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Heat mitigation in geosynthetic composite liners exposed to elevated temperatures

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ABSTRACT

The hydrothermal behaviour of single and double composite liners subjected to elevated temperatures is examined. Particular interest is given to the effect of the presence of wrinkles in the geomembrane (GMB) as well as defects, and the existence of a gap between the primary and the secondary liners caused by the presence of a leak detection system. Heat flow resulting from elevated temperature was found to be mainly influenced by the size of the air-filled gaps present within the composite lining systems. The larger the air-filled gap size, the lower was the heat flow through a barrier system. The presence of a leak detection layer (i.e., large air-filled gap) and GMB layers were found to be the primary factors to reduce heat flow substantially through the lining systems. Therefore, the presence of a leak detection layer combined with a secondary GMB can improve the overall thermal insulation capacity of a double liner system, minimise heat flow through the secondary liner and offer the possibility of protecting the GCL (if present) and the subgrade from possible heat induced drying/desiccation. A leak in the geomembrane can minimise the gain in thermal insulation. However, this effect can be reduced if the liquid is regularly pumped out.

1. Introduction

Composite liners comprised of geosynthetic clay liners (GCLs) combined with geomembranes (GMBs) are routinely used as engineered hydraulic barriers in different waste containment facilities. These facilities include hazardous solid waste (HSW) landfills, tailings dams, liquid (residue of industrial/mining processes) storage ponds (e.g. hot brine ponds), etc. (Bouazza, 2002; Rowe, 2014; Touze-Foltz et al., 2016). The diversified nature of many wastes (often having extreme chemistries) in these facilities pose significant challenges not only to the hydraulic performance of composite liners but also to their longevity to aggressive liquors or chemical solutions (Rowe, 2005; Rowe et al., 2008; Gates et al., 2009; Gates and Bouazza, 2010; Hornsey et al., 2010; Shackelford et al., 2010; Rowe, 2012; Liu et al., 2013, 2014; Mazzieri et al., 2013; Bouazza and Gates, 2014; Abdelaal et al., 2014, 2015a,b; Liu et al., 2015; Tian et al., 2016; Fehervari et al., 2016a,b).

Elevated temperatures are often present in these facilities and have the potential to impact both the hydraulic performance and the durability of composite liners (Rowe, 2005; Bouazza et al., 2013, 2014). Lining systems in mining and industrial infrastructure applications may remain exposed to elevated temperatures for prolonged periods of time (Thiel and Smith, 2004; Hornsey et al., 2010; Bouazza et al., 2014). Smith (2008) reported that liners in mining facilities might remain exposed to temperatures as high as 80 °C continuously due to ore extraction processes. Bouazza et al. (2014) indicated that temperatures of the bottom liner in storage ponds containing warm liquid (generated as a by-product of industrial processes, for example shale gas/coal seam gas extraction) can reach up to 80 °C due to both solar radiation and initial liquid

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temperatures, with long-term (>5 years) temperatures ranging between 60 °C and 80 °C continuously acting on the lining system. Similarly, liners in solar ponds can experience high temperatures ranging from 30 °C at the surface to over 90 °C at the bottom (Lu et al., 2001; Silva and Almanza, 2009).

Presence of elevated temperatures on the surface of the liner gives rise to temperature gradients across any liner system and also the subsoil below it. These thermal gradients, in turn, can potentially lead to heat-induced drying or desiccation cracking in the GCL layer and/or the mineral liner (Azad et al., 2011, 2012; Southen and Rowe, 2011; Hoor and Rowe, 2013; Rowe and Verge, 2013; Bouazza et al., 2014). This condition presents practical challenges as very often the hydraulic performance of liners exposed to elevated temperatures is not anticipated in the design process mainly due to the paucity of research addressing this condition and lack of experimental data. Estimating heat flow through a lining system and the ensuing possible drying/desiccation of GCLs and/or mineral liners and identifying possible ways of minimising this impact in field applications is thus of paramount importance.

The objective of this paper is to examine the hydrothermal behaviour of a combination of lining systems that are frequently encountered in field applications. The focus is on elevated temperatures commonly encountered in coal seam gas water storage ponds (i.e., brine ponds) or similar. Therefore, the work presented in this paper concentrates on the study of heat and water transfer through different types of liners subjected to thermal gradients simulating field conditions. The second objective is to examine methods of reducing the effect of elevated temperatures on liner systems and consequently to explore means of protecting both the GCL and the subgrade against possible heat-induced drying or desiccation.

