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Update on designing with geocomposite drainage layers in landfills—Part 2 of 4: geocomposites on bioreactor landfill sideslopes to control seeps and gas

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Not since the first Designer's Forum article dedicated to geocomposite design (Richardson and Zhao, *GFR* June/July 1998) has there been any further discussion in the magazine regarding the collection of landfill gas below covers. There were, in fact, significant errors in the portion of that article that dealt with landfill gas pressure dissipation. Since that time there have been several other literature references that have presented more complete and correct design approaches for relieving landfill gas pressures below landfill covers (e.g., Thiel 1998; Richardson and Zhao 1999; Bachus et al. 2004). This article updates *GFR*'s series regarding designing with geocomposites—see Part 1 (January/February 2005) for complete *GFR* bibliography of geocomposite-related articles since 1998—and expands the documented design applications of geocomposites in landfills by describing how they can be utilized for side slope seep collection in modern bioreactor-style landfills.

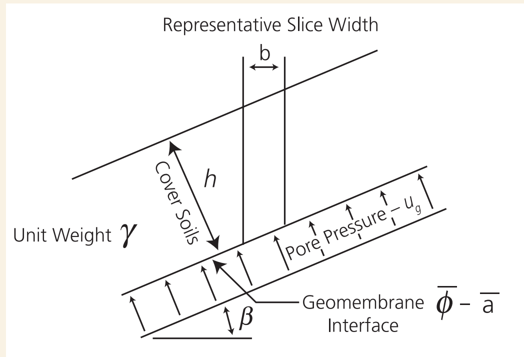
Landfill gas pressure dissipation

Landfill gas (LFG) is continuously generated in a landfill as the waste decomposes. Ideally, landfill gas would be withdrawn from the landfill at the rate it is generated. The concern for final landfill cover designs incorporating geomembranes is that an uplift pressure can be caused by the gas. From a slope-stability point of view, gas pressure is an excess pore pressure that serves to reduce the effective normal stress. This pressure results in a decrease in the effective stress beneath the final cover geomembrane that, ultimately, can lead to slope stability failure or surface "whales" (**Photo 1**). Furthermore, inadequate gas venting immediately below new cover systems on old landfills has been identified as the cause of sudden increases in groundwater monitoring volatile organic compound (VOC) inputs, because the LFG is being constrained to migrate down and laterally outward. The primary purpose of the geocomposite in a landfill gas collection system is to provide flow capacity to maintain the landfill gas pressure within the geocomposite at an acceptable level, such that the computed factor of safety against slope stability failure is acceptable, and gas collection out of the top of the landfill is facilitated; thus, reducing the potential for downward pressure gradients of VOCs.

Photo 1. Geomembrane gas bubble during final cover construction.

Design methodology for gas control beneath final covers

The method for designing gas venting layers below landfill final covers was originally developed by Thiel (1998). The primary design criterion for geocomposites is to provide enough flow capacity to reduce the landfill gas pressure to an acceptable level in terms of factor of safety for slope stability. The fundamental design equations for a typical cover slope configuration (**Figure 1**), repeated from the references, are as follows:



Infinite Slope Factor of Safety:

$$FS = \frac{\bar{a} + (h\gamma \cos\beta - u_g)\tan\bar{\phi}}{h\gamma \sin\beta}$$

Figure 1. Infinite slope stability equation with gas forces.

Equation 1

$$u_{max} = \gamma_{cover} \bullet h_{cover} \bullet \cos\beta - \frac{(FS_s \bullet \gamma_{cover} \bullet h_{cover} \bullet \sin\beta)}{\tan\delta}$$

where u_{max} = allowable gas pressure (kPa); γ_{cover} = cover soil density (kN/m^3), h_{cover} = soil cover thickness (m); FS_s = factor of safety against sliding; δ = interface friction angle (degrees) for geocomposite-geomembrane interface; β = slope angle.

The value of the calculated maximum allowable gas pressure then controls the design of the gas relief system that can be designed based on the geometry shown in **Figure 2**. The design equation for the gas pressure that might exist within a drainage geocomposite and pipe network can be calculated as follows (Thiel 1998):

Equation 2

$$u_{max} = \frac{q_g \bullet \gamma_g}{\theta_{greq}} \left[\frac{D^2}{8} \right]$$

where q_g = landfill gas supply flux estimated by the designer or in accordance with Thiel (1998) (m^3/m^2/sec); D = slope distance between strip drains (m); and θ_{greq} = required transmissivity of gas drainage layer (m^3/sec per m width); γ_g = unit weight of gas (kN/m^3).

