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## **Guidance for monitoring enclosed landfill gas flares, LFTGN05**

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## Contents

<b>Executive summary</b> .....	<b>3</b>
<b>1 Introduction</b> .....	<b>5</b>
1.1 Purpose of the guidance .....	5
1.2 Document structure .....	5
1.3 Relationship with other guidance.....	6
<b>2. Emissions standards and legislation</b> .....	<b>7</b>
2.1 UK legislation on landfill gas emissions.....	7
2.2 Air quality standards.....	7
<b>3. Flare monitoring safety</b> .....	<b>9</b>
3.1 Health and safety guidance and regulations .....	9
<b>4. Standards for monitoring enclosed flares</b> .....	<b>10</b>
4.1 Emission standards .....	10
4.2 Testing frequency.....	12
4.3 Flow determination .....	13
4.4 Future monitoring options.....	13
4.5 Interim position .....	14
4.6 Supplementary inspections .....	14
4.7 Relocating and reusing flares .....	14
<b>5. Data assessment and reporting</b> .....	<b>15</b>
5.1 Data standardisation .....	15
5.2 Representative sampling.....	17
5.3 Errors and uncertainty .....	18
5.4 Assessing compliance .....	20
<b>Appendix A: Flare height and dispersion assessment</b> .....	<b>24</b>
<b>Appendix B: Proforma for recording preliminary site visits.</b> .....	<b>27</b>
<b>Appendix C: Further information on calculations</b> .....	<b>28</b>
<b>Appendix D: Example flare emission report</b> .....	<b>35</b>
<b>Appendix E:</b> .....	<b>36</b>
Technical Guidance Note TGN 024.....	36
<b>Glossary</b> .....	<b>39</b>

## Executive summary

This guidance is concerned only with emissions from enclosed flares and does not consider emissions from other forms of landfill gas combustion. A separate guidance document is available that discusses the operation and emissions from landfill gas engines.

This technical guidance document draws upon information from collaborative research undertaken by Natural Resources Wales and the Biogas Association.

Table A summarises the emissions testing requirements for enclosed landfill gas flares. For each determinand, the reference method and recommended analytical techniques used are identified, along with the required testing frequency and emission standards based on best practice.

Table A Summary of emissions testing requirements for enclosed landfill gas flares

Determinand	Reference method	Sampling and analytical technique	Minimum testing frequency	Emission standard (mg/m <sup>3</sup> ) <sup>b</sup>	
				Flare commissioned before 31 December 2003	Flare commissioned after 31 December 2003
NO <sub>x</sub>	BS EN 14792:2005	Chemiluminescence	Annually	150	150
CO	BS EN 15058:2006	Non-dispersive infra-red analysis	Annually	100	50
Total VOCs	BS EN 12619 <sup>d</sup> BS EN 13526 <sup>e</sup>	Extractive sampling and flame ionisation detector analysis	Annually	10	10

<sup>a</sup> Technical guidance note M2 <sup>b</sup> These limits are based on normal operating conditions and load. Temperature: 0°C (273K); pressure: 101.3 KPa; and oxygen: 3 percent (dry gas). <sup>c</sup> NO<sub>x</sub> expressed as NO<sub>2</sub> <sup>d</sup> At sites with low VOC concentrations.

<sup>e</sup> At sites with low to moderate VOC concentrations.

These emission standards are for a minimum suite of determinands; emission limits may be modified and additional determinands identified by site-specific risk assessment. Alternatives to the reference methods stipulated in Table A can be used, provided they are shown to be fit-for-purpose and a suitable justification is presented before sampling is undertaken.

In addition to the numerical emissions limits, you must also meet the following provisions:

- Sample ports must be fitted in accordance with the requirements of Technical Guidance Document M1 or, an alternative method using in situ probes can be utilised.
- Sampling must be undertaken downstream of the flame. Flare designs must include sufficient shroud to fully enclose the flame at all times.
- Emissions must not be impeded by cowls or any other fixture on top of the flare during operation.
- The indicative operational requirements for an enclosed landfill gas flare is to maintain operational control so as to achieve a minimum temperature of 1,000°C and 0.3 seconds retention time at this temperature across the likely range of landfill gas composition and throughput.

An equivalent validated set of conditions to give complete combustion are acceptable providing compliance with the emission standard is demonstrated. You must monitor the operating temperature.

- You must monitor the flow and composition of the input gas at the flare to demonstrate consistency with operational requirements and the design specification of the flare.

Flares that are unable to meet their operational requirements of 1,000°C and 0.3 seconds retention time at this temperature, or have not been maintained, are unlikely to be monitored in a representative or safe manner. They are unlikely to meet the emission standard and must be regarded as non-compliant. Do not undertake emissions testing on these flares until these operational faults have been rectified.

Due to the practical difficulties of performing representative measurements inside the combustion chamber of flares and the hazards associated with such measurement procedures, a new monitoring strategy is required for sampling emissions from enclosed flares. Several alternatives are under consideration. Until we have agreed how we will regulate flares, take this guidance as the best method for the interim.

# 1 Introduction

The 2004 version of this guidance was based on the Research and Development P1-405, undertaken by netcen.

## 1.1 Purpose of the guidance

The purpose of this document is to provide a best method approach to sampling and analysing emissions from enclosed landfill gas flares. We are reconsidering how we regulate the emissions from enclosed landfill gas flares. This guidance has been issued in the interim until we decide on a future approach.

The guidance aims to:

- ensure a consistent and transparent approach to measuring emissions from enclosed flares;
- ensure that the most appropriate sampling and analytical standards are followed.

Enclosed (ground) flares are those where the landfill gas is combusted in a vertical enclosure. Monitoring from such flares is for many reasons, a high risk activity. Research is ongoing into designs for single and multiple-point sampling technology.

Section 5.1 sets out the emission standards that enclosed gas flares must meet.

### 1.1.1 Elevated/Open flares

It is not possible to accurately or safely sample emissions from open flares, therefore this document provides no guidance on sampling from open flares. Do not consider installing an open flare unless it is an emergency. Open flares are not suitable for standby flares. Elevated flares at operational and closed sites will be subject to a risk based emissions review and where identified, a subsequent improvement programme.

## 1.2 Document structure

The document is divided into six sections:

- Section 1: Introduction including a summary of the purpose of the guidance
- Section 2: Review of emissions limits
- Section 3: Health and safety issues relating to the measurement of emissions from landfill flares
- Section 4: Guidance on monitoring flares
- Section 5: Data assessment and reporting
- Section 6: Appendices

## 1.3 Relationship with other guidance

This is one of a series of linked documents that support the overarching document *Guidance on the management of landfill gas* (Natural Resources Wales, 2010a)

The full series comprises:

- Guidance for monitoring trace components in landfill gas
- Guidance on gas treatment technologies for landfill gas engines
- Guidance for monitoring landfill gas surface emissions
- Guidance for monitoring landfill gas engine emissions

We've also drawn information from the following documents:

- *Sampling requirements for monitoring stack emissions to air from industrial installations.*

Technical Guidance Document (Monitoring) M1

- *Monitoring of stack emissions to air.* Technical Guidance Note (Monitoring) M2.

The monitoring procedures and emission standards in this document supersede those recommended in previous guidance.

In the medium term (pending further development), it may be possible to augment emissions-based regulation with a system of type approval/operational monitoring (see Section 4). The UK waste industry is keen to develop other methods for the future management of emissions from landfill gas flares. We support such research as it may lead to more cost effective monitoring of landfill gas flares, content in the knowledge that the emissions standards are being met.

This document sets out guidance on determining emissions from enclosed landfill gas flares.

Enclosed (ground) flares are those where the landfill gas is combusted in a vertical enclosure. Monitoring from such flares is for many reasons, a high risk activity. Research is in progress into designs for single and multiple-point sampling technology.

# 2. Emissions standards and legislation

## 2.1 UK legislation on landfill gas emissions

The principal legislation covering landfills in Europe is the Landfill Directive (Council of the European Union, 1999), which provides for measures and procedures to prevent or reduce as far as possible the negative environmental effects of landfilling waste.

Landfills and their operation are now regulated under a single regime that complies with both the Landfill Directive and the Integrated Pollution Prevention and Control (IPPC) Directive. In the UK, this is through the Environmental Permitting Regulations (EPR) 2007.

Emissions from landfill gas flares are regulated through the Environmental Permit for the landfill. The emission limit values in Table 2.1 were derived from comparable European standards and from various research projects, and published in the previous version of this guidance

As outlined in Section 4 below, we are reviewing whether emissions based regulation of flares is the best method of regulation. However in the meantime we consider that the emission standards below are applicable and monitoring of enclosed landfill gas flares can be undertaken safely. We will continue to apply and enforce the emission standard and monitoring requirements through the Environmental Permits until our review of how we regulate landfill gas flares is complete.

