REA LANDFILL GAS

REPORT

Area Classification for Landfill Gas Extraction

Dangerous Substances and Explosive Atmospheres Regulations (DSEAR)

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This work was commissioned by the Landfill Gas Forum of the REA.

Honace Limited was contracted to update and revise landfill gas industry guidance first produced in 2005 by the Environmental Services Association (ESA) following the introduction of EU Directives and enacted by the UK in Regulations of the Health and Safety at Work Act 1974.

The information contained in this publication is provided as a guide to demonstrate best practice and has been reviewed and amended prior to publication by members of the REA Landfill Gas Forum who are acknowledged for their technical contributions and assistance in updating this document.

August 2020
Published by REA
Brettenham House
2–19 Lancaster Place
London
WC2E 7EN

EXECUTIVE SUMMARY

This document revises the guidance issued by ESA in 2005 entitled Area Classification for Landfill Gas Extraction, Utilisation and Combustion (ESA, 2005) and was commissioned by the Landfill Gas Forum of the REA with contributions provided by the landfill gas utilisation industry, ESA and the HSE, providing a definitive and authoritative high level document which if followed, should provide sufficient information and guidance to illustrate **good practice for application in the landfill and landfill gas industry**.

The Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) provides for the protection against risks from fire, explosion and similar events arising from dangerous substances used or present in the workplace including, since June 2015, gases under pressure and substances that are corrosive to metals as a result of EU Chemical Agents Directive, the physical hazard aspects of which are enacted in Great Britain through DSEAR.

Landfill gas is a naturally produced flammable gas derived as a result of the biological degradation of organic wastes in the absence of oxygen. Consequently, the gas is primarily methane and carbon dioxide although other gases and large variations in primary gas concentrations occur at different parts of the landfill and through time, as the organic waste slowly reduces, and environmental conditions change. It is for this reason it is important that any DSEAR assessments are reviewed periodically and amended as risk changes.

Where dangerous substances are present, used or produced, compliance with DSEAR requires **risk assessment** and an important principle is to separate storage areas from process areas where the two occur on the same or shared premises. Information on storage of dangerous substances is found in other HSE and non-HSE guidance. In contrast, process activities are very variable and should be considered in more detail applying the principles of risk assessment to specific activities. This Industry Code of Practice (ICoP) provides guidance for these process activities for the design of new works, the refurbishment of existing works and during operation and management of infrastructure within landfill environments.

Risk assessment should identify safety risks arising from the **hazardous properties of dangerous substances** present or liable to be present by conducting a structured, thorough and referenced assessment which should be used to take practical action to eliminate or reduce the risk.

The risk assessment also identifies locations and places where, there is a potential for an explosive atmosphere. Subsequently, applying area classification which involves;

- the identification of all flammable materials;
- the identification and grading of all (potential) releases of flammable material;
- the assessment of the level of ventilation and/or housekeeping;
- the determination of the resulting types and extents of the zones;
- the allocation of zones enables the correct equipment, practices and procedures to be applied to protect the health and safety of workers concerned with the facility and others such as the general public; and
- applying barriers, segregation, isolation and marking/signing where hazardous areas have been classified and where explosive atmospheres may occur.

This document follows a step by step process, colour coded to aid referencing and considers the most common infrastructure elements where landfill gas could escape. This provides guidance of area classification, zoning and zone extents utilizing calculations derived from other guidance.

Application

- Understand DSEAR principles including the Regulations and interaction with other legislation.
- Understand LFG properties, the risk of an explosive atmospheres and changing conditions.

Risk Assessment

- Identify the dangerous substance and their properties.
- Identify Hazardous Areas where dangerous substances can be released.
- Consider whether release is unavoidable, intentional or foreseeable.
- Consider likelihood of an explosion, through experience, calculation and situation.

Area Classification

- Consider whether safe systems of work are adequate.
- Consider whether potential release is continuous, primary or secondary.
- Consider probability of explosive atmosphere being present and asign zone number.
- Record Area Classification related to documents.
- Calculate zone extent.

Eliminate Risk

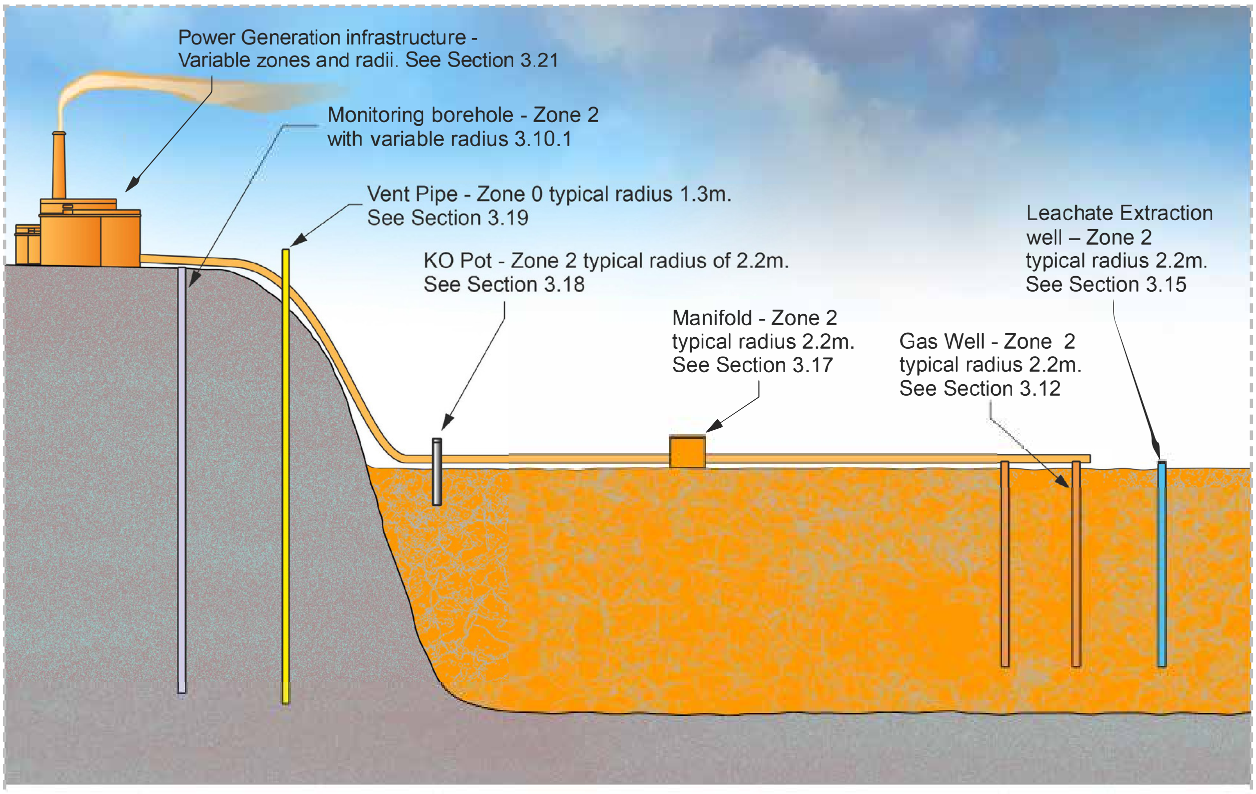
- No smoking should be mandatory.
- Choose suitable ATEX equipment.
- Remove potential hot surfaces and sparks.
- Provide adequate ventilation to reduce explosive atmosphere to below LEL.

Marking Areas of Risk

- Where explosive atmospheres may occur, provide warning signs.
- Isolate areas including erection of barriers and fences.

Accidents, Incidents & Emergencies

- Provide information and training to staff, visitors and public.
- Provide fire/explosive atmosphere alarm systems where appropriate.
- Provide evacuation and assembly points.
- Provide documentation of risk assessments, safe systems of work, reviews and incidents.



Schematic cross section of landfill site and infrastructure

TABLE OF CONTENTS

TABLES

FIGURES

APPENDIX

1. Application

1.1 Definitions and terms

Term	Explanation
Apparatus Group	The part of the certification code (IIA, IIB, IIC or II) that indicates the range of gases and vapours for which the equipment is suitable. Equipment marked IIC or II is suitable for all gases and vapours (provided the temperature class is appropriate). IIB equipment is suitable for IIA and IIB gases. IIA equipment is suitable only for IIA gases.
Area Classification	The process of zoning the site to delineate between hazardous areas and non-hazardous areas.
Basal Seal	Clay liner, plastic membrane or other impermeable material underneath the waste, primarily engineered to prevent leachate from seeping into the ground below the landfill.
Category 1G Equipment	Equipment with a very high level of protection, suitable for installation in Zone 0; it may equally be used in Zones 1 and 2. Most Category 1G electrical equipment is protected by intrinsic safety.
Category 2G Equipment	Equipment with a high level of protection, suitable for installation in Zone 1; it may equally be used in a Zone 2.
Category 3G Equipment	Equipment with a standard level of protection, suitable for installation in Zone 2.
Condensate	The liquid that forms as moist landfill gas cools and is usually acidic with numerous other dissolved chemicals.
Dangerous Substance	Any substance or mixture which meets the criteria for classification under a physical hazard class laid down in the Classification, Labelling, Packaging of Chemicals (Amendments to Secondary Legislation) Regulations 2015 (CLP). These are substances used or present at work that could, if not properly controlled, cause harm to people as a result of a fire or explosion or corrosion of metal.
Hazardous Area	An area where there is a reasonable probability of finding a potentially explosive atmosphere.
Landfill Gas (LFG)	A gas found in a landfill site containing major constituents of methane and carbon dioxide, but which may contain numerous other constituents.
Leachate	Water-based liquid that collects in a landfill site, containing numerous contaminants depending on the constituents in the landfill mass.
Lower Explosive Limit (LEL)	The minimum amount of flammable gas that, mixed with air, will produce a potentially explosive atmosphere; it is usually expressed as a percentage by volume.
Negligible Extent	Where the estimated volume of a potentially explosive atmosphere is small (< 0.1 m^3, equivalent to a sphere of radius 0.3 m), it is defined as having 'negligible extent' and no zoning applies.
Potentially Explosive Atmosphere (PEA)	A mixture of gas and air that is within the flammable range, i.e. between the LEL and UEL (see below).
Temperature Class	Equipment is designated with a temperature class, T1 to T6; T6 equipment is the coolest (below 85°C), whereas T1 equipment is the hottest (below 450°C). Gases and vapours are also assigned temperature classes T1 to T6 to allow suitable equipment to be chosen.
Upper Explosive Limit	Equipment is designated with a temperature class, T1 to T6; T6 equipment is the coolest (below 85°C), whereas T1 equipment is the hottest (below 450°C). Gases and vapours are also assigned temperature classes T1 to T6 to allow suitable equipment to be chosen.
Zones (0, 1, 2)	Described in Section 3.3.

1.2 General Landfill

Landfill involves the infilling with putrescible waste in a void such as a quarry or a landraise which is an above ground facility. Under certain conditions (see Section 1.4), landfill gas (LFG) can be created which requires containment and controlled removal to a gas combustion flaring facility, for utilisation via engines, turbines or direct use facilities or in some cases may be vented to atmosphere.

This document does not consider in detail;

- Well drilling operations and landfill gas collection system installation activities for which a safe system of work is required as part of the risk assessment and management process;
- Catastrophic failures, within the meaning (British Standard, 2015) (see Section 3.5);
- Safety issues associated with toxic, asphyxiant or other hazards associated with landfill gas;
- Utilisation systems with a delivery pressure above 350 mbarg; and
- Landfill site activities concerned with flammable materials other than landfill gas.

The design, operation and management of landfills and landfill gas facilities are comprehensively detailed in other published documents listed in Appendix I, some of which reference DSEAR and ATEX.

This ICoP document provides a standalone guidance and reference for DSEAR application in the landfill gas industry.

1.3 Legislative Background

DSEAR 2002 implements, under the Health and Safety at Work etc Act 1974, the following EU Directives:

- Directive 94/9/EC (ATEX 95 or ATEX Equipment Directive) concerning equipment and protective systems in use in potentially explosive atmospheres;
- Directive 99/92/EC (ATEX 137 or ATEX Workplace Directive) concerning the minimum requirements for improving health and safety protection at risk from explosive atmospheres; and
- Directives 98/24/EC (Chemical Agents) covering gases under pressure and substances that are corrosive to metals with the physical hazard aspects enacted through DSEAR.

DSEAR provides specific duties on employers to assess and control the risk from dangerous substances to contractors, subcontractors and self-employed people. Account must be taken to the risks to others including visitors and members of the public occupying premises or space nearby. Such requirements will impact landfill sites still producing landfill gas after landfilling has ceased and when the surface afteruse is implemented which can include controlled public access.

The Health and Safety Executive (HSE) website (**http://www.hse.gov.uk/fireandexplosion/dsear-regulations.htm#dsear**) provides a useful explanation and practical advice of DSEAR and ATEX implementation including an Approved Codes of Practice (ACOP - 2013) but this is not specific to the landfill and landfill gas industries. These documents should be used in conjunction with this ICoP to provide the most up to date information and practical guidance on how the landfill gas industry can comply with the law.

Risks from dangerous substances or explosive atmospheres may also be subject to other legislation including;

- Risks from major hazard activities, covered by the Control of Major Accident Hazards Regulations 2015 (COMAH);
- Transport of dangerous goods covered by Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009; and
- The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 1996 (EPS) is also known as the ATEX Product Directive (ATEX). ATEX applies to both electrical and mechanical equipment and protective systems intended for use in potentially explosive atmospheres.

1.4 Landfill Gas Derivation

LFG is produced by the microbial degradation of biodegradable organic material which takes place in several stages, each defined but which may all be present throughout the landfill at any one time. Stages include an aerobic phase where oxygen in the waste is consumed and carbon dioxide, water and heat are produced. Without further air ingress, oxygen and nitrogen will diminish through consumption and purging. Conditions then move into an anaerobic phase with the production of mainly methane and carbon dioxide (and in the early stages hydrogen) and eventually a steady state of equilibrium may be reached whereby a typical ratio of 3:2 (60% v/v methane:40% v/v carbon dioxide) of landfill gas may be present.
After several decades of methanogenesis, the LFG composition in the landfill will gradually assume that of atmospheric air. Importantly therefore, the relative gas concentrations within LFG will change significantly over time and could be affected by atmospheric pressure changes and landfill gas management practice over short periods, changing the volume and concentrations of the various gases at different locations.

