Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

Summary Report - Independent Assessment of Landfill Gas Emissions and Management Systems at 29 EPA Licensed Landfills in the Republic of Ireland

Performed by Odour Monitoring Ireland on Behalf of the Environmental Protection Agency (Office of Environmental Enforcement)

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CONTENTS

EXECUTIVE SUMMARY

Waste management facilities and especially landfill sites produce odours. Like the majority of industries, the operation of landfills is faced with the issue of preventing odours causing impact to the public at large. Design, operational and management techniques can reduce the impact of odours from landfills. The assessment of the effectiveness of such odour minimisation and mitigation techniques is limited utilising traditional sampling and measurement of odours. Traditional odour measurement techniques (e.g. Lindvall hood and US EPA flux hood) on facilities which evolve rapidly are very limited in their application and speed on delivery of real-time information.

An assessment of landfill gas surface emissions and management systems was carried out at twenty nine EPA waste licensed landfill facilities during 2009. The site assessments included surface Volatile Organic Compound (VOC) monitoring together with a review of the landfill gas infrastructure, systems and practices being employed at the facilities. Following the completion of each survey, those areas identified as significant sources of emissions in terms of detected VOC concentrations were communicated to the landfill management team for immediate remediation. The landfill gas collection systems were also assessed with specific emphasis on pipe work size, condensate management, vertical well spacing, vacuum pressure and flare capacity. This survey system provided real-time data, identification of surface emissions hotspots and facilitated implementation of immediate remediation at the facility. The information generated provided the landfill management team with specific details on the effectiveness of landfill cover material, landfill gas collection system operation and the location of where additional mitigation was required within the operational facilities. Additionally flux box measurements and speciated VOC's monitoring were carried out at three facilities nominated by the OEE. This report should be read in conjunction with the individual site evaluation reports developed for each facility.

KEY STUDY FINDINGS:

A number of key findings have been compiled from the individual site surveys which will facilitate the reduction of surface emissions from landfills. These include:

- Understanding has improved in 2009 on landfill gas abstraction systems on the 29 facilities assessed. The interaction of monitoring, balancing, design and process control of this system should be used to optimise landfill gas abstraction on each facility. Further training and ongoing training is required in the area, particularly for new staff operating these facilities in the future.
- Surface emissions monitoring in conjunction with a thorough investigation of the installed collection infrastructure at landfills is an effective means of reducing emissions of landfill gas with entrained odourous compounds.
- Flanks and sloped areas had a greater propensity for surface emissions occurrence than any other areas within the landfills surveyed.
- Improvements in management procedures towards reducing incidence of blockage due to condensate build-up and oxygen ingress which lead to reduced landfill gas abstraction is required.
- Emissions from leachate side slope risers and leachate chambers were noted on a number of facilities. Any protrusions of the waste body should be adequately sealed so as to reduce surface emissions.
- Additional resources in terms of landfill gas infrastructure across a number of facilities is required if surface emissions are going to be adequately reduced. All elements pertaining to the landfill gas collection system should be carefully designed to minimise landfill gas emissions to atmosphere.
- Flux box monitoring was not considered to be a robust technique in assessing landfill gas surface emissions. Flux box monitoring does not have the spatial coverage or the ability to provide robust real time results needed by landfill management on a day to day basis to reduce landfill surface emissions.

2. INTRODUCTION

Disposal of municipal solid waste in landfills is one of the main methods used to dispose of waste in Ireland. Landfill gas (LFG) is produced continuously by microbial action on biodegradable wastes under anaerobic conditions. The decomposition of the organic component of municipal waste in landfills produces landfill gas containing approximately 50% methane (CH_4). Methane is a potent greenhouse gas, it has a global warming potential 21 times greater than carbon dioxide. There is significant motivation towards greater containment of such emissions especially given recent commitments by the European Union on further reductions in greenhouse gas emissions (GHG) by 2020. Emissions from the Waste sector in 2008, primarily methane gas released from landfills, amounted to 1.106 Mt CO_2eq. This figure shows a 7 percent decrease on the 2007 emissions, representing was the main sectoral percentage decrease in 2008. Landfill gas utilisation and on-site flaring offset more than 60 percent of methane production in 2008 (EPA, 2009).

Landfill gas also contains trace amounts of other compounds, such as hydrogen sulphide, mercaptans and non-methane volatile organic compounds. These other compounds may cause odours or affect local air quality. Uncontrolled landfill gas can also migrate underground affecting groundwater and in some cases may cause explosions in correct conditions. LFG emissions can be controlled by installing a network of collection wells and directing the gas to a combustion plant for the production of electricity, for use as fuel by a nearby industry, and by flaring (i.e. burning).

LFG emissions are highly variable (Maurice et al. 1995) and several factors account for these variations. The emission is influenced by the type of degradation, the quantity of abstracted gas, barometric pressure variation (Christophersen et al. 2001) and soil conditions (e.g., higher soil water content or freezing of the soil, dry soil resulting in lower biological methane oxidation) (Maurice, and Lagerkist, 2003). The quality and quantity of emitted LFG depends on the waste composition, moisture content of waste, the landfill degradation state, and the methane oxidation activity in the landfill cover. These processes result in diurnal, seasonal, and spatial variations in emissions that make it difficult to estimate emission rates from facilities (Maurice, and Lagerkist, 2003).

Over 500 compounds have been identified as contributors to landfill odours (Parker et al. 2002). These compounds are either components of waste placed in the landfills or are degradation by-products. The main sources of these VOC emissions within landfills are:

- Inadequate Operational and management techniques within the landfill,
- Poor Cover management techniques,
- Faults in capping or gas collection systems,
- Open leachate chambers and tanks,
- Faults in the liners and covers of closed cells; (Chiriac et al. 2007).

2.1 SCOPE OF THE PROJECT

The study was carried out in the following format:

- Landfill surface emissions monitoring, using continuous kinematic Volatile Organic Compound (VOC) with an integrated Global Positioning System (GPS) to detect areas of potential landfill gas release/flux, was carried out at each nominated facility. Detected landfill gas surface emissions areas were geo-referenced and plotted upon a basemap for visual interpretation and remediation.
- An assessment of landfill gas management systems including a review of facility procedures and records for landfill gas management systems was carried out. This assessment included flare capacity evaluation, gas flow rate measurements, static pressure measurements across the collection pipe work and collection wells and a visual inspection of the condition and layout of the pipe work. In addition, in some cases, the landfill manager

attended the survey and received general guidance on the significance of the results gathered throughout the survey.

- Additionally flux box and speciated Volatile organic compound surveying was carried on three licensed facilities nominated by the Office of Environmental Enforcement (OEE).
- A meeting was held with the landfill management team after the survey. The purpose of the meeting was to inform the landfill management team of the outcome of the survey, and to allow the landfill management team to communicate any continued engineering issues currently occurring on the site. Recommendations to reduce emissions were presented to each landfill manager within a report which was issued to the facility by the EPA within a month of the survey.

Odour Monitoring Ireland has used this assessment technique on 10 EPA licensed landfill facilities in 2007, 27 EPA licensed landfill facilities in 2008 and 29 EPA licensed landfill facilities in 2009 on behalf of the EPA OEE. The results from all 29 EPA licensed landfill facilities are presented within this summary report.

2.2 ADOPTED TECHNIQUE FOR STUDY

The method adopted for the purpose of this study aimed to identify VOC surface emissions using continuous kinematic VOC/GPS; geo-reference detected landfill surface emission areas and plot them upon a basemap for visual interpretation and remediation.

