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HEAVY OIL MANAGEMENT TECHNOLOGY AND BEST PRACTICES

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HEAVY OIL MANAGEMENT TECHNOLOGY AND BEST PRACTICES

FINAL REPORT

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Prepared by:

Anya Gawor, M.Sc., E.Pt., E.I.T.
Junior Air Quality Scientist

Reviewed by:

Piotr Staniaszek, Ph.D.
Senior Technical Specialist, Air Quality

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EXECUTIVE SUMMARY

The Environment & Geoscience business unit of SNC-Lavalin Inc. (SNC-Lavalin) was retained by PTAC to conduct a study and provide industry with tools to minimize or eliminate odours resulting from emissions by providing a review of technologies and operational practices. Presented in this report includes a summary of mitigation technologies and a best management practice guide for operations.

The project scope of this report included: Odour Overview (TASK 1), Description of Technologies (TASK 2), Selection Factors (TASK 3), and Facility Best Management Practice (TASK 4). As such, the report is organized into the following sections:

1. **Introduction**. This provides more information on the project scope, the definition of odour, and current regulatory requirements on odour control in Canada.
2. **Background**. Describes the motivation behind preparing this report.
3. **Overview of Odours from Heavy Oil Processes**. Provides a summary of odours as related to heavy oil processes and what are the common processes that contribute to odour problems.
4. **Air Pollution Control for the Abatement of Odorous Emissions**. Lists technologies and techniques that can treat odorous emissions in heavy oil industries.
5. **Facility Best Management Practice (BMP)**. Provides recommendations to treat odorous emissions during normal, upset, and operation and maintenance conditions.

SNC-Lavalin's review and analysis drew the following conclusions:

1. Major odour-causing emitters during heavy oil operations include reduced sulphur compounds (RSCs) and some volatile organic compounds (VOCs).
2. Major sources of odour emissions include (from highest to lowest): battery facilities (which includes storage tanks), wellheads, produced water systems, transportation, loading/off-loading, piping components, boilers, flares, heaters, turbine generators, waste stockpiles.
3. Technologies and techniques will vary depending if it is a fugitive, point, or area source emissions.
4. Selection criteria for point/vented source emissions are dependent on multiple variables, which include pollutant concentration, size (volume) and its constituents.
5. SNC-Lavalin provided an exercise on numeric scoring for technologies to use on point source emissions. Based on the exercise, the following technologies are recommended, from most preferable to least preferable: Adsorption >> Absorption > Biotreatment > Non-Thermal Oxidation Processes > Incineration >> Condensation.
6. A BMP for the management of odorous emissions is provided and it includes management of: material quality, process parameters, fugitive emissions, tanks and vessels, buildings, vented emissions using odour control technologies, transportation and loading/unloading, produced water systems and stockpiles, separation distances/buffer zones, maintenance, housekeeping, and training.

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AER	Alberta Energy Regulator
AGS	Alberta Geological Survey
APC	Air Pollution Control
API	American Petroleum Institute
Area Source Emissions	Emissions that are spread over a spatial extent and are unmovable. They are generally difficult to contain due to nature and size of activity related to that emission
AUPRF	Alberta Upstream Petroleum Research Fund
BMP	Best Management Practice
CAPP	Canadian Association of Petroleum Producers
CCME	Canadian Council of Ministers of the Environment
CO_2	Carbon Dioxide
CHOPS	Cold Heavy Oil Production with Sand
CAPEX	Capital expenditure
CSS	Cyclic Steam Simulation
D&IM	Directed Inspection and Maintenance
EOR	Enhanced Oil Recovery
EPAC	Explorers and Producers Association of Canada
Fugitive Emissions	Unintentional emissions that aren't captured and released through specific discharge point. Unintentional hydrocarbon leaks due to normal wear and tear on different piping components such as: valves, connectors, flanges, and pumps.

GHG	Greenhouse Gas
GOR	Gas-Oil Ratio
H_2O	Water
H_2S	Hydrogen Sulphide
HVAC	Heating, Ventilating, and Air Conditioning
LDAR	Leak Detection and Repair
LEL	Lower Explosive Limit
MAML	Mobile Air Monitoring Laboratory
MCf	Million Cubic feet
n	Number
Normal Conditions	Standard operating conditions; Process conditions are going as is.
NO_x (NO, NO_2, NO_3)	Nitrous Oxides
NTOP	Non-Thermal Oxidation Process
OP	Odour Potential
OU	Odour Unit
OPEX	Operating Expenditure
O&M	Operations and maintenance
Point Source Emissions	Emissions that are captured, contained and released from anticipated discharge location
ppbv	Parts per billion per volume

ppm	Parts per million
PPT	Pressure Pulsing Technology
PTAC	Petroleum Technology Alliance Canada
RSC	Reduced Sulphur Compounds
SAGD	Steam Assisted Gravity Drainage
SO_x (SO_2)	Sulphur Oxides
TVA	Toxic Vapour Analyzer
Upset Conditions	Any sudden and unavoidable failure in the process
UV	Ultraviolet
VOC	Volatile Organic Compounds
VRU	Vapour Recovery Unit

1 INTRODUCTION

1.1 Scope of Work

The Environment & Geoscience business unit of SNC-Lavalin Inc. (SNC-Lavalin) was retained by Petroleum Technology Alliance Canada (PTAC) to conduct a study and provide industry with tools to minimize or eliminate odours resulting from emissions by providing a review of technologies and operational practices. The report contains a summary of mitigation technologies and a best management practice guide for operations. The project scope is as follows:

- **Odour Overview**. Summary of the compounds likely to cause of odour issues from various sources. Review of possible sources at heavy oil production sites (TASK 1).
- **Description of Technologies**. Review of main categories of APC technologies. Applicability, advantages, expected control efficiency, and limitations of each method are discussed, together with review of specific requirements for installation and use (TASK 2).
- **Selection Factors**. For each listed technology, SNC-Lavalin analyzed factors that influence technology selection (e.g. cost, GOR, distance to populated or sensitive areas, meteorology and terrain considerations, etc.) (TASK 3).
- **Facility Best Management Practice (BMP)**. Odour prevention BMP with or without odour mitigation technologies is included. The possible compliance assessment is discussed relative to identified heavy oil odour sources (TASK 4).

This project was facilitated by PTAC on behalf of the AUPRF. AUPRF Funds are distributed with direction from the CAPP and the EPAC member of companies.

1.2 Introduction to Odours

Odour can be defined as the property of substance which stimulates olfactory receptors in the nose. Odour can be also described as distinctive and very often unpleasant smell. Pleasant odours generated by food and cosmetic industry are often referred as aromas or fragrances. However, even generally pleasant aromas can be offensive for some individuals, especially if they have prolonged exposure to these fragrances. Unpleasant odours are referred as stink, malodour or stench.

Odour sensation depends on the nature and concentration of the substances affecting olfactory receptors during breathing of air. A single odorant is typically recognized by multiple receptors. With mixtures of odorants, the receptors do not distinguish separate compounds, but rather the entire mixture of compounds. In such a case odour perception does not necessarily correspond to the concentration or intensity of any single compound. There is a non-linear relationship between the intensity of odour and the concentration of the volatile compounds which cause the odour.

1.3 Meteorological Conditions and Terrain Effects

Odour concentrations can have high spatial and temporal variability. They depend on emission sources, terrain and meteorological conditions.

Odorous emissions from all kind of sources (processing plants, tanks, storage piles, ponds, etc.) are usually higher in summer months when substances' volatility is high due to warmer weather. High humidity and higher ambient temperatures increase the probability of odour detection. For the most part, precipitation suppresses odour concentrations in the atmosphere. Emissions from open tanks and storage piles will be higher when wind velocities and ambient temperatures are higher (usually around spring time, or in summer).

Other meteorological factors which are important to consider in dispersion of odorous substances are: mixing height, inversions, and atmospheric stability. Mixing height is the lower atmospheric layer characterized by relatively constant temperature. Above this layer there is layer with higher temperature called the inversion. Mixing heights are usually low during winter months, when there is snow on the ground, and sun is not hot enough to warm up the ground and generate upward air movement. In western Alberta, warm Chinook winds create very strong inversions which trap emissions near the surface, causing odour and air quality problems. Plume cannot easily penetrate the layers above mixing height. The stable atmospheric conditions, low mixing height and light winds prevent the odorous plume from dispersing and causing high probability of odour complaints.

Close to odorous sources, terrain features may also influence odour dispersion. If odorous emission sources are located in a valley or depression, dispersion of odour is inhibited. Sources located well above the ground may disperse more easily. Valleys may channel air flow carrying odorous substances for longer distances. Ground cover (trees, bushes, obstacles) reduces odour concentration by enhancing dispersion and providing surface for deposition of substances.

The terrain features and ground cover are particularly important when planning of the location for a new facility.

1.4 Odour Measurements and Odour Units

The OU or OU/m^3 is defined as the number of times that odour sample will be diluted with odour free air, so that 50% of the general population won't be able to detect the sample. In olfactometry, general population is represented by odour panel consisting of four to eight panellists (depending on the jurisdiction). Although there are other methods to measure odours, human noses following the standard procedures pertaining to the odour panels are considered as the most accurate. In North America the odour concentrations are sometimes expressed as dilution to thresholds ratios (D/T). In general, values of odour concentrations are the same but units used to express them are different

(OU, OU/m^3, D/T). The odour unit (1 OU) corresponds to odour threshold (or odour threshold perception). For example, if there was a need to dilute odour sample 10 times, it means the sample has strength of 10 OU, and the ambient concentration of odorous compound obtained after 10 times dilution is the odour threshold (often expressed in parts per million - ppm, and sometimes in µg/m^3 units). Alternatively, the odour threshold is defined as the minimum concentration of an odorant which produces a noticeable change in the odour of the system (1). The ratio of the odorous substance concentration over the odour threshold is sometimes referred to as OP. It is used in modelling of emissions from the oil sands operations, where all substances are modelled separately and results are divided by their respective odour thresholds and summed in order to estimate if a total mixture may cause odour problems. When an OP value is 1 or greater, it means that in an average population, 50% or more of the people would be able to smell or 'detect' the emissions. An OP value lower than 1, the population would still be possible to smell or 'detect' the emissions, although less would be able to detect the odour (1).

1.5 Current Regulatory Requirements

Canada does not regulate odours through the federal government, leaving that responsibility to provinces and territories.

In Alberta, there are few regulatory measures dealing with unpleasant odours from the oil and gas industries. Most of these pertain to the odour management in upstream oil and gas, and include (2):

- **Oil and Gas Conservation Rules** (OGCR) – Sections 7.035, 8.050, 9.050 (3)
- **Environmental Protection and Enhancement Act** (EPEA) – Section 11.6 (4)
- **Directive 058** – Oilfield Waste Management Requirements for the Upstream Petroleum Industry – Section 11.6 (5)
- **Directive 060** – Upstream Petroleum Industry Flaring, Incinerating, and Venting – Section 8.2 (6)
- **Draft Directive** – Requirements for Hydrocarbon Emission Controls and Gas Conservation in the Peace River Area (7)

In summary, these regulations are concerned with spills or releases of products, waste management and processing, investigative methods when an offensive odour is reported, and ensuring that any venting and/or fugitive emission releases exclude disagreeable hydrocarbon odours outside the lease boundary. The two chemicals that are controlled, based on odour perception, are ammonia (hourly-basis) and hydrogen sulphide (hourly- and daily-basis). Aside from the above, there are no currently detailed regulations for the control of odorous emissions based on the odour thresholds in Alberta (8).

The province with the most detailed odour control guideline, or rather 'nuisance law', is Ontario, with over 70 chemical compounds listed with the odour-based point of impingement standards (8). Manitoba has an *Odour Nuisance Management* strategy, which focuses on those odorous contaminants that have health-related or other adverse (non-odour related) impacts, using ambient air quality criteria (9). The Manitoba Government encourages facilities (especially developing ones) to incorporate preventative measures, and in the event an odour nuisance does occur, to co-operate with the affected members of the community to discuss and implement an appropriate way to minimize the odour issue. Saskatchewan requires modelling of odours and has odour criteria for urban residential, urban commercial, industrial, and agricultural zones (10). In British Colombia, a report was submitted to governmental agencies with recommendations for odour management approaches (8). However, no policy has been developed since then. Just like Alberta – Newfoundland, Labrador and New Brunswick have standards for odorous compounds like hydrogen sulphide and/or ammonia. The remaining provinces and territories do not have any odour standards or policies in place (11).

In addition to all of the above, the Odour Management Team prepared a report for Clean Air Strategy Alliance team that can potentially lead to further regulatory requirements in Alberta (12). In this report, seven topics related to odour were examined, which included: Health, Complaints, Odour Assessment, Prevention and Mitigation, Enforcement and Role of Regulation, Education Communication and Awareness, and Continuous Improvement. The document is broad-based, not touching any industry in particular, and aims to provide a good practices guide for assessing and managing odours in Alberta.

2 BACKGROUND

In March of 2014 AER published a *Report of Recommendations on Odours and Emissions in the Peace River Area* (2). The report summarized results of the inquiry dealing with the residential concerns about the odours resulting from emissions from the heavy oil operations in the Peace River area. Recommendations included a proposal for operational changes to eliminate venting, reduce flaring and/or conserve produced gas whenever feasible. The main goal of the recommendations is to eliminate odours caused by the heavy oil operations in the Peace River area to such extent that complaints and health symptoms allegations of the area residents will be eliminated.

This report will advise about specific actions and/or technology changes which may help to achieve this goal. Beyond the Peace River Area, this report can be extended to other areas where the oil and gas industry may have odour issues.