1.5 Landfill Gas Properties

Landfill gas has the following properties;

TABLE 1 – LANDFILL GAS PROPERTIES

Property	Values	Comments
Constituents	Methane (CH_4) 60% v/v Carbon dioxide (CO_2) 40% v/v 35.3% CH_4 by mass	Proportions of constituents may vary but these values will be used for calculation purposes.
Molecular mass	Methane = 6 kg/kmol Carbon dioxide = 44 kg/kmol Average air = 29kg/kmol LFG = 27.2 kg/kmol (60% CH_4)	
Explosive limits	4.4 – 16.5% v/v	Assumed for pure methane in air. Reference BS EN 60079-29-1:2007. It is likely that the LEL for landfill gas is higher than that of pure methane due to quantities of carbon dioxide but the conservative LEL for pure methane has been used where applicable in calculations.
Relative density	Landfill gas = 0.94 Average air = 1	
Minimum temperature	Landfill gas = 10°C	For calculation purposes based upon LFTGN03.
Apparatus group	IIA	As for methane.
Auto-ignition temperature	537°C	As for methane.
Temperature class	T1	As for methane.

This ICoP does not consider the presence of hydrogen or hydrogen sulphide both of which have explosive properties. Hydrogen is usually associated with the early stages of the degradation process and is therefore not common. Whereas, hydrogen sulphide is usually present only at low levels <1000ppm. However, where significant concentrations are detected, specific risk assessment based on actual measurements should be undertaken to identify any risk of a potential explosive atmosphere being created.

Methane is highly explosive when mixed with air at a concentration between its Lower Explosive Limit (LEL) and the Upper Explosive Limit (UEL) as shown in Table 1 above. At concentrations below the LEL and above the UEL, methane is not explosive. However, LFG with a methane concentration above the UEL has the potential to mix with air and be diluted to a level between the LEL and UEL and could therefore be explosive. This is explained schematically in the Figure 1 below.

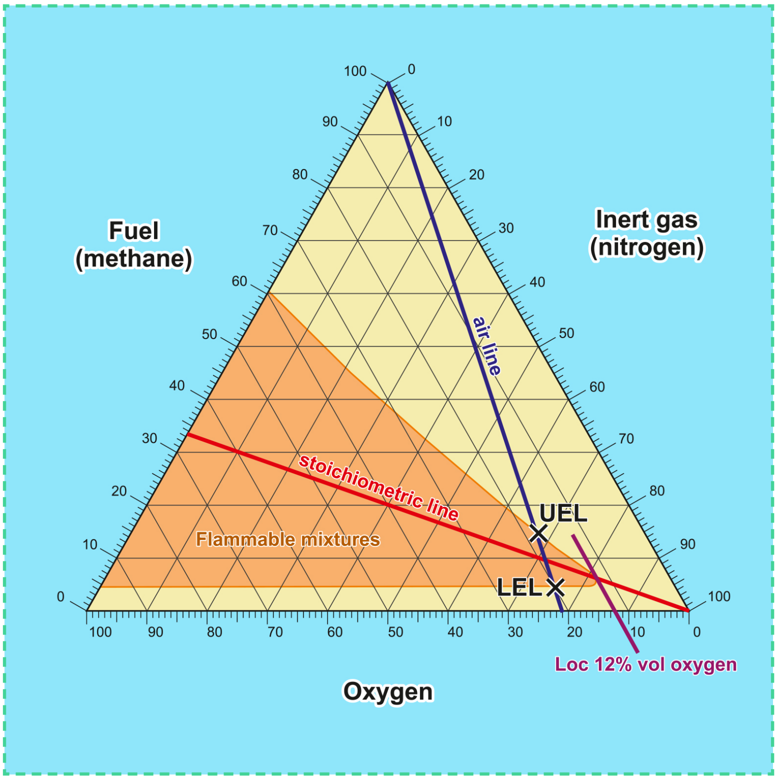


FIGURE 1 – RELATIONSHIP OF METHANE, OXYGEN AND INERT GAS

1.6 Principles of DSEAR

A hazard in DSEAR is confined to the properties of a substance that can potentially lead directly or indirectly to fires, explosions and other similar events including:

- thermal radiation (burns caused by radiating heat);
- thermal injury (burning substances on the skin);
- over-pressure (blast injuries);
- smoke, fire gases, unintended releases (asphyxiation); and
- corrosion of metals (damage to equipment and vessels).

There are seven key areas and duties associated with the application of DSEAR compliance in the landfill and landfill gas industry;

- The application of **risk assessment** (Regulation 5);
- The **elimination or reduction of the risk** (Regulation 6);
- The application of **area classification** (Regulation 7);
- Responding to **accidents, incidents and emergencies** (Regulation 8);
- Delivering **training and information** (Regulation 9);
- Identification of **containers and pipes** (Regulation 10); and
- The duty of **co-ordination** (Regulation 11).

DSEAR in landfill is concerned with potentially explosive atmospheres rather than fires. A leak of landfill gas from a faulty joint may mix with air forming a potentially explosive atmosphere if within a confined area but most landfill gas wells, and other field infrastructure tend to be outdoors and under vacuum. However, the variation in positive and negative pipeline pressures, the exposure of infrastructure to several external physical forces and the internal chemical forces plus the variable inspection and maintenance procedures evidenced over the last 20 years of experience, suggest that predicting a typical infrastructure scenario is difficult.

The ATEX Worker Protection Directive requires an 'Explosion Protection Document' (EPD) to be produced to bring together in a single document all the various aspects of compliance with the Directive. DSEAR does not specifically reference an EPD but does require that documentation exists detailing any significant findings of the explosion risk assessment and to demonstrate that organisational arrangements are in place.

It is recommended that an EPD is produced but does not need to repeat risk assessments undertaken under other legislation such as Management of Health and Safety at Work Act 1999 (MHSW) and Control of Substances Hazardous to Health (COSHH) but references to other appropriate documents should be made. The EPD must be produced before the commencement of work and revised when changes occur in the workplace.

The typical gas pressures involved in the LFG industry are relatively low compared with other process industries and, indeed, much of the gas collection 'in field' side is under a suction pressure. Likewise, any positive pressure is very modest by comparison with the pressures encountered in the process industry in general. Consequently, this ICoP can be used as the primary source of guidance for mass release rates and zone extents for the LFG industry.

Since June 2015, there is a requirement under DSEAR to assess the risk of gases under pressure (for example in a cylinder) and substances that can corrode metals and reduce the integrity of structures. If, following risk assessment there remains a significant risk, then suitable control and mitigation measures should be implemented. Any substances with intrinsic hazards that are used or present, should already have in place procedures for their safe use under the general requirements of the Health and Safety at Work etc Act 1974 and the Management of Health and Safety at Work Regulations 1999. The LFG industry is unlikely to have the gases under pressure hazard class (defined under the Classification, Labelling and Packaging of Chemicals (Amendments to Secondary Legislation) Regulations 2015 (CLP Regs). However, substances classified as corrosive to metals under CLP Regs could include LFG condensate and acid gases and should require an assessment to ensure integrity remains for any metal structures including pumps, valves and knock-out pots.

The HSE produce a technical note (http://www.hse.gov.uk/comah/sragtech/techmeasmaterial.htm) that covers corrosion of materials and the selection of materials for construction.

2. Risk Assessment

- DSEAR Hazard – Dangerous substance that could lead to fire, explosions, corrosion of metals
- Risk Assessment – Indentification of potential LFG release
  – Unavoidable, intentional or forseeable gas release
  – Elimination of risk
- Ignition sources – Hot surfaces, electrostatic, unprotected electrical instruments, smoking, pilots
- Labelling – Marking of place where explosive atmosphere can occur

The risk assessment requirements of DSEAR should already have been largely met by compliance with the Management of Health & Safety at Work (MHSW) Regulations 1999. Risk assessment should be suitable and sufficient, and updated as activities or practices change. An important principle is to separate storage areas from process areas where the two occur on the same or shared premises.

When considering risks from releases of dangerous substances, the following should be considered;

- Unavoidable releases;
- Intentional releases; and
- Foreseeable releases;

Additionally, the assessment should consider the likelihood of an explosive atmosphere forming and how long it is likely to remain. To identify hazardous and non-hazardous areas, and then subsequently assign zones to those areas classified as hazardous, an assessment should consider:

- the hazardous properties of the dangerous substances involved;
- the amount of dangerous substances involved;
- the work processes, and their interactions, including any cleaning, repair or maintenance activities;
- the temperatures and pressures at which the dangerous substances will be handled;
- the containment system and controls provided to prevent liquids, gases, vapours or dusts escaping into the general atmosphere of the workplace;
- any explosive atmosphere formed within an enclosed plant or storage vessel; and
- any measures provided to ensure that any explosive atmosphere does not persist for an extended time, for example, by the introduction of ventilation.

When special precautions are required, for example to allow short-term maintenance or repair, there is no requirement to draw up a revised area classification plan but there is still a requirement to take a proportionate approach to risk and assess the short-term conditions. Some potential sources of release may be so small that it is not necessary to specify a zoned area. This will be the case if the consequence of an ignition following a release is unlikely to cause danger to people in the vicinity. For example, if a dangerous substance is being carried through a seamless pipe, and that pipe has been properly installed and maintained, it is extremely unlikely that the substance will be released, so an explosive atmosphere would not be expected to occur from this source and the area surrounding the pipe would not be considered as hazardous.

3. Area Classification

- Determining the grades of release of landfill gas – continuous, primary or secondary
- Determine Zone Numbers – considers the probability of a release
- Consider the ventiliation aspects of a probable release
- Calculate the Zone radius either through examples or via calculation

3.1 Introduction

The first step to comply with DSEAR is to undertake an area classification of the site, without which, the other necessary steps cannot be taken. The key steps are:

- Conduct **risk assessments** of activities involving flammable materials and establish whether the exisiting safe systems of work are adequate;
- Study and consider **risk reduction** opportunities;
- Record the measures already in place (or required to be implemented) to **control ignition sources**;
- Justify the existing electrical and non-electrical equipment in the zoned areas;
- Ensure new equipment (both electrical and non-electrical) is **ATEX-marked**;
- Set up an **inspection system** against (British Standard, 2014) for electrical equipment and a similar system for non-electrical equipment;
- Ensure staff are adequately **trained**; and
- Ensure hazardous areas are **marked** where appropriate.

The primary purpose of area classification of a hazardous area is to allow the selection of suitable electrical and non-electrical apparatus as well as identifying areas where additional precautions are required as a result of the explosion risk. Within this Landfill ICoP, a ‘hazardous area’ is one in which a flammable gas/air mixture is, or could be, present.

3.2 Grades of Release

The potential releases of flammable materials are assigned 'grades of release' from (British Standard, 2015) with descriptive and implied definitions from (Energy Institute, 2005).

TABLE 2 – GRADES OF RELEASE

Grade of Release	Definition	Implied Definition from IP15
Continuous	A release which is continuous or is expected to occur frequently or for long periods.	Typically > 1000 hours per year.
Primary	A release which can be expected to occur periodically or occasionally during normal operation.	Typically, between 10 and 1000 hours/year.
Secondary	A release which is not expected to occur during normal operation and if it does occur, is likely to do so only infrequently and for short.	Typically < 10 hours per year or short periods.

3.3 Zone Definitions

The probability of an explosive atmosphere being present in a given location is assigned a **Zone Number**.

TABLE 3 – ZONE NUMBERS

High Probability of an Explosive Atmosphere		
ZONE 0	A release which can be expected to occur periodically or occasionally during normal operation.	
Medium Probability of an Explosive Atmosphere		
ZONE 1	A place in which an explosive atmosphere consisting of a mixture with air or flammable substances in the form of gas, vapour or mist is likely to occur occasionally in normal operation.	
Low Probability of an Explosive Atmosphere		
ZONE 2	A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only.	

Areas where there is an even lower probability of an explosive atmosphere being present can be classified as non-hazardous but possible catastrophic events leading to the formation of an explosive atmosphere in such areas are still subject to a risk assessment (See Section 2).

3.4 Grades of Release, Zones and Equipment

In open-air unrestricted locations, the following would generally apply:

TABLE 4 – GRADES OF RELEASE AND ZONES

Grade of Release	Corresponding Gas Zone	Zone Definition Used in drawings
Continuous	ZONE 0	
Primary	ZONE 1	
Secondary	ZONE 2	

Electrical equipment manufactured and certified against the ATEX Product Directive is labelled to indicate the '**Category**' in which to select the '**Zone**' in which it may be used.

TABLE 5 – ATEX CATEGORY AND ZONE USE

Atex Category	Permitted Zones of Use	Design Requirements
IG	0, 1, 2	Safe with two Independent Faults or Safe Even when Rare Malfunctions Area Considered.
ID	20, 21, 22*	Safe with two Independent Faults or Safe Even when Rare Malfunctions Area Considered.
IG	1, 2	Safe When Foreseeable Malfunctions are Considered.
2D	21, 22*	Safe When Foreseeable Malfunctions are Considered.
3G	2	Safe in Normal Operation.
3D	22*	Safe in Normal Operation.

*Zones 20, 21 and 22 refer to dusts and are not discussed further in this icop

The grade of release and zone are not synonymous. Poor ventilation may result in a more stringent zone (typical of pits, trenches and indoor situations where ventilation is limited). High levels of ventilation (e.g. local extract ventilation) may be used to allow a less stringent zone classification to be defined.

3.5 Catastrophic Failures

It is important to note that area classification only deals with reasonably foreseeable events and does not consider highly improbable ('catastrophic') events. (British Standard, 2015) defines 'catastrophic' failures as "beyond the concept of abnormality dealt with in the standard" and lists "the rupture of a process vessel or pipeline and events that are not predictable" as examples. Thus, a 'catastrophic' failure may cause an explosive atmosphere to be present in an area defined by area classification as 'non-hazardous' and such situations are subject to a risk assessment by the operator under other legislation. Consequently, catastrophic failures are outside the scope of this ICoP.

The extent of the zone is dependent on several factors, e.g. the properties of the flammable materials, process pressure, leak aperture, ventilation, safety factors applied and etc.

The process of area classification, therefore, involves the identification of all flammable materials, the identification and grading of all releases of flammable material, the assessment of the level of ventilation and/or housekeeping and the determination of the resulting types and extents of the zones. The allocation of zones enables the correct equipment, practices and procedures to be applied to protect the health and safety of the workers concerned with the facility.

3.6 Information Required for Area Classification

Area classification should be carried out by those who have knowledge of the properties of LFG and the process and the equipment, in consultation, as appropriate, with safety, electrical, mechanical and other engineering personnel.

This ICoP builds upon previous guidance for classifying areas in which there may be an explosive gas atmosphere and on the extent of Zones 0, 1 and 2. However, BS EN 60079-10-1:2015 provides opportunities to refine calculations to consider release in freely ventilated outdoor locations where the release characteristics and ventilation velocity provides dilution opportunities to reconsider zones. Some LFG operators argue that such an approach can be applied to LFG field applications such as wells. Clearly, this ICoP provides a conservative general approach but also provides the information to calculate alternative specific zoning around LFG infrastructure where justification can be identified and robustly defended in all circumstances.

