

Application of Thermal Insulation in Landfill Liners

A. Hoor¹, and R. K. Rowe², F. ASCE

¹Ph.D. Candidate, Geo-Engineering Centre at Queen's- RMC, Department of Civil Engineering, Queen's University, 58 University Ave., Kingston, ON, Canada K7L6N6; PH (613) 533-6000 ext. 77142; FAX (613) 533-2128; email: a.hoor@ce.queensu.ca

²Professor, Geo-Engineering Centre at Queen's- RMC, Department of Civil Engineering, Queen's University, 58 University Ave., Kingston, ON, Canada K7L6N6; PH (613) 533-3113; FAX (613) 533-2128; email: kerry@civil.queensu.ca

ABSTRACT

Until recently the temperature of landfill liners and its effects on the service-life of composite liners have received relatively little attention. However, there is growing evidence that the temperature may be sufficient to significantly reduce the service-life of the liner components, in particular that of the high-density polyethylene geomembrane. This paper presents a numerical study of the use of expanded polystyrene (EPS) geofoam and shredded tires as thermal insulators between primary and secondary liners. The temperature level on the secondary geomembrane is shown to be lower than the case without thermal insulation. Accordingly, the service-life is longer. The paper also highlights some of the challenges that would be associated with the potential use of geofoam or shredded tires and suggests that while using geofoam or shredded tires warrants consideration, much care would be required in the detailed design and construction of the liner.

INTRODUCTION

Modern landfills increasingly use engineering barrier systems typically comprised of leachate collection system (LCS), a high density polyethylene (HDPE) geomembrane (GM) and a geosynthetic clay liner (GCL) to minimize contaminant migration to the environment. The barrier system is expected to provide protection for what is called the contaminating lifespan of the landfill (for large modern landfills this could be hundreds of years, Rowe et al. 2004). To ensure long-term environmental protection is achieved, it is necessary to minimize the factors that reduce service-life of the barrier system.

Heat generated by biodegradation of waste and the hydration of incinerated ash in landfill can have undesirable impacts on the long-term performance of landfill liner. High temperature accelerates the aging of the GM and it may result in the desiccation of the GCL (Rowe 2005). The liner temperature is reported to range from 7 to 60°C (Rowe and Islam 2009, Rowe and Hoor 2009). Although not documented in the literature, the writers are aware that even higher liner temperatures have been observed in some landfills.

The barrier system may involve a single liner or a double liner. In a double-lined landfill, the service-life of the secondary geomembrane (SGM) is expected to exceed that of the primary geomembrane (PGM). The difference in leachate exposure and temperature improves the SGM's long-term performance compared to that of the PGM. However, Rowe and Hoor (2009) showed that, in some cases, the temperature of the SGM was likely to be high enough to noticeably affect its service-life. In situations where service-life is predicted to be inadequate, options including changing the method of the landfill operation (Rowe 2005), cooling the liner (see Hoor et al. 2008 and Rowe et al. 2010 for one possible cooling technique) and revising the type of barrier system (e.g. thickness, geometry).

As shown by Rowe and Hoor (2009), the thickness and the geometry of the barrier system considerably influence the temperature of the SGM. That study indicated that a thick layer of soil between the primary and the secondary liner can reduce the temperature of the SGM. However, in addition to the cost of construction, this takes up volume in the landfill. Rowe and Hoor (2009) observed that ideally a material with lower thermal conductivity than soil should be used. Thus, the objective of the present study is to explore the possible effectiveness of using EPS geofoam and shredded tires as thermal insulation between primary and secondary liners. Geofoam and shredded tires are commonly used in geotechnical applications as thermal insulators (Horvath 1995, Humphrey 1999).

Recently, geofoams and tire shreds have also been used in landfill applications. For example, geofoam has been used to thermally insulate landfill liners during the period of time before the liner is covered with the overlying drainage layer. Horvath (1994) suggested that landfill designers consider using geofoam as a thermal insulator against desiccation due to solar radiation and freezing of the clay liner during the period before the liner is covered. Field tests performed by Benson et al. (1996) showed that geofoam was an effective thermal insulator in this application.

