Assessment and management of hazardous ground gases

Contaminated Land Guidelines

NSW EPA

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Building	Method	Requirements
Large commercial and industrial buildings	Slabs	These buildings generally have slabs constructed to high engineering standards, including post-stressed slabs and thick, well-reinforced slabs with high vehicle load–bearing capacity. There are usually opportunities to uprate slabs to assist with ground gas protection in this type of development. Most intrusion occurs through cracks, poorly sealed expansion joints and gaps around service penetrations. Post-tensioned structural slabs have higher resistance to vapour penetration than raft slabs, although cracking is not unknown and regular inspection during the tensioning period is required. A number of concrete mix additives that claim to reduce the liquid and vapour permeability of concrete are available. If a slab is to be relied on as a component of a gas management system, it is essential to seal all joints and penetrations, preferably with water bars, and carry out an independent inspection.
	Ventilation	Generally, these buildings have a high volume relative to the floor area, with good ventilation, but may include small rooms that require additional ventilation.

A.6.2.3 General gas-resistant membrane considerations

Gas-resistant membranes are thin sheets of material used to restrict the entry of ground gases. They form part of the gas protection system for buildings. These membranes are not impermeable. Gases can pass through membranes by advection and diffusion; both of these processes may occur together but their relative importance depends on the gas regime at the site, the nature of the gas and the composition of the membrane.

When there is differential pressure across the membrane, advection will dominate. This is most likely to occur where bulk ground gases are present. The transmission rate depends on the pressure gradient across the membrane, its permeability to the gas and the frequency of defects. Conversely, in the absence of differential pressure, transmission occurs primarily by diffusion. Diffusion alone is unlikely to transmit bulk ground gases through an intact (defect-free) membrane at a rate high enough to cause acute risks in an affected building. However, due to the much lower chronic toxicity values for trace ground gases, diffusive transmission of these gases may generate significant risks.

Once a gas has penetrated the surface of the membrane, the rate of diffusion depends on the concentration gradient across the interior of the membrane and the ease with which the gas can diffuse through the free volume between its molecules or crystals. Mechanistically, the gas molecules must partition (dissolve) into the membrane surface and then migrate through the intermolecular spaces in its interior in a Brownian motion, before desorbing from the opposite surface. The combination of these processes is termed ‘permeation’, and the permeation coefficient of a gas through a solid material (SI unit m^2/s) is the product of the partition constant and the diffusivity. Unless a gas can first dissolve into the membrane surface, diffusive transport cannot occur.

Factors that contribute to the solubility component of the permeation coefficient are the polarity of the gas and the membrane material (solubility will be greater if both are polar or both non-polar) and the size and shape of the gas molecule. Smaller and more streamlined molecules penetrate the surface of the membrane more easily than larger, bulky molecules; very large molecules may be excluded. Molecular size and shape also affect the diffusion component, as does the molecular structure (crystallinity) of the membrane and its free volume. More detailed discussion of the mechanism of gas transport through membranes is provided in Section 2 of CIRIA C748 and Chapter 13 of Hansen (2007).

When selecting an appropriate membrane for ground gas protection at a site, it is important to consider the permeation rate of the gases of concern through different membranes, as well as the risk of membrane deterioration due to chemical attack. In an initial assessment, the polarity of the membrane material relative to that of the gases of concern provides a reasonable guide to the permeation rate. Polar solutes will dissolve more readily in polar solvents, and vice versa. In this case, the gas is the solute and the membrane the solvent.

Polarity of a solute gas can be assessed from the chemical and physical data provided in Appendix 2. High log K_{ow} (>1) and low Hansen δ_P indicate non-polar solutes. Most gases discussed in these guidelines fall into this category. Conversely, low log K_{ow} and high Hansen δ_P indicate polar solutes.

An indication of the polarity of polymer membranes can be obtained by considering the monomers from which they are formed. Alkenes (ethene and propene) are non-polar, and so are the respective polymers, polyethylene and polypropylene. Conversely, polymerised alcohols, ethers and amides are polar, like the monomers.

At a more advanced level, the Hansen Solubility Parameters (HSPs) for gases and membrane materials can be used to model gas–membrane interactions. The three HSPs represent the three major types of interactions common in organic materials: respectively, non-polar or dispersive interactions (δ_D), polar cohesive energy (δ_P) and hydrogen bonding (δ_H). A fourth, experimentally determined parameter, the interaction radius (R_0), is available for many polymers. HSPs for gases are provided in Appendix 2, and parameters are provided in Table 26 for the membranes listed in those tables.

