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The Society of Brownfield Risk Assessment

SOCIETY OF BROWNFIELD RISK ASSESSMENT

Ground Gas Flux

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PUBLICATION

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The publication presents a summary of calculation methods collated from good practice guidance and literature to estimate ground gas flux within the ground.

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Contributor	**Employer**
Andrew Fellows	RSK Geosciences
Barry Mitcheson	WSP
Damian Watkin	AECOM
Steve Wilson	EPG

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CONTENTS

LIST OF FIGURES

1 INTRODUCTION

The SoBRA Ground Gas subgroup have produced the following guidance paper to aid practitioners with the estimation of mass flux of ground gas.

1.1 Structure of this Publication

This guidance document is structured to provide the information needed to allow practitioners to undertake gas flux estimations:

Section A – How to calculate gas generation rate
Section B – How to calculate gas flux where gas monitoring data is available
Section C – Whether the transport is diffusion or advection dominant
Section D – Is flux significant? Considering ground gas flux in context
Section E – Other factors that are not considered in this paper

The calculations referenced in this paper are based on existing ground gas guidance and literature which is referenced throughout the report. The calculations to estimate diffusion and advection are the same equations used in the Johnson and Ettinger model (as used in the Contaminated Land Exposure Assessment (CLEA) model (Environment Agency, 2005) for vapour intrusion assessment.

1.2 Competence

Estimating gas generation and flow in the ground requires a good understanding of the issues relating to ground gas. The calculations are not mathematically complex. The primary consideration is in choosing robust and defensible calculation input values and parameters and making sure they are appropriate for the situation, and that they reflect the site-specific conceptual site model (CSM). The users of the guidance should be competent and demonstrate sufficient knowledge, skills, experience, and qualifications in the area of ground gas risk assessment. One method for demonstrating competence in ground gas risk assessment is through SoBRA accreditation in permanent gases (SoBRA, 2025).

1.3 Conceptual Site Model for the Calculations

The first step in determining whether to apply calculation methods is to ensure that the ground gas CSM is sufficiently understood. It is often very useful to draw a diagram to set out the ground gas CSM and to consider how equations are being applied as part of this.

Further guidance on the development of CSMs is provided in British Standard BS EN ISO 21365:2020 (BSI, 2020), SoBRA Hazardous Ground Gas Top Tips (SoBRA, 2023) and the National House Building Council (NHBC) Foundation Hazardous Ground Gas – An essential guide for housebuilders (NF94) (NHBC, 2023).

Before undertaking any calculations, the risk assessor should demonstrate that the proposed analytical solutions are appropriate to the conceptual model for the site, ground conditions, and the building.

TOP TIPS

The risk assessor should ask themselves “*Am I modelling the right thing and using appropriate parameters?*”. Common considerations at this stage should include:

- Presence of open or more highly permeable pathways present that are not represented in the model.
- Rates of gas flow into a basement may be estimated assuming gas flow through the unsaturated zone when this is not the case as the basement is below groundwater.
- An assumption is made that flow across the floor slab is via a 2mm perimeter crack around a room or building with an un-reinforced ground bearing concrete slab. This is rarely the case for UK buildings which have a variety of floor types depending on age and construction.

A. How to calculate the gas generation rate

The estimation of gas generation and flux is commonly undertaken in support of the risk assessment and design practices adopted in UK landfill construction and management in the UK and associated good practice guidance.

In line with Environment Agency guidance LFTGN03 (Environment Agency, 2004), landfill gas emissions require assessment to inform the landfill CSM and gas management plans. The volume of gas being produced is important in estimating gas risk assessment. Data on this can be obtained experimentally in two ways:

1. Laboratory measurement

Gas generation can be estimated from soil samples using laboratory methods commonly adopted to assess the potential for waste use in anaerobic digestion plants or to verify a treatment process for biodegradable municipal waste. Such tests may be useful for Part 2A assessments under the Environmental Protection Act 1990 where the potential for future gas emission from a material may be considered. Relevant guidance on the use of biological methane potential and dynamic respiration (DR4) tests is published by the Environment Agency (Environment Agency, 2009).