Shredded tires have been used as a drainage medium in the barrier system at the base of landfills, as a foundation layer beneath the landfill cover, and also as daily cover in landfills (Humphrey 1999, Jesionek et al. 1998, Rowe and McIsaac 2005). A layer of shredded tires was also found to be an acceptable protection layer to limit GM strains and GCL extrusion for the GM-GCL composite liner (Dickinson and Brachman 2008). Benson et al. (1996) found tire chips are an effective means of insulating landfill liners prior to waste placement.

The objective of this paper is to evaluate numerically the potential effectiveness of geofoam and shredded tires in reducing the temperature of the SGM in a double composite liner and also to discuss some of the construction and long-term challenges associated with the potential application of these materials. To provide an estimate of the magnitude of effect, the likely service-life of the SGM is calculated and compared with the minimum required by Ontario Regulation 232/98 under the Ontario Environmental Protection Act (MoE 1998).

METHOD

The landfill barrier system examined is comprised of the PGM and GCL, a geonet (GN) leak detection system (LDS), SGM and GCL underlain by a 3m-thick sandy silt subsoil (Figure 1). While no insulation layer is used in the case shown in Figure 1a, all other cases (shown schematically in Figure 1b) have an insulation layer between the primary and the secondary liner as listed in Table 1.

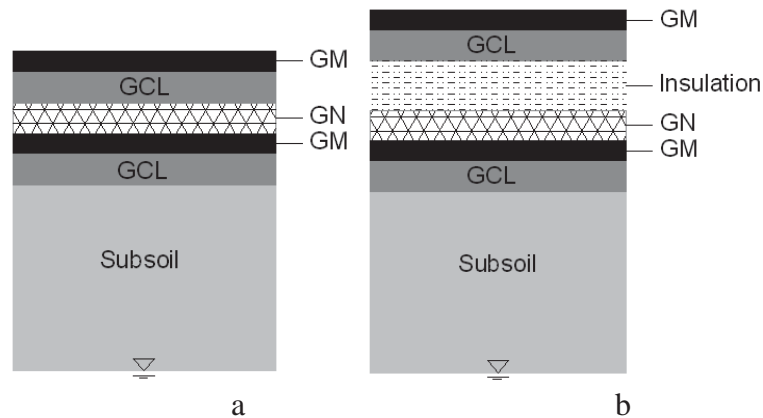


Figure 1. Configurations of barrier systems studied (a) without insulation (b) with insulation: GM: geomembrane (2mm); GCL: geosynthetic clay liner (10mm); GN: geonet (5mm); subsoil (3m). Sand, geofoam and shredded tires are used as insulation (thicknesses vary)

Modelling heat conduction

Transient heat conduction was modeled using the finite layer contaminant migration analysis program Pollute v7 (Rowe and Booker 2005; also see Rowe and Hoor 2009 for the details of the numerical model). The form of the heat conduction equation is the same as contaminant diffusion equation where concentration is analogous to temperature. Therefore, heat conduction can be modeled in Pollute by replacing concentration by temperature, diffusion coefficient by thermal diffusivity and porosity by heat capacity. To describe the landfill barrier system in Pollute, two specified temperature boundary conditions were defined. Analyses were performed for a PGM temperature of 50°C (upper boundary) and groundwater temperature of 10°C (lower boundary). To model transient heat conduction, thermal conductivity, thermal diffusivity and/or heat capacity are required (when any two of these parameters are defined, the third one can be calculated).

Thermal conductivity: Thermal conductivities adopted for soil, shredded tires, GM, GN, GCL and geotextile (GT) are within the range reported in literature (Humphrey et al. 1997, Shao and Zarling 1995, Rowe and Hoor 2009). For GCL, the thermal conductivity was calculated using the thermal conductivity values for a layer of bentonite and two layers of GT.

