Evaluation of performance of double composite landfill liner

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ABSTRACT: Performance of landfill liners is evaluated with respect to leakage rate and mass flux. The composite liners considered in this study include a single geosynthetic clay liner (GCL), the Subtitle D liner system, the Wisconsin NR500 liner system, and the recently utilized double composite liner system, which consists of a geomembrane (GM) – GCL – GM – compacted clay layer (CCL). The leakage rate through circular and long defects in the GM of the landfill liners was analyzed using analytical equations and numerical models. For the mass flux criterion, the analyses of contaminant transport through defects in the GM component of liner systems and diffusion of volatile organic compounds through intact landfill liners were conducted using numerical models. The comparison shows that the double composite liner systems are superior to the other kinds of liner systems according to the performance-based evaluation.

1 INTRODUCTION

Three types of composite liner systems widely used in solid waste landfills comprise the GCL composite liner (a popular alternative liner system), the Subtitle D liner (the liner prescribed in Subtitle D of the Resource Conservation and Recovery Act, US EPA), and the Wisconsin NR500 liner (the liner prescribed in the Wisconsin Administrative Code Section NR500). The GCL composite liner is a combination of a GM and a GCL. The Subtitle D and Wisconsin liners are formed by a GM and a thick layer of compacted clay (61 cm (2 feet) and 122 cm (4 feet), respectively). Foose et al. (2002) analyzed the three composite liners based on the performance estimation of leakage rate and mass flux. Cadmium and toluene were used in his analysis as two typical inorganic and organic leachate constituents, respectively. The results of his analysis were that the GCL composite liner had the lowest leakage rate and the mass flux for toluene from the GCL composite liner was two to three orders of magnitude greater than that from the Subtitle D and Wisconsin NR500 liners. Therefore, the need for a more effective composite liner, which has not only low leakage rate but also low mass flux, has emerged recently. The double composite liner, which is formed by a GM, a GCL, a GM, and a compacted clay layer (61 cm (2 feet) or 91.5 cm (3 feet)), has been used in several landfill constructions. This type of liner is believed to satisfy all performance requirements for a landfill liner. However, there is no study on the performance of this type of liner to date.

In this paper, the double composite liner was compared with the other composite liners based on two performance criteria: (1) leakage rate, and (2) mass flow rate from the base of liner system. Analysis of leakage rate is implemented in the cases of defects in GM. Solute transport analysis is performed in the case of intact liners.

2 LEAKAGE RATE

2.1 *Leakage model*

Foose (1997) employed the MODFLOW program (McDonald and Harbaugh 1988) to calculate the leakage rates through the composite liners having defects. The modeling of the composite liners and the boundary conditions were instructed in Foose (1997) and Foose et al. (2001, 2002). The results reported by Foose et al. (2001) were in good agreement with those that were computed using the equations by Walton & Seitz (1992) and Giroud (1997). Foose et al. (2001) recommended empirical equations for predicting leakage rates through defects with perfect contact based on the results of numerical model. The equations were verified by comparing their results with that of other equations (Walton & Seitz 1992, Walton et al. 1997).

In this study, a new version MODFLOW 2000 was used to simulate the 3D flow through double composite liners for the steady-state condition. The conceptual model for flow through two vertically coaxial defects in double composite liners is presented in the fig. 1. Only one quadrant of the leakage through a circular defect was modeled due to the symmetry of the steady-state flow. Two layers of no-flow cells were used to simulate the two GMs. To consider the most critical case, the two defects on each GM were assumed to be vertically coaxial. The upper defect was simulated as constant head rectangular cells. The constant head assigned to these cells is $h_t = 2t_{gm} + L_{s1} + L_{s2} + h_p$, where h_p = depth of leachate equal to 30 cm. It was assumed that the depth of leachate was constant due to the lack of data about the variation of leachate depth with time (Foose et al. 2002). The side boundaries were also modeled as no-flux boundaries. The bottom boundary was modeled as a fully draining boundary with a constant head of zero. The geosynthetic and compacted clay liners were assumed to be saturated, homogeneous, and isotropic. The width of the model is 100 cm, which is large enough for a simulation of flow through defects to converge to an analytical solution (Foose et al. 2001). The contacts between the GMs and soil liners are assumed to be perfect.

