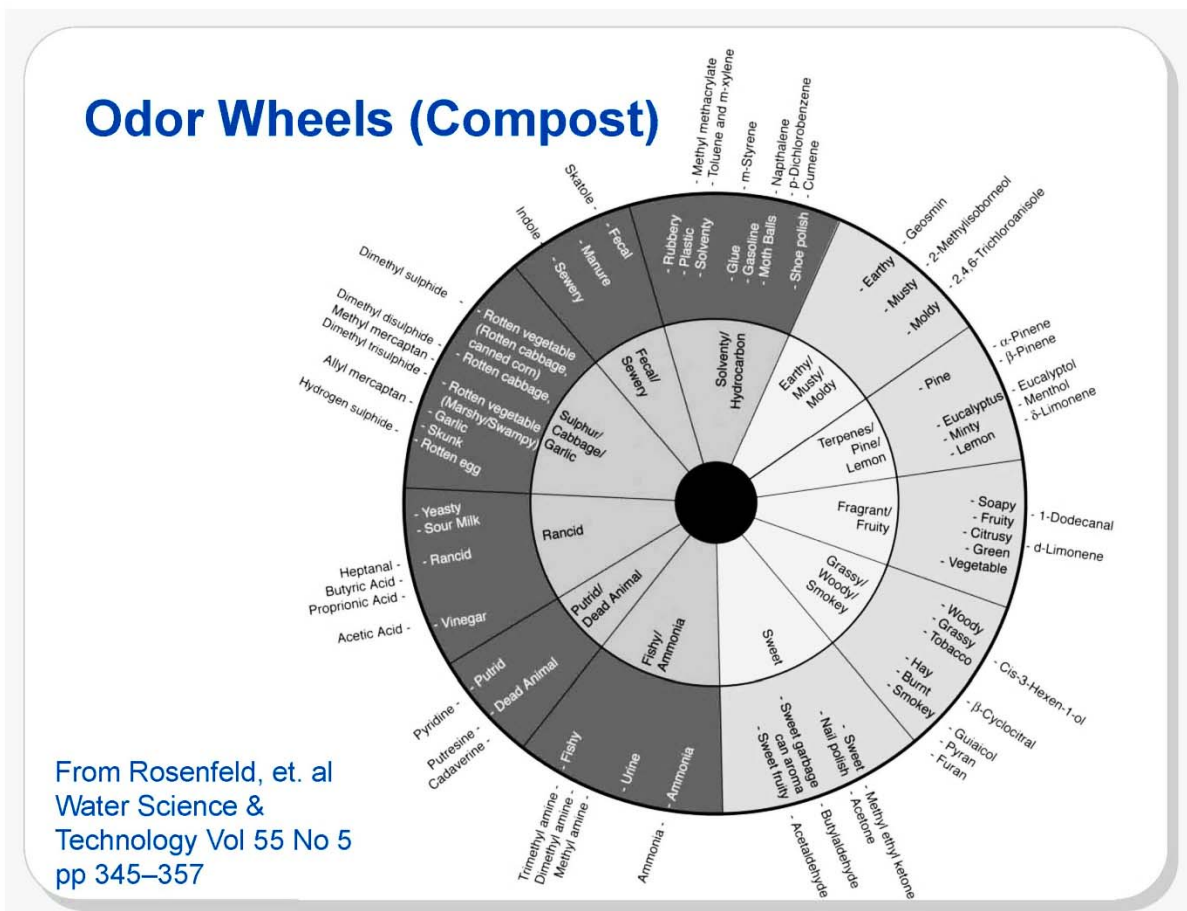


Figure 4.4-1 Sample Odour Wheel

4.4.3 Categorical Scale Analysis

Odour character is a nominal (categorical) scale of measurement and requires sensory (subjective) methods compared with odour detection threshold value determinations, which are objective. Sensory methods include odour intensity and hedonic tone of the odour (Section 2.2). Determination of sensory parameters is most useful for samples that are collected undiluted at a receptor (rather than at an emission source) and then evaluated by an odour panel without dilution.

Further information is provided in Section 6.4.3.

4.4.4 Olfactometry

Olfactometry is considered the best available approach for measuring odours directly to objectively quantify the perception of odours.

A dynamic olfactometer is an instrument used to detect and measure odour dilution, most often with trained and screened panelists in controlled laboratory settings. Olfactometers are used to determine the odour detection thresholds of individual odourants or the odour units (*i.e.*, concentration) of an odour sample. In olfactometry, the odour sample is diluted with odour-free air, according to precise ratios, to determine odour concentrations using an odour panel.

In many cases the detection limits of analytical instruments for individual or multiple odourants are higher (worse) than the human nose (Pandey *et al.* 2012).

Olfactometry is described in more detail in Sections 6.4.4 and 6.4.5.

4.4.5 Community Odour Assessment

Community surveys can do more than provide information on nominal scales, as they are valuable sources of descriptive data that can be used in odour descriptor wheel analysis and categorical scale analysis.

Community odour assessments for ambient monitoring are described in Section 4.2.3, with additional details in Section 6.2.3 and in sections on Odour Diary (Section 4.4.6 and 6.4.6).

4.4.6 Odour Diary

An odour diary is a record of odour (and especially odour episodes) by individuals living near sources. Typically diaries are kept by those experiencing odour annoyances. Characteristics of the odour are recorded such as intensity of the odour, character, duration, and pleasantness. Date and time of the odour episode should also be recorded. More information about odour diaries is provided in Section 6.4.6.

4.5 Dispersion Modelling for Odour and Odourants

4.5.1 Modelling Types

Odour models can be classified according to their working principles (Olesen *et al.* 2005):

- Gaussian plume models assume that dispersion takes place in odourant plumes with specific geometry (Gaussian distribution). This kind of model is sometimes called a “lighthouse” model where the plume moves from the source in the direction of the wind, independently in each hour. Examples of this model are:
 - U.S. EPA AERMOD (EPA 2004) - AERMOD has recently replaced a number of models, including the Australian AUSPLUME model (EPA VIC 2014b). AERMOD performance relative to the STINK model, which was developed by Smith (1993), is documented in Guo *et al.* (2006). AERMOD is approved for use in Alberta for air quality purposes (ESRD 2013a) (see Section 6.5.1 for details);
 - Danish OML-Lugt (Olesen *et al.* 2005; Olesen *et al.* 2007); and
 - British ADMS3 (CERC 2014).
- Gaussian puff models assume the odourant is emitted as series of puffs. This allows each puff to travel a curved path as the wind direction changes. Examples of this model are:
 - U.S. EPA CALPUFF (Exponent 2014a) - CALPUFF is capable of modelling odour units or concentrations of individual odourants (TRC 2011), and is approved for use in Alberta for air quality purposes (ESRD 2013a) (see Section 6.5.2 for details); and
 - Danish RIMPUFF and Eulerian Accidental Release Model (DREAM) (for nuclear accidents; Brandt *et al.* 1996).
- Lagrangian particle models release a large number of individual virtual particles whose fate is followed and summarised. According to the Lagrangian approach, virtual particles follow a wind field modified by turbulence. An example of this model is the German AUSTAL2000G (EIONET 2010).
- CFD (Computational Fluid Dynamics) models are sophisticated codes for fluid dynamics and transport problems (*e.g.* Large Eddy Simulations (LES) techniques), based on numerical solution of the governing fluid flow and dispersion equations (Pope 2004). These models are useful for near-field application in the vicinity of buildings and complex structures. CFD models could be used for odour modelling but they are complicated (Prata *et al.* 2014). They are rarely, if ever, used for odour assessments.
- In Eulerian models, emissions are assigned to grids rather than to specific geographic coordinates. Eulerian models were typically designed for long range transport and include complex chemistry. They do not track odourant plumes from specific sources. As such, they

are best suited for regional modelling rather than odour assessments. Examples of Eulerian models are:

- Comprehensive Air Quality Model with Extensions (CAMx) (Environ 2013); and
- Community Multi-scale Air Quality Model (CMAQ) (U.S. EPA 2014b), which is used in Alberta for regional air quality modelling purposes.

A set of models are designed specifically for agricultural odours; for example, the Austrian Odour Dispersion Model (AODM) (Piringer *et al.* 2011), the Scottish SCAIL (Simple Calculation of Atmospheric Impact Limits)-Agriculture (Hill *et al.* 2014), and the German AUSTAL2000G (EIONET 2010). In these models, emissions are optimized for agriculture and convert hourly predictions to shorter periods (*e.g.*, one minute for AUSTAL2000G).

In general, odour models used in Europe, New Zealand, or Australia either lack proper evaluation, or underperform compared to CALPUFF or AERMOD (*e.g.*, Langner and Klemm 2011; Guo *et al.* 2006). AERMOD and CALPUFF are approved models in Alberta for regulatory purposes (ESRD 2013b). AERMOD has limitations that may affect its use for odour in some circumstances, such as low wind speeds which are conducive to odour events (Paine and Connors 2013).

4.5.2 Model Input Requirements

To run dispersion models for odour assessments, the following inputs are generally required:

- Emission and source parameters, including nearby buildings – Model user guides (TRC 2011; U.S. EPA 2004) or regulatory guidance (ESRD 2013a) should be consulted for details. Specific aspects of modelling in odour units, rather than in mass emission units, are listed in (Piringer and Schaubberger 2013).
- Meteorological data – The kind and format of meteorological data required for modelling is model dependent. ESRD prepared a standard five-year meteorological data set (from 2002-2006) for AERMOD and CALPUFF regulatory applications (ESRD 2014b).
- Terrain data – Digital terrain elevations can be obtained from the Shuttle Radar Topography Mission (SRTM3) (Exponent 2014b). Alternatively, Canadian digital elevation model files can be downloaded from Natural Resources Canada (NRCAN 2012). Alternative data sources include:
 - Global 30 Arc-Second Elevation (GTOPO30) (Exponent 2014b);
 - 30-second Shuttle Radar Topography Mission (SRTM30) data, which have a grid resolution of about 1 km. (Exponent 2014b);
 - Alberta's forest and vegetation inventories (ESRD 2014c);
 - the Alberta grassland vegetation inventory (APCF 2014); and

- Moderate Resolution Imaging Spectroradiometer (MODIS) datasets available from NASA (2014)
- Land use characteristics – Some models (*e.g.*, the meteorological modules within CALPUFF and AERMOD) require land use characteristics. Standardised Canada Land Use Categories data (*e.g.*, forest or agricultural land) are available from NRCAN (2009).

4.5.3 Short Averaging Periods

The time resolution of most dispersion models is one hour. Within that hour, odour concentrations fluctuate about the model-predicted mean value. The variation is not constant but changes with meteorology, distance from source, height above ground, and source configuration (*e.g.*, stack diameter or building geometry).

The method most often used for estimating peak concentration from an hourly mean value is multiplication of the hourly mean concentration (C_i) by a constant conversion factor (p). The principal formula is:

$$\frac{C_2}{C_1} = \left(\frac{t_1}{t_2}\right)^p$$

Where: C_i is the mean concentration over averaging time t_i and p is an empirical constant in the range 0.2 to 0.5 (Venkatram 2002). More advanced models use a conversion factor dependent on the atmospheric stability and/or distance, where the exponent p could be between 0 and 0.68 (Piringer and Schauburger 2013). The recommended Alberta value for p is 0.5 (ESRD 2013b), although there are restrictions on its applicability.

4.5.4 Accuracy and Uncertainty

There are several sources of uncertainty in odour modelling (Irwin (2014):

- Uncertainty in emissions:
 - For new or modified facilities, engineering methods are used to estimate emissions (*e.g.*, based on U.S. EPA AP 42 emission factors) and these are typically representative of long term (annual) and industry-average conditions.
 - Measured emissions are more relevant to specific facilities; these measurements are typically made over periods of minutes to hours and may not reflect changes to odour processes that change on a daily, weekly or seasonal basis, or that reflect production cycles. Continuous emission monitors provide data typically at hourly intervals. Odour events may also be the result of plant upsets that can't be reliably predicted or measured. Hourly average meteorology may not reflect short term variations and measured values have instrument uncertainty.

- Meteorology varies with location and this variation may not be fully reflected in the data used to drive models. For the ESRD standard meteorological set, there is additional uncertainty associated with interpolation of measurements from distant stations (Peltier *et al.* 1986).
- The model itself has limitations as described in user manuals (*e.g.*, TRC 2011; U.S. EPA 2004) that reflect the ability of model physics to replicate reality.
- Background odour is a factor in assessments. This background also fluctuates due to odourant measurement uncertainty, the ability of hourly average values to reflect short term variations, and the spatial representativeness of the background odourant measurements.

4.5.5 Output Limitations

Output limitations of models are the result of the above factors, as well as model misapplication (*e.g.*, the application of Gaussian models in very complex terrain).

Overall, these limitations can be minimized by using the best available odourant emissions and current measurements of odour thresholds. If possible, modelling should use sub-hourly time steps, and the best available terrain and meteorological data.

4.6 Trend Analysis

Trend analysis for patterns in odour data could take the following forms:

- temporal trends in odour concentrations or odour character measured at specific locations;
- identification of potential upwind source regions based on measurements at one or more locations; and
- spatial trends in odour concentrations or odour character.

Temporal trends can be represented in time series format and can provide information on odour concentrations from olfactometry to analytical approaches or odour character over multiple years to indicate long term trends. The number of odour complaints and changes in odour character can be examined over time. Changes in threshold values can also be examined over time to identify adaptation. Within shorter periods, time series analysis could be used to identify emission or odour concentration changes with season or time of day and to identify the efficacy of control measures. An example of a trend analysis for 1-hour H₂S in major urban areas of Alberta is shown in Figure 4.6-1.