Determinand	Emission standard mg/m <sup>3</sup> *	
	Flare commissioned before 31 December 2003	Flare commissioned after 31 December 2003
Oxides of nitrogen as NO <sub>2</sub>	150	150
Carbon monoxide	100	50
Total volatile organic compounds as carbon	10	10

Table 2.1 Emission standards for enclosed landfill gas flares

\* At STP (273K (0°C), 101.3 kPa), dry gas, 3 per cent oxygen.

## 2.2 Air quality standards

Landfill gas flares can contribute to local air quality and landfill operators must consider the impact of flare and other emissions on local air quality. You can use dispersion models to derive ground level concentrations from emission, process, meteorological, and other data (see Appendix A).



Air quality standards for the UK are published in Air Quality Strategy for England, Wales, Scotland and Northern Ireland (Defra, 2007). A summary of these standards, which are largely based on EC directives on air quality, is given in Table 2.2. Further guidance on these standards and how they apply to landfill sites is given in Horizontal Guidance Note EPR H1 on Environmental Assessment.

In the absence of air quality standards (for example, hydrogen chloride and hydrogen fluoride don't have air quality standards), you can assess the modelled concentrations against other environmental benchmarks such as Environmental Assessment Levels (EALs). We publish these, and typically base them on occupational exposure standards

Table 2.2 UK air quality objectives and European Directive limit and target values for the protection of human health

Pollutant	Date to be achieved by and maintained thereafter	Criteria based on	Value
			$\mu\text{g}/\text{m}^3$
Nitrogen dioxide	31 December 2005	1-hour mean. Not to be exceeded more than <b>18</b> times per calendar year.	200
	31 December 2005	Annual mean	40
	31 December 2000	Annual mean NO <sub>x</sub> vegetation guideline	30
Sulphur dioxide	31 December 2005	15-minute mean. Not to be exceeded more than <b>35</b> times per calendar year.	266
	31 December 2004	1-hour mean. Not to be exceeded more than <b>24</b> times per calendar year.	350
	31 December 2004	24 hours (daily mean). Not to be exceeded more than <b>3</b> times per calendar year.	125
	31 December 2000	Calendar year annual mean vegetation guideline.	20
	31 December 2000	Winter mean vegetation guideline.	20
Benzene	31 December 2003	Running annual mean	16.25
	31 December 2010 England/Wales	Annual mean	5
PM <sub>10</sub>	31 December 2004	24 hours (daily mean). Not to be exceeded more than <b>35</b> times per calendar year.	50
	31 December 2004	Calendar year annual mean	40
Carbon monoxide	31 December 2003	Running 8-hour mean	10,000 (10mg/m <sup>3</sup> )

Source: DEFRA (2007)

# 3. Flare monitoring safety

## 3.1 Health and safety guidance and regulations

Neither SEPA nor Natural Resources Wales regulates health and safety at work. Discuss any issues or concerns you have with the Health and Safety Executive (HSE).

The Health and Safety at Work Regulations 1974, and similar legislation places a duty on employers to have a safety policy and to carry out risk assessments for any work programme. Any work you carry out to MCERTS (Natural Resources Wales, 2008a) standards also requires you to produce a risk assessment. Technical Guidance Note M1 contains detailed guidance on assessing safety requirements at a test site.

Also consider the guidance in our Technical Guidance Note M2. This provides more detailed guidance on safely monitoring emissions from stacks.

The Source Testing Association (STA) also provides guidelines such as the general hazards and potential risks associated with emissions testing (STA, 2001a) and example risk assessments for stack sampling operations (STA, 2000).

Documents from the STA are reviewed and revised from time to time and the reader should check the STA website for the most up to date information.

# 4. Standards for monitoring enclosed flares

## 4.1 Emission standards

Table 4.1 sets out the emissions standards your enclosed landfill gas flares must achieve.

For closed sites where a waste management licence became an Environmental Permit we will require the permit holder to carry out a landfill gas emissions review.

For each flare, assess the emission standards given in Table 4.1 on an individual basis. This may require a stricter emission standard based on risk, either in terms of the primary emission standards or in terms of additional parameters.

Guidance on carrying out generic environmental risk assessment (DETR et al., 2000) and specific information on landfill gas risk assessment are available (Natural Resources Wales; Horizontal Guidance Note EPR H1)

The factors to consider include but are not limited to:

- topography
- receptor location
- composition of the landfill gas.

The primary emission determinands are based on research undertaken by Natural Resources Wales and the UK waste industry. Analysing the landfill gas can provide a good indication of the requirement for additional emission monitoring. Landfill gas analysis also provides valuable information on the likely combustion products.

### Example

The presence of sulphur and chlorine compounds in the landfill gas suggest that SO<sub>2</sub>, HCl and other chlorinated compounds will be present in the emissions.

Table 4.1 Emission standards for enclosed landfill gas flares

Determinand	Emission standard mg/m <sup>3</sup> *	
	Flare commissioned before 31 December 2003	Flare commissioned after 31 December 2003
Oxides of nitrogen as NO <sub>2</sub>	150	150
Carbon monoxide	100	50
Total volatile organic compounds as carbon	10	10

\* At STP (273K (0°C), 101.3 kPa), dry gas, 3 percent oxygen.

Commission all new flares to meet the post 31 December 2003 standards. In addition to the numerical emission standards, you must also meet the following provisions:

- Sample ports must be fitted in accordance within the requirements of Technical Guidance Note M1 or, alternatively, in situ sample probes.
- Undertake sampling after combustion is completed (that is, downstream of the flame). Flare designs must include sufficient shroud to fully enclose the flame at all times.
- Emissions must not be impeded by cowls or any other fixture on top of the flare during operation.
- Operational control must be able to achieve a **minimum of 1,000°C and 0.3 seconds retention time at this temperature** (or an equivalent validated set of conditions).
- Monitor the flow and composition of the input gas regularly to demonstrate consistency with operational requirements and the flare's design specification.

### Monitoring

You must monitor the flame temperature to demonstrate the consistent performance output of the enclosed flare.

You must monitor the inlet gas to demonstrate that:

- the enclosed flare is operating within design limits for gas flow and gas composition;
- the performance of the flare at the time of the periodic emissions monitoring is representative of normal operation.

In order to monitor input gas, install suitable sampling points for flow and gas composition in the pipework at a representative location close to the flare. The minimum monitoring requirement for inlet gas composition is methane and oxygen.

The frequency and degree of automation your monitoring will require will depend on the operational circumstances. Where a flare is operating on a stable, consistent gas field, a small number of readings per day will be sufficient to demonstrate performance. Where a flare is handling gas from a large field with multiple manifolds, you may require frequent readings to provide a signal trace.

Log monitoring data associated with the inlet gas (such as, methane, oxygen and flow rate) and the output (for example, temperature) of the enclosed flare.

We recommend that monitoring data is transferred by telemetry to those responsible for operational control. The need for telemetry will depend on the site-specific risks that may result from short-term deviation from

operational standards. Factors that will influence the need for telemetry include:

- the proximity to receptors;
- size of the enclosed flare;
- whether the flare is associated with an engine installation.

#### 4.1.1 Landfill gas emission review

An emissions review is based on developing a risk screening/conceptual model of gas management for the site and will include providing flaring.

The emissions review must contain, but is not limited to:

- site history
- conceptual model including cap/liner details
- gas control system including drawings identifying infrastructure
- assessment of risk
- conclusion
- improvement programme schedule if required including time line.

#### Unacceptable site specific risks

Where the review identifies unacceptable site-specific risks from landfill gas, we will require an emissions improvement programme that incorporates the appropriate best practice contained within this guidance and industry specific codes of practice. You must carry out an emissions review and improvement programme according to site-specific risk and complete this as soon as is reasonably practical.

## 4.2 Testing frequency

Derive the frequency of emission testing required from a flare from an individual site environmental risk assessment. Once you have established a consistent emissions profile, you may reduce the monitoring frequency to the minimum frequency, in agreement with us. Test **annually** as a minimum.

Where an enclosed flare is used as standby equipment to back up landfill gas engines then you do not need to carry out emissions testing unless the flare has been operational for **more than 10 per cent of a year** (876 hours).

Consider test work to verify combustion temperature and residence time when commissioning a new flare.

In addition to servicing, you must carry out combustion spot checks to demonstrate the unit is functioning as designed. Also consider installing permanent sample systems to enable this to be undertaken easily at ground level without the need to fit platforms. Basic instrumentation exists on most flares (for example, to indicate the combustion chamber temperature) and spot checks using hand-held systems allow combustion gases such as CO, CO<sub>2</sub> and O<sub>2</sub> to be monitored easily.