For lined landfills that do not recirculate leachate, the gas generation rate, r_g, can be conservatively assumed to equal 0.1 scf/year/lb. of MSW. A conservative gas flux at the surface could be calculated as:

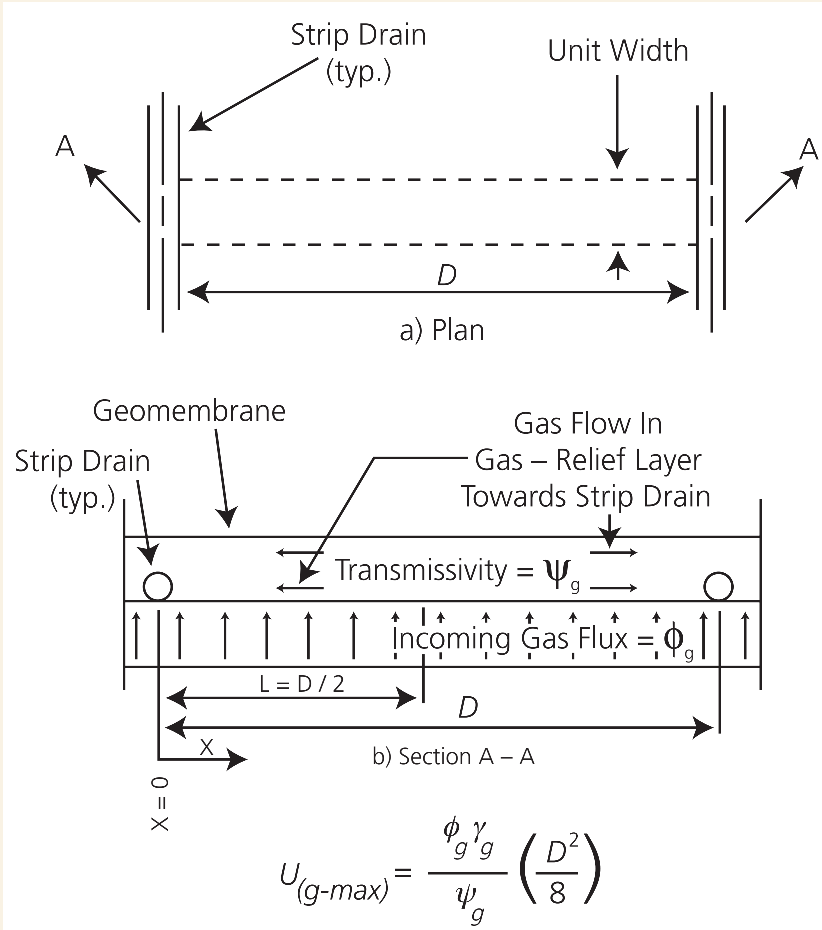


Figure 2. Model of gas flow to strip drains.

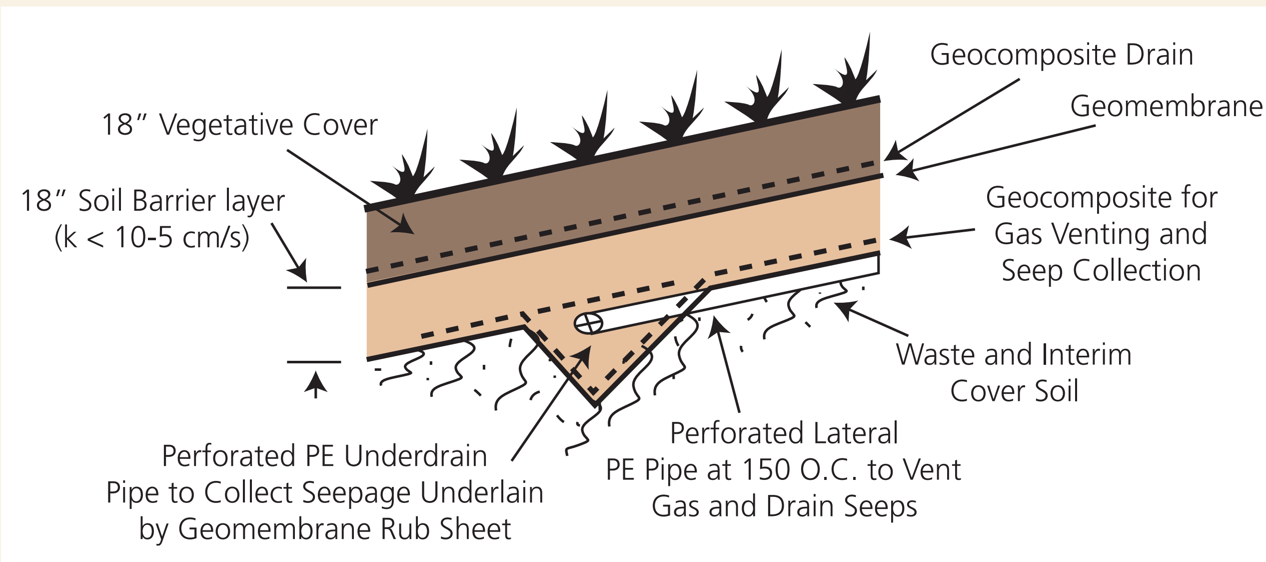


Figure 3. Seep collection at toe of gas collection layer under final cover system.

Equation 3

$$q_g = r_g \gamma_{waste} H_{waste}$$

where r_g = the gas generation rate; γ_{waste} = unit weight of the waste; and H_{waste} = average height of the waste.