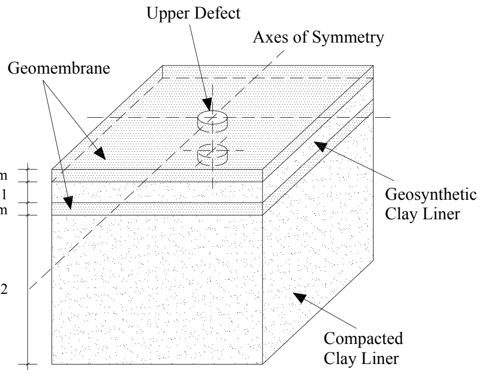

Figure 1. Conceptual model for flow through two defects in double composite liners

2.2 *Results*

The leakage rates through defects of liner systems popularly used in practice for evaluating the performance of liner systems were presented in this section. Two first cases (Subtitle D) are two systems of 61 cm (2 feet) or 92 cm (3 feet) thick compacted clay liner underlain a GM. Two other cases are double composite liners with 2 or 3 feet of compacted clay liner. The two systems have the identical structure consisting of a first GM, a 6.5 mm thick GCL, a second GM, and 61 cm (2 feet) or 92 cm (3 feet) thick compacted clay liner. Lastly, the leakage rates through the GCL composite liner were also calculated for comparison.

2.2.1 *Circular defects*

Fig. 2 shows the leakage rates for the GCL, Subtitle D, and double composite liners obtained from the simulations. The proposed double composite liner system with a 0.6 or 0.9 m thick soil liner yields significantly lower leakage rates than the Subtitle D liner system. Similarly to the cases of Subtitle D liners, the thicker double composite liner has slightly higher leakage rate. The leakage rates for the proposed double composite liner system ranges from 0.86 to 11.94 mL/defect/year for a defect radius of 1 to 6 mm. These leakage rates are slightly higher than those of the GCL composite liner system because of the small thickness of the GCL. Of course, this small thickness is detrimental to diffusion or solute transport across the GCL and puncture resistance. Foose (1997) reasoned that due to the total head of zero everywhere in the soil liner, the total potential drop in the thicker liner is greater and the leakage rate for the thicker liner is greater. Foose et al. (2002) obtained the similar results with the higher leakage rate for the thicker Wisconsin NR500 liner than that for the 2-feet-thick Subtitle D liner.

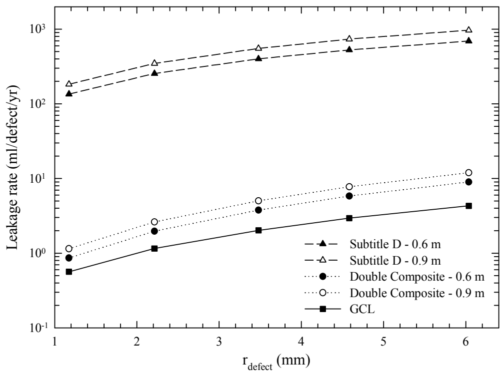

Figure 2. Leakage rates through circular defects in composite liners with perfect contact

2.2.2 *Long defects*

Fig. 3 shows the results of leakage rates per unit length of defect for typical and double composite liners. The leakage rates calculated by the Foose et al.'s (2001) equation are in very good agreement with those that were obtained using MODFLOW 2000. The leakage rates for the 3 feet thick Subtitle D liner are about 30 to 40 mL/cm of defect/year higher than those that for the 2 feet thick Subtitle D liner. The leakage rates through long defects for the double composite liners are about 30 to 40 times lower than those that for the Subtitle D liners. Similarly to the cases of circular defects, the leakage rates for the double composite liners are slightly higher than that for the GCL composite liners. The authors discovered that with the width of defect equal to 2 mm, the leakage rates for the double composite liners start to be higher than that for the GCL composite liners when the length of defect exceeds 65 cm and 87 cm for the cases of 3 feet and 2 feet thick double composite liners, respectively (see fig. 4). Similar to the cases of circular defects, the 3 feet thick double composite liner also has the higher leakage rates than does the 2 feet thick double composite liner.