Key elements from techniques

The key points from the technique adopted for this study are:

- Integrated "Odour Hog" intrinsically safe, survey VOC dual monitor, which provides fast and accurate readings of organic and inorganic vapours. A Photo Ionisation Detector (PID) uses an Ultraviolet (UV) light source (photo) to ionise a gas sample and detect its concentration. Ionisation occurs when a molecule absorbs the high energy UV light, ejecting a negatively charged electron and forming of positively charged molecular ion. The gas becomes electrically charged. These charged particles produce a current that is easily measured at the sensor electrodes. Only a small fraction of the VOC molecules are ionised. A PID does not respond to methane. A Flame Ionisation Detector (FID) is similar to a flame thermocouple detector, but measures the ions from the flame instead of the heat generated. The FID detects the methane fraction, which provides greater sensitivity in terms of methane leakage detection but not necessarily odour hence why the PID data is also sometimes interpreted. Using the continuous kinematic "Odour hog" with integrated GPS, the capping of the landfill can be surveyed for potential leakage areas. Those areas identified are geo-referenced and highlighted for remediation.
- Measurements taken every four seconds continuously within the landfilled area and marked upon a map.
- Meteorological conditions were recorded to include wind speed, cloud cover, barometric pressure, air temperature.
- Other information recorded includes cap moisture content classified as dry, medium or wet.
- Surfaces were scanned (<5 cm) from ground with a portable FID / PID fitted with a specialised sampling probe with a 150ml funnel at the tip.
- Calibrated in accordance with USEPA Method 21 and methodology contained within EN13526:2002.
- Surveyor identifies all features to include working faces, gas vents, leachate side slope risers, etc. which may contribute to gas flux and log these within the GPS handheld unit.
- Suggested recommendations and remedial actions were included within report (e.g. sealing gaps and fissures, closing inspection points, maintaining pipework, installing adequate wells, balancing the field, etc.).
- Generation of contour colour coded map accompanied by tabulated information with grids reference points including remedial action for each location.
- Flux box surveying in accordance with USEPA methodology. This is discussed in detail in *Section 4*.
- Speciated volatile organic compound monitoring on inlet feed landfill gas to flare and headspace gas of flux box. This is discussed in detail in *Section 4*.

3. OVERVIEW OF SURFACE EMISSIONS MONITORING ON 29 WASTE LICENSED FACILITIES

The following section highlights the principal findings of the study site assessments and Appendix 2, Table 3.1 summaries the key issues encountered on a site by site basis. These tables should be read in conjunction with the notes provided in Appendix 2, Table 3.1 and Section 3.1.1 to 3.1.8.

3.1 KEY ISSUES IDENTIFIED ON FACILITIES

As part of the study a number of key findings and issues became apparent. These were based on observations, surface emissions results and discussions with the various facility managers.

3.1.1 Vertical abstraction wells

Problems with vertical abstraction wells and gas management systems were encountered on all the surveyed landfill facilities *(see Tables 3.1).* Insufficient LFG abstraction subsequently gave rise to surface emissions from the area in and around the well and in the zone of influence of the vertical well. Insufficient abstraction augments into a number of points, which are discussed further in this section. These were:

Inadequate well sealing:

- Inadequate sealing of landfill gas wells was a significant problem encountered on 16 facilities *(see Tables 3.1 and Figure 3.1).* No adequate LFG systems were in place on one facility. This resulted in surface emissions in and around the feature and also resulted in preferential pathways for the ingress of Oxygen into the system. This resulted in landfill managers turning back the applied vacuum pressure on the wellhead in order to prevent the risk of landfill fire.
- On permanently capped areas, surface emissions occurred as a result of settlement resulting in liner detaching from the pipe work.

Construction of vertical well:

- If vertical wells are not constructed to a sufficient diameter they may become perched with leachate. Sites with a high occurrence of perched leachate should optimise vertical well construction to take account of this fact.

Inadequate condensate removal:

- Surface emissions due to insufficient condensate removal from pipe work and removal of leachate from vertical wells was encountered on 3 facilities during the visits *(see Appendix 2, Table 3.1 and Figure 3.2).* No adequate LFG systems were in place on one facility. Inadequate removal of condensate results in failure to maintain gas vacuum pressure at the wellhead. Accumulation of condensate should be engineered out using sufficient falls and condensate removal pots.
- Condensate management plans should be implemented within each facility to allow for the development of progressive and proactive procedures and equipment for the removal of condensate. It should form an integral component of daily operations within every licensed facility in Ireland.
- Sufficient consideration given to the design of the landfill gas collection system include barometric drip-legs, pumped and gravity drain knock-out pots, correct falls in pipe work to allow easy removal, dewatering well heads and legs and correct sizing of pipe work so as to prevent frequent blockages.
- Consequences of inadequate condensate management lead to flooded spurs and headers, low vacuum at wellheads which in turn gives rise to increased surface emissions.

Inadequate abstractive capacity:

- It was noted at one facility *(see Appendix 2, Table 3.1),* that sufficient abstraction capacity was not being delivered to the gas field. No adequate LFG systems were in place on another facility.

Inadequate flow control:

- On a number of facilities in previous years, there was limited capacity to control landfill gas flow because either ball valves were faulty, corroded or installed incorrectly. In some circumstances there were not replaced. This was not the case in

2009, because in most cases valves which were identified as being faulty, corroded or installed incorrectly from assessments carried out in 2008 were replaced or rectified. Typically valves encountered included ball and socket valves, butterfly valves, linear valves, and Angle seat valves. Butterfly valves should only be used on spur or sub headers. Ball valves appeared to be the main choice on wellheads while a small number of facilities had linear and angle seat valves installed. Since ball valves can have poor flow control of gas, these should be sized correctly to allow for sufficient headloss and flow control at the vertical and horizontal gas abstraction well. Careful consideration should be given to the type of valve, level of control required with that valve and ease of maintenance / replacement.

Gas field balancing and lack of understanding:

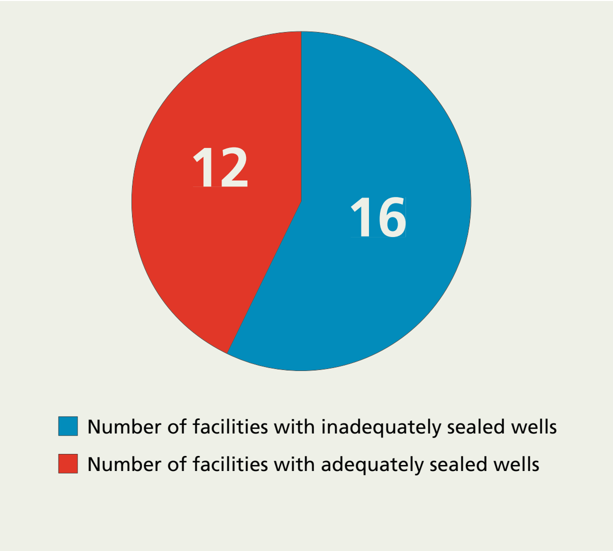
- Understanding has improved in 2009 on landfill gas abstraction systems on 28 of the 29 facilities assessed. The interaction of monitoring, balancing and process control of this system should be used to optimise landfill gas abstraction on each facility. Further training and ongoing training is required in this area, particularly for new staff operating these facilities in the future.