### 4.3 Flow determination

Carry out a theoretical determination of the exhaust flow rate based on the flow and composition of the incoming gas. Use this in combination with the manufacturer's specification to determine the volumetric flow rate for your flare. Appendix C details how to carry out a theoretical flow determination. Remember to correct the resulting flow for moisture and oxygen content using the correction factors in Appendix C.

### 4.4 Future monitoring options

Due to the practical difficulties of performing representative measurements inside the combustion chamber of flares and the hazards associated with such measurement procedures, a new monitoring strategy is required for sampling emissions from enclosed flares. Several alternatives are under consideration.

One possibility could be the adoption of a type-approval system for flares. Under such a system, appropriate flares would be certified capable of complying with the emissions standards specified in Table 4.1. This approach avoids as far as possible any working at height or hot work, thereby eliminating most of the risks associated with sampling emissions from high temperature flares.

#### **Records**

We would also require a record of annual maintenance to the manufacturer's specifications to demonstrate efficient operation in lieu of any monitoring of the flare emissions. This approach avoids as far as is possible any working at height or hot work, thereby eliminating most of the risks associated with sampling emissions from high temperature flares.

#### **Alternative approaches**

An alternative approach could be based on current research into the design and installation of single point and multiple point sampling probes. This research is looking at technologies capable surviving the harsh conditions within flares. Such technologies may form the basis of future guidance. This envisaged approach relies on a permanent sampling system installed on each flare so a sample can be collected from ground level. The gas conditioning required between sampling and analysis would be partly performed by the permanent installation, and partly by mobile laboratory attached to the sampling line.

This method will also avoid most of the risks associated with sampling high temperature flares.

Other approaches under consideration are a commissioning trial whereby an envelope of operating parameters would be established across the maximum and minimum rated capacity that demonstrates the flare meets the emission

standards. Monitoring of these operating parameters, such as flow and temperature, would demonstrate the flare was within the operational envelope.

## 4.5 Interim position

Pending the development of an effective alternative monitoring system you are still required to conduct emissions tests on flares that are operational for more than 10 per cent of a year (876 hours). The Source Testing Association has produced a Technical Guidance Note (TGN No. 24) on how to carry out emissions tests from flares safely. This is available from their website and is reproduced in Appendix E.

Follow this guidance where your permit requires you to test the flare.

## 4.6 Supplementary inspections

Your management systems and gas management plan must include a **six monthly** inspection of your flare and its immediate ancillary infrastructure to ensure operation in accordance with the manufacturer's specifications. This inspection must be carried out by a suitably qualified person.

Ancillary infrastructure includes:

- the booster and motor;
- mechanical systems (such as joints and valves);
- safety systems (flame arrestors and slam shut valves);
- electrical systems;
- instrumentation;
- gas conditioning vessels.

Where possible, six monthly inspections should observe the flare's operation at both its maximum rated capacity and its minimum rated capacity (normally a 5:1 or 10:1 turndown).

Ensure you record any faults and defects that occur during normal operation. You must rectify all faults as soon as is practical.

### **Emergency flares**

Emergency flares and their supporting infrastructure must undergo an annual inspection to ensure they are able to operate efficiently when required.

You must retain the details and records of your inspections and any modifications or repairs and make them available to us if we ask to see them.

## 4.7 Relocating and reusing flares

There are currently two separate enclosed flares emissions standards depending on when a flare was first commissioned. Relocating flares

commissioned under earlier standards should be considered on a site-specific risk assessed basis following Natural Resources Wales Horizontal Guidance Note EPR H1.

Do not relocate open flares unless for emergency purposes and then only for a limited time until you can replace them with a temporary enclosed flare.

## 5. Data assessment and reporting

### 5.1 Data standardisation

#### 5.1.1 Reference conditions

All emission concentrations determined at enclosed landfill gas flares should be standardised to reference conditions of:

- mass concentration;
- standard temperature and pressure (STP), that is, 273K (0°C) and 101.3 kPa (1 atmosphere);
- 3 per cent v/v oxygen;
- dry gas. Nitrogen oxides should be expressed as NO<sub>2</sub> and VOCs as carbon. Details of the calculations used to standardise emission data are given in Appendix D, but the key calculations are described below.

You must report all landfill gas flare emissions as concentrations and mass emission rates, together with supporting information. To convert the measured emissions concentrations to the reference conditions, apply a series of correction factors to the data. Basic details about these correction factors are provided below and more detail is given in Technical Guidance Note M2.

#### 5.1.2 Conversion from volume concentration to mass concentration

Many emission measurements using instrumental techniques report emission data as volume concentrations such as parts per million (ppm). These can be converted to mg/m<sup>3</sup> at STP using the following formula:

$$\text{mg/m}^3 = \frac{\text{ppm} \times Mw}{22.4}$$

where: *Mw* = molecular weight (for example, NO<sub>2</sub>=46 and CO=28).

#### 5.1.3 Oxygen correction

Standardising emission concentrations to a fixed oxygen concentration removes dilution effects caused by different excess air levels in the flare. This allows a true comparison of emission concentrations.



The relationship between the measured oxygen and measured emission species concentration is not linear as oxygen from air is added or removed. The equation for the concentration at reference conditions can be written as:

$$C_r = C_m \times \frac{(20.9 - (O_2)_r)}{(20.9 - (O_2)_m)}$$

where:

$C_r$  = emission concentration at reference conditions

$C_m$  = measured emission concentration

$(O_2)_r$  = reference oxygen concentration (percentage v/v dry)  $(O_2)_m$  = measured oxygen concentration (percentage v/v dry).

As the reference oxygen condition for landfill gas flares is 3 per cent, this equation becomes:

$$C_r = C_m \times \frac{17.9}{(20.9 - (O_2)_m)}$$

If you use oxygen enhancement, you can apply a modified form of the equation (see Appendix D).

#### 5.1.4 Moisture correction

Standardised concentrations are expressed in the dry condition and, although some emission concentrations are measured dry, other measurements are undertaken on 'wet' gas. The moisture content of such gas is usually expressed in volume/volume (v/v) terms.

For example, the percentage volume of water vapour is the total wet gas volume.

Correct emission concentrations to the standardised dry condition using the following formula:

$$C_{dry} = C_{wet} \times 100 / (100 - \%H_2O)$$

where:

$C_{dry}$  = concentration of emission at dry condition

$C_{wet}$  = concentration of emission at wet condition

$\%H_2O$  = moisture content of exhaust gas (percentage v/v wet).

### 5.1.5 Emission rate

You determine the emission rate from the flue gas flow rate and emission concentration. It is essential you express the emission concentration and flow rate at the same temperature, pressure, oxygen and moisture content.

Due to the high temperature and low velocities within an enclosed flare, direct flow measurements may not be practical at many sites. However, you can determine flow from the combustion calculation and landfill gas analysis, for example, using calculations in USEPA Method 19 (USEPA, online 1).

## 5.2 Representative sampling

The four recognised types of monitoring used to measure emissions are:

- **continuous** – a complete series of measurements covering all operating conditions;
- **periodic** – intermittent measurements covering different conditions of normal operation;
- **group** – a number of measurements made under the same operating conditions;
- **individual** – lone measurements, which are not part of a group.

The emissions standards presented in this guidance are derived from a group of measurements collected at a range of landfills and from a number of different flare designs representative of normal operations in the UK. The measurements were generated as an average over one-hour test periods.

### Periodic measurements

The guidance on monitoring requires periodic measurement to determine the emissions profile of an enclosed landfill flare. The protocol involves sampling over an hour but, inevitably, this only covers a small period in the emissions from the flare. Consequently, it's necessary to assume the periodic measurement is representative of operation outside the monitoring periods.

Increased confidence in this assumption can be provided by developing an emissions profile for the flare. This profile may be built up over time and by making targeted measurements under a range of different conditions in normal operation. In addition, surrogate determinands and operational information (such as, maintenance logs and gas flow) can be used to confirm consistent operation of the flare.

If the operational information during the monitoring period differs substantially from that recorded for the preceding months, the sampling is unrepresentative of the earlier operation. It will only be representative of future operations if the operating profile does not change further.

Ensure the quality and consistency of the representative samples by using the methods and techniques outlined in this guidance.

## 5.3 Errors and uncertainty

Measurements of flow and chemical emissions in enclosed flares do not meet the MCERTS standard. Therefore, when assessing compliance against the emission standards for flares, you must take account of the representative nature and reliability of the measured values. The uncertainty arising from unrepresentative sampling and the errors from measurement uncertainty are considered below.

### 5.3.1 Measurement uncertainty

A number of different uncertainties (such as, uncertainty from sampling position, sampling equipment, analytical equipment and chemical/physical uncertainty) have to be combined to assess the overall uncertainty of measurement.