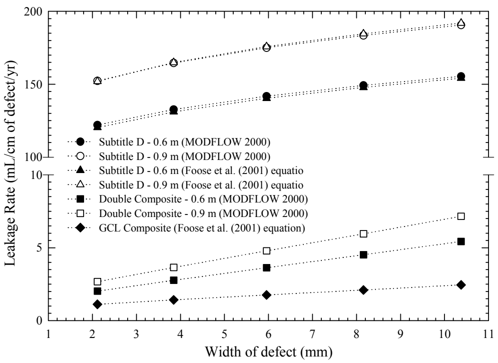

Figure 3. Leakage rates through long defects in composite liners with perfect contact

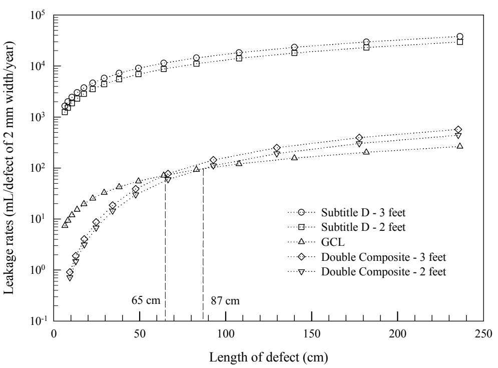

Figure 4. Leakage rates through the defects of 2 mm width and varying length with perfect contact

The leakage rates through long defects are much higher than that through circular defects for the Subtitle D liners (Foose et al. 2001). For the double composite liners, the similar trend was observed. Therefore, the long defects are the major source of leakage in the constructions of liner. The thicker liners tend to have higher leakage rates in most cases of defects. It can be seen that the leakage rate is not the crucial criterion in the assessments of liner systems. The double composite liners show very good performance based on the criterion of leakage rate compared to the Subtitle D liners.

3 SOLUTE TRANSPORT

3.1 *Model of diffusive transport*

The mass flow rate for cadmium solutes can be calculated based on the leakage rates through defects in the GM of the composite liners (Foose et al. 2002). Since the leakage rates for the defective double composite liners are lowest, the mass flow rate of cadmium solutes through defects in the GM of double composite liners is also smallest.

For the organic solute transport, the mass transport through defects can be negligible if compared with that through the intact portion of composite liners (Foose et al. 2002). The organic solute transport through the intact composite liners can be analyzed by a one-dimensional model of diffusive transport due to the large extent of the landfill construction and the small number of defects. Foose et al (2002) provided a numerical approach for analyzing the organic solute transport through intact composite liners. A block-centered finite-difference model of diffusive transport through intact double composite liners has been developed in the present research using the explicit method to calculate the mass flow rate of toluene transport. The bottom boundary conditions for the block-centered models were chosen as previously defined by Foose (1997) and Foose et al. (2002). The constant concentration at the bottom boundary was zero and the locations of it were at the base of the liner or 9 m from the base of liner.