Although a reasonable amount of data has been published on thermal properties of geofoam, the effect of geofoam deformation on thermal conductivity has rarely been addressed. In usual geotechnical applications, it is commonly assumed

that this parameter is relatively insensitive to the density of the geofoam material (Horvath 1995). However, at the base of landfill, due to the weight of the waste, geofoam blocks experience much larger compressive strains than in other geotechnical applications. This may be expected to affect their thermal properties. To take account of the effect of high stress on thermal conductivity of geofoam, the thermal conductivity was recalculated based on the properties of its constituents and the void ratio after compression (see Rowe and Hoor 2009 for the details). Thermal conductivity values calculated using this approach are 2-3 times higher than the values reported for uncompressed geofoam. Therefore, they yield more conservative results than the uncompressed values.

The thermal conductivity of geofoam is also very dependent on the magnitude of water absorption. In the present analysis, the focus was on the case of a dry geofoam. This case represents a situation in which minimal leachate percolates through the primary liner and the geofoam cannot take up moisture from beneath. In order to evaluate the effect of water absorption on the performance of the landfill barrier system, one additional case with volumetric water content of 15%, the high end of what is expected to be achieved in pavement applications (Horvath 1995), was simulated.

Heat capacity: The heat capacity values were taken from the published literature (Horvath 1995, Humphery et al. 1997, Rowe and Hoor 2009). Heat capacity of compressed geofoam was recalculated using the characteristics of its components (EPS beads, air and water).

Thermal diffusivity: Thermal diffusivity was defined as thermal conductivity divided by heat capacity. Table 1 shows thermal conductivity and thermal diffusivity values used for this analysis.

Table 1. Thermal properties and thickness of liner materials

	Thickness	Thermal conductivity (W/m°C)	Thermal diffusivity (m ² /s)
GM	2mm	0.45	2.5×10^{-7}
Geotextile (GT)	2mm	0.7	2.0×10^{-7}
GN	5mm	0.15	1.8×10^{-7}
Bentonite (used in GCL)	6mm	2	1.0×10^{-6}
Subsoil (sandy silt)	3m	0.75	5.0×10^{-7}
Insulation:			
Sand	varies	0.9	4.5×10^{-7}
Geofoam-dry*	varies	0.085	7.0×10^{-7}
Geofoam-wet*	0.35**	0.17	2.5×10^{-7}
Shredded tires	varies	0.2	2.5×10^{-7}

*covered with 0.3m of sand, **thickness after compression under 360 kPa(about 25-30m of waste)

Prediction of geomembrane service-life

Service-life was calculated as the sum of all three stages of degradation: (1) antioxidant depletion, (2) induction time to the onset of polymer degradation and (3) polymer degradation (Viebke et al. 1994; Hsuan and Koerner 1998). Service-life estimates were based on the methodology described by Rowe (2005). The stage 1 times for PGM were estimated based on recent data published by Rowe and Rimal (2008a) for a GM as a part of a primary composite liner with leachate above the GM and GCL and foundation layer below the GM. The leachate reaching the SGM is largely attenuated by passing through the primary liner. Thus, to estimate the Stage 1 times for SGM, the data for a GM in a composite liner separated from the leachate by a GCL was used (Rowe and Rimal 2008b). Stage 2 times were calculated based on service-life data obtained for GM samples immersed in leachate (Rowe et al. 2009). The Stage 3 times were estimated based on the current lab data for GM immersed in leachate at 85°C (Rowe et al. 2009) and activation energy of 80kJ/mol obtained in the tests conducted by Viebke et al. (1994). To take into account the effect of contact with the underlying soil in a composite liner, Stages 2 and 3 times were adjusted based on the difference in composite liner (Rowe and Rimal 2008a,b) and leachate immersion test data (Rowe et al. 2009). Both unadjusted and adjusted values are reported as the likely lower and upper-bound estimates to the service life of SGM.

