Proceedings of the Geosynthetics Conference for Young Professionals
4 & 5 July 2024 – Irene Country Lodge, Irene, Centurion

The Influence of Temperature on the Durability of HDPE Geomembranes

G. P. Zwane

[1]Jones and Wagener, Johannesburg, Gauteng, gugu@jaws.co.za

Abstract

Geomembranes are a very low permeability synthetic barrier used to control or prohibit the migration of fluid or gas in a human-made structures. They are recognized as being ideal for safeguarding the environment against contaminated/hazardous substances from infiltrating into the earth and water bodies over a long period of time. They are therefore designed to have long-term thermal resistance and stability. This resistance is limited, and HDPE geomembranes are used to contain a wide range of wastes, which may generate heat within the waste and leachate. The mechanics of thermal degradation of HDPE geomembranes and their effects on the geomembrane service life are discussed. A case study is conducted on the effects of a compacted clay liner on the temperature at the primary and secondary geomembrane liner layers. Temperature readings received from sensors installed in the leachate collection and leakage detection layers of two cells in a landfill site are analyzed and discussed. Analysis shows that the compacted clay liner notably decreases the temperature at the secondary geomembrane liner layer in the long-term.

Keywords: *HDPE geomembrane, durability, thermal resistance, compacted clay liner*

1 Introduction

High-density polyethylene (HDPE) geomembranes are synthetic liners used in various civil engineering and environmental applications. They are made from high-density polyethylene, a thermoplastic polymer known for its high strength, durability and chemical resistance. Geomembranes in landfill and mining applications play a crucial role in preventing the leakage and migration of pollutants into the surrounding soil and groundwater. Landfill monitoring has shown that heat produced by waste decomposition, hydration of combustion ash and combustion ash reactions can notably increase the temperature at the liner system below the waste body. Temperatures of 30°C to 40°C can be anticipated at the liner system level, and in some instances, temperatures of 80°C were recorded (Cander and Stark 2011).

Geomembranes are exposed to different aging mechanisms, which include biological degradation, thermal degradation, UV degradation, extraction degradation, swelling, and oxidative degradation that can significantly decrease the geomembranes' durability. HDPE geomembranes are produced with 96-97.5% polyethylene resin, 0.5-1.0% thermostabilisers and antioxidants, 2-3% of carbon black and 2-3% UV protection (Hsuan and Koerner, 1995) and they can undergo changes in mechanical, chemical, and physical properties due to molecular scission, bond breaking, and crosslinking. Due to space constraints, this paper will focus on the thermal degradation aging mechanism and will omit discussions on the other listed aging mechanisms.

Thermal durability is a crucial aspect due to the geomembranes' exposure to wide temperature fluctuations, ranging from extreme cold in polar regions to intense heat in desert environments. Moreover, they may also be subjected to thermal cycling, where temperatures fluctuate rapidly over short periods, leading to thermal expansion and contraction. Therefore, understanding the thermal behavior and durability of geomembranes is essential for ensuring their long-term performance and reliability. One of the many applications of geomembranes is to contain leachate, water that has percolated through waste and leached out some of its constituents, which is susceptible to temperature variations according to the climate of where the waste body is located.

This paper focuses on HDPE geomembrane aging mechanisms due to elevated temperatures. It reviews a few studies conducted on various papers and a case study looking at temperature readings in a double-lined barrier system to analyze the effect that a compacted clay liner may have in the temperature observed at the primary and secondary geomembrane liner levels.

2 Literature Review

As per the introduction, HDPE geomembranes are made from a combination of polyethylene resin, thermostabilisers and antioxidants, and carbon black. The characteristic structure of polyethylene is composed of a repetitious sequence of linked carbon atoms that are bonded with hydrogen atoms. The polyethylene in a geomembrane may develop crystal lamellae, where the polyethylene chains are neatly folded and tightly packed, and looser amorphous layers where the chains are disordered. Some properties of polyethylene depend on this packing structure and thus, any changes in the molecular packing can change the durability and the overall performance of the geomembrane.

