Design and performance of a passive dilution gas migration barrier

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Introduction

The use of in ground barriers, particularly vent trenches, is a common method used to protect development from landfill gas migration. A new system for installing passive venting barriers is described which overcomes many of the disadvantages associated with conventional trench systems. It uses highly efficient geocomposite vent nodes, which are driven into the ground and connected to a collection/dilution duct, to allow safe venting to atmosphere. The system minimises spoil and contact by installers with contaminated soils and can be installed in restricted spaces.

There is little design guidance available for such barriers. A method is described which allows the spacing of vents and the ventilation requirements to be determined. This should ensure that gas vented to atmosphere from the system is at acceptable concentrations.

A monitored trial of the system has been undertaken which demonstrates the barrier is effective in reducing migration of landfill gas.

Conventional gas migration barriers

Vertical in ground barriers are used extensively to prevent gas migration from landfill sites to below susceptible targets (usually a nearby development).

There are two common methods of forming a barrier to gas migration:

- Using very low permeability materials to resist gas flow,
- Using highly permeable materials to allow the gas to vent to the surface.

Current methods of forming a gas resistant barrier usually involve the excavation of a trench and backfilling with either an impermeable material such as bentonite, or the inclusion of a gas resistant membrane. Vent trenches are normally constructed using trenches backfilled with either gravel or geocomposite venting media to promote gas flow to the surface. An alternative method is to provide a series of discrete vent wells at regular spacings. These methods allow the gas to exhaust directly to atmosphere without any dilution in the system.

Legislation

Recent European legislation[1] suggests that the primary method of gas management from heavily gassing landfill sites should comprise enclosed flaring or energy utilisation. This prevents emissions of methane (a greenhouse gas) to atmosphere. Control contingencies to support the primary gas management system may include perimeter gas barriers as a secondary method of preventing off site migration.

In the past it has also been common to manage gas in the ground by uncontrolled venting to atmosphere. The Pollution Prevention and Control (England and Wales) Regulations (2000)[2] implemented the Landfill Directive and apply to all new landfills and all existing ones from 2003. This requires the use of best available technology (BAT) and therefore the venting of undiluted gas to atmosphere should be avoided wherever possible.

It is, therefore, now considered unacceptable to passively vent gas to atmosphere which contains greater than 1% v/v methane or 1.5% v/v carbon dioxide, on both environmental and health and safety grounds. One implication of this is that vent trenches must dilute gas to tolerable levels before discharge to the atmosphere.

Passive dilution barrier

Concept

The concept of the passive dilution barrier is to form a low pressure area relative to the surrounding gassing ground, to encourage gas to flow towards the barrier. This is achieved by driving discrete vent nodes into the ground, which are connected to a collection/dilution duct running along the top of the strips. The nodes comprise highly efficient geocomposite strips. The duct has a high flow of fresh air through it by means of passive ventilation. This is one of the key advantages of the system as it:

- dilutes gas emissions to tolerable levels,
- causes a venturi effect in the geocomposite vents which enhances gas flow from the ground towards the vents.

Ventilation of the duct can be achieved using a combination of vent stacks, bollards or ground level boxes, depending on the gas regime and wind conditions at a particular site. A schematic layout for the barrier is shown in Figure 1.

