Geosynthetic biogas barriers under buildings: case studies using a geomembrane

A. Rollin
École Polytechnique, Montréal, Québec, Canada

J.F. Fournier
Soprema, Montréal, Québec, Canada

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ABSTRACT: Building on or very near a former landfill site cannot be done without proper consideration for the health and safety risks associated with the gas generated by the decomposition of organic waste. In this article, the design principles and the actual remedial measures involving a geomembrane are described for a specific case.

1 INTRODUCTION

Faced with the modern phenomenon of urban sprawl, promoters are increasingly looking at former landfill sites. These sites, located outside urban centres and previously thought to be of little worth, are now much sought after by developers. Since they were not operated according to modern standards, controlling the biogas they produce can be a problem. While using them for golf courses, parking lots, or green spaces is relatively easy, erecting buildings on them is another matter altogether.

2 RISK PREVENTION IN LANDFILL REMEDIATION

All landfill sites containing domestic waste generate biogas. The gas can migrate through the soil and accumulate in building basements, where gas mixtures can potentially reach the lower explosive limit (LEL). To obtain permission to erect buildings on former landfill sites, developers must meet standards set by municipal, provincial, state, and/or other permit-issuing authorities. The main hazards associated with building near or on top of closed landfills include the following:

- Biogas explosion, flammability, toxicity, and odours
- Poor ground conditions (settlement)
- Biogas corrosion of foundation materials

Many engineered solutions have been reported in Japan, the United Kingdom, Denmark, France, and Canada. These have involved a variety of projects, including high-rise residential buildings, school buildings, facilities for handicapped children, residential developments, shopping centres, service stations, and industrial and commercial buildings.

In all cases, a gas control system was designed to achieve the following main objectives:

- Venting of volatile contaminants from the affected soil and installation of a remedial system to control explosion, flammability, toxicity, and odour risks
- Elimination of gas intrusion (methane) into the building and installation of accessible services, ducts, and enclosed spaces

To achieve these objectives, two levels of stringent controls were imposed on the areas supporting the buildings, which were generally piled. The floors had to be built as described below to prevent the intrusion of biogas into the buildings [Bote 1997; Grantham 1993]:

- Two permeability contrasts on top of the residual soil (Fig.1):
  - A detailed venting system installed in a gravel layer to constantly flush it with air in order to maintain methane concentrations well below the 5% LEL [Wilhelm 1995]
  - A low-permeability layer (geomembrane) bonded to the peripheral wall, piles, pipes, and tubing to act as a covering for the ventilated gravel layer
- Permanent gas monitors with alarm systems in subfloor voids in confined areas in amenity buildings to warn of gas ingress (set to go off at concentrations > 0.5% [Thomas 1993])
- Voids under floor slabs ventilated to flush out gas, and gas detectors installed in voids and constantly swept with air

Other considerations:

- the drainage system of the buildings and parking areas should reduce the percolation of rainwater and so reduce the groundwater impact
- parking areas (with asphalt) should be built with a gas evacuation system to prevent any risk of gas migration to nearby buildings

One remedial measure was the installation of a geomembrane barrier to prevent the migration of biogas into the building and to prevent possible contact with concrete and foundation work materials to minimise corrosion. Barrier performance depends on the low diffusivity coefficient of the geomembrane material, the thickness of the product, and the integrity of the installed liner.