RESULTS

Table 2 summarizes SGM temperatures and estimated service-lives for all cases examined.

Table 2. Summary of SGM temperatures and service-lives

Thickness of insulation (m)	SGM temperature (°C)	SGM service life (years)
-	48.3	60- 200
0.5 sand	45.4	80- 270
1.0 sand	41.8	100- 400
4.0 sand	28.2	370- 2000
0.3 sand + 0.25 (0.05*) geof foam	40.4	120- 470
0.3 sand + 0.5 (0.1*) geof foam	37.3	160- 680
0.3 sand + 1.75 (0.35*) geof foam	28.2	370- 2000
0.3 sand + 1.75 (0.35*) geof foam- wet	33.8	220- 1000
0.5 (0.25*) shredded tires	38.6	140- 580
1 (0.5*) shredded tires	33.4	230- 1100
1.75 (0.875*) shredded tires	28.4	370- 2000

* Thickness after compressed under 360kPa. Service lives rounded to 2 significant figures.

Sand layer between the primary and secondary liners: The predicted SGM temperatures are compared in Figure 2 for the barrier system with a layer of sand between the primary and the secondary liner and the barrier system with no insulation. For the case with no insulation, the barrier system reached thermal equilibrium very quickly (200 days) and the steady state SGM temperature was very close to that of the PGM (50°C for PGM and 48.3°C for SGM). Thus, in this case, the estimated service-lives for PGM and SGM were not significantly different (45-100 years for PGM versus 60-200 years for SGM) with the difference primarily being due to the different exposure to leachate.

For the case with sand, it took much longer to reach thermal equilibrium than the case with no insulation. As illustrated in Figure 2, the use of a 0.5m to 4m-thick layer of sand as a part of the primary liner drops the temperature of SGM, relative to the case with no insulation, by between about 3°C to 20°C . This difference has a considerable effect on the service-life of SGM. The SGM service-life ranges from 80-270 years for a 0.5m-thick sand layer to 370-2000 years (for a 4m-thick sand). With a 4m-thick layer of sand, the service-life exceeded 350 years, which is the minimum required by Ontario Regulation (MoE 1998). However, a 4m-thick sand takes up a considerable amount of volume in a landfill and would be an expensive solution. A layer of geofoam or shredded tires could be a better option.

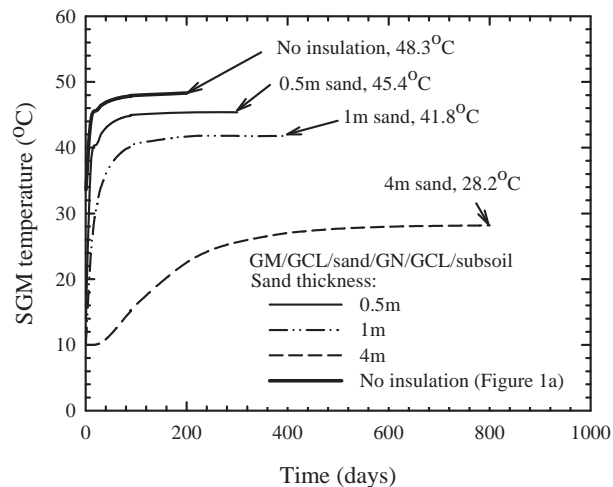


Figure 2. Variation in temperature with time for SGM for the case with sand insulation and no insulation

Geofoam between the primary and secondary liners: The insulation used in this case involves a layer of geofoam with a 0.3m-thick sand cover. The sand cover is primarily to protect the geofoam blocks against the damage caused by construction equipment when placing the overlying materials. The thickness used in thermal analysis was the thickness after compression under 360kPa. As shown in Figure 3 and Table 2, the use of a 0.25 to 1.75m-thick layer of geofoam (covered with 0.3m of sand) can reduce the temperature on the secondary liner, relative to the configuration shown in Figure 1a, by between about 8°C and 20°C (specifically SGM temperatures

of 28.2°C to 40.4°C compared to 48.3°C). A 1.75m-thick layer of geofoam (0.35m after compression under the waste), drops the temperature and prolongs the service-life of SGM similar to a 4m-thick layer of sand but saves a great deal of airspace. Also, due to low specific heat of EPS, the barrier system involving geofoam comes to thermal equilibrium faster than with sand alone.