Chapter 1 of Hansen (2007) provides an equation for calculating a difference parameter (Ra) between two materials (in this case a gas and a membrane material) using their HSP:

$$(Ra)^2 = 4(\delta_{D2} - \delta_{D1})^2 + (\delta_{P2} - \delta_{P1})^2 + \delta H_1 - \delta_{H2})^2$$

This method is also summarised in CIRIA C748.

A relative energy difference (RED) is then calculated between the two materials as the ratio of Ra and the tabulated parameter R_0:

$$RED = Ra / R_0$$

The interpretation is as follows:

RED < 1 – the gas is likely to permeate the membrane

RED ≈ 1 – borderline condition

RED > 1 – the gas is unlikely to permeate the membrane.

The HSP approach may be used as a relatively simple screening technique to help select a suitable membrane, as permeation data are difficult to obtain from membrane suppliers. It should be noted that the HSPs provided were derived by Hansen using a combination of experimental work and calculation. Much of the work involved concentrated permeants; as aspects of permeation – particularly entry resistance – have a concentration dependency, the resistance of membranes to dilute gas mixtures may be underestimated.

CIRIA C748 recommends testing the permeation of candidate membranes in accordance with ISO 15105-2:2003. In NSW, such testing should be considered when there is any doubt about the suitability of a proposed membrane for a ground gas protection application.

A6.2.4 Types of gas-resistant membrane

Two types of gas-resistant membrane are described in this section. These are cold spray-applied barriers and loose-laid polymer (plastic) sheet geomembranes.

Spray-applied barriers

In southern Australia, where (with some exceptions) weather conditions are usually favourable for their use, cold spray-applied bitumastic or asphaltic barriers are currently the most commonly used membranes for protecting buildings against the entry of hazardous ground gases. When properly applied, they are effective for bulk ground gases and some commonly encountered VOCs.

Due to the problems encountered in applying and curing these membranes in wet conditions, they are not frequently used in the UK. The standards and procedures used for their specification, application and testing in Australia were originally developed in the USA, particularly for methane protection in Los Angeles, California.

A number of products are available in Australia, including Liquid Boot and Geo-Seal. The former is a water-based asphaltic emulsion modified with chloroprene (2-chloro-1,3-butadiene), while the latter is a water-based asphaltic emulsion modified with a sulphonated co-polymer. Both are mixed with a catalyst on-site to initiate curing. These membranes may also serve as water barriers. They may be applied directly to the upper or lower surface of a slab but are more commonly applied to a geotextile (non-woven polypropylene in the case of Liquid Boot) placed under or over the slab. The former placement is preferred, as the slab will provide ongoing protection.

It is possible to retrofit spray-on membranes to the top surface of existing slabs during major building renovations.

The advantages of spray-on membranes include the ease of sealing around penetrations and complex edges, the ease of bonding to structural elements and resistance to damage; they are to some extent self-repairing, as the asphaltic co-polymer coating remains plastic. Defects can readily be repaired by over-spraying, puttying or patching. The main disadvantage is the difficulty of maintaining a constant membrane thickness during on-site application. This can be effectively managed by using a skilled operator and appropriate CQA testing.

The cured thickness for spray-applied membranes is generally 1.5 mm (60 mil) for gas-only applications (2.0 mm with the base geotextile), or 2.0 mm (2.5 mm) when the gas protection function is combined with waterproofing. Loose-laid protective geotextiles, with a thickness of 1.5 mm, are used below and above the membrane. These systems have a methane transmission rate of <40 ml/day/m^2/atm, measured as required by ASTM D1434-82 (2015).

Both CETCO (Liquid Boot) and REGENESIS (Geo-Seal) also offer composite barrier systems where the base geotextile is replaced with a geomembrane or geomembrane–geotextile composite. Liquid Boot Plus uses a 0.5-mm LLDPE/ethylene vinyl alcohol (EVOH)/LLDPE composite geomembrane, and Geo-Seal uses a HDPE/polyamide/HDPE base membrane and loose-laid HDPE protective cover.

These composites can provide protection against a wider range of gases; see below for a summary of the membrane components and Table 25 for further information.

Loose-laid polymer (plastic) sheet membranes

A number of gas-resistant membranes are available on the international market; some of these are also available from Australian suppliers. Similar membranes are used for both landfill gas and leachate control and, in some cases, in water retention and hydrocarbon secondary containment applications. Note that the bentonite geocomposite membranes that are widely used in leachate applications are not suitable to use for building protection from ground gases due to the difficulty of achieving and maintaining hydration, and the lack of an adequate confining load. The low-cost commodity plastic sheeting sold as 'builders' film' or 'builders' plastic' (typically 0.1 to 0.2 mm thick) is not suitable for use in gas protection systems.