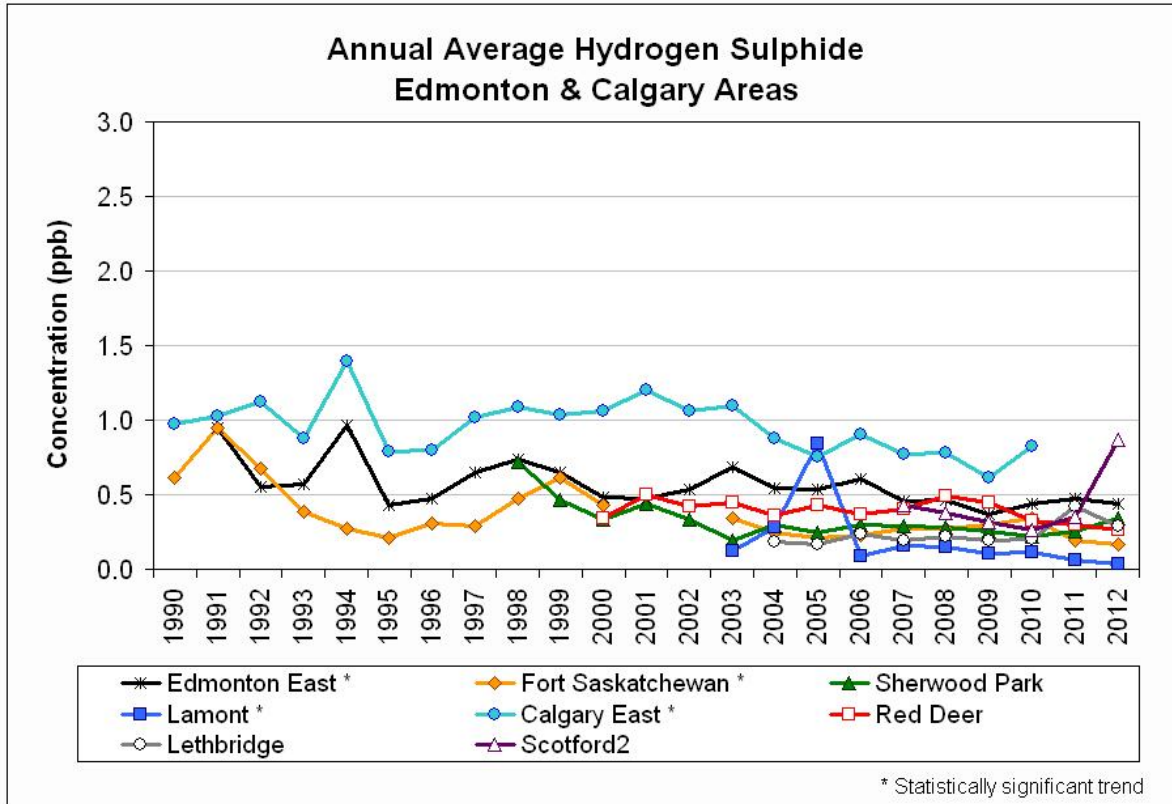


Figure 4.6-1 Temporal Trend Analysis (from ESRD 2014d)

Potential upwind source locations can be identified based on simultaneous odour and meteorological (especially wind direction) measurements taken at one or more known locations. Multiple measurement locations help to “triangulate” the source region. An example of this approach is presented in Jeng *et al.* (2012) which used continuous measurements of specific odourants in downtown Medicine Hat and illustrated the measurement results in “pollutant rose” form. The trend analysis could be limited to high concentration events only, as shown in Figure 4.6-2 from Jeng *et al.* (2012).

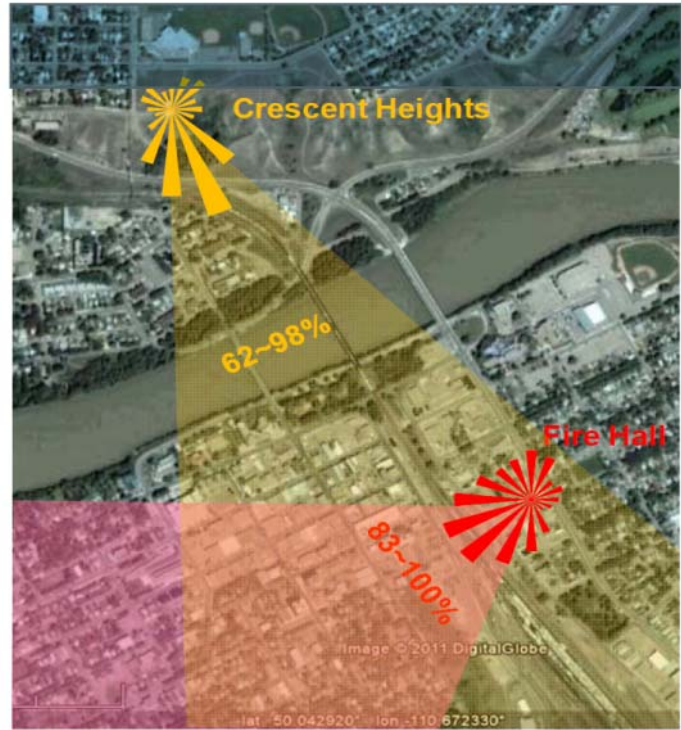


Figure 4.6-2 Trend Analysis Using a Pollutant Rose (from Jeng *et al.* 2012)

An example of spatial trends is the use of dispersion model output to examine predicted concentrations in areas in which measurements are not available. Model predictions are commonly presented in isopleth map form as shown in Figure 4.6-3. Spatial trends in odour may be at a local scale, as shown below, or over regional scales that contain large numbers of odourant sources.

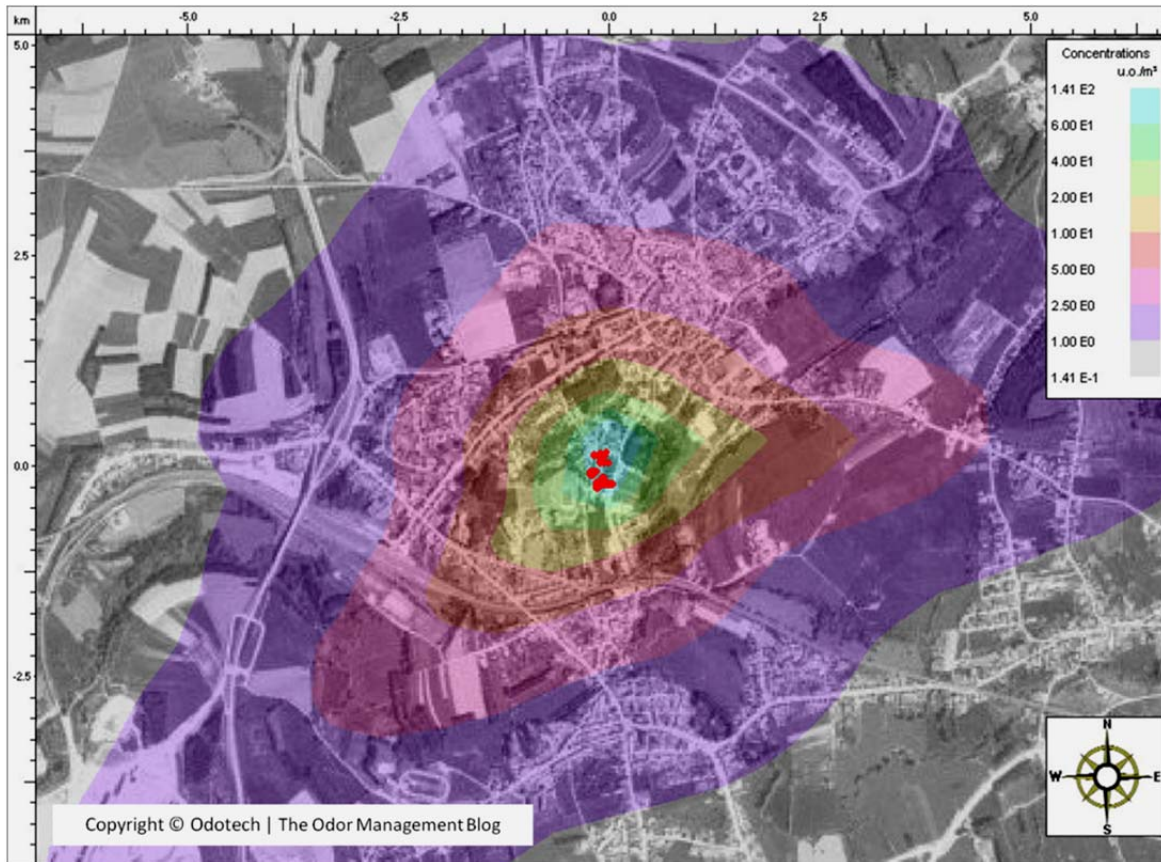


Figure 4.6-3 Isopleth Map of Model Predictions (from Odotech 2013)

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6.0 ODOUR ASSESSMENT TOOL DESCRIPTION

6.1 Source Sampling and Measurement

6.1.1 Point

Description:

Sampling methods vary by jurisdiction. In Europe most countries use the methods outlined by VDI 3880:2011 (VDI 2011) and/or European Standard EN: 13725:2003 (CEN 2003). The EN13725 standard is designed more for odour analysis, not sampling. Sampling in Australia and New Zealand follows methods outlined by the SA/SNZ (2001). Compliance sampling for odour in Ontario follows the Ministry of Environment (MOE) Method ON-6 (Ontario MOE 2010).

This tool is used to capture a whole air sample for subsequent analysis using analytical or non-analytical methods.

Lung Sampling Method

Used for collection of the samples with low odour. With the lung sampling method, an empty sample bag is placed inside a sealed rigid container and an uncapped sample bag valve is attached to a sampling line that passes through the container wall to the odour emission source. The sampling line material is usually inert Tedlar, Nalophan, or Teflon.

To remove residual air, the sample bag is purged with sample from the source before the test sample is collected. To collect the odour sample, a pump creates a vacuum inside the rigid container which draws a source sample into the sample bag. When sufficient sample has been collected, the pump is deactivated, the sample bag is removed from the rigid container, and the valve is capped.

The sampling time depends on the jurisdiction and the nature of the emission source. For example, in Europe a common sample period is 30 minutes for continuous sources, in Ontario it is ten minutes, while in other jurisdictions an instantaneous grab sample is common. The sampling time may be adjusted for batch processes.

The sampling equipment should be odourless on any surfaces that may contact an odour sample and the contact time between these surfaces and the sample should be minimized. Storage times between sample collection and evaluation by an odour panel should also be minimized. Criteria for the maximum allowed storage time are available in some standard test methods and generally range from six hours (VDI 2011) to 30 hours (Ontario MOE 2010; CEN 2003, SA/SNZ 2001).



Figure 6.1-1 Photo of a lung sampler (courtesy EOC)

Dilution Sampling Method

There are two methods of dilution sampling using bags: static dilution and dynamic dilution. In the static dilution method, a known volume of nitrogen is introduced into the sample bag, and then the odour sample is introduced into the bag using a syringe (VDI 2011). Dynamic dilution, used for collection of odourous samples, especially from point sources such as stacks and vents, helps prevent odour losses with time.

With the dynamic dilution method, a sample line passes from the inlet of the dilution sampling equipment to the odour emission source. The equipment dynamically pre-dilutes the sample as it is withdrawn from the emission source. The equipment is calibrated so that amount of pre-dilution can be accurately set before sampling commences. An empty sample bag is attached to the outlet of the

equipment to collect the sample. Pure air or nitrogen can be used to dilute the sample but nitrogen is preferred because it will retard the decomposition of odourants in the time period between sample collection and odour panel evaluation.

To collect an odour sample, the air or nitrogen under pressure at a known flow rate is used to create a venturi vacuum inside the sample line which draws a source sample into the sample bag at a predetermined rate. When sufficient sample has been collected, the pressurized gas is inactivated and the sample bag is removed from the dilution equipment and the valve capped. The odour sampler should be installed as close as possible to the odour source being sampled, and calibrated according to specific criteria based on the manufacturer's specifications and/or specific jurisdictional requirements.

As in the lung method, to remove residual air, the sample bag is purged with sample from the source before the test sample is collected. Sampling times vary with jurisdiction and source type.

The dilution sampling method is used to collect samples with a high odour concentration that exceeds the upper operating limit of the olfactometer, or if condensation of either moisture or odourants could occur in the sampling bag during the time between sample collection and evaluation. An acceptable time between sample collection and evaluation is within 30 hours (EN13725; CEN 2003).

Sample Containers

Generally, odour samples are collected in containers at the emission sources for transportation to the olfactometer or, occasionally, to an on-site olfactometer. Containers are made from material that does not interfere with the sample, such as polyvinylfluoride (PVF, Tedlar), polyethyleneterephthalate (PET, Nalophan), and tetrafluoroethylene hexafluoropropylene copolymer (FEP) (EN 13725; CEN 2003). Tedlar bags are the most commonly used containers in North America, while Nalophan material is commonly used in Europe. Tedlar is a trademark of Dupont de Nemours; Nalophan is a trademark of Kalle Nalo GmbH.

Some odourants containing small molecules may diffuse through the above materials, which may result odour concentration decreasing over time. The diffusion of specific compounds depends on several factors, such as bag thickness, material use, and storage conditions such as temperature and humidity (Zarra *et al.* 2012).

New bags may have background odours, which may be in the ranges of 20–100 OU (Tedlar) and 30–100 OU (Nalophan) if the bags are not cleaned before use. Bags can be cleaned with hot air; the background levels may be reduced so as to be undetectable by a person with a normal olfactory response. Sample bags are fabricated into sample containers with typical capacities ranging from 0.5 L to 60 L.



Information Output:
<p>The tool output is a collected sample that can be used in a variety of analytical or non-analytical analyzes.</p> <p>Samples collected on-site can be analyzed by an odour panel using an olfactometer. The olfactometer, which is used for accurately diluting an odour sample and presenting the diluted sample to the odour panel, is used for determining thresholds such as ODTV and ORTV.</p> <p>The samples may also be analyzed with analytical equipment (<i>e.g.</i> Gas-chromatography/Mass spectrometry (GC/MS)) to determine specific compound concentrations. This information together with a measured or designed volumetric flow rate is used to calculate odour or specific compound emission rates from the sources, which can then be used as input to dispersion modelling of odour or odourant emissions to predict off-site odour or specific compound concentrations.</p>
Ease of Use:
<p>Experience in sampling and in designing the source sampling program is essential and is typically conducted by trained and experienced professionals.</p> <p>Special consideration is needed for the selection of potential odour sources to sample, as some of sources which may play only a minor role in the final off site odour can be omitted. Choosing an appropriate procedure for each source is essential otherwise significant underestimation of odour emissions may result.</p>
Accuracy – Detection Limit and Calibration Requirements:
<p>Accuracy varies widely and is dependent on the method and the procedure used in sampling (and subsequent laboratory analysis).</p> <p>Variance arises from the method for sampling (<i>e.g.</i>, static dilution versus dynamic dilution, low dilution used for collection of samples, filter used during sampling). Typically, the sample volumes are well known and with the appropriate care and checks, reliable and reproducible data can be obtained.</p>



Approximate Cost, Resource Requirements and Logistical Considerations:
<p>Sampling for total odour is relatively inexpensive. However, sampling for specific compounds using odourant-specific sample methods or use of on-site instrumentation, varies widely and can be expensive.</p> <p>Cost per source will depend on the type of methodology chosen for the sampling (static dilution versus dynamic) and the number of samples collected per source. Costs to “stack sample” point sources in Alberta range up to \$4,000 for a single stack and odourant using standard test methods.</p>
Applicability to Multiple Odour Sources:
<p>Can be applied to one or more sources of odour.</p>
Measurement Scope – Single, Group or Mixture of Odourants:
<p>Appropriate for sampling total odour of mixtures.</p> <p>Sampling for specific compounds within mixtures may be limited, as some of the compounds are difficult and expensive to measure (<i>e.g.</i>, amines).</p>
Quality Control:
<p>Careful quality control is needed to ensure the results are reproducible. Quality control standards for all measurement types are available, which, if followed, result in reproducible measurements.</p> <p>Sampling equipment must be clean, including the sampling bags, which can have a residual odour if not cleaned. Additionally, equipment must be calibrated using a tracer gas, and blank samples must be collected and analyzed.</p>
Limitations:
<p>Sampling equipment - especially detection levels of instrumentation, which may be inconsistent with (<i>i.e.</i>, higher than) the sensitivity of the human nose.</p> <p>Sampling time - may be longer than the time associated with odour detection, to accumulate enough source odourant for analysis.</p> <p>Meteorological conditions under which sampling occurred - sampling may not have occurred under the most odour-prone conditions.</p>

Transportation – may take longer to deliver samples from point of collection to point of analysis than what is prescribed as an acceptable duration.