The water content of geofoam affects the secondary liner temperature. The cases of (i) dry geofoam, and (ii) wet geofoam with volumetric water content of 15% (the value recommended by Horvath 1995 as the upper limit) are examined in Figure 4. For a PGM temperature of 50°C, the steady state temperature at SGM was 28.2°C and 33.8°C for the dry and wet cases, respectively.

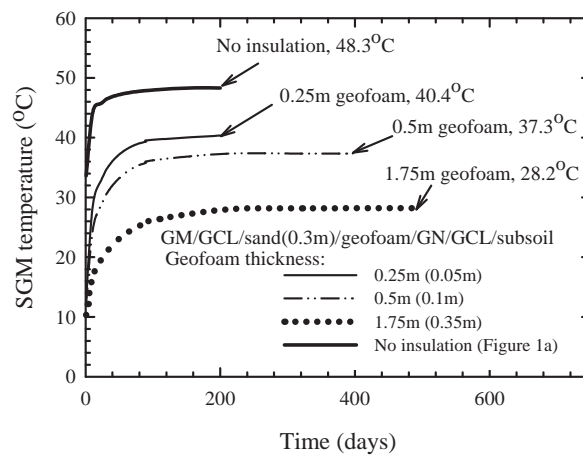


Figure 3. Variation in SGM temperature with time for a layer of geofoam (and 0.3m sand protection above geofoam). The geofoam thickness shown in brackets is the thickness after compression under 360kPa

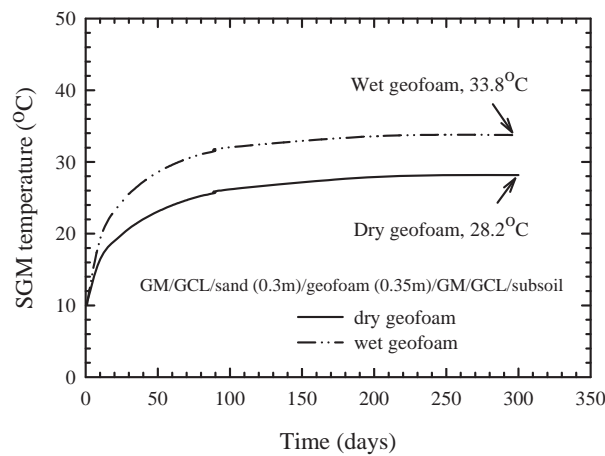


Figure 4. Variation in SGM temperature with time for dry and wet geofoam (0.3m sand thickness; 0.35m geofoam thickness after compression)

Shredded tires between the primary and secondary liners: Different thicknesses of shredded tire were examined. In the simulations performed, compression of the layer of shredded tire due to overburden stress was taken into account. As shown in Figure 5 and Table 2, introduction of a layer of shredded tires between the primary and the secondary liner can reasonably lower the temperature of SGM and can significantly increase its service-life. A 1.75m-thick layer of shredded tires (0.875m after compressed under 360kPa) reduced liner temperature by about 20°C relative to the case with no insulation. This is similar to the effect of a 4m-thick layer of sand or a 1.75m-thick layer of geofoam. The time required to reach steady state was shorter than for the case with sand.