3.1.2 Leachate side slope risers and leachate chambers

Problems with respect to surface emissions from leachate side slop risers and leachate chambers were encountered on 15 of the facilities *(see Appendix 2, Table 3.1 and Figure 3.3).* The issues encountered included inadequate sealing of the leachate side slope risers or chambers and the absence of landfill gas abstraction from the leachate side slope risers or chambers. Since the leachate side slope risers and chambers provide a direct connection into the waste body it is very important that they are capped, sealed adequately and placed under a slight negative vacuum to minimise landfill gas leakage.

3.1.3 Flanked areas

Flanked/sloped area surface emissions were encountered on 27 of the facilities surveyed. It should be noted that the one facility which did not have flanked/sloped area surface emissions had very high surface emissions on other surfaces. In general flanked/sloped areas were too steep therefore maintenance including reapplication of cover material and tracking in loose cover material could not be easily carried out. When a flanked/sloped area is not maintained adequately, it will become etched as a result of water damage *(see Appendix 2, Table 3.1).* Efforts should be made to construct flanked/sloped



*Note one facility excluded because there were no adequate LFG systems in place.

FIGURE 3.1 Graphical representation of the adequacy of well sealing across the surveyed facilities in 2009

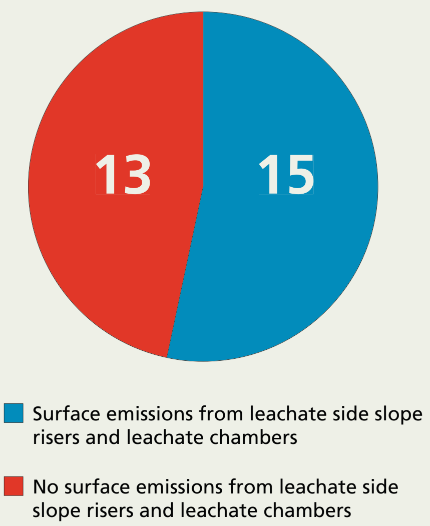
*Note one facility excluded because there were no adequate LFG systems in place.

FIGURE 3.2 Graphical representation of the adequacy of well sealing across the surveyed facilities in 2009

areas to concur with the recommendation contained in the Landfill design manual (EPA 2003). Surface emissions from flanked/sloped areas were greatest in comparison to all emission sources and this has been identified in other European countries as the greatest emission source due to the lateral permeability and pathways formed within the waste (i.e. anisotropic nature of waste). Gas abstraction techniques should be designed to minimise surface emissions from flanked/sloped areas.

Two successful techniques were utilised in surveyed facilities. This included benching of the flanked / slope areas *(i.e. utilised on 7 of the surveyed facilities see Appendix 2, Table 3.1)* and use of a GLC stitched membrane or LDPE geomembrane over a sloped area *(i.e. utilised on 10 of the surveyed facilities see Appendix 2, Table 3.1)*. The flanked / slope benching techniques were well constructed and had very minor emissions when monitored. However surface emissions were noted on other flanked areas within the same facilities. To effectively reduce surface emissions from all sloped / flanked areas within a landfill facility, the above techniques should be extended to cover all sloped flanked / areas within each landfill facility. The benching of a flanked / sloped area has a number of advantages over conventional formation. These include:

- More control for maintenance - it was observed on a number of landfill facilities during the survey's that maintenance was not possible on large flanked / sloped areas due to access problems. The use of correct benching alleviates access problems,
- Less storm water etching was observed, because benched flanks are generally compacted better, they do not have a tendency to ravel as easy with high rainfall,
- Better compact construction providing a barrier to gas transmission and Oxygen ingress - the bench is constructed by placing a bank of clay approximately 3.50m high along the edge of the lift. The clay bank acts as a barrier between the waste and the edge of the cell, therefore allowing for optimised abstraction to be placed upon the waste. Correct benching would be preferred over other types of flank construction based on the findings of this study.



*Note one facility excluded because there were no adequate LFG systems in place.

FIGURE 3.3 Graphical representation of the number of facilities surveyed in 2009 which had surface emissions from leachate side slope risers and leachate chambers.

3.1.4 Flare and blower capacity

Flare and blower static pressure capacity issues were encountered on one of the facilities (*see Appendix 2, Table 3.1*). No adequate LFG systems were in place at one other facility. Blower static pressure capacity issues are mainly due to insufficient static pressure within the flare blower to overcome the resistance to remove gas from the landfill gas field and to force it through the flaring system. This resulted in insufficient gas abstraction which resulted in over pressurisation in the landfill gas field. There was a lack of understanding with some landfill managers on the flare performance criteria for flaring systems and there appeared to be a dependency on overseas service, which was not readily available for immediate fixing of faults. In moving forward, all flaring systems should be performance tested to ensure they can achieve the stated treatment volume and pressure capacity. Sufficient flare blower static pressure should be incorporated into the flare design to also take account of pressure losses throughout the gas field pipework. Sufficient flare volume treatment capacity should be maintained on the flaring system for new fill phases and the quantity of gas volume capacity at least based on site data for recently fill cell (i.e. ascertain through site records the volume of landfill gas produced per tonne of waste material landfilled). The filling of additional cells should not occur until proof is provided of sufficient available flare treatment capacity within the system. It is important for the operator to observe continuous vacuum pressure applied to the field in order to trend any loss in performance throughout a working day. Flare volume flow sensors should be calibrated regularly and volume flow verification should be performed.

3.1.5 Gas management system

One facility visited in 2009 did not have active gas management in the active cell *(see Appendix 2, Table 3.1)*. On this one facility filled waste ages ranged from 9 months to 2 years. Gas management systems need to be introduced in active zones within the landfill as early as possible thereby minimising emission of odours and greenhouse gases. The enclosed flaring of landfill gas with low % methane concentration (i.e. down to 4 to 6%) can now be achieved using advance low calorific flaring systems so landfill gas from active cells can now be flared without any supplementary fuel required.

3.1.6 Other elements

A large amount of information is presented in *Appendix 2, Table 3.1.* Each facility must be evaluated on an individual basis. A comparison between facilities is of limited use due to the heterogeneous nature of landfill and indeed varying construction and operation techniques between landfills. The key focus on a site by site basis is to reduce surface emissions in each facility on a micro level. This data provides an overview of the survey findings from 2009.

One useful method of illustrating the data is presented on *Figures 3.4* and *3.5*.

Six facilities had surface emission concentrations which were greater than 40 times the recommended level for open surfaces (i.e. over the 100ppmv on surfaces) (see *Appendix 2, Table 3.1* and *Figure 3.4*). The greatest value recorded was 13,200ppmv (132 times the recommended limit on surfaces - see *Appendix 2, Table 3.1* and *Figure 3.4*).

Eight facilities had surface emission concentrations which were greater than 10 times the recommended level for features (i.e. over the 500ppmv on features - see *Appendix 2, Table 3.1* and *Figure 3.5*). The greatest value recorded was 18,980ppmv (38 times the recommended limit on features see *Appendix 2, Table 3.1* and *Figure 3.5*).