Applicability to Alberta:

Applicable to any facility or source in Alberta.

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Additional Comments:

No additional comments.

6.1.2 Area

Description:

Area source odourant emissions are, in general, unintended and somewhat uncontrollable vapours emitted by sources such as ponds and open excavations, and are therefore challenging to measure. Due to the breadth of area sources, non-standard and creative means can be used to collect whole air samples. There are three general techniques for directing samples from area sources to collection devices such as intermittent or integrated monitors.

Flux Chamber

In this method, a small domed chamber with the surface area of 0.13 m² is placed over a selected part of the surface and then sealed (Klenbusch 2002). Valves on the upper surface of the dome allow sweep gas to enter the dome and odour sample to exit the dome into a sample collector (Tedlar bag, canister, impinger, *etc.*). For a liquid surface, a flotation device is used to ensure that the chamber floats on the surface. Valves on the upper surface of the dome allow sweep gas to enter the dome and odour sample to exit the dome into a sample bag. During sample collection, pressurized sweep gas, which is usually nitrogen, enters the chamber and sweeps odourants from the solid or liquid surface into the sample bag. The sample bag may be filled with sample in conjunction with a lung sampler or a dilution sampler, depending on the expected odour concentration and the potential for condensation in the sample bag. A vent may be used to reduce the excess pressure in the chamber during sampling. The flow rate of the sweep gas and the sample collection rate are monitored.

Sample collection periods vary by jurisdiction and the nature of the emission source. Standardised sweep gas and odour collection flow rates are usually based on the U.S. EPA published method (Zarra *et al.* 2012).

This technique is used for collection of samples under light winds. The flux chamber must be according to standards (EN13725 - CEN 2003; ON-6 Ontario MOE 2010; or Australian/New Zealand standards – SA/SNZ 2001).

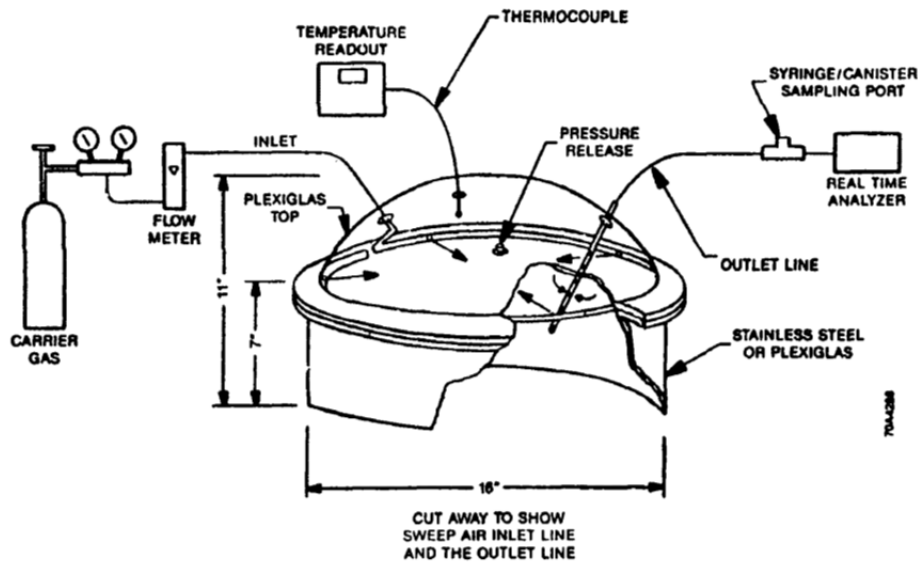


Figure 6.1-2 Diagram of Flux Chamber and Support Equipment (from Klenbusch 2002)

Wind Tunnel

The wind tunnel is designed to create an environment where the boundary layer is well developed and convective mass transfer occurs. The aerodynamic performance of the wind tunnel system can be repeated in the sampling process.

The tunnel is placed onto either a solid or liquid surface. Filtered air is passed through the tunnel at a controlled speed, creating a constant flow. The air velocity inside the wind tunnel is about 0.3 m/s. The odourants volatilize, or diffuse into the air, in an attempt to reach equilibrium between aqueous and air phases. Secondly, convective mass transfer takes place in the air phase. Convection occurs when air flows over the surface, sweeping odourants in the air phase near the surface. The convective mass transfer rate relates directly to airflow velocity over the water surface. Together, diffusion and convection determine rates of volatilization of odourants and odour emission rates from a water surface to the air.

The released sample odour is mixed with the air flow and flows out through the exhaust. Using a lung sampler, a portion of the mixed air is collected before it leaves the tunnel. This sample is tested for odour concentration using an olfactometer or other analytical instrument. During sample collection, a sweep gas, which is usually air, enters the wind tunnel.

An advantage of the wind tunnel, versus the flux chamber, for odour sample collection is that the wind tunnel can be used to simulate the effect of a range of velocities of wind blowing across the surface, whereas the flux chamber is usually operated at the standardized sweep gas flow rate.

Some studies show the wind tunnel method provides more realistic emission rates than the flux chamber method (Wang *et al.* 2001; Juarez-Galan 2008; Bokowa 2010).

The portable wind tunnel technique (Prata *et al.* 2014) provides odour emissions as a function of wind speed. The most common design is the Lindval model with a surface area of 0.33 m². Challenges in operation of wind tunnels include difficulty of set up and a source of clean sweep air. The wind tunnel must be made according to standards (EN13725 – CEN 2003; ON-6 - Ontario MOE 2010; or Australian/New Zealand 4323.3:2001 – SA/SNZ 2001).

The units of odour emission rates from area sources are OU/s/m².

Static Hood

This method is commonly used for active sources such as biofilters and aeration tanks (VDI 2011). In this method, a static hood is placed over the emitting surface (Capelli *et al.* 2013). The hood isolates a part of the emitting surface and channels the flow into the hood outlet, which is in the shape of a stack. Samples are collected at the port installed on the stack using point source methods (e.g., ON-6 - Ontario MOE 2010). The sampling hood must be odourless and inert, and made according to standards (EN13725 - CEN 2003; ON-6 - Ontario MOE 2010; or Australia/New Zealand 4323.3:2001– SA/SNZ 2001).

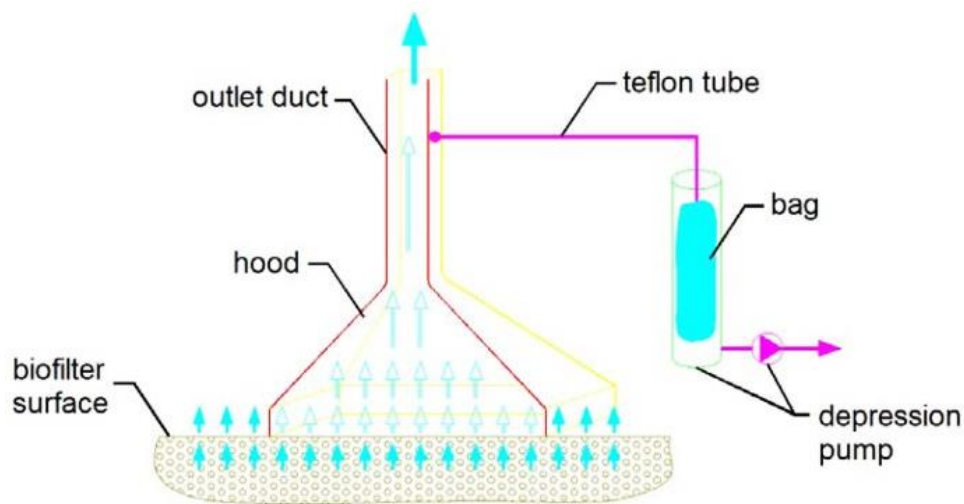


Figure 6.1-3 Schematic diagram of a Static Hood (from Capelli *et al.* 2013)



Information Output:
<p>The area source tool output is a collected sample that can be used in a variety of analytical or non-analytical analyzes.</p> <p>Collected samples are analyzed by an odour panel using standard olfactometry processes for ODTV determinations or with analytical equipment (<i>e.g.</i> GC/MS) to determine specific compound concentrations. This information, together with volumetric flow rate, is used to calculate odour or specific compound emission rates from area sources. The tool output can be used as input to dispersion models of odour or odourants to predict off-site odour or specific compound concentrations.</p>
Ease of Use:
<p>Wind tunnels are not easy to use as they are heavy and are difficult to set up and properly operate. A clean air supply is needed for sampling. They require nitrogen as a sweep gas.</p>
Accuracy – Detection Limit and Calibration Requirements:
<p>Detection limits are a function of the volume of odourant sampled for subsequent analytical testing.</p>
Approximate Cost, Resource Requirements and Logistical Considerations:
<p>Costs vary depending on the application, sampling approach and desired accuracy. Area source sampling may require a large number of replicates or sampling locations to accurately represent concentrations of odour or odourants from the whole area, which would be required for subsequent calculation of or modelling of emissions.</p>
Applicability to Multiple Sources of Odour:
<p>Applicable to all area sources of odour.</p>
Measurement Scope – Single, Group or Mixture of Odourants:
<p>Applicable to mixtures of odours.</p>



Quality Control:
Quality control for area source sampling is dependent on the chosen sampling method. Quality controls will include the use of blanks, following standard operating procedures for instrumentation. Standard operating procedures exist for the flux chamber, for air quality sampling.
Limitations:
<p>Sampling location – non-enclosed sampling locations/areas may affect sampling.</p> <p>Sampling time - may be longer than the time associated with the duration of emissions.</p> <p>Meteorological conditions under which sampling occurred - sampling may not have occurred under the most odour-prone conditions.</p>
Applicability to Alberta:
These methods are being used in Alberta for air quality purposes for many types of area sources.
References and Resources:
<p>Bokowa, A. 2010. The Effect of Sampling on the Measured Odour Concentration. Chemical Engineering Transactions, Volume 23:43-48. Available online at: http://www.aidic.it/cet/10/23/008.pdf. Accessed December 2014.</p> <p>Bokowa, A. and J. A. Beukes. 2012. How Reliable Are Odour Assessments? Water Science and Technology 66(10):2049-2055.</p> <p>Capelli, L., S. Sironi, and R. Del Rosso. 2013. Odor Sampling: Techniques and Strategies for the Estimation of Odor Emission Rates from Different Source Types. Sensors (Basel) 13(1):938-955. Available online at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3574713/. Accessed December 2014.</p> <p>Committee for European Normalization (CEN). 2003. Air Quality-Determination of Odour Concentration by Dynamic Olfactometry. European Standard (EN) 13725:2003. Available online at: http://www.sipe-rtd.info/directive/air-quality-determination-odour-concentration-dynamic-olfactometry. Accessed December 2014.</p> <p>Klenbusch, M. 2002. Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber. User’s Guide. U.S. EPA, Washington, DC, EPA/600/8-86/008. Available online at: http://cfpub.epa.gov/si/ntislink.cfm?dirEntryID=51253. Accessed</p>

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- Standards Australia/Standards New Zealand (SA/SNZ). 2001. AS/NZS 4323.3:2001 (R2014). Stationary Source Emissions –Determination of Odour Concentration by Dynamic Olfactometry.
- Verein Deutscher Ingenieure (VDI). 2011. VDI-3880, Olfactometry - Static Sampling. VDI Guidelines Department (ed.), Dusseldorf.
- Zarra, T., M. Reiser, V. Naddeo, V. Belgiorno, and M.Kranert, M. 2012. A Comparative and Critical Evaluation of Different Sampling Materials in the Measurement of Odour Concentration by Dynamic Olfactometry. *Chemical Engineering Transactions* 30:307–312. Available online at: <http://www.aidic.it/cet/12/30/052.pdf>. Accessed December 2014.

Additional Comments:

No additional comments.

6.1.3 Volume

Description:

Fugitive odourant emissions from volume sources are generally unintended vapours that are difficult to control, and that are emitted by sources such as pumps, valves, flanges, tanks, and process areas. These emissions are therefore challenging to measure.

Methods for collection of whole air samples from volume sources are typically point source methods:

- Covering the volume source (*e.g.*, during filling of a truck) and collecting samples at a port installed in the covering, using point sources sampling methods (*e.g.*, ON-6 - Ontario MOE 2010);
- Collection of undiluted ambient odour within the cavity of a building source. When the ambient odour concentration within the cavity is measured, dispersion modelling can be used to estimate the odour emission rate (Bokowa and Liu 2010);
- Direct measurements at building openings or in process areas using a Lung method, together with estimation of the opening area and the exit velocity at the opening.

Rather than collecting whole-air samples, the technology could equally be applied to single odourants or a group of odourants (*e.g.*, mercaptans).

In addition to sample collection, *in situ* measurement can be made using remote sensing techniques to estimate the concentrations of odourants at facility fencelines or over large area sources such as tailings ponds or sewage lagoons:

- Some studies (*e.g.*, in U.S. EPA 2008) utilized open-path spectroscopy techniques and forward looking infrared (FLIR) video cameras to detect releases, and indicated that high levels of fugitive VOCs may be emitted on a routine basis from storage tanks, pumps, pipes, cooling towers and wastewater separators, as well as in other operations.
- In Alberta, the upstream oil and gas industry effectively quantifies fugitive emission from storage tanks and facilities with Differential Absorption Light Detection and Ranging (DIAL) (ARC 2006, Chamber *et al.* 2006).
- Remote sensing methods commonly have relatively high method detection limits and therefore may not be applicable to the detection of odour.