It is important to note that LFG production changes over time, that operational parameters change as a result and that infrastructure is subject to external physical stresses and external environmental conditions both in short time periods and over longer timescales. Therefore, reviews should be carried out frequently during the life and operation of the plant, especially when less conservative and robust procedures might be justified.
An example of a method for recording the area classification is given in Table 6 below. Its use is not mandatory, but it may be useful where more unusual situations occur.

TABLE 6 – EXAMPLE OF AREA CLASSIFICATION AREAS RECORDING

<table>
<tr><th colspan="3">Corresponding Gas Zone:</th><th colspan="6">Drawing:</th><th colspan="4">Flammable Material:
Landfill Gas</th></tr>
<tr><td></td><td colspan="3">Release</td><td colspan="2">Operating Temp. & Press.</td><td colspan="3">Ventilation</td><td colspan="3">Hazardous Area</td><td></td></tr>
<tr><td rowspan="2">No</td><td rowspan="2">Plant item</td><td rowspan="2">Location</td><td rowspan="2">Grade</td><td rowspan="2">°C</td><td rowspan="2">mbar</td><td rowspan="2">Type</td><td rowspan="2">Degree</td><td rowspan="2">Availability</td><td rowspan="2">Zone No.</td><td colspan="2">Zone Radius (m)</td><td rowspan="2">See Note</td></tr>
<tr><td>Vertical</td><td>Horizontal</td></tr>
<tr><td>1</td><td>Pin well (In pipe)</td><td>On field</td><td>Secondary</td><td>10</td><td>20</td><td>Natural</td><td>Medium</td><td>Good</td><td>2</td><td>2.2</td><td>2.2</td><td rowspan="2"></td></tr>
<tr><td>2</td><td>Pin well (Seal)</td><td>North field boundary</td><td>Secondary</td><td>10</td><td>70</td><td>Natural</td><td>Medium</td><td>Good</td><td>2</td><td>2.2</td><td>2.2</td></tr>
<tr><td>3</td><td colspan="12"></td></tr>
</table>

Column explanation;

(1) Plant item: For example, pin well, manifold, etc. and should include the relevant part of the item, for example "interior", "bentonite seal". A single plant item may have two or more lines.
(2) Location: where the item is physically located, e.g. "gas compound", "various locations on gas field";
(3) Grade: the grade of release, i.e. 'continuous', 'primary' or 'secondary' (See Table 2);
(4) Operating temperature and pressure: Usually "ambient" and pressure, (low suction, low positive pressure)
(5) Ventilation type: 'natural', 'artificial' or 'both';
(6) Ventilation degree: 'high', medium' or 'low'. Outdoors, ventilation is 'medium' degree, whereas indoors it will be 'low' if there is very little ventilation, 'medium' with, say, 12 air changes/hour and only 'high' where the air flow is so strong as to effectively dilute any release almost immediately to below its LEL, giving rise to a dilution zone of negligible size;
(7) Ventilation availability: 'good', 'fair' or 'poor'. Outdoors, availability is 'good'; indoors, where forced ventilation is used, it will generally only be 'good' if there is a standby fan that starts automatically if the duty fan fails.
(8) Zone number: '0', '1' or '2' (See Table 3);
(9) Zone extent: the size of the zone; and
(10) See note #: should identify a reference to this document perhaps to aid justification and include any non-standard features and/or reasons for deviations from the ICoP.

3.7 Use of Calculation Methods

In practice, Zone extents for general situations involving leaks of landfill gas in outdoor locations can most easily be found by utilising the equations and examples shown in Appendix II. Examples where the calculation method is appropriate are:

- sample points;
- dipping points; and
- leaks from Bentonite seals;

where the parameters are other than those given in the examples in this ICoP. These calculation methods should not be used for joints and valve glands, since these are dealt with in Section 3.9 below.

(IGEM, 2013) calculates the zone extents associated with a natural gas installation, rounded up to the nearest 0.1 m where the value is less than 10 m, to add a conservative element to the evaluation.

3.8 Uncontained Landfill Area

Landfill sites are essentially contained vessels in which landfill gas is generated. LFG extraction exerts a suction pressure up to 80 mbarg via pipelines from the gas compound to wells and trenches within the contained landfill. Failure to apply the suction pressure relative to atmospheric pressure creates a positive pressure build up within the landfill, which is a continuous grade release, allowing LFG to move and take the route of least resistance to the surface, potentially resulting in a LFG and air mixture.

At landfill operational areas without containment capping and with LFG collection facilities either absent, unconnected or switched off, a potential non-uniform release over the whole area could be evident.

In practice, any such release or leak follows fissures or imperfections and so assigning Zone 0 over the whole uncapped waste surface is both impractical and unlikely. Any leaks into a well-ventilated open location, as is the case over the vast majority of the site, provide a very low risk of explosion and any ignition is highly unlikely to have a serious explosive consequence. Higher release rates may be encountered, for example, close to:

- exposed drainage blankets;
- exposed protection layers;
- zones around leachate extraction structures; and
- areas of generally poor compaction;

Although the potential should be recognised, experience over many years shows that such events are very rare and very difficult to predict. Enhanced monitoring procedures required for LFG management (see Appendix I) require regular low level (ppm level) testing and this has shown that significant concentrations of methane occur only within a few centimetres of the ground and are rarely within the flammable range. Furthermore, such higher rate releases and likelihood of accidental ignition creates even lower risk and so the zone will be assumed to be of negligible extent, and it is not necessary therefore to be shown on any area classification drawings.

3.9 Zoning Around Flanges, Screwed Fittings, Joints and Valves

Zoning – Flanges, Screwed Fittings, Joints & Valves

Pressure <80mbarg – **0.1m Zone 2** (ventilated/outdoor, regularly inspected, low risk)

Pressure <80mbarg – **1.0m Zone 2** (ventilated/outdoor, rarely inspected, med risk)

Guidance in (IGEM, 2013) indicates that, for pressures up to 2 barg, a 0.5 m Zone 2 is applicable to account for unintentional leaks around all joints and valves located in a freely-ventilated outdoor location and not subject to adverse conditions such as thermal shock, excessive vibration, etc. However, the actual maximum pressure of LFG is approximately 80 mbarg in the collection side and up to about 350 mbarg in the power generation side. **Smaller zone radii of 0.1 m for all pressures up to 80 mbarg and 0.2 m up to 350 mbarg can be calculated using the equations in Appendix II assuming a leak aperture of 0.25 mm^2**.

These zone radii may be applied where pipework is correctly installed and regularly inspected. Where adverse conditions may apply (e.g. vibration, corrosion) and pipework is not regularly inspected, then the **Zone 2 radius of 1.0 m** should be used. An inspection interval of not less than 6 months is recommended to cover changing atmospheric and environmental conditions.

LFG infrastructure best practice design guidance does not consider the use of metal pipework due to the corrosive nature of landfill gas (and condensate) on metal pipes that are more vulnerable to chemical attack from the inside. However, high-grade materials are used within the compound facility and mechanical elements of the flaring and utilisation system following considerations.

Gas flow measuring devices such as orifice plates should be treated as a pair of flanges for the purpose of area classification. Flow monitoring points whereby pitot tubes or similar are inserted within plugged holes during monitoring should be considered in Section 3.11.

All plastic pipework jointing within the industry have either electro-fusion (EF)couplings or butt-fusion welded joints. These are highly reliable if a construction quality assurance (CQA) procedure has been followed and are not considered as a source of release. However, the installation of pipework using these techniques may involve working on 'live' pipes that are temporarily sealed using an inflatable bladder (pig) or by squeezing the pipework. Such activities and other construction/ maintenance activities are outside the scope of this ICoP.

The use of any uncertified equipment in zoned areas is not dealt with in this ICoP and should be discouraged. However, to provide some guidance where there may be an absolute necessity and to facilitate a risk assessment of whether uncertified equipment may remain in a Zone 2 area, (IGEM, 2013) provides some guidance and follows the approach for individual joints and valves whereby the likelihood of a release is very unlikely and may not warrant classification as hazardous. Where a risk-based approach is followed, such items may not require a specific hazardous area unless several possible leak sources together could be anticipated. As a guide, where there are greater than 10 leak sources (from valves and flanges) within close proximity (i.e. where the Zone 2 areas overlap), the area should be classified as a Zone 2 area.

- pressures are low and, on the collection side, the gas is usually at a suction pressure;
- there are no operations leading to thermal shock or pressure hammer;
- the pipes are generally well-protected;
- there is usually low occupancy.

Therefore, non-classification of joints and valves aligns with the general principle adopted in Section 3.8, whereby releases from uncapped areas (which could exceed the release rate from a flange or valve in certain cases) are also not classified.

3.10 Sampling

3.10.1 Perimeter Monitoring Boreholes

Zoning – Perimeter Monitoring Boreholes

Consistent/infrequent LFG >LEL – **Zone 1** internally

Rarely elevated – **Zone 2** internally

Positive pressure up to 6mbarg – **0.3m** external zone

These are outside the waste boundary, used to monitor regularly for LFG migration and therefore LFG is usually absent, are usually unconnected to the extraction system but are capped and sealed.

The LFG within the borehole may be a small volume and above the LEL. On poorly contained sites, gas extraction influence on the borehole may be evident and could provide a suction pressure relative to atmospheric. On modern landfills, a slight positive pressure relative to atmospheric could be evident.

Where individual perimeter boreholes are known to have a history of consistent or frequent elevated levels of LFG above the LEL, **a Zone 1 should be applied internally, otherwise, a Zone 2 would apply**.

Most sampling points on perimeter boreholes have a 3 mm orifice.

The positive pressure is much less than the peak of 80 mbarg typically found in gas wells. The external zone caused by opening the sample point are dependent on the positive pressure and can be taken as 0.3 m up to 6 mbarg.

Where end seals or plugs require removal for investigations or water sampling or extraction, a different-sized zone applies for this and should be calculated on a site-specific basis using the calculations within Appendix II.

3.10.2 In-waste Gas Extraction Wells

Zoning – In-waste Gas Extraction Wells

Pressure 0-80mbarg – **0.6m Zone 2** (ventilated/outdoor, regularly inspected, low risk)

Sampling – **Zone 1** of negligible extent

Sampling is normally performed by opening the sample point (a 3 mm diameter hole) and attaching a flexible tube that allows a small volume of gas to be drawn through a hand-held gas analyser. The flammable gas is then vented to atmosphere. This will produce a Zone 1, but of negligible extent.

Sampling is a normal operation and opening the sample point would normally be classified as a primary grade release, but the suction pressure of the well reduces this to a secondary grade release. Should a positive pressure exist, and the sample point be left open, then a LFG release at up to 80 mbarg positive pressure (and at 60% v/v methane) could escape. Calculations based on the equations in Appendix II give a **Zone 2 radius of 0.6 m for dilution to 0.5 LEL**.

Intrinsically safe gas analysers are now common, but consideration should be given to the risk of using any uncertified gas analyser. Although outside the scope of this document, it is noted that the major risk from an ignition (itself a low risk) is a situation when the gas being sampled is within its explosive range, potentially allowing a flame to burn back into the pipe.

3.11 Dipping and Flow Monitoring Points

Zoning – Dipping Points

Pressure <80mbarg – **3.6m Zone 2** at 25mm hole, (**5.8m** at 50mm hole)

Dipping points are located on gas wells and knock-out pots. Similarly, Gas Flow Monitoring Points (other than orifice plates which are considered in Section 3.9) are located on the connection pipelines. Both are typically a 25mm (1”) plug which is removed and a dipping probe (or flow measuring device) is lowered in, for a few minutes. As with sampling, dipping and flow measurement is a normal operation and would normally be classified as a primary grade release, but the suction pressure induced by the extraction system reduces this to a secondary grade release.

Where a positive pressure may exist, LFG at up to 80 mbarg could escape through a hole of outside diameter 25 mm (1”) (with internal diameter of 17 mm). Calculations based on the equations in Appendix II give a **Zone 2 radius of 3.6 m for dilution to 0.5 LEL for this orifice size. A larger 50 mm (2”) plug (internal diameter 34 mm) gives a 5.8 m Zone 2**.

This zone radius exceeds that calculated for leaks around the Bentonite seal (2.2 m – see Section 3.12.2) and will be unacceptably large for certain locations. If the 3.6 m zone is impractical due to the need to use fixed uncertified electrical equipment for example, within a potentially explosive atmosphere, there are several options to address this;

Option 1: wait until the well is at a suction (negative) pressure before performing the dipping;

Option 2: isolate the nearby fixed electrical equipment; or

Option 3: perform a risk assessment (by a qualified person) to determine whether it is acceptable to allow the nearby fixed electrical equipment to remain energised.

Where dipping does extend the 2.2 m Zone 2, it can be justified by being performed under a Safe Operating Procedure (SOP) that ensures potential ignition sources (e.g. vehicles, mobile phones) are excluded from the larger zone while dipping is in progress.

3.12 Vertical Gas Well and Well Head

Zoning – Gas Wells

Positive pressure >10hr year, interior **Zone 1**

Bentonite leak gives **Zone 2 of 2.2m** radius

3.12.1 Operation of the Gas Well

Vertical gas wells are the most common of LFG extraction techniques with several acceptable designs achieving best practice status. A simplified vertical well is shown in Figure 2 below. The inner liner and outer wellhead are usually separated by an airtight seal consisting of an inorganic Bentonite clay.

The fabricated wellhead consists of a regulating valve and sample tap. The valve may be a butterfly type fixed between flanges or a ball or gate type with threaded connections. Flexible joints are usually fitted where the wellhead enters the liner and between the wellhead and the gas collection pipe to allow for settlement of the waste mass.

A dipping point is usually fitted with a screwed 1” (25 mm) plug that can be removed for dipping the gas well (see Section 3.11).

Under normal operation, gas wells are operated under a suction pressure of <30 mbar. Monitoring and control management would minimise the air ingress to the well but cannot be reliably prevented and the presence of air in the landfill gas must be considered likely although unadvisable. Furthermore, as landfill gas diminishes over time or where gas extraction is ceased temporarily for landfill operational reasons, air ingress is more likely via imperfections or damaged infrastructure or where valves, flanges or sampling taps may have been left open.

Positive pressure is possible under foreseeable abnormal conditions, which may occur relatively frequently where gas production in the waste around the well is greater than the flowrate from the well (across the control valve). A positive pressure may slowly build up with a typical positive pressure between 10 and 80 mbarg (excluding 'catastrophic' conditions). Therefore, a worse case of 80 mbarg has been used in calculations.

