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Field-Scale Modeling of Landfill Gas Emission through Intermediate Cover with Gas Collection System

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ABSTRACT

In this study, transport of odiferous landfill gas [e.g., Hydrogen sulfide (H_2S)] was evaluated using the finite element method (FEM) simulating intermediate covers with the gas collection system. As an intermediate cover, linear low-density polyethylene (LLDPE) and co-extruded geomembrane comprised of a thin inner layer (0.05 mm) of ethylene-vinyl alcohol (EVOH) sandwiched between two layers of LLDPE overlain by 0.3-m silty soil were used. For numerical simulation, the effects of the gas collection system, the type of geomembrane on the gas transport, and the combined condition were seperately investigated. Predictions made with a numerical simulation parameterized by experimental data indicate that gas fluxes from intermediate landfill covers with the EVOH geomembrane are approximately two orders of magnitude lower than gas fluxes from an intermediate cover with the conventional LLDPE geomembrane. Furthermore, it was observed that the gas collection system associated with the geomembranes has a significant influence on gas transport through the intermediate covers. The co-extruded EVOH geomembranes with gas collection system can be more effective at reducing the emission of odiferous H_2S relative to the LLDPE alone cover.

INTRODUCTION

Intermediate covers are being used with increasing frequency to manage exposed waste and to control emission of odiferous gases such as hydrogen sulfide (H_2S) during operating period of municipal solid waste (MSW) landfills. It is particularly important for landfill operators to manage the landfill properly during operation and to reduce upset landfill neighbors, resulting in strained relationships with the community, regulatory actions, and, in some cases, costly litigation effectively. For an intermediate cover with an intact geomembrane, gas transport occurs primarily by diffusion (Haxo 1990; Haxo and Pierson 1991; Pierson and Barroso 2002; Stark and Choi 2005), with the rate of diffusive transport controlled primarily by the boundary conditions and the properties of the geomembrane (Haxo et al. 1984). For example, tests conducted by Stark and Choi (2005) showed that gas transport of methane was highest for a linear-low density polyethylene (LLDPE) geomembrane, intermediate for a polyvinyl chloride (PVC) geomembrane, and lowest for a high-density polyethylene (HDPE) geomembrane.

However, the intermediate cover with the geomembrane alone can still emit considerable amount of landfill gas from the landfills (Eun at al. 2018a, b), which might annoy landfill neighbors and community. As an alternative and supplement of the intermediate cover with the geomembrane alone, the gas collection system is being applied to control strong landfill odors as well as to gather and process the methane gas to produce electricity even in the operation period of landfills. The gas collection is typically accomplished through the installation of vertical and horizontal wells in the waste mass. The design and construction is highly depending on various factors such as waste composition, gas generation and etc. associated with site conditions. However, there are limited studies have been investigated on landfill gas emission through the cover when the landfill gas collection system is installed.

In this study, a series of numerical simulations were performed for an intermediate cover system consisting of a conventional LLDPE geomembrane and co-extruded ethylene-vinyl alcohol (EVOH) geomembrane overlain by 0.3-m cover silty soil. Comparisons are made between the covers with different geomembranes in terms of flux and relative concentrations. The simulation was also conducted with and without gas collection system to investigate the effect on the gas transport. Based on the results, the effects of installation of gas collection system on landfill gas transport through intermediate covers are evaluated relative to the type of geomembrane and the presence of the gas collection system.