Available tests include:

- Biological methane potential tests: Biodegradability under methanogenic condition (BMc) tests are commonly used to determine the volume of gas produced from the material in an anaerobic environment. These tests can take several months (until anaerobic degradation is considered to have stopped), and results are expressed as loss of organic matter (expressed as l/kg Loss on Ignition).
- Dynamic respiration test (DR4): Measures aerobic degradability of material over four days and provides data on level of carbon dioxide that may be generated.

2. Large Scale Field Tests – Testing Gas Generation of Soils.

Large scale empirical tests of gas generation (often referred to as Drum tests) involve filling a new clean oil drum with material (soils) and the addition of site groundwater in order to replicate site conditions as closely as possible. The drums are then sealed and monitored regularly over time for gas concentration, temperature and gas pressure. The duration of tests is dependent on the material being tested but could take in excess of 90 days. The drums need to be maintained with a temperature range that replicates in ground conditions. The drum test method should be carefully considered and is bespoke for the given site conditions and objectives.

Estimating Gas Mass Flux Rates

The estimation of gas mass flux can be undertaken where ground gas monitoring data is not available or to validate estimates where monitoring data is available.

Equation 1, which is provided in this section, is used to estimate gas generation rates that can be used to help estimate risk from ground gas and should be used alongside other lines of evidence identified through the conceptual site model and site investigation data, if available. This section does not consider the migration of gas from the source which is further considered in Section B.

The Environment Agency guidance LFTGN03 (Environment Agency, 2004) provides a simple and highly conservative approximation for estimating methane emission from 'fresh' (e.g. deposited within 1-2 years) biodegradable waste of 10m^3 of methane per year per tonne of waste. However, the LFTGN03 is aimed at the management of gas from operational landfill sites and so the rate is likely to be conservative for sites where a lower gas generation source is anticipated, in which case it may be more suitable to use more sophisticated models that are available.

Calculations (such as those implemented in commercially available models e.g. GasSim model (Environment Agency, 2002) which can be used to estimate landfill gas generation with consideration to the material waste composition, moisture content, and other site factors such as presence of a capping layer. Similar models include the ACUMEN Gas Estimation Tool (GET) that, for closed non-inert Landfill in the UK (Southampton University, 2015), estimates gas generation from waste based on the years of material emplacement and the unit gas production rate since closure. The supporting gas generation rates are based on empirical English landfill data from the late 1990s. It should be noted that the ACUMEN GET model was developed to indicate approximate gas generation during post-closure period of non-inert landfills. ACUMEN GET is not intended to inform on the gas management regimes on specific landfills.

A further calculation approach for estimating the rate of gas generation at any time following deposition is also outlined in CL:AIRE RB17 (CL:AIRE, 2012) for analysis using gas generation modelling.

First-order decay models are used in the landfill industry to estimate gas generation rates – single phase and multiphase (such as used in GasSim). Many approaches are based around similar equations to estimate gas generation (Scharff et al., 2006).

The following approach can be used to estimate potential gas generation from soils or fill and help to aid assessment of subsequent risk to receptors. The approach can also be used for determining limiting values of total organic carbon (TOC) in fill material as was demonstrated in CL:AIRE RB17 (CL:AIRE, 2012).

It should be noted by the practitioner that various models, such as those discussed in available literature (Scharff et al., 2006), to estimate gas generation are available and these vary in approach with respect to use of degradable organic carbon, organic matter, and stated values of methane production per unit weight of waste. Further assumptions could then be made by the practitioner with respect to the proportion of gas comprising methane and whether methane oxidation takes place. The models also adopt a number of constants based on the studies underlying the development of these models, such constants for example relate to moisture content or methane generation potentials. Temperature may also affect gas generation to a significant degree on some sites.

If using a modelling approach to gas generation, care should be taken by the practitioner that they understand the model approach and adopt input values that are suitably justified for their site and subjected to sensitivity analysis. The degradation rate constant (and thus rate of gas production) varies based on the relative rapidity of organic degradation and whether the material being assessed is considered to be dry, wet or an average moisture content, and associated temperature.