The sheet membranes most commonly used in Australia are:

- HDPE, with joints welded on-site
- LLDPE, also with welded joints
- LLDPE/EVOH composite.

Other sheet membranes available in Australia are:

- flexible polypropylene (fPP), with joints welded on-site
- low-density polyethylene (LDPE), with lapped and taped joints
- polyester-reinforced LDPE composite membrane with an aluminium core
- HDPE/polyamide composite.

Most of these membranes are available in a range of thicknesses. Table 25 gives membrane properties.

Other geomembranes that are used for gas protection overseas – including chlorosulphonated polyethylene (CSPE or Hypalon), PVC and coated polyester – are available in Australia but appear to be used only as waterproofing membranes.

The primary considerations in selecting membrane specifications for a particular site are:

- membrane permeation by the gases of concern
- chemical resistance
- mechanical strength and elongation at break

- tear and puncture resistance during and after installation
- the requirements for joining and patching sheets (welding or tape)
- the thickness required to meet permeation and strength requirements
- the process of sealing around penetrations and the availability of accessories to do this
- the overall practicality of installation.

These characteristics are all functions of both material composition and thickness. Their relative importance will vary between sites and will depend on the:

- gas hazard at the site
- role and importance of the membrane in the total gas protection system
- potential exposure of the membrane to chemicals of concern (concentration and phase – gas/vapour, condensate, dissolved phase, NAPL)
- potential exposure of the membrane to aggressive environments (acidic or alkaline conditions, UV radiation, temperature extremes, etc.)
- tensile loads on the membrane
- overall scale and complexity of the installation and detailing required
- potential for post-installation damage.

Resistance to damage during and after installation is always a major consideration because small punctures or tears in a membrane will result in a drastic increase in the overall gas transmissivity of the installation.

Annex C of BS 8485:2015+A1:2019 and CIRIA C748 provide further information on the general performance and specifications of plastic membranes used as gas barriers. Lucas and Wilson (2019) discuss the durability of aluminium-core LDPE composite membranes.

Table 25 Loose-laid polymer sheet geomembranes for ground gas protection – general characteristics (properties as stated by manufacturers/suppliers)

Material	Available thickness range (mm)	Thickness commonly used for gas protection (mm)	Tensile strength (N/mm)	Tear strength (N)	Elongation at break (%)	Puncture resistance (N)	Joining	Advantages	Disadvantages	Comments	Some known Australian manufacturers/ suppliers
HDPE	0.75–2.5	1.0	26	120	700	380	On-site welding	High chemical resistance, high puncture resistance, generally robust	Rigid, difficult to handle on-site, difficult to detail, difficult to repair	Specialist welding and weld testing required	GSE Curtis
LDPE	0.2–1.0	0.5	10	83	700	250	Lap/tape, extrusion welding possible	Cheap, good chemical resistance, flexible	Relatively high gas permeability, very easily damaged, degraded by UV light	Thin (0.2–0.4 mm) commodity membranes (usually imported from China or India as concreting membrane) are generally not adequate for gas control	Monarflex Curtis
LDPE/ medium-density poly-ethylene (MDPE) co-polymer	0.4	0.4	9	100	800	–	Lap/tape	Moderate gas permeability, high chemical resistance, flexible, relatively low cost	Easily damaged during and after installation	Not widely available	Rhinoplast

Material	Available thickness range (mm)	Thickness commonly used for gas protection (mm)	Tensile strength (N/mm)	Tear strength (N)	Elongation at break (%)	Puncture resistance (N)	Joining	Advantages	Disadvantages	Comments	Some known Australian manufacturers/ suppliers
LLDPE	0.5–2.0	0.75	20	70–100	850	205	On-site welding or lap/tape	Moderate gas permeability, high chemical resistance, flexible, relatively low cost	Easily damaged during and after installation	Readily available	GSE Permathene Curtis
LLDPE/ EVOH co-extruded	0.5	0.5	Not available in consistent units	63 × 66	464	240	Lap/tape overspray	Low diffusion and permeation coefficients for non-polar chemicals (most VOCs)	–	Readily available	CETCO (VI-20)
fPP	0.3–1.5	1.5	22	65	900	250	On-site welding	Low gas permeability, high chemical resistance, flexible	Easily damaged during and after installation	–	Permathene Curtis
Reinforced LDPE composite with aluminium core	0.4–0.8	0.4	14–44	216–400	–	–	Lap/double-sided tape	Lowest gas permeability and VOC permeation, flexible, relatively low cost	LDPE degraded by UV light, core can corrode if exposed to alkaline conditions (cement)	Aluminium core has very low methane transmission rate and VOC permeation rates, but the composite is not particularly robust	Visqueen Protech Monarflex

