MALAYSIAN STANDARD

MS 2547:2014

Landfill safe closure - Requirements

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Committee representation

The Industry Standards Committee on Environmental Management (ISC Z) under whose authority this Malaysian Standard was developed, comprises representatives from the following organisations:

Association of Consulting Engineers Malaysia
Association of Environmental Consultants and Companies of Malaysia
Balai Ikhtisas Malaysia
Centre for Environment Technology and Development Malaysia
Department of Environment
Department of Standards Malaysia
Environmental Management and Research Association of Malaysia
Federation of Malaysian Manufacturers
Malaysian International Chamber of Commerce and Industry
Malaysian Nuclear Agency
Malaysian Palm Oil Association
Malaysian Palm Oil Board
Malaysian Palm Oil Council
Malaysian Plastics Manufacturers Association
Malaysian Rubber Board
Malaysian Rubber Glove Manufacturers' Association
Malaysian Textile Manufacturers Association
Ministry of Domestic Trade, Co-operatives and Consumerism
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Ministry of Housing and Local Government
Ministry of International Trade and Industry
Ministry of Natural Resources and Environment
Ministry of Plantation Industries and Commodities
Ministry of Science, Technology and Innovation
SIRIM Berhad (Environmental Technology Research Centre)
SIRIM Berhad (Secretariat)
The Electrical and Electronics Association of Malaysia
The Institution of Engineers, Malaysia
Universiti Malaya
Universiti Putra Malaysia

The Technical Committee on Waste which supervised the development of this Malaysian Standard consists of representatives from the following organisations:

Association of Environmental Consultants and Companies of Malaysia
Department of Chemistry, Malaysia
Department of Environment
Department of National Solid Waste Management
Federation of Malaysian Manufacturers
Malaysian Industry-Government Group for High Technology
Malaysian International Chamber of Commerce and Industry
Malaysian Nuclear Agency
Malaysian Palm Oil Association
Malaysian Rubber Board
Ministry of Health Malaysia (Engineering Services Division)
SIRIM Berhad (Secretariat)
Universiti Malaya
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Committee representation *(continued)*

The Working Group on Site Remediation which developed this Malaysian Standard consists of representatives from the following organisations:

Department of Chemistry, Malaysia

Department of Environment

Department of National Solid Waste Management

IRIS Eco Power Sdn Bhd

Malaysian Nuclear Agency

Ministry of Health Malaysia (Engineering Services Division)

Perbadanan Pengurusan Sisa Pepejal Dan Pembersihan Awam

SIRIM Berhad (Secretariat)

SWM Environment Sdn Bhd

The Institution of Engineers, Malaysia

Universiti Kebangsaan Malaysia

Universiti Malaysia Pahang

Universiti Sains Malaysia

Foreword

This Malaysian Standard was developed by the Working Group on Site Remediation under the authority of the Industry Standards Committee on Environmental Management.

Compliance with a Malaysian Standard does not of itself confer immunity from legal obligations.

Introduction

A landfill where waste-filling activities have been completed shall be closed properly for safe storage of the waste and prevention of pollution to the surrounding environment.

Prior to a landfill site closure, appropriate measures shall be taken to minimize environmental impact caused by leachate or landfill gas resulting from the decomposition and degradation of the waste. Even long after closure of the landfill, post-closure management (including environmental monitoring) should be carried out continuously.

The aims and purposes of this Malaysian Standard are:

a) to protect public health and the environment by proper management of landfill safe closure and post closure land use; and

b) to prevent environmental pollution and risks from the closed landfill sites and uncontrolled development of closed landfill sites (i.e. leachate and gas emissions).

Management of landfill sites in Malaysia is in accordance to *Solid waste and public cleansing management Act* 2007 (Act 672). The intended future land use shall comply with the *Contaminated land management and control guidelines*, Department of Environment, Malaysia.

Landfill safe closure - Requirements

1 Scope

This Malaysian Standard specifies requirements for landfill safe closure. This Malaysian Standard is intended to assist managers, regulators, practitioners and owners of solid waste management facilities to carry out a safe closure of landfill. This standard is developed specifically for landfills which receive solid waste (excluding scheduled and nuclear wastes). This standard is applicable to closed and existing landfills or other disposal sites.

2 Normative references

The following normative references are indispensable for the application of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the normative reference (including any amendments) applies.

MS 2072, *Guidelines for developing and implementing early action for site remediation*

MS 2303:2010, *Waste and waste management - Terminology*

MS 1056-5, *Soils for civil engineering purposes - Test method - Part 5: Compressibility, permeability and durability tests*

MS 1056-6, *Soils for civil engineering purposes - Test method - Part 6: Consolidation and permeability tests in hydraulic cells and with pore pressure measurement*

MS 1850-14, *Water quality - Sampling - Part 14: Guidance on quality assurance of environmental water sampling and handling*

MS ISO 9359, *Air quality - Stratified sampling method for assessment of ambient air quality*

ASTM D5994, *Standard test method for measuring core thickness of textured geomembrane*

ASTM D1505, *Standard test method for density of plastics by the density-gradient technique*

ASTM D792, *Standard test methods for density and specific gravity (relative density) of plastics by displacement*

ASTM D6693, *Standard test method for determining tensile properties of nonreinforced polyethylene and nonreinforced flexible polypropylene geomembranes*

ASTM D4833, *Standard test method for index puncture resistance of geomembranes and related products*

ASTM D1004, *Standard test method for tear resistance (graves tear) of plastic film and sheeting*

ASTM D1603, *Standard test method for carbon black content in olefin plastics*

ASTM D5596, *Standard test method for microscopic evaluation of the dispersion of carbon black in polyolefin geosynthetics*

ASTM D5397, *Standard test method for evaluation of stress crack resistance of polyolefin geomembranes using notched constant tensile load test*

ASTM D3895, *Standard test method for oxidative-induction time of polyolefins by differential scanning calorimetry*

ASTM D5885, *Standard test method for oxidative induction time of polyolefin geosynthetics by high-pressure differential scanning calorimetry*

ASTM D6392, *Standard test method for determining the integrity of nonreinforced geomembrane seams produced using thermo-fusion methods*

ASTM D5820, *Standard practice for pressurized air channel evaluation of dual seamed geomembranes*

ASTM D5641, *Standard practice for geomembrane seam evaluation by vacuum chamber*

ASTM D1777, *Standard test method for thickness of textile materials*

ASTM D5993, *Standard test method for measuring mass per unit of geosynthetic clay liners*

ASTM D5890, *Standard test method for swell index of clay mineral component of geosynthetic clay liners*

ASTM D5891, *Standard test method for fluid loss of clay component of geosynthetic clay liners*

ASTM D6496, *Standard test method for determining average bonding peel strength between the top and bottom layers of needle-punched geosynthetic clay liners*

ASTM D4595, *Standard practice for collection of channel samples of coal in a mine*

ASTM D5887, *Standard test method for measurement of index flux through saturated geosynthetic clay liner specimens using a flexible wall permeameter*

BS 1377-9, *Methods for test for soils for civil engineering purposes. In-situ tests*

3 Terms and definitions

For the purposes of this standard, the following terms and definitions apply.

3.1 closed landfill site

The landfill site where the waste filling activities have been completed.

3.2 disposal site

Any site, other than sanitary landfills and inert landfills, where controlled solid waste is placed to remain.

[MS 2303:2010]

3.3 final capping

The final sealing of a landfill to prevent the entry (ingress) of precipitation and the escape (egress) of gas, odour and other fugitive emissions.

3.4 landfill site

The site where controlled wastes are disposed off by land filling. Such sites should be provided with adequate landfill facilities.

3.5 landfill stabilisation

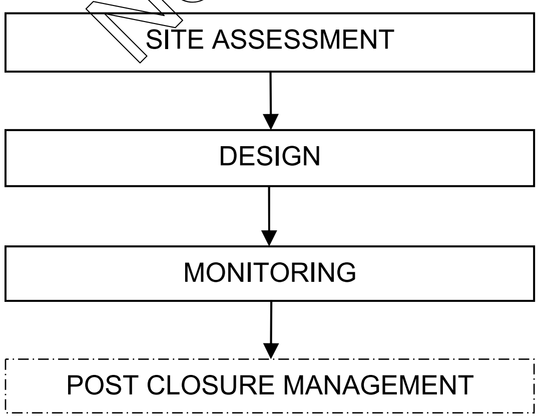
The state or condition where a landfill poses no adverse effects (health, safety, amenity and environment).

3.6 landfill safe closure

Complete steps and measures taken to achieve landfill stabilisation.