3 OVERVIEW OF ODOURS FROM HEAVY OIL PROCESSES

3.1 What is Heavy Oil?

Heavy oil can be defined as having API gravity less than 22. The American Petroleum Institute's "API gravity" is a standard to express specific weight of oils and it is inversely proportional to a specific gravity. The lower the specific gravity value, the higher the API gravity will be. Heavy oil can be described as asphaltic, dense and viscous. Raw bitumen from various oil sands operations can have the API gravities as low as 8, which is close to the range of the extra heavy oils. The extra heavy oils are defined as having the API gravity below 10. Such heavy oils have limited ability to be recovered by the conventional primary or secondary means (wells and pump jacks). The lower the API gravity, the more likely the tertiary recovery methods, such as EOR, are required.

Examples of areas producing heavy and extra heavy oils in Canada are:

- Lloydminster Area in Saskatchewan and Alberta;
- Cold Lake, Alberta;
- Surmont, Alberta;
- Peace River, Alberta;
- Athabasca Area, Alberta; and
- Southeastern part of Alberta.

3.2 Substances and Compounds Causing Odours

The major odour emitters, during heavy oil primary and secondary extraction operations and water processing, include: RSCs, VOCs, sulphur oxides, ammonia, organic acids, aldehydes, nitrous oxides, and petroleum coke (2, 13-14):

- **Reduced Sulphur Compounds (RSCs):** A family of substances which includes a sulphur atom in a reduced state. H_2S and mercaptan (organo-sulphur) compounds are the most commonly known RSCs. The other sulphur containing compounds are dimethyl disulphide and dimethyl sulphide. Major sources of these compounds include: processing units, drains, tanks, casing gas, vents, hydrocracking unit, wastewater separators, oxidation ponds, and barometric condenser pumps (15).

- **Volatile Organic Compounds (VOCs):** Volatile organic compounds are carbon substances that mostly participate in atmospheric photochemical reactions. They have a high vapour pressure in room temperature and are emitted as gases from certain liquids and solids (16). Major sources of these odorants include: fugitive sources (from flanges, pump seals, connections, etc.), casing gas, transfer operations, and transportation vehicles (15). Casing gas for example may contain (17):
  - Alkanes (butane, pentane, hexane, heptane, octane, nonane);
  - Alkenes (butane, pentene, hexene);
  - Ketone;
  - Alcohols (ethanol, isopropyl alcohol); and
  - Ringed compounds (thiophene, benzene, styrene, toluene, o-xylene).
- **Other:** The above two groups are the major odour emitters in heavy oil industries, due to their odour intensities. Sulphur oxides, nitrous oxides, ammonia, and aldehydes are other contributors to detected smells. SO_2, ammonia, and NO_x are generally the result of combustion processes and major sources include: incinerators, flares, boilers, heaters, treating units, catalytic-cracking regenerators, and compressor engines.

Currently, there are few odour field measurement studies in Canadian heavy oil processing areas. Two studies that will be discussed here are directly related to heavy oil processes in the Peace River Area. The first study discusses the odour concentrations for both major odour groups (RSCs and VOCs) from casing wells – of which case venting is a major source of odour into the atmosphere. The second study discusses odour concentration in ambient air *near* heavy oil processing areas and focuses on one major odour group, which are VOCs.

In 2014, the AGS investigated geochemical and geological contributions to emissions and odours in the Peace River Oil Sands Area. As a part of their investigation, they collected casing gas (number, n = 10) and liquid (n = 12) samples from ten wells. A portion of those liquid samples were flashed to $25^{O}C$ (n = 10) and $80^{O}C$ (n = 3) for twenty-four hours to measure the compounds of interest's volatility from liquid.

Figure 1, adapted from AGS's Report # 2015-07 (18), illustrates, for casing gas samples, RSC concentrations generally exceed the odour threshold by at least 1,000 times (odours up to 1,000 OU), as compared to VOC concentrations which generally exceed odour threshold by ~10-100 times (odours 10-100 OU). The average odour threshold multiple (corresponding to OP) was obtained by averaging the concentrations in all 10 sampled wells, and dividing this average concentration by the documented corresponding odour threshold perception concentration values obtained from Nagata (19). The odour threshold values were obtained between 1976 and 1988, using the triangle odour bag method. The triangle odour bag method threshold is obtained by detecting the odour against an odour-free background using six panellists. For more information of the values, see Yoshio Nagata's report *Measurement of Odor Threshold by Triangle Odor Bag Method* (19)*.* Note that the values in Figure 1 measured by AGS are from casing gas samples. Casing gas is natural gas *enclosed* in a pipe assembled in a borehole, and therefore is more concentrated than in ambient conditions. What is being illustrated in this figure, are which odorous compounds are most prominent. It can then be conjectured, after the vented release from casing, which compounds would be most influential to malodorous emissions.

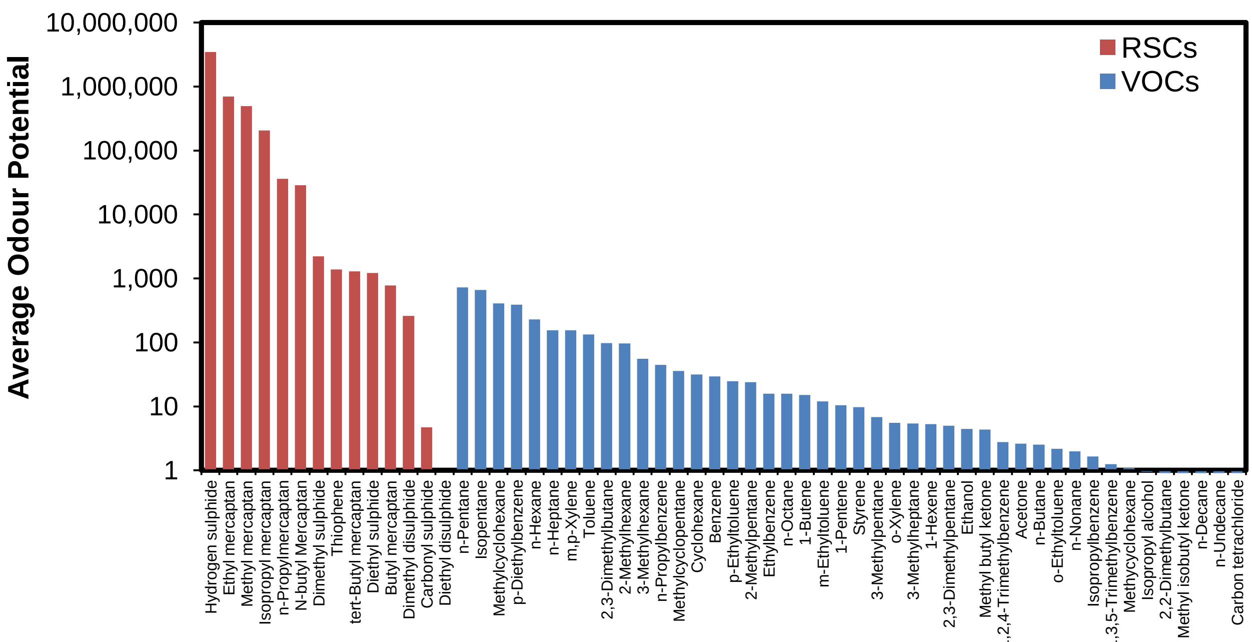

FIGURE 1 Graph Comparing Select RSCs and VOCs Based on Odour Threshold Exceedance Multiples (corresponding to OPs), adapted from AER/AGS Report #2015-07 (18).

In 2012, a survey was conducted by Alberta Environment and Parks (AEP) in Three Creeks, near the Peace River Area. AEP deployed a Mobile Air Monitoring Laboratory (MAML) equipped with various air monitoring instruments, to perform short-term ambient air quality surveys. The MAML monitored seven sites between January 31 and February 2 (20). Three of the sites, B, E and G, collected canister samples which were analyzed for VOCs – no RSCs were measured. Table 1 identifies which VOCs may contribute to odour problems the most.

The values presented in Table 1 are significantly lower than the values presented in Figure 1, as they are measurements conducted in ambient conditions, and would be influenced by meteorological conditions, as discussed in Section 1.2. In Table 1, all the OP values are less than 1, indicating that over 50% of the neighbouring residents would not be able to detect the odour. However, what these OP values do not capture are the population that is more sensitive to odours (in which, odour threshold perception concentration would be significantly lower), and the OP values focus on individual components. As it has been determined (21, 22), a combination of odorous compounds could enhance odour perception, which is not captured in the information listed in Table 1.

TABLE 1 Three Creeks MAML Survey VOC Canister Results for Odorous Substances – January 31 to February 1, 2012 (20)

Name	**Odour Threshold Perception**[1] *(ppbv)*	**Odour Potential (OP) – Measured Concentration/Odour Threshold (ppbv/ppbv)**			
		Site B *31-Jan-12*	Site E *02-Feb-12*	Site B *02-Feb-12*	Site G *02-Feb-12*
Acetone	42,000	3.40E-05	2.19E-05	1.69E-05	1.95E-05
Benzene	2,700	0.00017	3.85E-05	8.26E-05	4.48E-05
1-Butene	**360**	**-**	**-**	**0.019**	**-**
Butane	1,200,000	1.84E-05	9E-07	1.10E-05	2.1E-06
Cyclohexane	2,500	0.0032	-	0.0014	7.6E-05
2,2-Dimethylbutane	20,000	-	-	1.45E-05	-
2,3-Dimethylbutane	420	0.0052	-	0.0025	0.0003
2,3-Dimethylpentane	4,500	0.0003	-	0.0002	1.20E-05
Ethylbenzene	170	0.0035	-	0.0009	-
Heptane	670	0.002	-	0.0002	-
Hexane	1,500	0.0027	-	0.0020	0.0002
Isopentane	**1,300**	**0.0154**	**0.0002**	**0.0102**	**0.0014**
Isopropylbenzene	100	0.0011	-	0.0005	-

Name	Odour Threshold Perception[1] *(ppbv)*	Odour Potential (OP) – Measured Concentration/Odour Threshold (ppbv/ppbv)			
		Site B *31-Jan-12*	Site E *02-Feb-12*	Site B *02-Feb-12*	Site G *02-Feb-12*
3-Methylheptane	1,500	0.0001	-	8.20E-05	-
2-Methylhexane	420	0.0022	-	0.0019	0.0002
3-Methylhexane	840	0.0037	-	0.0026	0.0002
2-Methylpentane	8,900	0.0011	3.4E-06	0.0008	6.98E-05
3-Methylpentane	20,000	0.0004	-	0.0002	1.66E-05
Methyl Ethyl Ketone	**440**	**-**	**-**	**0.0182**	**-**
Methylcyclohexane	**150**	**0.1107**		**0.0589**	**0.0030**
Methylcyclopentane	1,700	0.0040	-	0.0019	0.0001
Pentane	1,400	0.0091	-	0.0052	0.0007
Toluene	330	0.0057	-	0.0016	0.0001
m, p-Xylene	**41**	**0.0359**	**-**	**0.0094**	**-**
o-Xylene	380	0.0014	-	0.0004	-

Note 1 (Nagata, 2003)

From Table 1 it can be concluded that, Methylcyclohexane, m,p-Xylene, 1-Butene, Methyl Ethyl Ketone (MEK), and Isopentane (in **bold**) can potentially contribute the most to the odour problems, as they have the highest OPs. It is still expected that sulphur compounds (e.g. H_2S, mercaptans) are the biggest contributors to odour problems, as detailed in the AGS's study. In general, odour thresholds for RSCs are significantly lower than for VOCs. For example, ethyl mercaptan is at 0.0087 ppbv, methyl mercaptan at 0.07 ppbv, and H_2S is at 0.41 ppbv (19). From this and from what was determined from the AGS study, if RSCs were measured, they would be the most likely and prominent odorous compounds.

3.3 Common Processes Contributing to Odour Problems

3.3.1 Overview

Within the heavy oil sands industry, there are a few methods to extract oil, and the most popular ones include:

- **CHOPS:** Cold Heavy Oil Production with Sand[1];
- **SAGD:** Steam Assisted Gravity Drainage;
- **PPT:** Pressure Pulsing Technology; and
- **CSS:** Cyclic Steam Simulation.

Once extracted from the ground, oil is usually separated from the solids (sand) and water mixture using centrifugal pumps. During this process, oil can be heated and diluents can be added. Both methods lower crude oil's viscosity but they increase odour emissions. Sometimes demulsifying chemicals are added which may or may not contribute to odour problems.

Generally, unless the oil has been thermally affected (heated), its naturally high sulphur content is chemically tied up in heavy hydrocarbon molecules and there are little amount of H_2S or light mercaptans. The situation is different when water flood and steam operations are applied to the oil. Water used in these operations is pumped underground and may contain natural sulphates whose oxygen atoms are consumed underground by sulphate-reducing bacteria, resulting in H_2S production. The produced bacteria H_2S is readily absorbed by subsurface water and to some extent by the crude oil. The H_2S is liberated at the surface as the water is de-pressured and heated in the crude oil's primary treating process.

Condensate used as a diluent for treating is often a low quality light by-product of the heavy oil /oil sands upgrading. It is considered to have been "cracked" and may contain some very odour components. For example, sweet condensate's relatively high vapour pressure would result in odour emissions. These products are normally stored in floating roof tanks, pressurized bullets or tanks equipped with vapour recovery units.

[1] Primary method used in the Peace River Area (20)

Table 2 lists the major sources of odour in heavy oil industry, including emission characterization, potential odour impact, and source type (23). Potential Ambient Odour Impact is arbitrarily assigned to potential sources by OdoTech (23). Source type can be fugitive, point or area source emissions. Fugitive source emissions are generally defined as unintentional emissions discharge, released through a specific and expected discharge point, e.g. flange. They are generally characterized by low odour concentrations released from numerous locations. Point source emissions are captured, contained, and are released from a specific discharge location, e.g. casing vent. There are some activities where it is difficult to contain emissions due to the nature and the size of the activity. These are considered area source emissions and some examples include stockpiles, landfills, composts, land spreading, tank coatings, etc. (24).