Since a positive pressure can be relatively common in older less productive wells, the area classification around the well will assume that a positive pressure exists for more than 10 hours a year.

3.12.2 Zoning of the Gas Well

The following releases are identified:

TABLE 7 – GRADE RELEASES

Grade of Release	Description
Continuous	None.
Primary	Air ingress into the landfill resulting in a mixture within the flammable range. Normally, a primary grade release implies the fuel gas leaking into the air. However, the landfill gas is usually at a lower pressure than the air, so leaking of air into the landfill gas is, technically, a "release". It is primary grade because, although unwanted, it can frequently occur.
Secondary	Occurs when a leak exits the well under positive pressure. These may include via leaks in Bentonite seal due to drying out and/or poor compaction, opening sampling taps, flanges (leaking gasket), valve stem (leaking seal), joints on flexible hose (poor fastening clips), threaded pipe connections used on temporary gas collection systems. Leaking gaskets and sampling are dealt with in Section 3.10.

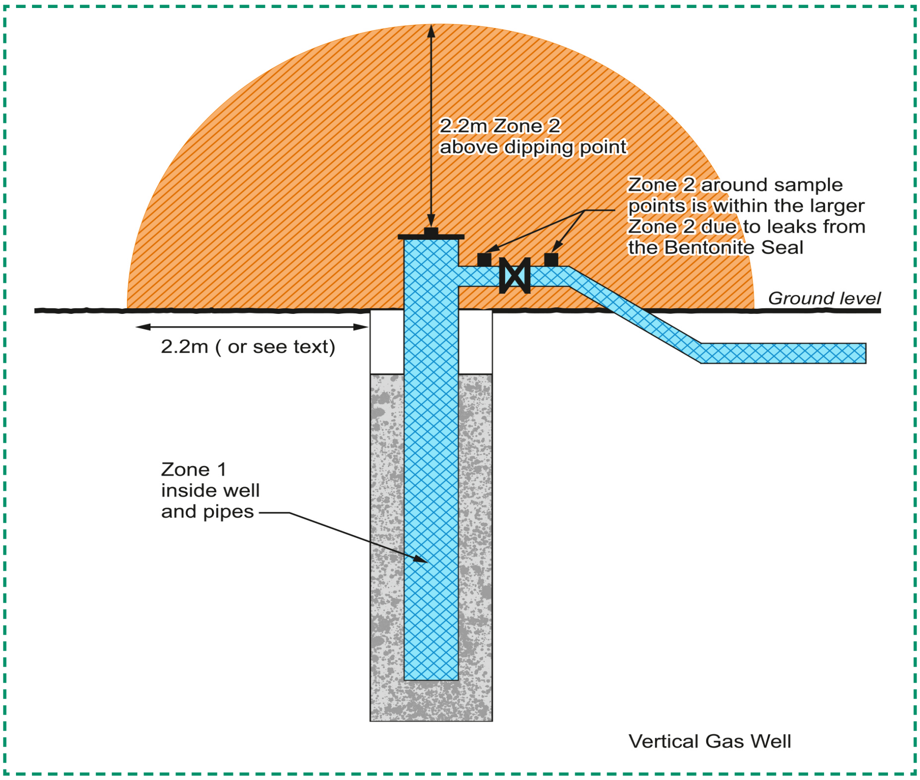


FIGURE 2 – VERTICAL GAS WELL ZONING

A well drilled into new waste is likely to contain a potentially explosive atmosphere. Once in production, the inside of the gas well is designated a **hazardous area** because ingress of air into the gas well is not uncommon and this could result in a potentially explosive atmosphere. Ingress results from a poor Bentonite seal and/or over extraction allowing air being drawn in via the landfill. In addition, older gas wells may have significantly higher oxygen levels than fully productive wells. **For this reason, the interior is designated a Zone 1**. A **Zone 2** is not appropriate since an explosive atmosphere could occur for more than 10 h/yr.

The gas well is usually under suction, so emissions of landfill gas will not normally occur even if there is a leak path. However, where a well may exhibit a positive pressure, the landfill gas may build and can leak out. Of the secondary grade releases, leaks from the Bentonite seal or sample points give the largest mass release rates. However, the probabilities of these two events are different.

Leaks from Bentonite seal:
Such a release requires two abnormal conditions: the well having a positive pressure and failure of the seal.
Area classification does not normally consider two independent abnormal events, but a well with positive pressure is unlikely though possible, in normal operation. Therefore, leaks from the seal will be considered. Furthermore, as landfill gas production diminishes over the decades, the potential for gas levels to be within the explosive range and at a positive pressure become more likely and careful re-assessment should be undertaken where monitoring data suggests this is required.

Quantifying the leak aperture is difficult and unforeseeable and could for example be the opening of a fissure, the size of which cannot be realistically estimated. A worst-case scenario may be a steady-state situation whereby the entire well production leaks out. Such individual well production values could be up to 30 m^3/h of landfill gas. This volume flow rate equates to a mass flow rate of 0.0094 kg/s. A zone radius calculation based on equations in Appendix II gives a **Zone 2 of 2.2m** in all directions from the point of release. This Zone 2 encompasses smaller zones from sampling and leaks. Assuming a lower leak rate of 25 m^3/h, this would give a zone radius of 2 m.

Some gas wells have different maximum yield rates. Provided the worst-case yield can be reliably predicted based on experience and/or measurement, then the **Zone 2** around the gas well has the radius shown in Table 8 below. Note that the lower values generally apply to pin wells rather than gas wells.

TABLE 8 – ZONE RADII AROUND WELLS DUE TO BENTONITE FAILURE

Zone Radii Around Wells Due to Failure of the Bentonite Seal	
Release Rate of Well (m^3/hr)	Radius of Zone 2 (x meters)*
1	0.4
2	0.5
3	0.7
4	0.8
5	0.9
10	1.3
15	1.6
20	1.8
25	2.0
30	2.2
40	2.6
50	30

* Rounded up to 0.1m

Where smaller values from Table 10 are taken, dipping activities may increase the zone extent beyond that from the Bentonite seal. Where the Bentonite seal is assessed as not subject to complete failure (e.g. increased depth, stable waste, regularly hydrated) a smaller zone may be assigned, equal to that of a flange. However, other releases (e.g. sampling, dipping) should still be considered.

Many modern wells utilise 'boots' or 'top hats; whereby the plastic membrane (usually a grade of polyethylene) capping liner is welded to the well or a collar that provides a gas-tight seal. Such a seal provides further security and reliability for sealing the well and is less reliant on a Bentonite seal and the dissociation that can cause fissures and leaks.

Not all capping methods utilise polyethylene. For example, geosynthetic clay liner (GCL) that comprises a hessian-based mat that can seal holes caused by movement of the gas well, should provide the same technical standard, but the ability to contain gas/air may vary and should be considered separately. All should be treated as a secondary grade release (leading to a Zone 2, as for Bentonite) or as 'catastrophic' (i.e. highly improbable), leading to a non-hazardous area around the seal.

3.13 Pin Wells

Zoning – Pin Wells

Internal pipe work is **Zone 1**

Around seal is **Zone 2 of 2.2m** radius

3.13.1 Sacrificial Pin (or Scavenger) Well in Uncapped Areas

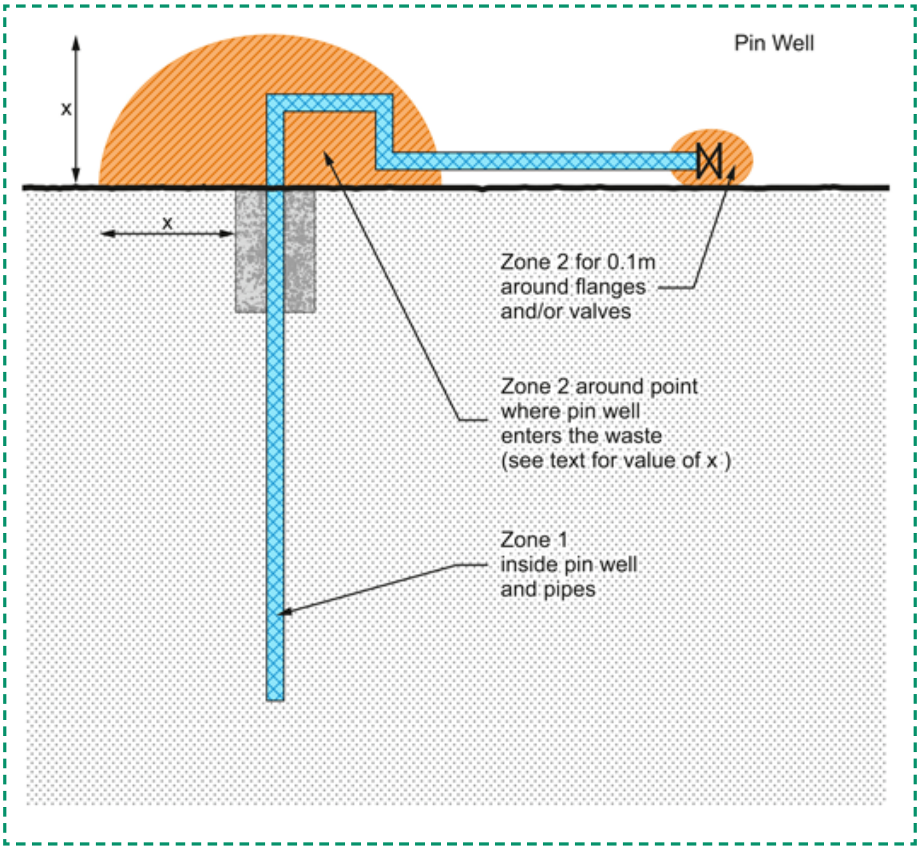


FIGURE 3 – PIN WELL ZONING

A pin well is constructed by piling a metal spike (typically 6m in length) into the waste, withdrawing and inserting a section of pipe perforated at the bottom section. A Bentonite seal is sometimes used to seal around the hole but not always. A valve is connected either at the well head or further along the collection pipework. Like the gas well, it should be classified as **Zone 1** internally. Pin wells are generally temporary and are usually covered over as waste infilling progresses. There are no external continuous or primary grade releases. The two secondary grade releases associated with pin wells are:

- valve seal (if a valve is fitted at the wellhead); and
- leaks through the Bentonite seal.

A small Zone 2 is required around the valve seal (see Section 3.12). The gas flow from a pin well is likely to be much less than from a gas well with values of 5 m^3/h identified as a maximum. If this leaks out around the side of the pipe, the zone radii (shown as X in Figure 3) from Table 10 can be applied, depending on the release rate of the pin well. Such wells are often employed within operational areas where the waste is freshly landfilled and the opportunity for hydrogen generation is more likely. Any detection in significant quantities of hydrogen should reassess the area classification.

3.13.2 Pin Wells in Capped Areas

Pin wells in capped areas are treated as gas wells (see Section 3.12). Therefore, a **Zone 2 for 2.2** m horizontally and vertically around the seal should be utilised.

3.14 Horizontal Gas Scavenger Wells

Zoning – Horizontal Wells

Internal pipe work is **Zone 1**

Zone 2 of 2.2m radius around seal

The area classification of horizontal gas scavenger wells is the same as those for vertical gas wells.

3.14.1 Description

Horizontal wells are generally used as 'sacrificial' or temporary gas collection wells installed in temporary/uncapped active landfilling areas and consist of fusion-welded perforated pipes laid horizontally, spaced between 5 to 20 metres apart. A length of solid pipe is used at the point where it leaves the waste mass to prevent air being drawn into the pipe. A seal is then formed between the waste mass and the pipework using either Bentonite (or equivalent) or an MDPE (or similar) sleeve-type 'top hat'. Pipes normally terminate at a valved connection in a collection manifold chamber.

Under normal operation, there may be a high risk of air ingress through the waste from those closest to the waste surface. Suction on scavenger pipes is likely to be <10 mbarg although site-specific applications may dictate the use of higher levels of suction. If LFG extraction is lost or stopped, positive pressure may rise to 80 mbar above atmospheric, within the pipe. Any leakage may occur at the rubber coupling or where the pipe exits the ground and potentially through the uncapped waste above. Gas scavenger pipes are normally very low maintenance with only gas monitoring and valve operation activities required at the gas collection manifold. Maintenance operations may include the connection and disconnection of the horizontal pipes or repairs to any pipework damage.

Most horizontal scavenger wells are installed then covered with more waste, in which case the situation outside the pipe is similar to an uncapped landfill area (see Section 3.8).

3.14.2 Zoning

Inside the horizontal scavenger well is Zone 1, for the same reason as the vertical gas well. A Zone 2 occurs where the horizontal scavenger well comes through the lining for connection to the main gas collection pipework. The radius of the **Zone 2** is the same as for the Bentonite seal of a gas well, i.e. **2.2 m** (see Section 3.12).

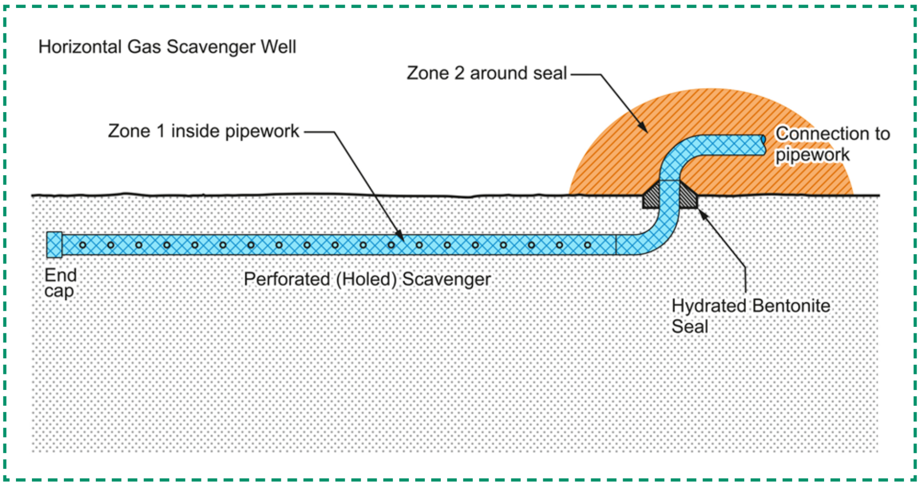


FIGURE 4 – HORIZONTAL WELL ZONING

3.15 Leachate Wells (Extraction Points)

Zoning – Leachate Wells
Above the leachate level is **Zone 1**
Around the seal is **Zone 2 of 2.2m**

3.15.1 Description

Leachate wells (extraction points) are primarily installed to remove leachate from the base of the waste. However, many are dual use also removing LFG. They are either horizontal, vertical or installed along the slope of the wall (side risers) of the cell, connecting to the leachate drainage blanket in the landfill base. All are all the same in terms of the area classification and are like gas wells. These principles can be applied to the various types of leachate extraction systems.