In addition, ambient sampling methods based on the point source techniques described above and used downwind of emission sources can give an indication of total fugitive emissions from volume sources. This approach may miss emissions from some elevated sources and/or capture some point

<p>source emissions; therefore, obtaining a representative and meaningful sample can be challenging.</p>
<p>Information Output:</p>
<p>Output consists of a whole air sample for use in subsequent analysis, or the concentration within the volume of measurement for remote sensing techniques.</p> <p>From these measurements, an estimate of odour emissions can be made. The estimate is based on calculations using dispersion modelling and measured odour concentrations.</p>
<p>Ease of Use:</p>
<p>These methods are not easy to use, and the level or ease or difficulty is dependent on the method used, which could range from sample bags to electronic noses to chemical analyzers to remote sensors. After measuring the odour, modelling or other calculations may be needed to estimate the actual emissions. Thus, this is typically a multi-step process, which increases difficulty.</p>
<p>Accuracy – Detection Limit and Calibration Requirements:</p>
<p>Detection limits are a function of the analytical methodology used. Ultimately, the accuracy and detection limit for the odour emission is a function of the estimates that are required – building air exchange rates, estimates of exit velocity, cavity areas, etc. – which are not part of the measurement method per se. Thus, accuracy and detection limits are difficult to quantify in a general sense. Accuracy is lower relative to point source sampling.</p>
<p>Approximate Cost, Resource Requirements and Logistical Considerations:</p>
<p>These traits are difficult to quantify because of the wide range in possible techniques. Costs vary depending on the application, sampling approach and desired accuracy. These methods could require a large number of replicates or sampling locations to accurately estimate concentrations of odour or odourants, which are required for subsequent calculation or modelling of emissions.</p>
<p>Applicability to Multiple Sources of Odour:</p>
<p>Applicable to all volume sources of odour. Some standard approaches exist but many are improvised to meet the site-specific circumstances.</p>



Measurement Scope – Single, Group or Mixture of Odourants:
Applicable to mixtures of odours.
Quality Control:
Quality control measures depend on the measurement method used. However, quality control will involve calibration of field or laboratory instruments; use of blanks, following standard operating procedures for instrumentation; and upwind sampling to determine the background odour, among many other procedures. Quality control measures are required for any analysis techniques and modelling procedures used.
Limitations:
Sampling of volume odour emissions is challenging and may be influenced by meteorological conditions.
Applicability to Alberta:
Can be, and is being, used in Alberta for air quality purposes for many types of volume sources.
References and Resources:
<p>Alberta Research Council Inc. (ARC). 2006. Refinery Demonstration of Optical Technology for Measurement of Fugitive Emissions and for Leak Detection. Prepared for Environment Canada, Ontario Ministry of Environment, and Alberta Environment. Report Number CEM9643-2006. Available online at: http://www.environmentalintegrity.org/pdf/publications/EIP_Att_D_Total_Upset.pdf. Accessed December 2014.</p> <p>Bokowa, A. and H. Liu. 2010. Quantification of Odour Emissions from Fugitive Sources. In: Frechen, F.-B. (ed.). Odour and VOCs: Measurement Regulation and Control. Kassel University Press, Germany.</p> <p>Canadian Association of Petroleum Engineers (CAPP). 2007. Best Management Practice - Management of Fugitive Emissions at Upstream Oil and Gas Facilities. Available online at: http://www.capp.ca/getdoc.aspx?DocId=116116&DT=PDF. Accessed December 2014.</p> <p>Chambers, A.K., M. Strosher, T. Wootton, J. Moncrieff, and P. McCready. 2006. DIAL Measurements of Fugitive Emissions from Natural Gas Plants and the Comparison with Emission Factor Estimates. 15th International Emission Inventory Conference: Reinventing Inventories – New</p>



Ideas in New Orleans, 16-18 May 2006, New Orleans, Louisiana. Available online at: <http://www.epa.gov/ttn/chief/conference/ei15/session14/chambers.pdf>. Accessed December 2014.

Committee for European Normalization (CEN). 2003. Air Quality-Determination of Odour Concentration by Dynamic Olfactometry. European Standard (EN) 13725:2003. Available online at: <http://www.sipe-rtd.info/directive/air-quality-determination-odour-concentration-dynamic-olfactometry>. Accessed December 2014.

Ontario Ministry of Environment (MOE). 2010. Ontario Source Testing Code , Method ON-6 Determination of Odour Emissions from Stationary Sources. Available online at: <https://dr6j45jk9xcmk.cloudfront.net/documents/1464/3-7-31-ontario-source-testing-code-en.pdf>. Accessed December 2014.

Standards Australia/Standards New Zealand (SA/SNZ). 2001. AS/NZS 4323.3:2001 (R2014). Stationary Source Emissions –Determination of Odour Concentration by Dynamic Olfactometry.

United States. Environmental Protection Agency (U.S. EPA) . 2008. 2nd International Workshop on Remote Sensing of Emissions: 2008: New Technologies and Recent Work.

Additional Comments:

No additional Comments.

6.2 Ambient Sampling and Measurement

6.2.1 Ambient

The lung sampling procedures for ambient odour monitoring are similar to those described in Section 6.1. Ambient measurements can also be made using analytical approaches which are described in Section 6.3.

6.2.2 Portable Olfactometry

The portable olfactometer is similar to the olfactometer in method of operation (see Sections 6.1.1 and 6.1.2). The olfactometer is capable of providing objective odour assessments (*i.e.*, the odour concentrations or intensity), even though the technique also can provide the basis for subjective assessments (*i.e.*, non-analytical results; see Sections 6.4.4 and 6.4.5).

6.2.3 Community Survey

Description:

A community odour survey consists of experienced and trained observers evaluating odour in a structured observation session, in which the odours are rated using a standard intensity scale at prescribed locations (Bokowa 2002; Brancher and de Melo Lisboa 2014). Survey members are trained and instructed by odour measurement specialists.

In Europe, Australia and Ontario, community odour surveys are common (Bokowa 2010), either performing long-term odour measurements at specific locations or downwind of a source (as in VDI Standard 3940, VDI 2006).

Odours can be described objectively with standard categories and the use of a standard reference vocabulary (McGinley and McGinley 2004). For community odour surveys, it is common practice to provide observers with a standard list of terms that can be used to describe the odours, with the terms organized into categories or groups of similar terms. An odour wheel may also be used (Section 4.5.1).

Information Output:

Information output can include:

- determinations of odour levels using a standard point intensity scale; and
- subjective characterization of hedonic tone, offensiveness, *etc.*

<p>The results can include the percentage of the time that odours above a certain intensity level were detected, the maximum distance at which odours attributable to the facility were detected, and a breakdown of the relative contribution of specific odour categories to the total number of odour observations.</p>
<p>Ease of Use:</p>
<p>Although easy to perform in principle, certain procedures must be observed (see NZMFE 2003; DEHP 2013).</p>
<p>Accuracy – Detection Limit and Calibration Requirements:</p>
<p>Accuracy is dependent on the sensitivity of the observers.</p>
<p>Approximate Cost, Resource Requirements and Logistical Considerations:</p>
<p>A large data set is required to determine the odour levels at specific locations covering a range of weather conditions. This requires a long period of observations, and therefore can be very expensive.</p>
<p>Applicability to Multiple Sources of Odour:</p>
<p>Community surveys can be applied to one or more odour sources or in ambient air.</p>
<p>Measurement Scope – Single, Group or Mixture of Odourants:</p>
<p>The method is designed to be applied to individual odourants and to mixtures.</p>
<p>Quality Control:</p>
<p>Trained odour observers describe and measure ambient odours using standard terminology and measurement practices. Training to maintain observation quality is highly recommended for community observers, and should include:</p> <ul style="list-style-type: none"> • screening for sensitivity according to established standards; • screening for intensity recognition and odour description; and • data collection, recording and reporting procedures.

Limitations of Tool Use in the Context of the Odour Assessment:

There are limitations to community odour surveys, such as:

Odour Adaptation – Observers in the community or from a facility may adapt to particular odours, and would therefore tend to under-report odour occurrence. To mitigate this limitation, independent outside observers could be used.

Odour Fatigue – Fatigue may occur with longer observation sessions and, therefore, longer exposure to odour. Fatigue is caused by a repetitive process of making and recording odour observations, not by adaptation to an odour

Hours of Operation – Community observers generally are not available for 24-7 observation, and therefore not all odour incidents, especially those that occur early in the morning or late in the evening, may be reported.

Omission – Some sources may be missed by near-field surveys. For example, sources from tall stacks may not reach ground level at the same location as low elevation sources.

Specificity – The identification of specific odour sources may not be possible, especially for facilities with large numbers of sources or those with large area sources.

Applicability to Alberta:

Can be applied in Alberta for different types of odour sources.

References and Resources:

Bokowa, A. 2002. Community Odor Survey. Proceedings of the Water Environment Federation, Odors and Toxic Air Emissions 2002: 641-656,

Bokowa, A. 2010. The Effect of Sampling on the Measured Odour Concentration. Chemical Engineering Transactions 23:43-48. Available online at: <http://www.aidic.it/cet/10/23/008.pdf>.

Brancher, M. and H. de Melo Lisboa. 2014. Odour Impact Assessment by Community Survey. Chemical Engineering Transactions 40:139-144. Available online at: <http://www.aidic.it/cet/14/40/024.pdf>.

Department of Environment and Heritage Protection (DEHP). 2013. Guideline – Odour Impact Assessment from Developments. Queensland Government. Available online at: <https://publications.qld.gov.au/dataset/5204ec9c-0991-4fd9-ae7d-b7774f60becb>. Accessed



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- McGinley, M.A. 1995. Quantifying Public Perception of Odors in a Community - Utilizing Telemarketing Protocol. Proceedings of Air and Waste Management Association International Specialty Conference: Odor and Environmental Air. Bloomington, MN: 13-15 September 1995. pp. 310-322. Available online at: <http://www.fivesenses.com/Documents/Library/2%20%20Quantifying%20Public%20Perception.pdf>. Accessed December 2014.
- McGinley, M.A. and C.M. McGinley. 2004. Developing a Credible Odor Monitoring Program. Proceedings of American Society of Agricultural Engineers (ASAE). Ottawa, ON:1-4 August 2004. Available online at: <http://www.fivesenses.com/Documents/Library/45%20Developing%20A%20Credible%20Odor%20Monitoring%20Program.pdf>. Accessed December 2014.
- New Zealand Ministry for the Environment (NZMFE). 2003. Good Practice Guide for Assessing and Managing Odour in New Zealand. Air Quality Report 36. Available online at: <http://www.mfe.govt.nz/publications/air/good-practice-guide-assessing-and-managing-odour-new-zealand>. Accessed December 2014.
- Verein Deutscher Ingenieure (VDI). 1994. VDI 3882, Part 1-Olfactometry, Determination of Odour Intensity; Part 2- Determination of Hedonic Odour Tone. VDI Guidelines Department (ed.), Dusseldorf.
- Verein Deutscher Ingenieure (VDI). 2006. VDI 3940, Part 1: Measurement of Odour Impact by Field Inspection – Measurement of the impact frequency of recognisable odours – Grid Measurement . VDI Guidelines Department (ed.), Dusseldorf.

Additional Comments:

No additional comments.

6.3 Analytical Methods

6.3.1 Electronic Nose

Description:

The typical electronic nose consists of head space sampling, a sensor array, and pattern recognition modules, to generate a signal pattern that is used for characterizing odours. Electronic noses also include a sample delivery system, a detection system, and a computational system. The sample delivery system enables the generation of the “headspace” of a sample, which is the sample fraction (of air odourants) analyzed. The system then injects this headspace sample into the detection system of the electronic nose. The sample delivery system guarantees constant operating conditions. The detection system, which consists of a sensor set, is the "reactive" part of the instrument; when in contact with odourants, the sensors react, which means they experience a change in electrical properties.

In most electronic noses, sensor arrays react with odourants causing a physical change in each sensor, which reacts uniquely. Recorded signals are interpreted based on statistical models. Some devices combine multiple sensor types in a single device. In recent years, other types of electronic noses have been developed that utilize mass spectrometry or ultra-fast gas chromatography as a detection system.

The computational system combines the responses of all sensors and performs odour fingerprint analysis and interpretation. Moreover, the electronic nose results can be correlated to those obtained from other techniques such as an odour panel or gas chromatography.

Before use, the electronic nose needs to be calibrated and trained against human noses (using olfactometry). The instrument recognizes new samples by comparing odourant fingerprints to those in its database. Therefore, they can perform qualitative or quantitative analysis.

As a note, NASA (2004) has developed a sensitive electronic nose for detecting ammonia leaks in space. It uses a collection of 16 different polymer films, which are specially designed to conduct electricity. When a substance (*e.g.*, ammonia) is absorbed into these films, the films expand slightly, resulting in a change in how much electricity they conduct.

Each polymer film reacts uniquely to each odourant. The collective change in conductivity of the 16 films produces a distinctive, identifiable pattern. The NASA electronic nose can detect an electronic change of 1 ppm.

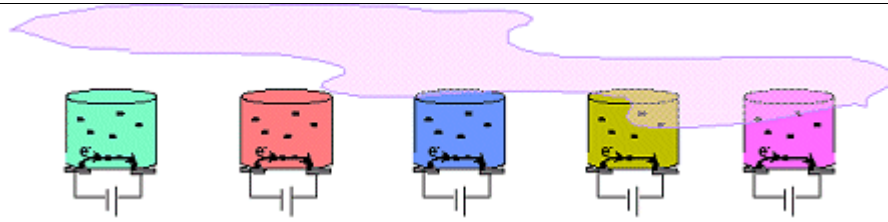


Figure 6.3-1 Conceptual Schematic of an Electronic Nose (from NASA 2004)

Information Output:

Approximate odour concentration.

Ease of Use:

Not so easy to use, needs calibration before use in three stages - see below, not applicable for all types of sources, sensors need to be changed frequently.

Accuracy – Detection Limit and Calibration Requirements:

Electronic noses must be calibrated to the characteristic odours to be monitored to quantify them (Odotech 2013). This calibration occurs in three stages:

- Odour samples from the sources to monitor are collected on site.
- The samples are subjected to olfactometry analysis (human odour panel) to define the odour concentration of the sample.
- The electronic noses are exposed to the same samples and their responses are compared with the results of the analysis. The correlation is then established between the two via a statistical non-linear multivariable calculation.

Approximate Cost, Resource Requirements and Logistical Considerations:

Very expensive. Hundreds of thousands of dollars for a basic unit plus cost for calibration, and to maintain the unit including cost of sensors.

Applicability of Multiple Sources of Odour:

Applicable to multiple odour sources, but not all types of sources.



Measurement Scope – Single, Group or Mixture of Odourants:
Appropriate for mixtures.
Quality Control:
Calibration, against an odour panel.
Limitations:
<p>Electronic noses have limitations. Hobbs <i>et al.</i> (1995) showed that an electronic nose system can discriminate between livestock wastes (pig and chicken slurries), but reported low sensitivity when compared to olfactometry measurements.</p> <p>Another potential limitation occurs when a sample contains odourants and odourless chemicals; the possible interference from the odourless chemicals may cause problems with reading signals for odourants.</p>
Applicability to Alberta:
Applicable for use in Alberta and currently used in Alberta.
References and Resources:
<p>Arshak, K, E. Moore, G.M. Lyons, J. Harris, and S. Clifford. 2004. A Review of Gas Sensors Employed in Electronic Nose Applications. <i>Sensor Review</i> 24(2): 181-198. Available online at: http://www.uta.edu/rfmems/BMC/0720/0902_backup/Background/A%20review%20of%20gas%20sensors%20employed%20in%20electronic%20nose%20applications.pdf. Accessed December 2014.</p> <p>Kim, K.-H. (ed.). 2013. Special Issue “Odor Detection: Electronic Nose, Olfactometer, and Advanced Instrumentation”. <i>Sensors</i> Vol. 13. Available online at: http://www.mdpi.com/journal/sensors/special_issues/odor_detection</p> <p>Hobbs, P. J., T.H. Misselbrook, and B.P. Pain. 1995. Assessment of Odors from Livestock Wastes by a Photoionization Detector, an Electronic Nose, Olfactometry and Gas-chromatography Mass-spectrometry. <i>Journal of Agricultural Engineering Research</i> 60: 137-144.</p> <p>National Aeronautics and Space Administration (NASA). 2004. Electronic Nose – NASA Researchers are Developing an Exquisitely Sensitive Artificial Nose for Space Exploration. Available online at: http://science.nasa.gov/science-news/science-at-nasa/2004/06oct_enose/. Accessed</p>



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Odotech. 2013. White Paper: How Does an Electronic Nose Work? The Odor Management Blog.
Available online at: <http://blog.odotech.com/bid/96333/White-Paper-How-Does-an-Electronic-Nose-Work>. Accessed December 2014.

Additional Comments:

No additional comments.