4 Requirements for landfill safe closure

The requirements for landfill safe closure are shown as in Figure 1.



NOTE. Post-closure management is not covered in this standard.

Figure 1. Flowchart on the process of landfill safe closure

4.1 Site assessment

Site assessment study should be carried out in order to determine the general conditions, environmental conditions and land use conditions of the site. From the results of the study, the environmental pollution potential and land use potential can be evaluated.

The amount and quality of information on which to base management decisions will vary considerably. Therefore, a staged approach to assessing environmental and human health risks is outlined, suitable for assessing very different sites.

The landfill site should be assessed properly based on the site survey/investigation. The survey items (see Table 1) will be required to evaluate the landfill site and to provide the proper measures for safe closure.

Table 1. Survey items for the site assessment

No	Items	Proposed measures
1	Topographic and geological survey	The topographic and geological data of the sites shall be collected.
2	Structures and facilities of landfill site	The details of the landfill facilities and records of the landfill operations should be collected. All the landfill facilities should be clearly identified and indicated on the plan.
3	Shape and stability of filled waste	The shape of the site should be clarified in order to evaluate the stability of the landfill site.
4	Total amount of disposed waste	The total amount of the filled waste should be estimated based on the operation record and topographic profile of the site.
5	Degradation of the filled waste	The information and data of the following should be collected and/or measured: a) amount and quality of the leachate; b) amount and quality of the landfill gas; c) temperature of the waste layers; and d) physical composition of the waste (if available). The variation in the leachate and gas concentration should be used to determine the rate of decomposition, degradation and the stabilisation of the landfill waste.
6	State of the surrounding environment	The conditions of surrounding environment should be surveyed and/or measured. All relevant information including the monitoring data should be collected.
7	Surrounding land use	The surrounding land use should be identified and the land use plan of the site should be collected (if any).

4.1.1 Initial assessment

An initial assessment [also known as Phase I Environmental Site Assessment (ESA)] is a systematic assessment process to identify any potential presence of subsurface environmental impacts based on a defined assessment protocol/procedure. It typically involves a desk top study, interview and a site visit. The initial assessment will also used to obtain useful information for scoping of the detailed assessment as described in MS 2072.

4.1.2 Detail assessment

4.1.2.1 A detailed assessment (also known as Phase II ESA) is a soil and groundwater investigation process that aims to determine if the subsurface environmental media is impacted. A detailed assessment would normally be carried out after an initial assessment, should the findings of the initial assessment suggest that the land is potentially impacted by onsite or offsite activities.

4.1.2.2 Typical activities included in a detailed assessment are:

a) soil boring;

b) groundwater well installation; and

c) soil and groundwater sampling.

4.1.3 Risk assessment

Risk assessment is a process of estimating the potential impact of a contaminant on an ecosystem under a specific set of conditions.The appropriate closure level should be assigned and applied for the prevention of environmental pollution and hazards. The relevant authorities at the state level should be responsible to determine target closure level for each landfill site within their jurisdiction.

4.2 Design

In designing landfill safe closure, the following elements should be considered:

a) shape (see 4.2.1);

b) final cover/final capping (see 4.2.2);

c) storm water management system (see 4.2.3);

d) gas management system (see 4.2.4);

e) leachate collection system (see 4.2.5);

f) leachate treatment facilities (see 4.2.6); and

g) services facilities (see 4.2.7).

4.2.1 Shape

The final shape of the closed landfill shall take into consideration of its future land use. Details on the plateau gradient (flat top) and side slope should be based on final capping.

4.2.2 Final cover/final capping

4.2.2.1 Final capping design

Landfill cover design should attempt to achieve the following:

a) stable slopes;

b) minimise the infiltration of rainwater and surface water into the landfill;

c) provide a growing medium for restoration planting and re-vegetation of the landfill;

d) minimise the uncontrolled ingress of air into the waste;

e) provide a suitable medium for the safe installation and operation of surface water, leachate and landfill gas management facilities, services, etc;

f) provide a barrier to upward movement of contaminated water by capillary action;

g) provide a restoration scheme that is safe for public use and is not injurious to flora and fauna;

h) minimise the uncontrolled egress of landfill gas and compatible with the landfill gas management system; and

i) contain waste to minimise potential environmental nuisances.

Figure 2 and Figure 3 are recommended design for final capping.

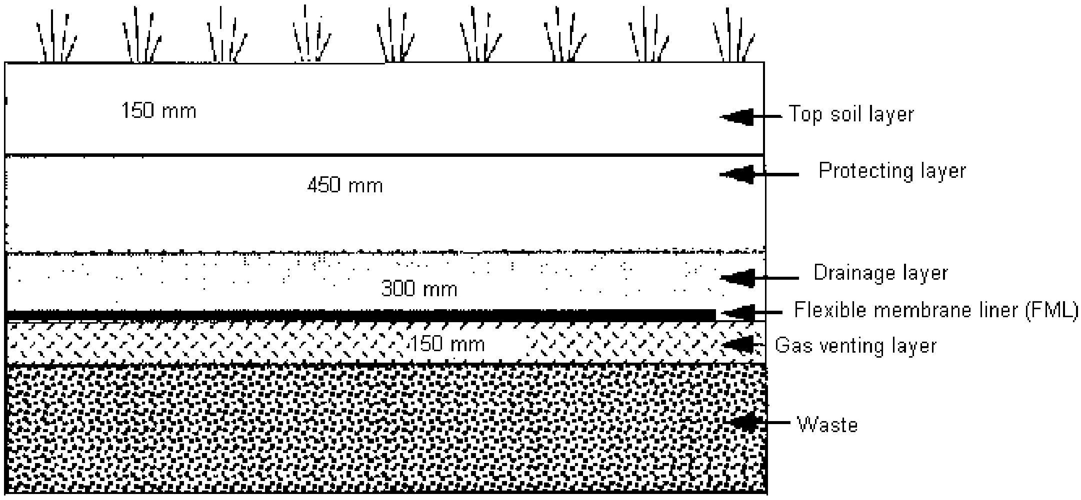


Figure 2. Recommended final cap (with synthetic liner)

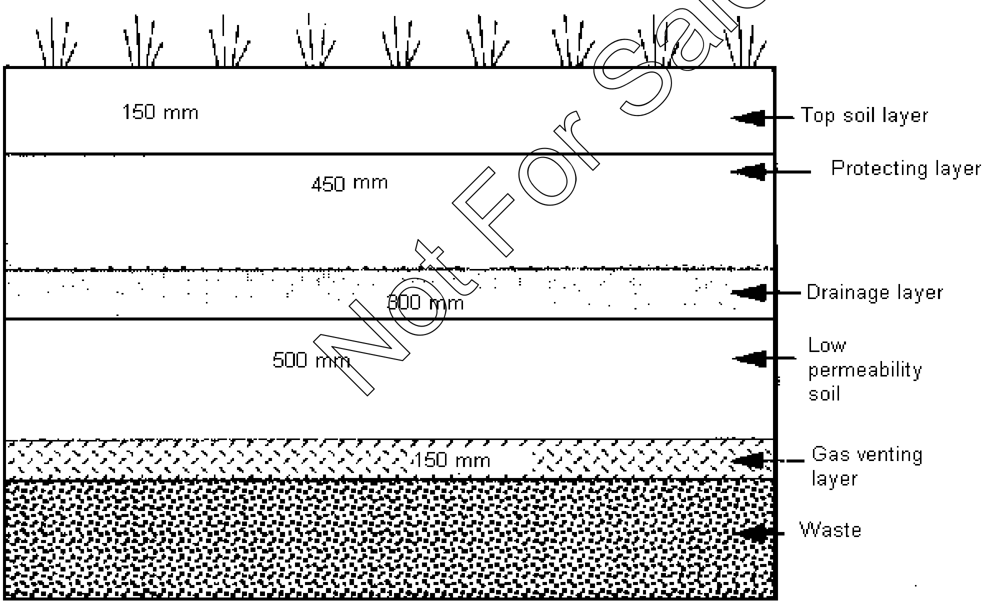


Figure 3. Recommended final cap (without synthetic liner)

4.2.2.2 Capping components

A cover design should further consider the following matters:

a) vegetation layer (top soil) (see 4.2.2.2.1);

b) general cover layer (protection layer) (see 4.2.2.2.2);

c) drainage layer (see 4.2.2.2.3);

d) liner (see 4.2.2.2.4); and

e) gas venting layer (see 4.2.2.2.5).