The side riser pipe is commonly a wide-diameter jointed pipe with no flanged joints between the top and the basal perforated leachate collection chamber. Inside this is a leachate pumping main. A pump (either electric, air-driven or other type) is located in the leachate chamber, in addition to a level float switch or transducer). The float switch (or similar) is used to monitor the levels of leachate at that point. An alternative is to have a separate pipe placed next to the side riser pipe where the float switch (or similar) is located. At a pre-set level, the pump automatically switches on/off with leachate flowing up the internal pipe.

The control system for the pump is located above ground, usually in the vicinity of the leachate extraction point. Under normal operating conditions, negative pressures will be evident, typically <-40 mbarg. When no gas extraction is taking place, positive pressures <80 mbarg could be present.

3.15.2 Zoning

Leachate wells are similar to gas well and the same area classification generally applies, with **a Zone 1 above the leachate level and a Zone 2 below it**. There is an external **Zone 2 of 2.2 m** around the seal (see Section 3.12.2). As for the gas well, removal of the dipping cap when the leachate riser is at a positive pressure gives an unacceptably large potentially explosive atmosphere with a radius of tens of metres, so the cap should only be removed under a considered maintenance procedure (see Section 3.11).

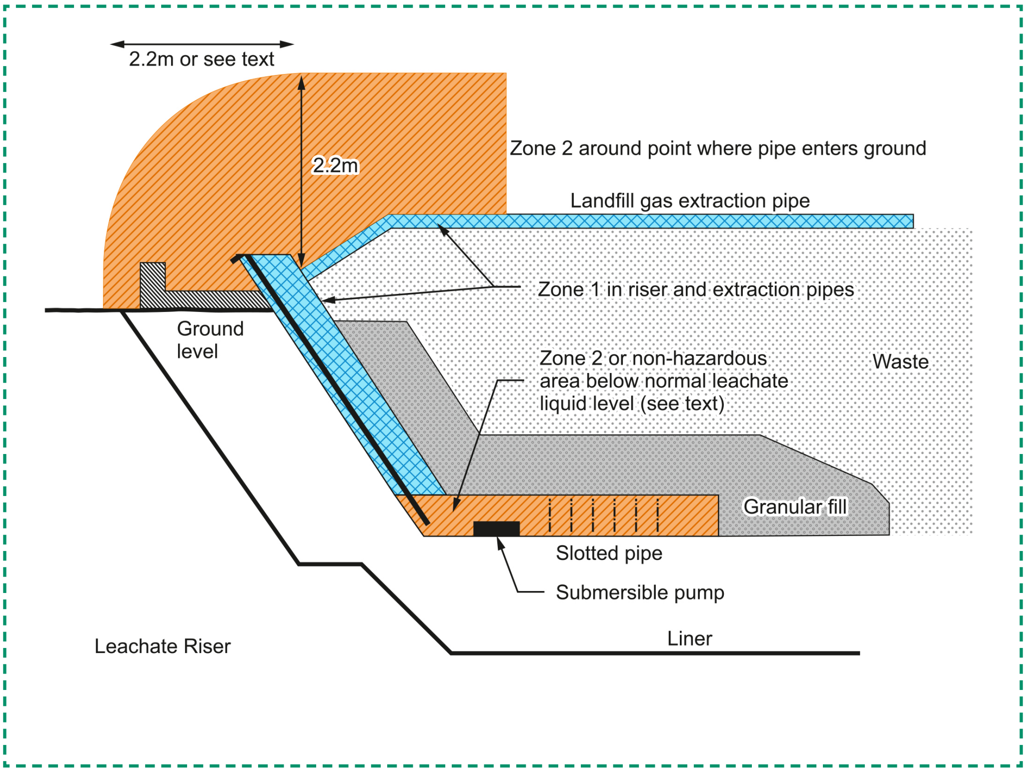


FIGURE 5 – LEACHATE SIDE RISER ZONING

Below the leachate level is Zone 2 by default. However, if the pump is highly designed and very reliable by design and cannot run dry, then the region below the leachate level may be classified as non-hazardous. Alternatively, if a top-fill pump is used and suitable measures such as;

- securing the pump on a 'sledge' prior to being offered into the opening of the leachate extraction point;
- or securing the pump in such a way that it cannot turn over when presented and located in the side riser;

Are taken to ensure it does not fall over when lowered into the well and pump itself dry (thereby becoming a potential ignition source), the region below the liquid level may also be classified as non-hazardous.

Whilst leachate is mainly water-based, it is possible it could contain flammable liquids with a low flash point if such liquids have seeped down through the waste. Whilst unlikely compared to the volume of landfill gas evolved, any potentially explosive atmosphere from leachate vapour is likely to be within the zones defined for landfill gas. Any significant variations with low flashpoint liquids will require further specific assessment.

3.16 Leachate Recirculation

Leachate recirculation involves the reintroduction of leachate to the waste by penetrating the capping and so like gas wells and leachate extraction wells, there is the possibility of leaks around the seal. A **Zone 2 typically of radius 2.2 m** applies (See 3.12.2).

3.17 Gas Collection Manifold

Zoning – Gas Collection Manifold

Internal from inlet pipework is **Zone 1**

Internal pipework from manifold to booster is **Zone 2**

Zone 2 within any enclosure

3.17.1 Description

Gas collection manifolds can be constructed of MDPE (or similar) or steel fabrication and is the collection point for several gas well pipelines prior to connection to a larger gas collection pipeline (or header). Gas monitoring is performed from sampling valves and gas flow adjustment made via valves on each individual well pipeline and on the exit pipe to the manifold.

There are three basic variations:

- Open design, used for above-ground manifolds that do not require protection from unauthorised access;
- Enclosed design used for above-ground manifolds that require security and/or protection. The box design can have mesh or a ventilated cover, others have a solid over; and
- Enclosed below ground chamber completed within the restoration soil. Such box chamber design can have either mesh and ventilated cover or solid lid.

Solid covers do not offer a good degree of ventilation whereas, open mesh or ventilated covers tend to allow flooding or silting up of the manifold chamber. Under normal operation, the manifold is under suction, <-80 mbarg. Fault conditions such as damage to a main collection pipe or loss of the gas extraction system may result in a positive gas pressure relative to atmospheric within the manifold.

3.17.2 Zoning

As previously identified, pipework within gas wells is designated as a **Zone 1 internally**. However, within the manifold where two or more wells are combined, the probability of the mixture being within the explosive range falls due to the likelihood of more than one well supplying explosive range gas being less and a less onerous zone is appropriate. The interior of pipework from the manifold valve downstream all the way to the booster should be designated as a **Zone 2**. However, the **Zone 1** extends from this manifold to the carrier main if the manifold only has one active pipe or because flammable concentrations are detected relatively frequently, e.g. in older sites where the landfill gas production has reduced.

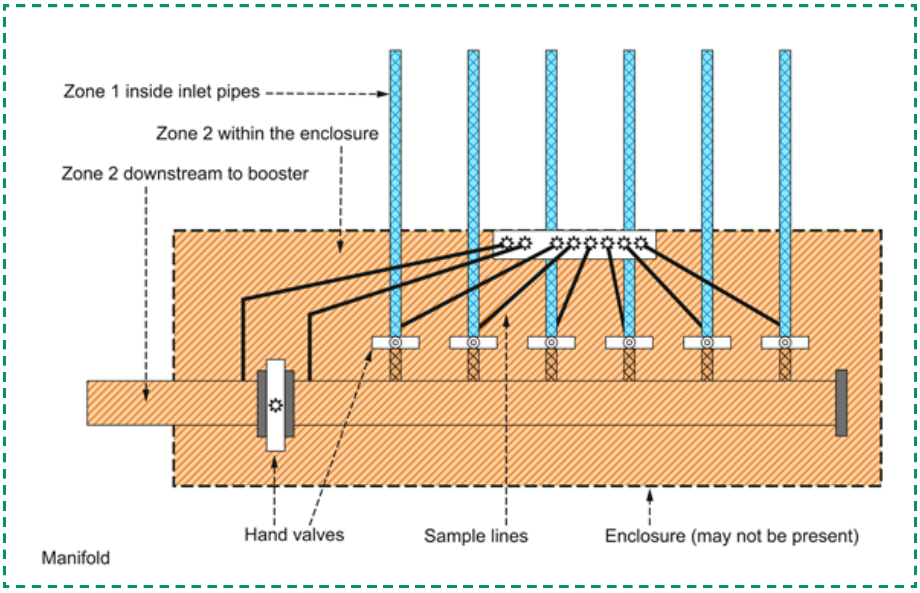


FIGURE 6 – ZONING OF A PIPEWORK MANIFOLD

Externally, the potential releases are secondary grade from;

- Flanges;
- Gas sampling valve stems;
- Condensate drainage plugs;
- Sample points; and
- Flow monitoring points.

Positive landfill gas pressures within the manifold pipework is more likely than in a single gas well, and, for a release to occur, a failure of the containment is also required. Therefore, no zone is applicable around flanges and valves. Removal of the drainage plug, opening of the sample point and flow monitoring point should not be done if the system has a positive pressure, so, again, no external zone is required. However, the enclosure, (if it exists), will be designated a **Zone 2**, since the ventilation could be poor, and any dissipation would be slow potentially reaching a dangerous level of landfill gas. Such scenarios should limit personnel access and be subject to a permit-to-work system.

3.17.3 Pipework from Manifold to Booster

The internal pipework from the manifold to the gas compound is classified as **Zone 2**. At some sites, usually after a shut-down or as gas production is reduced significantly in the aftercare phase, it is not possible to state that an explosive mixture within the pipe does not exceed 10 hours a year. Operators should therefore confirm by monitoring whether Zone 2 designation internally is still appropriate.

With intermittent operation of the gas extraction system that allows air ingress to the system, this potential air/gas mixture slug is relatively short and therefore unlikely that the booster will need to be rated for better than a **Zone 2** application.

3.18 Knock-out Pots

Zoning – Knock-out Pots

Within chamber is **Zone 2**

Outside chamber is **Zone 2**

Around the hatch is **Zone 2 with negligible extent**

3.18.1 Description

The knock-out (KO) pot is constructed from polyethylene (or similar) and acts as an in-line condensate collection vessel, located typically at low points within the main gas service carrier. During normal operation, the pot will be under suction pressure between 40 – 150 mbarg. A positive pressure <80 mbarg is possible under abnormal conditions.
There are three basic variations, which are identical from an area classification perspective:

- A pumped KO pot;
- Vacuumless KO pot; and
- Barometric drain KO pot.

The condensate is drained and collects from the pipework and is pumped out. Older systems may drain naturally to the waste. Condensate (or leachate where present) in some circumstances can liberate dissolved methane into a gas phase. Typically, the pump is automatically activated when the condensate level reaches a certain level and switches off when the condensate is at the required low level. The pump remains submerged except under abnormal conditions. There may be control systems in the KO pot.

Dependent upon the design, there may be a balance pipe between the main body and the inner sleeve to maintain equal pressures in both areas. The top of the knockout pot is housed within an enclosure with an opening lid.

3.18.2 Zoning

For reasons explained in Section 3.17.3, the pipework at this part of the system is a **Zone 2**. Therefore, the main chamber of the knock-out pot is also **Zone 2**. The zoning of a typical knock-out pot is shown in Figure 7 below.

The inner sleeve (if it exists) usually contains air. However, if the condensate is pumped out to below the level of the perforations, then landfill gas can enter the inner sleeve and, if the level of condensate rises again, it will be trapped along with the air. This mixture could be within the explosive range and cannot readily dissipate, so will persist. Thus, a **Zone 1** rather than a zone 2 applies for the inner sleeve above the liquid level, Zone 2 below. However, if a top-fill (as opposed to a bottom-fill) pump is installed below the condensate and there is further protection against the pump becoming unsubmerged by means of a level transducer, then the area below the liquid level is a non-hazardous area as explained within Section 13.15.2.

Leaks into the outer enclosure over the knock-out pot (via imperfectly sealed cable entries for example) are unlikely because the gas underneath is normally under negative pressure (main section) or atmospheric pressure (inner sleeve). Two faults are required (gas pipe at a positive pressure and failure of the seal) but ventilation is usually poor from this enclosure. As a precaution, a **Zone 2** is suggested with a further **Zone 2 of negligible extent** around the hatch.

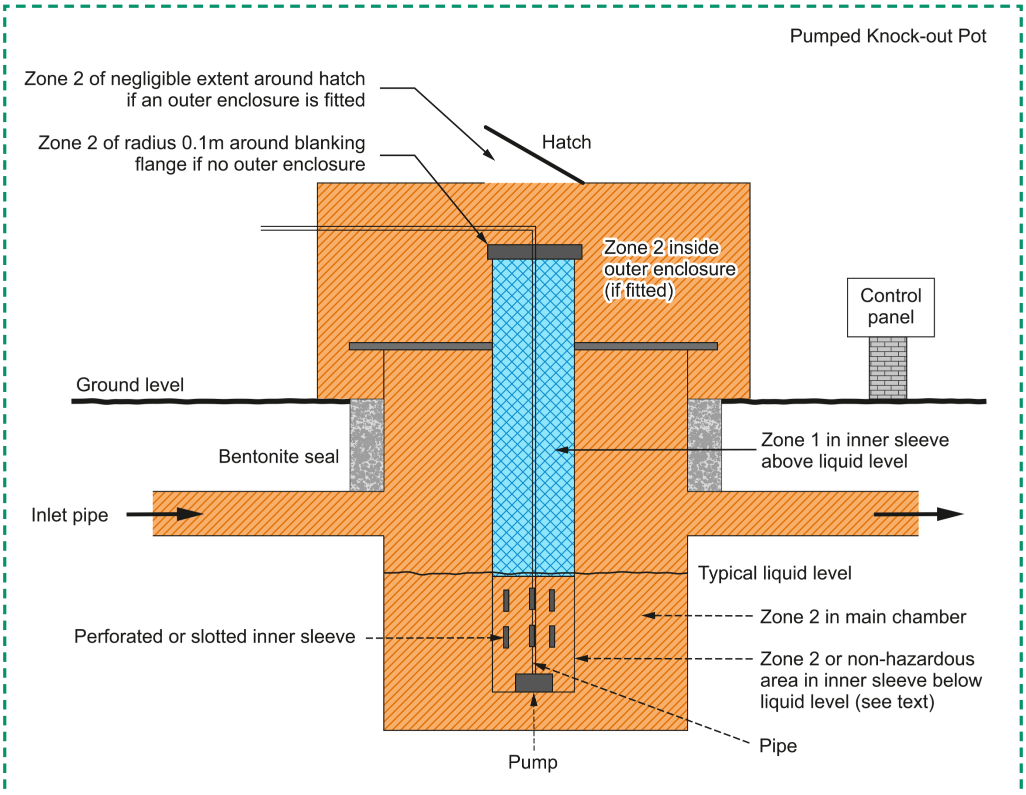


FIGURE 7 - ZONING AROUND A PUMPED KNOCK-OUT POT

Many knock-out pots are sunk into waste, in which case there is a zone around the Bentonite seal similar to those identified within Section 3.15.2.