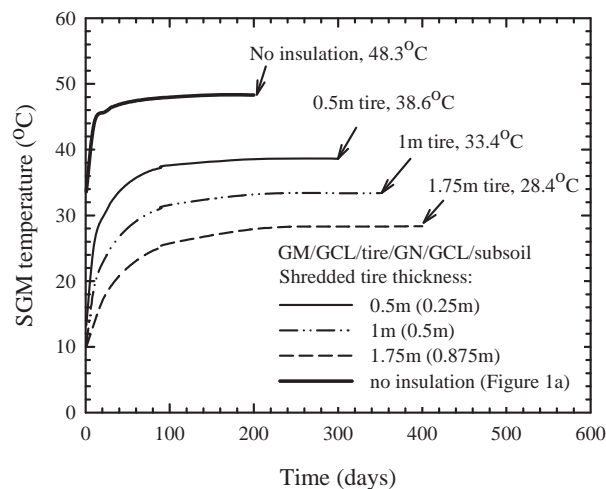


Figure 5. Variation in SGM temperature with time for a layer of shredded tires between primary and secondary liners . Thickness shown in brackets is the thickness after compression under 360kPa

DISCUSSION

The use of geofoam or shredded tires, as proposed here, would lower the temperature of SGM and would extend its service-life. However, considerable care would be required in the detailed design and construction of the liner. Issues such as differential settlement of the liner due to the highly compressible nature of these materials and its effect on leachate collection pipes and the primary liner (e.g. GM strain and stress, GCL overlaps) as well as long-term performance of geofoam and shredded tires in a landfill environment should be carefully addressed. Shredded tires should contain negligible wire or should be underlain by GN (as the case examined in this paper). Otherwise, it may damage the SGM. Intrusion of geofoam into the structure of underlying GN LDS, limited moisture uptake of overlying primary GCL due to the hydrophobic nature of geofoam, damage due to construction equipment above the geofoam and the relatively low maximum working temperature for typical

EPS geofoams (74°C) are some other issues associated with the possible use of geofoam.

This paper presented a preliminary study of one possible method to reduce the temperature of the secondary liner. The technique suggested in this paper should be regarded as experimental. Further numerical, laboratory and field study would be required to confirm its efficacy. Thermal properties of geofoam and shredded tires were taken from the very limited data published in the literature. Further laboratory tests would be required to confirm the values. Also, the service-life predictions are based on very limited data currently available and are likely to be conservative. In addition, it is assumed that the temperature remains constant over the period of time considered. In reality, the temperature will change with time. Consideration of a time-temperature history will give longer estimates of the service-life.

CONCLUSION

The studies presented in this paper give some insight into the effect of EPS geofoam and shredded tires on the temperature and service-life of the secondary geomembrane in a double-lined landfill. It is shown that theoretically, a suitable layer of geofoam or tire shreds could substantially reduce the temperature of the secondary geomembrane. The service-lives were found to be longer (in some cases very substantially longer) than the case without thermal insulation. It is suggested that using geofoam or shredded tires as a technique to reduce landfill liner temperature warrants consideration. Some of the challenges associated with the possible use of geofoam or shredded tires were discussed.

ACKNOWLEDGEMENTS

The research presented in this paper was funded by the Natural Science and Engineering Research Council of Canada (NSERC), Canada Foundation for Innovation (CFI), the Ontario Ministry of Research and Innovation and Ministry of Environment, and Terrafix Geosynthetics Inc. The writers are grateful to their industrial partners, Solmax International, Terrafix Geosynthetics Inc., Ontario Ministry of Environment, AECOM, AMEC Earth and Environmental, Golder Associates Ltd., and CTT group, however the views expressed herein are those of the writers and not necessarily those of our partners.

REFERENCES

- Benson, C. H., Olson, M. A., and Bergstrom, W. R. (1996). "Temperatures of insulated landfill liner." *Transportation Research Record*, 1534, 24-31.
- Dickinson, S., and Brachman, R. W. I. (2008). "Assessment of alternative protection layers for a geomembrane – geosynthetic clay liner (GM-GCL) composite liner." *Can. Geotech. J.*, 45(11), 1594-1610.
- Hoor, A., Rowe, R. K., and Pollard, A. (2008). "A method for reducing the temperature of landfill liners in MSW landfills." *Global Waste Management Symposium*, (CD-ROM), NSWMA, Copper Mountain, Colo.