4.2.2.2.1 Vegetation layer (top soil)

The vegetation layer should consider the following:

a) the vegetation cover is needed to minimise erosion and naturalisation process;

b) plant species for vegetation should not have a deep root system that can damage the barrier layer. Types of recommended vegetation are local varieties and those with minimal maintenance;

c) the recommended top soil layer should be able to accommodate non-woody cover plants. The surface should be raked to uniformly flat;

d) top slopes between 3 % and 5 % are recommended to avoid pooling and erosion;

e) a surface drainage system shall accommodate runoff to avoid rills and gullies;

f) a separation filter is recommended between the drainage layer and the vegetative support layer to avoid clogging; and

g) a thickness of 150 mm of top soil shall be laid upon completion of final capping layer.

4.2.2.2.2 General cover layer (protection layer)

A minimum thickness of 450 mm for plateau area, a minimum thickness of 300 mm at side slope of suitable fill material. It shall be compacted to a minimum 90 % of the standard proctor density. The general cover layer shall be locally thickened as necessary for the installation of pipework, chambers and services. Suitable material and unsuitable material for protecting layer are listed as follows:

4.2.2.2.2.1 Suitable material for protecting layer

Any type of soil and other alternative material, excluding unsuitable material.

4.2.2.2.2.2 Unsuitable material for protecting layer

Unsuitable fill and hazardous fill shall not be used at any location or part of the site, including landscapes areas. Unsuitable fill shall include but not limited to:

a) cohesive soils having a liquid limit in excess of 80 % or plasticity index in excess of 55 %;

b) any material susceptible to significant volume change (e.g. marine mud, swelling clays and collapsible soils);

c) any material containing top soil, wood, peat or waterlogged substances;

d) any material containing bio-degradable or organic material (more than 2.5 %);

e) any material containing scrap metal;

f) any material from contaminated sites; and

g) any material which by virtue of its particle size or shape cannot be properly and effectively compacted (e.g. some slate wastes).

4.2.2.2.3 Drainage layer

The construction of any drainage layer incorporated into capping systems on top of the low permeability layer or liner shall be subjected to the following requirements:

a) the thickness for drainage layer shall be minimum 300 mm;

b) it should be integrated with the surface water management systems and shall have controlled drain or pipe discharges to the surface water collection systems;

c) it should be able to accommodate any flow which may occur within the drainage layer;

d) the drainage layer should not less than 1.1 x 10^{-1}m/s for any drainage layer (poorly graded sand);

e) the permeability test should conform to MS 1056-5;

f) if a drainage layer comprising granular material is proposed, perforated pipes should be included within the drainage layer. These pipes shall be capable of withstanding operational loadings; and

g) care shall be taken to avoid clogging of any drainage layer during construction.

4.2.2.2.4 Liner

4.2.2.2.4.1 Natural liner

The permeability of natural liner should be less than or equal to (≤) 1 x 10^{-7}m/s with minimum thickness of 500 mm. The permeability test should conform to MS 1056-6 and BS 1377-9. Compaction should be 95 % of maximum dry density value with the layer not laid more than 300 mm thickness. Compaction test should conform to MS 1056-6 or BS 1377-9.

4.2.2.2.4.2 Synthetic liner

The minimum thickness of synthetic liner should be 1.5 mm.The installation and testing of commonly used synthetic liner such as High Density Polyethylene (HDPE) and Geo synthetic liner (GCL) should conform to the following standards as stipulated in Table 2 and Table 3 or equivalent.

Table 2. The installation and testing of HDPE liner

Item	Property	Standards
Conformance testing (upon shipment of HDPE to the site)	Thickness	ASTM D5994 or equivalent
	Density	ASTM D1505, ASTM D792 or equivalent
	Tensile properties (yield and break stress, yield and break elongation)	ASTM D6693 Type IV or equivalent
	Puncture resistance	ASTM D4833 or equivalent
	Tear resistance	ASTM D1004 or equivalent
	Carbon black content	ASTM D1603 or equivalent
	Carbon black dispersion	ASTM D5596 or equivalent
	Stress crack resistance	ASTM D5397 or equivalent
	Oxidative induction time	ASTM D3895, ASTM D5885 or equivalent
Start-up test weld	Welding equipment	Checked daily at start of works, and whenever the welding equipment is shut-off for more than 1 h or after significant changes in weather conditions.
	Weld conditions	Test weld strips will be required whenever personnel or equipment are changed and/or wide temperature fluctuations are experienced. Minimum 1.5 m continuous seam.
Destructive weld testing	Onsite, hand tensiometer in peel and shear	ASTM D6392 or equivalent
	Offsite, weld seam strength in peel and shear	ASTM D6392 or equivalent

Table 2. The installation and testing of HDPE liner *(continued)*

Item	Property	Standards
Non-destructive weld testing	All seams over full length	Air pressure test, ASTM D5820, vacuum box test, ASTM D5641 or equivalent
Visual inspection of geomembrane	Tears, punctures, abrasions, cracks, indentations, thin spots, or other faults in the material.	Every roll
Thickness of geomembrane	Onsite	Five per 100 m, 20 m apart, taken at the edge of the sheet
Source: EPA Victoria, Australia		

Table 3. The installation and testing of GCL liner

Item	Property	Standards
Conformance testing (upon shipment of GCL to the site)	Thickness (Dry)	ASTM D1777
	Mass per unit area of bentonite component of GCL	ASTM D5993
	Mass per unit area of GCL	ASTM D5993
	Swell index/free swell of clay	ASTM D5890
	Water absorption	ASTM D5891
	Peel strength (for needle-punchedproducts only)	ASTM D6496
	Tensile strength	ASTM D4595
	Index flux	ASTM D5887
Visual inspection of GCL	Colour, thickness, needle punching,presence of needles or broken needles, and sewing density or other faults in the material.	
Thickness of GCL (i.e. uniformity of bentonite distribution) and apparent variations in the as placed moisture distribution.	If thickness appears to be variable a check of the variability of the mass per unit area should be conducted.	Onsite for every roll during placement

NOTES:

1. Alternative materials which have similar properties may also be considered. The materials properties should comply with relevant standards.

2. All conformance tests need to be reviewed, accepted and reported by a consultant before deployment of the geomembrane.

3. All testing need to be performed on samples taken from the geomembrane delivered to site under the consultant supervision.

4. All laboratory tests need to be performed in a third-party independent accredited geosynthetics laboratory.

5. The required testing frequencies may be revised by the consultant to conform with improvements in testing methods and/or in the state of the art practice and/or to account for the criticality of the application (i.e. to account for the importance of the geomembrane for the safety of works).

6. Revisions need to be approved by the relevant authorities before application.

4.2.2.2.5 Gas venting layer

The construction of gas venting layer incorporated into capping systems should be subjected to the following requirements:

a) the thickness for gas venting layer should be 150 mm of poorly graded sand; and

b) the gas venting layer should be connected to vertical gas venting system.

4.2.3 Storm water management system

Storm water management system comprises of drainage works to the plateau, berm and toe of the slope. A surface drainage system shall accommodate runoff to avoid rills and gullies. The drainage system should be provided on the surface of the final cover, at the slopes, on the steps and at the perimeter of the landfill, to channel the surface water away from the landfill and to prevent soil erosion. The drains should be designed based on two years return period. Type of drains that should be considered are perimeter drain, cascade drain, berm drain, interceptor drain, etc.

4.2.4 Gas management system

4.2.4.1 Landfill gas management system at landfill sites shall be constructed in order to prevent the adverse impacts on health, safety, amenity and environmental due to landfill gases such as CH_4, H_2S and CO_2. As a consequence, landfill gas shall be appropriately monitored and managed at landfill sites to ensure there are no detrimental effects.

4.2.4.2 There are two types of landfill gas management systems:

a) active systems, where the system uses a vacuum to extract the landfill gas generated; and

b) passive systems, similar to active but with no vacuum pump.

4.2.4.3 The selection of an appropriate landfill gas management system (and associated monitoring program) will be based on the findings of a site-specific landfill gas risk assessment. Vertical and horizontal landfill gas collection systems are normally used. The selection of number and spacing of landfill gas collection pipes should be based on environment, economy and technology factors (see Table 4).