Modelling

The gas generation rate can be estimated using the following equation as used in GasSim (Gregory, 2003):

$$\alpha_i = 1.0846.A.C_i.k_i.e^{-k_i t}.\mathrm{F} \qquad \text{Equation 1}$$

α_i – gas generation rate at time t (m^3/year)

A – mass of waste in place (tonnes)

C_i – degradable organic carbon content of waste (kg/tonnes) at t = 0

k_i – gas degradation rate constant (yr^{-1})

t – time elapsed since carbon content estimate (yr) (of material deposited)

F – fraction of gas

The 1.0846 in Equation 1 is based on a conversion factor of 1.87 m^3 landfill gas produced/kg carbon degraded and a dissimilation factor (ς) which is the fraction of carbon that is degraded.

The gas generation rate derived from Equation 1 has been adjusted to consider the proportion of methane or carbon dioxide present by including the concentration F expressed as a fraction of total gas generated. The ratio of methane and carbon dioxide are dependent on the gas generation source. The ratio of landfill gas at source in a mature anaerobic landfill is typically in the region of 60% methane and 40% carbon dioxide (Environment Agency, 2004). The practitioner will need to consider assumptions made with regard to the respective volume of methane or carbon dioxide generation.

Sources of ground gas and associated gas ratios can also be indicated through interpretation via ternary plots as indicated in NHBC Foundation Report NF94 (NHBC, 2023).

It should also be noted that TOC, commonly measured in soil and material samples, can provide a conservative estimate of degradable organic matter (C_i) and it may be possible to further refine this via forensic logging and additional testing as outlined in CL:AIRE RB17 (CL:AIRE, 2012) and British Standard BS:8485 (BSI, 2019).

As indicated in CL:ARIE RB17 (CL:AIRE, 2012), the gas generation rate can be used to estimate surface emission rate however the practitioner should be aware that this may be highly conservative as this does not consider the soil permeability and processes that could reduce gas concentrations prior to surface emission such as oxidation of methane.

CL:AIRE RB17 indicates it can be used to provide preliminary assessment of equilibrium gas concentrations within structures assuming no attenuation from subfloor, floor slab or membrane. Where site-specific information is not available, such an assessment may require inclusion of some assumptions regarding the proposed development and these should be clearly stated. There is a requirement for sensitivity analysis on input parameters, and particular assumed values.

Key issues / Considerations / Limitations

- A key decision is on the gas degradation rate constant (ki) that should be used. It can be difficult to estimate with limited published information relevant to inert materials / made ground. The Environment Agency guidance LFTGN03 (Environment Agency, 2004) adopted values for the gas degradation rate constant of 0.185 (fast), 0.1 (medium), and 0.03 (slow).
- When selecting the gas generation rate, consideration should be given to processes likely to occur and the conditions present, such as the type of

material, depth of the material and potential for aeration, moisture content, and temperature as these factors may have a direct effect on the anticipated rate of gas generation rate.

- The approach is solely focused on source generation and does not consider gas migration pathways.
- Unless site-specific data is available, the proportion of each gas generated (F) needs to be assumed within the assessment as well as the site-specific estimate of the waste mass.
- The fraction of organic material available for degradation for use in the assessment (dissimilation factor) is assumed within the assessment and may be informed by forensic logging (BSI, 2019).
- The approach assumes no oxidation of methane as indicated in CL:AIRE RB17 (CL:AIRE, 2017). Where shallower deposits are present a large proportion of the material could be aerobic and generate more carbon dioxide and less methane.

Interpretation

The assessor must be confident that they have adequately characterised or made suitably conservative estimates for the material and extent of readily degradable material that may be present. Justification is required to clarify the selected gas generation rate constant, the material thickness, and selected values for degradable organic content.

Sensitivity analysis must be undertaken to manage uncertainty in the selection of key parameters. The generation rate assessment may help to clarify anticipated gas flow rates at a given site and may require further validation and confirmation through monitoring or other lines of evidence.

B. How to Calculate Gas Flux Where Gas Monitoring Data is Available

Prior to carrying out assessments of gas migration, it is vital that the ground model showing the strata that gas is passing through is set out, ideally in a scaled conceptual model as indicated in guidance including SoBRA Hazardous Ground Gas Top Tips (SoBRA, 2023) and NHBC Foundation Report NF94 (NHBC, 2023).