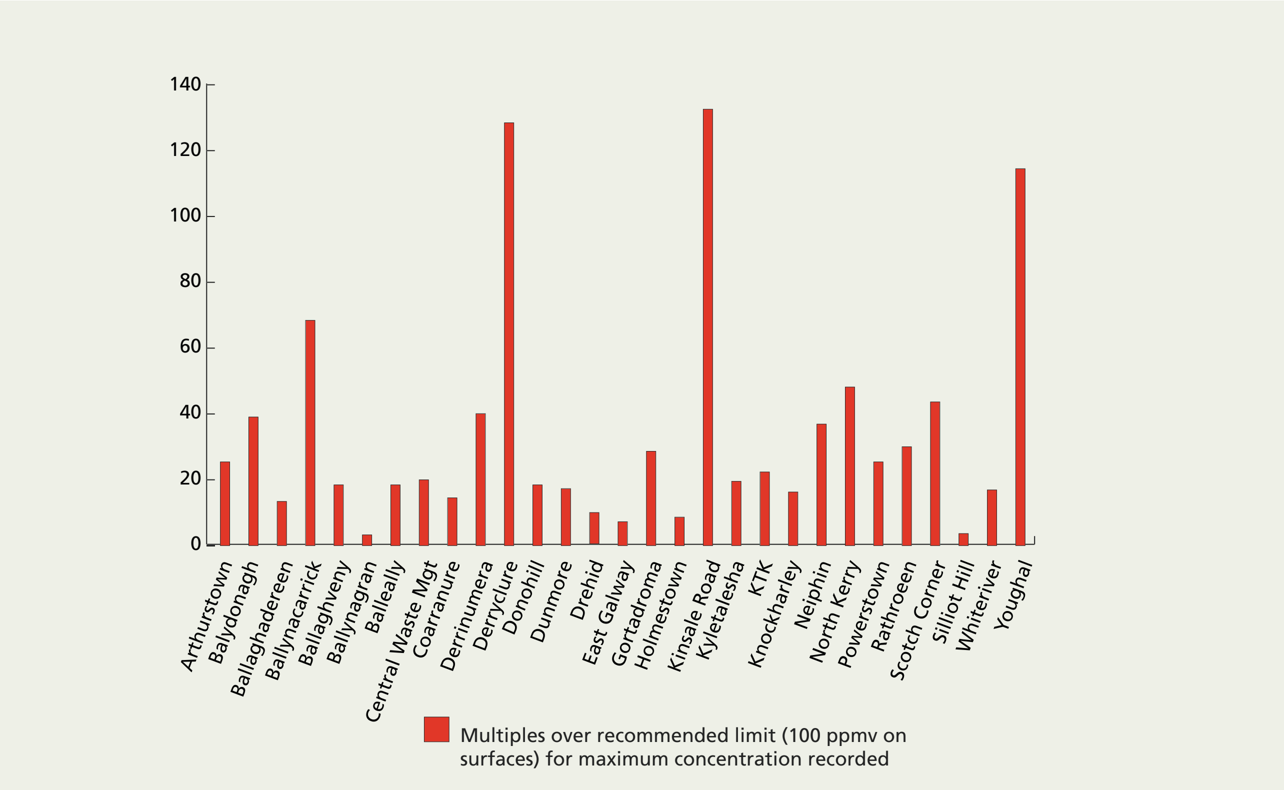


FIGURE 3.4 Graphical representation of facilities over the recommended limit for open surfaces (i.e. 100 ppmv on surfaces).

3.1.7 Records

Field balancing records were requested of all surveyed facilities. In general, field balancing records contained the appropriate amount of information in terms of documented parameters. All facilities should record Methane, Oxygen and Vacuum pressure at a minimum from each well or feature throughout the system. In some circumstances, volume flow measurements should be performed in order to obtain a flow profile versus applied vacuum pressure on each vertical well. This facilitates good landfill gas management on an ongoing basis through a better understanding of the characteristics of the system.

3.1.8 Moving forward - Resources and Training

The study illustrated knowledge and training within facilities is fragmented with some facilities having a different understanding of techniques and technologies associated with landfill gas management. The study also illustrated that the necessary resources required to adequately manage landfill gas in some facilities were not in place. The situation has improved from 2008 (see Section 5). However, a training course in landfill gas management should be mandatory for each landfill manager and deputy manager moving forward.

For large facilities it is suggested as best practice to have a staff member with designated responsibility for gas management and operations. This person should be trained on operation parameters (i.e. Landfill gas abstraction provisions, flaring types, cover material types and depth, flanked formation, expected methane and oxygen levels across the system, landfill gas abstraction pipe work and sizing, vertical and horizontal abstraction system, design installation and condensate management, etc.). Without putting the proper resources and training into landfill gas management, it will be difficult to reduce surface emissions. There currently is scope for improvement in this area within landfills.

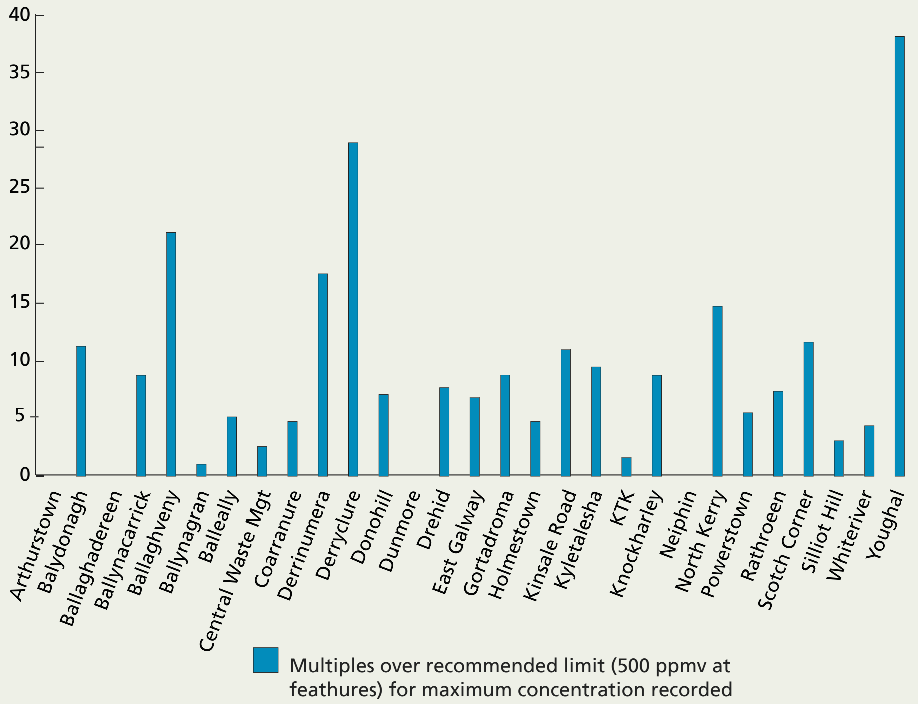


FIGURE 3.5 Graphical representation of facilities over the recommended limit on features (i.e. 500 ppmv on features).

4. FLUX BOX MEASUREMENTS AND SPECIATED VOC ANALYSIS

During the 2009 surveys, flux box measurements were carried out at three facilities nominated by the OEE. A dynamic surface emissions isolation flux chamber designed and operated in accordance with USEPA guidelines was utilised to perform flux emission measurements for Methane and Volatile organic compounds at pre-selected locations within the landfill. Twelve monitoring locations were utilised on two facilities namely Youghal and Corrunure Landfill facilities and thirty six locations were utilised on Knockharley Landfill facility.

In terms of speciated Volatile organic compounds (VOC's), one surface location was monitored for the flux of speciated VOC's while one composite sample was taken from the gas management system at the flare in accordance with the methodology contained in EN13649:2002 and MDHS 72.