You can calculate the overall measurement uncertainty by:

- defining the steps of a measurement;
- identifying the sources of uncertainty associated with these steps;
- quantifying the respective uncertainties;
- combining these uncertainties.

Combine the component uncertainties using the following formula, which involves taking the square root of the sum of the squares of the individual uncertainties.

$$U_{\text{combined}} = \sqrt{(u_1^2 + u_2^2 + u_3^2 + \dots + u_n^2)}$$

You must determine each measurement and associated uncertainty within a known confidence limit, that is, you're confident the interval chosen does contain the real value. For emission measurements associated with landfill gas flares, the confidence level is 95 per cent.

Wherever possible, you should report and use the specific uncertainty in a set of monitoring measurements in your assessment. A method for calculating uncertainty is given in *Guide to the expression of uncertainty in measurements* (ISO, 1995). However, where you can't reasonably estimate an uncertainty, use the guidance below to derive typical acceptable values.

**Errors and uncertainty greater than those given below generally indicate unsatisfactory monitoring.**

### Measurement uncertainty

The Source Testing Association (STA) has assessed the uncertainty associated with particular analytical methods used in monitoring combustion (STA, 2001b). Based on a review of literature and enquiries made to stack sampling contractors, they concluded the uncertainty associated with most analytical methods for measuring NO<sub>x</sub> and carbon monoxide was 12 per cent

(at the 95 per cent level of confidence). However, the method of NO<sub>x</sub> analysis using an electrochemical cell had an uncertainty of 20 per cent and methods of determining speciated VOCs using adsorption/thermal desorption had an uncertainty of 25 per cent. These uncertainties take account of:

- limitations in the method, such as, sampling, analysis, instruments, interferences;
- variations due to human factors between different, but competent, monitoring teams.

Where analytical methods are in accordance with a recognised measurement standard, the measurement uncertainty is better understood. Table 5.2 gives the quoted uncertainty for the methods referenced in this guidance.

The uncertainties quoted in Table 5.2 only apply when measurement complies fully with the standard method. However, the design and operation of enclosed flares means it's not usually possible to undertake fully compliant tests.

For example, measuring NO<sub>x</sub> and CO using ISO 10849 and ISO 12039, respectively, requires a species variation across the sample plane of less than ±15 per cent to justify a single point sampling campaign. Otherwise you must adopt a multi-point sampling procedure at the points described in ISO 9096 (ISO, 2003). Where you use this multi-point sampling, there will be additional uncertainties relating to the multi-point procedure.

Table 5.2 Quoted uncertainty for reference methods

Determinand	Reference	Quoted uncertainty
Nitrogen oxides	BS EN 14792: 2005	<10 percent of full scale deflection
Carbon monoxide	BS EN 15058: 2006	<10 percent of full scale deflection
Total volatile organic compounds	BS EN 12619 :1999 BS EN 13526 : 2002	0.28-0.42 mg/m <sup>3</sup> for a concentration range of <1 to 15 mg/m <sup>3</sup>

In addition, the measurement standard also requires five hydraulic diameters of straight shroud before the sampling plane and five hydraulic diameters from the shroud exit. This is often not possible; consequently, your measurements will have different uncertainty from those quoted in the measurement standards. You will therefore need to calculate an overall measurement uncertainty.

Nevertheless, it is important you attempt to improve the uncertainty by taking samples further from the shroud exit. However, don't undermine the primary need to sample above the flame. Measurement uncertainty is unacceptable if the sampling plane is less than a metre below the shroud exit to avoid sampling within the flame. For this reason, you must install flares with the maximum height of post-combustion shroud consistent with planning requirements.

## Large Combustion Plant and the Waste Incineration Directives

The Large Combustion Plant and the Waste Incineration Directives (Council of the European Union, 2002 and 2001) cover the monitoring of several relevant combustion products. They quote measurement uncertainties at the daily emission limit value level. The directives state the values of the 95 per cent confidence intervals of a single measured result must not exceed the percentages of the emission limit values quoted in Table 5.3.

Table 5.3 Measurement uncertainties quoted for selected determinands in Large Combustion Plant and Waste Incineration directives

Component	Measurement uncertainty (percent)
Hydrogen chloride	40
Sulphur dioxide	20
Nitrogen oxides	20
Carbon monoxide	10

Table 5.4 Typical measurement uncertainty for methods used in monitoring emissions from enclosed flares

Determinand	Method description	Typical uncertainty (percent)
Nitrogen oxides	Extractive NDIR and chemiluminescence (BS EN 14792: 2005)	20
Carbon monoxide	Extractive NDIR (BS EN 15058: 2006)	12
Total volatile organic compounds	Flame ionisation detection BS EN 12619 : 2002	25

Regard the values in Table 5.3 as 'target uncertainties' for monitoring flare emissions.

Table 5.4 shows the uncertainty you can expect in measurements by the recommended methods.

These values are based on:

- the degree of the uncertainty in the standard methods;
- guidance from relevant directives and the extent of deviation needed when applying these to flares;
- results obtained from Natural Resources Wales R&D on monitoring (Natural Resources Wales R&D Report CWM 142/96A 1997).

## 5.4 Assessing compliance

The way we assess compliance of the measured values against the emissions standards can be divided into four stages:

- confirmation of evidence
- determination of compliance with emission standard
- reporting
- consideration of response.

As the operator, you will normally be responsible for the first three stages, while we will assess your report and consider our response.

#### **5.4.1 Confirmation of evidence**

The quality and representative nature of the measurements have to be addressed in order to ensure that the data are within the scope covered by the limit value.

Questions you need to address include:

- Is the data of adequate quality?
- Have the correct monitoring methods been used?
- Have the monitoring methods been used correctly?
- Have there been any deviations from the recommended monitoring methods? If so, are these justified and what effect have they had on the quality of measurement?
- Does the emission profile indicate that the sample was representative?

If you can't answer any of these points satisfactorily, your data may be inadequate for a full compliance assessment. Further action may be required to achieve representative monitoring.

The reported uncertainty in measurements won't take into account the variability of the emissions at times between the periodic monitoring. The uncertainty arising from unrepresentative sampling periods will be site-specific and will change during the operational period at the site.

Where you can deduce this from the flare's operating profile that is, variations in flow, composition and temperature, you should state this and add the additional uncertainty to the measurement uncertainty. Where you can't deduce this, we will assume that the total uncertainty, including that related to the representative nature of the measurements, will not exceed the values given in Table 5.5. If your calculated total uncertainty exceeds these values, it generally indicates unsatisfactory monitoring or erratic flare performance.

#### **5.4.2 Determination of compliance with the emission standard**

All monitoring data is subject to error and uncertainty. Any assessment of compliance must take account of this. Our fundamental principle is that the emission standard itself is fixed and any allowance for uncertainty is associated with the monitoring data. Our compliance assessment of emissions from landfill gas flares is subject to the same general principles we apply to the regulation of other emissions. These are covered in our Compliance Classification Scheme guidance.

The values in Table 5.5 are the maximum uncertainty for the associated tests. Assess compliance using the value of uncertainty in table 5.5 or that which is quoted in the report, whichever is the lower.

Table 5.5 Apply maximum values for measurement uncertainty when assessing compliance of emissions from enclosed flares.

Determinand	Method description	Typical uncertainty (percent)
Nitrogen oxides	Extractive NDIR and chemiluminescence BS EN 14792: 2005	30
Carbon monoxide	Extractive NDIR BS EN 15058: 2006	20
Total volatile organic compounds	Flame ionisation detection (BS EN 12619 : 1999)	40
Hydrogen chloride	Integrated method with ion chromatography (BS EN 1911) (BSI, 1998)	60
Sulphur dioxide	Integrated method with ion chromatography (ISO 11632) (ISO, 1998)	30

**Compliance:** Compliance is when all measurements give results that are within the standard, irrespective of uncertainty.

**Approach to limit:** All measurements giving outcomes that are above the standard, but by an amount that does not exceed the uncertainty, will be regarded as approaching the limit. These will be deemed compliant.

**Non-compliance:** All measurements giving outcomes that are above the standard after subtracting the uncertainty will be regarded as non-compliant.

These situations are illustrated in Figure 5.1.