TABLE 2 Major Sources of Odour in the Heavy Oil Industry, adapted from ref. (23)

Source	Emissions	Potential Ambient Odour Impact	Source Type
Battery facilities/storage tanks	VOCs, RSCs	High	Fugitive/Point
Wellheads	VOCs, RSCs	High	Point
Produced water systems	VOCs, RSCs	High	Area
Transportation	VOCs	High	Point
Loading/off-loading	VOCs	High	Fugitive
Piping components	RSCs, VOCs	Moderate	Fugitive
Boilers	SO_x, NO_x, NH_3	Moderate	Point
Flares	VOCs, RSCs, SO_x, NO_x, NH_3	Moderate	Point
Heaters	SO_x, NO_x, NH_3	Moderate	Point
Turbine generators	SO_x, NO_x, NH_3	Low	Point
Waste stockpiles	VOCs, RSCs	Low to Moderate	Area

3.3.2 Battery Facilities – Oil Storage, Separating and Tank Maintenance

Battery facilities are locations where tanks receive gas or oil from wells prior to market delivery or disposition, and may be areas where oil is separated and measured. These tanks are usually kept at a specific temperature, generally warmer than ambient conditions (especially in winter). Tanks can be a source of odorous emissions, as they may leak due to an insufficient seal (e.g. due to corrosion) and during tank maintenance, when an empty tank is opened and any residual odorous emissions escapes.

Pressure-vacuum vents release pressure in tanks that can develop when light hydrocarbons “flash out” or vaporize. They are designed to allow small pressure increases and decreases within tank to avoid explosions. These vents operate different, depending on roof type. Storage tanks and vessels either have fixed or floating roofs. For the fixed roof tank, hydrocarbon vapours evaporate into the gas space above liquid and are vented to the atmosphere when the new liquid is added to the tank or when the liquid surface level changes (e.g. due to change in the pressure). The gas is released through the vent placed at the top of the tank. For the floating roof tanks, hydrocarbon vapours may pass around the floating roof rim seal and openings for fittings.

Thief hatches are closable apertures that are located on tanks and vessels and are used to sample tank contents. They are also one of the most common sources of emission leaks due to a failing seal.

If the tanks are designated to accept new products, they need to be cleaned prior to accepting new products. During this process hydrocarbons are purged several times from the tank, releasing the odorous vapours to the atmosphere. Removal and collection of the sludge may also release some of these odorous hydrocarbon vapours.

At well sites, storage tanks are used to separate the different phases of the slurry. Usually there are four different phases: gas (mainly methane), heavy crude oil, process water, and sand. Those tanks require regular cleaning, when the liquid hydrocarbon is pumped out, then the tank is purged of the hydrocarbon vapours and sand is removed from the tank’s floor and walls. Removal of sand may cause release of the hydrocarbon vapours to the air, resulting odour problems.

3.3.3 Wellheads

One significant emission source is casing gas vents from wellheads. Oil extraction through production casing/open-hole and production/surface casing may cause enough pressure to be built up resulting in the migration of gas to surface and be released into the atmosphere. These gases are not treated and are usually vented into the atmosphere.

As it is shown in Figure 1 of the AGS study, these vents can contain substantial amounts of odorous RSCs and VOCs.

3.3.4 Produced Water Systems

Water, produced or used (e.g. as steam) during the primary and secondary extractions, is heavily contaminated with oil. The water collection and treatment systems (including ponds) are typically open to the atmosphere. For that reason, the treated water is a source of the odorous emissions, as compounds may volatilize into the atmosphere, especially during warm and windy days.

3.3.5 Transportation and Loading/Unloading Sources

A major task of the heavy oil process is the transportation of cold heavy oil by trucks or rail to the processing facilities for the secondary extraction. During the loading and unloading process of the transportation process, there are two major sources of emissions which may supply odorants into the atmosphere:

1) The vapours remaining in rail or truck tank from previous cargo are pushed out by new cargo of oil and water.

2) New product loaded to truck or rail tank evaporates to atmosphere during loading/unloading.

3.3.6 Combustion Activities – Flaring, Boilers & Heaters

Combustion activities, such as flaring, boilers, heaters, catalytic-cracking regenerators and treating units, are another source of odorous emissions into the atmosphere. These burning activities are a significant source of SO_x, NO_x and VOCs into the atmosphere. Combustion activities involve heat, which would trigger increased volatilization/formation for some of the compounds, and destruction for others.

Most of these combustion activities are continuously operating, and therefore can be a continuous source of odorous emissions into the atmosphere. Flaring, on the other hand, normally occurs during upset conditions (emergency flaring) or be used during routine burning of the waste gases. While less frequent, flaring can be a more significant emission source, and emit odorous compounds during these scattered occasions. The key problem with gas burning is maintenance of the high flame efficiency due to inconsistent supply of the process or well gas. In the case of flaring, i) under some meteorological conditions, ii) and/or due to improper use of the steam assisted flare, iii) and/or adding too much lift gas may result in incomplete combustion or, iv) in extreme cases, choked flame causing gas to be vented to the atmosphere. Flare stacks are equipped with pilot burning small amounts of the gas. These pilots are usually insignificant sources of emissions (including odours). Operators should attempt to reduce flaring by following the Directive 060 flaring and venting decision chart (6), as shown in Figure 2.

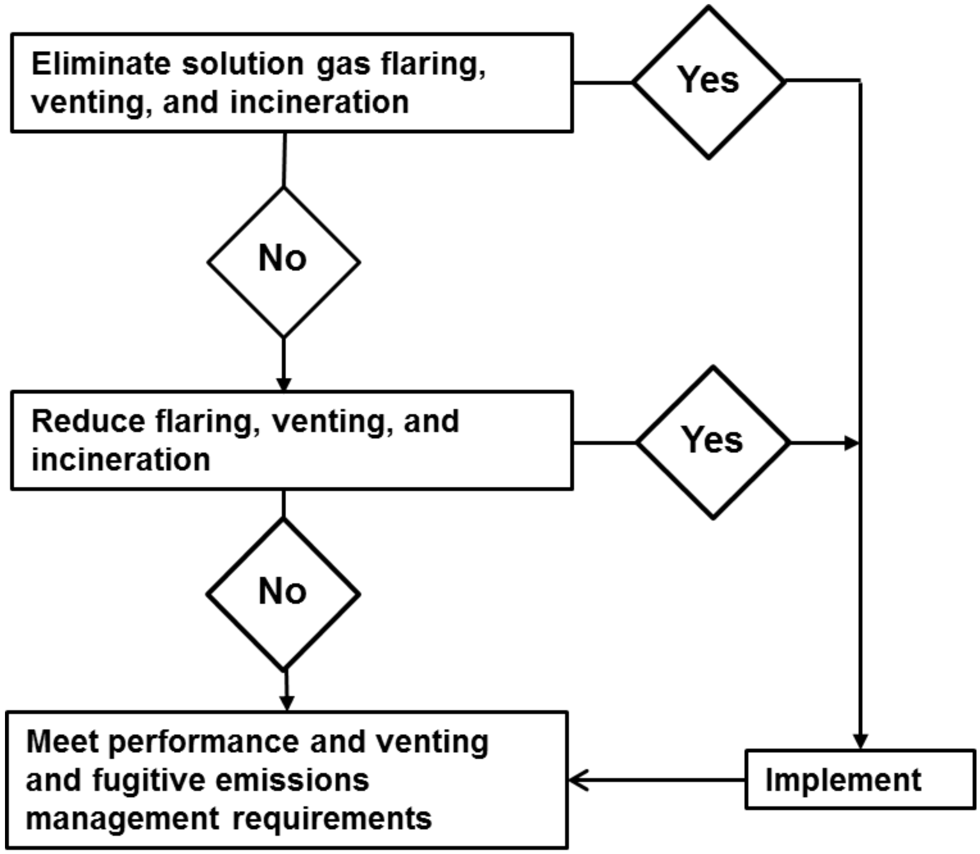

FIGURE 2 Gas Faring/Venting Decision Tree, adapted from Directive 060 (6)

3.3.7 Piping Components

Fugitive emissions from piping components occur when there are unintentional leaks of hydrocarbons to atmosphere due to normal wear and tear on different components such as valves, connectors, flanges, and pumps. Odorous emissions from piping components are continuously being emitted into the atmosphere and they contribute to background concentrations.

3.3.8 Waste Stockpiles

Heavy oil processing, particularly CHOPS, generates large volumes of sand contaminated with oil, which are disposed in waste stockpiles. Disposing substantial volumes of waste is a significant aspect for CHOPS, contributing between 15-30% of the OPEX factor (25). Waste in CHOPs is generally sand containing approximately 20% water and 2-6% oil. Odorous emissions from stockpiles, similarly like emissions from the tanks and produced water systems are enhanced by hot and windy weather. They depend on the number of times waste is added to the stockpiles (several times a day, daily, monthly, etc.). There is usually a limited amount of volatile material available to be emitted. If the stockpiles are left undisturbed for a longer time, they start to emit low levels of the odorous compounds. Eventually, a crust (a thin layer of harder material) will be formed on the stockpile preventing wind to spread dust and exposing a fresh source of volatile emissions.

4 AIR POLLUTION CONTROL FOR THE ABATEMENT OF ODOUROUS EMISSIONS

4.1 ODOUR CONTROL TECHNIQUES – OVERVIEW

There are many ways to control odour emissions from heavy oil and gas industries. A summary of different odour control techniques are listed in Table 3, followed by the detailed descriptions in the ensuing sections. These technologies are grouped by the odorous source emissions treatment (i.e., fugitive, point, area), as described in the Section 3.3.1, and the suitability in the heavy oil industry. Technologies that treat point sources (or vented emissions) will go into more depth with selection criteria and grading.

Recommendations and the best practice approaches will be provided in further detail in Section 5 of the report.

TABLE 3 Summary of Odour Abatement Technologies and Techniques[1-7]

Technology	Types	Description	Suitability
Technologies or Techniques to Treat Fugitive Source Emissions			
Containment	Tank covers, seals, vapour recovery units	Keeps emissions contained by use of covers (lining) and/or regular maintenance (e.g. replacement of seals)	Can be local part of process, or used for entire process. Most suitable for tanks, sewers, waste water handling facilities, truck loading/unloading/transportation.
Fuel quality management	Fuel type, keep streams separate, equipment material , separation of high odour concentrated streams from low odour concentrated streams	Control of gas quality as to not generate and/or release odorous impurities	Suitable for re-directing pipes to keep high and low concentrated streams separate and therefore can be further treated more efficiently, in addition to not combine streams that may create off-gases. Also, suitable for any equipment which material may react with process stream and create off-gases or corrode (and release fugitive emissions). The especially pertains to heat exchangers, separators, compressors which tend to foul. Suitable for replacing existing process gas stream to alternative, as effective gas type

Technology	Types	Description	Suitability
Fugitive emissions detection and control	Portable VOC analysers, Optical Gas Imaging technology, Lasers, Ultrasound Detection, Soap solution	Use of technology to detect/measure emissions. Decreases leaks if followed by prompt repair.	Control efficiency after fugitive emissions (leaks) are found on pumps, compressors, pressure relief devices, valves, connectors, open-ended lines, sampling connections. Pipefitters repair the equipment.
Neutralizing agents	N/A	Reacts with compounds to reduce odours.	Effective with odour abatement at source. Good for quick and temporary solutions, such as handling spills or any other process failures or emergencies. Additionally, helpful during maintenance or plant modifications.
Masking agents	N/A	Disguises emissions and blocks odorous receptors.	Effective with odour abatement at source. Good for quick and temporary solutions, such as handling spills or any other process failures or emergencies. Additionally, helpful during maintenance or plant modifications.
Technologies or Techniques to Treat Point Source Emissions			
Adsorption	Fixed bed, Fluidised bed	Solid surfaces used to capture odorous compounds.	Generally used as an enrichment step prior to thermal gas treatment. Can be useful to treat emissions from inside buildings, treating process streams,
Absorption	Spray, plate, packed bed, tray towers, moving bed, fibrous bed	Scrubbing liquid used to dissolve off-gas compounds.	Well-established technology – familiar in the petrochemical industries. Possible to form fertilizer bi-products. Primarily used to remove acid gases from combustion sources (i.e. heaters, boilers, and treating units – not to be used with catalytic combustion).
Biotreatment	Bioscrubbers, Bio-filters	Vapour-phase contaminants passed through material bed and adsorbed to substrate surface and degraded by micro-organisms.	Few chemical agents are required for this treatment, and micro-organisms destroy odorous contaminants. Suitable for treating off-gases from absorption towers.

Technology	Types	Description	Suitability
Non-thermal Oxidation processes	UV, Non-thermal plasma	UV/radiation induced formation of radicals and ions to oxidise molecule.	Treats air inside of facility (not only exhaust). No wastes produced. Needs to be combined with other technologies such as scrubbers, adsorption units, biotreatment units, containment units, etc.
Incineration (excluding flares)	Thermal, Catalytic	Treats odorous materials at high temperatures.	Suitable for more stringent exhaust air requirements. Versatile in treating most odorants.
Flares control	Enclosed, Open	Treats odorous materials at high temperatures.	Primarily for upset/accidental releases. Elevates products of combustion to be dispersed. Primary application is in petrochemical industries. Versatile in treating most odorants.
Condensation	Direct contact, surface, air cooled surface, pressurized, cryogenic	Reduce volume and moisture content of gas stream.	Reduces load and energy requirements of secondary control equipment. Needs to be used alongside scrubber/ incinerator as it is usually used as an enrichment step.
Technologies or Techniques to Treat Area Source Emissions			
Biotreatment	Bioscrubbers, Bio-filters	Vapour-phase contaminants passed through material bed and adsorbed to substrate surface and degraded by micro-organisms.	Few chemical agents are required for this treatment, and micro-organisms destroy odorous contaminants. Suitable for processes that produce large volumes of foul air at low concentrations (for example, water treatment ponds and stockpiles).
Containment	Covers for stockpiles, water treatment ponds	Keeps emissions contained by use of covers (lining)	Suitable for covering stockpiles and water ponds that are not too large and are not heavily active.
Neutralizing agents	N/A	Reacts with compounds to reduce odours.	Routine maintenance required. Effective with odour abatement at source. Good for quick and temporary solution, e.g., during maintenance. Can be applied on stockpiles and water treatment ponds.