The heat produced by a waste containment facility depends on the waste degradation process and the accepted waste management practice. For example, it has been reported by Brune et. al. (1991) that increasing the rate of waste deposition correlates with the increase of the rate of temperature increase. Moisture available in the waste body can expedite the rate of temperature increase by increasing the rate of waste degradation. Manufacturers of HDPE geomembranes do not recommend sustained temperatures above 57°C. Higher temperatures can increase the rate of depletion of antioxidants added during the manufacturing process of the geomembrane resulting in the acceleration of subsequent oxidation of the polymer, causing stress crack resistance losses and a decrease in the geomembranes' service life (Rowe et. al. 2010).

The degradation of HDPE geomembranes has been investigated by a number of researchers and has been generally observed to include three stages. Stage A represents the depletion of antioxidants, Stage B is the beginning of polymer degradation and Stage C is the degradation of the polymer and the changes of the critical physical properties (Hsuan and Koerner 1998). In the course of Stage A, the oxidants in the geomembrane are steadily oxidized. The length of Stage A is crucial as the active antioxidants protect the polymer from degradation. During Stage B, polymer degradation starts, but there are no quantifiable changes in the geomembrane's physical properties, regardless of the significant reduction of the active antioxidants. This stage continues until the effects of the scission of the polyethylene chains due to oxidation can be quantified. Stage C starts when the changes of the geomembrane engineering properties are measurable and ends when the service life is reached (Koerner 1998). The service life of the geomembrane is the sum of the three stages. Table 1 shows the service life of geomembranes exposed to temperature range of 20°C to 60°C in a landfill liner system simulated in a laboratory (Rowe 2005) using a 50% tensile of strength at break reduction as the end of service life (i.e. stress cracking).

Table 1. Approximated HDPE geomembrane service life (Rowe 2005).

Temperature (°C)	**Service life (years)**
20	565-900
30	205-315
35	130-190
40	80-120
50	35-50
60	15-20

Table 1 shows the reduction of service life with the increase of temperature. Rowe and Islam (2009) conducted a study where a geomembrane aging in air, water, and leachate was examined at 95, 105, and 115° C. The depletion of antioxidants (Stage A) was analyzed for all samples. The geomembrane samples immersed in liquids were tested in sealed stainless-steel containers and glass jars open to atmospheric pressure. The antioxidant reduction in the air aged geomembranes was as expected; increased with increasing temperature in a linear manner. For the samples in the sealed stainless-steel containers, the results showed that the rate of antioxidants reduction decreased linearly with the increase of temperature for both water and leachate tanks. For the open glass jars, the rate of antioxidant reduction of the leachate sample increased linearly with increasing temperature, while with the water sample, the initial rate of antioxidant reduction was rapid, and then a change in response was recorded as the antioxidant depletion rate decreased. This change in response remained unexplained by the authors, but the disparity in the stainless-steel results was thought to be due to the pressure build up that may have affected the aging of the samples.

3 Case Study: Holfontein

The Holfontein Hazardous Waste Management Facility (HHWMF) is located in Breswol, Gauteng. The facility is located where it is considered a hot climate, as temperatures recorded during the summer have been as high as 40°C. It receives hazardous waste from four South African provinces, as well as neighbouring countries. The site is licensed as a Class A waste disposal site according to the Minimum Requirements for Waste Disposal by Landfill (1998) as published by the Department of Water Affairs and Forestry (DWAF). This means that the containment barrier system must follow the configuration shown in Figure 1.