Table 26 Loose-laid polymer sheet geomembranes for ground gas protection – gas transmission and permeation

Material	Thickness (mm)	Methane gas transmission rate (GTR)[a] (ml/m^2/d/atm) (m/Pa.s)	Permeation coefficient P_g at 23°C (m^2/s × 10^{10})[b]								
			Benzene	Toluene	Ethylbenzene	m- and p-xylene	o-xylene	PCE	TCE	DCM	1,2-DCA
HDPE	2.0	150	0.1	0.3	0.5	0.6	0.4	–	–	–	–
LDPE	0.5	700	–	–	–	–	–	–	–	–	–
LDPE/MDPE co-polymer	0.4	150	–	–	–	–	–	–	–	–	–
LLDPE	0.76	320–690	1.0	1.8	1.6	1.4	1.1	–	–	–	–
LLDPE	0.53	–	0.7 $0.1_{(v)}$	1.1 $0.2_{(v)}$	0.8 $0.3_{(v)}$	0.9 $0.3_{(v)}$	0.8 $0.2_{(v)}$	–	–	–	–
fPP	1.5	65	–	–	–	–	–	–	–	–	–
PVC	0.76	–	1.3	3.6	7.8	7.5	4.7	–	–	–	–
Reinforced LDPE composite with aluminium core	0.4	0.001	–	–	–	–	–	–	–	–	–
32mol% EVOH co-polymer	0.015	–	0.00190	0.00250	0.00130	0.00110	0.00110	0.00300	0.00350	0.00330	0.00200
44mol% EVOH co-polymer	0.02	–	0.00023	0.00026	0.00016	0.00015	0.00014	0.00040	0.00038	0.00036	0.00015
LLDPE/EVOH/ LLDPE co-extruded five-layer	0.53 (EVOH 0.002)	–	0.00004	0.00005	0.00006	0.00007	0.00004	–	–	–	–
LLDPE/EVOH/ LLDPE co-extruded five-layer	0.53 (EVOH 0.002)	–	0.018 0.001	0.030 0.002	0.056 0.001	0.048 0.006	0.041 0.003	–	–	–	–
LLDPE/poly-amide/LLDPE co-extruded five-layer	0.38 (PA 0.002)	–	0.07–0.10 $0.02_{(v)}$	0.11–0.14 $0.02–0.03_{(v)}$	0.21 $0.05–0.07_{(v)}$	0.22 $0.06–0.07_{(v)}$	0.20 $0.03–0.04_{(v)}$	–	–	–	–

[a] Manufacturer's literature, generally to ASTM International 2015c

[b] Islam and Rowe 2001, Jones and Rowe 2006, and McWatters and Rowe 2009, 2010 and 2015

(v) Measured in the vapour phase – all other permeation coefficient values measured in aqueous phase. Vapour phase values may be estimated by multiplying by the dimensionless Henry's Law volatility constant.

Table 27 Cold spray-applied geomembranes for ground gas protection

Material	Available thickness range (mm)	Thickness commonly used for gas protection (mm)	Methane gas transmission rate (GTR) (ml/m2/day/atm) and as (m/Pa.s)	Tensile strength (N/mm)	Tear strength (N)	Elongation at break (%)	Puncture resistance (N)	Joining	Advantages	Disadvantages	Comments	Known Australian manufacturer /supplier
Chloroprene-modified asphaltic spray-on	1.5–2.0 (sprayed and, therefore, variable)	1.5	<40 $<4.7 \times 10^{-5}$	Depends on geofabric base used	Depends on geofabric base used	Depends on geofabric base used	Depends on geofabric base used	Lap/ over-spray	Bonds to structure if required; effectively seamless; easy to install where complex detailing is required; easily repaired; has some self-healing capability	Requires specialist installation; difficult to maintain constant thickness; manufacturers do not provide adequate data on gas permeability/ GTR	Probably the best combination of physical robustness, system integrity and ease of installation; manufacturers unwilling to provide test data for GTR, other than a statement that the product meets the City of Los Angeles Criterion quoted in Column 4	Liquid Boot
Chloroprene-modified asphaltic spray-on with LLDPE/EVOH/LLDPE base	–	–	–	–	–	–	–	–	–	–	–	–
Sulphonated asphaltic spray-on	–	–	–	–	–	–	–	–	–	–	–	Geo-Seal
Sulphonated asphaltic spray-on with HDPE/ polyamide/ HDPE base	–	–	–	–	–	–	–	–	–	–	–	–