6.3.2 Continuous Monitoring

Description:
<p>Continuous monitors typically measure concentration for individual odourants every few seconds and record the data as one-minute average values. There are no intermediate steps and the gas sample is analyzed directly by the continuous emission monitor. Continuous monitors measure odourant concentration either at the source or in ambient air.</p> <p>All continuous monitors require that volumetric flow rate and temperature be measured in order to determine the compound emission rate or concentration. There are standard methods available for measuring the flow rate in enclosed streams but these measurements become more difficult for area and fugitive emission sources where the wind velocity and other factors influence the measurements.</p>
Information Output:
<p>Concentrations of individual odourants at short time intervals.</p>
Ease of Use:
<p>Systems are complex and installation and operation require substantial technical expertise.</p>
Accuracy – Detection Limit and Calibration Requirements:
<p>Depends on the measured compound and the instrument used for monitoring. For example, the detection limit for hydrogen sulphide is about 0.01 ppm using OdaLog analyzers.</p>
Approximate Cost, Resource Requirements and Logistical Considerations:
<p>Continuous emission monitors on industrial stacks cost \$100,000+ in capital costs, require professional installation, and may require facility changes to implement. Regular calibration, depending on the instrument, is required as well as periodic audits by third parties.</p>
Applicability to Multiple Sources of Odour:
<p>In principle, continuous emission monitors are applied to a variety of large stack emission sources. They are applicable to ambient measurements, which may be influenced by multiple sources of odour.</p>



Measurement Scope – Single, Group or Mixture of Odourants:
The method is designed to measure the concentrations of individual odourants but can be used for groups of compounds (e.g., total reduced sulphur or total hydrocarbons).
Quality Control:
<p>Operation of continuous emission monitors in Alberta requires the development and implementation of a quality assurance plan. The plan requirements are set by Alberta’s CEMS Code (AEP 1998).</p> <p>For some continuous systems, there is a need for introduction of blanks. Follow the operating instructions of the system manufacturer. Standard operating procedures exist under international standards.</p>
Limitations:
<p>Limited by the detection limit of the instrument- some odours may be detected by the human nose but not detected by the instrument.</p> <p>Some problems with interferences and false response of the instrument.</p> <p>Continuous monitors are generally used (in Alberta) for the largest stack sources for air quality purposes. Emissions from these sources are typically widely dispersed and may not contribute to local odour.</p> <p>Expensive.</p>
Applicability to Alberta:
The method is commonly used in Alberta, although not necessarily for odourant measurement.
References and Resources:
<p>Alberta Environmental Protection (AEP). 1998. Continuous Emission Monitoring System (CEMS) Code. Pub. No.: Ref. 107. Available online at: http://environment.gov.ab.ca/info/library/6997.pdf. Accessed December 2014.</p> <p>Mitra, S., N. Zhu, X. Zhang, and B. Kebbekus. 1996. Continuous Monitoring of Volatile Organic Compounds in Air Emissions Using an On-line Membrane Extraction-Microtrap-Gas Chromatographic System, <i>Journal of Chromatography A</i> 736(1–2): 165–173.</p> <p>Sironi, S., L. Capelli, P. Céntola, R. Del Rosso, and M. Il Grande. 2007. Continuous Monitoring of</p>



Odours from a Composting Plant Using Electronic Noses. Waste Management 27(3): 389–397.

United States Environmental Protection Agency (U.S. EPA). 2009. Continuous Emissions Monitoring Fact Sheet. Available online at: <http://www.epa.gov/airmarkt/emissions/continuous-factsheet.html>. Accessed December 2014.

Additional Comments:

No additional comments.



6.3.3 Semi-continuous Monitoring

Description:
<p>Semi-continuous monitors measure odourant concentrations over minutes or longer durations. This method of monitoring involves intermediate steps such as the separation of odourants by a gas chromatograph and detection of the odourants by a suitable detector (<i>e.g.</i>, flame ionization detector or a mass spectrometer detector). The time required to obtain successive measurements is dependent on the time required to separate the compounds by the gas chromatograph.</p> <p>For example, at landfill sites, an on-line analytical system including a gas chromatograph coupled with a photoionization detector may be installed to detect odourants at the $\mu\text{g}/\text{m}^3$ (ppbv) level in the atmosphere, with samples collected for, say, 15 minutes, followed by a period of 15 minutes of time for the gas to pass through the gas chromatograph (De Bièvre and Günzler 2003).</p>
Information Output:
<p>Concentrations of specific odourants at regular short intervals, which allows the fluctuations in these concentrations to be tracked and perhaps correlated with odour complaint periods or odour source emission profiles or events.</p>
Ease of Use:
<p>Easy to use for trained laboratory professionals but need regular calibration and maintenance, including changing batteries if operating in remote areas.</p>
Accuracy – Detection Limit and Calibration Requirements:
<p>Detection limits expected at the $\mu\text{g}/\text{m}^3$ (ppbv) level of accuracy, dependent on the type of equipment and the effect of interferences from other compounds present.</p>
Approximate Cost, Resource Requirements and Logistical Considerations:
<p>Costs will vary and will depend on the types of compounds analyzed and the quality of the equipment; perhaps in the range of tens of thousands of dollars to over one hundred thousand dollars.</p>

Applicability to Multiple Sources of Odour:
Applicable to all types of odour emission sources. However, most useful when the odour at each source is attributable to a single dominant odourant. When the odour is caused by a number of odourants but there is no dominate odour, it is usually difficult to estimate the overall odour concentration from the mixture of odourant concentrations.
Measurement Scope – Single, Group or Mixture of Odourants:
The method is less appropriate for complex mixtures, due to possible interference with other compounds present.
Quality Control:
Calibration of the equipment using a tracer gas. Collection and analysis of blanks. Quality control standards for this method are available, which, if followed, result in reproducible measurements.
Limitations:
Limited to detection limit of the instrument- some odours may be detected by the human nose but not detected by the instrument. Potential interferences and false responses of the instrument.
Applicability to Alberta:
The method is used in Alberta for air quality and odour applications, and is especially applicable for sources with high concentrations of odourant.
References and Resources:
Battelle. 2008. Test/QA Plan for Verification of Semi-Continuous Ambient Air Monitoring Systems. Version 1. Environmental Technology Verification Program, Advanced Monitoring Systems Center. 43 pp. Available online at: http://nepis.epa.gov/Adobe/PDF/P100EL2K.pdf . Accessed December 2014. De Bièvre, P. and H. Günzler (eds.). 2003. Measurement Uncertainty in Chemical Analysis. Springer Verlag, Berlin.



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United States Environmental Protection Agency (U.S. EPA). Method 16 - Semicontinuous Determination Of Sulfur Emissions From Stationary Sources. Available online at: <http://www.epa.gov/ttnemc01/promgate/m-16.pdf>. Accessed December 2014.

Additional Comments:

No additional comments.

6.3.4 Intermittent/Integrated Monitoring

Description :

Most integrated sampling methods use active sampling techniques in which odourants are collected by forced movement (*e.g.*, use of a pump) through an appropriate collection device such as a sorbent tube, treated filter, or impinger containing a liquid medium. The sampling period depends on the required total volume of sample to be collected (*i.e.*, on the collection methods).

Activated charcoal and silica gel granules are types of adsorbents that are frequently used for odourant collection. Others include porous polymers, Tenax[™], Porapak[™], Chromosorbs[™], and Amberlite XAD[™] resins. For some odourants or groups of odourants, special adsorbents are required. For example, silica gel granules coated with 2, 4-dinitrophenyl hydrazine are used to sample for aldehydes, a group of highly odourous compounds.

Several types of impinger solutions are used depending on the odourants being sampled. An example is the use of dilute sulphuric acid impinger solution to collect ammonia from source air streams or ambient air. Multiple impinger solutions can also be used in series to collect multiple odourants with just one sampling method.

After sample collection the odourants must be recovered from the adsorbent tubes or impinger solutions prior to analysis, although impinger solutions may be analyzed directly (ion chromatography directly analyzes ammonia in solution). Recovery methods for adsorbent tubes include thermal desorption and extraction with a suitable solvent. Analytical methods for the extracted odourants include gas chromatography with a flame ionization detector or a mass spectrometer detector, although some groups of odourants require other types of analytical methods. An example is the analysis of reduced sulphur compound species, which requires a chemiluminescence or a flame ionization detector (Luong *et al.* 2013).

Standard operating techniques apply to collection of samples using intermittent or integrated sampling (*e.g.*, U.S. EPA methods TO-15 and TO-17) that may need to be adjusted for odour measurement. Practical/operating differences between the two technologies favour specific applications. Evacuated canisters can be used in simple grab sampling where a valve is opened briefly and then shut or in more prolonged sampling with the use of a flow controller. Canisters exposed to high vapor concentrations can require extensive cleaning. The Watson and Cooper reference contains a helpful comparison of the differences between canister and integrated sampling.

Information Output:

Average odourant concentration over the sampling period.

Ease of Use:
Usually easy to use the sampling equipment. Laboratory procedures are needed to provide final concentrations.
Accuracy – Detection Limit and Calibration Requirements:
Detection limits are a function of the volume of sample collected, the laboratory analysis technique, and the collection media, and are odourant-specific. Sampling times can be extended to meet detection limit requirements, but long collection periods are inconsistent with the time frame of odour perception and risk the possibility of breakthrough of certain odourants, which results in an underestimating of odourant concentration.
Approximate Cost, Resource Requirements and Logistical Considerations:
The sampling equipment is relatively inexpensive, consisting of pumps, controllers, and collection systems. Price is in the thousands of dollars. The analytical cost will depend on the odourants being analyzed, but generally ranges from \$100 to \$1,000 dollars for a complete analysis for all possible odourants/compounds captured by the sampling method.
Applicability to Multiple Sources of Odour:
Applicable to all odour sources. Longer sampling times are required with lower compound concentrations.
Measurement Scope – Single, Group or Mixture of Odourants:
Designed for mixtures.
Quality Control:
Calibration of sample flow rates and laboratory analytical equipment, use standard sampling and analytical operating procedures, use blanks and duplicates in the analysis. Care to sample such that detection limit expectations are met and that breakthrough does not occur in the sample media. Follow the operating instructions of the system manufacturer. Standard operating procedures exist under international standards.



Limitations:
<p>Limited to detection limit of the instrument- some of the odours may be detected by human nose but are below the analytical detection level.</p> <p>Potential interference from other compounds and false response of the instrument.</p> <p>Prolonged sampling time (hours) may be required to obtain detectable amounts of odourants, longer than the odour response time of the human nose.</p>
Applicability to Alberta:
<p>The method is applicable in Alberta. It is a standard tool for air quality monitoring. Its use needs investigation to ensure limitations are reasonable for odour sampling.</p>
References and Resources:
<p>Luong, J., R. Gras, R.A. Shellie, and H.J. Cortes. 2013. Tandem Sulfur Chemiluminescence and Flame Ionization Detection with Planar Microfluidic Devices for the Characterization of Sulfur Compounds in Hydrocarbon Matrices. <i>Journal of Chromatography A</i> 1297:231-235.</p> <p>United States Environmental Protection Agency (U.S. EPA). 2004. Identification of Time- Integrated Sampling and Measurement Techniques to Support Human Exposure Studies. Available online at: http://www.epa.gov/heads/dears/children/pdf/time-integrated-hern.pdf. Accessed December 2014.</p> <p>United States Environmental Protection Agency (U.S. EPA). Method TO-12. Method for the Determination of Non-methane Organic Compounds (NMOC) in Ambient Air Using Cryogenic Preconcentration and Direct Flame Ionization Detection (PDFID). Available online at: http://www.epa.gov/ttnamti1/files/ambient/airtox/to-12.pdf. Accessed December 2014.</p> <p>Watson, N.M. and D. Cooper. Tube Sampling Versus Canister Sampling – The Pros and Cons of Each Approach. Available online at: http://events.awma.org/education/Posters/Final/Cooper_Poster.pdf. Accessed December 2014.</p>
Additional Comments:
<p>No additional comments.</p>

6.3.5 Passive Monitoring

Passive monitoring using diffusion samplers commonly used for air quality monitoring in Alberta are not suitable for screening-level odour assessment because of the commonly used 30-day exposure period.

6.4 Non-Analytical Methods

6.4.1 Triangular Odour Bag Method

Description:
<p>In the Triangular Odour Bag Method, a minimum of six panelists perform odour evaluation by sniffing directly from three sample bags, one containing a sample and two containing a clean air blank. The panelists identify the bag with odour, and the odourant is gradually diluted until it becomes impossible to identify the sample bag. The odour index is based on this final dilution.</p> <p>The maximum permissible odour index standard is determined by local authorities, which according to Japanese law must be in the range of 10 to 21. This range has been determined to be equivalent to odour intensities between 2.5 and 3.5 (JME 2006).</p>
Information Output:
<p>The tool allows a calculation of odour index. $\text{Odour Index} = 10 \times \log(\text{Odour Concentration})$, where the odour concentration is based on the dilution at which the odour panel can no longer correctly identify an odourous bag sample.</p>
Ease of Use:
<p>The ease of use is similar to other techniques employing non-analytical approaches.</p>
Accuracy – Detection Limit and Calibration Requirements:
<p>Depends on panelist sensitivity and the accuracy of the dilution</p>
Approximate Cost, Resource Requirements and Logistical Considerations:
<p>The cost is similar to other techniques employing non-analytical approaches and collection in various containers. The cost of a lab-based odour panel is less than a field based panel.</p> <p>In Japan, considered to be easy-to-operate and cost-effective as the method is necessary to be</p>

employed in nationwide municipalities and olfactometry laboratories.
Applicability to Multiple Sources of Odour:
Yes.
Measurement Scope – Single, Group or Mixture of Odourants:
The method is designed for use with mixtures.
Quality Control:
As in similar methods, blanks and clean syringes need to be used to maintain quality of analysis. Screened and trained odour panelists are needed.
Limitations:
The tool is designed specifically for use in odour assessments, and is the standard approach in Japan. The method is considered to produce similar odour threshold values as standard assessment methods in other jurisdictions (TCEQ 2010).
Applicability to Alberta:
The method could be used in Alberta, as there is no currently prescribed method nor are there odour control regulations that require a specific method. There is some familiarity in the province with the detection thresholds developed using the method.
References and Resources:
Higuchi, T. 2008. Odor Measurement in Japan. Japan Ministry of the Environment. Available online at: https://www.env.go.jp/en/air/odor/eastasia_ws/2-1-5.pdf . Accessed December 2014.
Japan Ministry of the Environment (JME) . 2006. Odor Index Regulation and Triangular Odor Bag Method. Office of Odor, Noise and Vibration Environmental Management Bureau, Ministry of the Environment, Government of Japan. Available online at: http://www.env.go.jp/en/air/odor/regulation/all.pdf
Nagata, Y. 2003. Measurement of Odor Threshold by Triangle Odor Bag Method. pp. 118-127 In: Odor Measurement Review. Ministry of the Environment, Government of Japan. Available online at: http://www.orea.or.jp/en/PDF/Odor_Measurement_Review,.pdf . Accessed



December 2014.

SYAES. 1993. National Standards of the People's Republic of China GB/T 14675-93, Air quality – Determination of Odour-Triangle Odour Bag Method. Shenyang Academy of Environmental Sciences.