The flux chamber is used to isolate a known surface area for emissions measurement. The flux chamber consists of a hemi spherical sealed chamber (see *Figure 4.1*) whereby clean, dry, VOC free standard sweep air (Air Products) was added to the chamber at a metered rate of less than or equal to 3.25 liters / minute and verified using a Primary flow calibrator. A temperature and pressure sensor was fitted to the headspace of the chamber. The headspace air within the chamber was allow to exchange a minimum of 5 times (i.e. 5 AC) before any measurements were made. Within the chamber, the sweep air is mixed with emitted vapors and gases from the measurement surface by the physical design of the sweep air inlet. The concentration of the exhaust gas was measured at the chamber outlet for Methane and speciated VOCs with a FID and sorbent tube method. The sample rate of the instrumentation was at minimum less than 40% of the sweep volume. Values were recorded when the exhaust gas concentration in the chamber exhaust had stabilised.

The emission flux from a surface can be calculated using the following equation:

$$E_i = C_i Q / A$$

where E_i = emission rate of component *i* (ug/m^2/s or mg/m^2/s); C_i = concentration of component *i* (ug/m3 or mg/m^3); Q = sweep air flow rate into chamber (m^3/s); and A = surface area enclosed by chamber (m^2).

Sample locations were informed by the results of the surface emissions survey.

The accuracy of the flux box method is dependent on the number of flux box chamber tests conducted and can only provide an average flux over the sampling period. As reported by the Environment Agency, grid spacing of 20 m to 30 m which are typical of densities for small areas (less than 3 hectares) or for academic research. Grid spacing of 20 m to 30 m have a probability of detecting a 25 m^2 circular feature of 6% and 3%, respectively, which is very low. Grid spacing of 35 m to 50 m which are more typical of densities applied on a commercial basis to sites of 5 to 20 hectares, have a probability of detecting a 25 m^2 circular feature that is even less than 3%. To improve the probability of detecting a significant emission feature, a walkover survey can be conducted (as was the case for the three facilities) prior to flux box testing. However, this can skew the results to high emission features if flux boxes are targeted at high emission features.

The advantages of the flux box method are that it is relatively simple and economical for small landfills and there are methodologies that are well established.

The disadvantages include:

- It is a point sampling method. Unless a very high density of flux box tests are used, statistically there will always be a relatively significant degree of uncertainty as to the actual emission flux.
- Cannot account for emissions from concentrated sources such as cracks, small emission features or leakage with LFG wells or monitoring points.
- Since it is labour intensive, it can be time consuming and costly for large landfills.

In terms of the three surveys, it was not possible to provide full spatial coverage across the entire landfill footprints due to the significant number of samples that would be required.

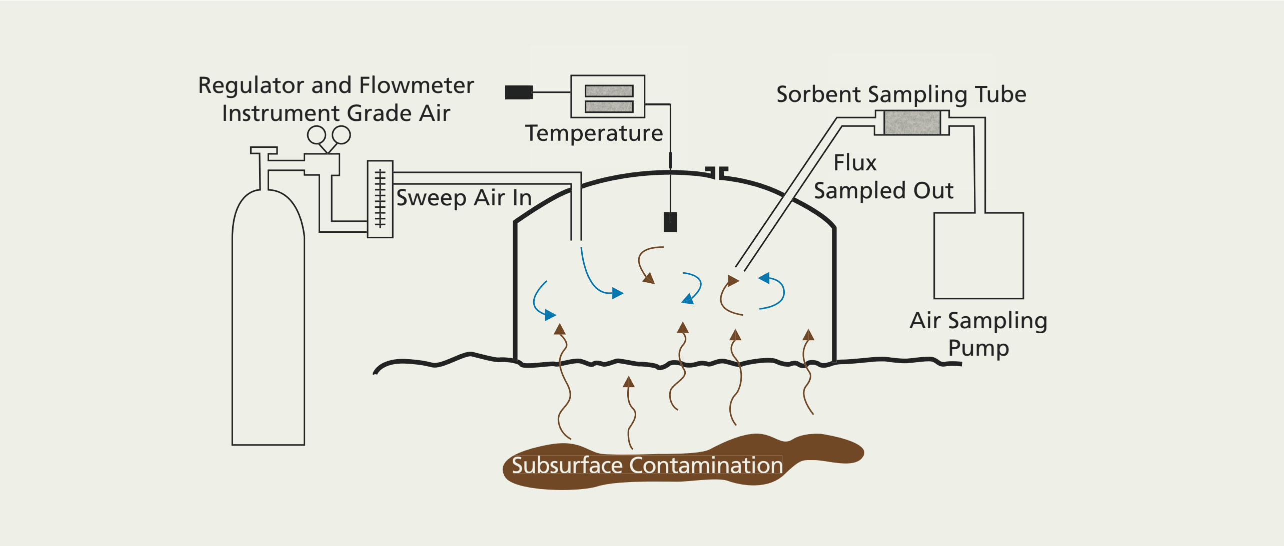


FIGURE 4.1 **Graphical representation of flux chamber sampling train.**

4.1. SUMMARY OF RESULTS OBTAINED FOR THREE LANDFILLS

The results from the flux box and speciated VOC's monitoring recorded the following results. These included:

1. Flux chamber monitoring was carried out at 36 distinct locations within Knockharley landfill footprint. The survey found that 9 of the locations were in excess of the recommended UK guideline surface emission flux levels for such locations.
2. Flux chamber monitoring carried out at 6 locations within Youghal landfill footprint found that 4 of the locations were in excess of the recommended UK surface emission flux values for such locations.
3. Flux chamber monitoring carried out at eleven locations within Corranure landfill footprint found that 6 of the locations were in excess of the recommended UK surface emission flux for such locations.
4. A tentative total methane flux emission rate was calculated for Knockharley landfill surface excluding any methane emission rates from the flaring compound itself. The tentative estimate total methane flux of 9.36 kg/hr was calculated on the day of the survey based on polyline area extent measurement of AutoCAD maps supplied by the licensee. Assuming a constant flux over the year, this equates to a total methane emission rate of 81,957 kg/yr/.
5. A tentative landfill gas collection efficiency estimated was calculated for Knockharley Landfill based upon the landfill flaring compound operation data collected on the day of the survey. The calculation suggests that a collection efficiency of up to 98% was being achieved on the day of the survey. This is inline with values reported by Huitric and Kong, (2006), Huitric et al., (2007) and Spokas et al., (2006).
6. In terms of speciated VOC's, typical compounds were detected in varying concentrations on all three landfill facilities. The main compounds detected and included landfill gas tracer compounds such as long chain hydrocarbons, Aldehydes, Aromatics, Alkenes, Alkanes, Ketones, Phthalates, Alcohol group, Sulphur containing organics, Reduced sulphur compounds and Nitrogen containing compounds.

If moving forward with flux measurement techniques the following should be considered:

- Consider performing flux box measurement at a greater spatial coverage across one research facility and to correlate the results of this with other viable techniques available for performing flux measurement. These techniques include:
    - Dynamic plume method which utilised enhanced surface emissions surveying with reverse dispersion modelling. This technique has been used and validated in the U.S.A. successfully and its key benefits in this respect are that it can be integrated into the existing surface emissions surveying technique.
    - OTM10 which has been validated by the USEPA and involves radial plume mapping methodology in a vertical configuration for the measurement of fugitive emission flux. This technique is easy to set up and is validated by the USEPA. It is not suitable for large landfills and can only be used to measure the emissions from the top platforms of a landfill (i.e. not the

slopes). It is also wind dependent and relies on measurement within the plume downwind of the emission source.