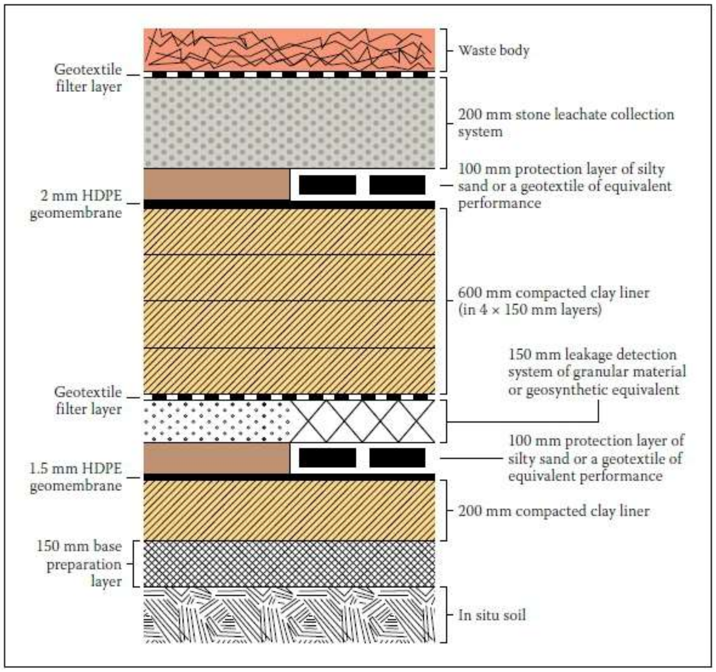

Figure 1. Typical Class 1 barrier system
(Minimum Requirements of Waste Disposal by Landfill 1998)

The existing HHWMF currently consists of 11 hazardous waste cells and the associated leachate and stormwater management infrastructure. The leachate generated in cells 5 and 8 was monitored by vibrating wire piezometers that were installed within the barrier system. Cell 5 was commissioned in 1999 and cell 8 was commissioned in 2012. Hazardous waste was deposited in cell 5 and hazardous waste mixed with ash was deposited in cell 8. Both cells' barrier system is of the configuration demonstrated in Figure 1. The temperature data received was logged and graphed and will be discussed in the next section. The monitoring period that was observed for this paper is from July 2012 to July 2013 for both cells. Three different temperatures were logged; 1) the temperature within the leachate collection layer, which lies directly above the primary HDPE geomembrane; 2) the temperature within the leakage detection layer, which lies directly underneath the compacted clay liner and above the secondary HDPE geomembrane, and 3) the ambient temperature.

4 Discussion and Analysis

The temperature data received from both cells is graphically represented below in Figures 2, 3, and 4. The data represented on Figures 3 and 4 was modified to exclude significant fluctuations that were probably due to day and night shifts so as to allow the data to be more clearly represented. The data was also analysed, with the results of the analysis tabulated in Tables 2 and 3. Figure 2 shows the temperature readings from cell 5 and Figures 3 and 4 show the temperature readings from cell 8.

The results show that there is a significant temperature decrease between the leachate collection layer and the leakage detection layer in the cell 5 barrier system. It is expected that this is due to the 600 mm compacted clay liner layer between the observed layers. It would therefore be expected that a similar observation would be made with cell 8. However, the recorded temperature difference between the leachate collection layer and the leakage detection layer of the cell 8 barrier system is significantly lower. This is shown graphically in Figures 3 and 4, with the data points from the leachate collection layer and the leakage detection layer plotted on different graphs, as the data points mostly occupy the same space in the graph, making it difficult to differentiate between the two data sets.

Table 2 shows the analysis of the temperature difference of the leachate collection layer and leakage detection layer. The results show that the average of the temperature difference between the two layers is 2.37°C for cell 5 and only 0.25°C for cell 8. Since both cells are from the same site, were monitored at the same time, and have the same barrier system, the only other variable that is relevant as to why the temperature difference between the observed layers varies between the two cells is the ages of the cells. By the time of monitoring, cell 5 had been commissioned more than a decade prior, and cell 8 had just been commissioned. It is thought that the different waste streams may explain the different temperatures recorded from the two cells (i.e. temperatures recorded from cell 5 are higher than temperatures recorded from cell 8), but they may not explain the temperature differences between the two layers (leachate collection and leakage detection) within the barrier systems of the two cells.

More research and analysis must be conducted to investigate how time and the level of activity around and within the cell may affect temperature within the barrier system of the cell. More cells that are commissioned around the same time and place must be investigated to observe if there is a trend that will corelate with the findings presented.