Texas Commission on Environmental Quality (TCEQ). 2010. Interim Guidelines for Setting Odor-Based Effects Screening Levels. TCEQ, Toxicology Division. Available online at: <http://www.tceq.state.tx.us/assets/public/implementation/tox/esl/guidelines/odor.pdf>. Accessed December 2014.

Additional Comments:

No additional comments.

6.4.2 Odour Descriptor Wheel

Description:

Numerous standard odour descriptor lists are available to use as referencing vocabulary. For example, eight recognized odour descriptor categories are illustrated as an odour wheel. A large number of standard descriptor lists are available and can be tailored for specific industries or industry mixes.

The first odour descriptor wheel was developed in the 1970s by American and British brewing and sensory scientists, as a “Beer Flavor Wheel” in a tiered system for describing the flavor (taste and odours) of beer (Rosenfeld *et al.* 2007). In the 1980s, the California wine industry developed a wine aroma wheel for the characterization of wines (Noble *et al.* 1984). The idea of the wheel is that general categorical descriptors are at the center of the wheel and more specific descriptors are placed towards the wheel rim. In 2003, St. Croix Sensory developed an odour descriptor wheel for use with environmental odour samples (St. Croix Sensory 2003).

The odour wheel is commonly used only in the U.S. In Europe, Australia, and New Zealand, the more common approach is for a panelist to describe an odour using a list of 20 to 40 common odour descriptors or to use their own words to describe an odour. Some Canadian provinces follow the European approach and use a descriptor list with 20 user-defined adjectives.

A descriptor list commonly used to describe odour includes: fishy, rotten eggs, cabbage, mouldy, soapy, plastic, chemical, garbage, rotten food, grass, soil, paint, compost, sweet, sour, chocolate, vinegar, urine, and non-industrial (Pullen 2007).

Information Output:

Identification of an odour using standard descriptor language. In some cases, the description of the odour and its placement on the wheel can lead to an identification of the odourant(s) involved and therefore the possible source of the odour emissions.

Ease of Use:

The odour wheel is easy to use when the odour is easily described.

Accuracy – Detection Limit and Calibration Requirements:

Accuracy depends on: the specificity in the descriptions included in the wheel (for example, the use of an odour wheel designed for emissions from composting will be more specific / accurate than a

<p>general global scent profile); and the complexity of the odourant mixture. Accuracy is improved if odour observers are screened and trained in the use of the wheel.</p>
<p>Approximate Cost, Resource Requirements and Logistical Considerations:</p>
<p>Minimal cost to use the tool. If specific odour wheels are developed for specific applications, some consulting will be required. Screening and training, to ensure consistency of description, is advisable.</p>
<p>Applicability to Multiple Sources of Odour:</p>
<p>Does not distinguish among emissions from sources unless the sources have unique / distinct odour emission profiles. Most applicable to single odourants or to simple mixtures in which the odour of each component is separately recognizable.</p>
<p>Measurement Scope – Single, Group or Mixture of Odourants:</p>
<p>The method was developed for describing odours associated with limited variables (<i>e.g.</i>, odours associated with wine and beer). Performance is poor for complex mixtures due to the difficulty of identifying specific component odourants.</p>
<p>Quality Control:</p>
<p>Periodic testing to ensure odour descriptions remain consistent within the pool of observers will maintain consistency of description.</p>
<p>Limitations:</p>
<p>Not applicable for complex mixtures of odourants. Accuracy is improved if odour observers are screened and trained in the use of the wheel, but the performance may still be poor with mixtures when a single identifiable odourant does not predominate.</p>
<p>Applicability to Alberta:</p>
<p>Odour wheels are specifically designed for odour assessments and are applicable to Alberta. To be most applicable, industry or geography-specific wheels could be used.</p>



References and Resources:

- Burlingame, G.A., I.H. Suffet, D. Khiari, and A. Bruchet. 2004. Development of an Odour Wheel Classification Scheme for Wastewater. *Water Science Technology* 49(9):201–209.
- Noble, A.C., R.A. Arnold, B.M. Masuda, S.D. Pecore, J.O. Schmidt, and P.M. Stern. 1984. Progress Towards a Standardized System of Wine Aroma Terminology. *American Journal of Enology and Viticulture* 35:107-109. Available online at: <http://sanpatriciowineconsortium.info/wp-content/uploads/2010/11/standard2.pdf>. Accessed December 2014.
- Pullen. J. 2007. Review of Odour Character and Thresholds. Environment Agency Science Report: SC030170/SR2. Available online at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/290981/scho0307bmkt-e-e.pdf. Accessed December 2014.
- Rosenfeld, P.E., J.J.J. Clark, A.R. Hensley and I.H. Suffet. 2007. The Use of an Odour Wheel Classification for the Evaluation of Human Health Risk Criteria for Compost Facilities. *Water Science & Technology* 55(5): 345–357. doi:10.2166/wst.2007.197
- St. Croix Sensory. 2003. A Detailed Assessment of the Science and Technology of Odor Measurement; St. Croix Sensory, Inc. Available online at: <http://www.pca.state.mn.us/index.php/view-document.html?gid=5358>. Accessed December 2014.
- Suffet, M. Odor Wheel Applications. Environmental Science & Engineering Program, UCLA, School - Public Health, Los Angeles. Available online at: <http://www.baaqmd.gov/~media/Files/Compliance%20and%20Enforcement/Compliance%20Assistance/Odor%20Conf/Odor%20Wheel%20Applications.ashx?la=en>. Accessed December 2014.

Additional Comments:

No additional comments.

6.4.3 Categorical Scale Analysis

Description:
<p>Odour character is a nominal (categorical) scale of measurement and requires sensory (subjective) methods compared with odour detection threshold value determinations which are objective. Sensory methods include odour intensity and hedonic tone of the odour. Determination of sensory parameters is most useful for samples which are collected undiluted at a receptor rather than at an emission source, and evaluated by an odour panel without dilution.</p> <p>Since these evaluations are subjective, it is recommended to use a large odour panel, such as eight members, to obtain statistically reliable sensory evaluation data. The odour panel notes odour intensity and hedonic tone. Determination of sensory parameters is most useful for samples which are collected undiluted at a receptor rather than at an emission source, and evaluated by an odour panel without dilution.</p> <p>The odour is described on a numerical scale for hedonic tone and intensity.</p>
Information Output:
Description of the odour and perhaps an indication how the description will influence complaints.
Ease of Use:
Easy to use.
Accuracy – Detection Limit and Calibration Requirements:
Accuracy depends on the ability of the individual or panel member to describe an odour. Since these evaluations are subjective, it is recommended to use a large odour panel, such as eight members, to obtain statistically reliable sensory evaluation data. There is no detection limit associated with this method.
Approximate Cost, Resource Requirements and Logistical Considerations:
Standard costs associated with operation of an odour panel.



Applicability to Multiple Sources of Odour:
The method can differentiate among odour sources provided the odour character is sufficiently unique at each source.
Measurement Scope – Single, Group or Mixture of Odourants:
Has limited value for mixtures because odourant mixtures often have a varying composition leading to a potentially wide range of sample descriptors.
Quality Control:
Training and screening of observers.
Limitations:
Limited use when the odour is barely identifiable, which can occur with complex mixtures when there is no predominant odourant, or with dilute samples.
Applicability to Alberta:
The method is applicable within its limitations.
References and Resources:
Committee for European Normalization (CEN). 2003. Air Quality-Determination of Odour Concentration by Dynamic Olfactometry. European Standard (EN) 13725:2003. Available online at: http://www.sipe-rtd.info/directive/air-quality-determination-odour-concentration-dynamic-olfactometry . Accessed December 2014.
Ontario Ministry of Environment (MOE). 2010. Ontario Source Testing Code, Part G, Method ON-6: Determination of Odour Emissions from Stationary Sources. Standards Development Branch, Ontario MOE. PIBs# 1310e03. Available online at: https://dr6j45jk9xcmk.cloudfront.net/documents/1464/3-7-31-ontario-source-testing-code-en.pdf . Accessed December 2014.
Standards Australia/Standards New Zealand (SA/SNZ). 2001. AS/NZS 4323.3:2001 (R2014). Stationary Source Emissions –Determination of Odour Concentration by Dynamic Olfactometry.
Verein Deutscher Ingenieure (VDI). 2006. VDI 3940, Part 1: Measurement of Odour Impact by Field Inspection – Measurement of the impact frequency of recognisable odours – Grid



Measurement . VDI Guidelines Department (ed.), Dusseldorf.

Verein Deutscher Ingenieure (VDI). 2011. VDI-3880, Olfactometry - Static Sampling. VDI Guidelines Department (ed.), Dusseldorf.

Additional Comments:

No additional comments.



6.4.4 Olfactometry

Description:
<p>In olfactometry, the odour sample is diluted with odour-free air, according to precise ratios, to determine odour concentrations using an odour panel. Olfactometers may be multi-station (four, six or eight stations with all of the panelists evaluating a sample simultaneously) or single station where the odour panelists evaluate the samples in turn.</p> <p>An olfactometer is an instrument used to detect and measure odour dilution, most often with trained and screened panelists in controlled laboratory settings. Olfactometers are used to determine the odour detection thresholds of individual odourants or the odour units of an odour sample. In olfactometry, the odour sample is diluted with odour-free air, according to precise ratios, to determine odour concentrations using an odour panel. Olfactometers consist of a carbon-filtered clean air source, an odourant sample, and a manifold for precisely mixing clean and sample air.</p> <p>According to standards, the materials used in olfactometer construction should not cause sample contamination or chemical reactions such as adsorption/desorption. Therefore inert materials such as stainless steel, Teflon, Tedlar, or glass are used for internal surfaces.</p> <p>There are different presentation modes for the olfactometer. These include: the Triangular Forced Choice Method, the Binary Forced Choice Method, and the Yes/No Non-Forced Choice Method (European Standard EN13725:2003 (CEN 2003); Australia/New Zealand AS/NZ S4323 (SA/SNZ 2001); or ASTM (2001) E679-04(2011)).</p>
Information Output:
<p>Determination of odour concentrations and odour detection thresholds as well as other parameters such as detection, recognition, offensiveness, and complaint thresholds.</p>
Ease of Use:
<p>Requires careful operation and experience to avoid any contamination of the system or misinterpretation of data (<i>i.e.</i>, the method requires a controlled laboratory setting). Screening and training of the odour panelists is required prior to use.</p>



Accuracy – Detection Limit and Calibration Requirements:
<p>The detection limit is based on olfactometer type. The range according to current EN 13725 standards is from less than 2⁷ up to at least 2¹⁴, with a range of at least 2¹³ between the maximum and minimum dilution. Some olfactometers have detection limits as low as 4 OU (2²).</p> <p>Calibration requires a tracer gas such as CO or propane. Calibration should be within a 3% range.</p> <p>The accuracy will depend on the step size between dilutions, which varies with the application.</p>
Approximate Cost, Resource Requirements and Logistical Considerations:
<p>A controlled laboratory setting with charcoal-filtered intake is required. Also, the number of air exchanges per hour per panelist in order to remove odour quickly during the evaluation of samples must be considered. The room should be temperature and humidity controlled. Air supply should also be humidity controlled and free of any odour.</p> <p>Cost for olfactometers ranges from \$20,000 to \$120,000. Filters and air samples are nominal. Odour panelist fees will apply and may vary depending on the number of samples or hours.</p>
Applicability to Multiple Sources of Odour:
<p>Applicable to one or more sources of odour.</p>
Measurement Scope – Single, Group or Mixture of Odourants:
<p>The method is designed for mixtures.</p>
Quality Control:
<p>As with similar methods, calibration, collection, and analysis of blanks and clean purging systems are needed to maintain quality of analysis. Screened and trained odour panelists are needed to maintain reproducibility of results. The laboratory room for odour evaluations requires specific conditions: temperature and humidity control and a specified air exchange rate per hour per person.</p>
Limitations:
<p>Limited to odour samples with odour concentrations of about 10 OU or higher, whether from source or ambient locations. Although it is possible to analyze samples that are below 10 OU, some</p>

precautions are required.

Limitation in number of samples analyzed per day per session in order to avoid any panelists fatigue (which affects data reproducibility), limitation in availability of the participants (panelists), *etc.*

Limitation in sample degradation from collection to assessment and the variability among panelists.

Applicability to Alberta:

Olfactometry is appropriate for use in Alberta.

References and Resources:

ASTM International (ASTM). 2011. ASTM E679-04(2011). Standard Practice for Determination of Odor and Taste Thresholds by a Forced-Choice Ascending Concentration Series Method of Limits. ASTM International, West Conshohocken, PA.

Bokowa, A. 2008. What is Offensiveness Threshold Value and Complaint Threshold Value, and what is their Correlation with the Detection Threshold Value? *Chemical Engineering Transactions* 15: 115-121.

Bokowa, A. and J. A. Beukes. 2012. How Reliable Are Odour Assessments? *Water Science and Technology* 66(10):2049-2055.

Committee for European Normalization (CEN). 2003. Air Quality-Determination of Odour Concentration by Dynamic Olfactometry. European Standard (EN) 13725:2003. Available online at: <http://www.sipe-rtd.info/directive/air-quality-determination-odour-concentration-dynamic-olfactometry>. Accessed December 2014.

Ontario Ministry of Environment (MOE). 2010. Ontario Source Testing Code, Part G, Method ON-6: Determination of Odour Emissions from Stationary Sources. Standards Development Branch, Ontario MOE. PIBs# 1310e03. Available online at: <https://dr6j45jk9xcmk.cloudfront.net/documents/1464/3-7-31-ontario-source-testing-code-en.pdf>. Accessed December 2014.

Standards Australia/Standards New Zealand (SA/SNZ). 2001. AS/NZS 4323.3:2001 (R2014). Stationary Source Emissions –Determination of Odour Concentration by Dynamic Olfactometry.

Verein Deutscher Ingenieure (VDI). 2011. VDI-3880, Olfactometry - Static Sampling. VDI Guidelines Department (ed.), Dusseldorf.



Additional Comments:

Olfactometry is considered the best available approach to objectively quantify the perception of odours.