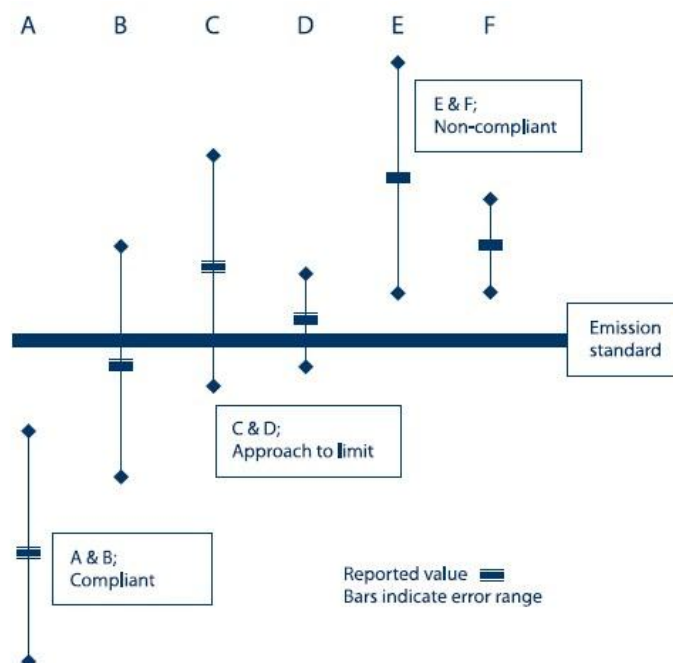


Figure 5.1 Schematic representation of the compliance classification used in assessing emissions from flares

### 5.4.3 Reporting

Your test report must include the following details along with the reporting requirements in the site permit:

- the test methods;
- any variations from standard methods;
- tabulated data summary;
- ambient conditions during sampling.

The results must be reported in the form of:

$$\text{Result} = X \pm U \text{ (units)}$$

where:

X = calculated value

U = measurement uncertainty.

Estimate the measurement uncertainty for the actual monitoring undertaken and, where this is not possible, follow the guidance above. Apply the uncertainty to the result, not to the emission standard.

Indicate in your report whether the sampling period was representative of the normal operating period of the flare. Give supporting evidence for this (such as, from the flare profile) or make allowance for it in the data where it appeared not to be fully representative. Make sure the report contains an assessment of the monitoring data from the flare for compliance against the relevant emission standard.

Ensure the appendix to your report records subsidiary information, including:

- landfill type and age
- meteorological conditions
- sample data sheets
- completed calculation proformas
- chart recorder printouts.

Appendix D provides an example of an emissions report sheet. You must submit the full report to us and, where possible, in electronic format.

### 5.4.4 Consideration of response

If we assess the data as compliant, then you can report it routinely in accordance with your permit requirements.

If we assess the data as approaching the limit, report it in accordance with your permit requirements; also provide information on how you will reduce the uncertainty on subsequent monitoring to ensure compliance with the standard.

If we assess the data as non-compliant, you must investigate why, and report it to us immediately. Our response will be in accordance with our



Compliance Common Classification Scheme. The urgency of your investigation will be determined by the degree of non-compliance and the risk associated with the emission.

### **Example**

A marginally non-compliant case (that is, up to 25 per cent over the standard after allowing for uncertainty) that is not close to a sensitive receptor would normally require a report within seven days. Alternatively, a grossly non-compliant case close to a sensitive receptor requires immediate investigation and a report within 24 hours. The action we take will be consistent with our enforcement and prosecution policy.

## **Appendix A: Flare height and dispersion assessment**

### **General**

This appendix provides a short overview of the dispersion and impact of enclosed flare stack emissions management. It includes elements of the design of discharge stacks and dispersion modelling applied to assess impacts.

In theory, a flare stack elevates the plume so the initial dispersion of the plume is at a greater altitude. By the time the plume has returned to ground level, emission concentrations should have reduced to acceptable levels. A flare stack should generally be high enough to ensure this occurs. 'Local' may mean anything from 10 metres to 1 kilometre. At large distances from a flare stack (100 stack heights), the effect of stack height on dispersion is no longer distinguishable (unless the plume has penetrated the boundary layer). In addition, the effects of single sources start to become indistinguishable at such distances from the background produced by other sources.

In carrying out its statutory duty, the local planning authority must consider other factors (such as, visual impact and noise) and thus may impose a restriction on flare stack height and location.

### **Adjustment of flare height**

The following impacts can be reduced by adjusting the height of the flare stack:

- odours
- effects of ambient concentrations
- deposition of emissions – mainly heavy metals, acidic materials or long-lived chemicals (for example PCDDs)
- noise
- nuisance dusts

- visibility/obscuration.

## The importance of emission exposure times

Where emissions are associated with a range of exposure limits with different exposure times (as, for example, with SO<sub>x</sub> and NO<sub>x</sub>), it is usually the short-term exposure which is critical. This is mainly because short-term exposures are not repeated very often at the same point; so although short-term concentrations may be high, the effect on longer-term averages is usually low in relation to their respective limit concentrations. With longer-term averages, the background concentrations of common emissions become more important and may make a larger contribution to overall levels than that from a single local source.

## Determining the appropriate height of the flare

You need the following information to calculate a flare stack height:

- details of the emission rate;
- details of the site and its surroundings;
- identification of the critical emissions including rates and typical background concentrations;
- a dispersion model;
- any controls or limitations imposed by guidance notes, and so on;
- meteorological conditions.

Typically, landfill gas flares have low emission velocity which can result in downwash being a common problem, regardless of the high temperature (hence thermal buoyancy). A standard method of determining stack heights for broader discharges is available (HMIP, 1993).

Table A1 lists emission exposure times for potential impacts.

Table A1: Emission exposure times

Impact	Emission exposure time
Odours	Very short-term, that is, a few seconds
Toxic effects	Short-term (a few minutes for exposure to acid gases)
Deposition	Mainly long-term, that is, annual
Nuisance dust and deposits	Can be short-term, but mainly daily or longer
Visibility/obscuration	Mainly short-term (a few minutes at most), but may repeat intermittently

## Identifying the critical emissions and their emission rates

The critical determinand is the one that requires the greatest flare stack height. This can be found by calculating the pollution index (PI) for each emitted determinand.

This is defined as:

$$Pi = D/(G_d - B_c)$$

where:

D = discharge rate of the  
determinand  $G_d =$   
guideline concentration of  
the determinand  $B_c =$   
background concentration  
of the emission.

Standard stack height calculation methods are used to determine these parameters, which can vary from simple formulae to complex computer-based methods.

## Dispersion modelling

There are many dispersion models covering a whole spectrum of complexity and reliability.

However, there are limitations in their use because:

- dispersion models are approximations to a very complex process;
- dispersion itself is a stochastic process, so that there is never a single, accurate, answer to a dispersion calculation.

For enclosed flare stack height calculations and hence dispersion calculations, you need to take the following into account when modelling:

- basic plume dispersion data as a function of atmospheric conditions;
- a method of determining plume rise;
- deposition modelling (if deemed necessary);
- ideally, the effects of buildings and other structures (including trees) on plume downwash and dispersion rates.

### Numerical models

Numerical models are most effective for straightforward dispersion calculations where the basic plume dispersion model can be applied. They account for large-scale meteorological effects, but are relatively poor at dealing with complex flows.

### Look-up tables

Alternatively, look-up tables specifically for landfill gas combustion systems (Natural Resources Wales 2008) provide a simple screening methodology. The calculations in these look-up tables assume typical exit velocities and emission temperatures for a range of stack heights, with off-site maxima depending on the distance from the stack to the landfill boundary.

### Plume dispersion calculations

Most numerical plume dispersion calculations are presently carried out using the Pasquill-Gifford type of Gaussian dispersion model in combination with a plume rise model. The ADMS 4 model (CERC, 2010) or AERMOD (USEPA, online 2) are state-of-the-art Gaussian plume dispersion models, which take

into account the effects of topography, buildings and other structures. When deciding which model to use, it is important to ensure it is fit-for-purpose.  
 Appendix B: Proforma for recording preliminary site visits.

Item Number	Permit number	Operator name	Installation name	Installation address
Section to be repeated for additional emission points				

Item	Emission point	Emission point	Emission point	Emission point
Emission point reference	A1	A2	A3	A4
Grid reference				
Emission point description				
Description of flare				
Reference conditions for reporting				
Description of sampling location				
Details of operator risk assessment				
Consultant risk assessment completed (Y/N)				
Personal protective equipment requirements				
Other special equipment required				
Confined space working requirements				
Requirements for intrinsically safe equipment				
Other health and safety issues				
Provision for parking of vehicles at sampling location(s)				
Horizontal distance from vehicle parking location to sampling point (metres)				
Vertical height of sampling platform or location above adjacent ground level (metres)				
Sampling platform or sampling location dimensions (metres)				
Required safe working load for sampling at the platform or sampling location (point load and uniformly distributed load)				
Actual safe working load capacity of existing platform or sampling location (point load and uniformly distributed load)				
Access arrangements for personnel to sampling platform				
Access arrangements for equipment to sampling platform				
Required safe working load for lifting equipment (Kg)				

# Appendix C: Further information on calculations

## Data standardisation

Make all data handling and calculations as described in fully documented procedures that comply with standards or equivalent requirements. All calculation formulae used must conform to the appropriate sampling and analysis standard.