METHODS AND MATERIALS

Geomembranes

Two geomembranes were used for numerical simulation. The geomembranes were co-extruded EVOH with LLDPE outer layers (0.76 mm) and homogeneous LLDPE (0.76 mm). The EVOH geomembrane contained composite configuration consisting of a 0.04-mm thick layer of EVOH surrounded by outer layers of LLDPE (0.36 mm). EVOH is a random copolymer of ethylene and vinyl alcohol that includes polar hydroxyl (−OH) groups. Because the monomer mainly exists in the EVOH, the copolymer is prepared by polymerization of ethylene and vinyl acetate to provide the ethylene vinyl acetate (EVA) copolymer, followed by hydrolysis (Lagarón et al. 2001; Armstrong 2011). EVOH copolymer is classified by the mole percentage of ethylene—lower ethylene content grades enable reduced gas transport; higher ethylene content grades require lower temperatures for extrusion. Eq. 1 describes the chemical formula of EVOH:

$$-(CH_2\text{-}CH_2)_m - \underset{\displaystyle OH}{\underset{|}{(CH_2\text{-}CH)_n}} - \qquad (1)$$

EVOH has outstanding barrier properties to non-polar gases such as oxygen, nitrogen, volatile compounds, and helium due to hydroxyl groups (Zhang et al. 1999; Zhang et al. 2000; Byun et al. 2007; McWatters and Rowe 2010, 2011, 2015, Eun et al. 2017). Moreover, EVOH laminar is typically a combination of a highly ordered crystalline structure interspersed with disordered amorphous regions that show high resistance to diffusion of gas and solvent. Hence, co-extruded EVOH geomembrane is expected to allow less migration of H_2S.

Numerical Modeling

Figure 1 shows a schematic of an intermediate cover system comprised of a waste material as contaminant resource, geomembrane, silty cover soil (= 0.3 m), and atmospheric air modeled by finite element method (FEM) via the COMSOL. The gas collection system was modeled as well at the right corner underneath the geomembrane [Fig. 1 (b)] to investigate the effect of the installation on the gas transport. The gas collection system has zero pressure, which induces the advective flow toward to the system from the entire waste material. The dominant mode for gas transport in this model is diffusive flow governed by Fick's law (Eq. 3).

$$\nabla . \Gamma_i + u . \nabla c_i = R_i + S_i \quad (2)$$
$$N_i = \Gamma_i + u c_i = -D_{e.j} \nabla c_i + u c_i \quad (3)$$

where N_i is the molar flux, D_i is the diffusion coefficient, c_i is the concentration, u is the velocity, R describes "sources" or "sinks" of the quantity c, and S_i is the source of contamination.

However, if the gas collection system exists, advective flow should be considered. For the advective flow, "Transport of Diluted Species in Porous Media" governed by Darcy's Law (Eq. 4) for the stationary study was additionally selected in the COMSOL with time-dependent study to account for different time intervals for advection and diffusion.

$$\nabla . (\rho u) = Q_m \quad (4)$$
$$u = -\frac{\kappa}{\mu} \nabla p \quad (5)$$

where Q_m is the total discharge, κ is the intrinsic permeability of the medium, u is the flux (discharge per unit area), and ∇p is the pressure gradient and μ is the viscosity.

H_2S gas was used for the numerical simulation. The diffusion coefficient and permeability of H_2S for soils and geomembrane were obtained from the laboratory diffusion column test (Eun et al. 2016, 2018b). In this study, the equivalent value of the diffusion coefficient for the EVOH geomembrane was used.

A 0.3-m thick layer of air-dried silt was placed on top of the geomembrane and lightly compacted to simulate conditions (porosity = 0.3) where the cover soil is placed over the geomembrane for protection and anchorage. Table 1 and 2 describes the input parameters of gas and cover materials including geomembrane and silty soil for the simulation.

The initial concentration of contaminated source is 25 ppm with lower pressure (< 10 kPa), which is closely simulated to field condition (Benson et al. 2012; Sun and Balaz 2015). The boundary condition of two sides is no flux which simulated an unbounded condition in the field. The mesh size was much finer around the layer of geomembrane, which eliminate the numerical discrepancy. The different widths of intermediate cover in the horizontal direction was simulated to investigate boundary condition on the gas collection system.