Where there is gas monitoring data available or where gas generation has been estimated using the approaches set out above, the gas flux at the surface can be calculated both for advection (pressure driven flow) and for diffusion. Gas flux at the surface can also be used alongside gas generation estimates as a second line of evidence, where the ground gas source is at depth and where there is shallow groundwater. Further information related to the estimation of gas migration through strata via advection and diffusion can be found in CIRIA guidance (Hooker & Bannon, 1993).

Advective transport

The gas flux at a defined point above the source (e.g., surface or basement slab level) from advective pressure driven flow can be calculated using soil permeability and pressure difference based on the approach outlined in the Ground Gas Handbook (Wilson et al., 2009) and other published guidance (Californian EPA, 2015; US EPA, 2019; Wang et al., 2024).

$$Q_{ad} = \frac{K_i \gamma A i}{\mu(gas)} \times C_{gas} \qquad \text{Equation 2}$$

Q_{adi} – flow of gas through area A (g/s)

K_i – intrinsic permeability of soil (m^2)

γ - unit weight of gas (N/m^3)

A – area perpendicular to migration direction (m^2)

i – pressure gradient along migration route ((gas pressure (Pa) / unit weight [N/m^3]) / length [m]) (unitless)

C_{gas} – gas concentration (g/m^3)

$\mu(gas)$ – viscosity of gas being considered (Ns/m^2) (i.e., methane 1.03×10^{-5} Ns/m^2, carbon dioxide 1.4×10^{-5} Ns/m^2 from the Ground Gas Handbook (Wilson et al., 2009).

This approach can be used to calculate the volume of gas migrating from the source through this pathway. Key parameters include the soil permeability and the pressure gradient.

Intrinsic permeability of soil

The intrinsic permeability can be estimated from hydraulic conductivity values (see section 4.6.2 of the Ground Gas Handbook (Wilson et al., 2009)). The hydraulic conductivity of soils can be estimated from:

- Literature values of hydraulic conductivity – where appropriate; and/or,
- Direct measurement of hydraulic conductivity at boreholes or from soil samples.

Direct Measurement

Direct in-situ measurement of soil permeability should be used where possible. Laboratory based permeability tests should be used with caution, for instance consideration should be given to whether changes in soil moisture and sample integrity between the laboratory sample and the field could affect the test results.

Intrinsic permeability for soil for gas migration can also be estimated using measured flow rates, soil temperature, and pressure differentials as set out in the California Environmental Protection Agency (Californian EPA, 2015) and United States Environmental Protection Agency guidance (US EPA, 2018).

Estimation from Hydraulic Conductivity

Particle size distribution analysis (PSD) analysis and estimation of hydraulic conductivity (such as using the Hazen formula, Kozeny-Carman or other techniques (Wang, et al, 2024)) can be utilised to provide an indication of the potential conductivity of the stratum.

It should be noted however that the use of hydraulic conductivity parameters from literature or from quantitative estimation have significant uncertainties and may range by several orders of magnitude. Care must be used with these techniques and consultation with a hydrogeologist is advised. Furthermore, it should be noted that these are measurements of the flow of water within the soil rather than gas.

Once the hydraulic conductivity of the stratum is estimated, this can be converted to an intrinsic permeability using Equation 3.

Estimation using groundwater permeability:

$$K_i = \frac{K_{Darcy}\mu(water)}{\rho_{water}\, g}$$ Equation 3

K_i – intrinsic permeability of soil (m^2)

K_{darcy} - hydraulic permeability of soil through which gas is flowing (m/s)

ρ_{water} – density of water (1000 kg/m^3)

g – acceleration due to gravity (9.81 m/s^2)

$\mu(water)$ – dynamic viscosity of water (1.002×10^{-3} (Ns/m^2)

Pressure gradient is calculated as per Equation 4:

$$i = \frac{Driving\ pressure\ (\Delta P)}{\gamma L}$$ Equation 4

L – distance over which pressure difference occurs (m)

ΔP -Driving pressure N/m^2

This means Equation 2 can be simplified to Equation 5 as follows:

$$Q_{ad} = \frac{K_{Darcy}\mu(water)A}{\rho_{water}g\mu(gas)}\frac{\Delta P}{L} \times C_{gas}$$ Equation 5

Consideration of multiple strata

Consideration of the potential for gas migration through strata where more than one layer is present either vertically or horizontally in series can be undertaken by deriving an average hydraulic permeability and substituting this into Equation 3 above for K_{darcy}.