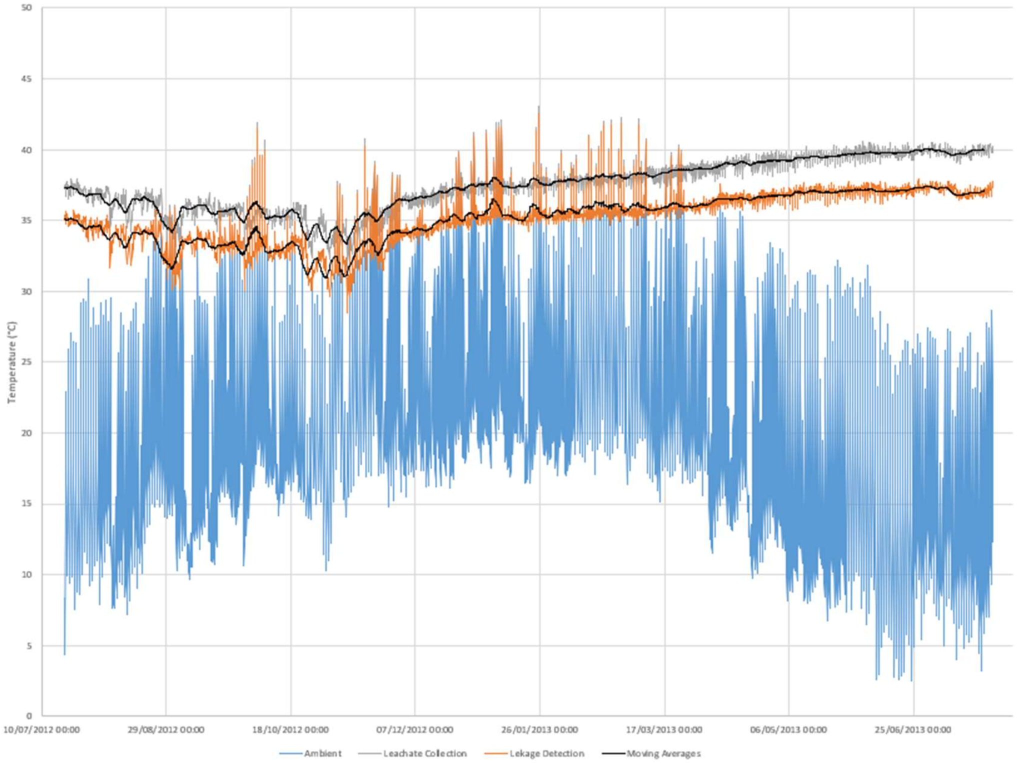

Figure 2. Cell 5 recorded temperatures.