4.2.4.4 Typical engineering details of landfill gas management systems can be referred in Annex A.

Table 4. Guideline on selection of type of gas management systems

Landfill gas generation rate	Potentially suitable landfill gas treatment technologies
> 1000 m^3/h	Combined heat and power generation Substitute fuel Power generation Intermittent use and off-time flaring High-temperature flaring
> 250 m^3/h - < 1000 m^3/h	Power generation Intermittent use and off-time flaring High-temperature flaring Low-calorific flaring
> 100 m^3/h - < 250 m^3/h	Power generation High-temperature flaring Low-calorific flaring Other oxidation and discharge (e.g. passive flares, biofilters, biocover)
< 100 m^3/h	Other oxidation technology and discharge (e.g. passive flares, biofilters, biocover)
Source: EPA Victoria	

4.2.5 Leachate collection systems

4.2.5.1 Leachate collection pipes should be constructed around the perimeter of the landfill or at locations and depths to safely collect, control the migration and control the odor of only the perched leachate trapped from beneath the engineered capping system into the leachate collection pond.

4.2.5.2 The leachate collection pipes shall be used to collect and convey the leachate to a sump. Manning's equation or Colebrook White formula shall be used to design the pipe carrying capacity of gravity flow.

4.2.5.3 The leachate collection pipes are installed in a trench filled with granular drainage layer, protected with lightweight non-woven geotextile filter material with permeability of 1.1×10^{-1}m/s.

4.2.5.4 The leachate collection pipes should be made double walled of HDPE or material with similar properties. The leachate collection pipes should be half perforated with the solid section at the bottom half. The leachate collection pipes should be designed to slope at a minimum 2 % gradient. The leachate collection pipes should be constructed above seasonally high water table.

4.2.5.5 Leachate from existing refuse should be extracted and treated to reduce the migration of contaminants.

4.2.6 Leachate treatment facilities

For closed landfills which do not have leachate treatment facilities, the leachate:

a) should be treated on site (construct new leachate treatment plant); or

b) could be pre-treated and sent to offsite leachate treatment plant; or

c) could be sent to the offsite leachate treatment plant.

4.2.7 Service facilities

The following facilities should be constructed and/or maintained:

a) administration building;

b) guard house, gate and signage;

c) perimeter fencing;

d) access road; and

e) monitoring facilities i.e. water quality, air quality and settlement.

4.3 Monitoring

The primary objective of monitoring is to determine the stage of landfill stabilisation. To ensure the primary objective is met, the monitoring facilities (see 4.2.7 e)) should be maintained regularly. Monitored media includes groundwater, surface water, leachate and air, and landfill settlement.

4.3.1 Environmental monitoring

4.3.1.1 The objectives of an environmental monitoring system are to ensure:

a) the closed landfill is performing as designed;

b) the emission and discharge from the closed landfill is conforming to the environmental standards; and

c) the stabilitisation of the closed landfill is achieved (refer Table 5).

Table 5. List of parameters to measure the landfill stabilisation

Parameter	Target value
Leachate (untreated)	Comply with Environmental Quality Regulation 2009, *Control of pollution from solid waste transfer station and landfill*
Landfill gas	Methane (CH_4): < 1 % of landfill gas composition
Subsidence rate	< 20 mm per year

4.3.1.2 Monitoring programmes at a landfill site should be carried out in three zones:

a) on and within the landfill;

b) the surface water and groundwater around the landfill; and

c) the atmosphere/local air above and around the landfill.

4.3.1.3 The parameters to be monitored regularly are:

a) leachate and gas quality within the landfill;

b) long-term movements of the landfill cover;

c) quality of surface water and groundwater; and

d) air quality above the landfill, at buildings on or near the landfill and along any preferential migration paths.

4.3.1.4 The parameters and frequency of monitoring should be carried out to meet the requirement of relevant authorities. The analysis of monitored parameters should be conducted by accredited laboratories.

4.3.1.5 Method of sampling and analysis should conform to MS ISO 9359 and MS 1850-14.

4.3.2 Landfill settlement monitoring

4.3.2.1 The landfill settlement monitoring is conducted through periodic topographical survey of the closed landfill. Landfill settlement plates with established levels are placed on the landfill surface and the levels are measured using survey equipment. Temporary Bench Marks (TBMs) are established at landfill site to facilitate survey work.

4.3.2.2 Differential landfill settlement results in the occurrence of depression of landfill surface. The problems associated with differential landfill settlement include water ponding, interrupted surface water flow, increased leachate production and increased landfill gas generation.

NOTES:

1. The main factors affecting the rate of landfill settlement and/or subsidence are:

a) initial compaction;

b) characteristics of wastes;

c) height of completed filled;

d) degree of decomposition; and

e) effects of consolidation.

2. The two landfill settlement types that may occur are:

a) differential settlement; and

b) subsidence or uniform settlement.

3. The main causes of differential landfill settlement are:

a) traffic;

b) non-uniform compaction;

c) placement of waste with differing decomposition rates; and

d) landfill settlement due to creation of voids by decomposition.

4. Subsidence results in uniform landfill settlement where the whole mass settles. The occurrence of subsidence is slow over time. The main reasons are:

a) weight of fill; and

b) poor initial compaction.

5. In general, 90 % of anticipated landfill settlement occurs within the first 5 years after placement of waste. The total settlement within this period can range from 10 % to 25 % of the total fill depth.

Annex A
(informative)

Landfill gas management systems

A.1 Landfill gas monitoring and protection systems

A.1.1 System description

A.1.1.1 Landfill gas (LFG) operations typically involve monitoring gas composition and related gas parameters that may serve as performance indicators. These include:

- methane;
- carbon dioxide;
- oxygen;
- liquid levels (e.g, condensate, leachate);
- gas pressure and vacuum;
- gas flow;
- hydrogen sulfide; and
- other trace gases.

A.1.1.2 Landfills also are typically required to monitor for the subsurface movement of LFG, and to show that LFG migration control systems are working properly. As already noted, this is because LFG can migrate from the landfill in all directions, can accumulate, and possibly explode under certain conditions. LFG generally flows from areas of high pressure or concentration to areas of low pressure or concentration.

A.1.1.3 The lateral movement of LFG can be controlled by either ventilation or barrier systems (see Figure A.1). Ventilation systems include gravel-filled vents, vertical and horizontal wells, trenches, or combinations thereof. These may be either induced exhaust systems or passive systems. Barrier systems are built outside the landfill area and extend to a bottom seal that has low permeability or to a natural barrier like bedrock.

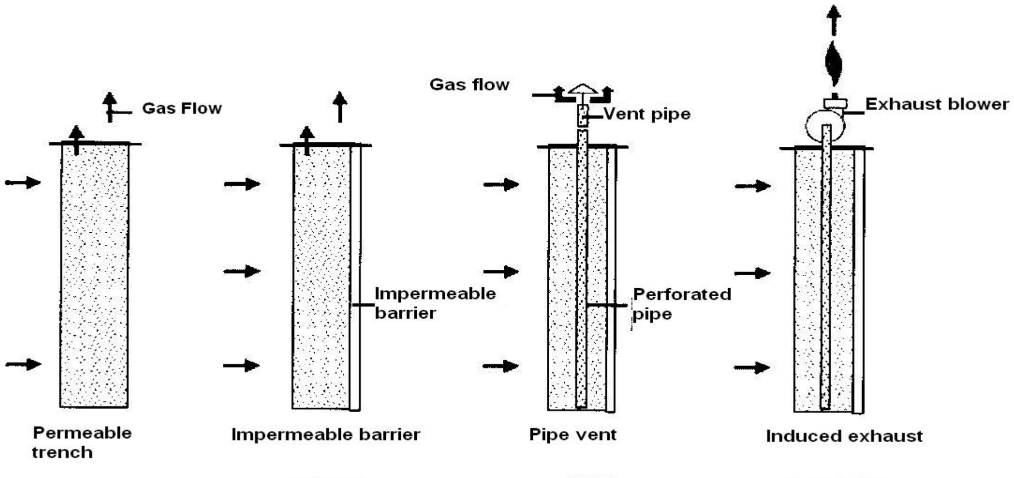


Figure A.1. Gas control systems

A.1.1.4 The monitoring of LFG surface emissions also may be necessary, depending upon the air quality regulations in the area where the landfill is located. Specific reasons why LFG monitoring is necessary include:

- to determine whether LFG migration exists;
- to assess the degree to which LFG migration has occurred;
- to figure out whether there is any potential for a gas explosion;
- to document how well the LFG system is operating; and
- to be in compliance with environmental regulations.

A.1.1.5 LFG monitoring and sampling can be conducted within the collection system piping, in buildings and structures to maintain a safe work environment, in soils near the landfill perimeter, at the landfill surface, at the extraction wells to show that the collection system is in balance, in monitoring wells, etc. Many different types of instruments are used to monitor LFG. Monitoring and sampling can be accomplished using both portable and stationary devices and instruments. Such devices typically measure LFG in terms of the percent volume occupied in the air.