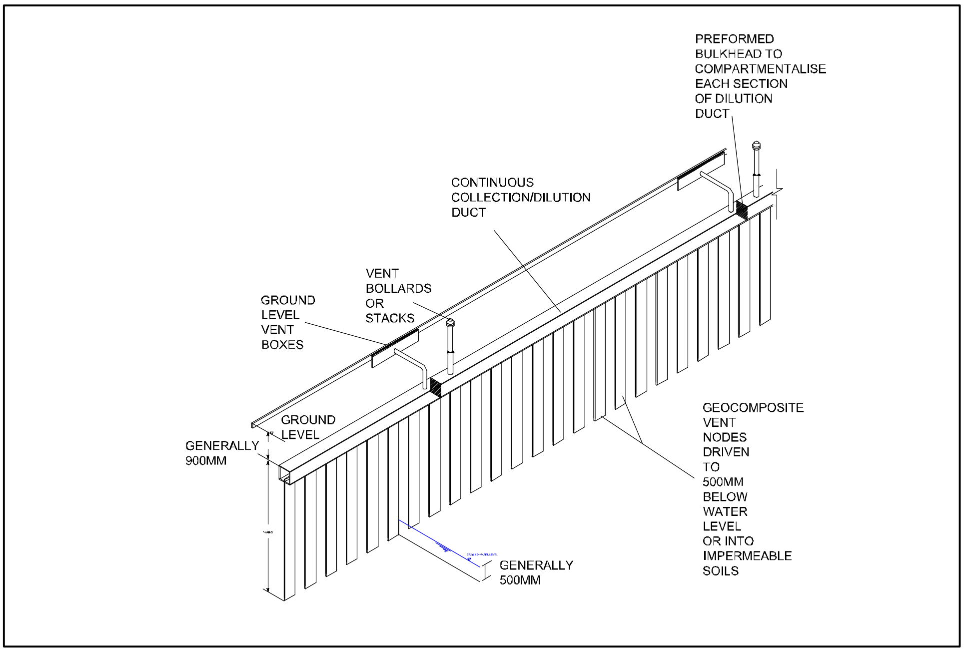

Figure 1 Schematic layout of passive dilution barrier

Theory

Gas flow to barrier

Generally the flow of gas of gas in the ground towards a well or barrier can be modelled using the equations for planar flow of fluids based on D'Arcy's law. One of the most common situations is shown in Figure 2, where a permeable layer is overlain by an impermeable barrier (a capping layer or hard cover). A relatively shallow groundwater table or impermeable clay layer typically provides a lower confinement to gaseous flow. In this situation we may use the equation for flow of fluids in a confined aquifer towards a horizontal slot based on work by Chapman (1959)[3] and the United States Environmental Protection Agency (1975)[4].

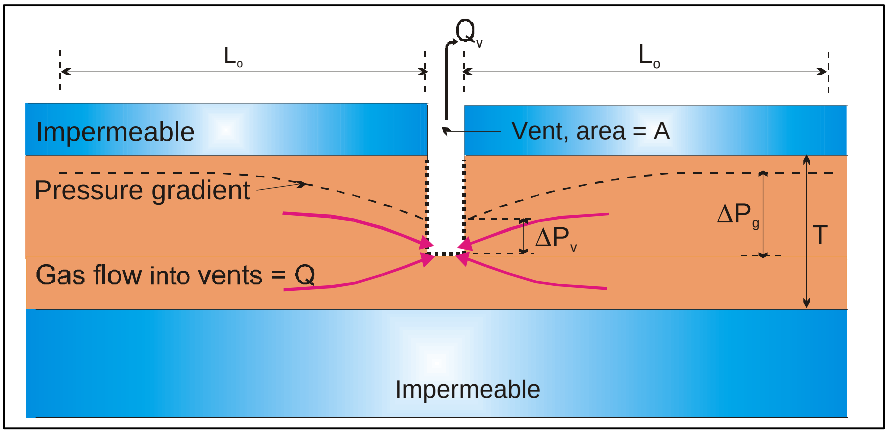

Figure 2 Flow to a slot penetrating a confined aquifer

Flow to a slot in a confined aquifer is given by

$$Q = \frac{\left[\frac{2K_i g}{m}\right] T L \Delta P_g}{L_o} \qquad (1)$$

(Based on D'Arcy flow), where:

Q = flow in m/s from both sides of barrier

K_I = intrinsic permeability of the ground in m^2.