Technology	Types	Description	Suitability
Masking agents	N/A	Disguises emissions and blocks odorous receptors.	Effective with odour abatement close to source. Good for quick and temporary solution, e.g., during maintenance. Can be applied on stockpiles and water treatment ponds.

1 *Odours from Stationary and Mobile Sources* (15)
2 *Odour Guidance 2010* (24)
3 *Good practice guide for assessing and managing odour in New Zealand* (26)
4 *Principles and Practices of Air Pollution Control and Analysis* (27)
5 *Odour management and treatment technologies: an overview* (28)
6 *Biosolids and Residuals Management Fact Sheet* (29)
7 *Horizontal Guidance for Odour Part 2 – Assessment and Control* (30)

4.2 Technologies or Techniques to Treat Fugitive Source Emissions

As mentioned previously, fugitive source emissions are defined as unintentional emissions that are not released through an anticipated discharge location and can come from numerous locations. In the heavy oil industries, these fugitive emissions can come from battery facilities, loading/off-loading equipment pieces, and equipment. Listed here, are five odour treatment/prevention techniques which can resolve odorous fugitive emissions.

4.2.1 Containment

There are several forms of containment techniques that can be implemented in the heavy oil industry. The requirements for these applications are listed in detail in Appendix A.

The most basic containment strategy is to keep doors and windows of processing buildings closed to keep odorous processes from escaping into the ambient environment. In heavy oil processing facilities, some processing units are contained within buildings for more controlled conditions. Closing doors and windows would reduce the amount of odorants released outside and does not cost or require anything extra (including power, infrastructure, etc.). An airlock entry can be installed that would prevent odorous emissions from escaping. However, the concern is the build-up of emissions which may cause conditions in these building units to become dangerous. As such, HVAC + air treatment units should be installed to reduce this overload along with air quality sensors (including LEL detectors). HVAC systems are generally integrated in buildings, and thereby the costs will be primarily on installing air treating unit(s). Types of treatment units that can be used will be described in Section 4.3.

Containment strategies can also be implemented for tanks, vessels, and towers (henceforth, "containers") on heavy oil sites. One such strategy is the installation of floating covers on top of the oil, below containers' roof. These covers are interconnected on the surface of heavy oil and reduce evaporation of the heavy oil in the heated containers. These covers are well established technology, used in water and waste water treatment plants. They are very simple to install (no energy required, no infrastructure requirements), immediate installation, and access to oil is not inhibited. There still may be very volatile emissions passing through these covers, however most of the odorants will be captured in this way. Floating covers are cost-efficient, approximately 5% of the cost of installing a VRU.

VRUs are common and recognized piece of technology used in petrochemical industries, and have been installed on tanks (31). VRUs are beneficial pieces of equipment as they can recover and market the vapours simultaneously. There are different types of VRUs that can be used (absorption, condensation, adsorption), and these different types will be discussed in more detail in Section 4.3.

Another strategy relating to containers involve tank covers. Covers would cover the entire container and are already established for residential and small-scale operations. They are simple to install, require minimal space, and no energy is required to operate. They would be most useful in upset conditions, where there may be a leak in the container, which results in spills. Instead of spilling onto the ground where it may volatilize and release odorous emissions, it can be contained by the cover and have a less impact on the environment. It may not contain all of the emissions, especially the more volatile ones, and its limitation is the additional complexity of accessing the tank.

Floating roof tanks are known to reduce emissions significantly, compared to fixed roof tanks due to the use of vapour seals. Internal floating tanks have the additional benefit of an extra roof which is used to protect the moving/floating roof element from external conditions which may reduce the lifespan of the roof (and result in roof leaks). Replacing the roof type should be considered when repairs/maintenance is being made on the tank.

4.2.2 Fuel Quality Control

There are few materials used to aid in the extraction and processing of oil from underground oilfield. Some of these include: injection gas, lift gas, blanket gas, fuel gas, and process liquids. These are generally constituted of steam, natural gas, glycol, or methanol. Natural gas may contain compounds, specifically H_2S and mercaptans, which emit unpleasant odours. It is known that odorous substances are occasionally added into sweet natural gas to assist with gas leak detection. These additives are necessary to prevent fires and explosions. They should not be removed from gas, even if they may cause odour problems. In these cases, good leak detection and repair programs, which will be described in Section 4.2.3, should be responsible to eliminate leaks and odours.

In some instances, natural gas can be replaced with another type of gas, namely compressed air or propane. Using compressed air would be favourable as it reduces costs and chances of odorous emissions. These replacements are generally for pneumatic devices and in Alberta, a carbon offset protocol has been developed to incentivise 'instrument gas' to 'instrument air' conversion (32). A study by Natural Gas STAR Partners reported savings as much as 70,000 MCf/yr/facility of natural gas with this conversion (33). Capital cost considerations for the conversion include a compressor, power source, dehydrator, and volume tank (to supply air without having to run a compressor continuously). Operating costs are continuous power supply to run the compressor and dehydrator and maintenance. Space requirements are very dependent on the size of the facility, size of equipment required, the number of operating control devices and their typical bleed rates. Payback for converting from natural gas to instrument air could occur within one year (33).

It is also important to avoid combining two or more incompatible materials/gases together that would result in off-gassing or corrosion. For example, when H_2S is in contact with water, it will enhance the process of corrosion of the equipment. This would propagate the release of unintentional odorous emissions as it would create pathways from the equipment for gas to escape into the atmosphere (i.e., fugitive emissions). It is important to be mindful what material is being selected for equipment, especially heat exchangers with extreme temperature differences.

4.2.3 Fugitive Emissions Management

Successfully implemented LDAR scheme would reduce fugitive emissions. There are many technologies that have been developed to be used in the detection of fugitive emissions. Fugitive emissions under LDAR are defined as any unintentional leaks due to normal wear and tear on different piping components. Table 4 summarizes and indicates the effectiveness for each of the available screening and measurement techniques. They are split between the traditional approach of detecting emissions (adapted from CAPP's BMP practice (34)) and the specific approach in detecting odorous compounds (35, 36).

TABLE 4 Summary of Screening and Measurement Techniques for Fugitive Emissions[1]

Equipment	Uses	Advantages	Disadvantages
Traditional Hydrocarbon Emissions Detection Equipment			
Optical Gas Imaging Camera	Quick leak screening on targeted components.	- Fast - Can operate from distance	- Influenced by wind, temperature, background distance to targets - Small leaks may not be detected - Technical experience required
TVA	Inspect emissions of individual components	- Low detection limit - Can detect most compounds	- Time consuming - May not reach all components (> 2 meters high, insulated, etc.) - No response to non-organic gases
Ultrasound technology	Detects leaks of any component	- Can detect non-organic gases	- Influenced by ambient noise - Technical experience required
Soap Solution	Verifies leaks of small components	- Low cost - No training required	- Cannot use on high temperature equipment - May not work on open-ended lines, big valves - Time consuming - May not reach all components (> 2 meters high, insulated, etc.) - Challenging on large-scale facilities
Hi-Flow sampler	Quantifies total hydrocarbon emissions	- Accurate, quantifies emissions - Useful in testing out known components	- Slow - Difficult to find leaks at a large scale facilities
Odour-Specific Emissions Detection Equipment			
Traditional (Human) Olfactory System	Humans detecting odours using their noses	- Quick – may be conducted immediately - Reliable	- Variability in people's sensitivity to smell - May be costly to hire people with more sensitive noses - May detect smell, but uncertain from where
Mammalian Olfactory System/ Biosensors	Animals detecting odours using their noses	- Strong sense of smell - Can detect source of smell	- Unsafe to have animals on site, normally not allowed

Equipment	Uses	Advantages	Disadvantages
Electronic Noses (E-Noses)	Chemical sensor/instrumental analyzer developed to imitate human olfactory system.	- The most recent models are more sensitive and specific in detecting smells than human nose	- Developing technology - Needs to be trained to detect specific odours
Real-time Detection Systems	Systems utilizing continuously operated air sample and send signal to mass spectrometer	- Immediate response when an odour is detected	- Costly to install

[1] There may be other methods which are not listed here which can aid in odorous fugitive emissions detection.

Traditional Hydrocarbon Emissions Detection Equipment

As listed in Table 4, there are numerous methods that can be implemented for odour detection. The traditional approaches are well-established in many industries, as industries are required to report greenhouse gas emissions to the regulator and use one or more of the listed techniques. The most commonly used techniques are the portable analyzer (TVA) and optical imaging device. These two techniques are the most established and the most effective in surveying facilities. The portable analyzer is a well-known method known to be precise and compatible with regulatory requirements and emission estimate protocols. The portable analyzer inspects all components, which may become time-consuming; however, it will ensure that all the leaking components will be addressed. Leak imaging device uses radiative energy entering the sensor to produce an image. This method requires trained professionals with a well-trained eye to use this device, as the leak would have a slight contrast against the background scene and leak detection can be affected by temperature and wind.

One limiting step about these two established methods is that they are designed for specific hydrocarbons, and are not designed for odorous emissions which can be a result of a cumulative set of different emitters. Heavier hydrocarbons (8 carbons and higher) are also difficult to detect and measure with traditional equipment.

Odour-Specific Emissions Detection Equipment

Equipment specific for detecting odours is still a developing process, leaving the traditional olfactory method to be used the most, which involves humans. This is also one of the simplest odour detection techniques, as it can involve the workers at the industrial site (thereby no additional costs incurred) and can be resolved immediately. The limiting aspect about this method is the human's sensitivity to odours. The people who would be involved may not be the most sensitive and susceptible to odorants, and possibly, the people who work on-site may become desensitized to odours over time. It is also not specific enough to detect the source of the emissions, especially if there is more than one source of the fugitive odours. Mammals would be more sensitive to odours and would be able to detect the source of the leak. However, the risks of bringing mammals on the oil sites make this an implausible technique.

One of the more promising technologies in the field of odour detection are electronic noses ('E-Noses'). They are designed to mimic a sensitive biological system in which they are able to broadly sense a wide range of odours as well as specify to one type of odours. They provide the advantage of an immediate, sensitive detection. However, as E-Noses are still in the developing stages (35, 26). They are not very well-known and also need to be trained for specific applications.

The other odour detection systems listed in Table 4, i.e. real-time detection systems, would be most suitable to be installed in buildings.

4.2.4 Masking/Neutralizing Agents

Masking and neutralizing agents are chemicals used to limit pungent odours. Masking agents, also known as deodorizers, disguise odorous emissions and block odorous receptors. Neutralizing agents react with the odorous compounds to create a mixture that will emit fewer odours. These agents can be applied directly (generally sprayed) to odour sources. These agents are most effective for quick and temporary solutions, particularly during process failures, emergencies, and maintenance (e.g. for spills). These agents, however, may not be 100% effective in removing/masking odours, as odours still be present (only hidden by another chemical), or possibly, an alternative offensive odour may result from treating the odour.

4.3 Technologies or Techniques to Treat Point Source Emissions

There are numerous locations in heavy oil industries that emissions may not be treated and are vented into the atmosphere, as described in Section 3. There are two approaches that can be done for these vented emissions, which are: recovery and destruction.

In recovery, these emissions can be treated and be reused within the process, resulting in reduction of emissions, odours, and costs. Recovery techniques should be implemented where it is simple to re-route the treated streams back into the process.

VRUs are well known in petrochemical industry, and in many facilities, VRUs are applied for tanks and vessels. VRUs, as the name suggests, is a broad term where vented vapours are 'recovered' and the captured emissions will be treated and be re-routed back into the process. Industries have reported substantial savings from using VRUs. The savings involved in the use of VRUs are dependent on the cost of natural gas, which is what will be treated and routed back into the process. The basic equations for cost savings using VRUs are shown here in equations 1 and 2. Equation 1, details how much savings will be acquired if natural gas is re-used instead of using new natural gas. There are some costs involved with the usage of VRUs – main one being installation costs followed by operations and maintenance. These costs will vary based on type of VRU used to treat the emissions. Equation 2, payback method, is a quick method that calculates the amount of time it will take for an investment to be recouped. The payback method is often used as a first screening method for an investment; however it ignores the time value of money. More details about costing and examples are listed in Appendix B.

$$R = C \times Q \times P \times \eta \times 365 \times 24 \quad (1)$$

$$PP = I/(R-OM) \quad (2)$$

Where:

R = Revenue from gas savings ($/year)

C = Fraction concentration of captured gas

Q = Rate of vapour recovery (m^3/hr)

I = Implementation cost ($ - first year only)

P = Price of natural gas ($/$m^3$)

OM = Operations & maintenance costs ($/year)

η = Capture efficiency (fraction)

PP = Payback period (year)

These VRUs include: absorption units, adsorption units, and condensers. Most of the VRU technologies that will be described here report a capture efficiency ranging between 50 to 99%. These technologies can be applied to different processes to reduce or treat emissions. Table 3 summarized the list of available technologies and their suitability in the oil and gas field. For more details pertaining to each technology (in particular, their expected control efficiency and design requirements), please refer to Appendix A**.**

In destruction, odorous emissions will be completely destroyed either by degradation or oxidation. Destruction techniques should be considered an option when the emission stream is unable to be recovered due to uncertain conditions (e.g. in cases of emergencies/upsets), the treated waste stream would have no value to the process, and/or costs of treating are too high. The most commonly known destruction techniques include: biotreatment, incineration, thermal oxidation (catalytic and otherwise) and NTOPs.