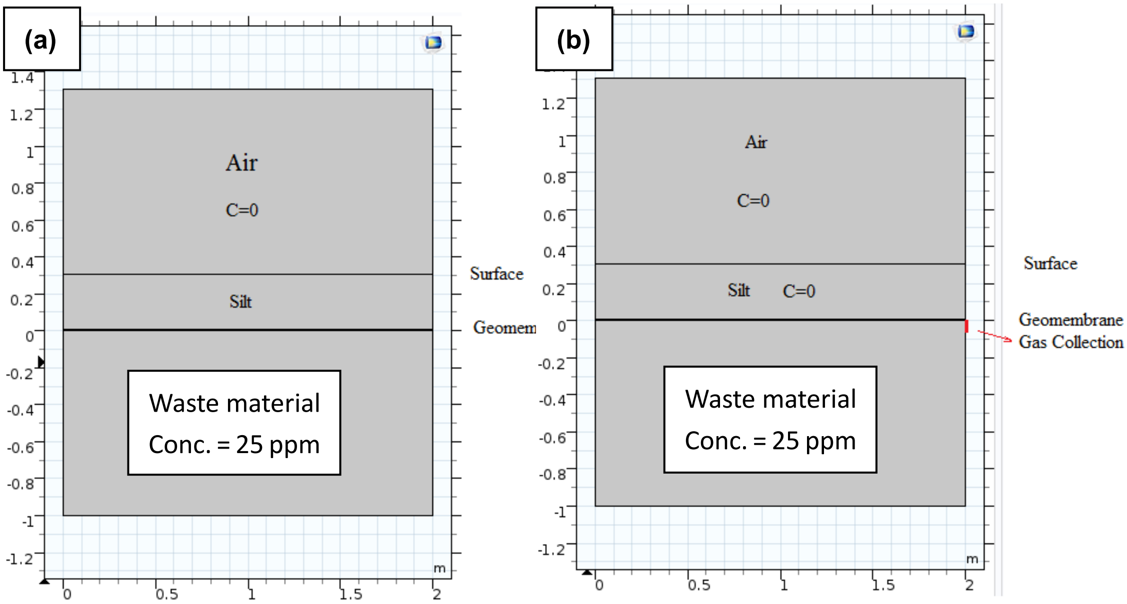

Figure 1. A schematic of an intermediate cover for numerical simulation using COMSOL: (a) without gas collection system and (b) with the gas collection system.

Table 1. Input parameters of gas for numerical simulations

Hydrogen Sulfide (H_2S)	
Density (kg/m^3)	Dynamic Viscosity (Pa.s $\times 10^5$)
1.36	1.3

Table 2. Input parameters of cover materials for numerical simulations

Type	Porosity (n)	Permeability (m^2) ($m^2/s \times 10^{10}$)	H_2S Diffusion Coefficient ($m^2/s \times 10^{10}$)
Silt	0.3	1000	50000
LLDPE	0.1	10	0.87
EVOH	0.1	1	0.011

RESULTS AND DISCUSSION

Comparison of Gas Flux through Intermediate Covers between LLDPE and EVOH without Gas Collection System

Steady-state gas fluxes (i.e., H_2S) for the intermediate covers without gas collection system are shown in Fig. 2. The flux from the soil cover reached 730 g/ha-y. The flux from cover with the LLDPE reaches 0.23 g/ha-y. The hierarchy of the steady-state fluxes is consistent with the magnitude of the diffusion coefficients of the geomembranes. The transient period ranged from 220 hours for the conventional LLDPE geomembrane. In contrast, flux from the EVOH geomembrane was less than 0.003 g/ha-y, and the transient period was approximately 10 months. Using LLDPE geomembrane in an intermediate cover can reduce the flux by approximately four orders of magnitude in comparison to an intermediate cover of soil alone. Using an EVOH geomembrane can reduce the fluxes more than six orders of magnitude relative to soil alone. These findings suggest that intermediate covers with a geomembrane can be very effective in controlling odors from H_2S.