3.19 Passive Vents

There are few sites now with open vents allowing LFG to dissipate to atmosphere. However, as LFG production slowly diminishes within landfills over time, there may be a need to reconsider such installations with added treatment systems such as biofilters to treat low levels of methane at <15% v/v and therefore potentially within the explosive range.

Vents were typically installed using 150 mm (6") pipe with a static or aspiromatic (rotating) cowl on the top usually with a flame arrestor fitted. The discharge height is typically between 1 m and 3 m. Vents should only ever have been installed in relatively unproductive areas where the gas quality is low and positive flow rates are very low and likely to be <5 m^3/h. Based on this value and the equations in Appendix II, a **Zone of extent of 1.3 m radius** is applicable for dilution to 0.25 LEL. This will be a **Zone 0**, since gas emission is a continuous grade release (although atmospheric pressure changes can have variable impacts).

3.20 Drilling Operations

Drilling operations are usually undertaken by outside contractors. Such activities are outside the scope of this ICoP and should be considered through risk assessment and Permit to Work Systems as part of the responsibilities of the specialist contractor. However, the principles contained within this document should be utilized in order to assess these risks.

3.21 Overview of Power Generation Infrastructure

LFG from the field gas collection system is transported via main collection pipelines (headers) towards the booster fan within a secure gas compound (Utilisation Plant). LFG is extracted at a small suction pressure (<-150 mbarg) supplied by the booster fan, which then generates a positive pressure (<350 mbarg) for reciprocating engines. A typical process flow is shown in Figure 8.

Where too lean LFG with high oxygen or low methane, the engine cannot operate, and generation stops. Some engines are designed to operate at lower calorific values than others. Where engines are not able to operate, lean gas is usually diverted to a high temperature flare for treatment prior to discharge to atmosphere.

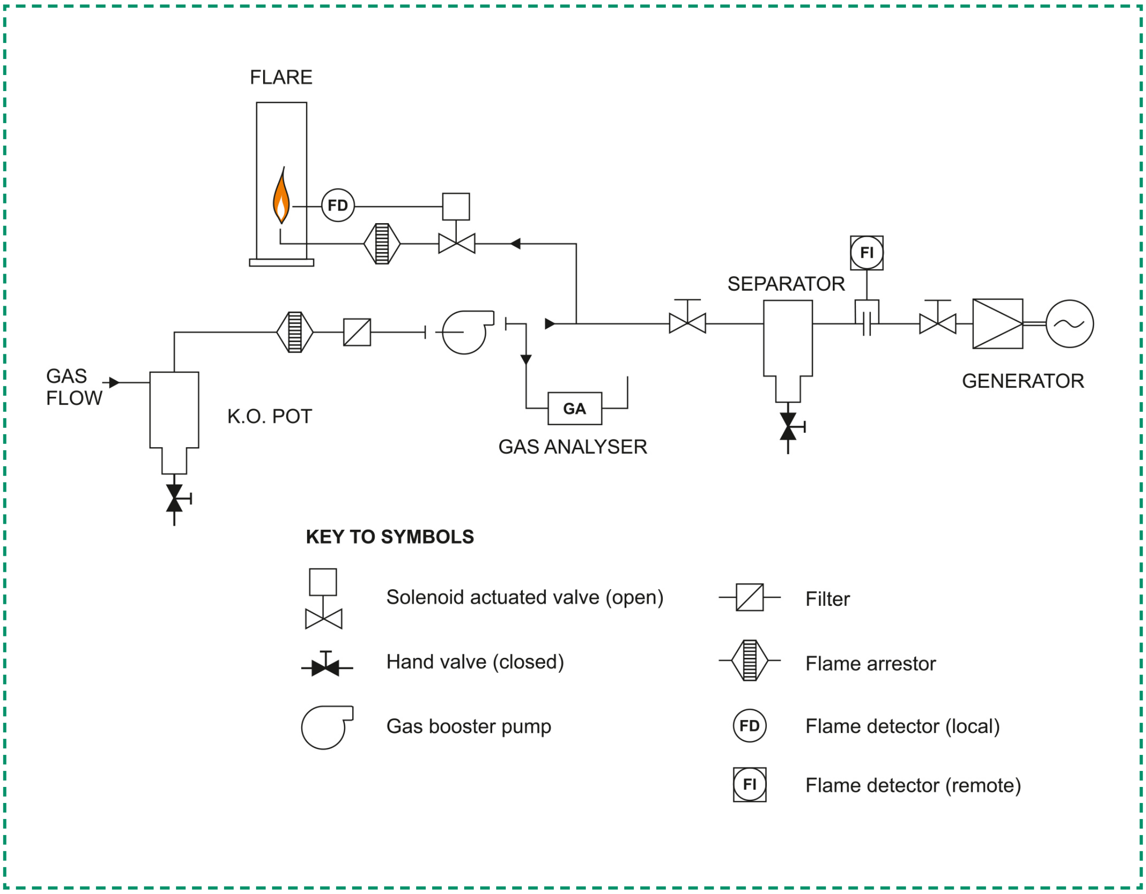


FIGURE 8 – LFG COMPOUND PROCESS DIAGRAM

Due to the large number of wells feeding a Utilization Plant, it is unlikely that the landfill gas will actually contain enough oxygen to be within the explosive range, therefore, for the reasons given in Section 3.17.3, the interior of the pipe to the booster fan is classified as a **Zone 2**. For this reason, flame arrestors are fitted.

All equipment is now modern and generally designed with detailed Hazard and Operability Studies (HAZOP) to anticipate DSEAR and ATEX with ventilation designed in where required and includes explosion-protected equipment where necessary. Where gas generating compounds may be built on former landfill sites where LFG may still be produced, the possibility of migration into areas classified as non-hazardous (e.g. switch rooms) should be carefully anticipated during the design stage.

3.22 Manual Sampling/Monitoring at Utilisation Plant

Manual sampling is normally performed by opening a 3mm diameter sample point that allows a small volume of gas to be drawn through a hand-held gas analyser. The flammable gas is then vented to atmosphere.

Sampling is a normal operation and is classified as a primary grade release, leading to a **Zone 1**. The sample point may be left open, in which case landfill gas <350 mbarg positive pressure can escape through a hole of diameter 3 mm. (British Standard, 2015) gives a 1 m zone for a 4 barg release of gas from a 5 mm hole. Since the release of landfill gas will be much less, this value is very conservative.

3.23 Continuous Gas Monitoring at Utilisation Plant

There are several different automatic insitu-gas analysers all enable continuous monitoring of LFG. These typically have a permanent connection of a 3 mm pipe into the gas pipeline. The analyser is usually located in a small GRP enclosure in the open air. A pump on the analyser removes gas to be sampled, which after analysis is then vented to atmosphere via a high-level vent, usually via a flame trap. The inside of the analyser compartment should be classified as a **Zone 2**, with a **Zone 0 of radius 1.2 m** around the vent. This assessment considers the different types of analyser, providing this worst-case assumption of a 350 mbarg positive pressure via a 3 mm diameter outlet and dilution to 0.25 LEL giving a conservative value for most applications.

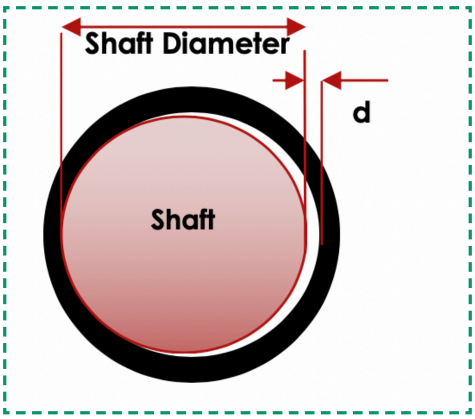
Such gas analyser should not be located in a non-hazardous area, such as the control compartment of the engine enclosure. If it is, leakage from the pipework needs to be assessed and a zone extent estimated based on the available ventilation.

3.24 Freely Ventilated Gas Booster Fan

The inlet pipe is at a suction pressure, so leaks of LFG are not considered, thus there is no external zone. Internally, the composition of the gas is usually above its upper explosive limit. Very occasionally, it is possible that air can be drawn into the pipe from the waste site, so, to take account of this possibility, the pipework is classified as **Zone 2** internally. Flame arrestors, which are designed to halt an explosion and are considered as 'safe devices' under ATEX95 are typically fitted immediately downstream of the booster. All modern installations should utilize flame arrestors that are ATEX-marked as part of their HASOP design.

The only potential releases from the booster fan itself are flanges (see Section 3.9) and shaft seals, both potential secondary grade releases. Shaft seal leaks are especially difficult to quantify, since there are many designs and levels of integrity, ranging from basic to highly sophisticated sealing arrangements. The failure of a 'basic' seal can lead to a significant release of gas whereas, at the other end of the spectrum, a high integrity seal need not be considered as a source of release. It is therefore recommended that the manufacturer is consulted where necessary to obtain a leak aperture and the zone extent calculated (see Appendix II). In some cases, a decision can be made that the seal is of sufficient integrity such that failure can be considered 'catastrophic' within the definition in (British Standard, 2015) i.e. a significant leak (i.e. one leading to a zone of larger than 0.3 m) is highly improbable.

(Energy Institute, 2015) quotes leak diameters giving the most common ("Level I"), less common ("Level II") and rare ("Level III") failure modes of different types of pump seal. The 'Levels' take account of the fact that there is no single failure mode for seals. (Energy Institute, 2016) should be consulted for fuller details on how these levels relate to the 'risk-based approach'. However, where available manufacturer guidance should be sought.



Without this information, the following example provides a booster fan with a single seal and a throttle bush (or an equivalent level of integrity), (Energy Institute, 2015) gives a leak diameter of 0.1SD (shaft diameters) for a 'Level I' failure.

(British Standard, 2015) calculates that a V_z <0.1 m^3 (i.e. a sphere of radius 0.3 m) allows the ventilation to be assessed as degree 'high'. From the definition of degree 'high', a zone of negligible extent results.

The mass flow rate (g) from a failed seal requires the value of the cross-sectional area of the leak (A), where

$$A = \pi ([SD+d]/2)^2 - \pi (SD/2)^2$$

(Energy Institute, 2015) does not give zone extents at such low pressures encountered in the LFG application, so the zone extents for dilution to 0.5 LEL are calculated from the equations used in Section 3.7 of this ICoP. It can be seen from the leak area in Table 9 below that these are unrealistically high, particularly for larger shaft diameters, leading to zone radii that are also unrealistically high.

TABLE 9 – LEAKS AREAS AND SHAFT DIAMETERS

Booster Pump at 150 mbarg – Level I Leak (SD = 10 to 100mm)							
Shaft Diameter SD (mm)	10	15	25	40	50	80	100
Leak Area (mm^2)	16.5	37.1	103	264	412	1056	1649
Zone 2 Radius (m)	1.1	1.6	2.8	4.7	6.0	10	13
Booster Pump at 200 mbarg – Level I Leak (SD = 10 to 100mm)							
Shaft Diameter SD (mm)	10	15	25	40	50	80	100
Zone 2 Radius (m)	1.1	1.8	3.0	5.1	6.5	11	14
Booster Pump at 250 mbarg – Level I Leak (SD = 10 to 100mm)							
Shaft Diameter SD (mm)	10	15	25	40	50	80	100
Zone 2 Radius (m)	1.2	1.9	3.2	5.4	6.9	11	15
Booster Pump at 300 mbarg – Level I Leak (SD = 10 to 100mm)							
Shaft Diameter SD (mm)	10	15	25	40	50	80	100
Zone 2 Radius (m)	1.3	2.0	3.4	5.7	7.2	12	15
Booster Pump at 350 mbarg – Level I Leak (SD = 10 to 100mm)							
Shaft Diameter SD (mm)	10	15	25	40	50	80	100
Zone 2 Radius (m)	1.3	2.0	3.5	5.9	7.5	13	16

3.25 Enclosed Gas Booster Fan

When the gas booster fan is inside an enclosure (usually an acoustic enclosure), there is the potential hazard of an explosion if a gas/air mixture is ignited. By providing a suitable level of ventilation to the enclosure the likelihood of such an event is much lower. Releases are secondary grade and therefore, by definition, improbable and ventilation failure also improbable. Area classification does not normally consider two improbable events happening at the same time, so it is not necessary to consider a leak when the ventilation has failed, provided the ventilation is reliable.

Ensuring secondary grade releases do not persist in excess of the time allowed for a Zone 2 to be appropriate, (Energy Institute, 2015) requires twelve air changes per hour. Such air changes can be provided by forced ventilation or by adequate openings in the structure to allow sufficient air change rate by natural ventilation. A simple way is to designate a **Zone 2** throughout the enclosure, with no external extent since forced or outdoor natural ventilation will rapidly dilute LFG from a small leak.

A more rigorous approach can be found in (British Standard, 2015) allowing a hypothetical volume (V_z). Where this may be negligible (V_z <0.1 m^3 (i.e. a sphere of radius 0.3 m) and allows the ventilation to be assessed as degree 'high' and therefore a zone of negligible extent results and no zone is required.

3.26 Flame Arrestor

Flame arrestors can be considered as flanges for area classification purposes and these are discussed in Section 3.9.

3.27 Separator/Knock-out Pot Vessel

3.27.1 Description

The Separator or Knock-out Pot Vessel is typically the last vessel before entry to the engine and removes condensate from the LFG fuel. There are several designs all typically located outdoors. Collected condensate is removed either by a manual drain (less common) or by a float-operated valve. Manual drains usually release a small volume of LFG, which shows all liquid has been drained. The tap is closed at this point. The float-operated valve opens/closes on certain pre-set points.

3.27.2 Zoning: Manual Drain Type

Section 3.24 demonstrates the pipework at this part of the system is a Zone 2 (as shown in Figure 9), therefore the main chamber of the separator is also **Zone 2**. A **Zone 1 radius of 1m** is assigned around the drain point to take account of the primary grade release of a small volume of landfill gas during operation.