- Mass balance method which involves measuring the wind and contaminant concentration profiles through the full height of the plume, and integrating the concentration and wind speed with respect to the height above the ground surface. The existing methods use masts of balloons to obtain variations of concentration with elevation. It is the most accurate method with error range of -18% to +5% accuracy. It is wind dependent and is very expensive to implement.
- Mobile plume FTIR spectroscopy which has been used extensively in Sweden to monitor the flux of gases from a range of facilities. This technique involves the release of a tracer gas from within the study area and the monitoring of the concentration in ambient air of the tracer gas as a target gas. Once the micrometeorological conditions and tracer gas emission rate is known, the flux of methane in the downfield can be measured and related to a mass emission concentration. The tracer gas basically acts as an internal standard. The technique theory is simple and the method can be quality checked by making measurement at several locations to check the methane tracer ratios are similar. The technique is only suitable for sufficiently strong sources at a sufficient distance downwind (so as to allow for sufficient mixing (range 100 to 1,000 m downwind). An expensive FTIR is required although this can be hired in for a period of time and it is wind direction dependent.

The assessment of one or a combination of the techniques may allow for the validation of a suitable technique for landfills in Ireland to provide more accurate figures on mass emission rates of methane which will feed directly in greenhouse gas figures which will be important in allowing Ireland achieve its reduction commitments.

5. COMPARISON WITH 2008 ASSESSMENTS

During the assessments in 2009, a comparison with 2008 assessment findings on each facility was carried out. Comparisons were categorised into three distinct groups:

- "Improvements" indicating that a reduction in surface emissions was attained since the 2008 assessment.
- "Minor improvements" indicating that a minor reduction in surface emissions was attained since the 2008 assessment.
- "No improvements" indicating no reduction or a worsening in surface emissions since the 2008 assessment.

In total 29 facilities were surveyed in 2009 and 27 in 2008. The two new facilities surveyed in 2009 could not be compared, leaving a cohort of 27 facilities that could be compared. Improvements were recorded at 14 of the 27 facilities in 2009 (see *Figure 5.1*). Minor Improvements were recorded at 6 of the 27 facilities in 2009 (see *Figure 5.1*). No Improvements were recorded at 7 of the 27 facilities in 2009 (see *Figure 5.1*). Therefore in 52% of cases there was an improvement in surface emissions when comparing 2008 with 2009 assessments. It should be noted that no improvements were recorded at one facility which had very low surface emissions in 2008. Surface emissions at this facility remained low in 2009.

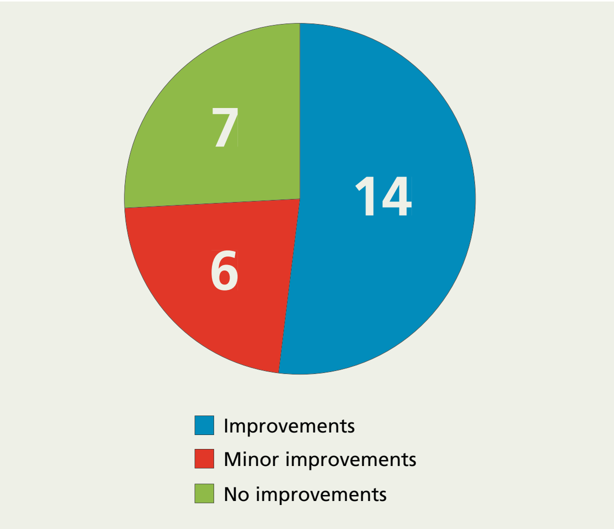


FIGURE 5.1. Status of improvements in surface emissions since 2008 based on 2009 study findings

6. CONCLUSIONS

The following conclusions were generated from the study. These include:

- Landfill surface emissions and landfill gas collections systems were assessed at 29 licensed facilities in Ireland during the period of 2009,
- Flux box measurements and speciated VOC's monitoring were carried out at three facilities nominated by the OEE. Typical speciated compounds were detected in varying concentrations on all three landfill facilities,
- Overall, improvements in surface emissions were realised in 52% of cases when compared with 2008 survey results,
- Landfill gas collection systems were assessed, in terms of effective operation and abstractive capacity on the each facility,
- The technique for the assessment of surface emissions proved very effective in monitoring and surface emissions at the landfill facilities,
- This technique allows for auditing of the effectiveness of the landfill gas collection system and the identification geographically the location of surface emission zones within the operating landfill. Persistent surface emission zones can be identified from subsequent surveys. This will allow for the implementation of focused mitigation of surface emissions within the operating landfill and audit the effectiveness of implemented mitigation.

7. RECOMMENDATIONS

- Training should be provided to licensees on landfill gas management systems operation, design issues and troubleshooting such a system (e.g. the key drivers for operating and maintaining landfill gas collection system including methane levels, oxygen levels, vacuum pressure and volume flow). A section on landfill gas management system operation, typical design and troubleshooting of the system should be provided in the FAS course on Waste management.
- A structured forum for landfill managers and landfill operations staff to meet and discuss issues pertaining to landfill gas management and surface emissions reduction would facilitate greater understanding of possible mitigation options.
- In moving forward, a number of guidance documents should be prepared to include, as a minimum, the following:
    - Monitoring of landfill gas, interpretation of results and troubleshooting,
    - Surface emissions monitoring – minimum requirements,
    - Typical landfill gas system design, operation and pitfalls,
    - Key methods for the control of landfill gas surface emissions.

8. REFERENCES

1. Casey, J., Sheridan, B., Henry, M., Reynolds, K. (2008). Effective Tools for Managing Odours from Landfill Facilities in Ireland. International Conference on Environmental Odour Monitoring and Control, Rome 6-8 July.
2. Chiriac, R., Carre, J., Perrodin, Y. and Fine L. (2007). Characterisation of VOC emitted by open cells receiving MSW. Journal of Hazardous Materials 149, pp 249-263.
3. Christophersen, M., Holst, H., Chanton, J., Kjeldsen, P. (2001). Lateral gas transport in soil adjacent to an old landfill: factors governing emissions and methane oxidation. Waste Management & Research 19, 126– 143.
4. Environmental Protection Agency (EPA), (2003). "Landfill Manuals Landfill Monitoring". ISBN: 1-84095-127-3.
5. Environmental Protection Agency (EPA), (2009). "Irelands Greenhouse Gas Emissions in 2008". Release 13th December 2009. Available at www.epa.ie/downloads/pubs/air/.../Prov_GHG_Inventory_Dec_%202009.pdf
6. Environmental Protection Agency (EPA). (2000). "Landfill Manuals Landfill Site Design". ISBN 1 84095-026-9.
7. Huitric R. and D. Kong (2006). "Measuring landfill gas collection efficiency using surface methane concentrations", Solid Waste Association of North America (SWANA) 29th Landfill Gas Symposium, St. Petersburg, FL.
8. Huitric, R., D. Kong, L. Scales, S. Maguin, and P. Sullivan (2007). "Field Comparison of Landfill Gas Collection Efficiency Measurements," Proceedings from the Solid Waste Association of North America's 30th Annual Landfill Gas Symposium. Monterey, California.
9. Maurice, C. and Lagerkvist, A. (2003). LFG emission measurements in cold climatic conditions: seasonal variations and methane emissions mitigation. Cold Regions Science and Technology 36, pp 37-46.
10. Maurice, C., Bergman, A., Ecke, H., Lagerkvist, A. (1995). Vegetation as a biological indicator for landfill gas emissions: initial investigations. Sardinia '95, Fifth International Landfill Symposium, CISA, Cagliari, Italy, pp. 481– 494.
11. Parker, P., Dottridge, J., Kelly, S. (2002). Investigation of the Composition and Emissions of Trace Components in Landfill Gas. R&D Technical Report P1-438/TR, Environment Agency, 2002, ISBN 1-84432-018-9, 140 pp.
12. Spokas, K., J. Bogner, J. Chanton, M. Morcet, C. Aran, C. Graff, Y. Moreau-le-Golvan, N. Bureau, and I. Hebe, (2006). Methane mass balance at three landfill sites: what is the efficiency of capture by gas collection systems? Waste Management, 26, pp. 516-525.
13. Wilcox, L. (2007). Landfill Gas Collection and Control Regulation. Ministry of Environment. Ontario, Canada.