6.4.5 Field Olfactometry

Description:
<p>Measurement of odour concentrations using a field olfactometer (<i>e.g.</i>, a Scentometer[®], Nasal Ranger[®], or Scentroid products). All instruments are based on individual readings through either a small hole (Scentometer) or a mask (Nasal Ranger and Scentroid) to determine odour concentration. The Nasal Ranger has carbon filters at the sides of the instrument, which are used for filtering ambient air to provide odour free air for sample dilution. The Scentroid uses a clean air supply (small tanks).</p> <p>In the U.S., a common practice for assessing ambient odours is to determine the detection to threshold ($D/T = \text{volume of carbon-filtered air} / \text{volume of odourous air}$), which is a measure of the number of dilutions needed to dilute the odour to the threshold of being detected.</p> <p>Beginning in 1959, a scentometer was used for field purposes (Bokowa 2008). The instrument is a rectangular clear plastic box containing two activated carbon beds. Six sample inlet holes on one end of the box provide six D/T values (2, 7, 15, 30, 170, and 350). The other side of the box contains two glass nostril tubes for sniffing.</p> <p>The Nasal Ranger Field Olfactometer provides a sealed mask for an individual to determine the detection to threshold (D/T). The Nasal Ranger contains six inlet orifices with different D/T values (2, 4, 7, 15, 30, and 60) as well as a check for odour in clean (carbon filtered) air. If the odour is strong, higher D/T values can be used, such as 60, 100, 200, 300, 400, and 500 (St. Croix Sensory 2003).</p>
Information Output:
<p>D/T determination = volume of carbon-filtered air/volume of odourous air for the Nasal Ranger and the Scentometer, and odour concentration for Scentroid.</p> <p>Approximate odour concentration.</p>
Ease of Use:
<p>Easy to use.</p>
Accuracy – Detection Limit and Calibration Requirements:
<p>Detection Limit is 2D/T for Nasal Ranger and 4 OU for the Scentroid.</p>



Approximate Cost, Resource Requirements and Logistical Considerations:
Inexpensive to purchase (about \$2,000), low cost to use compared to olfactometry and other methods. The cost for training observers is dependent on the number of observers who are present at a training session, but may typically be \$1,000 per observer.
Applicability to Multiple Sources of Odour:
Applicable to multiple odour sources.
Measurement Scope- Single, Group or Mixture of Odourants:
Measures whole air odour; therefore appropriate for mixtures.
Quality Control:
Requires calibration, use of blanks, and screened and trained operators.
Limitations:
<p>All instruments are based on individual readings for one minute, whereas ambient sampling for laboratory olfactometry generally occurs for a longer time. Considered to be a screening tool only because the method is expected to be less accurate than olfactometry.</p> <p>Limitations of the Nasal Ranger include (St. Croix Sensory 2008):</p> <ul style="list-style-type: none"> • the carbon filters attached to the instrument may not be capable of filtering some odourants sufficiently; • the Nasal Ranger readings provide peak instantaneous odours, whereas ambient sampling provides odour concentrations averaged over, say, ten minutes. However, the Nasal Ranger results, even for peak concentrations, are significantly lower (Bokowa 2008); • use of masks which is not normal breathing process and may affect the results; • readings are based on one-person sensitivity; and • fatigue over a time of the person using Nasal Ranger. <p>Several instruments which are equivalent to the Nasal Ranger are available, and are often referred to as scentometers (of which Scentometer® is one example). Limitations of scentometer are:</p> <ul style="list-style-type: none"> • readings provide peak instantaneous odours, whereas ambient sampling provides odour



concentrations averaged over, say, ten minute;

- use of masks which is a not normal breathing process and may affect the results;
- readings are based on one-person sensitivity; and
- fatigue of person using the scentometer.

Applicability to Alberta:

Applicable for use in Alberta.

References and Resources:

Bokowa, A. 2008. Ambient Odour Assessment- Comparison of Two Techniques used for Assessing Ambient Odours. In: Frechen, F.-B. (ed.). *Odour and VOCs: Measurement, Regulation and Control* Kassel University Press, Germany.

Bokowa, A. 2012. Ambient Odour Assessment Similarities and Differences between Different Techniques. *Chemical Engineering Transactions* 30: 313-318. Available online at: <http://www.aidic.it/cet/12/30/053.pdf>. Accessed December 2014.

Bokowa, A. and J. A. Beukes. 2012. How Reliable Are Odour Assessments? *Water Science and Technology* 66(10):2049-2055.

Hobbs, P. J., T. H. Misselbrook, and B. P. Pain. 1995. Assessment of Odors from Livestock Wastes by a Photoionization Detector, an Electronic Nose, Olfactometry and Gas-Chromatography Mass-Spectrometry. *Journal of Agricultural Engineering Research* 60: 137-144.

IDES Canada (IDES). 2014. Scentroid. Available online at: <http://www.scentroid.com/>. Accessed December 2014.

St. Croix Sensory. 2008. The Nasal Ranger® Field Olfactometer. Operation Manual, Version 6.2. Available online at: <http://www.nasalranger.com/Operations.cfm>. Accessed December 2014.

Additional Comments:

No additional comments.

6.4.6 Odour Diary

Description:
Odour diaries are records of odour and odour episodes by individuals living close to the source of odour (<i>e.g.</i> , waste water treatment plant, compost/landfill facilities, <i>etc.</i>) and typically those individuals who are experiencing odour annoyance (see ATSDR 2014 and EPA VIC 2014 for examples). The diary consists of odour observations (<i>e.g.</i> , intensity of the odour, character, duration, and pleasantness) made by the individual. Date and time of the odour episode should also be recorded, as well as environmental conditions at the time.
Information Output:
Odour intensity, hedonic tone, character of detected odour, and duration.
Ease of Use:
Easy to use.
Accuracy – Detection Limit and Calibration Requirements:
Depends on each observer’s sensitivity, but odour diaries are typically less accurate than odour panels unless the author is trained.
Approximate Cost, Resource Requirements and Logistical Considerations:
No cost, except for training diary authors, which may typically be \$100 per person.
Applicability to Multiple Sources of Odour:
Yes, applicable to multiple odour sources.
Measurement Scope – Single, Group or Mixture of Odourants:
Appropriate for mixtures.
Quality Control:
No quality control required as these are personal observations. However, quality can vary dramatically from author to author.

Limitations:
May be helpful for initiating an investigation of potential odour or potential odour sources in the area. Results are based on the sensitivity of one or more individuals who may not be trained.
Applicability to Alberta:
Applicable for use in Alberta.
References and Resources:
Agency for Toxic Substances & Disease Registry (ATSDR). 2014. Air Pollution Odor Diaries. Available online at: http://www.atsdr.cdc.gov/odors/air_pollution_odor_diaries.html . Accessed December 2014. Department of Environment, Food, and Urban Affairs (DEFRA). 2010. Odour Guidance for Local Authorities. Available online at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69305/pb13554-local-auth-guidance-100326.pdf . Accessed December 2014. EPA Victoria (EPA VIC). 2014. Odour Diary. Available online at: http://www.goldenplains.vic.gov.au/webdata/resources/files/EPA%20Odour%20Diary.pdf . Accessed December 2014.
Additional Comments:
No additional comments.

6.5 Dispersion Modelling

6.5.1 Gaussian Model

Description:
<p>The U.S. EPA (2004a, b, c) AERMOD is a Gaussian model, where pollutants are dispersed in the atmosphere based on meteorology at a single location. The model was not specifically designed for odour modelling but pollutants can include odourants. The model does not consider chemicals that create secondary pollutants. The model accepts point (<i>e.g.</i>, stacks), volume (<i>e.g.</i> explosions, buildings), and area (<i>e.g.</i>, mines) sources. AERMOD is recommended by the U.S. EPA for air quality assessments at distances up to 50 km from the source.</p>
Information Output:
<p>The model predicts the air concentration of one odourant on a grid or at specific locations. The maximum concentration and other predicted values are provided, particularly the maximum concentration at a point over a period of time. Averaging periods are one or more hours, typically corresponding to air quality standards. The model is able to produce frequency of odour events from one odourant at one receptor point, or the number of hours with predictions above thresholds at all receptor points. Since the lowest averaging period is one hour, hourly results should be converted to shorter averaging periods for odour applications. There is no accepted methodology for achieving sub-hourly concentrations.</p>
Ease of Use:
<p>AERMOD is easier to use than CALPUFF; however, some experience in air quality modelling is required. More user-friendly versions of AERMOD are commercially available. Meteorological data for AERMOD can be relatively easily obtained from ESRD MM5 data (ESRD 2014) for 2002-2006 as they were determined to be typical years for Alberta meteorology. Users who choose to use other years will be required to create their own meteorological data set or to purchase it from commercial suppliers.</p>
Accuracy – Detection Limit and Calibration Requirements:
<p>Several studies have compared model results to observations (<i>e.g.</i> Dresser and Huizer, 2011). In general, models (including AERMOD) may under-predict or over-predict concentrations by a factor of two (<i>e.g.</i> Langner and Klemm, 2011; Dresser and Huizer, 2011).</p>

<p>Model variance can be attributed to limitations in the model physics, representative nature of emissions (worst case air quality measurements may not occur with the average emission rates often modelled), representative nature of meteorology, and uncertainty in background concentrations.</p>
<p>Approximate Cost, Resource Requirements and Logistical Considerations:</p>
<p>The model is free of charge from the U.S. EPA (2014). Consultant costs to run the model will be the order of \$10,000 and up depending on complexity of modelling. A user-friendly version of the program will be \$2,000 and up, with annual maintenance \$700 USD. Five years (2002-2006) of meteorological data can be freely obtained from ESRD (2014) and terrain elevation data are available from NRCAN (2012).</p>
<p>Applicability to Multiple Sources of Odour:</p>
<p>Can be applied to many sources of odour but one odourant is modelled per model run. Alternatively, emissions in OU can be modelled, with the limitation identified in the following box.</p>
<p>Scope – Single, Group or Mixture of Odourants:</p>
<p>If the mixture of the emitted substances is converted to odour units (OU), a mixture can be modelled as one substance (odour). Alternatively, the mixture constituents can be separately modelled as concentrations, converted to respective OU, and then summed.</p> <p>Care must be taken with modelling mixtures however as OU are not linear with concentration. As such, odour is at best estimated using either approach.</p>
<p>Quality Control:</p>
<p>Careful quality control of model inputs and model switch settings is needed to ensure the reasonability of results. Processing of model output is needed to produce useful information, and this processing step must also be quality controlled.</p>
<p>Limitations:</p>
<p>AERMOD limitations include:</p> <ul style="list-style-type: none"> • Predictions for averaging times relevant to odour (minutes) must be estimated empirically as the model shortest averaging period is 1h; • The model can estimate only the odour of mixtures (OUs are not linear with concentration and mixture constituents cannot be closely determined);

- The model does not consider chemicals that create secondary pollutants; and
- The model is not a strong performer in very light winds or complex terrain.

ESRD has no guidelines for odour modelling, and does not recommend AERMOD for applications in complex terrain that can exacerbate the concentration of pollutants and odourants.

Applicability to Alberta:

ESRD has no guidelines for odour modelling. However, AERMOD is recommended and widely applied for air quality assessments.

References and Resources:

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Additional Comments:

No additional comments.



6.5.2 Gaussian Puff Model

Description:
<p>The Air Quality Dispersion Model “CALPUFF” (TRC 2011, 2014) is a Gaussian puff dispersion model, where pollution parcels (puffs) move in the atmosphere. A meteorological sub-model (CALMET) produces a three dimensional meteorological field varying in space (vertically and horizontally) and in time. The model accepts point sources (<i>e.g.</i>, stacks), volume (<i>e.g.</i> explosions, buildings), area (<i>e.g.</i>, mines), and line sources (for hot buoyant sources on building roofs).</p>
Information Output:
<p>The model predicts the air concentration of multiple pollutants including odourants and deposition to surfaces on a grid or at specific locations. The maximum concentration and other predicted values are provided given periods of time. Averaging periods are one or more hours, typically corresponding to air quality standards. The post-processor (CALPOST) is able to produce the frequency of odour events at one receptor point, or the number of hours with predictions above thresholds at all receptor points. An odour event is defined as the detection of odour at a receptor. It is possible to run the model at shorter time-steps if appropriate meteorological data are available. For odour applications, hourly odour concentration results should be converted to shorter averaging periods since odour complaints usually occur when an odour is detected over a period of minutes or even seconds; however, there are no guidelines for converting to sub-hourly concentrations.</p>
Ease of Use:
<p>Experience in air quality modelling is definitely required. To create input files, less experienced modellers may use a Graphical User Interface (GUI) supplied with the model or a user-friendly version from commercial sources. Output files are binary and must be processed using CALPOST. CALMET requires knowledge (and tools) to assemble land use categories, terrain, and meteorological data.</p>
Accuracy – Detection Limit and Resource Requirements:
<p>Several studies have compared model results to observations (<i>e.g.</i> Dresser and Huizer 2011). In general, models (including CALPUFF) may under-predict or over-predict concentrations by a factor of two. In some situations this discrepancy could be even higher. Typically, when applied over five years of hourly meteorological values, predictions of near-extreme concentrations are well within a factor of two.</p>

Model variance can be attributed to limitations in the model physics, representative nature of emissions (worst case air quality measurements may not occur with the average emission rates often modelled), representative nature of meteorology, and uncertainty in background concentrations.

Approximate Costs, Resource Requirements and Logistical Considerations

The model is free of charge from the TRC Solutions (TRC 2014). Substantial training is needed to correctly run the model. External support in modelling would begin near \$10,000 for a simple assessment and range over \$100,000 for a complex multi-source assessment. Meteorological data can be obtained from ESRD (2014), and from other providers. Land use and terrain data can be downloaded from NRCAN (2009) and NRCAN (2012), respectively. Computer requires relatively high processor speed with running memory of up to 100 GB or more.

Applicability to Multiple Sources of Odour:

The model is designed to be applied to one or many sources of odour. Modelling can be done for odours expressed as OU/s or individually for one or more odourants.

Scope – Single, Group or Mixture of Odourants:

The model may be run for single or multiple odourants, or in OU/s form, but does not model secondary odourants. The model includes limited chemical reactions.

Quality Control:

Careful quality control of model inputs and model switch settings is needed to ensure the reasonability of results. Processing of model output is needed to produce useful information, and this processing step must also be quality controlled. It is recommended that modelled meteorology be compared to actual measurements, and that predicted concentrations be compared to actual measurements where available.

Limitations:

CALPUFF (Version 6) (TRC 2014) can be used for sub-hourly time steps necessary for odour assessment; however, sub-hourly meteorological data needs to be available. This may create large storage requirements.

For hourly time steps, conversion to shorter time periods is required which introduces uncertainty. Note that there are no guidelines for converting to sub-hourly concentrations.

In addition, the model can only estimate the odour of mixtures (OUs are not linear with concentration and mixture constituents cannot be closely determined).

Applicability to Alberta:

CALPUFF is approved for use in Alberta for air quality rather than odour assessments, and is recommended for use in complex terrain or regional assessments. Odour assessments using the model have been widely conducted typically using averaging periods of three minutes either using individual odourants or in OU form.

References and Resources:

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Additional Comments:

CALPUFF is a model of choice in complex terrain and when more accurate air pollutant concentration results are required.

Appendix A - The CASA Odour Assessment Guide

Purpose

The purpose of this guide is to assist in the determination of odour assessment options. It is recommended that, prior to using this guide, Section 2 and Section 3 of the Review of Odour Assessment Tools and Practice be read. This will provide the reader/user with background knowledge to assist in understanding this guide.

Use of the Guide

The following approach is suggested:

1. Identify the purpose of the odour assessment, in the following table
2. Review the suggested steps in the assessment, for the intended purpose
3. Examine the matrix of tool options for each step, and identify the possible tools that meet your needs

As a simplified example (the preparation of a robust assessment plan at the outset is strongly recommended that may differ from the steps suggested here), if the purpose is to verify an odour complaint, choose a non-analytical assessment tool as a first step. An odour wheel may confirm that the “strong solvent smell” complaint may be due to toluene or xylene emissions. A follow-up ambient measurement program at the location of the complaint could involve exposure of a number of sealed canisters followed by laboratory analysis for the odourants of interest (and others). The resultant odourant concentrations and frequency of high concentrations could be compared to established odour thresholds. If the measurements suggest that a specific source may be responsible for the observations, a source measurement program may be appropriate. At each step, the guide offers options based on such attributes as cost, the type of source, whether odour or odourants is the issue, etc. A glossary has been provided at the end of this guide to assist with understanding of terms and acronyms.