For detailed information regarding odour treating technologies, please refer to following documents:

- Odour Guidance. 2010. Scottish Environment Protection Agency. (24);
- Odour Management and Treatment Technologies: An Overview. 2005. M. Schlegmilch, J. Streese, and R. Stegmann. (28);
- Horizontal Guidance for Odour Part 2 – Assessment and Control (draft). 2002. Integrated Pollution Prevention and Control (IPPC). Environmental Agency. (30);
- Odor Control "ABC's": How to Compare and Evaluate Odor Control Technologies. K. Corey and L. Zappa. (37);
- Review: Removal of Volatile Organic Compounds from polluted air. 2000. F.I. Khan and A.K. Ghoshal. (38); and
- Chapter 8.0: Gas Phase Odor Treatment. 2007. WERF. (39).

4.3.1 Adsorption

Adsorption technology considers the adherence of odorous material onto a solid, porous surface. There are two types of adsorbent systems, which are:

- Fixed bed adsorbers; and
- Fluidised bed adsorbers.

The most commonly used adsorbent to treat emissions is activated carbon, but also activated alumina, silica gels, zeolites and polymers can be used. The specific design considerations when it comes to selecting a proper scrubber include:

- Selection of adsorbent and what it can treat;
- Adsorbent capacity; and
- Process conditions.

Adsorption technology is well-established and well-known in petrochemical industries. It is mostly used as an enrichment step prior to thermal gas treatment, and can be useful to treat emissions from inside buildings, and treating process streams. Adsorbers can treat 95-98% of emissions, including odours in low volume and concentrated streams.

Aside from the adsorption bed and adsorbents, other requirements for an adsorption system include: fans, dampers, and a large area to install the adsorber. Life cycle of adsorbents is dependent on the design and can often be regenerated and reused. There is low maintenance on an adsorbent system, and there is little energy considered (depending on pressure drop).

Costs of installing and operating an adsorber are considerably low to moderate, in comparison with other techniques. The costs of designing depend on the size requirements of the adsorbent, the cost of the adsorbent, auxiliary equipment, and the manpower to design and build the adsorber. The single most important factor impacting the cost of an adsorption system is dependent on volumetric throughput of emissions. There are low operating costs, which mostly depend on the regeneration or disposal of adsorbents. Costs on adsorption beds can range widely, and it is recommended to contact vendors to estimate the capital costs.

For more information regarding adsorption units, please refer to ref. (40), *Adsorption Technology & Design*.

4.3.2 Absorption

Absorption involves the selective transfer of odorous material from a gas to the contacting liquid. The principle of absorption involves a liquid used to dissolve off-gas compounds. This process can also be referred to as scrubbing or washing. There are many different types of absorption scrubbers, which include:

- Spray absorbers;
- Plate absorbers;
- Tray towers;
- Packed bed absorbers;
- Moving bed absorbers; and
- Fibrous bed absorbers.

Generally, water is used as the absorptive liquid, but ozone, hydrogen peroxide, sodium hypochlorite, and sulphuric acid are other scrubbing liquids that can be used. Caution should be considered when selecting the scrubbing liquid as it could form toxic, potentially odorous bi-products. The specific design considerations when it comes to selecting a proper scrubber include:

- Solubility of the odorous compound(s);
- Gas-liquid contact time;
- Contact surface area; and
- Process conditions.

Absorption units are well-established and well-known in petrochemical industries, primarily used to remove acid gases from combustion sources (i.e., heaters, boilers and treating units, excluding catalytic). Absorption units are best suited to treat concentrated emissions (10-50 g/m^3) with moderate gas flow rates (~100-10,000 m^3/hr). Absorption techniques are primarily used to remove gases from combustion sources, as they can handle high temperature streams. Scrubbers are efficient in treating over 90% of the emissions. Scrubbers are effective in treating H_2S, however they are not as effective in treating VOCs. The treatment efficiency of scrubbers is as follows, going from the contaminants most effectively treated to least: alcohols > esters > ketones > aromatics > alkanes.

Aside from the scrubbing liquid and tower, other requirements for a scrubber include: measuring instruments, metering pumps, recirculation pumps and level switches. Life cycle of the scrubbing liquid is generally between 1 and 2 months. With this considered, maintenance of a scrubbing tower is rather high. Energy requirements are moderate for scrubbers; energy is required to move gas and reactant in two or more stages.

Costs of installing and operating a scrubber(s) are considered moderate, when comparing with other odour abatement techniques. The cost of designing a scrubber depends on scrubbers' size, the material used, scrubbing liquid, fittings, packing, the instrumentation, and the manpower to design and build the scrubber. The operating costs consist of the scrubbing liquid, blower power, electricity/energy, regeneration of the reagents (if considered), and the constant maintenance of the tower. Costs can vary widely, and it is best to contact vendors.

For more information regarding absorption units, please refer to ref. (41), *Wet Scrubbers*.

4.3.3 Biotreatment

Biological treatment of odorous material is a relatively new concept for the petrochemical industry. The fundamental principal of biotreatment involves treating odorous pollutant with microbes, which destroy the odour compounds. Biotreatment systems can treat over 90% of emissions. There are two categories of biotreatment techniques, which are:

- Bio-filtration; and
- Bio-scrubbing/Bio-reactors.

The specific design considerations when it comes to selecting a proper biotreatment system include:

- Suitable matrix for biological organisms to grow;
- Water to maintain high moisture content;
- Nutrient loading; and
- Process conditions (especially pressure drop, aerobic conditions, and pH-level).

Biological treatment systems are quite sensitive and are best suited to treat off-gases from absorption towers. Biotreatment units prefer treating low molecular weight, highly soluble, uncomplex compounds. Biotreatment units are most efficient in treating H_2S, followed by aromatics, aldehydes and ketones and then chlorinated compounds

Aside from the media bed/tower and microbes, other requirements for a biofiltration system include: sprinklers, fans, dampers, front-end loaders, and a large area to install the system. Life cycle is dependent on the design – usually it is a couple of years. There is low maintenance on an adsorbent system aside from daily inspection, and there is little energy used.

Costs of installing and operating a biotreatment system are considered moderate. The costs of designing a system depend on the size requirements of the bed/tower, the microbes, and auxiliary equipment. Operating costs are dependent on the high water usage, and replacements of the biological media every couple of years.

For more information regarding biotreatment units, please refer to refs. (42 – 44).

4.3.4 Non-Thermal Oxidation Processes

NTOPs induce the formation of radicals and ions to oxidize molecules completely to CO_2 and H_2O. These radicals are produced by electrical discharges or electron beam irradiation.

Specific design considerations with respect to NTOP include:

- Electricity availability; and
- Possible integration with another odour control technology.

NTOPs are relatively new techniques, still requiring research. In practice, NTOPs are applied along with other technologies in order to enhance the other technology's efficiency and selectivity. NTOPs can treat the odours at source and no wastes are produced aside from ozone. NTOPs are alleged to be cost-effective, non-disruptive, can treat all ranges of gas volumes, and are effective at treating low concentrated odour streams. Studies have shown that NTOPs can eliminate 80-99.9% of odours. NTOPs are most effective at treating odours with free electrons, followed by saturated hydrocarbons, unsaturated hydrocarbons which require additional radical addition following oxidation to result in the destruction of odours.

For more information regarding NTOPs, please refer to refs. (45 – 48).

4.3.5 Incineration/Flares Control

Incineration involves the destruction/combustion of odorous emissions using very high temperature with air or oxygen. Incineration is well known process in the petrochemical industry and it is suitable for more stringent exhaust air requirements. Incinerators are non-specific and can destroy up to 99.9% of emissions, however they may also create secondary emissions containing nitrous or sulphur oxides. Incinerator stacks should be carefully designed, as the shorter stacks in close proximity to buildings may get influenced by building downwash in which emissions would be forced down to the ground.

There are two types of incinerating techniques, which are:

- Thermal incineration; and
- Catalytic incineration.

The specific design considerations when it comes to selecting a proper incinerator include:

- Fuel availability;
- Process conditions (i.e., high temperature); and
- Legislative requirements.

Incinerator consists of a: burner, mixer, combustion chamber, and possibly catalyst. Life cycle of an incinerator is relatively long, and many petrochemical industries already may have one or more in their facility. Given their destruction capability (up to 99.99% removal), incinerators are suitable for more stringent exhaust air requirements. Incinerators are non-specific and can destroy all odorous emissions. Maintenance, energy use, and costs are high for incineration technologies.

Flaring in comparison incinerating is cheaper and are used during emergency situations. However, destruction of compounds by flaring are dependant on meteorological conditions. For example high winds may decrease flare efficiency. In some cases low efficiency may result in the production of soot (black smoke). Some facilities are using steam or neutral gas (air or nitrogen) to boost dispersion of flare emissions. However, too high flow rates may result in choking the flame which results in venting. Since incinerators are immune from weather conditions they have constant, controlled efficiency and they may be much cleaner sources of emissions.

4.3.6 Condensation

Condensation applies the concept of converting a gas stream into liquid steam by reducing the temperature of the gas. There are five types of condensers, which are:

- Direct contact condensers;
- Indirect contact (surface) condensers;
- Air cooled surface condensers;
- Pressurized condensers; and
- Cryogenic condensers.

The specific design considerations when it comes to selecting a proper condenser include:

- Process conditions (i.e. low temperature, pressure); and
- Suitable coolant.

Condensation is usually a pre-treatment technology used in conjunction with other air treatment technologies (49), as their efficiencies are inconsistent (ranging between 50 to 95%). Condensers are non-specific and will treat both odorous and non-odorous compounds alike. Condensers create waste effluent which needs to be disposed properly and may be a possible source of odour.

Requirements for a condenser system include: condenser itself, heat exchanger, refrigeration unit(s), and auxiliary equipment (pre-cooler, recovery/storage tank, pump/blower, piping).

Costs of installing and operating a condenser are high. Operating costs are mostly dependent on maintenance, the high water usage, high energy requirements, and effluent disposal.

4.4 TECHNOLOGIES OR TECHNIQUES TO TREAT AREA SOURCE EMISSIONS

The technologies/techniques that would best treat area source emissions include: biotreatment, containment, and masking/neutralizing agents. These techniques have been described in previous sections. How these treatment techniques can be applied for area source emissions depend on two aspects:

- Size of area source (is it 10 m^2, 100 m^2, etc. in area?); and
- Frequency of odour emissions (is it continuous or fluctuating?).

These two aspects would influence the selection of odour control technology. Biotreatment units' are capable of continuously treating odours, treating small to large area sources, and are not intrusive for surrounding activities. Containment units in conjunction with a VRU would be more useful for smaller areas and will be able to contain both continuously and fluctuating emissions. Masking and neutralizing agents are capable of treating sporadic emissions, can treat odorous emissions immediately, and can treat both small and large area sources.

4.5 SELECTION CRITERIA FOR VENTED/POINT SOURCE EMISSIONS

There are several considerations to be made when selecting which technology would be the most suitable to abate odour release in the heavy oil process areas. The above sections detailed the specific design requirements needed to be considered for each technique, and here will go into broader detail on what is required for odour abatement.

It is important to gather information on what is being treated. Some information required include (adapted from (30)):

- Odorous pollutant constituents and their related thresholds;
- Pollutant concentration;
- Pollutant volume;
- Gas stream type (is it a process or ventilation gas);
- Properties of treated gas (is it aerosol or vapour phase);
- Temperature of gas stream; and
- Moisture content of gas stream.

In addition to what is being treated, it is important to consider the process area (and thereby – physical constraints of the technology) where odours are being treated. Some considerations include (adapted from (30)):

- Applicability of technology to petrochemical industries (has it ever been used in petrochemical industries);
- Required efficiency (how much odour can the technology remove);
- Disposal of waste products (are any generated, and are they in gas, liquid, or solid form);
- Physical size (can the technology be stacked, require sufficient space, or can be added onto existing infrastructure);
- Energy usage (how much power does the technology need to operate);
- Noise output (does the technology generate sufficient noise that may affect the surrounding area);
- Reliability & maintenance requirements (e.g. down time, start-up, shut-down);
- Seasonal fluxes (is the technology sensitive to changing environmental conditions);
- Life cycle (how often do parts need to be replaced);
- Complexity & training (does the technology require basic or extra training);
- Consistency of odorous pollutant (can the technology adapt to the variability of the pollutant's composition and concentrations);
- Location (is the site remote, or in proximity to a town, etc.);
- Local factors (topography, weather conditions, discharge height); and
- Cost (capital, operating, disposal, electrical costs, replacement).

How the above criteria tie in with each technology can be found in Appendix A.

4.6 Optimizing Technology Selection for Vented/Point Source Emissions

In the previous sections, it was discussed: 1) What are the major odour sources in heavy oil processing facilities, 2) What odour abatement technologies are commercially available, 3) What factors influence technology selection.

Odorous emissions from fugitive and area sources are less controlled and as described above, have specialized technologies and methods to treat them. For point source/vented emissions, there are a couple of available technologies to treat them. Which technology will be selected will ultimately be the choice of the company. This section will provide guidance for the selection of the proper technologies.

One important factor to consider when selecting which technology to use is the applicability of the technology to treat the odour. If the stream is out of range that the abatement technology can treat, it won't be able to capture the odours. Figure 3, adapted from Environmental Agency's Integrated Pollution Prevention and Control (IPCC)'s *Horizontal Guidance for Odour Part 2* (30), illustrates the suitability of the listed technologies to treat point source odorous streams, based on their flow and concentrations.