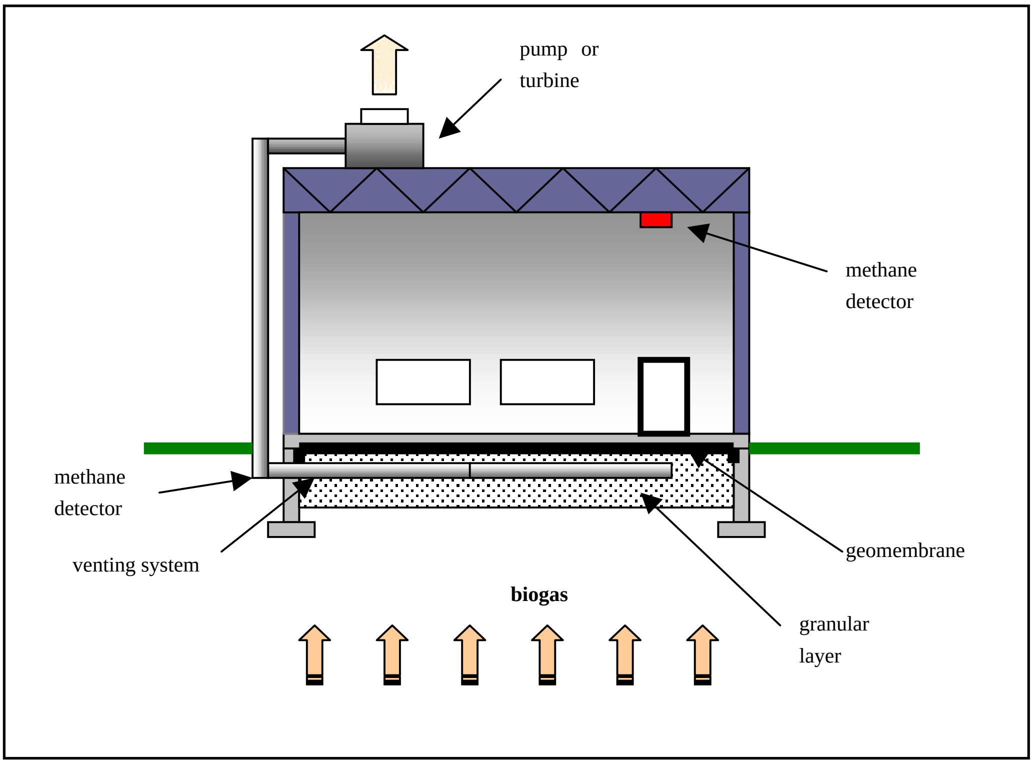

Figure 1

3 LANDFILL GAS

The mass flux of biogas from the soil surface is site-specific. The amount of gas depends on the type of waste, the site history, and the presence of other gas venting or migration avenues within the soil structure.

Among the various decomposition products, the gas mixture is made up of primary carbon dioxide and methane along with small amounts of trace contaminants including hydrogen sulfide [Hammond 1995; Luning 1993]. Landfill gas (LFG) contains high concentrations of methane (approximately 60% v/v) and carbon dioxide (approximately 30 to 40% v/v) during the decomposition period. Hydrogen sulfide is found in concentrations ranging from 50 to 500 ppmv. LFG also contains certain aromatic hydrocarbons such as benzene and toluene as well as chlorinated solvents in concentrations ranging from 5 to 20 ppmv, which are usually oxidized over time. Methane is produced by the fermentation of organic matter by mixed cultures of a wide variety of microorganisms.

Organic matter + water = methane + carbon dioxide

With time, microbial oxidation of methane and other elements to carbon dioxide is carried out by methyotrophic and methanotrophic micro-organisms gaining energy from oxidation of reduced carbon species with one or more carbon atoms in presence of oxygen [Grantham 1997, Haarstad 1997] :

Methane + oxygen = carbon dioxide + water

When transported in soil layers before emitted to the air, it is mixed with atmospheric air due mainly to diffusion process. The LFG constituents may therefore be oxidised. It is controlled by different environmental factors such as temperature, water content, nutrients, substrate and oxygen concentrations. For aged affected sites, the production rate is expected to be very low and the methane concentration in the venting layer should be in the order of 0,25% [Bote 1997].

Landfill gas also contains certain aromatic hydrocarbons, benzene and toluene, and chlorinated solvents. The degradation of benzene, toluene, tichloroethelyne and trichloroethane in the soil were observed in presence of methane [Kjelden 1997]. His results showed that a substantial degradation of these components took place in strata surrounding landfills.

4 BIOGAS DIFFUSION AND TRANSPORT THROUGH A GEOMEMBRANE

Even though geomembranes cannot be considere as porous media, there can be movement of biogas component due to molecular diffusion. The diffusive motion (molecular diffusion) depends on the energy available and the relative mobilities of the organic molecules. Diffusion involves the movement of molecules or ions in air as a result of their own random kinetic activity from areas of higher concentration to areas of lower concentration. This will depend on gas temperature, pressure and concentration, the size of the penetrant and the geomembrane material.