Emission concentrations should be reported, as appropriate, to reference conditions of:

- mass concentration
- standard temperature and pressure (STP), that is, 0°C (273K), 101.3 kPa • 3 per cent v/v oxygen
- dry gas.

All flue gas emissions must be reported as concentrations and mass emissions, together with supporting information using our standard monitoring report forms.

## Conversion from volume concentration to mass concentration

Emission concentrations are often measured in volume/volume (**v/v**) terms, such as parts per million (ppm) or percentages. This approach is most common for gaseous air emission species, especially when the measurement is carried out using an instrumental monitoring technique. For example, carbon monoxide monitors normally present measured data as **ppm**, while oxygen meter readouts are given as percentages. For ideal gases, concentrations measured in volume/volume terms are independent of temperature and pressure.

This approach has an important advantage for on-line monitoring applications, as there is no need to correct the readings on the monitors for analyser cell temperature and pressure conditions. This condition holds as long as the certificated concentration value of the calibration cylinder and monitor scale are both given in volume/volume units.

The emission standards for enclosed landfill gas flares are expressed in mass volume terms (**mg/m<sup>3</sup>**). For reporting purposes and to assess compliance, you will need to convert measured data from **volume/volume** terms to **mass/volume** units.

## Conversion

The conversion from ppm to mg/m<sup>3</sup> is straightforward. The relationship is derived from the ideal gas equations and relies on the fact that one mole of an ideal gas occupies a volume of 22.4 litres at STP.

As moles and volumes of ideal gases are interchangeable, all that is required to convert from a ppm concentration to mg/m<sup>3</sup> at STP is to multiply the ppm figure by the ratio of the molecular weight of the emission component to 22.4,

$$\text{mg/m}^3 = \text{ppm} \times \frac{\text{Mw}}{22.4}$$

where:

Mw = molecular weight

For example:

for NO<sub>x</sub>, Mw = 46 (NO<sub>x</sub> is expressed as NO<sub>2</sub> for regulatory purposes); for CO, Mw = 28.

## Oxygen standardisation

If excess air is added to an enclosed landfill gas flare (for example, to promote better combustion), measured flue gas emission concentrations of non-combustible species such as SO<sub>2</sub> will fall. However, emission concentrations only appear to be reducing while, in reality, emission mass rates have remained constant. Thus, it is necessary to compare concentrations at a standard oxygen concentration.

However, the relationship between the measured oxygen and measured emission species concentration is not linear as oxygen from air is added or removed. For example, halving the flue gas oxygen content does not result in a doubling of the emission concentration. The oxygen found in the flue gases is a measure of the excess air over that required for theoretical complete combustion (termed the stoichiometric air requirement).

Therefore, the measured oxygen level is a measure of the dilution of the flue gases from the stoichiometric condition. The percentage of oxygen in dry air is 20.9 per cent (v/v) and the proportion of excess air (X/V) can be calculated using the following formula:

$$\frac{X}{V} = \frac{(O_2)_m}{(20.9 - (O_2)_m)}$$

where:

X = volume of excess air (m<sup>3</sup>)

V = stoichiometric volume of the flue gases (m<sup>3</sup>)

(O<sub>2</sub>)<sub>m</sub> = percentage of oxygen (v/v) in the flue gas (dry basis).

The proportion of excess air can be converted to the percentage excess air by multiplying X/V by 100.

The dilution factor (D) at oxygen concentration (O<sub>2</sub>)<sub>m</sub> is given by:

$$D = 1 + \left( \frac{(O_2)_m}{(20.9 - (O_2)_m)} \right) = \left( \frac{20.9}{(20.9 - (O_2)_m)} \right)$$

The general equation for the conversion factor, which is the ratio of the dilution factors at the measured and reference conditions is obtained from the above equation. Thus the ratio D<sub>m</sub>/D<sub>r</sub> is given by:

$$\frac{D_m}{D_r} = \frac{[20.9 - (O_2)_r]}{[20.9 - (O_2)_m]}$$

Where:

D<sub>m</sub> = dilution factor at the measured (O<sub>2</sub>)<sub>m</sub> concentration

D<sub>r</sub> = dilution factor at the and reference (O<sub>2</sub>)<sub>r</sub> oxygen concentration.

Table C1 gives conversion factors for the **3 per cent oxygen** reference concentration used for enclosed landfill gas flares.

Table C1 Conversion factors for different oxygen percentage concentrations

Oxygen concentration (percent)	Conversion factor to 3 percent O <sub>2</sub>
1	0.90
2	0.95
3	1.00
4	1.06
5	1.13
6	1.20
7	1.29
8	1.38
9	1.50
10	1.64
11	1.80
12	2.01
13	2.26
14	2.59
15	3.03

Since the emission concentration C is equal to the reciprocal of dilution D, the equation for the concentration at reference conditions can be written as:

$$C_r = C_m \times \frac{(20.9 - (O_2)_r)}{(20.9 - (O_2)_m)}$$

Because the reference condition being used for enclosed landfill gas flare is 3 per cent, this equation becomes:

$$C_r = C_m \times \frac{17.9}{(20.9 - (O_2)_m)}$$

## Enhanced oxygen

Under enhanced oxygen conditions (that is, where oxygen is added to aid combustion and reduce gas volumes), the conversion to standard oxygen conditions is not so straightforward.

The percentage of oxygen by volume in dry air is 20.9 per cent. Under normal combustion conditions, the sum of the carbon dioxide and oxygen concentrations (measured on a wet basis), together with half the moisture content of the flue gas (from the combustion of hydrogen in the fuel – not the fuel moisture) is equivalent to 20.9 per cent of the volume of the flue gas.

That is:

$$[(CO_2) + (O_2) + 0.5(H_2O)]_m = 20.9$$

### Using a modified equation

Under enhanced oxygen conditions, the normal oxygen standardisation equation is not appropriate as the sum of these items is not 20.9 per cent, but some larger figure depending on the enhanced oxygen input. Unless the degree of enhancement is known or can be measured directly, it will be necessary to estimate it from other measurements such as the oxygen and carbon dioxide concentration in the flue gas.

If you know the hydrogen/carbon ratio, you can use a modified equation that takes account of the water emitted as a result of the hydrogen in the fuel. If the percentage of carbon in the fuel is C and that of hydrogen H, the equation is as follows:

$$C_r = \frac{C_m \left[ (CO_2)_m \left( 1 + 3 \frac{H}{C} \right) + (O_2)_m - (O_2)_r \right]}{(CO_2)_m \left( 1 + 3 \frac{H}{C} \right)}$$

## Moisture correction

Moisture content is usually expressed as in volume/volume terms. For example, as the percentage volume of water vapour in the total wet gas volume.

Water content is normally determined gravimetrically by passing extracted flue gases through a weighed drying train. The volume of dried sample gas is measured and the increase in mass of the drying train is recorded. The ratio of volumes of water vapour and of dry gas is the same as the ratio of the



moles of water vapour and dry gas (treating them both as ideal gases at STP). The number of moles of water (MW) is found by dividing the increase in mass of the drying train in grams by the molecular mass of water (18).

The number of moles of dry gas MD is found by dividing the metered volume of dry gas (in m<sup>3</sup> corrected to STP) by 0.0224 (the molar volume of any gas at STP). The percentage H<sub>2</sub>O v/v can then be calculated as follows:

$$H_2O(\%) = 100 \times \frac{M_w}{M_w + M_D}$$

Thus, the emission concentration converts as follows:

$$C_r = C_m \times \frac{100}{(100 - H_2O(\%))}$$

where:

C<sub>r</sub> = concentration of emission at reference condition (dry) C<sub>m</sub> = concentration of emission at measured

The correction of a flow rate to dry condition is given by:

$$F_r = F_m \times \frac{(100 - H_2O(\%))}{(100)}$$

where:

F<sub>r</sub> = flow rate at reference condition (dry)  
F<sub>w</sub> = flow rate at measured moisture content.

## Temperature correction

Emission standards for enclosed landfill gas flares are quoted in terms of mass/unit volume, (mg/m<sup>3</sup>). They contain a gas volume term (in this case m<sup>3</sup>) and, since the volume of a gas may vary according to the temperature and pressure, the volume needs to be fixed to a reference temperature and pressure. Converting from the temperature and pressure under the actual measurement conditions to a standard temperature and pressure is based on the gas laws and is relatively straightforward. If each correction is considered in isolation, then the effect of a temperature change on the measured gas volume is:

$$V_r = V_m \times \frac{273}{T_m}$$

where:

$V_r$  = gas volume at reference conditions (273K) ( $m^3$ )  
 $V_m$  = measured volume ( $m^3$ )  
 $T_m$  = measured temperature (K)

Thus, emission concentrations, which are mass over volume, convert as follows:

$$C_r = C_m \times \frac{T_m}{273}$$

where:

$C$  = concentration (the subscripts 'r' and 'm' indicate reference and measured conditions)  
 $T_m$  = measured temperature ( $^{\circ}K$ )

### Pressure correction

Pressure correction is also based on the ideal gas laws.