One approach for assessing the average permeability for layers in series is the use of the harmonic average (Arbogast, 2024) which is derived using the thickness and permeability for each layer as follows:

$$K_{ave} = \frac{\sum_{i=1}^{n} LT}{\sum_{i=1}^{n} (Li/Ki)i}$$ Equation 6

Where:

L_T = total thickness of all layers (m)

L_i = thickness of each individual layer (m)

K_i = hydraulic permeability of each individual layer (m/s)

Other formulas are available but, regardless of the specific formula selected, consideration should be given to the following and how these affect confidence in the results of modelling:

- the difference between soil matrix permeability and mass permeability
- discontinuities (.e.g., Fissures/fractures)
- difference in vertical and horizontal permeability

Relevant discussion on potential variation in vertical and horizontal permeability and anisotropy is provided in texts (Nowak & Gilbert, 2015; Todd, 1980) and in scientific literature (Cortellazzo & Simonini, 2001).

Diffusive transport

Where there is little active gas generation or low permeability strata is present, the gas flow is likely to be diffusion driven and can be derived using Fick's Law as indicated in section 4.6.4 of the Ground Gas Handbook (Wilson et al., 2009).

The gas concentration (as measured or assumed) will need to be converted into ppm and then to a volumetric measure (e.g., g/m^3 or mg/m^3).

The diffusive rate of mass transfer of gas is estimated by Equation 7:

$$E_D = \frac{A.D_{eff}}{L} \times (C_{source} - C_{surface})$$

Equation 7

E_D – mass flux by diffusion (g/s)

A = area through which migration occurs (m^2)

C_{source} = concentration of gas being considered at source (g/m^3)

$C_{Surface}$ = concentration of gas being considered at limit of migration (g/m^3)

D_{eff} = effective diffusion coefficient in the medium being considered (m^2/s)

L = distance over which migration occurs (m)

Effective diffusion coefficient, the Ground Gas Handbook (Wilson et al., 2009):

$$D_{eff} = D^{air}\frac{\theta_v^{3.33}}{\theta_T^2} + \left(\frac{D^{H2O}}{H_i}\right)\frac{\theta_m^{3.33}}{\theta_T^2}$$

Equation 8

Where:

D_{eff} = effective diffusion coefficient in the medium being considered (m^2/s)

H' = chemical-specific Henry's law constant (µg/m^3-vapour)/(µg/m^3-water)

θ_m = volumetric moisture content (m^3-water/m^3-soil)

θ_T = total porosity (m^3-voids/m^3-soil)

θ_V = volumetric vapour content (= $\theta_T - \theta_m$) (m^3-vapour/m^3-soil)

D_{air} = chemical-specific molecular diffusion coefficient in air (m^2/s)

D_{water} = chemical-specific molecular diffusion coefficient in water (m^2/s)

The US EPA's documentation for Johnson Ettinger model (US EPA, 2017) provides guidance on deriving an overall effective diffusion coefficient where more than one layer is present between the contamination source and the enclosed space floor:

$$D_T^{eff} = \frac{L_T}{\sum_{i=0}^{n} L_i / D_i^{eff}}$$

Equation 9

Where:

D_T^{eff} = Total overall effective diffusion coefficient (m^2/s)

L_T = Distance between the source of contamination and the enclosed space floor (m)

Li = Thickness of soil layer (m)

D_i^{eff} = Effective diffusion coefficient across layer (m^2/s)

Key issues

A key issue is whether the data collected is suitable and consistent with the conceptual site model. Where literature values are adopted these need to be appropriately justified and appropriate to the ground conditions. Models used to estimate gas flow are simplified and assume no change in gas composition as it flows through the ground.

The assessor will need to confirm whether diffusion or advection (or both) is likely to be the driving force for gas migration at the site or within the specific strata. An approach for assessing whether migration is likely to be dominated by diffusion or advection has been provided in Section C.