The diffusion of gas molecules through a geomembrane can be modelled by the Fick second law of diffusion in a solid. Taking into account the molecular weight, the equation can be rewritten:

$$Mg = - Dg\, dCg / dz$$

where Mg = mass flux in M/L^2 –T (g/m^2-day or m^3/m^2-day-atm); Dg = diffusion coefficient in L^2 /T (m^2/s-atm); Cg = gas concentration in the geomembrane in M/L^3 (g/m^3); z = distance parallel to the direction of diffusion in L (m).

It is well known that the mass diffusivity D_{AB} will increase with increasing temperature, increasing pressure and increasing concentration. On the contrary, diffusion will decrease with increasing molecular weight and molecular structure complexity.

These equations state that mass transport of a gas through a geomembrane occurs because of a gradient in mass concentration across the thickness of the material as shown schematically on the next figure.

For a geomembrane to fulfill its main function, biogas diffusivity should be very low. Unfortunately there are few reports in the literature on gas diffusion through geomembranes. However, the methane flux values presented in Table 1 [Betec 1993; EPA 1998; Soprema 2000] can serve as a basis for designing barrier systems incorporating geomembranes. The relatively lower geomem-

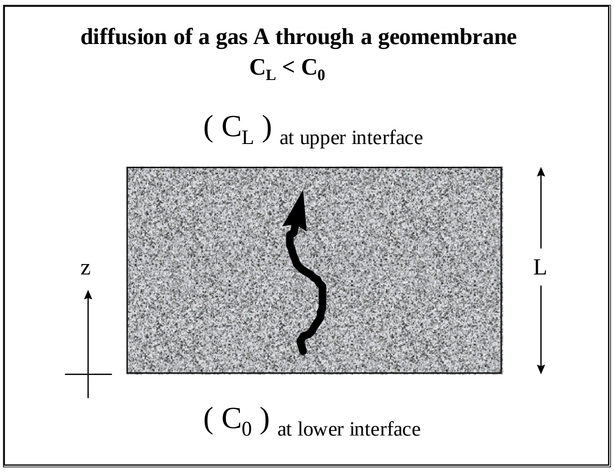

Figure 2 : schematic of diffusion through a geomembrane

brane methane flux values probably result from the greater thickness and density (1.23 g/cm^3) of the material.

Table 1 shows that methane diffusion through geomembranes is minimal at atmospheric pressure and they can thus be considered as good biogas barriers. The uncertainty regarding precise parameters is of little practical consequence for this specific application since the geomembrane is only one of many elements used in the remedial system, and gas pressures and concentrations are very low.

Table-1 : gas diffusion through geomembranes

		mass flux through geomembrane [m^3/m^2-day-atm]					
GM	reference	test	pressure	methane	nitrogen	CO_2	water vapor
			kPa				
bituminous	Soprema 2000	D 1434	345	7,3 x 10^{-5}			
	Betec 1993	D 1434	50 or 150	9,3 x 10^{-7}	<7,8 x 10^{-7}	<7,8 x 10^{-7}	
	Durin 1998	NF P 84-515	10				4,0 x 10^{-4}
PVC	EPA 1988			4,5 x 10^{-4}	1,0 x 10^{-4}	3,0 x 10^{-3}	
	Durin 1998	NF P 84-515	100				9,3 x 10^{-9}
	Eloy-Giorni 1993		100				1,7 x 10^{-8}
	Pelte 1993		100				3,0 x 10^{-9}
HDPE	EPA 1988			1,0 x 10^{-4}		4,7 x 10^{-4}	
LLDPE	EPA 1988			3,2 x 10^{-4}		1,4 x 10^{-3}	
CSPE	EPA 1988			2,1 x 10^{-5}	2,6 x 10^{-5}	1,0 x 10^{-4}	
EPDM	Durin 1998	NF P 84-515	100				6,0 x 10^{-9}

5 CASE STUDY: COMMERCIAL BUILDING NEAR FORMER LANDFILL SITE

A remedial system was incorporated into the design of a commercial building to be erected at the boundary of a closed landfill site in Kirkland, Canada. While little to no methane was migrating out of the site, which was active from 1980 to 1993, the municipal fire and engineering department imposed the system because methane had been found in adjacent lots and sewage systems (street between the proposed building and the landfill site).

To control gas infiltration, a collection and evacuation layer consisting of 100 mm diameter drainage pipes embedded in a 300 mm thick layer of 50–100 mm diameter granular material was installed. Four chimneys with methane detectors at the base were also installed. A vacuum to vent methane into the atmosphere was created using four turbines located on the roof of the building. A geomembrane was installed between the collection layer and the concrete floor of the building (Figure 3) as a second level of protection to prevent the migration of biogas into the building, which covers an area of 7,430 m^2.