A.1.1.6 Further, operators should be prepared to trouble-shoot problems that arise from operating a LFG system. Examples include:

- repairing broken equipment;
- re-igniting the flare;
- unclogging a blocked pipe;
- odors; and
- reduced LFG flow.

A.1.1.7 Operators should keep good records of trouble-shooting activities to facilitate the correction of future problems.

A.1.2 Typical components

A.1.2.1 A primary monitoring system component is known as the monitoring probe or well. The purpose of such probes is to show whether LFG has migrated beyond an established boundary such as the landfill property line. Unless they are being used to collect LFG samples, monitoring probes should be placed outside the waste mass. Probes may also be located elsewhere to monitor landfill structure, specific LFG migration patterns, etc.

A.1.2.2 Monitoring probes can be driven into the soil, instead of using a borehole, if the probe depth is less than about 5 m. Probes can also be single-depth or multi-depth, with multi-depth probes consisting of varying depth pipes within the same borehole (see Figure A.2). Depths should typically be determined by how deep the landfill is in the area of the probe.

A.1.2.3 The LFG probes typically monitor for the following types of indicators: methane, carbon dioxide, pressure, and balance gas (indicating nitrogen).

A.1.2.4 To determine methane levels, the following kinds of instruments or equivalent are used:

- an organic vapor analyser/flame ionisation detector (OVA/FID);

- a combustible gas analyser; and

- an infrared analyser.

A.1.2.5 Other key LFG monitoring equipment includes:

- pressure measurement devices;

- oxygen detectors; and

- flow measurement devices.

A.1.2.6 Specific knowledge about each instruments capabilities, limitations, and requirements is important. For example, an OVA/FID can also be used to measure the following:

- low levels of VOCs or combustible gases;

- surface emissions;

- human exposure in specialised applications; and

- fugitive leaks from pipes and equipment.

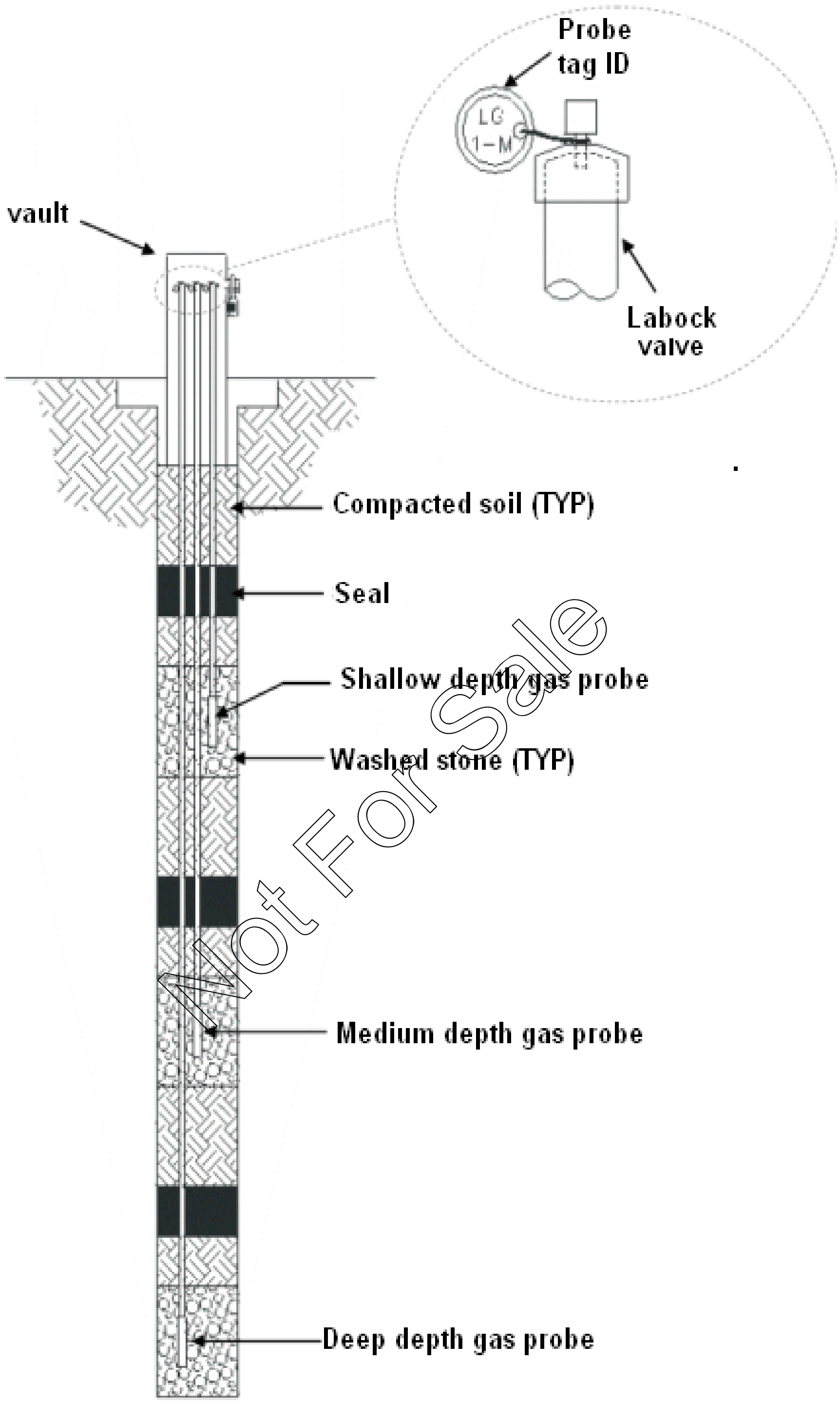


Figure A.2. Multi-depth LFG monitory probe

A.1.2.7 In addition, landfill surface emissions monitoring may be accomplished using various monitoring devices, and applying different collection methods such as:

- immediate random landfill surface sweeps using an OVA/FID and a site map;

- immediate direct landfill surface sweeps covering a defined area using an OVA (plus optional strip chart recorder or data logger);

- collection of an emission sample over time covering a defined landfill area using a bag sampler (OVA used to derive and average grid reading); and

- ambient air sampling using up-wind and down-wind integrated bag samplers to measure total non-methane hydrocarbons (TNMHC) and track priority pollutants from the landfill.

A.1.2.8 Portable measurement instruments are typically comprised of a detector element, an electronic circuit that responds to the detector, and a user interface such as a digital meter or analog current meter. The instrument shall be calibrated to ensure accurate measurements. Also, the term indicator is sometimes used instead of the term analyser to reflect the fact that the instrument in not that precise. For example, the presence of a combustible gas may be measured but not the actual quantity. One example is provided by the simple combustible gas analyser or indicator (i.e., CGA or CGI).

A.1.2.9 Such instruments can determine the presence of most combustible gases and, therefore if, the CGI is calibrated for methane, other gases that are present may impact the accuracy of the reading.

A.1.2.10 Typical instrument types and associated LFG application include:

- flame ionisation detector (for methane detection);

- thermal conductivity detector (methane);

- catalytic combustion sensor (methane);

- infrared bench detector (methane, CO_2);

- chemical reaction (oxygen, H_2S, CO);

- infrared bench detector (methane, CO_2); and

- chemical reaction (oxygen, H_2S, CO).

A.2 Landfill gas (LFG) well field, conveyance, and condensate systems

A.2.1 System description

A.2.1.1 LFG well field and conveyance systems

A.2.1.1.1 The LFG well field system is comprised of a network of wells or collectors in the landfill, coupled with conveyance piping for the transport of LFG to a blower-flare facility, other treatment and disposal, and/or energy recovery equipment. Vertical extraction wells are commonly installed into the interior landfill waste mass for LFG emission control and energy recovery, once the filling operations have been completed. They are also installed along the landfill perimeter for LFG migration control (see Figure A.3 and Figure A.4).

