Assessment of the Long-term Performance of Containment Systems

Abstract

Few decades prior to the twenty-first century, the dire consequences of subsurface contamination stemming from the improper disposal of waste material on the earth surface was uncovered. Contaminants in materials such as mine tailings, nuclear, chemical and solid wastes are transported across the pores in soil media and these finally make their way to the aquifer system. Harmful gases emanating from the degradation of these wastes are also released into the atmosphere. Engineered containment systems were designed and constructed as a solution to the subsurface and atmospheric pollution conundrum. Although these engineered waste repositories have served purposely to impede the transport of contaminants, they have come with challenges. Materials used in the construction of these containment systems are affected not only by the toxic chemicals they accommodate, but also by environmental stressors. Some of the materials used also age with the passage of time.

In this study, three types of engineered containment systems; horizontal, vertical and surface barriers were investigated. Data on these containment systems were collected and analysed to assess the long-term performance of these barrier systems.

The main objective of this research work was to assess the long-term performance of containment systems. The components of this study are the use of field data to evaluate the long-term performance of two alternative bottom lining systems, two slurry wall landfills and finally to investigate the impact of climate change on the long-term performance of surface barriers.

In the first study, the field leakage data of three landfills lined with the double geomembrane lining system was collected. Based on the field leakage data, theoretical equations were used to compute the leakage that may occur across the secondary geomembrane and soil underlying it. For double geomembrane lining systems, leakage occurs to the subsurface only when the defect in the secondary geomembrane is in the wetted area of leachate flow in the leakage detection system. A statistical analysis of 100,000 runs was conducted to establish the probability of leakage into the subsurface. In addition, the double geomembrane lining system was simulated in the COMSOL Multiphysics finite element software to determine the leakage across the system. The results of the use of field data and theoretical equations, statistical analysis and numerical simulation was

compared to the theoretical leakage across the United States Environmental Protection Agency's (USEPA's) geomembrane – compacted clay liner single composite system.

For the use of field data and theoretical equations to compute leakage across the double geomembrane lining system, the theoretical leakage rate across the geomembrane – compacted clay liner system was forty times higher than that of the double geomembrane system for the worst case scenario. Analyses conducted using the statistical and numerical simulations for the double geomembrane system showed that the leakage across USEPA's geomembrane – compacted clay liner system is 8 and 3.8 times greater than that of statistical and numerical simulations respectively. From the analyses conducted in this research, the double geomembrane lining system is hydraulically equivalent to EPA's geomembrane – compacted clay liner single composite lining system.

The focus of the second objective was the assessment of the long-term field performance of a landfill having the base lined with geomembrane – geosynthetic clay liner double composite system. The leachate pumped from the leakage detection system of a landfill with the geomembrane – geosynthetic clay liner system was collected and analyzed. It was observed that the average field leakage data was eight times higher than the leakage rate computed using the poor contact interface condition scenario and forty-five times higher than the good contact condition scenario. The probable causes of the high field leakage rate from the landfill investigated were; the landfill having more defects in the geomembrane than assumed in the theoretical equations, a high leachate head on the primary geomembrane, an ineffective geosynthetic clay liner and groundwater intrusion.

The results of the use of theoretical equations and the numerical modelling showed that 2-12 % of the liquids pumped from the leakage detection system of the landfill with a geomembrane – geosynthetic clay liner double composite lining system can be attributed to leakage across the primary geomembrane – geosynthetic clay liner system whereas 88-98 % was because of groundwater seeping into the leakage detection system.

The third objective was on analyzing the liquid balance of two slurry wall landfills that are officially closed (i.e. in post closure care). One of the landfills was capped with a geomembrane and soil cover whereas the other had only a soil cover. Over twenty years of leachate pumping data was collected for the two landfills. A liquid balance analysis was conducted for the two slurry wall landfills. Components of the liquid balance analysis were; the seepage of rainwater across the final cover, and the seepage of groundwater across the slurry wall and the clay confining unit that underlies the landfill. For the seepage of rainwater across the geomembrane - soil cover, an innovative methodology was developed by using the Hydrus 1D model to simulate seepage across the soil and the COMSOL Multiphysics finite element software was used to simulate leakage through a defect in the geomembrane.

Per the simulations conducted for the landfill capped with geomembrane and soil, the analysis revealed that 14.9 to 23.5 % of the leachate pumped was due to water leaking across the geomembrane – soil cover into the waste mass. Less than 1.5 % of the leachate pumped was due to groundwater seepage across the slurry wall and upward intrusion of groundwater from the confined aquifer into the landfill. Over 75 % of the leachate pumped is attributed to other unaccounted sources. These unaccounted sources include groundwater flow across ‘windows’ or defects in the slurry wall, groundwater flow across portions where the slurry wall is not keyed into the natural clay confining unit, the geomembrane having more defects than the assumptions made in the simulations conducted and the squeezing of liquids from the waste material.

The quantity of rainwater seeping across the final cover for the second slurry wall landfill was far greater than that of the first landfill (capped with geomembrane and soil) mainly because the second landfill was capped with only a soil cover. From the year 2000 to 2013, the annual average quantity of water seeping across the soil cover was greater than the average leachate pumped annually.

The final part of this research was dedicated to evaluating the long-term performance of a monolithic and capillary evapotranspiration cover in the face of a changing climate. The use of evapotranspiration covers which are nature-based covers for capping hazardous and non-hazardous waste material is currently on the increase. Soils used in these covers usually have high water holding capacity to store water during a rainy day and release it via evaporation or through the roots of the vegetation in a transpiration process. Due to the way evapotranspiration barriers work, they are affected by the vagaries in the weather. In this study the impact of climate change on the long-term performance of evapotranspiration covers was assessed.

Climate data from three global circulation models and two emissions scenarios were used in the study. Thirty years of historical (1990 – 2019) and of forecasted (2020 – 2049) daily weather data

were used. The FAO – Penman Monteith equation was used to compute the reference evapotranspiration for the landfill site. The Hydrus 1D model and LandSEM models were used to assess the long-term hydraulic performance and the methane oxidation capacity of the soil covers.

A statistical t-test analyses conducted on the mean annual percolation obtained from the simulations conducted showed that, there is no statistically significant difference between the mean percolation in the historical and the forecasted 30-year periods for the three global circulation models and the two emissions scenarios. It can therefore be inferred that landfills capped with evapotranspiration covers having similar characteristics like the covers simulated in this study are not expected to have near-future (next 30 years) percolation rates that are significantly different from what has been observed in the past. Concerning the oxidation of methane gas in the soil cover, the analyses conducted with the LandSEM numerical model showed that there is an increase in the amount of methane oxidized in the soil cover for the simulations conducted using the forecasted climatic parameters as compared to the historical climatic parameters. This increase in the methane oxidation in both the monolithic and capillary evapotranspiration covers can be attributed to the increase in soil temperature due to the increase in ambient temperature for the forecasted 30-year period.

Keywords: landfill liners, leakage, liquid balance, slurry walls, final covers, climate change