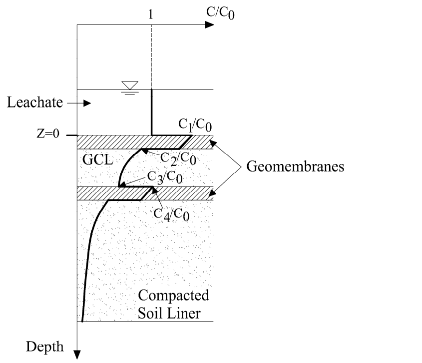

Figure 5. Concentration profile of transport of toluene in intact double composite liners

Fig. 5 shows a typical concentration profile of the transport process of toluene having concentration C_o through the intact double composite liner. The toluene compound as an organic contaminant in the leachate initially partitions into the upper GM ($C_1 = K_{d,gm}C_o$, where $K_{d,gm}$ = partition coefficient for geomembrane and toluene), then diffuses downward through the upper GM and partitions back into the pore water at the base of the upper GM (C_2). Subsequently, toluene diffuses through the GCL until partitioning again into the lower GM ($C_4 = K_{d,gm}C_3$).

The transport process through the lower GM and the compacted soil liner is identical to that through the upper GM and GCL.

3.2 *Results*

The following figures present the results for intact double composite liners with comparison of the other composite liners. The mass fluxes of toluene through other intact composite liners were provided by Foose et al. (2002).

Fig. 6 shows that the double composite liners are the most effective liners in terms of the mass flow rate of toluene at 100 years for the case of a constant concentration of zero at the base of the liners. The intact double composite liners permit minimum diffusion of toluene among the composite liners. The mass fluxes of toluene through intact double composite liners at the end of the simulation are 1432 and 489 mg/ha/year for the cases of the compacted clay liner layers having thicknesses of 2 and 3 feet, respectively.

For the case of the semi-infinite bottom boundary condition, which was represented by the bottom boundary at the depth of 9 m from the base of the liner, the results also show that the double composite liners are most efficient for the landfill constructions (see fig. 7). With the double composite liner of 2 feet of compacted clay liner, the mass flux after 100 years is almost equal to that for the Wisconsin NR500 liner. In this case, the mass fluxes at the end of the simulation are 445 and 153 mg/ha/year for the cases of the compacted clay liner layers having thicknesses of 2 and 3 feet, respectively.

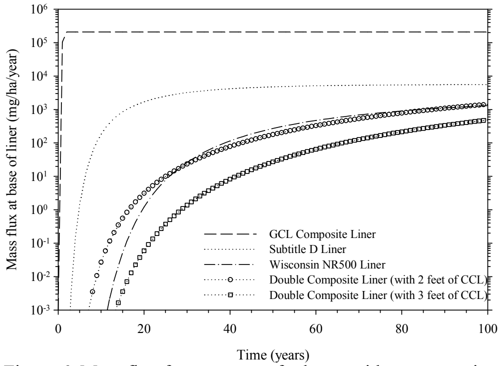

Figure 6. Mass flux for transport of toluene with concentration at base equal to 0 μg/L

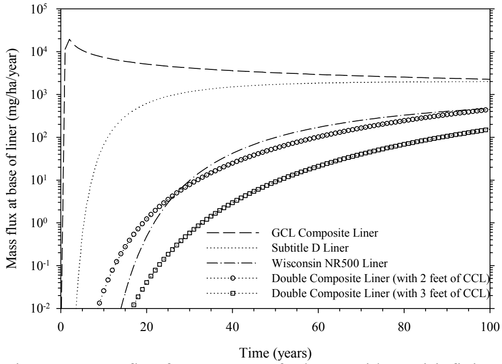

Figure 7. Mass flux for transport of toluene with semi-infinite bottom boundary condition

4 CONCLUSIONS

The performance of double composite liners has been analyzed and compared to other composite liners based on leakage rate and mass flux using numerical models. The leakage rates through defects in double composite liners are very low compared to other thicker composite liners. Compared to the GCL composite liner, the leakage rates for the double composite liners comparable is insignificantly higher. On the criterion of mass flux, the double composite liners are the best choice for landfill constructions. The mass flux after 100 years of toluene transport through intact double composite liners is smallest compared to those that through other composite liners. For the cadmium solute transport, the mass flux should also be smallest since the leakage rates through defects in the GM of double composite liners are lowest. Therefore, the authors strongly suggest the consideration of double composite liner in design progression for landfill liner constructions.

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