9. APPENDIX 1 WASTE LICENSE NUMBERS AND FACILITY NAMES AND ADDRESSES

Licence Number	Facility Name and Address
W0004-01	Arthurstown landfill facility, Kill, Co. Kildare.
W0028-01	Ballydonagh Landfill Facility, Ballydonagh, Dublin Road, Athlone, Co. Westmeath.
W0109-01	Ballaghaderreen landfill facility, Ballaghaderreen, Co. Roscommon.
W0024-01	Ballynacarrick Landfill Facility, Ballynacarrick, Ballintra, Co. Donegal
W0078-02	Ballaghveny Landfill, Ballymackey, Co. Tipperary
W0165-01	Ballynagran landfill facility, Ballynagran, Co. Wicklow.
W0009-02	Balleally Landfill, Balleally, Lusk, Co. Dublin
W0109-01	Central Waste Management Facility (CWMF), Ballyduff Beg, Inagh, Co. Clare.
W0077-02	Corranure landfill facility, Cootehill Rd, Cavan, Co. Cavan.
W0021-01	Derrinumera Landfill Facility, Derrinumera/Drumilra (Townlands), Newport, Co Mayo
W0029-01	Derryclure Landfill Facility, Derryclure, Co. Offaly.
W0074-02	Donohill Landfill, Garryshane, Donohill, Co. Tipperary
W0030-02	Dunmore Landfill Facility, Dunmore, Co. Kilkenny.
W0201-01	Drehid landfill facility, Killinagh Upper, Carbury, Co. Kildare
W0178-01	East Galway landfill facility, Killagh More, Ballyhaun, Ballintober, Ballinasloe, Co. Galway.
W0017-03	Gortadroma landfill facility, Ballyhahill, Co. Limerick.
W0191-02	Holmestown landfill facility, Glenduff, Bolgerstown, Muchwood, Ballyeaton, Co. Wexford
W0012-01	Kinsale Road Landfill, Ballyphehane, Curraghconway, Inchisarsfield, South City Link Road, Cork.
W0026-02	Kyletalesha landfill facility, Clonsoughy, Kyleclonhobert, Co. Laois
W0081-01	KTK Landfill Limited, Brownstown and Carnalway, Kilcullen, Co. Kildare
W0146-01	Knockharley landfill facility, Knockharley, Navan, Co. Meath.
W0047-02	Neiphin Trading Ltd, Kerdiffstown, Naas, Co. Kildare
W0001-01	North Kerry Landfill, Muingnaminnane, Tralee, Co. Kerry
W0025-02	Powerstown landfill facility, Kilkenny Road, Co. Carlow.
W0067-01	Rathroeen Landfill Facility, Rathroeen, Ballina, Co. Mayo
W0020-02	Scotch Corner Landfill, Letterbane, Annyalla, Castleblaney, Co. Monaghan
W0014-01	Silliot Hill Landfill Facility, Silliot Hill and Brownstown, Co. Kildare, Kildare.
W0060-02	Whiteriver landfill facility, Dunleer, Co. Louth
W0068-02	Youghal Landfill Facility, Youghal Mudlands, Youghal, Co. Cork.

10. APPENDIX 2

TABLE 3.1 Tabular overview of summary findings from Surface emission survey's carried out in 2009

Parameter	W0017-03	W0191-02	W0012-01	W0026-02	W0081-01	W0146-01	W0047-02	W0001-01	W0025-02	W0067-01	W0020-02	W0014-01	W0060-02	W0068-02
Surface emissions from Vertical Wells:														
Due to Uncapped vertical well	×	×	×	×	×	×	×***	×	×	×	×	×	✓	×
Due to Inadequate abstraction from wells	✓	✓	×	✓	×	×	×***	✓	✓	✓	×	✓	✓	✓
Due to Inadequate condensate removal	×	×	×	×	×	×	×***	×	✓	×	×	×	×	×
Due to Inadequate abstractive capacity	×	×	×	×	×	×	×***	×	×	×	×	×	×	✓
Due to inadequate well sealing	×	×	×	✓	×	✓	×***	✓	✓	✓	×	×	✓	✓
Leachate slope risers:														
Surface emissions from leachate side slope risers and leachate chambers	✓	×	✓	✓	✓	×	×***	✓	×	✓	✓	✓	×	✓
Abstraction from leachate riser, chambers or leachate drainage layer	✓	✓	✓	✓	✓	✓	×***	×	✓	✓	✓	✓	✓	×
Flanked areas:														
Surface emissions on flanked areas	✓ (3*)	✓ (2*)	✓ (2*)	✓ (1*)	✓ (5*)	✓ (4*)	×***	×	✓ (8*)	✓ (6*)	✓ (10*)	✓ (1*)	✓ (3*)	✓ (6*)
Flank construction:														
Sloped	✓	✓	✓	✓	✓	×	✓***	✓	✓	✓	✓	✓	✓	✓
Benched	×	✓	×	×	×	✓	×***	×	×	×	×	×	×	✓
Geo Membrane Or liner	✓	×	×	✓	×	×	×***	×	✓	×	×	×	×	✓
Surface emissions:														
Due to Inadequate abstraction from area	✓	✓	✓	✓	✓	✓	✓***	✓	✓	✓	✓	×	✓	✓
Due to Inadequate cover material application	×	✓	✓	✓	✓	✓	✓***	✓	×	×	✓	×	✓	✓
Due to Inadequate tracking	×	×	×	×	×	×	×***	×	×	×	×	×	×	×
Other Elements														
LFG Management Systems in operation	✓	✓	✓	✓	✓	✓	×***	✓	✓	✓	✓	✓	✓	✓
Sufficient Flare and blower static pressure capacity	✓	✓	✓	✓	✓	✓	×***	✓**	✓	✓**	✓	✓	✓	×
Abstraction in active cell	✓	✓	✓	✓	n/a	✓	×***	✓	✓	✓	✓	n/a	✓	✓
Surface Emissions in active cell	✓	✓	✓	✓	n/a	✓	✓***	✓	✓	✓	✓	n/a	✓	✓
The system was adequately labelled	✓^^	✓^^	✓^^	✓	✓	✓	×***	×	✓^^	✓	✓	✓	✓^^	✓
Methane & Oxygen Concentrations at the flare were acceptable	✓	✓	✓	✓	✓	✓	×***	×	✓	✓	✓	×	✓	×
Vacuum pressure across the abstraction system was acceptable	✓	✓	✓	✓	✓	✓	×***	✓	✓	✓	✓	×	✓	×
Blockages were noted in gas collection pipe work	×	×	×	×	×	×	×***	×	✓	×	×	×	×	×
Surface Emissions Locations 100 ppmv to 500ppmv	1^^^	1^^^	3^^^	1^^^	1^^^	2^^^	4^^^	2^^^	3	5	3	3	2	3
Surface Emissions Locations 500 ppmv to Maximum ppmv recorded	8^^^	5^^^	9^^^	8^^^	5^^^	6^^^	10^^^	19^^^	7	9	10	1	7	23
Number of localised sources over the recommended guideline limit around features (500 ppmv)	5	2	5	6	1	2	0	21	0	3	1	3	6	20
Number of diffuse sources over the recommended guideline limit from surfaces (100 ppmv)	4	4	7	3	5	6	14	5	10	10	12	1	3	6
Multiples over recommended limit (500 ppmv at features) for maximum concentration recorded	8.79	4.75	10.79	9.47	1.59	8.62	0	14.51	5.41	7.27	11.68	3.24	4.17	37.96
Multiples over recommended limit (100 ppmv on surfaces) for maximum concentration recorded	29.01	9.57	132.53	20.14	23.34	17.14	37.15	48.58	26.13	30.56	43.31	3.66	17.68	114.29
Total Number of Surface Emissions locations	9	6	12	9	6	8	14	26	10	14	13	4	10	26

