

Landfill Gas Effects on Vegetation and on Water Balance

Mark D. Ankeny and Gregory J. Stormberg

Idaho National Engineering and Environmental Laboratory
Idaho Falls, ID

Abstract. Landfill gas (LFG) inhibits plant growth on landfill covers. Well-established plant growth and deep root penetration are critical to the success and effectiveness of vegetated landfill covers. Poor vegetative stands can result in reduced transpiration, increased percolation, and increased erosion regardless of the thickness of the cover. Therefore, it is important to evaluate the potential effects LFG may have on cover performance.

Bare (vegetation-free) areas are not uncommon on landfill covers. Often, shallow digging in these areas shows reducing conditions that are not present in vegetated areas at similar depths. Methane and carbon dioxide moving up from waste into an overlying soil cover displaces oxygen, which is required in the soil-rooting medium to maintain healthy root activity. In addition, soil microbes consume oxygen in the presence of methane that reduces oxygen available for plant root respiration. Typically, even low methane levels indicate minimal oxygen concentrations.

Landfill gas also directly affects landfill cover water budgets because biological activity in landfill covers can consume, produce, and release water. Degradation of waste typically occurs in two steps: (1) anaerobic fermentation followed by (2) oxidation. Biological activity can result in biogenic water production on the order of centimeters of water per year. This amount of water is often larger than that calculated for percolation by standard cover water balance models. The implication is that standard hydrologic models that ignore both water production and consumption may result in significant water balance errors.

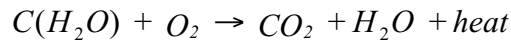
Landfill Gas Generation. The potential for advective subsurface gas flow is increased as gas is generated in the buried waste. A default value of 170 m³ methane generation potential/Mg waste is used in 40 CFR 60.754(a)(1). We also know that landfill waste has a typical dry bulk density range of 0.30 to 0.45 Mg/m³. Assuming a four-meter refuse thickness in a 'typical' landfill, we calculate a methane generation potential of

$$0.4 \text{ Mg/m}^3 * \frac{170 \text{ m}^3 \text{ methane}}{1 \text{ Mg waste}} * 4\text{m} = 272 \text{ m}^3 \text{ methane/m}^2 \text{ of landfill surface}$$

From the stoichiometry, we can assume an approximately equal volume of carbon dioxide will be generated. This gives an estimate of about 544-m³ landfill gas/m² of landfill. If we make a simplifying assumption that 5% of the potential gas generation occurs annually, this is about 544/20 or 27 m³ landfill gas/m² /year. Because of its high carbon dioxide content, landfill gas is often more dense than air. In addition, landfill gas from older facilities often contains ppm concentrations of a wide variety of toxic VOCs.

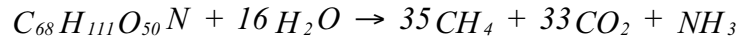
Thermodynamic and Stoichiometric Aspects. Biological activity in landfills can consume, produce, and release water. Water is consumed in anaerobic fermentation and produced in aerobic oxidation. Water is also released when wet cellulosic waste is degraded and drainage occurs. These processes often involve tens of centimeters of water.

Oxidation of celluloses, carbohydrates ('hydrated carbon'), or sugars can be simply expressed as



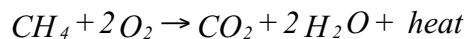
In landfills, where much of the waste is cellulose and related compounds, this equation suggests that approximately 60% of the mass of the cellulosic compounds will turn into water (formula weight of water divided by the formula weight of cellulose).

In landfills, decomposition of celluloses typically occurs in two steps: (1) anaerobic fermentation followed by (2) oxidation. The approximate formula for anaerobically decomposing landfill material is



For each kilogram of waste in the equation above, about 450 liters of methane gas are generated. Due to recalcitrant compounds, daily cover, soils, and side reactions, the typical gas volumes are significantly less than theoretical.

Errors in Traditional Landfill Cover Water Balances. In the calculation above, we generated 272-m³ methane/m² landfill. Oxidation of methane yields



Oxidation of 272 m³ of methane at standard temperature and pressure yield

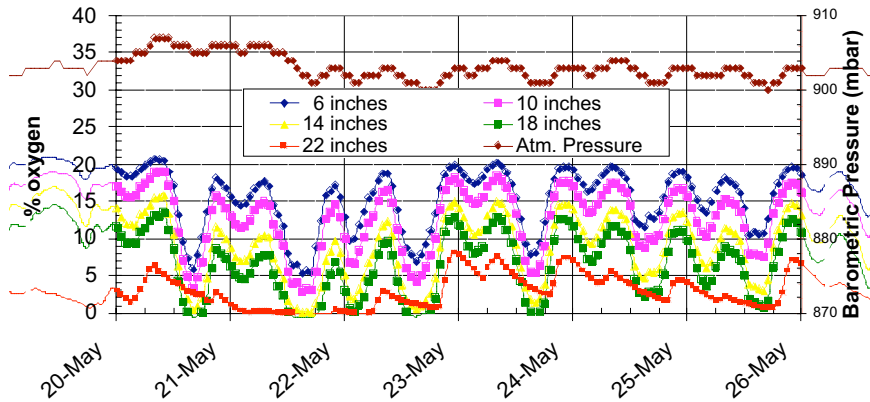
$$272 \text{ m}^3 \text{ CH}_4 * \frac{1 \text{ mol}}{0.0224 \text{ m}^3 / \text{mol}} * 1 \text{ m}^2 * \frac{36 \text{ g H}_2\text{O}}{1 \text{ mol CH}_4} * \frac{1 \text{ kg}}{1000 \text{ g}} * \frac{0.001 \text{ m}^3}{1 \text{ kg}} = \frac{0.437 \text{ m}^3 \text{ water}}{1 \text{ m}^2 \text{ landfill surface}}$$