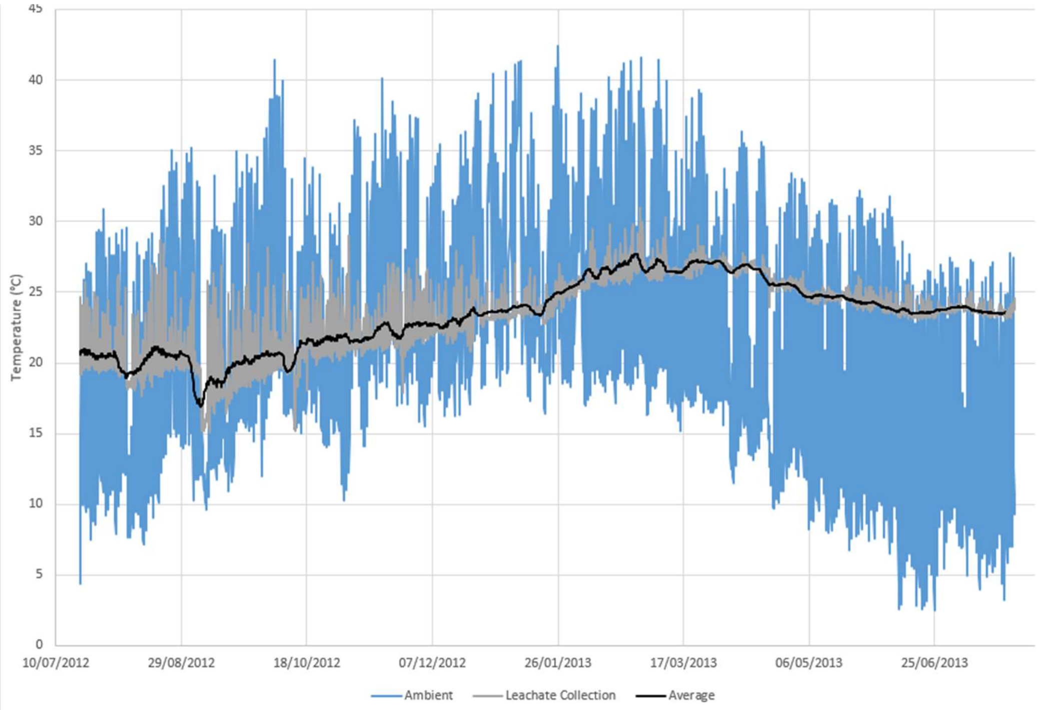

Figure 3. Cell 8 leachate collection recorded temperatures.

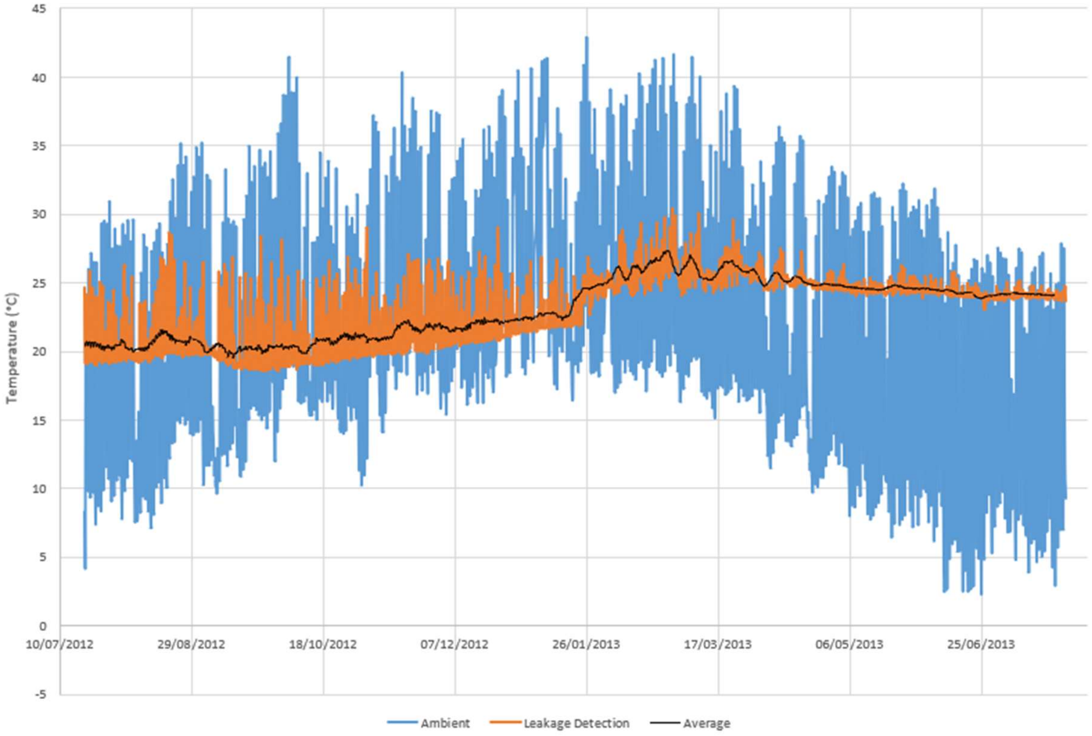

Figure 4. Cell 8 leakage detection recorded temperatures.