Advection considerations:

- A key decision is on the pressure difference which will vary in reality – for example, consider what is a reasonable worst-case scenario? (CL:AIRE, 2018)
- Continuous monitoring data of pressure and gas concentrations can be useful in reducing uncertainty and clarifying the CSM.
- Multiple soil strata with different ground permeabilities may need to be considered. This may be undertaken using models for combining conductivity in layered formations.
- What to do with other preferential pathways (e.g., fissures/fractures in bedrock, migration along service ducts, foundations)
- Advection may be of concern where there is ground gas in deeper confined layers.

Diffusion considerations:

- Estimates of diffusive flow are based on a concentration gradient rather than pressure gradients and, therefore, careful consideration should be given to the source concentration and depths used within the assessment (the length of pathway over which diffusion may occur).
- Multiple soil layers may be present at the site and therefore consideration may need to be given to diffusion through variable strata.
- Diffusive flux will provide the dominant flow mechanism for peat / organic alluvial soils where these are cohesive near to the surface.

A sensitivity analysis should be used to support modelling of gas migration via advection or diffusion processes and for the gases of concern. The equations assume the gas is incompressible. Different gases are compressible and may have lower or higher viscosities and densities that affect how transmissible they are in a given medium.

C. Whether the transport is diffusion or advection dominated?

This section considers how to assess whether diffusion or advective flow are likely to be considered the dominant mechanisms for gas migration within soil. It does not consider gas migration into buildings or via preferential pathways (such as foundations and services).

As identified in scientific literature, the Peclet Number (Huysmans & Dassargues, 2004; Costanzi-Robinson & Brusseau, 2006) may be of use when determining whether advection or diffusion is likely to be the dominant flow mechanism:

$$P_e = \frac{Advective\ transport\ rate}{Diffusive\ trasport\ rate} = \frac{\frac{K_{Darcy\mu(water)}A\Delta P}{9810L\mu(gas)} \times C_{source}}{\frac{A.D_{eff}}{L} \times (C_{source})} = \frac{K_{Darcy}\Delta P\mu(water)}{9810D_{eff}\mu(gas)}$$

Equation 10

Assuming ρ_{water} is 9810, P_e <<1 indicates diffusion is likely to be dominant, P_e >>1 indicates that advection is likely to be dominant.

Figure 1 presents an example of the calculated Peclet number for different permeabilities versus changes in advective pressure.

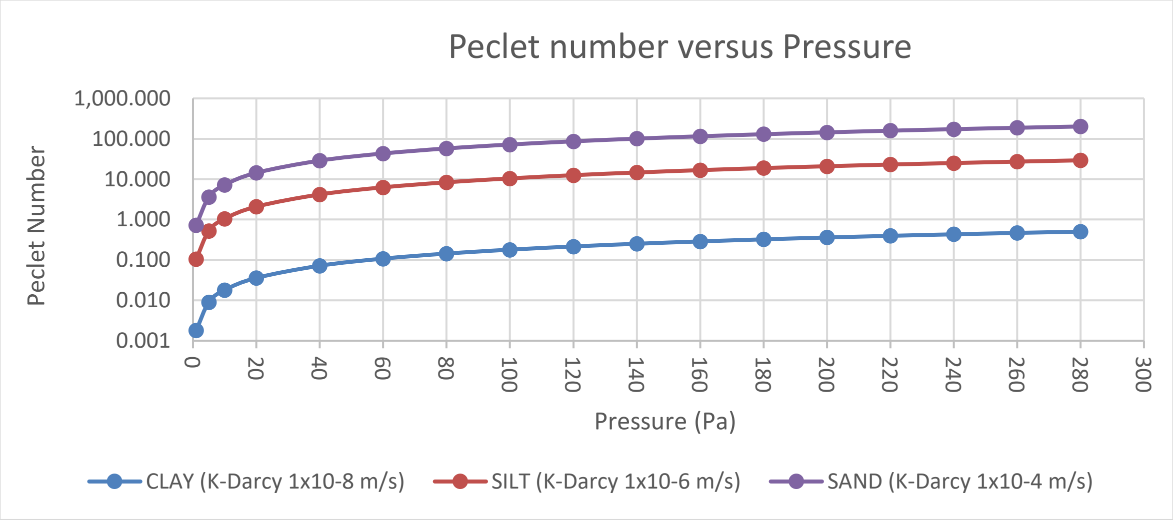

Figure 1: Example of variation in peclet number versus pressure and permeability

It is indicated that in clay diffusion is often the dominant mechanism whereas in sandy soils advection is more likely to be dominant even at low driving pressures. For some soils, pressure driven flow and diffusion may both need to be considered.