2. Materials

A commercially available needle-punched GCL (Elcoseal X-2000, Geofabrics Australasia Pty. Ltd, Australia) was examined. The powdered sodium bentonite which formed the core of this GCL had a dry processed particle size varying from 0.3 μm to 1 mm, with ~75% finer than 75 μm (0.075 mm). The GCL had a nonwoven polypropylene geotextile cover layer and a nonwoven polypropylene geotextile with a woven scrim-reinforced carrier and was thermally treated. The GCL specimens used in the current study were selected in such a way that their mass per unit area fell within the representative range of mass per unit area histogram shown in Fig. 1 indicating that a GCL specimen with a mass per unit area of 4.91–5.15 kg/m^2 may be considered representative of the roll. Therefore, only specimens with a mass per unit area within this range were used in this study. The physical characteristics of the specimens (based on Fig. 1) are summarised in Table 1. The mass per unit area of bentonite (M_b) was calculated as the difference between the total mass per unit area of GCL (M_{GCL}) and mass per unit area of geotextiles (M_{GT}). M_{GCL} and M_{GT} were obtained following the procedures outlined in ASTM D-5993 and ASTM D-5261, respectively. The mineralogy of the bentonite extracted from the GCL was analysed by quantitative X-ray diffraction (Mineralogical Services, CSIRO Land and Water, Adelaide). The analysis showed that the bentonite comprised 74% montmorillonite, 8% cristobalite, 14% quartz, 4% albite/anorthite and <1% calcite (all estimated within ±1% error).

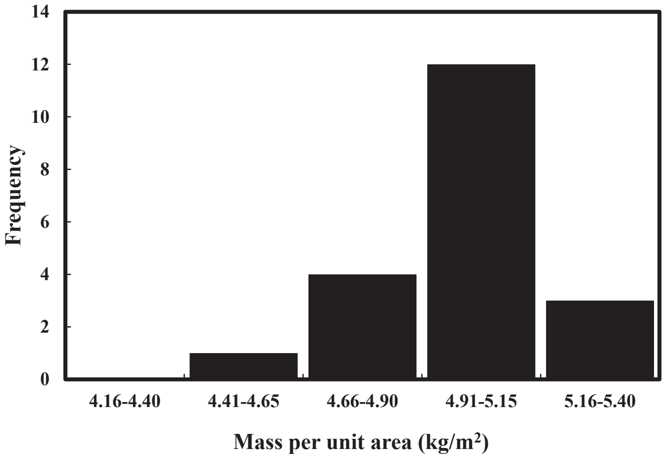

Fig. 1. Histogram of mass per unit area (at as received gravimetric water content) of GCL specimens.

A clayey sand, sourced from a waste containment site, was used as subgrade material below the lining system to simulate an attenuating layer or a native re-engineered soil. It had 39.5% of its particles finer than 75 μm and other properties as given in Table 2. The maximum dry density and optimum moisture content from the standard Proctor compaction curve were 1620 kg/m^3 and 17%, respectively.

The mineralogical composition of the soil was obtained by X-ray diffraction (Mineralogical Services, CSIRO Land and Water, Adelaide) [similar to the process adopted for the bentonite] and the result summary is presented in Table 3 (with ±1% error).

A high-density polyethylene (HDPE) geomembrane (GMB) having a nominal thickness of 2 mm and a geocomposite (GC-composed of geotextiles and geonet) were used in this study. The GMB was used to form the top impermeable layer in all the lining systems investigated in this study. The GCL was used to complement the GMB, when required, to form a composite liner. The GC was primarily used to create a gap in the lining system constituted of a single GMB-GCL composite liner (for one condition) and to act as a drain or leak detection layer in some of the other three conditions investigated in the current study.

The thermal conductivity of the GMB, measured in the laboratory, was around 0.3 W/mK (Singh and Bouazza, 2013; Ali et al., 2016). The GCL thermal conductivity was measured using a thermo-cell (Barry-Macaulay et al., 2013) based on the procedure outlined by Ali et al. (2016). Fig. 2 shows that the GCL thermal conductivity ranges from 0.2 to 0.7 W/mK over the range of gravimetric water content investigated in the current study, with the lower value corresponding to the lower gravimetric water content. The GC used in this study had two layers of geotextile (one on each side of the geonet); the parent material of geotextile (polypropylene) has a very low thermal conductivity (0.1–0.2 W/mK) (Ali et al., 2016). The thermal conductivity of air is very low, being of the order of 0.027–0.029 W/mK for 40–70 °C. This is an order of magnitude lower than that of the GMB, GCL or GC and almost two orders of magnitude lower than that of the subsoil, which varied between 1.7 and 2.0 W/mK depending on its gravimetric water content (Ali, 2017).

3. Column test apparatus

A custom designed test column (Bouazza et al., 2014) was utilised in this investigation to simulate the field conditions that take place within and below a lining system exposed to a low overburden pressure and elevated temperatures in waste containment facilities that contain warm liquids for prolonged time periods.

A schematic diagram of the column is presented in Fig. 3. The column had the provision of applying a temperature gradient across a liner system and a subsoil of known initial properties under controlled conditions. The column was composed of three

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