γ = bulk density of methane in N/m^3

μ = viscosity of gas being considered in Ns/m^2

T = thickness of confined aquifer or migration layer in m

L = length of section of barrier being considered in m

ΔP_g = driving pressure of gas from ground Pa

L_o = distance of influence of barrier (decreases as spacing of nodes decreases) in m

The calculated flow of gas towards the barrier is very sensitive to the chosen value of the distance of influence of the barrier. Evidence[5, 6, 7] suggests the radius of influence for passive vent wells is likely to vary between 2m and 30m, depending on ground conditions, type of well, etc, and it seems reasonable to use similar values for L_o.

However because the calculated value of gas flow is sensitive to any variation in L_o a sensitivity analysis should usually be carried out.

Using these equations and the measured pressures from monitoring wells, the flow of gas to the line of vent wells can be estimated. The peak values of pressure recorded when a borehole tap is first opened should be used, as this represents the pressure in the surrounding ground that has achieved equilibrium with the borehole and is the driving pressure for gas towards the vent curtain. It is therefore vital for this design method that both peak and steady state borehole flow and pressures are recorded when undertaking gas monitoring. This calculated gas flow from the ground is the volume that requires dilution in the duct.

Flow capacity of geocomposite vents

The flow capacity of a single geocomposite vent can be calculated directly using D'Arcy's law, and the value of intrinsic permeability, K_i, for the particular geocomposite used. In this case the pressure difference causing the flow can be assumed to be the equilibrium or steady state recorded from boreholes.

The flow in the vents is given by;

Total flow capacity of vents $Q_v = \left[\frac{K_i g A i}{m} \right] x\, N$ (2)

Where

K_i = intrinsic permeability of geocomposite in m^2

A = area of vents in m^2

N = number of vents

i = pressure gradient = ΔP_v/length of vent node.

The sum of the flows from all the vents must be greater than the flow into the system from the surrounding ground.

Dilution

The flow of fresh air through the collection/dilution duct, required to dilute the methane to less than 1%, can be calculated using the gas flow calculated in (1) and the guidance in CIRIA Report 149[8] and British Standard BS 5925[9].

Using: $Q_{duct} = Q \ x \ c_{\max} \ x \left(\frac{1 - c_e}{c_e} \right)$ from CIRIA 149 (3)

Where c_e = design equilibrium concentration in %

Q_{duct} = fresh air flow through system in l/hr

Q = flow of soil gas into the system for each 25m length in l/hr

C_{max} = design concentration of methane in soil gas, %

The ventilation area required to provide this flow can be calculated using the guidance for designing natural ventilation provided in British Standard BS 5925. Using these design criteria the arrangement and type of ventilation can be determined.

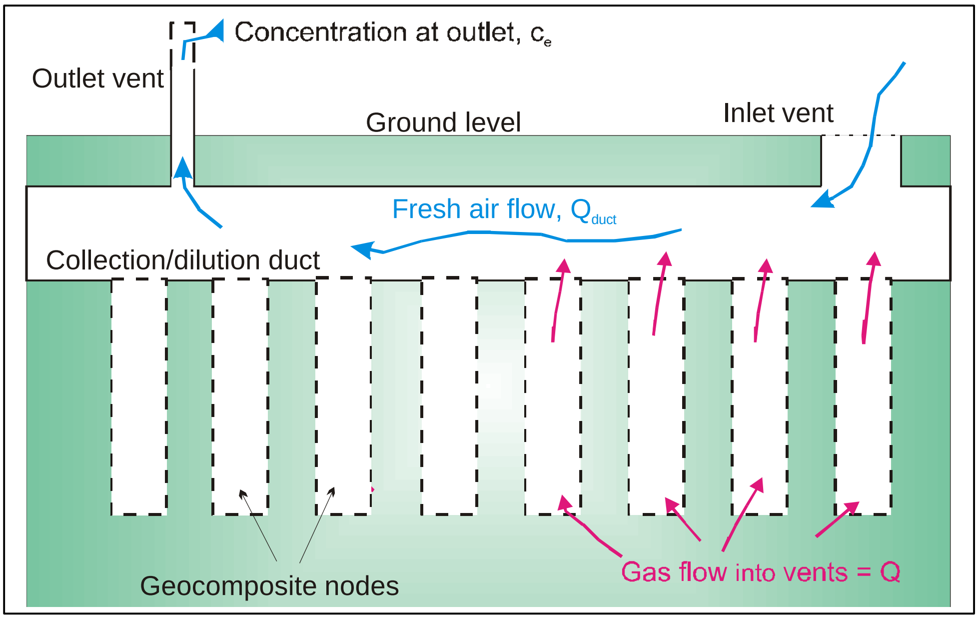

figure 3 Fresh air flow in collection/dilution duct

Factors of safety

The calculations require a factor of safety to be incorporated to allow for the effects of:

- uncertainty in the gas regime,
- constrictions to flow in the system,
- blocking of vents or other breakdowns of the system.

It is usual to apply the following factors of safety in gas ventilation design

- the use of maximum concentrations, flow rates and pressures regardless of spacial or temporal variation across a site gives an inherent factor of safety, because the calculations assume constant flows from the ground across the whole site, at the design values,
- design gas values - apply a factor of safety of between l and 5 depending on the amount and reliability of the gas monitoring data and site investigation data,
- on ventilation air flow - apply a factor of safety of between l and 5 depending on the sensitivity of the development , risk, what management systems will be in place, how critical the dilution barrier is, etc,
- on ventilation outlets - apply factor of safety of between l and 3 on the same basis as the air flow.

Installation

The passive dilution barrier is installed using a unique no dig method in which a steel mandrill is vibrated up to 5m into the ground, using a vibrating piling hammer supported by a 360^o excavator. (Figure 4). Once the hollow mandrill is in the ground the central cutting shoe can be removed (see Figure 5) and a geocomposite strip inserted. The mandrill is then withdrawn, leaving the vent in the ground.

Figure 4 vibrating mandrill into ground

The key advantages of this method of installation are:

- speed – up to 30 vents per day can be installed,
- cost – there is a reduction in excavation costs and disposal of spoil that is frequently contaminated,
- safety – contact with contaminated materials by the installers is minimised.

A further advantage is that walls can be constructed very close to site boundaries and in areas where access is restricted and conventional barriers could not be constructed, as shown in Figure 4.

Figure 5 Inserting geocomposite vents into ground

Site trials

Background

A site trial of the new system was undertaken at a landfill site in North West England. The site was formally a brickworks which ceased operations in 1975, leaving open clay pits. Filling of the site began in 1981, with approximately 2.5 million tonnes of domestic refuse being placed. The site was completed in 1995 leaving depths of waste up to 33m, which was covered by a capping layer.

The site is underlain by Glacial Till overlying Millstone Grit and the Till generally comprises relatively impermeable clays which act as a natural barrier to landfill gas migration. The site has been retro fitted with a gas extraction system which collects the gas and burns it off at flares. Routine monitoring by the landfill operator and the

Environment Agency identified one area where gas appeared to be migrating off site. The monitoring borehole in question was approximately 20m outside the landfill, beyond the influence of the extraction system.

The migration is thought to be occurring along a granular lense or infilled glacial overflow channel within the Glacial Till, which comprises sand and gravel. These features are common in the area. The conceptual gas migration model is shown in Figure 6.