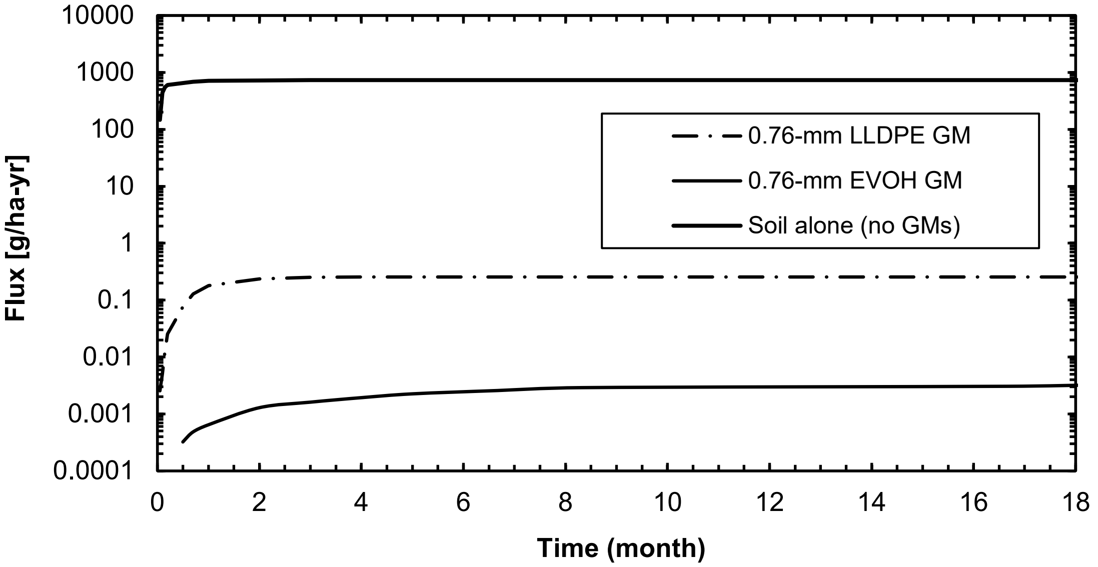

Figure 2. Landfill gas fluxes for intermediate cover with 0.3 m-thick layer of cover soil alone or the soil underlain by 0.76mm-LLDPEand 0.76 mm-EVOH geomembranes.

Effect of Gas Collection System on Gas Transport

Figure 3 shows the comparison of gas fluxes along with the width (2 m) of the geomembrane through an intermediate cover with gas collection system and without gas collection system. If the gas collection system was installed under the cover, the flux generated from the cover is significantly reduced. The total flux simulated with a gas collection system is more than two orders of magnitude smaller than that without gas collection system as shown in Fig. 4. Thus, the gas collection system is critical to control gas emission from the landfill.