D. Is flux significant? Considering Ground Gas Flux Estimates in Context

Simple checks for the significance of gas flux to a receptor such as an overlying building can be undertaken. Consideration could be given to the potential for the presence of background sources of gas generation and subsequent gas concentrations in soils that may be argued as being of low gas generation potential that can include, but not be limited to the following:

- carbon dioxide in or over carbonate rocks;
- carbon dioxide in natural soils such as River Terrace Deposits; and
- methane in natural alluvium and buried peat deposits.

Further guidance on the assessment of ground gas associated with low gas generation sources can be found in the NHBC Foundation report NF94 (NHBC, 2023).

The ingress of ground gas from gas generation sources to a building could be further considered in context of typical other sources of ground gas emission. Internal sources of hazardous ground gas includes the respiration of the building users, flatulence associated with building users, and leaks from natural gas appliances. The practitioner may wish to consider whether estimated ground gas emissions in volumes similar to such typical sources may indicate a low or tolerable level of gas ingress (which is managed through typical building usage and ventilation) or whether, subject to the site-specific circumstances, there may be a cumulative effect from multiple potential sources. For example, if the extent of ground gas emission from the ground equates to a similar effect of additional occupancy in the property, and that this is consistent with the proposed use and design of the building with respect to allowing for sufficient ventilation then the risk from ground gas could be deemed low. Alternatively, were methane ingress to be identified arising from ground gas sources the potential for accumulation may need to consider potential additive effects of leaky gas appliances that may be present.

British Standard BS 5925 (BSI, 1991) indicates that rates of estimated carbon dioxide generation through respiration in buildings varies from 15 to 115 l/hr. Therefore, although this does not correspond to an assessment of risk, the assessor may want to consider the rate of gas ingress from soils as compared to occupancy rates in the property to place such considerations in an appropriate context.

Studies into methane indicate leaks from gas hobs can be of further concern (Lebel et al., 2022) with respect to methane emission within buildings. In the United States, natural gas emitted from stoves included 0.8-1.3% of gas emitted as unburned methane. The majority of methane emission measured originated when cooking stoves were switched off. Mean emission rates reported for a range of gas stoves was 649g methane per year (approximately 0.13 l/hr) with lower and upper 95th confidence intervals of 427g methane per year (approximately 0.087 l/hr) and 949g methane per year (approximately 0.2 l/hr) respectively.

Recent studies have indicated that indoor ventilation measures such as extraction fans and trickle ventilators are not routinely used and, therefore, new residential buildings can suffer from poor air quality as indicated via odour, bio-effluents, and volatile organic compounds (AECOM, 2019). Therefore, in such instances indoor ventilation measures may not provide mitigation against gas intrusion and accumulation. As summarised in the Ground Gas Handbook, emission of methane can also occur from the human body at rates up to 4.5 l/day and such rates can be similar to emission from low risk ground gas sources (Wilson et al., 2009).

Consideration needs to be given by practitioners as to whether the estimated flux of ground gas poses a risk to occupants and where these emissions may be consistent with rates anticipated from internal sources (i.e. respiration or body odour, flatulence) that may be covered by adherence by building designers to existing good practice for internal ventilation. Conversely, consideration can be given to the extent that the estimated gas flux from internal sources could comprise a baseline and whether the emission of ground gas could increase potential for accumulation of gases to hazardous concentrations should these accumulate in the property. Such considerations may help as a qualitative basis for decision making and place the anticipated gas flux into an appropriate context in accordance with the objectives of the investigation. The practitioner should be careful that such considerations do not override the requirement for providing safe development and a that risks to human health are acceptably low.

E. Other factors not considered in this paper

This paper principally focuses on source generation and migration in soil rather than along preferential pathways or into buildings. There are number of other specific scenarios not covered in this paper that may need to be considered as part of a gas flux risk assessment and are discussed in other guidance documents, such as ground gas migration where foundations are introduced (Wilson, 2021), ground gas sources in groundwater (EPG, 2018), and assessment associated with mine gas sources (Wilson et al., 2021).

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