Equation 2 can be re-arranged to calculate the required transmissivity of gas drainage layer relative to the pipe spacing as follows:

Equation 4

$$\theta_{greq} = \frac{q_g \bullet \gamma_g}{u_{max}} \left[\frac{D^2}{8} \right]$$

Photo 2. Geocomposite placed directly on waste interim cover—below final cover construction.

Notice that the above equation provides required transmissivity for the flow of gas—not water. Transmissivity tests in the laboratory, however, are performed using water as the test fluid. To compare the measured performance of drainage layers, the required transmissivity from **Equation 4** must be converted to an equivalent water transmissivity, or vice versa. This is accomplished with the help of the relationship between transmissivity, viscosity and density as shown:

Equation 5

$$\theta_{req} = \theta_{greq} \frac{u_{gas}}{u_{water}} \frac{\gamma_{water}}{\gamma_{gas}} \cong 10 \bullet \theta_{greq}$$

where θ_{req} = required hydraulic (i.e., water) transmissivity for geonet or geocomposites (m^3/sec per m width); u_{gas} = dynamic viscosity of landfill gas (kPa); u_{water} = dynamic viscosity of water (kPa); γ_{water} = unit weight of water (kN/m^3); and γ_{gas} = unit weight of gas (kN/m^3).

Design example

Assume an average waste height of 60 ft. with an average density of 50 lb./ft.^{3} (We will use English units here because of their prevalence in this situation and the gas generation rate units.) Also, assume that slope stability calculations indicate that the maximum allowable gas pressure for the cover systems is 6 in. of water column (1490 N/m^2) for a gas venting pipe spacing of about 30 ft. (10 m). Assume the density of landfill gas is 12.8 N/m^3. Calculate the required hydraulic transmissivity of the venting layer.

Solution

Calculate the surface gas flux as:

q_g = 0.1 x 50 x 60 = 300 ft.^{3}/ft.^{2}/yr.
= 2.9E(-06) m^3/m^2/s

Calculate required transmissivity from **Equation 4**:

$$\theta_{gas} = \frac{(2.9 \times 10^{-6})(12.8)}{1490} \frac{10^2}{8}$$
$$= 3.1 \times 10^{-7} \, m^2/s$$

Note that this gives the required gas transmissivity. From **Equation 5** we know that the equivalent hydraulic transmissivity is approximately 10 times the gas transmissivity. Therefore the equivalent required water transmissivity is approximately 3.1 x 10^{-6} m^2/s. Applying reduction factors for creep, chemical and biological clogging, and an overall factor of safety would likely result in a design specification of approximately 2 x 10^{-5} m^2/s for a geocomposite long-term in-soil transmissivity.

Seep collection

A complementary function served by the gas venting layer is the collection of side slope seeps. This can be especially relevant for landfills in high-precipitation areas or bioreactor landfills where liquid is added to the waste or where daily cover layers are not periodically removed or breached to promote vertical percolation of liquids. The seeps would be collected at the toe of the geocomposite gas collection layer (**Figure 3**).

Uncontrolled lateral seepage can manifest itself by distressed vegetation, unsightly wet zones on the landfill sideslopes, local slope instabilities, the release of leachate and an increase in odor. Although it may be possible to explicitly design a drainage layer just for these seeps, the authors have found that adequate seep collection capacity is provided, even in situations where seeps are a chronic problem, if a drainage composite is designed to facilitate gas collection in accordance with the procedures described above. A case history illustrates the significance of this issue.

Photo 3. Vent and leachate collection seep pipes installed below geocomposite.

Case history

The authors were involved with a project that involved partial closure on one face of a landfill that had received leachate recirculation. The landfill had been exposed to approximately 40 in. per year of rainfall; in addition, a significant portion of the waste had received leachate recirculation on an experimental basis at a rate of between 50–75 gallons per ton of waste.

As one of the landfill subcells reached final grades sideslope seeps began to develop. Waste filling operations were moved to another location and approximately 5 acres of 3(H):1(V) slope face were to be final-closed with barrier, drainage and soil layers very similar to the schematic cross section illustrated in **Figure 3**. A photo of the geocomposite placed directly on the waste interim cover is shown in **Photo 2**. The underdrain pipes, installed approximately every 150 ft. directly below the geocomposite for the collection of gas and seeps, are shown in **Photo 3**. In the period of the first year after the closure was completed, the gas underdrain pipes yielded approximately 30–50 cubic feet per minute of gas, and over 2 million gallons of seepage liquids were collected (a steady 4 to 5 gpm); these continue to be collected. In addition, the underdrain system allowed the cover to be installed with none of the typical problems related to gas-billowing of the geomembrane during construction.

This case history illustrates the benefit of installing an underdrain layer below landfill final covers, especially where landfill gas and side slope seeps may exist. Observations suggest that if the underdrain layer transmissivity is designed for the collection of landfill gas in accordance with the suggested method, then the transmissivity will be adequate for the landfill seeps as well. GFR

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