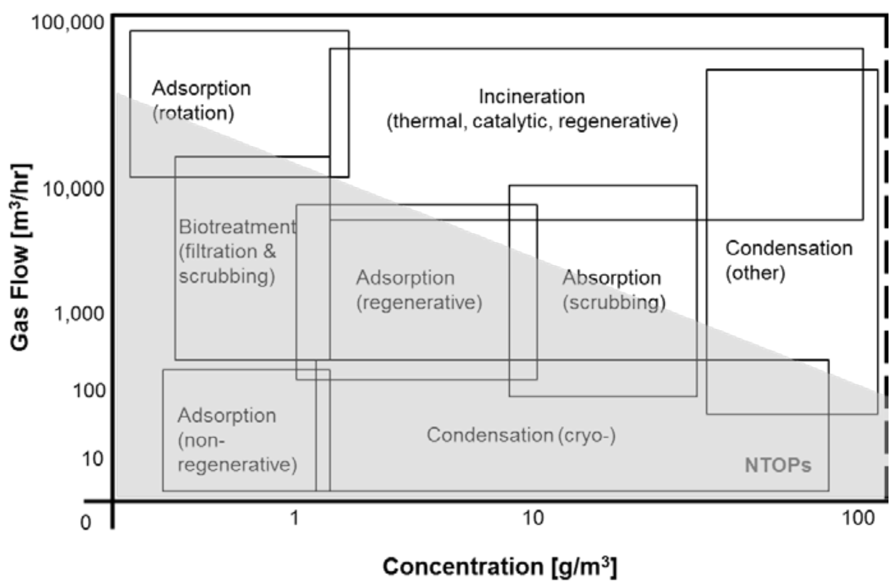

FIGURE 3 Guidance for the Application of Abatement Techniques – adapted from (30). In grey area is treatment capability of NTOPs.

Table 5 lists the pros and cons of each technology, based off Appendix A. In Appendix A, there is a table of criteria and how each technology works for each criterion. From Appendix A, a numeric scoring, Table 6 was developed to determine the suitability of the technologies to treat the odorous streams in heavy oil industries.

TABLE 5 List of Pros and Cons for Each Odour Abatement Technology

Technology	Advantages	Disadvantages
Adsorption	- Highly efficient, > 95% recovery - Adsorbents can be regenerated and reused - Well established technology in petrochemical industry - Flow rate threshold matches vented emissions - Concentration threshold matches most vented emissions - Low maintenance - Low energy usage (except for regeneration of adsorbent - dependent on pressure drop) - Low waste (can be minimized if regeneration is considered) - Low cost (due to low maintenance, low energy usage, low waste generated) - Adaptable to seasonal fluxes - Adaptable to varying pollutant composition and concentration - Treats odour emissions so can be re-used in system	- Doesn't work well in high temperatures and humidity - Rapidly gets saturated and thereby lowers efficiencies - Preconditioning may be required - Require two beds to alert breakthrough - Considerable space needed - May be clogged if there's high particulate content - Contaminants may flash off unless contained
Absorption	- Highly efficient, > 90% recovery - Can handle large volumes of air - Well established technology in petrochemical industry - Total odour control can be contained in one tower - Treats odour emissions so can be re-used in system - Adaptable to seasonal fluxes	- May not capture low flow streams (and low concentrated) streams: problem for odour emissions which can still be detectable at low concentrations - Scaling and corrosion may be a problem - Slurries generated - Waste can be toxic - Contacting liquid can only treat specific chemicals - Salt formation may result - May be clogged if there's high particulate content - Insoluble odours may not be removed - May result in secondary formation of odours - Saturation of contacting liquid - Maintenance is high - energy required to move gas and reactant, and high infrastructure requirements

Technology	Advantages	Disadvantages
Biotreatment	- Low maintenance - Long life cycle - Regenerability --> Keeps maximum adsorption capacity available - Destroys odour emissions - Minimal secondary pollution/waste - Low cost (due to low maintenance, low waste, long life cycle) - Few chemical agents required for process - Concentration threshold matches most vented emissions	- Space required - Not suited for high concentrations - Very sensitive to transient conditions: inlet conditions must be maintained within narrow bands - High water use: otherwise may result in drying. Trouble in frost conditions - Developing technology, used in other industries, not well known in petrochemical industry - Nutrients may be required to support microbial population - Requires skilled attention
NTOPs	- Destroys odour emissions - Treats all emissions - Operation flexibility (can be turned on when required) - No wastes are generated - Compact equipment - Adaptable to seasonal fluxes	- Developing technology in discovery stages, not well known in petrochemical industry - May generate ozone - Need access to electricity to generate radicals - Costs of installation and operating is not certain as this is a developing technology
Incineration	- Can handle large volumes of air - Highly efficient, up to 99.9% destruction - Non-specific and can treat all odours at all concentrations - Existing incinerators can be adapted for use - Possible heat recovery - Well established technology in petrochemical industry - Potential to recover heat	- High energy use - High capital and operating costs (NG addition) - Secondary emissions may be created
Condensation	- Well established technology in petrochemical industry - Reduces load and energy requirements of secondary control equipment - Flow rate threshold matches vented emissions - Treats odour emissions so can be re-used in system - Can work in humid conditions	- Not efficient enough to be used independently, 50-99% recovery - High energy requirements - No specificity on treating odours - High capital and operating costs - Effluent disposal

Table 6 has been created as an example of a qualitative assessment for industries to use when determining which of the odour control technologies they should use to treat controlled vented emissions. The numbering assigned, while to some degree relevant, are qualitative and were based off of Appendix B information and generic limited gathered information, and on generalized vented emissions (i.e. numbering may change based on what vented emission is being treated). These numeric ranking may change based on more detailed information gathered from vendors.

The listed evaluation criteria are the top criteria that can be assigned a numeric value. The numeric value answers the following questions for each criterion.

- Industrial Experience: Does the mentioned technology already have application in the heavy oil industry? Is the technology well developed?
- Efficiency: How well does the technology destroy or treat the odorous emissions? Over 95%? Over 80%? 50%?
- Applicability to stream flow: Does the vented emissions fall within the range of flow rate that said technology is capable of treating?
- Applicability to stream concentration: Does the vented emissions fall within the range of concentration that said technology is capable of treating?
- Reliability/sensitivity: Will the technology continuously operate or will any change impact the effectiveness of the technology?
- Physical size: Does the technology require a lot of space to operate or is it non-intrusive?
- Regenerability: Can the material that the technology uses be re-used?
- Water/fuel/chemical usage: Does the technology heavily use water/fuel/chemicals?
- Vapour recovery: Does the technology treat the emissions for re-use or does it destroy the emissions?
- Energy usage: Does the technology use a lot of energy (i.e. electricity)?
- Operations and Maintenance (O&M) requirements: Is there a lot of operations and maintenance required for the technology?
- Training: Does the technology require significant training for use? Would operators be familiar how to operate said technology?

- Waste management: Does the technology produce any waste and is it a significant amount?
- CAPEX: Is there high capital costs tied into the said technology?
- OPEX: Is there high operation and maintenance costs tied into the said technology?

Significance factor places a numeric value of importance for each evaluation criteria. Significance factors were assigned from 1 to 4 with 4 indicating that the evaluation criterion is very significant and 1 has little to no significance. For example, removal efficiency was assigned 4 as the aim here is to remove odorous emissions. Applicability factor places a numeric value for each technology and how each evaluation criterion applies for that technology. Applicability factors were mostly assigned 1 to 4 where 4 is very applicable and 1 is little applicability or low technology development. For example, adsorption and absorption units are very applicable (=4) to oil and gas as they are already used in this industry. NTOPs were assigned 1 as they have limited application in the petrochemical industry and it is still in the research and development stage.

Each applicability factor was multiplied by the significance factor to determine a weighted score. The weighted scored were summed for each technology option. From this, the results indicate that for treating vented emissions, the ranking of selection preference is:

Adsorption >> Absorption > Biotreatment > NTOPs > Incineration >> Condensation

TABLE 6 Generic Numeric Scoring of Odour Technology

Evaluation Criteria	Significance Factor	Applicability Factor					
		Adsorption	Absorption	Biotreatment	NTOPS	Incineration	Condensation
Industrial Experience	4	4	4	2	1	4	3
Removal Efficiency	4	4	3	3	3	4	1
Applicability to stream flow[1]	3	4	3	3	3	3	3
Applicability to stream concentration[1]	3	4	2	3	4	3	2
Reliability/Sensitivity	4	4	4	2	3	4	3
Physical Size	1	2	3	1	4	3	2
Regenerability	3	4	3	4	1	2	1
Water/Fuel/Chemical Usage	3	3	2	1	4	1	2
Vapour Recovery[2]	4	1	1	0	0	0	1
Energy Usage	3	4	3	4	1	1	1
O&M Requirements	2	3	1	3	3	1	1
Training	2	4	3	1	1	3	4
Waste Management	3	3	2	3	4	2	1
CAPEX	4	4	2	4	3	1	1
OPEX	4	3	2	2	3	1	1
Total weighted score[3]		162	120	111	106	103	86

Significance Factor: 1 = no significance; 4 = having significant impact

Applicability Factor: 1 = little applicability/technology development; 4 = very applicable

[1] This may vary, depending on the emission being treated. This is based on the average expected stream.

[2] Applicability factor is this evaluation criteria can either be applicable or not. Scoring of 0 indicates no applicability. 1 indicates there is.

[3] Weighted score = ΣWeighted Factors = Σ(Significance factor x Applicability factor)

Note that this evaluation study in Table 6 is a generic, sample exercise and can change depending on what is required to be treated. In heavy oil industries, the above evaluation will be best applied to the following sources:

- Battery facilities/storage tanks;
- Wellheads/casing gas vents;
- Glycol dehydrators;
- Boilers;
- Heaters;
- Turbine generators;
- HVAC systems on buildings; and
- Produced water systems.

Considering the costs of installing these technologies, priorities should be placed on sources with high emission releases. The above list is ranked from highest to lowest emission releases, suggesting that storage tanks and casing gas vents should prioritized first. Appendix B illustrates examples on estimating costs of capturing emissions from storage tanks and casing gas vents.

Considering boilers, heaters and turbine generators release combustible material at high temperatures, absorption units which can handle high temperature streams would be the technology choice. For other equipment, adsorption units would be more useful and cost-effective – as determined from Table 6.

5 FACILITY BEST MANAGEMENT PRACTICE

In the previous section, common technologies and techniques that can be used to abate odour emissions have been described, and in what area of the heavy oil industry they would be best suited to treat the emissions. A recommended practice for preventing odorous emissions will be described, which will include the technologies as described in Section 4.

The following has been adapted from a few resources, which contain recommendations on how to odorous emissions:

- Odour Guidance. 2010. Scottish Environment Protection Agency. (24);
- Horizontal Guidance for Odour Part 2 – Assessment and Control (draft). 2002. Integrated Pollution Prevention and Control (IPPC). Environmental Agency. (30); and
- Assessment and management of odour from stationary sources in NSW. 2006. Department of Environment and Conservation (NSW) (50).

5.1 Normal Conditions

Normal conditions are defined as conditions that go without any operational interruptions (which would be maintenance and equipment failures).

5.1.1 Material Quality Management

There are two items to consider: 1) Better 'fuel' quality that does not contain any unnecessary compounds that will contribute to unpleasant odours, and 2) Avoid mixing incompatible materials that would create off-gases.

It is essential to reduce the amount of H_2S and mercaptans in the natural gas before it is used in the heavy oil process. This 'sweetening' of the natural gas is well established in the petrochemical industry and most plants would have technologies to strip off the unwanted constituents. However, there are still sites that are considered 'sour' (i.e., H_2S present > 5.7 mg/Nm^3) (51, 52). ST101: *Sulphur Recovery & Sulphur Emissions at Alberta Sour Gas Plants* (53) provides a guideline on the process of sulphur recovery (i.e., H_2S and mercaptans) for Alberta industries, including heavy oil processes. It should be noted that some mercaptans are still necessary to aid in detection of leaking components. The odour levels in the natural gas should be close enough to the odour threshold, which can be achieved in 'sweet' gas plants. Additionally, the practice of converting instrument gas to instrument air, as described in Section 4 will provide additional savings and reductions of odorous (and greenhouse gas) emissions.

Two examples of creating off-gas emissions would be when natural gas, containing H_2S and mercaptans, is in contact with water/vapour; and when glycol comes into contact with hydrocarbon/amine aerosols. At the present moment, it is unavoidable for natural gas to not get into contact with vapour; however, the contact of glycol with hydrocarbons can be controlled. A lessons learned document has been created from a group of oil and natural gas companies (Natural Gas STAR Partners) suggesting to replace glycol dehydrators with desiccant dehydrators (54). Natural Gas STAR Partners have found that this replacement reduces emissions by 99% and operating and maintenance costs. The concept of the desiccant dehydrator is for wet gas to pass through a drying bed of desiccant tablets.

5.1.2 Process Parameters Adjustments

Processes – or a portion of the processes, whenever possible, should be run during favourable conditions. This will be particularly relevant for maintenance and (controlled) upset conditions, and as such, will be discussed in the succeeding sections.

In heavy oil industry, there is parameter standards in which a process will optimally run, however, these should be re-visited, especially in older production areas where parameters might not have been updated in accordance to new research or standards. For example, heating of bitumen may enhance the odorous emissions into the atmosphere, as concluded by AGS (55). For example, production decreases at facilities can occur, so centralizing liquid storage facilities would reduce emissions from tanks (56).