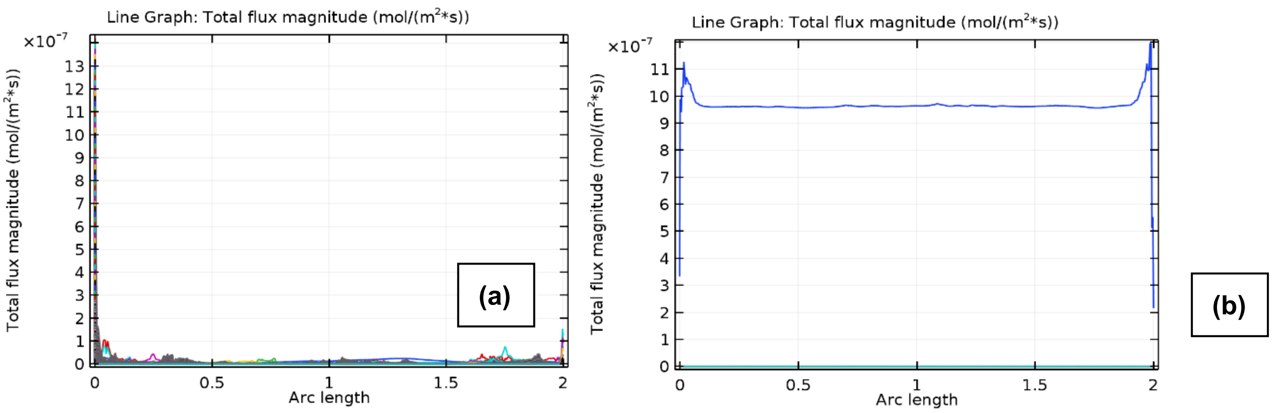

Figure 3. Total flux magnitude (mol/m^{2}s) through intermediate covers with LLDPE geomembrane: (a) with gas collection system and (b) without gas collection system.

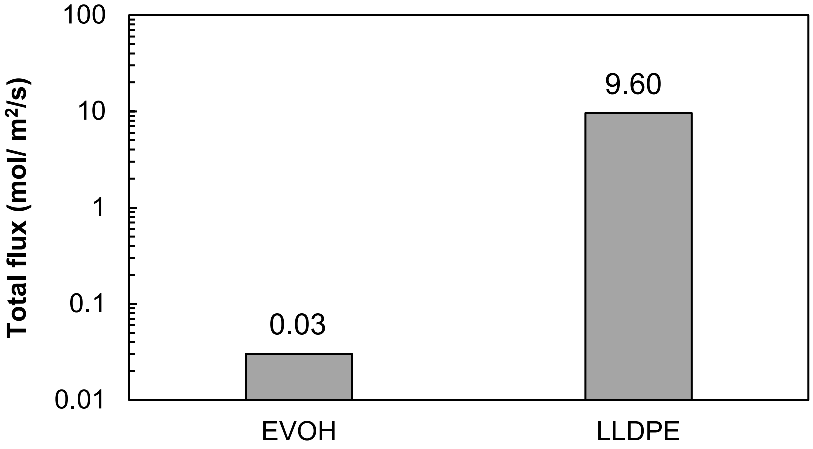

Figure 4. Comparison of average flux through the entire surface of geomembrane layer between EVOH and LLDPE.

Comparison of Gas Emission through Intermediate Covers Containing EVOH and LLDPE Geomembrane with Gas Collection System

Figure 5 shows the contour and vector velocity of gas emission through an intermediate cover comprised of soil and geomembrane with the gas collection system. The effect of the gas collection system was comparatively evaluated on the gas transport between EVOH and LLDPE intermediate cover. In the case of EVOH, the gas emission through the cover is significantly lower than that of LLDPE. The gas emission through the intermediate cover is almost zero. For EVOH, gas concentration does not change meaningfully, which shows mostly red color, and gas transport mostly occurs in the gas collection system. The blue color presenting zero concentration is radically distributed around horizontal well in right side within 0.1 m. However, in the case of LLDPE, gas concentration changes remarkably in the entire gas source of waste material, which shows various color. Because of the generation of the gas emission through the intermediate cover, the different colors in the contour and velocity vector were observed. Thus, the EVOH does not allow the leak of gas through the cover and induce to gas transport only through the collection system. This might increase the efficiency of the gas collection system in the field.