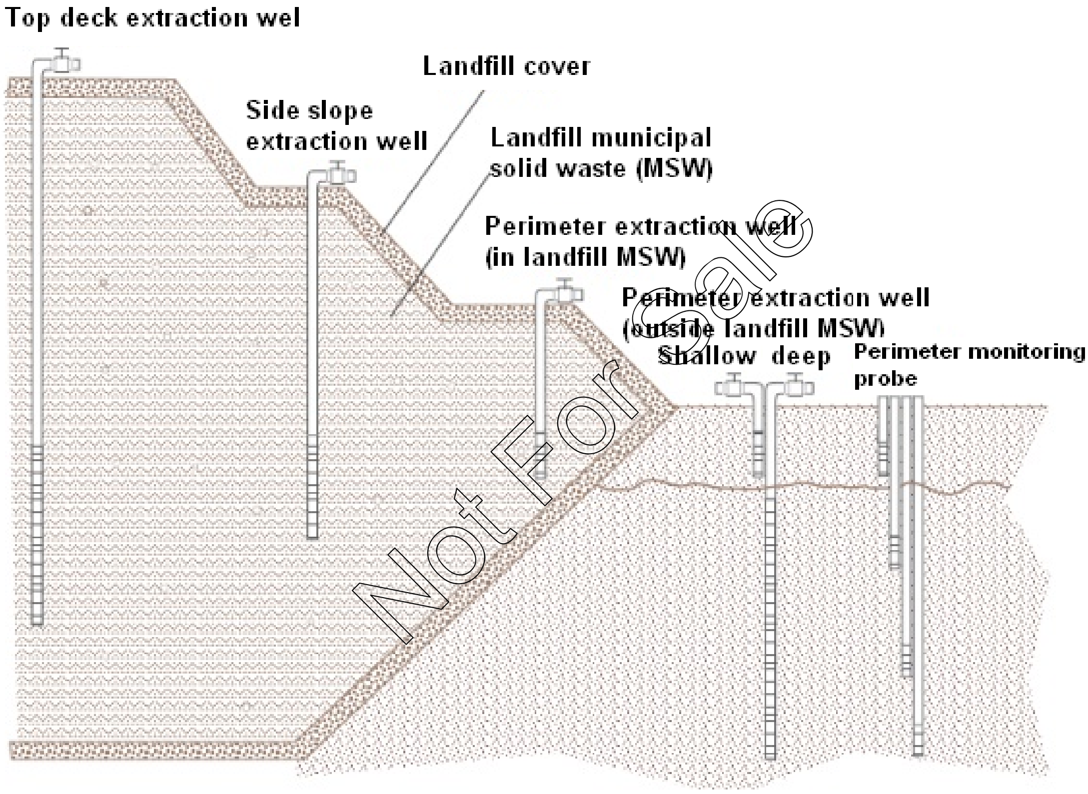


Figure A.3. Vertical LFG extraction wells

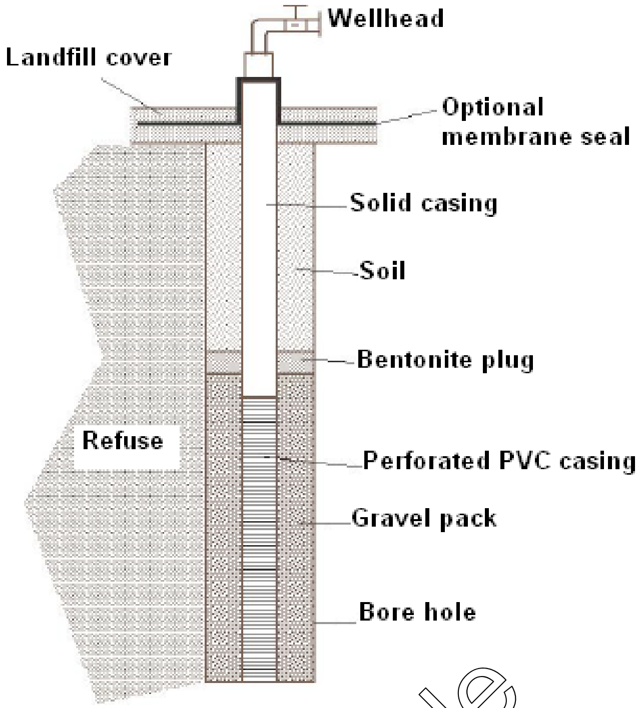


Figure A.4. Vertical LFG extraction well detail

A.2.1.1.2 The installation of horizontal wells (e.g. trench collectors) serves as another efficient LFG collection method, particularly in landfills that are still being actively filled (see Figure A.5 and Figure A.6). Once a lift of waste has been placed and compacted in the landfill, perforated collection pipes are installed and another layer of waste is placed on top. This allows for LFG collection directly below an active fill area.

Figure A.5. Horizontal LFG extraction well

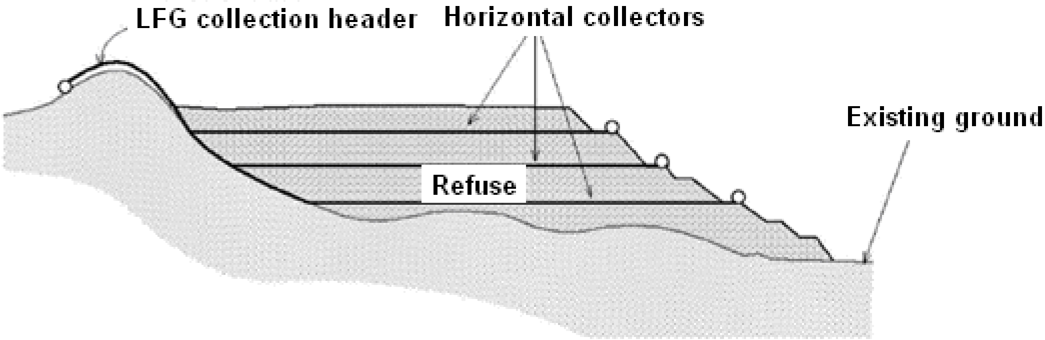


Figure A.6. Horizontal collectors diagram

A.2.1.1.3 A piping network is constructed to connect the LFG collection LFG well field to the blower and flare facilities. The main pipe used to transport LFG from the LFG well field to the processing facilities is known as a header. Lateral pipes connect landfill wells and trenches to the header(s). Subheader pipes connect the lateral pipes. There are different header piping configurations including: matrix, branch, and looped arrangements (see Figure A.7). A primary objective when designing the collection header piping configuration is to achieve effective LFG drainage.

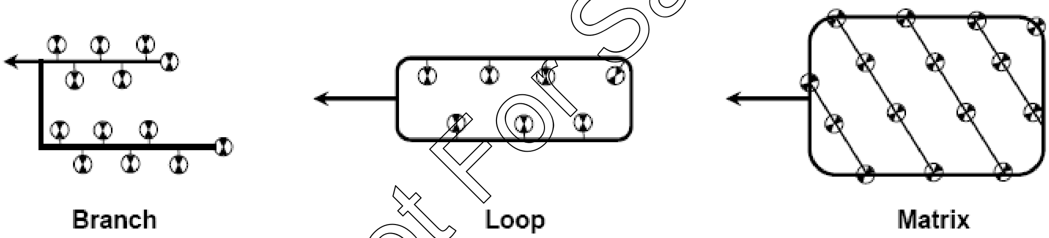
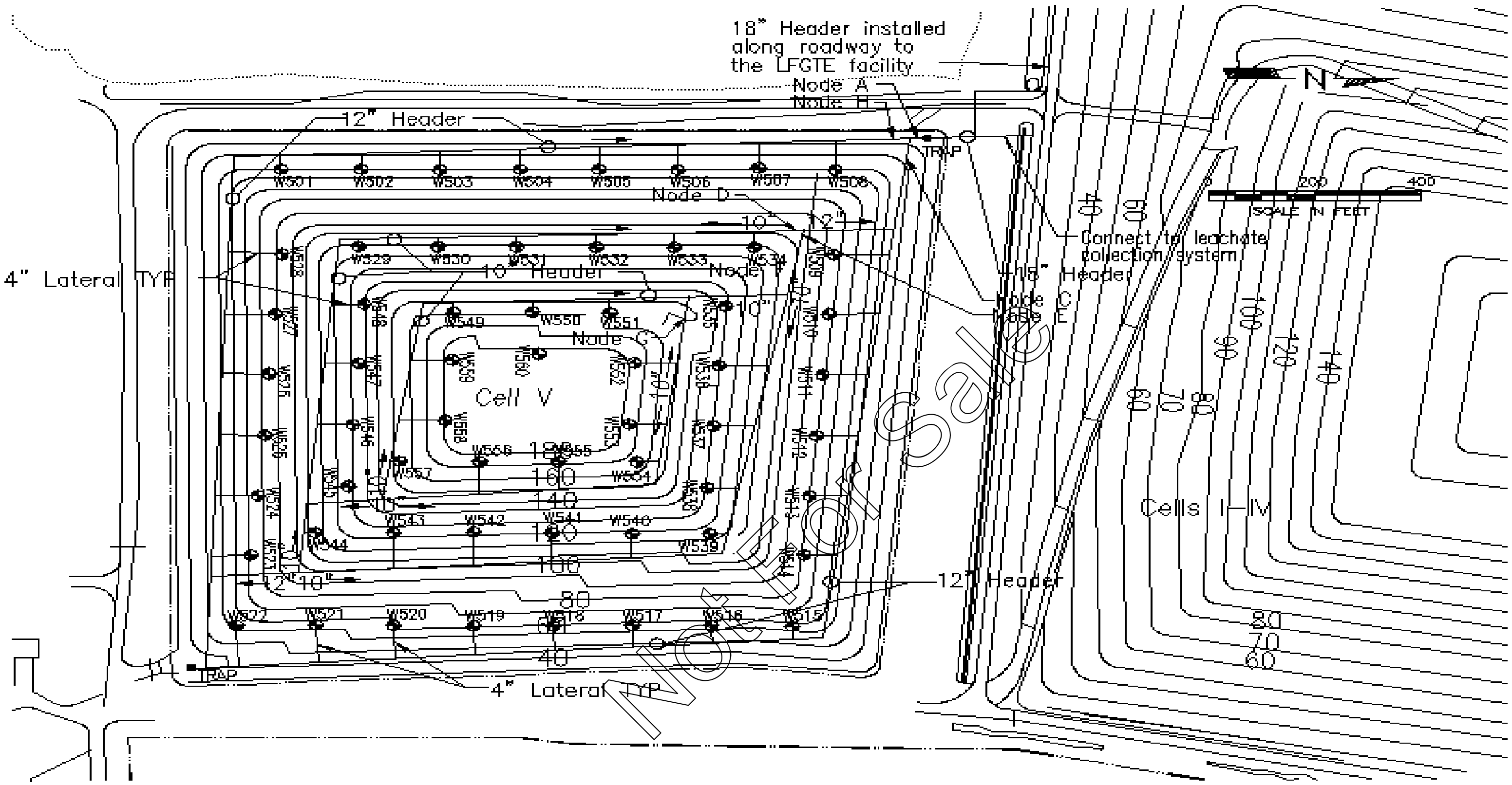