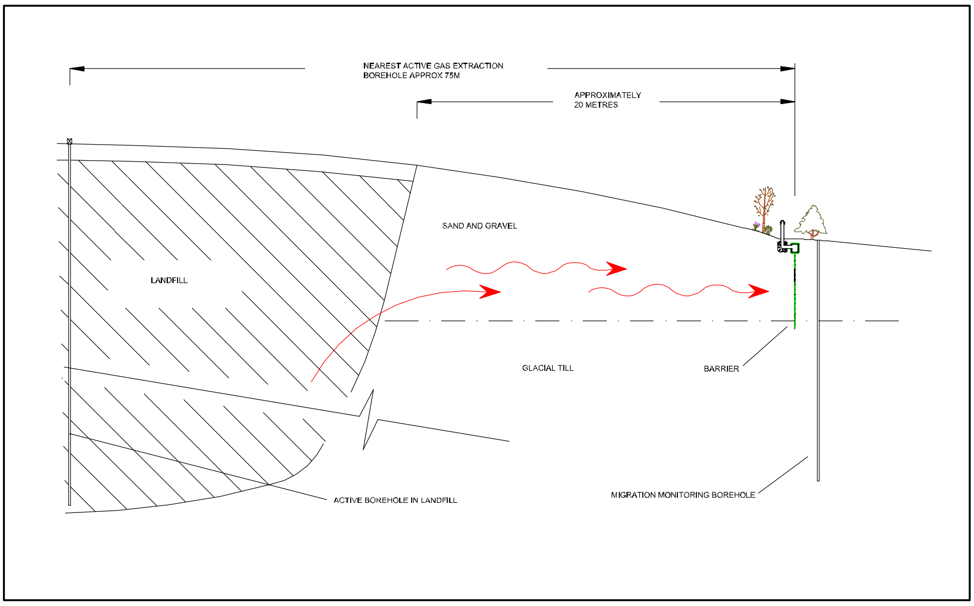

Figure 6 Conceptual gas migration model

Before installation of the barrier methane concentrations in one monitoring borehole were consistently in excess of 30% v/v with peak levels of 50% v/v. Carbon dioxide concentrations were typically between 10% v/v and 20% v/v.

Installation

The passive barrier was installed over a length of 20m offset from one of the affected borehole by 1m. It runs 10m either side of the borehole, between it and the centre of the landfill. It is 75m from the nearest extraction well within the landfill and 20m from the landfill boundary.

The passive dilution barrier comprises 14 No vertical geocomposite vent nodes (410mm by 30mm) spaced at 1400mm centres. They are driven to a depth of 5m below ground level. A collection/dilution duct has been placed over the nodes and is 450mm deep by 410mm wide. It is vented via a 3m vent stack at one end and a 0.9m high venting bollard at the opposite end, which provides 18,000mm^2 ventilation area.

The system was installed over a period of 4 days and was commissioned on 18 October 2000.

Performance

Gas monitoring has been undertaken on a daily basis before and after installation of the barrier. The results presented in Figures 7 and 8 show a clear and dramatic reduction in gas concentrations after the barrier was commissioned. Both methane and carbon dioxide concentrations have dropped to generally less than 1% v/v in the ground. This demonstrates the effectiveness of the system.