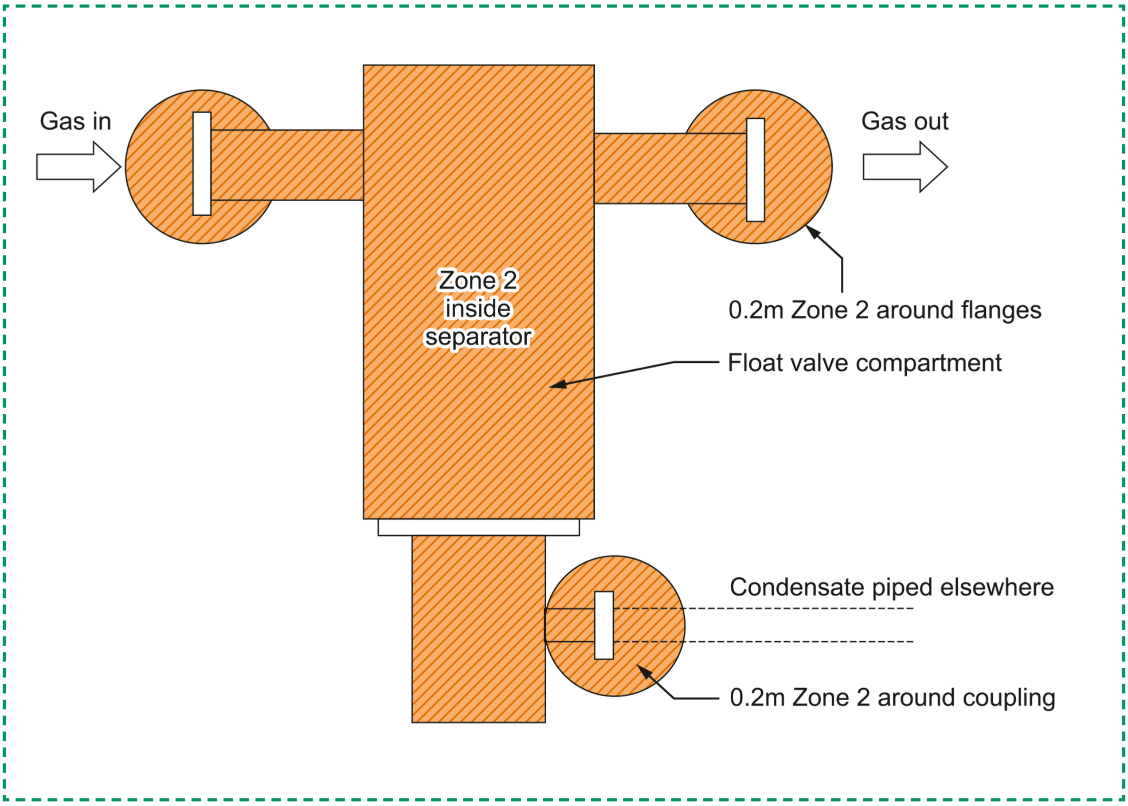


FIGURE 9 – MANUAL DRAIN KNOCK-OUT POT ZONING

3.27.3 Zoning: Float Operated Valve Type

The separator is a **Zone 2** internally. As these are sealed systems, the only releases are secondary grade around flanges, for which a zone radius of 0.2 m applies as described within Section 3.9.

The usual failure mode is for the valve to jam shut. It is feasible that the valve can jam open, in which case LFG will be released when all condensate has drained out. This is therefore a secondary grade release. The seal may fail to close properly allowing a slow leak, so should be treated as a primary grade release and assigned a 0.3 m Zone 1 where the condensate pipe ends.

3.28 Condensate Cyclone/Separator

The area classification is the same as for separators.

3.29 In-line Gas Filter/Treatment Systems

In-line filters comprises a fabricated housing with lid and drain point with flanged connections to the pipe. Internally, the pipework is Zone 2 for the reasons given in Section 3.11. All leaks are secondary grade releases and are dealt with in Section 3.9.

The access lid is infrequently removed and should always be performed under a maintenance procedure, so is outside the scope of area classification but should be considered through normal risk assessment routines.

3.30 Gas Receivers (Pressurised Systems, Gas Compressors)

Such installations involve gas pressures <4 barg. Reference should be made to;

- (a) (HSE, 2003);
- (b) (HSE, 2003);
- (c) (IGEM, 2009);
- (d) (IGEM, 1995); and
- (e) (IGEM, 2013).

For general guidance, the zone radii in freely ventilated outdoor locations for typical leak apertures calculated using the equations in Section 3.7 are given in Table 10 below, by using a pressure of 4 barg and a temperature of 10°C being assumed.

TABLE 10 – ZONE RADII FROM RELEASES AT 4 BARG

	Leak aperture (mm^2)		
	0.1	**0.25**	**2.5**
	Leak from High integrity joint	Typical Flange of Valvestem Leak	Major Flange or Valvestem Leak
Zone radius (m) for Gas at 4 barg	0.2	0.3	0.9

3.31 Engine Enclosures

Engine enclosures fall into three categories:

- Engine Container;
- Compartmentalised Engine Halls; and
- Open Engine Halls.

All gas engine systems should comply with (IGEM, 2015) and as such the following criteria are assumed to be in place:

- Control rooms are separate from the engine compartment and cables passing through dividing walls are appropriately sealed;
- Connecting doors are normally shut (except for access) when the engines are running, and landfill gas may be present in the engine compartment.
- They have forced draft or convection ventilation with the ventilation inlet located within a Zone 2 created by other sources. Such ventilation can also be used to supply engine combustion air, or this may be sourced independently from outside of the container;
- Ventilation for the control room is independent of engine hall ventilation and generally is for electrical cooling and personal comfort purposes; and
- Engine housings are fitted with appropriately installed and maintained explosive gas detection.

3.32 Containerised Engines

Typically, this is a metal container with two compartments, one for the control equipment and a larger compartment housing the engine.

3.33 Compartmentalised Engine Halls

Often a large engine hall with multiple engine sets. Each set is housed within a separate enclosure with no free air movement between them and other areas. Control units are either located in a common passageway connecting the engine compartments or in a separate control room.

3.34 Open Engine Hall

These are usually large halls containing multiple engine units without any permanent gas tight divisions between engines. Each engine is fed independently with LFG, but usually ventilation, air supply and other systems are common. Control rooms and other areas are connected to the engine hall.

The larger compartment housing the engines will have numerous secondary grade releases from joints and seals. There should be no primary or continuous grade releases. Although zoning should be considered, boiler rooms (to which this is similar) have historically not been zoned. As a result, uncertified electrical equipment may be installed. The relevant standard in the UK is (BS, 1988)., partially replaced by (British Standard, 2003/2008).

These identify where there is a very low risk of presence of flammable gases in the vicinity of burner pipework and control equipment installed in accordance with recognized standards and codes, unless a hazard can exist from some extraneous source then the area may be declared non-hazardous.

To ensure an adequate degree of ventilation, IP15 recommends that twelve air volume changes per hour to be implemented in all areas of the enclosure that contains potential releases. Twelve air volumes should be considered as a minimum and is not usually sufficient to reduce the zones to negligible extent. Therefore, where the integrity of the pipework/equipment is in doubt and a risk assessment shows that there is a significant risk to personnel (e.g. where workers are frequently in or around the enclosure), a mitigating measure might be to install gas detection equipment. However, the number and location of detectors is critical, as is the routine calibration and testing. Excessive reliance should not be placed on a system of gas detection without ensuring that it can reliably detect leaks from all the potential leak sources.

3.35 Multiengine Facilities

3.35.1 Open Engine Halls

The ventilation characteristics of open engine halls are likely to be less well defined compared to bespoke engine enclosures described in the previous section. They should, however, be treated in the same way, i.e. not zoned provided that the ventilation is assessed as adequate.

3.35.2 Individual Enclosures

These should be considered as for open engine halls.

3.36 Flares and Associated Pipework

A number of different types of flares are used as a disposal technique.

Joints and valves associated with a flare will be outdoors and are dealt with in Section 3.9. The area classification implications of the flare itself require consideration of possible fault conditions.

Any pilot is lit by a spark from the igniter and if this does not occur, the system activates the igniter several times until the flare does not light and shuts down. Some, less common systems use permanently lit pilots (using landfill gas or propane). The unburnt pilot gas is released inside the flare stack, so no zoning is required for this level of flow, since it is in a region usually containing a flame. Only when the pilot is lit is a large flow of gas possible.

If the flame fails, a slam-shut valve operates. Some systems will then automatically go through further ignition cycles, whereas for others this is manually initiated. For there to be a significant release of unburnt gas, a number of failures are required, so such a situation will be treated as a 'catastrophic' failure (as detailed in Section 3.5) of the flare control system and therefore outside the level of probability dealt with in area classification. A risk assessment, however, should be performed.

Consequently, there is no zone around the top of the flare stack unless the flare control system is so rudimentary that major releases are considered reasonably foreseeable.

3.37 Vents

Landfill gas power generation operations require various venting actions including;

- Purge points are used to blow the gas down newly installed pipe; and
- Relief valve vents associated with pumps that do not vent back into the suction side.

Venting of new pipework should be carried out to (IGEM, 2005). Purge points should be sized to suit the IGEM, 2005 procedures and ideally, all purge points should be valved and capped or plugged, which avoids the hazardous area consideration in normal plant operation.

Venting of new or re-commissioned pipework is an infrequent, controlled procedure and should be carried out with its own risk assessment (sometimes involving permit to work procedures). If carried out to the IGEM 2005 procedure, the activity has a short purge time (a few minutes). The extent of the potentially explosive atmosphere should be monitored and carefully controlled so there should be no ignition sources present.

A vent should be designed so that the gas will be unimpeded and directed upwards. The main consideration is the possible extent of any 'downward dispersion', since this may affect operations at ground level. (IGEM, 2013) quantifies downward dispersion for various pipe diameters and vent heights, but is independent of the maximum release rate, since downward dispersion mainly occurs at low release rates.

Vent pipes with an internal diameter of under 15 mm are not covered in IGEM/SR/25.

3.38 Summary of Area Classification

The process of area classification, therefore, involves the identification of all flammable materials, the identification and grading of all releases of flammable material, the assessment of the level of ventilation and/or housekeeping and the determination of the resulting types and extents of the zones. The allocation of zones enables the correct equipment, practices and procedures to be applied to protect the health and safety of the workers concerned with the facility.

4. Elimination of risk

DSEAR requires employers to reduce risk as far as reasonably practicable. The hierarchy of hazard control describes elimination of hazard as the key priority. Substitution of flammable materials (landfill gas) is not possible. Reducing the quantity of flammable material on site is likewise not practical.

Maintenance work is often the activity where the greatest risk of the release of the flammable material, LFG, can occur. Consequently, potential ignition sources must be carefully controlled.

Ignition sources can be initiated by, for example:

- Unprotected fixed electrical apparatus;
- Spark producing portable equipment;
- Electrostatic discharges;
- Electrical equipment that is overheating or sparking due to a fault;
- Hot surfaces of heating equipment;
- Hot surfaces or sparks from mechanical equipment (by design or failure);
- Smoking;
- Open flames;
- Spontaneous combustion; and
- Lightning.

(British Standard, 2011) identifies the following possible ignition sources and examples of where these may be found on landfill have been added:

TABLE 11 – POTENTIAL IGNITION SOURCES

Ignition Source	Landfill Example	Possible Control
Live Flames e.g. arc welding, smoking, pilot lights.	Vandalism by unauthorized access at on-site infrastructure and within compounds.	Close supervision by trained personnel, removal of flammable hazard, hot-work permit, no smoking policy.
Sparks and hot surfaces from electrical equipment.	Unsuitable condensate pumps, automated valves at on-site infrastructure and compounds.	Suitably protected equipment designed for hazardous area use or otherwise assessed as compliant.
Electrostatic discharges – equipment.	Landfill gas compounds at on-site booster stations.	Earthing normally inherent in the landfill gas compound but should ensure a good earthing point outside waste infilled landfilled.
Electrostatic discharges – personnel.	Monitoring personnel, mobile phone usage. Monitoring and sampling equipment.	Most modern clothing is made from synthetic textiles and can readily become electrostatically charged. However, in general, an ignition risk providing that the wearer is earthed by means of suitable footwear and flooring is rarely an issue. Further mitigation should ensure clothing should be as close fitting as is practical and should not be removed or unfastened in areas where there could be flammable atmospheres.
Lightning.		Site buildings in hazardous areas may need to be fitted with lightning protection.

Ignition Source	Landfill Example	Possible Control
Sparks and hot surfaces arising from engineering activities.	Electrofusion and butt fusion pipe jointing on site. Other engineering activities within the compound.	Sites should operate a permit to work system for such hot work.
Stray electric currents, cathodic corrosion protection.	Condensate pumps, booster stations, compound infrastructure.	Suitable design and construction quality assurance to reduce this risk. Unlikely to be present.
Electromagnetic fields in the frequency range from 9 kHz to 300 GHz.		Unlikely to be present.
Electromagnetic radiation in the frequency range from 3 x 1011 Hz to 3 x 1015 Hz or wavelength range from 1000 µm to 0.1 µm (optical spectrum).		Unlikely to be present.
Ionising radiation.		Unlikely to be present.
Ultrasonics.		Unlikely to be present, unlikely to be at an energy level sufficient to cause an ignition.
Adiabatic compression, shock waves, gas flows.		Unlikely to be present.

5. Marking areas of risk

Identification and marking of pipes and containers, particularly those that are visible, alerts employees and others to the presence of a dangerous substance so that they can take the necessary precautions.

Where there are two or more employers sharing a workplace, the employer is responsible for co-ordination and implementation of DSEAR to protect employees and others from risks from explosive atmospheres.

On landfill sites, the 'employees and others may include outside contractors, visitors and potentially the general public. Landfill operators should consider this carefully since some landfills in aftercare are fields yet still may have hazardous areas. This situation can be addressed by segregating such persons and their vehicles from zoned areas by careful routing of the access roads sufficiently far away from wells and other locations where landfill gas collects. Suitable warning signs at the entrance to the site and a no-smoking policy may be sufficient.

Examples are provided below:

Where access to zoned areas is part of the work of outside contractors (e.g. drilling, pipe-laying, work within parts of the gas compound), then contractors must be required to provide risk assessments and method statements and only send in suitably qualified persons for such work. Compliance with this regulation may also be achieved by means of a site induction (verbal or audio-visual), a permit-to-work system, accompanying visitors, or other methods deemed appropriate to the level of assessed risk.