Figure A.7. LFG Header routing configurations

A.2.1.1.4 Before LFG from the LFG well field reaches the blower and flare systems, it typically passes by an inlet block valve which serves as the primary LFG well field LFG flow throttle. During maintenance activities, the throttle may also be used to isolate the blower and flare facilities from the LFG well field.

A.2.1.1.5 Next, the LFG typically passes through a liquid knockout vessel (i.e., mist eliminator) installed in a piping segment which removes the flowing liquid and particulate from the gas. The liquid may be collected in sumps or drained back into the landfill. A big advantage associated with inline knockouts is that they can be used in LFG piping where there is little or no slope. Figure A.8 shows a typical LFG well field and conveyance systems layout.



NOTE. The number, location, configuration and depth of proposed wells may be adjusted at time of installation per field conditions encountered.

Figure A.8. Typical LFG well field and conveyance system

A.2.1.2 Condensate system

The LFG condensate system is responsible for removing water that condenses in the system as a result of gas cooling as it passes through the header piping and processing equipment. The condensate system uses traps, sumps, and knockouts, specifically located in the collection system, blower, and flare facilities, to collect and remove water. Such liquid gets in the way of LFG flow and shall be properly managed, either through treatment and disposal back in the landfill or elsewhere. Typical LFG condensate system locations are shown in Figure A.9.

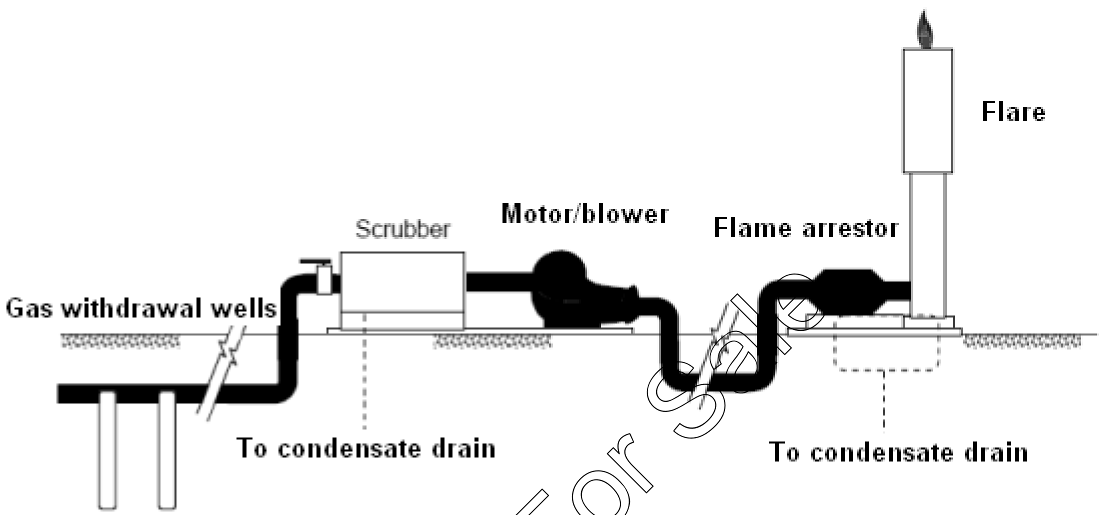


Figure A.9. Typical LFG condensate system locations

A.2.2 Typical components

A.2.2.1 LFG well field and conveyance systems

The primary components of the LFG well field and conveyance systems include:

- horizontal and/or vertical extraction wells (collectors);
- well monitoring ports and flow control assembly for the extracted gas;
- piping for the LFG collection and conveyance;
- block valve;
- liquid knockout vessel;
- surface collectors; and
- cover cap for the landfill.

A.2.2.2 LFG conveyance systems are typically made up of one or more of the following plastic materials: high density polyethylene (HDPE), and/or fiberglass-reinforced plastic (FRP) pipe. Such pipe may be placed either underground or aboveground

A.2.2.3 Condensate system

The primary components of the condensate system include:

- condensate water traps;
- sumps;
- drain lines;
- oil and water separator;
- pumps;
- treatment equipment;
- air compressor; and
- storage tank.

A.3 Landfill gas blower systems

A.3.1 System description

A.3.1.1 As noted in previous sections, landfill gas is transported from the landfill LFG well field to the blower facility by way of the main gas collection header. LFG then typically passes through a liquid knockout vessel for the removal of gas particles and liquid, before being routed to the blower. Block valve and bypass valves may be actively used at some landfills if there is a desire to route gas around the liquid knockout vessel. This is generally not recommended because condensate removal helps to protect processing instrumentation and equipment.

A.3.1.2 The blower facility and associated control equipment can either be housed inside a building or be exposed to the elements outside (see Figure A.10). It should be centrally located with room for expansion and supplied power. It should also have the capacity to handle 100 % of the LFG peak production estimate, plus additional size for LFG migration control. Butterfly valves are often installed on the inlet and outlet piping for each blower being used to allow for continuous blower operation during scheduled maintenance and shutdowns.

Figure A.10. Typical blower facility

A.3.1.3 The purpose of the LFG blower (also known as a compressor) is to create a vacuum for the extraction of gas from collection wells and trenches under pressure, the pulling of the LFG to the blower, and the pushing of the LFG to the flare or other treatment equipment. This process is known as actively controlling LFG, which contrasts with passive LFG control (i.e. LFG is allowed to move without any mechanical assistance).

A.3.1.4 Passive systems, where LFG is typically allowed to vent into the atmosphere with little or no treatment (i.e., treatment options might include removal of VOCs using granular activated carbon and flaring at vent wells), most often are not advocated for modern landfill operations.

A.3.1.5 The start-up procedure associated with the blower system will vary depending upon the design of individual facility. Landfill operators should follow the recommended procedure of the blower system manufacturer.

A.3.2 Typical components

A.3.2.1 The primary mechanical component of the blower system is the gas compressor or blower itself. Other associated equipment may include:

- valves (automatic block, check);
- flow metering and recording;
- gages to measure pressure, temperature, etc.;
- condensate treatment and handling equipment;

- electrical equipment;

- instrumentation; and

- utilities.

A.3.2.2 Selection of the appropriate blower is determined by such factors as the quantity and end use of the LFG, the vacuum required to extract the gas, the pressure required for processing, etc. The main types of blowers used for LFG applications include:

- Single and multi-stage centrifugal blowers (i.e., constant vacuum/pressure, variable gas volume machines, incorporating a butterfly valve at the unit inlet).