How will the results be interpreted?

There is a wide range in the information output by the various tools, and the interpretations will vary as widely. For example, the output of a *continuous ambient monitor* (page 2) will be a series of concentration measurements for an odourant (such as H₂S). The data can be compared to odour detection thresholds, or summarized to establish frequencies of observations above thresholds. When coupled with wind data measured simultaneously, a preferred direction from which odourants emanate may be determined. As a second example, the information output of an odour wheel is the identification of a possible odourant (*e.g.*, H₂S) based on the characteristics of the odour (*e.g.*, rotten eggs) as determined by an individual.

In many cases, the addition of a dispersion modelling step will provide greater understanding of the issue, by identifying odour or odourant hot-spots or conditions under which high odour is predicted that might not be identified by monitoring alone.

Who should use the guide?

This guide is primarily intended for non-experts who need to decide the steps necessary for conducting an odour assessment. This could include representatives of municipalities dealing with odour complaints, industry wishing to change their operations, communities with odour concerns, provincial government, and regulators.

Purpose of Odour Assessment	Suggested Steps
To verify and investigate odour complaints	<ol style="list-style-type: none"> 1. Non-analytical assessment 2. Ambient sampling and measurement 3. Source sampling and measurement
To comply with conditions outlined in operating/industrial permits	<ol style="list-style-type: none"> 1. Source sampling and measurement 2. Ambient sampling and measurement
To determine compliance with odour legislation	<ol style="list-style-type: none"> 1. Source sampling and measurement 2. Ambient sampling and measurement
To assess long term odour exposure levels in an area	<ol style="list-style-type: none"> 1. Non-analytical assessment 2. Ambient sampling and measurement
To rank potential odour sources for mitigation purposes	<ol style="list-style-type: none"> 1. Source sampling and measurements (OU or individual compounds)
To determine background odour concentrations before building a new facility	<ol style="list-style-type: none"> 1. Ambient sampling and measurement
To determine the off-site odour impact from existing operations	<ol style="list-style-type: none"> 1. Non-analytical assessment 2. Ambient sampling and measurement
To determine the expected changes in off-site odours resulting from new facilities, expansions of existing facilities, or other operational changes.	<ol style="list-style-type: none"> 1. Source sampling and measurement 2. Ambient sampling and measurement 3. Dispersion modelling

Tool Type	Tool	Odour Episode Characterization								Level of Detail	Target		Cost	Source type					Application		Facility Type		Quantifiable	
		Frequency		Intensity		Duration		Offensive	Location Sensitivity		Odourant(s)	Odour		Point	Area	Volume	Line	Multi-Source	Source	Ambient	Existing	Planned		
		High	Low ^a	High	Low	Long	Short																	
Source																								
Point Source - Analytical	CEMs	✓	✓	N/A	N/A	✓	✓	N/A	N/A	High	✓	N/A	\$\$\$\$	✓	✓ ^b	✓ ^b	✓ ^b	✓ ^b	N/A	✓	N/A	✓	N/A ^c	✓
	Semi-continuous	✓	✓	N/A	N/A	✓	✓	N/A	N/A	High	✓	N/A	\$\$\$	✓	✓ ^b	✓ ^b	✓ ^b	✓ ^b	N/A	✓	✓	✓	N/A	✓
	Intermittent / integrated	✓	N/A	✓ ^c	✓ ^c	✓	N/A	N/A	N/A	High	✓	✓	\$\$	✓	✓ ^b	✓ ^b	✓ ^b	✓ ^b	N/A	✓	✓	✓	N/A	✓
Point Source - Sample Collection ^d	Grab bag / canister	✓	N/A	✓ ^c	✓ ^c	✓	N/A	N/A	N/A	High	✓	✓	\$	✓	✓ ^b	✓ ^b	✓ ^b	✓ ^b	N/A	✓	✓	✓	N/A	✓
Area Source - Sample Collection ^d	Flux chamber	✓	✓ ^e	✓ ^c	✓ ^c	✓	✓	N/A	N/A	N/A	✓	✓	\$\$	N/A	✓	N/A	N/A	N/A	N/A	✓	N/A	✓	N/A	✓
	Wind tunnel	✓	✓ ^e	✓ ^c	✓ ^c	✓	✓	N/A	N/A	N/A	✓	✓	\$\$	N/A	✓	N/A	N/A	N/A	N/A	✓	N/A	✓	N/A	✓
	Static Hood	✓	✓ ^e	✓ ^c	✓ ^c	✓	✓	N/A	N/A	N/A	✓	✓	\$\$	N/A	✓	N/A	N/A	N/A	N/A	✓	N/A	✓	N/A	✓
Volume Source - Analytical	Remote sensing	✓	✓	N/A	N/A	✓	✓	N/A	N/A	Medium	✓ ^f	N/A	\$\$\$	✓	✓	✓	✓	✓	✓	✓	✓	✓	N/A	✓

^a Low frequency odour events are those occurring only a few times each year. High frequency events occur more often but the characterization is subjective.

^b Under the assumption that the source emits uniformly

^c Source emission estimates are needed for new or modified facilities prior to construction. However, they would typically be provided by engineering estimates rather than measurements.

^d This tool or technique collects a sample, or facilitates the collection of a sample. This sample must be analyzed separately using appropriate non-analytical or analytical laboratory techniques. Non-analytical tools are discussed below. The range of laboratory analytical techniques that could be applied to sample collections is broad, application dependent, and beyond the scope of this document

^e Only if the sampling equipment underlying the method is operated continuously or semi-continuously, as the method only acts as a means to direct the sample to a collection device

^f Generally, remote sensing devices have higher detection limits than other methods.

✓: The tool is applicable. N/A: The tool is not applicable

Tool Type	Tool	Odour Episode Characterization								Level of Detail	Target		Cost	Source type					Application		Facility Type		Quantifiable	
		Frequency		Intensity		Duration		Offensive	Location Sensitivity		Odourant(s)	Odour		Point	Area	Volume	Line	Multi-Source	Source	Ambient	Existing	Planned		
		High	Low	High	Low	Long	Short																	
Ambient																								
Analytical	Continuous	✓	✓	N/A	N/A	✓	✓	N/A	High	High	✓	N/A	\$\$\$	N/A	N/A	N/A	N/A	N/A	N/A	✓	✓	N/A	✓	
	Semi-continuous	✓	✓	N/A	N/A	✓	✓	N/A	High	High	✓	N/A	\$\$	N/A	N/A	N/A	N/A	N/A	N/A	✓	✓	N/A	✓	
	Intermittent / Integrated	✓	N/A	✓ ^c	✓ ^c	✓	N/A	N/A	High	High	✓	✓	\$\$	N/A	N/A	N/A	N/A	N/A	N/A	✓	✓	N/A	✓	
	e-Nose	✓	✓	✓ ^c	N/A	✓	✓	N/A	Medium	Medium	N/A	✓	\$\$	N/A	N/A	N/A	N/A	N/A	N/A	✓	✓	N/A	✓	
	Passive ^g	✓	N/A	N/A	N/A	✓	N/A	N/A	Low	Low	✓	N/A	\$	N/A	N/A	N/A	N/A	N/A	N/A	✓	✓	N/A	✓	
	Remote sensing	✓	✓	N/A	N/A	✓	✓	N/A	Multiple	Medium	✓	N/A	\$\$\$	✓	✓	✓	✓	✓	✓	✓	✓	✓	N/A	✓
Sample Collection ^d	Grab bag / canister	✓	N/A	✓ ^c	✓ ^c	✓	N/A	N/A	High	High	✓	✓ ^s	\$	N/A	N/A	N/A	N/A	N/A	N/A	✓	✓	N/A	✓	
Non-Analytical																								
	Odour index	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Low	Low	N/A	✓	\$	✓	✓	✓	✓	✓	✓	✓	✓	✓	N/A	N/A
	Odour wheel	N/A	N/A	N/A	N/A	N/A	N/A	✓	Low	Low	N/A	✓	\$	✓	✓	✓	✓	✓	✓	✓	✓	✓	N/A	N/A
	Categorical scale	N/A	N/A	N/A	N/A	N/A	N/A	✓	Low	Low	N/A	✓	\$	✓	✓	✓	✓	✓	✓	✓	✓	✓	N/A	N/A
	Field-based olfactometry	N/A	N/A	✓	N/A	N/A	N/A	✓	Medium	Low	N/A	✓	\$\$	✓	✓	✓	✓	✓	✓	✓	✓	✓	N/A	✓
	Lab-based Olfactometry	N/A	N/A	✓	✓	N/A	N/A	✓	High	High	N/A	✓	\$\$	✓	✓	✓	✓	✓	✓	✓	✓	✓	N/A	✓
	Community survey	N/A	N/A	N/A	N/A	N/A	N/A	✓	Low	Low	N/A	✓	\$\$\$	✓	✓	✓	✓	✓	✓	✓	✓	✓	N/A	✓ ^a
	Odour Diary	N/A	N/A	N/A	N/A	N/A	N/A	✓	Low	Low	N/A	✓	\$	✓	✓	✓	✓	✓	✓	N/A	✓	✓	N/A	N/A
Dispersion Model																								
	Gaussian Puff (CALPUFF)	✓ ^b	✓	N/A	N/A	✓	✓	N/A	Medium	High	✓	✓	\$\$\$	✓	✓	✓	✓	✓	✓	N/A	✓	✓	✓	✓
	Gaussian (AERMOD)	✓ ^b	✓	N/A	N/A	✓	✓	N/A	Medium	High	✓	✓	\$\$	✓	✓	✓	N/A	✓	✓	N/A	✓	✓	✓	✓

Footnotes:
^a A community survey can quantify frequency of detection, etc., but are not used to quantify odour concentration or intensity.
^b Standard model output includes worst case (i.e. low frequency) occurrences. Hourly predictions are available with additional analysis.
^c Odour intensity can be determined based on olfactometry assessment of samples collected using this method
^d This tool or technique collects a sample, or facilitates the collection of a sample. This sample must be analyzed separately using appropriate non-analytical or analytical laboratory techniques. Non-analytical tools are discussed below. The range of laboratory analytical techniques that could be applied to sample collections is broad, application dependent, and beyond the scope of this document
✓: The tool is applicable. N/A: The tool is not applicable.

Glossary of Terms, Definitions and Acronyms

Analytical: A monitoring method that is quantitative and repeatable and where a single instrument collects and analyzes a sample.

Application: An indication of whether the tool is appropriate for source or ambient assessments. For example, a CEM is appropriate only for source odour emission rate estimation, not an ambient assessment, while remote sensing techniques are generally applicable to both kinds of assessments.

Categorical Scale: A means of systematically categorizing odour by means of a ranking scale, often from 0-5 or 0-7.

CEMS: Continuous emission monitor typically used to measure air quality and odourants in the stacks of combustion sources.

Cost: \$\$\$\$ (more than \$100,000) \$\$\$ (more than \$50,000) \$\$ (more than \$10,000) \$ (more than \$1,000) for a single occurrence. All costs are order of magnitude and will depend on the application. For example, a year-long sampling campaign at multiple locations using grab or canister sampling might be rated as \$\$\$ rather than \$.

Community Survey: Community questionnaires to establish perception of odours within an area of investigation.

Duration: How long the odour is perceived in each occurrence. Short duration may be the order of a few minutes. Long could refer to hours or days although duration is relative.

E-Nose: Refers to the capability of reproducing human senses using sensors.

Facility Type: An indication of whether the tool is appropriate for existing or planned facilities.

Flux Chamber: A device to isolate the surface area for collecting gaseous emissions. Nitrogen is usually used as a sweep gas.

Frequency: The rate at which odourant or odour can be assessed corresponding to the tool type. For example, a CEM monitor may sample and analyze odourants every few seconds. Ambient grab samples are usually made infrequently, perhaps once a week, and so are not likely to collect a sample during an infrequent odour event.

Grab Bag / Canister: A means of collecting a whole-air sample.

Intensity: The strength of the odour, as a function of the concentration of odour or odourant. High or low refer to the intensity that can be addressed by the method. Olfactometry or e-noses are the approaches used to estimate intensity, based on a collected sample. For example, field-based olfactometry is typically less useful for low intensity measurements than high intensity measurements. Continuous analyzers cannot measure intensity.

Intermittent / Integrated: An air sampling device that air samples over a period of time, on a medium. The types of media include canisters or sample bags, solid adsorbents tubes, etc. The concentration of odourants is determined through laboratory analysis of the sample medium. The term intermittent indicates the sampling is done periodically, say once each week.

Level of Detail: A determination of whether the method can be used to provide a high level of detail for odour assessments, or is useful as an indication of potential (e.g., a medium or low level of detail) which may require a subsequent more detailed confirmatory assessment. In this Guide, detail refers to the number of odourants that can be addressed with a single measurement.

Location Sensitivity: Location accounts for the type of land use and the nature of human activities. These factors determine the sensitivity of the receiving environment. As such, source measurement tools are not strictly applicable as they do not refer to the receiving environment. Attempt has been made to identify the tools that might be most effective in high sensitivity receiving environments such as hospitals, schools, etc.

Odourant: A gas that causes the sensation of odour.

Odour Diary: Individual observations related to odour over a period of time.

Odour Episode Characterization: Description of an odour episode based on the FIDOL framework.

Odour Index: A scale of odour intensity, Odour Index = $10 \times \log_{10}$ (odour concentration).

Odour Wheel: A means of documenting various odour characters in a circular chart, along with chemicals that are consistent with each character.

Offensive (ness): The level of unpleasantness or disagreeability.

Olfactometry: The presentation to odour panel members of a sufficiently complete set of diluted samples to calculate the odour concentration for a sample.

Passive – passing a fixed volume of odourant through a glass tube packed with an adsorbent material.

Quantifiable: An indication of whether the tool can provide quantifiable results (odour emission rates, odour concentrations, or other numerical output), as opposed to documentation of sensory perceptions.

Receptor Modelling: A method for determining the sources of air pollution based on air monitoring data. Receptor models use odourant (or odour) measurements at an individual monitoring site (the receptor) to calculate the relative contributions from major sources to the pollution/odour at that site.

Remote Sensing: The acquisition of information about odour without making physical contact with the odour plume. Typical techniques include Tunable Diode Laser Absorption Spectroscopy (TDLAS), Differential Absorption Light Detection and Ranging (DIAL), Open Path Fourier Transform Infrared (OP-FTIR) Spectroscopy, Differential Optical Absorption Spectroscopy (DOAS), or Correlation Spectroscopy (CS) that measure specific odourants or groups of odourants.

Sampling: A method whereby a sample of gas is collected and then analyzed separately (for example in a lab using olfactometry).

Source Type: The type of source, in these categories, the method is appropriate for.

Static Hood: A device that isolates a part of the emitting surface which directs the sample air into the hood outlet duct for sample collection.

Target: The target of the assessment, or capability of the method, and its appropriateness for odourants or groups of odourants, or odour.

Wind Tunnel: A device to isolate the surface area for collecting gaseous emissions with the capability to regulate the air velocity inside the device.