Thus:

$$V_r = V_m \times \frac{P_m}{101.3}$$

and:

$$C_r = C_m \times \frac{101.3}{P_m}$$

where:

$P_m$  = measured pressure (kPa) and 101.3 (kPa) is atmospheric pressure

$V_r$  = gas volume at reference conditions (273K)( $m^3$ ).

$V_m$  = measured volume ( $m^3$ )

$C$  = concentration (subscripts 'r' and 'm' indicate reference and measured conditions, respectively).

### Mass emission calculation

The mass emission rate (ER) calculation, which is outlined below, combines the measured concentration and flow rate data.

$$ER = C_m \left( \frac{mg}{m^3} \right) \times \text{flowrate} \left( \frac{m^3}{s} \right)$$

This gives an emission rate in mg/second.

To convert...	to...	Perform this calculation
mg/second	g/second	Divide by 1,000
g/second	kg/second	Divide by 1,000
kg/second	kg/hour	Multiply by 3,600

**It is essential that the emission concentration and emission flow rate are expressed at the same conditions (temperature, pressure, water content and oxygen content).**

## Determining theoretical flow rate from inlet gas monitoring Theory

Knowledge of the volumetric flow rate of gas to the flare at STP together with the proportion of methane enables determination of the amount of air required for combustion at STP.

Corrections must be applied to account for the quantity of moisture present in the exhaust gas from input and generated during combustion. The resulting normalised (relative to STP) dry gas flow rate must then be corrected for oxygen presence to meet the reporting standard.

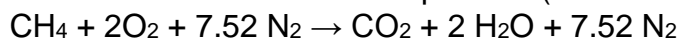
### Input parameters

Monitor the input gas parameters listed in Table C2 to allow you to determine the theoretical exhaust gas flow rate.

Table C2 Inlet gas parameters to monitor to determine theoretical exhaust flow rate

Inlet gas parameter	Symbol	Units
Volumetric flow rate	$Q_{in}$	Nm <sup>3</sup> /hr
Methane content	%CH <sub>4</sub>	% v/v
Oxygen	%O <sub>2</sub>	% v/v

Stoichiometric combustion equations (based on 21% oxygen in air)



### Methane input

Volume of methane combusted ( $Q_{\text{CH}_4}$ ) =  $Q_{in} \times \% \text{CH}_4 / 100$

### Combustion air requirement

Volume of air for combustion ( $Q_{air}$ ) =  $Q_{\text{CH}_4} \times (7.52 + 2.00)$

### Total input flow

Total input flow ( $Q_{Tot}$ ) =  $Q_{in} + Q_{air}$

Total input flow = Total output flow

There is no net volume change during methane combustion

### Moisture correction

Water vapour is generated during combustion and may be present in significant quantities in the inlet gas. Measure the total moisture flow in the

exhaust gas and correct the total output flow to account for the moisture content to give the normalised dry gas flow rate ( $Q_{dry}$ ).

### Oxygen correction

Using the stoichiometric combustion equation assumes any oxygen present in the exhaust gas is present in the inlet gas as all the oxygen from the supplied combustion air is used to oxidise methane. The volume of air (oxygen + nitrogen) required for combustion is 9.52 times the volume of methane in the incoming LFG (from the stoichiometric combustion equation).

Therefore, the percentage of oxygen from the incoming gas is corrected to account for dilution from the stoichiometric combustion air, as follows:

$$\%O_2 \text{ adjusted} = (Q_{in} \times \%O_2) / Q_{dry}$$

Therefore the flow correction to the guidance value of 3% O<sub>2</sub> (Q) is given by:

$$Q = Q_{dry} \times (20.9 - \%O_2 \text{ adjusted}) / 17.9 \text{ (Nm}^3\text{/hr, dry gas, 3\% O}_2\text{)}$$

**Note:** This calculation assumes a negligible amount of hydrogen and other combustible gases (such as H<sub>2</sub>S). In the event the inlet gas contains significant quantities (of the order of several per cent) of these gases, you will need additional calculations to account for their combustion.

## Appendix D: Example flare emission report

Report period .....to.....Installation address.....  
 Permit number .....  
 Operator name .....  
 Name of monitoring organisation(s) .....  
 Name of analytical organisation(s) .....  
 Date issued by operator (dd/mm/yy) .....

Emission point					
Substance					
<b>Summary</b>					
Permit limit (value, units)					
Concentration (value, uncertainty, units)					
Mass emission (value, uncertainty, units)					
<b>Measurement details</b>					
Sampling method (for example, CEN, ISO, national standard)					
Accreditation of sampling method (for example, UKAS ref No.)					

Analytical method (state technique , for example, gravimetric)						
Accreditation of Analytical method (for example, UKAS Ref No.)						
State if sampling compliant with method						
State if analysis compliant with method						
Date of sampling (dd/mm/yy)						
Time sampling started						
Time sampling finished						
Date of analysis (dd/mm/yy)						
Limit of detection (LOD) of overall method (value, units)*						
Span gas concentration (if applicable)(value, units)						
<b>Process conditions</b>						
Process status**						
<b>Supporting information</b>						
Emission point grid reference						
Interval between sampling						
Date of previous sampling (dd/mm/yy)						
Percentage of base load						
Ref. conditions used (273K and 101.3 KPa) wet/dry, oxygen						

\* Ideally LOD should be <10 percent of the permit limit \*\*

Process conditions:

N = normal

A = abnormal (for example, failure of abatement control)

T = transitional (for example, start-up)

## Appendix E:



Technical Guidance Note TGN 024

**Monitoring of Landfill Gas Flares and Gas Engines**

**Issue Date April 2006, supersedes none**

**Source Testing Association**

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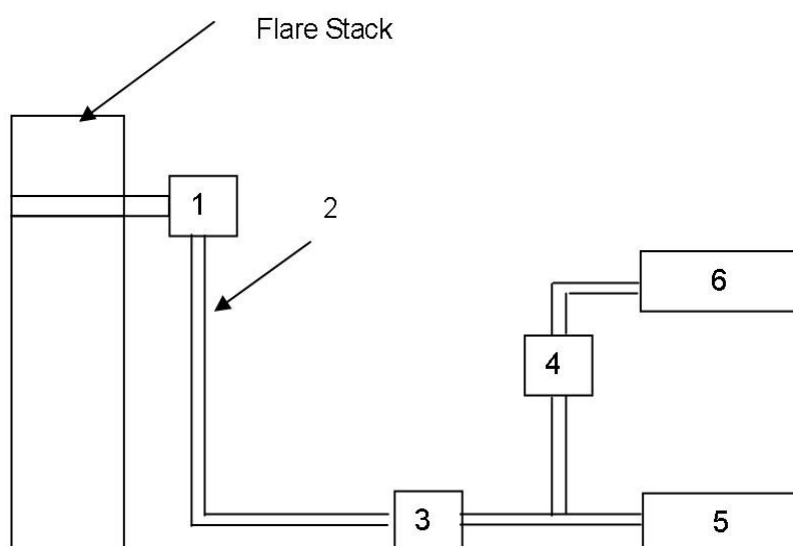
Fax +44(0) 1462 457157 E-mail technical@s-t-a.org

## Background

Natural Resources Wales Guidance on Landfill gas flare monitoring outlines a monitoring strategy that requires pre-installation of an extraction system to take a representative sample from above the flame within the enclosed flare stack. It presumes (unless demonstrated otherwise) that there may be non-uniform distribution of gas concentrations across the sampling plane and that a multipoint sample probe/sampling would normally be required.

## Sampling System

The installed system, see figure 1, comprises a ceramic multi-hole probe which is fitted across the stack with a coil condenser (heat exchanger) fitted to a temperature-controlled heated sample line. The heated line has an integral calibration line and a thermocouple to monitor the temperature of the sample gas entering the heated line.



**Figure 1 Gas sample system**

### Legend

1. Sample probe and cooler
2. Heated sample line with integral calibration line
3. Heated purge valve system
4. Gas conditioning system
5. Heated FID TOC analyser
6. Analyser(s) for monitoring CO, NO<sub>x</sub> and optional SO<sub>2</sub>

## Flare operation

Flares must meet operational standards as well as emission standards. Part of risk minimisation is to avoid monitoring flares that fail to meet operational standards. It is the responsibility of the operator to ensure that operational standards are met. In addition, the effectiveness of permanently installed sampling equipment is also the operator's responsibility.

For the duration of emissions testing, monitoring teams must ensure that the flare is operating under acceptable conditions.