Natural Gas STAR Program has listed recommended technologies and practices to reduce methane emissions[2]. Some of the listed recommendations can be applied for odorous emissions as well, as the emissions may include a mixture of compounds not only methane. Some suggestions from the list include:

- Eliminate Unnecessary Equipment and/or Systems (56);
- Installing Automated Air/Fuel Ratio Controls (57); and
- Convert Pneumatics to Mechanical Controls (58).

5.1.3 Fugitive Emissions Management

To reduce fugitive odour emissions, facilities must apply a DI&M Plan.

[2] http://www3.epa.gov/gasstar/tools/recommended.html

In many heavy oil industries, leak detection is already conducted in a yearly basis, focusing on GHG emissions. CAPP's document *Management of Fugitive Emissions at Upstream Oil and Gas Facilities* (34) already provides guidance for the management of fugitive emissions, however, the purpose of that document is designed to apply to components in the sweet gas service. This signifies that it focuses on components where gas contains H_2S of concentrations less than 10 mol/kmol. This eliminates a major contributor to odour nuisance. Given that odorous emissions are different than typical emissions, (i.e. odour nuisance is the result on cocktails of numerous chemicals and not focusing on a single constituent's influence on emissions (59)), this should be stressed the additional controls put in place for odorous fugitive emissions.

DI&M Plan

Each facility should have its site specific DI&M plan to mitigate fugitive emissions. The plan should be reviewed and updated regularly to reflect situations of leak findings and repairs. The key components of the plan include:

- Targeted pipelines and equipment;
- Leak inspection and quantification;
- Inspection Frequency;
- Leak Repairs and tracking; and
- Record keeping.

Targeted Pipelines and Equipment

The pipe lines and equipment that may emit odours are the inspection targets. A complete list of targets equipment should be made and maintained in order to keep track and not to overlook any equipment pieces. Example of equipment that would appear on this list include: connections (flanged, threaded, tubing, plug), valves (manual and control-type), regulators, pumps, separators, dehydrators, compressors, etc. Table 7 is an example of such list:

TABLE 7 Example of a Targets Equipment List for Pipelines

ID	Equipment/Line	Content	Note	Inspection Frequency
1	Injection well #1/ Lift gas line	Natural gas		Annually
2	Production well #1/ Lift gas line	Natural gas		Annually
3	Production well #1/ Production pipe	Crude oil emulsion		Annually
4	Production well #1/ Casing gas pipe	Casing gas		Annually
5	Control Valve #1028	Crude oil emulsion	The valve is located on top of the main module. The production pipe is from well #1.	Quarterly

Leak Detection and Quantification

All the leaks should be physically tagged out.

There are two manners in which this can be conducted:

1) Adapt the current CAPP's BMP for fugitive emissions, and re-define the leak definition from the screening concentration of 10,000+ ppm to a lower concentration such as 1,000 ppm or odour threshold concentration of a dominant odorant (e.g. H_2S).

2) Use instruments specific for odour detection.

The equipment used for these two manners have been listed in Table 4 in Section 4.2.3. The first manner, where existing methods for fugitive emissions are implemented with a re-defined leak definition is advantageous for the heavy oil industry. This is heavily practiced in the petrochemical industry and the costs are generally lower than for olfactory methods. One limiting aspect of these processes is that the technologies/techniques generally focus on one or couple sets of chemicals, and not a broad scheme of chemicals which can all contribute together to odour detection. It would be important then to select the chemical which is the most prominent in process and select its odour threshold, keeping in mind that if the odorous chemical cocktail is complex enough, it may not be sufficient in capturing the odorous chemicals. Additionally, the selected odour threshold may be below the technology's detection limit.

The advantage on using the second manner, where instruments that specialize in odour detection are used, is that these techniques were developed to consider the complexity of odour emissions. The limiting aspects are the costs and the relative novelty of the techniques in the petrochemical industry. This does not include the classical olfactory system, which uses humans to detect odours. When industry uses their own personnel to detect odours by walking around the site, the costs can be lowered by combining odour detection task with the other daily tasks of the personnel, noting that each person's sensitivity to smell may vary.

Regardless which method is selected, it is important to conduct fugitive emission surveys during warm weather conditions, when there will be more pronounced odour detectability (See Section 1). Employing experienced fugitive emissions workers would be preferred, as they would be more efficient in identifying the emissions.

Leak Repairs and Tracking

Leaks must be repaired, confirmed and tracked as soon as possible. For those to be done during turn-around, they should be documented and arranged early.

Inspection Frequency

Operators should design a frequency monitoring program best suited for its operations while ensuring maximum cost-effective fugitive emissions reductions. The frequency should at least fulfill the requirement of CAPP's BMP.

Record keeping

Operators should keep and track all the records of documents that are related to the DI&M program, for example, DI&M plan, inspection reports, work orders, leak repairs and confirmations, etc.

5.1.4 Tanks and Vessels Management

CCME's document *Environmental Guidelines for Controlling Emissions of Volatile Organic Compounds from Aboveground Storage Tanks* (60) lists guidelines on methods to reduce emissions from storage tanks. The information in that document is still applicable, and some will be repeated here with some modifications/updates.

Inspection, Maintenance and Operation Plan

Facilities should already have site-specific plan on the operations and management of tanks and vessels. Regular, annual reviews should be conducted to reflect any changes on equipment inventory, inspection findings, repairs, etc. Key components of the plan will include:

- Targeted equipment;
- Odour Emission Technologies;
- Roofing;
- Venting;
- Tank Seal Repairs;
- New Tanks;
- Inspection Frequency; and
- Record Keeping.

Targeted Equipment

An inventory of tanks and their auxiliary equipment that would release odours will be listed and maintained regularly to ensure that odours will not be released. Examples of equipment that would appear on this list include: thief seal hatches, pressure-vacuum vents, manholes, drains, and rim seals.

Table 8 is an example of such inventory.

TABLE 8 Example of a Targets Equipment List for Tanks

ID	Tank #	Target	Contents	Comments
1	10	Thief hatch	Glycol	
2	22	Vent	Heavy oil	

Odour Emission Reduction Technologies

Installing floating covers should be first considered as suitable technology for tanks and vessels. Floating covers is an efficient, cost-effective method to reduce emissions from tanks immediately without disrupting the process. They are installed by pouring onto the liquid's surface through thief hatches, where then they would realign to form a cover, creating a secondary 'roof'.

If floating covers are not suitable or are unable to trap all of the emissions, installing vapour balance lines connecting tanks to an odour treating unit should be considered. If the measured odour/hydrocarbon emission concentrations are 10 g/m^3 or lower, an adsorption unit is recommended to be installed to collect all the vented emissions from nearby tanks. If higher than 10 g/m^3, an absorption unit should be installed.

Roofing

Tank seals are one source of emissions to the atmosphere. Regular inspection and maintenance should be conducted annually on tanks, checking on tank seals, thief hatch seals, etc.

Thief hatch seals usually wear out over time. Regular maintenance on thief hatch seals should be conducted. This should be done by a proper maintenance crew following safe work practices. In the inspection of thief hatches, the following questions should be answered:

- Is thief hatch holding pressure?
- Are gaskets and moving parts free of dirt and residue?
- Are gaskets cracking and/or swelling?
- Are there any cracks on the thief hatch seals?

Inspection of the thief hatches should be conducted at an annual basis, ideally during tank cleaning. Fugitive emissions management should include tanks, targeting thief hatches.

Changing the roof top from a fixed to floating roof should be considered during maintenance or turn-around operations, especially for older tanks holding large volumes of product.

Venting

Pressure/vacuum vents are installed on tanks to relieve any excess pressure or vacuum on tanks. Pressure/vacuum vents should be inspected monthly and the following questions to be answered:

- Is the vent closed? Vents should remain closed, except during pressure changes, to prevent unwanted emissions.
- Any debris or ice around the vent pipe?
- Any debris or ice around the vent poppet?
- Any evidence of physical damage, corrosion, heat damage, blockage on vent?

During freezing conditions, inspections should be conducted immediately to assure venting device is properly functioning – especially when filling or unloading a tank.

Vent arrestors should be included on tank vent piping, to protect tank from any ignitable sources.

New Tanks

New tanks will be designed to have a floating roof and a vapour balancing /vapour control system in place. Tanks should be welded instead of riveted, to reduce fugitive emissions.

Inspection Frequency

Inspections should be conducted on an annual basis, except for vents which should be conducted on a monthly basis. During any significant freezing events, more regular inspections should be conducted.

Record Keeping

Records should be kept indefinitely online and there should be regular back-ups on information.

5.1.5 Buildings

Buildings may contain emissions from fugitives or combustion reactions. To maintain integrity of the building and to reduce odorous emissions from escaping, the following is recommended:

- Careful selection of construction materials that would minimally corrode.
- Good housekeeping – eliminate unintentional holes in equipment, ducts, etc.
- Keep doors and windows shut.
- Use of air-lock entries for more odorous processes.
- Sufficient ventilation to ensure adequate capture of odours.
- Appropriate alarms installed in place to detect any accumulation of dangerous vapours.
- Use of air treating units in conjunction with HVAC if there are very odorous processes in the building which may contribute to dangerous, explosive conditions. See Section 4.2.1 for more detailed information.

5.1.6 Treating Vented Emissions using Odour Control Technologies

Inspection and Operation Plan

Facilities should maintain a list of vents in facilities and be aware of which ones are top emitters and whether they vent regularly. Vents that are continuously emitting odour emissions should already have, or will have control technology in place to reroute, treat, or destroy emissions. Facilities should set up a plan on how to approach these vents, and key components of the plan should include:

- Inventory and Diagnosis;
- Selection of Odour Control Technology;
- Inspection Frequency; and
- Record Keeping.

Inventory and Diagnosis

A complete list of vented emissions from the site should be created and sustained, including any control technique that has been installed to treat or destroy the emissions. An example of such list is shown in Table 9.

TABLE 9 Example of a Targets Equipment List for Vented Emissions

ID	Process Area	Source	Release Point	Content	Control Technology in Place?	Verified using Fugitive Emissions Technology?	Emissions	Note
1	Tank farm	Tank #3	Tank hatch	Natural gas	VRU – adsorption unit	Yes – high leak		
2	Injection well #1	Casing gas	Casing gas	Natural gas	None	Yes – high leak		
3	Separator Building #1	Tubing vent from control valve	Vent	Instrument gas	None	Yes – small leak		For turn-around, consideration of replacing instrument gas (natural gas) with instrument air.

Selection of Odour Control Technology

Once all venting sources have been identified, the next step is to determine the optimal technology to use for that source. Where the content is instrument gas, emission flow rates are low, and venting is from multiple sources, converting to instrument air is optimal and would result in gas savings and credits.

Section 4.6 went into detail analyzing the different technologies used to capture vented emissions. From the analysis, adsorption units would be best applied to treat the emissions based on their technology advancement, cost, etc. Two adsorption beds should be installed to ensure that there no breakthrough. Each company should analyze different technologies by creating a scoring table, similar to Table 6 to determine the optimal technology(/ies) for the site.

Inspection Frequency

Operators should build a planning scheme to track all the operations and maintenance of the odour control technologies following manufacturer's standards. Additional inspections with respect to odours will be described in Section 5.1.9.

Record Keeping

Operators should keep and track all documentation records and ensure that it is all up to date.

5.1.7 Transportation and Loading/Unloading

Operation Plan

Operators should be informed of all moving vehicle activity within the facility particular in the transportation of material goods. They should be informed what material is being transported, in what volume, and whether it is being transported to or out of the facility. The documented information provided should look similar to Table 10. Similar documentation should be already in place for most facilities.

TABLE 10 Example of Material Goods Transportation Documentation

Date (y/m/d)	Time	Name	Company	Transporting In or Out?	Material	Measures in Place to Control Emissions?	Volume (m^3)
2015/10/22	15:55	Joe Smith	Waste Management Inc.	Out	Stockpile	Material within container	50

If odorous materials are continuously being loaded and unloaded, tank trucks entering the facility should have vapour balance lines installed that uses automatic flow demand systems. Drivers should have documentation on them stating the maintenance of the vehicle and when the truck was last inspected. To reduce the amount of spills, dry break couplings should be used on trucks.

For transportation of waste material, for example spent adsorbent material, biological waste, sludge, they should be transferred into the contained truck as soon as possible. The doors on the trucks should open and close as soon as the waste material is in close proximity. There should a plan to consider any spilled wastes.

Preferably the material should already be enclosed in a sealed container before being transferred to a truck, as this would greatly minimize emissions being unintentionally released into the atmosphere.

5.1.8 Produced Water Systems and Stockpiles

Produced water systems and stockpiles should be placed in locations with key factors in mind:

- Wind speed: Systems should be located in areas where sufficient dispersion takes place before reaching sensitive receptors (including communities). Installing wind breaks, like fences or trees, will help form a barrier to reroute odour dispersion, especially away from communities.
- Wind direction: Systems should be placed in consideration of wind direction, and avoid locations where the wind is blowing towards communities.
- Proximity to communities.
- Containment stability. Is there a chance that there can be an overflow, due to the combined produced water and precipitation in the systems?

In addition to the above considerations, facilities should also determine the following, in order to optimally and economically treat odorous emissions. This will help answer what type of technology would be best suitable to treat odorous emissions

- Frequency of odours. Are the odorous emissions continuous or occur occasionally?
- What is the size of the produced water system(s)/stockpile(s)?

Figure 4 is a proposed decision tree for facilities to consider on what odour treatment technique to use for their site.