- Horvath, J. S. (1994), "Expanded polystyrene (EPS) geofilm: an introduction to material behavior." *Geotext. Geomembr.*, 13(4), 263-280.
- Horvath, J. S. (1995). *Geofilm geosynthetic*, Horvath Engineering, P.C., Scarsdale, New York.
- Hsuan Y.G., and Koerner R.M. (1998). "Antioxidant depletion lifetime in high density polyethylene geomembranes." *J. Geotech. Geoenviron. Eng.*, 124(6), 532-541.
- Humphrey, D. N., Chen, L. H., and Eaton, R. A. (1997). "Laboratory and field measurement of the thermal conductivity of tire chips for use as subgrade insulation." *Transportation Research Board, 76th annual meeting*, Washington D.C.
- Humphrey, D. N. (1999). "Civil engineering application of tire shreds." *Tire industry conference*, Hilton Head, South Carolina.
- Jesionek, K. S., Humphrey, D. N., and Dunn, R. J. (1998). "Overview of shredded tire applications in landfills." *Tire Industry Conference*, Clemson University.
- MoE (1998). "Landfill standards: a guideline on the regulatory and approval requirements for the new or expanding landfill sites." Ontario Ministry of Environment, Ontario Regulation 232.98, Queen's Printer for Ontario, Toronto.
- Rowe, R. K., Quigley, R. M., Brachman, R. W. I., and Booker, J. R. (2004). *Barrier systems for waste disposal facilities*. Taylor and Francis (E and FN Spon), London.
- Rowe, R. K. (2005). "Long-Term performance of contaminant barrier systems." 45th Rankine Lecture, *Geotechnique*, 55(9), 631-678.
- Rowe, R. K., and Booker, J. R. (2005). *POLLUTEv7: Pollutant migration through a nonhomogeneous soil*. GAEA Environmental Engineering Ltd, Whitby, Ontario, Canada.
- Rowe, R. K., and McIsaac, R. (2005). "Clogging of tire shreds and gravel permeated with landfill leachate." *ASCE J. Geotech. Geoenviron. Eng.*, 131(6), 682-693.
- Rowe, R.K., and Rimal, S. (2008a). "Depletion of antioxidant from HDPE geomembrane in a composite liner." *J. Geotech. Geoenviron. Eng.*, 134(1), 68-78.
- Rowe, R.K., and Rimal, S. (2008b). "Aging of HDPE geomembrane in three composite liner configurations." *J. Geotech. Geoenviron. Eng.*, 134(7), 906-916.
- Rowe, R. K., and Hoor, A. (2009). "Predicted temperatures and service-lives of secondary geomembrane landfill liners." *Geosynthet. Int.*, 16(2), 71-82.
- Rowe, R.K., and Islam, M.Z. (2009). "Impact on landfill liner time-temperature history on the service life of HDPE geomembranes." *Waste Manage.*, 29(10), 2689-2699.
- Rowe, R. K., Rimal, S., and Sangam, H. (2009). "Ageing of HDPE geomembrane exposed to air, water and leachate at different temperatures." *Geotext. Geomembr.*, 27, 137-151.
- Rowe, R. K., Hoor, A., and Pollard, A. (2010). "Examination of a method for reducing the temperature of MSW landfill liners." *J. Geotech. Geoenviron. Eng.*, 136(8), 1-10.

- Shao, J., and Zarling, J. P. (1995). "Thermal conductivity of recycled tire rubber to be used as insulating fill beneath roadways." *Alaska Department of Transportation and Public Facilities*. Report No. SPR-UAF-9309A.
- Viebke, J., Elble, E., Ifwarson, M., and Gedde, U. W. (1994). "Degradation of unstabilized medium-density polyethylene pipes in hot-water applications." *Polymer Eng. and Sci.*, 34(17), 1354–1361.