Flares can be operating outside acceptable standards; if for example:

- The flame extends beyond the shroud at any time (it should be below the sampling ports) – elevated or un-enclosed flares must not be monitored.
- On noting the operating temperature, it is outside the design range **by more than 100° C**. Normal operation for most designs is 1000° C.
- The temperature fluctuates **by more than 100° C over a 5 minute** period (indicative of problems in the gas field so may be noted as a factor in representativity of data).
- The thermocouple temperature is significantly different from that shown on the flare control temperature instrument.
- There are missing or broken louvers on the air control (this will affect estimation of flow).
- The orifice plate or similar flow gauge is not operational.
- There is a strong smell of landfill gas in the compound.
- A recent value for gas composition is not available.

### Monitoring

The main measurements that are to be carried out are;

- Nitrogen Oxides (NO<sub>x</sub>) to BS EN 14792:2005
- Carbon Monoxide (CO) to BS EN 15058:2006
- Total Organic Compounds (TOC) to BS EN 13526

### Optional:

- Sulphur Dioxide (SO<sub>2</sub>) to BS 6069 part 4.4 (ISO7935)

### Preparation at site

The test team is to verify, before sampling, that the heated line system is functioning correctly by ensuring that:

- the heated line has no hot or cold spots within its length;
- the temperature of the sample gas (downstream of the cooler and before the heated line) is above 180°C;
- after the analyser(s) system is connected, there are no leaks by following the procedure in BS EN 14792 paragraph 8.4.2.3;
- the analysers must be calibrated by introduction of span and zero gases directly into the analyser and then via the sample system. The difference between the two readings must be less than **two per cent** of the estimated measured concentration as stated in the relevant standards.

### Measurements

The sampling period for the measurement must be determined and should cover at least one cycle of flare operation. The analyser data recording system must be able to record **one minute** averages.

On completion of the sampling period you must carry out a check of the sample system as stated in the relevant standards.

# Glossary

## **Absorption**

This is a process in which a gas is taken up by a liquid or a solid.

## **Adsorption**

This is a process in which a layer of atoms or molecules of a substance collect on the surface of a solid or liquid.

## **Biodegradable waste**

Any organic waste that is capable of undergoing anaerobic or aerobic decomposition, such as food, garden waste, paper and paperboard.

## **Chemiluminescence**

This is the emission of light during a chemical reaction.

## **Deposition**

This is the removal of particles or gases from a gas stream through surface adsorption, impaction, and so on. In the context of the flare gas emissions, this includes dry deposition -- direct absorption or uptake on soil and vegetation. It may also include wet deposition -- removal in rainfall passing through the plume as it disperses.

## **Design capacity**

The maximum gas flow rate the flare is designed to burn at.

## **Dew point**

Temperature at which the water vapour contained within a gas mixture will condense to form liquid water.

## **Dispersion**

The tendency for components of the flare/stack emission to spread out from the path they would be expected to follow as a result of mechanical mixing and thermal kinetic energy. It causes dilution of the components in the free atmosphere.

## **Duct**

This is an enclosed structure through which gases travel.

## **Enclosed flare**

This is a flare in which combustion conditions are improved by enclosure of the flame in a shroud.

## **Flare**



Structure designed to facilitate combustion of landfill gas under controlled conditions.

**Flue**

See Duct.

**Fugitive gas**

The proportion of emissions of landfill gas that are not accountable by known point sources on site. Typically, diffusive loss or leaching through the surface of a landfill generates fugitive losses.

**Gravimetric**

A method for determination of particle concentrations in air by direct weighing of the mass present in a collected sample.

**Greenhouse gas**

This is a gas that, when present in the atmosphere, contributes to global warming because of its radiative properties.

**Intra-red (IR)**

A form of electromagnetic radiation, longer in wavelength than visible light

**Isokinetic sampling**

Condition required when sampling particles at which the gas entering a sampling nozzle is at the same velocity and direction as the bulk flow of gas in the sample duct or stack. This condition minimises any sampling error that might arise due to inertial properties of the particles.

**Landfill gas**

All gases generated from the landfilled waste.

**Sampling plane**

The plane normal to the centreline of the duct at the sampling position.

**Sampling point**

The point(s) on the sample plane where the sample is collected.

**Sampling ports**

Points on the wall of the stack, duct or flue through which access to the emission gas can be gained.

**Semi-volatile organic compounds**

The volatility of a pure organic compound depends on its vapour pressure. The form in which a substance is present in air is dependent upon the vapour pressure. Typically, in air, an organic compound with a vapour pressure greater than  $10^{-7}$  atmosphere will be gaseous. At a vapour pressure below  $10^{-11}$  atmosphere, the compound is almost exclusively in the particle phase.

In between these ranges, compounds can be present in both gaseous and particle phases depending upon temperature and pressure; these are referred to as semi volatile organic compounds.

### **Stack**

This is a structure (that is, chimney) through which emissions are released to atmosphere.

### **Stoichiometric**

These are the exact proportions in which substances react. For combustion, the theoretical minimum amount of air or oxygen required to consume the fuel completely.

### **Tenax**

Proprietary medium used for the adsorption and collection of organic compounds from sample gas streams or air. Subsequent desorption of the collected material allows determination in the laboratory.

### **Ultraviolet (UV)**

A form of electromagnetic radiation, shorter in wavelength than visible light.

### **NMVOCs (Non-methane Volatile organic compound)**

Organic compounds that can be measured in the gas phase at ambient temperature (VOCs) but excluding methane, the predominant VOC in landfill gas.

### **VOCs (Volatile organic compound)**

Organic compounds that can be measured in the gas phase at ambient temperature

### **UV fluorescence**

A process by which, some substances emit radiation when excited by radiation of shorter wavelength (UV). The emitted radiation can be used to determine concentrations of the particular substance.

## Acronyms

<b>BSI</b>	British Standards Institution
<b>CEN</b>	Comité Européen de Normalisation
<b>CH<sub>4</sub></b>	Methane
<b>CO</b>	Carbon monoxide
<b>CO<sub>2</sub></b>	Carbon dioxide
<b>Defra</b>	Department for Environment, Food and Rural Affairs

<b>EN</b>	Norm Européenne (European Standard)
<b>FID</b>	Flame ionisation detection
<b>FTIR</b>	Fourier transform infrared spectrometry
<b>GC</b>	Gas chromatography
<b>GC-FID</b>	Gas chromatography with flame ionisation detection
<b>GC-HRMS</b>	Gas Chromatography with detection by high resolution mass spectrometry
<b>GC-MS</b>	Gas Chromatography with detection by mass spectrometry
<b>HCl</b>	Hydrogen chloride
<b>HF</b>	Hydrogen fluoride
<b>HPLC</b>	High performance liquid chromatography
<b>HSE</b>	Health and Safety Executive
<b>IR</b>	Infra-red
<b>ISO</b>	International Standards Organisation
<b>MCERTS</b>	Natural Resources Wales's Monitoring Certification Scheme
<b>MS</b>	Mass spectrometry
<b>NDIR</b>	Non-dispersive infra-red spectrometry
<b>NDUV</b>	Non-dispersive ultraviolet spectrometry
<b>Nm</b>	Nanometre ( $10^{-9}$ of a metre)
<b>NMVOC</b>	Non-methane volatile organic compound
<b>NO</b>	Nitric oxide
<b>NO<sub>2</sub></b>	Nitrogen dioxide
<b>NO<sub>x</sub></b>	Nitrogen oxides (sum of NO and NO <sub>2</sub> )
<b>PCDDs</b>	Polychlorinated dibenzo-p-dioxins
<b>PCDFs</b>	Polychlorinated dibenzo furans
<b>PID</b>	Photo ionisation detector
<b>PM<sub>10</sub></b>	Particulate matter of 10 microns ( $10^{-6}$ of a metre) or less in diameter
<b>ppb</b>	Part per billion (1 ppb is 1 volume of gas in $10^9$ volumes of air)
<b>PPE</b>	Personal protection equipment
<b>ppm</b>	Part per million (1 ppm is 1 volume of gas in $10^6$ volumes of air)
<b>PTFE</b>	Polytetrafluoroethylene
<b>PUF</b>	Polyurethane foam
<b>SO<sub>2</sub></b>	Sulphur dioxide
<b>STA</b>	Source Testing Association
<b>STP</b>	Standard temperature and pressure (0°C and 1 atmosphere pressure)
<b>UK</b>	United Kingdom

<b>UKAS</b>	United Kingdom Accreditation Service
<b>USEPA</b>	United States Environmental Protection Agency
<b>UV</b>	Ultraviolet
<b>VDI</b>	Verein Deutscher Ingenieure (German national standards body)
<b>VOCs</b>	Volatile organic compounds

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