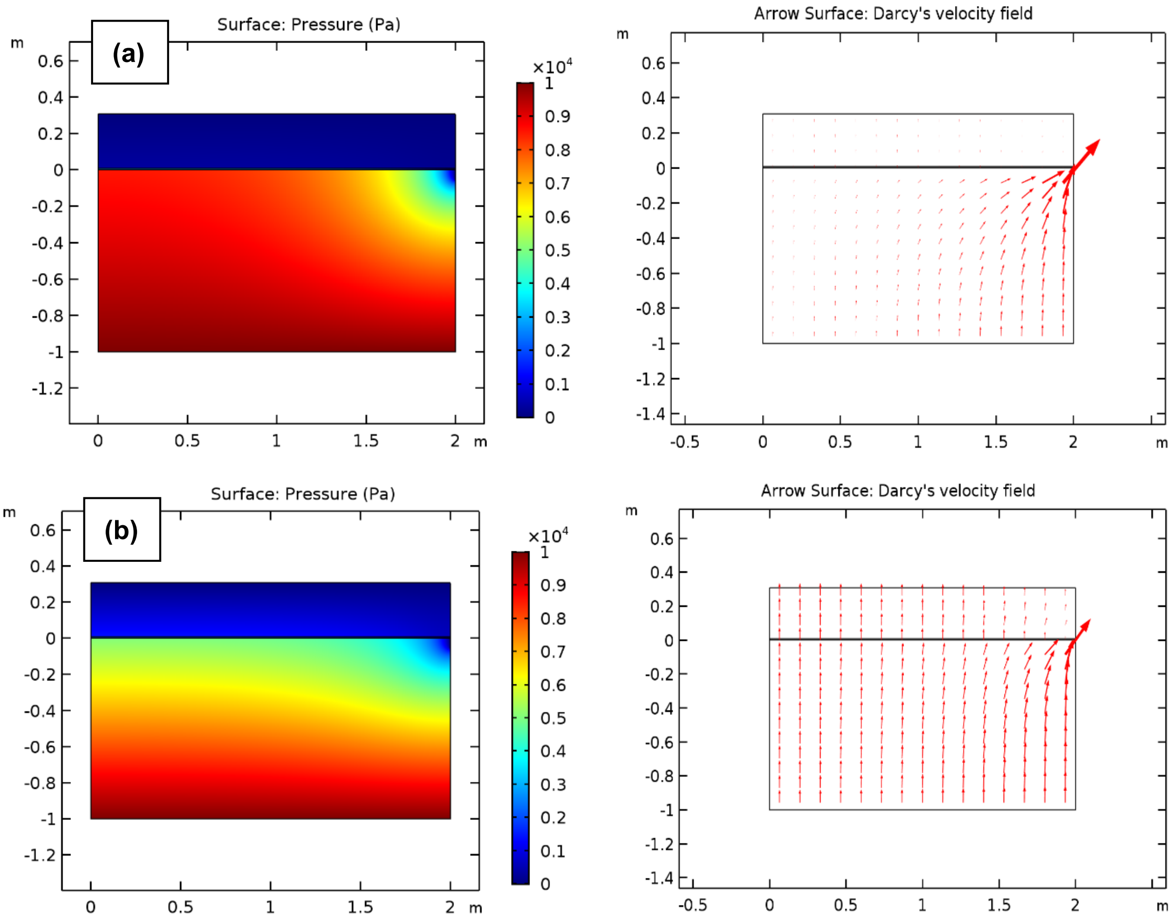

Figure 5. Pressure contour and velocity vectors (Darcy's flux) of gas emission through an intermediate cover comprised of EVOH (a) and LLDPE geomembrane (b).

CONCLUSIONS

Landfill gas transport through simulated intermediate covers comprised of LLDPE and co-extruded EVOH geomembrane overlain by 0.3-m silty soil with gas collection system was evaluated in this study. The steady state of gas fluxes (i.e., H_2S) occurred at 9 days with the LLDPE geomembranes compared to 10 months with the EVOH geomembrane, even though these geomembranes had the same thickness (0.76 mm). Using LLDPE geomembrane in an intermediate cover can reduce the flux by approximately four orders of magnitude in comparison to an intermediate cover of soil alone. Furthermore, gas fluxes from intermediate landfill covers with the EVOH geomembrane are approximately two orders of magnitude lower than gas fluxes from an intermediate cover with the conventional LLDPE geomembrane. It was observed that the gas collection system associated with geomembrane type has a significant influence on gas transport through the intermediate covers. The EVOH cover does not allow the leak of gas through the cover and induces to gas transport only through the collection system. These findings suggest that EVOH geomembranes may be much more effective in controlling emission of odiferous H_2S from MSW landfills than conventional LLDPE alone cover.

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