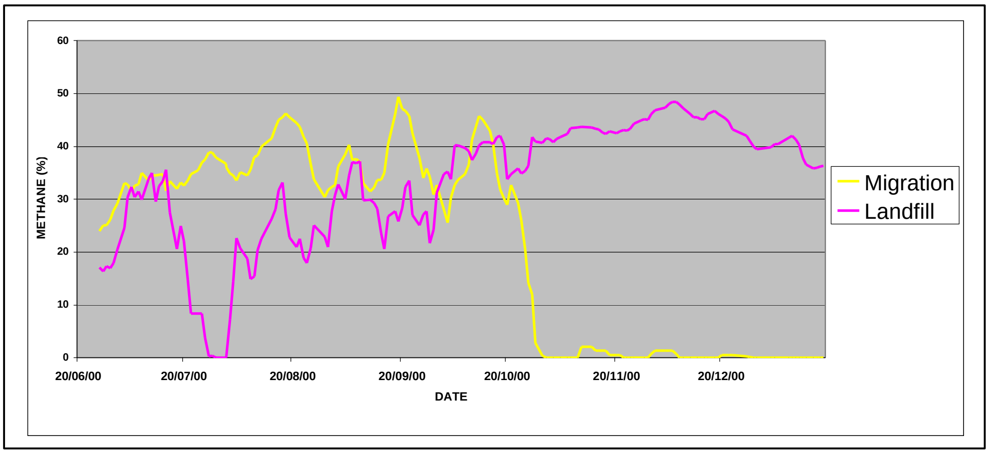

Figure 7 Reduction in methane concentrations after installation of barrier

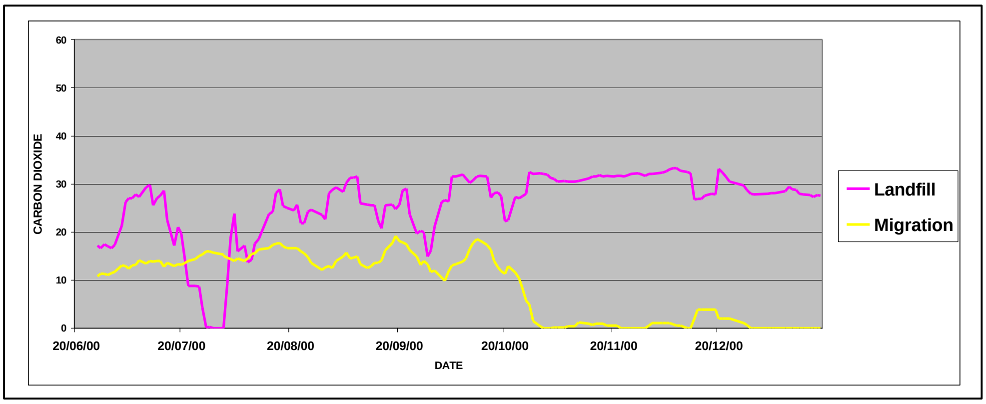

Figure 8 reduction in carbon dioxide concentrations after installation of barrier

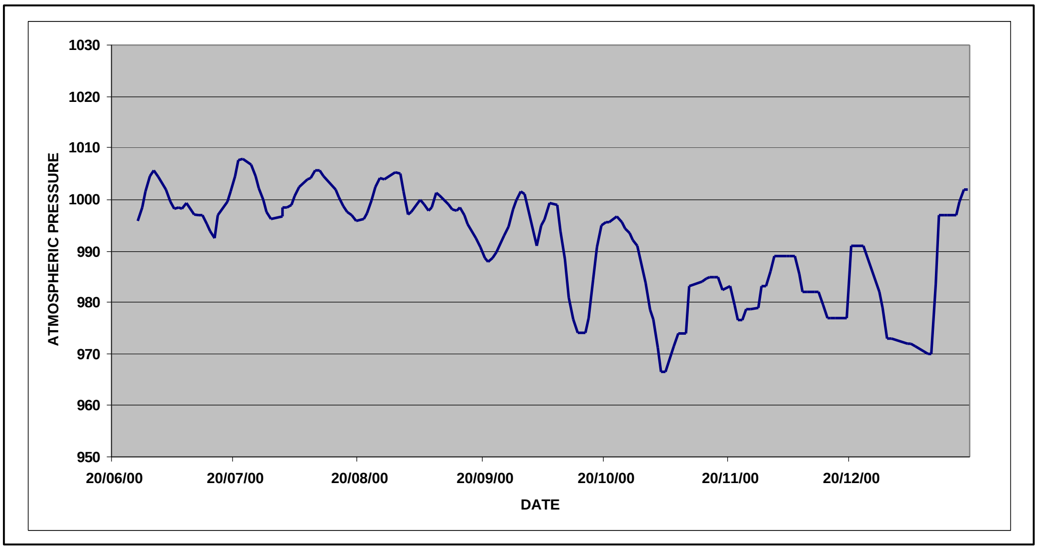

Figure 9 Atmospheric pressure during monitoring

Conclusions

The passive dilution gas migration barrier offers several advantages over conventional vent trenches and vent wells:

- speed of installation,
- reduced costs,
- increased safety as contact with contaminated materials by the installers is minimised,

- efficient ventilation dilutes gas emissions to tolerable levels,
- can be installed in restricted areas.

The system can be designed to deal with different ground conditions, gas regimes and wind conditions to ensure the safe venting of gases at tolerable concentrations, using accepted principles of fluid flow in the ground.

A monitored site trial has demonstrated the effectiveness of the barrier in reducing landfill gas migration.

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