6 MATERIAL SELECTION

To meet the performance criteria, a 3 mm thick prefabricated bituminous geomembrane (PBGM) was installed under the concrete floors of the buildings for both projects. The PBGM acts as a barrier to prevent the migration of biogas and offers a number of benefits for the cost:

- Low methane diffusivity
- Ease of installation on and attachment to a large number of protruding elements
- Quick installation (fast track project)

PGBM is a factory-made material consisting of nonwoven textile, elastomeric modified bitumen, and filler . Like polyethylene or PVC, PGBM is delivered in large rolls and is heat-welded on site with special portable welders. Seam quality controls using vacuum boxes, peel tests, and electric leak detectors were performed on site using ASTM standard procedures (please refer to the new ASTM D6455-99 Guide for the Selection of Test Methods for Prefabricated Bituminous Geomembranes PGBM).

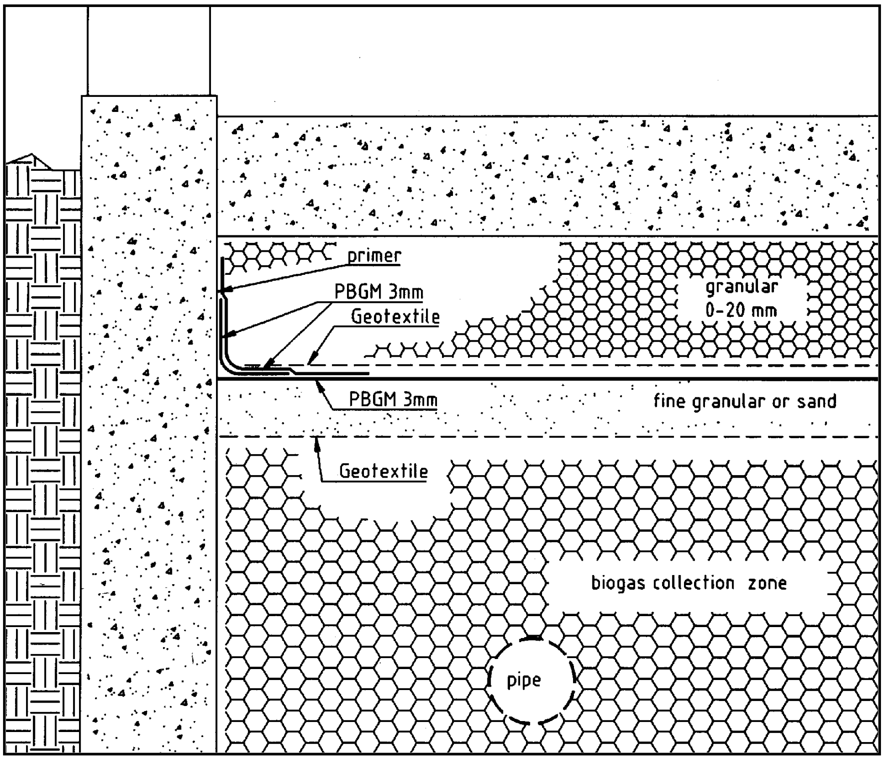

Figure 3

The very large number of protruding elements was the key factor in selecting a bituminous geomembrane: 144 pipes, 400 linear meters of peripheral wall, and many structural steel columns.

The ease of installation and good bonding performance on structural and protruding elements are the overriding features of bituminous geomembranes. They can be welded to concrete surfaces (as shown in fig. 3). Applying primer to the concrete prior to welding helps improve bonding. Standard techniques used with other types of geomembranes would have been difficult to apply and, in fact, impossible in the short time available. The cost/benefit ratio of installing a PBGM was the lowest of all the proposed solutions.

7 CONCLUSION

Experience has shown that it is possible to construct buildings on former landfill sites. By using an appropriate remedial system that incorporates a geomembrane as a biogas barrier, risk prevention can be achieved. For this application a prefabricated bituminous geomembrane can offer a low biogas diffusion and one of the lowest cost/benefit ratio. The PBGM is especially appreciated for its ease of installation around accessories and protruding elements as well as for its durability.

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