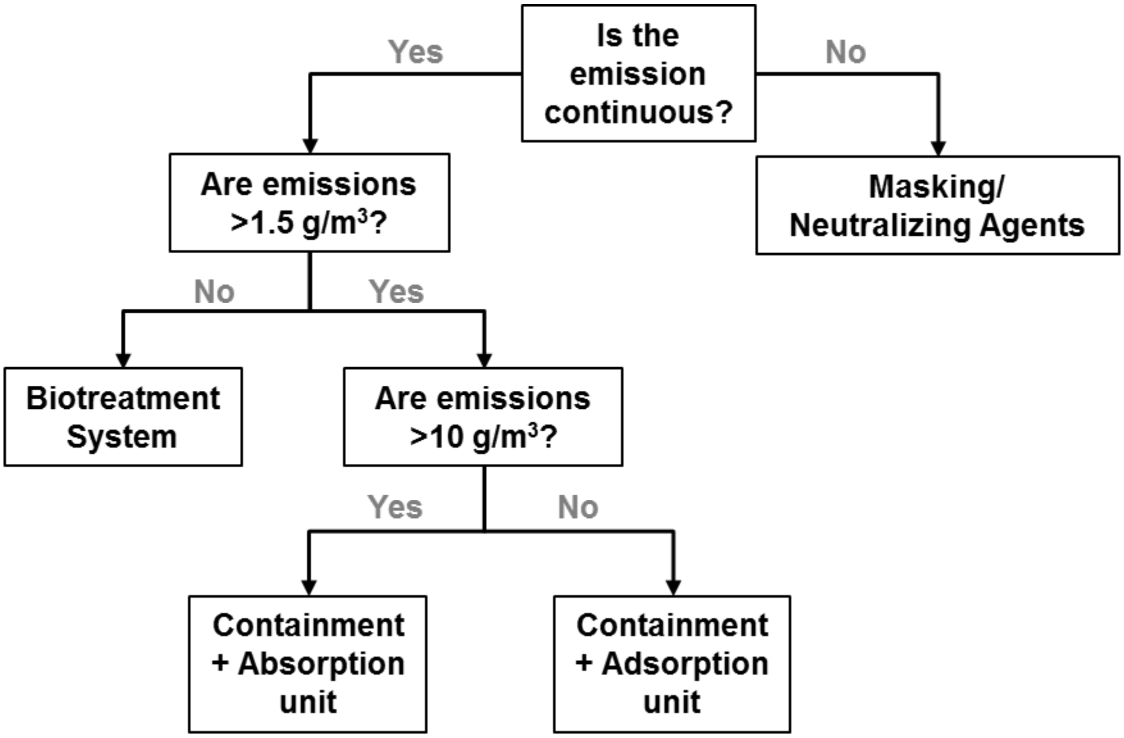

FIGURE 4 Decision Tree on Selecting Proper Odorous Abatement Technique for Produced Water Systems and Stockpiles

5.1.9 Separation Distances/Buffer Zones

Visual perception influences the human olfactory senses (61 – 63). When someone perceives that there are emissions in the air, their olfactory senses may be enhanced to the environment. Breaking line of sight from surrounding communities, as this will reduce some of the psychological effect of odorous emissions. This can be done by landscaping the site, e.g. growing trees or earth banking, to block the view of the facility. Breaking line of sight also may also curb wind dispersion of emissions and reduce odorous emissions (if present) from reaching neighbouring communities.

5.1.10 Maintenance, Housekeeping, Training

In previous sections, it was repeatedly mentioned about creating an inventory list of the top odour emitters. All this information can be merged into one list, divided appropriately by location or type, and given to the operators who will assign tasks to personnel. In this way, duplicates won't occur and missing data won't be overlooked. An example of such spreadsheet is listed in Table 11.

TABLE 11 Example of Equipment List for Odorous Emissions

ID	Responsible Personnel	Process Area	Source	Release Point	Content(s)	Measures in Place to Control Emissions?	Verified using Fugitive Emissions Technology?	Emissions (L/min)	Inspection Frequency (Date, Time)
1	J. Smith	Battery Facility	Tank #10	Hatch	Fuel gas	VRU - Adsorption unit	Yes - IR Camera	50	Monthly
2	J. Public	Wellhead	Injection Well #1	Casing vent	Natural gas	VRU - Adsorption unit	Yes - IR Camera	700	Annually
3	J. Bloggs	Produced Water System	Pond #1	Pond	Water with crude oil (vapours)	Biotreatment unit	Yes - IR Camera	100	Weekly
4	R. Roe	Transportation	Truck (XXX ###)	Material within containers	Fuel gas	Double sealed containers	Yes - IR Camera	10	Each time
5	R. Miles	Loading/ Offloading Area	Loading dock #1	Transferring waste	Crude oil vapours	Rapid transfer,	Yes - IR Camera	20	Each time
6	M. Major	Piping system	Production pipe	Flange	Natural gas	Fugitive emissions surveys	Yes - TVA Analyzer	2	Annually
7	J. Doe	Boiler	Boiler #1	Vent	Combusted material	VRU - Absorption unit	Yes - IR Camera	5	Annually
8	J. Stiles	Flare	Flare stack #2	Flare	Combusted material	VRU - Absorption unit	No	50	Whenever activated
9	B. Bolton	Heaters	Heater #3	Vent	Combusted material	VRU - Absorption unit	Yes - IR Camera	5	Annually
10	T. Atkins	Turbine Generator	Backup generator	Vent	Fuel gas	None – Used in emergencies	Yes - IR Camera	1	Annually

ID	Responsible Personnel	Process Area	Source	Release Point	Content(s)	Measures in Place to Control Emissions?	Verified using Fugitive Emissions Technology?	Emissions (L/min)	Inspection Frequency (Date, Time)
11	S. Dick	Stockpile	Waste stockpile	Stockpile	Sand contaminated with crude oil	Neutralizing agents	Yes - IR Camera	20	Annually

It should be emphasized for personnel to avoid becoming complacent with their surroundings. Over time, staff may lose their sensitivity to detecting odours as they are continuously exposed or they may detect the odours and tolerate them. Meetings should include the awareness of the surrounding odours, and discussions on ways to deal with it. A review of the process flow diagrams, mass balance data, and piping and instrumentation diagrams with the group would be helpful to identify possible release point sources.

In addition to the above, what each personnel can do include:

- **Walk-arounds:** Personnel should do a “walk-around” the site at least once daily and note any observation of unpleasant odours.
- **Forms:** If an odour is detected, a form can be filled out by the person detecting the odour. See Figure 5 for a sample odour detected tag.
- **Good housekeeping:** Ensure that items are closed if they are intended to be closed, valves are not left open when they should be closed (tagging will help to ensure that personnel are aware if valve is left intentionally open), spills are properly cleaned up, avoid mixing of materials, etc.
- **Integration:** Employees working in the environmental division should focus their efforts not only on greenhouse gas emissions and noise, but as odour emissions as well.

Odour Detected!

Date:__/__/____
By: __________

Process Stream: ___________
Smells Like: ☐ gasoline ☐ solvent ☐ sweet
☐ rubbery ☐ sulfurous ☐ burnt
☐ decayed cabbage ☐ other

Description:
____
____
____
____

FIGURE 5 Sample Odour Detected Tag

5.2 UPSET CONDITIONS

Upset conditions occur when something unusual and unexpected happens at an operating facility. Upset conditions would occur when equipment fails, outages, or there is a surge in inlet loading (which would overload the equipment, causing it to fail), releasing unintentional emissions.

In the event that an abnormal event occurs, it is critical to determine the source and cause of the odorous release. It may help to look at the inventory list, example shown in Table 11, which can aid in determining where and which source would be most likely to fail during upset conditions. Some sources may include:

- **Doors:** Door left open when it should be closed?
- **Heat exchangers:** The high temperature may have corroded the equipment?
- **Valves:** Is there a valve that is left open when it should be closed?
- **Tanks:** Has a thief hatch been left open or was there a seal failure?

Once it is determined the cause of the odorous release, it is necessary to address the odour issue as soon as possible – see Figure 6. For some, this may be fixed immediately (e.g. close door, close valve), and some may take some to repair. In the instances where it may take longer to fix and the odour is too strong, it is suggested to overcome the odour with masking or neutralizing agents.

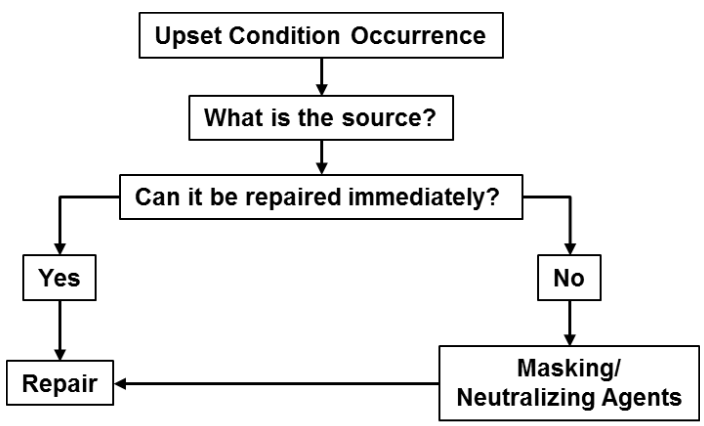

FIGURE 6 Decision Tree for Treating Emissions during Upset Conditions

There may be instances where equipment breaks down and/or corrodes, resulting in fugitive emissions escaping into the atmosphere. Methods to avoid or mitigate breakdown conditions include:

- Routine inspections on the equipment;
- Use materials that are more resistant to corrosion;
- Ensure minimal contact of corrosive compounds with the equipment; and
- Keep close observation on sensitive equipment during extreme weather conditions, including drastic changes in temperature.

5.3 Operation and Maintenance Conditions

There are instances when equipment at heavy oil facility will be taken off-line. This could be due to routine maintenance, plant turnarounds, or emergency maintenance when equipment fails. Some examples include:

- Tank cleaning;
- Odour abatement technology maintenance;
- Piping insulation replacements;
- Equipment replacements; and
- Flaring.

Ideally, maintenance should be conducted during cold conditions, in order to depress the spread of odorous emissions. It should also be attempted during slower periods when there is low activity in the facility.

5.3.1 Tank Cleaning

In preparation for cleaning, tanks are generally degassed (i.e., vented) into the atmosphere to reduce the internal gas content to a level that would make it incapable of producing a flash of fire (<LEL). During tank cleaning, emissions can be released during idling between cleaning steps, sludge removal, and refilling of the tank. Tank cleaning is an occasional event, generally occurring no more than once a year and lasting no more than one or two days.

During degassing the vacuum breaker vent opens, releasing emissions into the atmosphere. If it is any way possible, this vent should be connected to a VRU to reduce release of emissions into the atmosphere. Otherwise, degassing should be conducted during an event when wind conditions are favourable in which the emissions will disperse in the direction away from communities. Similarly for tank refilling, this can be done during conditions where wind dispersion will blow the emissions away from communities.

There may be sludge remaining in the tank, in which volatile chemicals may be released into the atmosphere. Disposal of the sludge should be done immediately, by placing the sludge in containers Masking and/or neutralizing agents can be applied to sludge initially, before it is sealed in containers and shipped off to other locations.

5.3.2 Odour Abatement Technology Maintenance

There will be instances when the technologies that treat odorous emissions themselves will require maintenance – either to replace the media, the structural integrity of the technology itself, etc. One option is the use of by-pass pipes. When one piece of odour abatement equipment is taken off for service, the gases can be re-routed to secondary odour abatement equipment. In some circumstances, e.g. adsorption units, there are typically two beds to ensure that there is no break-through. For maintenance purposes, one bed would be sufficient to treat odours until the other bed returns into process. Another practice is to consider self-regenerating material, to reduce the number of times the units need to go through maintenance.

Maintenance of the odour treating technologies can also be conducted during facility turnarounds, which occur every few years. Most of the equipment is capable of treating emissions for a few years.

5.3.3 Piping Insulation Replacements

Occasionally, piping insulation requires to be replaced due to extreme temperature changes between pipe and ambient conditions, especially during the winter months. In some instances, the insulation could be a proponent in slowing down fugitive emissions from escaping into the atmosphere as it creates a barrier. As a result, when insulation is taken off, and depending on when insulation gets replaced, there can be atmospheric releases of odorous emissions.

Piping insulation replacements should occur during favourable weather conditions, where wind direction is away from communities. If possible, one of the fugitive emissions technologies listed in Section 4.2.3 can be used while insulation is removed, to ensure that there are no fugitive emissions released from piping components. Simplest and most cost-effective would be to use soap solution to determine any leaks in the components.

5.3.4 Equipment Replacements

There will be equipment replacements periodically, as material corrodes, seals wear off, etc. Every couple of years there are also turn-arounds where the entire process unit is taken offstream for extended period of time for revamp and/or renewal of equipment. During this period, it is important to properly isolate equipment so emissions won’t be unintentionally released.

Natural Gas STAR Partners released a document listing recommendations of reducing emissions when taking compressors off-line (64). In the document, they list four options for reducing emissions:

- Keep compressors pressurized;
- Connect Blowdown vent lines to fuel gas system;
- Install static seals on compressors' rod packing; and
- Install ejectors on compressor blowdown vent lines.

Of these, the largest source of emission releases is associated with depressurizing the compressors. These recommended techniques can also possibly carried out for other equipment pieces.

5.3.5 Flaring

Facilities should follow guidelines as outlined in Directive 060's Upstream Petroleum Industry Flaring, Incinerating, and Venting when necessary (6). Flaring should occur very occasionally, and only during upset and maintenance operations. The Directive 060 lists the minimum flare performance requirements applicable to all flares and incinerators in the upstream oil and gas industry systems for burning sweet, sour and acid gas, including portable equipment used for temporary operations such as well completions, servicing and testing. One requirement relates to the efficiencies of the carbon conversion, sulphur conversion and combustion such that when flares are operated they do not result in the off-lease H_2S odours, odour complaints or visible emissions. In addition, the Directive outlines a minimum heating value and exist velocity requirements. All these conditions must be met despite various meteorological conditions.

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