Notes: *****denotes number of instances. ******denotes not conclusive. *******denotes no adequate systems in place.
^denotes it was not possible to accurately identify exactly the nature of emissions. **^^**denotes in place but not adequate.
^^^denotes that the number of surface emission locations does not necessarily represent the extent and intensity of the surface emission zone.
^^^^denotes that elevated oxygen concentrations were recorded at one enclosed flare.
✓ denotes Yes (i.e. yes there was surface emissions from facility or yes parameter was in operation) dependant upon question asked in parameter box.
× denotes No (i.e. No there was not surface emissions from facility or No parameter was in operation) dependant upon question asked in parameter box.

TABLE 3.1 Tabular overview of summary findings from Surface emission survey's carried out in 2009

Parameter	W0004-01	W0028-01	W0109-01	W0024-01	W0078-02	W0165-01	W0009-02	W0109-01	W0077-02	W0021-01	W0029-01	W0074-02	W0030-02	W0201-01	W0178-01
Surface emissions from Vertical Wells:															
Due to Uncapped vertical well	×	×	×	✓	×	×	×	×	×	×	×	✓	×	✓	×
Due to Inadequate abstraction from wells	×	✓	×	✓	✓	✓	✓	✓	×	✓	✓	✓	×	✓	×
Due to Inadequate condensate removal	×	×	×	×	✓	×	×	×	×	×	✓	×	×	×	×
Due to Inadequate abstractive capacity	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Due to inadequate well sealing	×	×	×	×	✓	✓	✓	✓	×	✓	✓	✓	×	✓	✓
Leachate slope risers:															
Surface emissions from leachate side slope risers and leachate chambers	×	✓	×	×	✓	×	✓	×	×	✓	✓	✓	×	×	×
Abstraction from leachate riser, chambers or leachate drainage layer	✓	✓	✓	×	×	✓	✓	✓	✓	×	✓	✓	✓	✓	✓
Flanked areas:															
Surface emissions on flanked areas	✓ (9*)	✓ (5*)	✓ (5*)	✓ (4*)	✓ (6*)	✓ (1*)	✓ (4*)	✓ (3*)	✓ (5*)	✓ (5*)	✓ (5*)	✓ (5*)	✓ (6*)	✓ (4*)	✓ (3*)
Flank construction:															
Sloped	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Benched	✓	×	×	✓	×	✓	×	✓	×	×	×	×	×	×	×
Geo Membrane Or liner	✓	×	✓	×	×	×	×	✓	✓	×	×	×	×	×	✓
Surface emissions:															
Due to Inadequate abstraction from area	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓
Due to Inadequate cover material application	✓	×	×	×	✓	✓	✓	×	×	×	✓	×	✓	×	✓
Due to Inadequate tracking	×	×	×	×	✓	×	×	×	×	×	×	×	×	×	×
Other Elements															
LFG Management Systems in operation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sufficient Flare and blower static pressure capacity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Abstraction in active cell	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Surface Emissions in active cell	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
The system was adequately labelled	✓	✓	✓	✓	×	✓	✓	✓	✓	✓^^	✓^^	✓	✓	✓	✓
Methane & Oxygen Concentrations at the flare were acceptable	✓^^^^	×	✓	✓	✓	✓	✓	✓	✓^^^^	✓	✓	✓^^^^	✓	✓	✓
Vacuum pressure across the abstraction system was acceptable	✓	×	✓	×	×	✓	✓	✓	✓	✓	✓	✓^^	✓	✓	✓
Blockages were noted in gas collection pipe work	×	×	×	✓**	✓	×	✓	×	×	×	✓	×^^	×	×	×
Surface Emissions Locations 100 ppmv to 500ppmv	5^^^	2^^^	5^^^	2^^^	6^^^	2^^^	3^^^	2^^^	5^^^	4^^^	0	3^^^	3^^^	1^^^	2^^^
Surface Emissions Locations 500 ppmv to Maximum ppmv recorded	6^^^	10^^^	3^^^	8^^^	16^^^	1^^^	8^^^	4^^^	5^^^	7^^^	11^^^	9^^^	3^^^	10^^^	5^^^
Number of localised sources over the recommended guideline limit around features (500 ppmv)	0	6	0	2	12	1	6	1	1	3	0	4	0	7	4
Number of diffuse sources over the recommended guideline limit from surfaces (100 ppmv)	11	6	8	8	11	2	5	4	9	8	11	8	6	4	3
Multiples over recommended limit (500 ppmv at features) for maximum concentration recorded	0	11.2	0	8.7	21.17	1.09	5.06	2.42	4.68	17.44	28.81	7.12	0	7.58	6.84
Multiples over recommended limit (100 ppmv on surfaces) for maximum concentration recorded	25	39.6	13.6	68.39	19.03	4.42	18.93	20.22	15.54	39.98	128.59	19.39	18.11	10.51	8.28
Total Number of Surface Emissions locations	11	12	8	10	23	3	11	5	10	11	11	12	6	11	7

Office of
Environmental
Enforcement

Headquarters and South East Region
Environmental Protection Agency
PO Box 3000, Johnstown Castle Estate
County Wexford, Ireland
Bosca Poist 3000, Eastát Chaisleán Bhaile Sheáin
Contae Loch Garman, Éire
T: +353 53 916 0600
F: +353 53 916 0699
South/South West Region
Inniscarra, County Cork, Ireland
Inis Cara, Contae Chorcaí, Éire
T: +353 21 487 5540
F: +353 21 487 5545
East/North East Region
McCumiskey House, Richview
Clonskeagh Road, Dublin 14, Ireland
Teach Mhic Chumascaigh
Dea-Radharc, Bóthar Cluain Sceach
Baile Átha Cliath 14, Éire
T: +353 1 268 0100
F: +353 1 268 0199
West/North West Region
John Moore Road
Castlebar, County Mayo, Ireland
Bóthar Sheán de Mórdha
Caisleán an Bharraigh, Contae Mhaigh Eo, Éire
T: +353 94 904 8400
F: +353 94 904 8499
E: info@epa.ie
W: www.epa.ie
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