- Positive displacement lobe blowers (i.e., constant volume, variable pressure machines, where volume is varied only by a speed change of the rotating lobe).

A.4 Landfill gas flare systems

A.4.1 System description

A.4.1.1 Once LFG gas has been routed through the blower system, it typically passes through check valves and an automatic block valve enroute to the flare facility. The automatic block valve is usually fitted with a valve position indicator. LFG then travels to a flame arrester and into the flare facility where it is burned (i.e., in systems without energy recovery). The high temperature flaring of LFG converts methane to carbon dioxide and water, eliminates odorous gas compounds, and ensures that trace chemicals are largely destroyed. LFG is burned by one of two types of flares. The first is an enclosed ground flare which burns at a controlled and predetermined temperature range (see Figure A.11). These flares are commonly equipped with air dampers to control combustion temperature. Such dampers can be manual, automatic, or a combination of both. The second type is a candlestick or open flame flare which is less sophisticated and not temperature controlled (see Figure A.12). Either flare system provides for a LFG disposal alternative.

A.4.1.2 Flares are also typically equipped with a pilot ignition system (i.e., natural gas or propane) and a safeguard system for flames. The flame safeguard controller has the following two functions:

i) makes sure that the pilot and main flame are lit and the on-going operation of the main flame; and

ii) shuts down the flair unit if the flame goes out.

Figure A.11. Typical enclosed ground flare

Figure A.12. Typical candlestick flare

A.4.1.3 The primary goal of proper flare design is to burn all of the LFG collected from the landfill. Optimising this objective usually requires making sure a balance is achieved between the flare having enough capacity to handle the LFG flow, and making sure the LFG flow is sufficient to optimise the flare handling capacity. Flares may also be used as a backup for energy recovery systems during scheduled and unscheduled down times. While the most common LFG treatment and disposal method is destruction by combustion in a flare, venting LFG through granular activated carbon (i.e., for the removal of VOCs and non-methane organic compounds (NMOCs) emissions) is also practiced.

A.4.2 Typical components

A.4.2.1 The primary components of the flare system may include:

- valves;
- flow metering;
- pilot ignition system; and
- flame safeguard system

A.4.2.2 Flame arrester (prevents flare flame from moving backwards into piping):

- flare;
- electrical controls and service;
- gages to measure temperature, pressure etc.;
- instrumentation;
- condensate equipment (traps, drains, sumps, pumps); and
- utilities.

A.5 Landfill gas energy recovery systems

A.5.1 System description

A.5.1.1 Methane from LFG can be recovered and put to beneficial use as a renewable energy resource. There are many applications for methane use including in furnaces, vehicles, fuel boilers, as a feedstock for chemical processes, engines, etc. See Figure A.13 for a summary of alternative LFG energy uses.

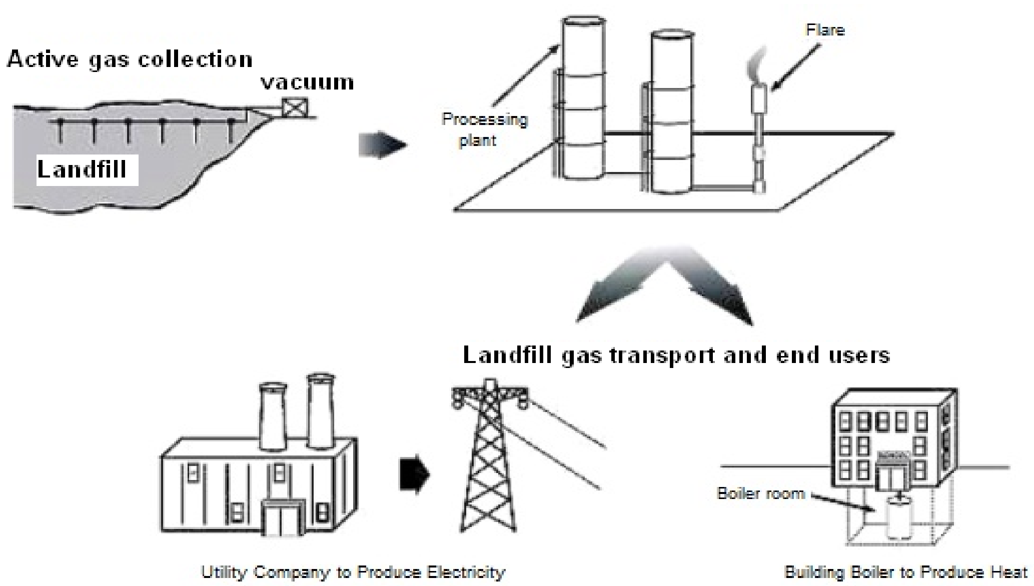


Figure A.13. LFG energy uses

A.5.1.2 In LFG systems designed with energy recovery as the end objective, the goal is to maximise the BTU flow rate and meet established emission limits. See Figure A.14 for an example of a typical LFG energy recovery facility. With this type of operation, combustion is typically used to destroy LFG volatile organic compounds (VOCs). This is one of the side benefits associated with generating energy from LFG.

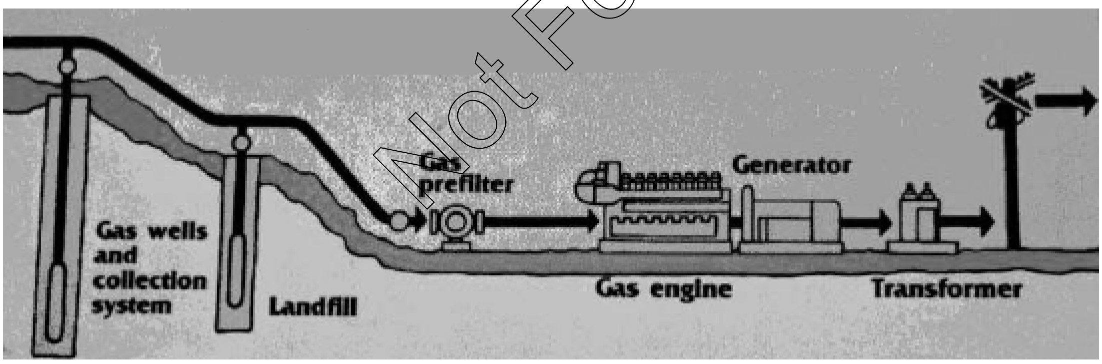


Figure A.14. Typical LFG energy recovery facility

A.5.1.3 The energy generated from LFG can range from low-grade to high-grade, depending upon the level of processing the gas is subjected to. A brief description of the processing associated with each fuel type follows:

- Low-grade fuel production requires little processing, primarily involving condensate removal as part of the LFG collection system, and the use of liquid knockout vessels to reduce LFG moisture quantities.

- Medium-grade fuel requires additional LFG treatment (e.g., compression, refrigeration, scrubbing, and/or chemical treatment) to extract more contaminated moisture and finer particles.

- High-grade fuel requires extensive gas pretreatment to remove carbon dioxide and other gases (i.e., with no heat value) from the methane, to remove impurities such as VOCs, and also requires gas compression for gas dehydration.

A.5.2 Typical components

Typical LFG energy recovery operations include the following types of system components:

- heat exchangers;
- process chillers;
- engines;
- gas compressors;
- gas turbines;
- electrical generators; and
- boilers.

A.5.3 A brief description of each component is listed as follows:

- Heat exchangers are used to cool and heat LFG; examples include: a gas/chilled water exchanger used to cool LFG and capture water condensate to meet dew point specification of the gas; a gas/gas exchanger to reheat LFG back to above its dew point; air exchanges to cool LFG or water from compressors; jacket water radiators for the compressor, engine, or turbine to maintain cooling jacket oil or water within a set temperature range; cooling tower to cool compressor and engine water jacket water.

- Process chillers are used for LFG dew point suppression in order for the LFG product to meet use specification and not condense out liquids that might interfere with LFG use.

- Engines are responsible for driving generators and compressors in medium BTU LFG operations, and usually require a minimum gas quality of 50 percent to function properly.

- Gas compressors are responsible for pressurising LFG for use in engines, turbines, boilers, and gas pipelines.

- Gas turbines are responsible for driving generators to create electric power, and may be adversely impacted by corrosion and poor gas quality.

- Electrical generators are typically linked to a gas turbine or engine and are responsible may be adversely ion and poor LFG quality.

- Boilers are used to generate steam through the heating of water, under high or lowpressure. Like turbines, boiler performance may be adversely impacted by corrosion and poor LFG quality. Delivery of consistent LFG pressure also facilitates good combustion and operation.

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Acknowledgements

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