Table 2. Analysis of temperature difference of the leachate collection layer and leachate detection layer.

	Cell 5	Cell 8
Maximum	3.7	4.9
Minimum	0.1	-5.0
Mean	2.35	0.25
Standard deviation	0.55	0.91

It was also observed that the temperatures recorded from cell 5 are higher that the temperatures recorded from cell 8 as seen in Table 3. Since the monitored cells are in the same area, the temperature was recorded within the same timeframe, and the barrier systems of both cells is the same, the different waste stream that was deposited in each cell was looked at to explain the difference between the observed results. As mentioned in the previous section, hazardous waste was deposited in cell 5 and hazardous waste mixed with ash was deposited in cell 8. The different proportions of organic waste in each cell could explain the difference in results, that is the less amount of organic waste in cell 8 due to mixing the hazardous waste with ash results in less heat generated due to reduced waste decomposition.

Table 3. Summary of recorded temperatures.

	Leachate Collection		Leakage Detection	
	Maximum (°C)	Minimum (°C)	Maximum (°C)	Minimum (°C)
Cell 5	43.1	31.6	42.5	28.5
Cell 8	31	15.1	30.4	14.9

5 Conclusion

HDPE geomembranes are incorporated in landfill barrier systems due to their superior resistance to chemical degradation and their potential long service life. However, exposure to high temperatures could affect the durability of these materials. A temperature change of 5°C could vary the service life of the geomembrane by ±50 years as per the findings presented in Table 1. The analysis of the temperature readings from cell 5 show a significant temperature decrease between the leachate collection and leakage detection layers. It was deduced that this was attributed to the compacted clay liner layer that lies between the two layers. Temperatures received from Cell 8 did not show the same behavior however, and it was logicized that could be due to the different ages of the cells, with cell 5 having been commissioned more than a decade prior and cell 8 being commissioned close to the start of the monitoring period. More research must be conducted to explore this hypothesis. It is concluded that the compacted clay liner may offer heat protection to the secondary geomembrane liner in the long-term as seen with cell 5, as a temperature difference of 3.7°C was recorded (Table 2), which could result in the increase of the service life of the secondary HDPE geomembrane by 50+ years.

References

Calder, G.V., and Stark, T.D. 2010. Aluminum reactions and problems in municipal solid waste landfills. *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management,* Vol. 14

Coccia, C.J.R, McCartney, J.S. 2013. Municipal solid waste landfills as geothermal heat sources. *Renewable and Sustainable Energy Reviews,* Vol 19, pg. 463-474.

Hsuan, Y.G., and Koerner, R.M. 1995. The single point-notched constant tensile load test: A quality control test for assessing stress crack resistance. *Geosynthetics International*, Vol. 2, No. 5.

Hsuan, Y.G., and Koerner, R.M. 1998. Antioxidant depletion lifetime in high density polyethylene geomembranes. *Journal of Geotechnical and Geoenvironmental Engineering,* pg. 532-541.

Jafari, N.H., Stark, T.D. and Rowe, R.K. 2014. Service Life of HDPE Geomembranes Subjected to Elevated Temperatures. *Journal of hazardous, toxic, and radioactive waste,* 18, 16-26.

Koerner, R.M. 1998. Designing with geosynthetics, 4th Ed.

Row, R.K. 2005. Long-term performance of contaminant barrier systems. *Geotechnique*, pg. 631-678

Rowe, R.K., Hoor, A., and Pollard, A. 2010. Numerical examination of a method for reducing the temperature of municipal solid waste landfill liners. *Journal of Environmental Engineering*, pg. 794-803.

Rowe, R.K., and Islam, M.Z. 2009. Impact of landfill liner time-temperature history on the service life of HDPE geomembranes. *Waste Management,* Vol 10, pg. 2689-2699.

Rowe, R.K., Abdelaal, F.D., Islam, M.Z., and Hsuan, Y.G. 2010. The strange effect of increasing temperature in accelerated ageing of HDPE geomembranes immersed in liquids. *9th International Conference on Geosynthetics.*