6. Accidents, incidents and emergencies

DSEAR requires information and training on the hazardous properties of substances possibly present including LFG and employees should be made aware of the potentially explosive nature of LFG and risk reduction measures that may include;

- A no-smoking policy in or near hazardous areas;
- The prohibition of the use of uncertified electrical equipment in hazardous;
- The prohibition of the use of uncertified electrical equipment in hazardous areas such as test equipment, mobile phones, personal audio equipment, etc; and
- The correct use of intrinsically safe test equipment, e.g. oxygen analysers.

Those installing, maintaining and inspecting electrical and non-electrical equipment in hazardous areas require more detailed training that gives an understanding of the methods of protection of equipment and the corresponding checks and precautions to be applied. It is recommended that such persons attend a training course offering the required level of detail.

Arrangements must be in place to deal with accidents, incidents and emergencies. The following points should be addressed, amongst others:

- Occupied buildings should have a fire alarm system that is tested regularly
- Evacuation and assembly points should be designated and clearly marked
- Emergency exits should be identified, and housekeeping maintained to ensure un-obstruction
- Fire drills should be held at suitable intervals
- Visitors should be alerted to escape routes and muster points
- Notice boards in every workplace should detail the local emergency arrangements

7. References

British Standard. (2003/2008). EN 676:2003+A2:2008. ***Automatic Forced Draught Burners for Gaseous Fuels***. UK: BS.

British Standard. (2011). BS EN 1127-12011. ***Explosive Atmospheres, Explosion Prevention and Protection.Basic Concepts and Methodology***. UK.

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BS. (1988). BS 5885-1. ***Automatic Gas Burners. Specification for Burners with Input Rating 60kW and Above***. UK: BS.

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HSE. (2003). PM84 2nd Edition. ***Control of Safety Risks at Gas Turbines used for Power Generation***. UK: HSE.

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IGEM. (2009). UP/6 Ed 2. ***Application of Compressors to Natural Gas Fuel Systems***. UK: IGEM.

IGEM. (2013). SR/25 Edition 2. ***Hazardous Area Classification of Natural Gas Installations***. UK: IGEM.

IGEM. (2015, Nov). UP/3 Edition 3. ***Gas Fuelled Spark Ignition and Dual Fuel Engines***. UK: IGEM.

APPENDIX I

Specific ICoP's used within the landfill industry;

LGG ICoP 111 'Design of Capping Systems'
http://www.esauk.org/application/files/5415/4454/1178/LGG_111_Capping_systems.pdf;

LGG ICoP 113 'Leak Location Surveys – Geophysical Testing of Geomembranes used in Landfills'
http://www.esauk.org/application/files/4515/4454/1198/LGG_113_Leak_location_testing.pdf;

LGG ICoP 114 'Using Drainage Geocomposites in Landfill Engineering'
http://www.esauk.org/application/files/9115/4454/1217/LGG_114_Drainage_geocomposites.pdf;

LGG ICoP 115 'Geosynthetic Interface Shear Resistance Testing'
http://www.esauk.org/application/files/2215/5257/7966/LGG_115_Interface_Shear_Resistance_Testing_with_appendix.pdf;

LGG ICoP 116 'Sizing of Surface Water Management Systems at Landfill Sites'
http://www.esauk.org/application/files/6615/4454/1254/LGG_116_Surface_water_management.pdf;

UK Landfill Industry Code of Practice 'Establishment of Appropriate Containment Standards for Leachate Storage Infrastructure'
http://www.esauk.org/application/files/5015/3589/6447/20161228_424_00156__00197_ICoP_Leachate_Storage_Containment.pdf;

ICoP For the Management of Landfill Gas: ESA, March 2012.

Other guidance associated with the general management of landfill gas is available in the following Environment Agency documents;

LFTGN03 – Guidance on the management of landfill gas; 2004, EA
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/321606/LFTGN03.pdf;

LFTGN04 – Guidance on monitoring trace components is landfill gas: 2014, EA
https://www.gov.uk/government/publications/monitoring-trace-components-in-landfill-gas-lftgn-04

LFTGN05 – Guidance on monitoring enclosed landfill gas flares; 2014, EA
https://www.gov.uk/government/publications/monitoring-enclosed-landfill-gas-flares-lftgn-05

LFTGN06 – Guidance on gas treatment technologies for landfill gas: 2014, EA
https://www.gov.uk/government/publications/gas-treatment-technologies-for-landfill-gas-engines-lftgn-06

LFTGN07 – Guidance on monitoring landfill gas surface emissions: 2014, EA
https://www.gov.uk/government/publications/monitoring-landfill-gas-surface-emissions-lftgn-07

LFTGN08 – Guidance on monitoring landfill gas engine emissions: 2014, EA
https://www.gov.uk/government/publications/monitoring-landfill-gas-engine-emissions-lftgn-08

Guidance associated with the drilling operations at landfills can be found in the following;

Guidance on Managing the Risk of Hazardous Gases when Drilling or Piling Near Coal, BDA; 2015
https://www.gov.uk/government/publications/guidance-on-managing-the-risk-of-hazardous-gases

Other landfill industry DSEAR guidance is contained in the following;

DSEAR Implementation for the Waste Management Industry; ESA ICoP1 Ed 1: Nov. 2005.

DSEAR Area Classification for Leachate Extraction, Treatment & Disposal: ESA ICoP3 Ed 1: May 2006.

Waste Management Industry Landfill Operations Involving Potentially Explosive Atmospheres: ESA ICoP5 Ed1: Aug 2007.

Control of Substances Hazardous to Health Regulations 2002 (SI 2002/2677) (COSHH). The health effects from substances and preparations are not within the scope of DSEAR but are covered by such legislation.

Health and Safety (Enforcing Authority) Regulations 1998. DSEAR is enforced by the HSE or local authority inspectors in accordance with this legislation.

APPENDIX II

The following calculations and examples have been progressed from XXX

Mass Flow Rate

The mass flow rate from a leak of landfill gas have been developed for area classification purposes using molecular mass of landfill gas in the equations derived from those for natural gas in IGEM/SR/25 Ed 2 (Hazardous Area Classification of Natural Gas Installation). These are shown below:

$$g = 1500\, C_d\, A\, (MP/T)^{0.5} \qquad \textbf{Equation 1}$$

where g = mass flow rate of landfill gas in kg/s though a leak

C_d = coefficient of discharge of orifice = 0.8 (0.97 for relief valves)

A = cross-sectional area of the orifice in m^2 ($1\ mm^2 = 10^{-6}\ m^2$)

M = molecular mass = 27.2 kg/kmol for landfill gas containing 60% v/v methane

P = gas pressure in bar gauge (barg)

T = absolute temperature of gas upstream of orifice in K.

The ambient and release temperatures of landfill gas have for simplicity been assumed to be 10º C (10°C = 283 K (from LFTGN03)).

The cross-sectional area assumed in this ICoP for a leak from a flange, screwed fitting, joint or valve gland is based on IGEM/SR/25 Ed 2 (Hazardous Area Classification of Natural Gas Installations), i.e. 0.25 mm^2. This applies to 'normal' conditions and is generally applicable because pressures are low and temperature changes are modest. Where 'adverse' conditions might prevail for example, the likelihood of a large leak from a very large diameter joint fitting, IGEM/SR/25 Ed 2 recommends 2.5 mm^2. It is considered unlikely that such an 'adverse' environment may exist, but the equations allow recalculation of the zone extent to be determined should this be needed.

IGEM/SR/25 Ed 2 identifies a zone radius of 0.5 m for pressures up to 2 barg ('normal' conditions) but this does not differentiate between the zone radii at 2 barg and 0.1 barg, therefore the zone radii have been calculated from first principles using these equations leading to zone extents smaller than those quoted in IGEM/SR/25.

Volume Flow Rate Equation

As BS EN 60079-10-1:2015 (Explosive Atmospheres. Classification of Areas. Explosive Gas Atmospheres) and IGEM/SR/25 Ed 2 (Hazardous Area Classification of Natural Gas Installations) provide no suitable equations for calculating the zone extent from a release of gas in a freely-ventilated outdoor location, ESA ICoP 2 Ed 1;2005 (Area Classification for Landfill Gas Extraction Utilisation and Combustion) identified empirical based equation modelling of release rates to zone extents to directly convert a volume release rate to a zone extent.

The mass release rate calculated from equation 1 is converted to a volume release rate by using the Ideal Gas Equation with landfill gas being at sufficiently low pressure to approximate to ideal behaviour.

pV = nRT

where p = absolute pressure of the gas in Pa = 101,325 Pa at atmospheric pressure

V = volume of the gas in m^3

N = number of moles = (mass in kg)/(molecular mass in kmol) = g/M

R = gas constant = 8,314.4 J/kmol/K

T = absolute temperature in K

The standard atmospheric pressure (101,325 Pa) will be assumed as the variations in atmospheric pressure has a very small effect on the calculations.

Thus: V = nRT/p = gRT/Mp

= (g x 8,314.4 x T)/(M x 101,325)

V = 0.0821gT/M

Converting to volume/s and mass/s gives;

Q_{LG} = 0.0821gT/M

Where Q = volume flow rate of landfill gas in m^3/s

g = mass flow rate in kg/s

T = absolute temperature of gas in Kelvin (K)

M = molecular mass = 27.2 kg/kmol for landfill gas (assumed 60% methane)

The constant in this equation (0.0821) has units and is derived by combining the individual constants for known parameters. Since this ICoP assumes that landfill gas has a maximum of 60% methane by volume, the volume release (flow) rate of methane (in m^3/s assuming 60% v/v methane) is:

Q_{CH4} = 0.0493gT/M Equation 2

The molecular mass of landfill gas is used because the calculation is for the volume release rate of landfill gas, which if it is then multiplied by 0.6 converts this to methane release rate. For percentages of landfill gas other than 60% v/v, the value of Q_{LG} can be calculated using the values of molecular mass in the table below and then multiplying by the appropriate value to obtain Q_{CH4}.

TABLE 12 – MOLECULAR MASS VARIATION FOR LANDFILL GAS

Variation of Molecular Mass with % of methane						
% Methane	30	40	50	60	70	80
M (kg/kmol)	35.6	32.8	30.0	27.2	24.4	21.6

Zone Radius Equation for Outdoor Releases

The zone radius can be calculated directly from the following empirical equation taken from ESA ICoP 2 Ed 1;2005 (Area Classification for Landfill Gas Extraction Utilisation and Combustion) is:

$x = (180Q_{CH4}/kE\%)^{0.55}$ Equation 3

Where x = zone radius (assumed a sphere) in m

1840 = constant of proportionality derived from the empirical formulae (not a dimensionless constant)

Q_{CH4} = volume flow rate of methane in m^3/s calculated from Equation 2

K = Safety Factor applied to the LEL
0.5 for secondary grade releases or
0.25 for primary grade releases

$E_{\%}$ = Lower Explosive Limit (LEL) in % v/v

This equation takes account of obstructions caused by proximity to the ground, walls or other objects. It is only applicable to freely ventilated outdoor locations and assumes a wind-speed sufficient for turbulent diffusion. BS EN 60079-10 2015 (Explosive atmospheres. Classification of Areas. Explosive Gas Atmospheres) states that 2 m/s is a minimum for this mechanism, whereas the minimum wind-speed that can be relied upon virtually continuously is only 0.5 m/s. Thus, the wind speed is not always sufficient for equation 3 to be fully applicable, so some 'layering' will occur at low wind-speeds. However, in view of the low pressure assumed in landfill gas collection systems (<350 mbarg) and with the safety factor (k) included, this equation gives an acceptably conservative result for area classification purposes.

The zone radius is measured from the point of release in all directions and is thus independent of the density of the release.

Worked Examples

Example 1 – This worked example uses equations 1 to 3 to find the zone radius from a leaking flange on pipework containing landfill gas at 350 mbarg and at 10°C.

Step 1: Use Equation 1 to calculate the mass release rate, g

$g = 1500\ C_d\ A\ (MP/T)^{0.5}$

where g = mass flow rate of landfill gas in kg/s though a leak

Cd = constant = 0.8 for most releases

A = cross-sectional area of the orifice in m^2 = 0.25 mm^2

M = molecular mass = 27.2 kg/kmol for landfill gas

P = gas pressure in bar gauge (barg) = 0.35 barg

T = absolute temperature of gas upstream of orifice in K = 283 K

Therefore

$g = 1500 \times 0.8 \times (0.25 \times 10^{-6}) \times (27.2 \times 0.35/283)^{0.5}$

$= 5.51 \times 10^{-5}$ kg/s (rounding up)

Step 2: Use Equation 2 to convert g to a volume release rate, Q

Q_{CH4} = 0.0493gT/M

Where Q_{CH4} = volume flow rate of methane in m^3/s

g = mass flow rate in kg/s = 1.95 x 10^{-5} kg/s (from Step 1)

T = absolute temperature of gas in K = 283K

M = molecular mass for landfill gas = 27.2 kg/kmol

Therefore

Q_{CH4} = 0.0493 x 5.51 x 10^{-5} x 283/27.2 = 2.83 x 10^{-5} m^3/s

Step 3: Use Equation 3 to find the zone radius, x

x = $(1840Q_{CH4}/kE_{\%})^{0.55}$

Where x = zone radius in m

Q_{CH4} = volume flow rate of methane from Step 2 = 2.83 x 10^{-5} m^3/s

K = safety factor applied to the LEL = 0.5 (for a secondary grade release)

$E_{\%}$ = lower explosive limit (LEL) in % v/v = 4.4

Therefore

x = $(1840 \times 2.83 \times 10^{-5}/[0.5 \times 4.4])^{0.55}$ = 0.127 m, rounded up to 0.2 m.

Example 2 – To find the zone of radius from a gas well venting freely. This could also be used for a vent/ interceptor from a borehole or cut-off trench pipe.

This worked example assumes that the gas well is not under a suction pressure but is in a steady-state venting situation whereby the entire production, taken as 30 m^3/hr, is venting to atmosphere. This gives the zone radius around a Bentonite seal that has completely failed.

Equations 1 and 2 are not required since the volume release rate (Q^{CH4}) is already known.

Using equation 3 to find the zone radii in m:

x = $(1840Q_{CH4}/kE_{\%})^{0.55}$

Where x = Zone radius in m

Q_{CH4} = volume flow rate of methane, which is 60% of 30 m^3/h

= 18m^3/hr = 18/3600 = .005 m^3/s

K = safety factor applied to the LEL – 0.5 (for a secondary grade release)

$E_{\%}$ = lower explosive limit (LEL) in % v/v = 4.4

Therefore

x = $(1840 \times 0.005//[0.5 \times 4.4])^{0.55}$ = 2.197m, rounded up to **2.2m**.

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