The equation (which neglects highly variable methane escape) suggests that about 44 cm of water can be generated by microbial metabolism of methane within the landfill profile. From the stoichiometry above: (1) 16 moles of water are consumed for each 35 moles of methane produced; (2) each mole of methane is oxidized to two moles of water; (3) and 16 moles of water are hydrolyzed during methanogenesis for each 70 moles of water produced by oxidation of methane. Thus, approximately 10 cm of water is hydrolyzed in the landfill profile. Net water production in the system is 33.7 (43.7-10.0) cm, or over a 20 year time frame, approximately 1 or 2 cm/yr. Net water consumption is likely to occur within more anaerobic waste and net water production is likely to occur in the near-surface soil cover.

Water Release. Degradation of wet landfill wastes also reduces the water-holding capacity of the wastes and increases the possibility of transient drainage (i.e., when wet newspaper holding its weight in water is converted to carbon dioxide and methane, that held water is free to drain). Dependent upon the moisture status of the buried waste, this retained water may exceed biogenic water in volume. Thus, microbial consumption, production, and release of water are important issues in alternative landfill cover water balances.

Effects of barometric pumping on landfill systems. Barometric pumping caused by atmospheric tides cause a twice-daily rise and fall of surface atmospheric pressure of a few millibars (Chapman and Lindzen, 1970), and this oscillation of the surface pressure is sufficient to cause fluctuations in the rate of landfill gas emission from the ground, especially where the depth to groundwater is great. Our own observations at the Apple Valley, CA landfill show that landfill gas concentrations are greatest during periods of falling barometric pressure, which occurs approximately from 10:00AM to 4:00PM, and from 10:00PM to 4:00

AM. During periods of rising pressure, landfill gas concentrations fall as fresh air enters the soil from above as a result of the greater atmospheric pressure (LANL, 1998). The patterns can be temporarily obscured by the passage of synoptic weather



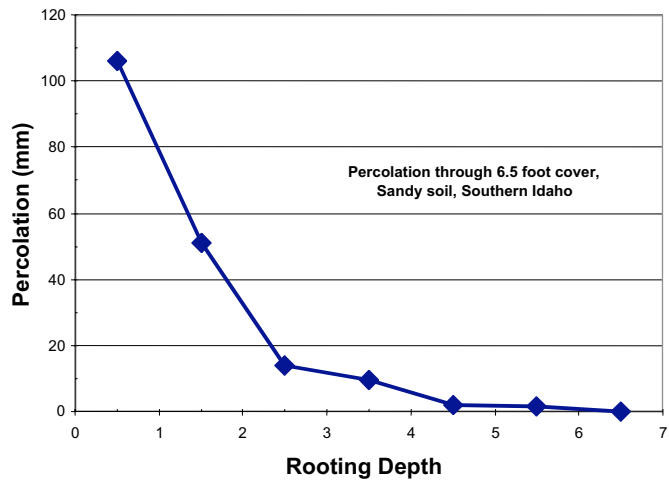
systems, which can cause even larger fluctuations in barometric pressure. The figure also shows that average oxygen concentrations change rapidly as a function of depth.

The figure also shows that oxygen concentrations can also change rapidly with time across depths with barometric pressure fluctuations. These data indicate anoxic conditions can persist very near the surface during daily barometric pressure fluctuations.

Low-pressure fronts result in even more dramatic changes in landfill cover oxygen availability to roots.

Plant-Landfill Gas Interactions. When anoxic landfill gas encounters oxygen, methanogenic bacteria rapidly oxidize the methane (Barlaz et al., 1990). This occurs both at the ground surface and at the irregular outer perimeter of the landfill gas "halo" within the vadose zone. This results in consumption of the methane, and production of carbon dioxide, which in turn changes the redox status of the soil. Around a landfill perimeter, it is not uncommon to find soil gas with up to 20% carbon dioxide, 80% nitrogen, and virtually no oxygen.

Well-established plant growth and deep root penetration are critical to the success and effectiveness of vegetated landfill covers. However, low oxygen levels and landfill gas (LFG) inhibit plant growth on many landfill covers. Poor vegetative stands can result in reduced transpiration, increased percolation, and increased erosion regardless of the thickness of the cover. Therefore, it is important to evaluate the potential effects LFG or periodic anoxia may have on cover performance.



Plant transpiration helps prevent percolation of water in underlying waste. However, bare (vegetation-free) areas are not uncommon on landfill covers. Often, shallow digging in these areas shows reducing conditions that are not present in vegetated areas at similar depths. For example, methane and carbon dioxide moving up from waste into an overlying soil cover displaces oxygen in the soil, which is required to maintain healthy root activity. Additionally, when methane is present, soil microbes will consume oxygen and that also reduces oxygen available for plant root respiration. Typically, even low methane levels indicate sub-optimal oxygen concentrations.

Conclusions.

Vegetation is typically adversely affected by landfill gases and low oxygen concentrations on gas-emitting landfills. Surface cover, rooting depth, and potential transpiration are often reduced. Water balance modeling that assumes vegetative characteristics on normal soils may under predict percolation into waste.

The combined effects of increased heat flux, anaerobic consumption of water, aerobic production of water, and pressure-driven movement of water vapor and methane further affect water balance modeling. Soil moisture potentials, gradients, and gas

concentrations in a landfill setting should be interpreted in the context of likely processes controlling both liquid and vapor flux.

References.

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