PROBLEMS AND SOLUTIONS FOR GCLs USED IN WASTE CONTAINMENT FACILITIES

Temperature Concerns and Polymer Treatment Related to GCLs Used in Waste Containment Areas

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ABSTRACT

In this study, first, various geosynthetic clay liner (GCL) application areas were briefly defined and afterwards, the details of GCL usage in mine applications were given. GCLs are barrier materials that are preferred in mining facilities such as heap leach pads, tailing dams or waste landfills. In these applications, GCLs might be in contact with aggressive leachates that could deteriorate the hydraulic properties of the GCLs. The hydraulic capability of the GCLs is decreased by an increase in hydraulic conductivity or a decrease in swell index of the bentonite component of the GCL. Due to the biodegradation of the organic substances in a waste containment area, heat is generated and the temperature of the leachates increases. In order to investigate the effect of temperature, triaxial permeability and free swell tests were conducted on the GCLs that were permeated with 0.5 M $MgCl_2$ solution and deionized water. The temperature of the permeation fluid was chosen as 20^{o}C and 40^{o}C. Furthermore, a cationic polymer having 1% and 2% amounts of mass, was added to the bentonite component of the GCL in order to enhance the hydraulic capability of the GCL. Test results indicated that temperature increase in 0.5 M $MgCl_2$ solution from 20^{o}C to 40^{o}C caused both an increase in the swell index and the permittivity of the GCLs. The increase in permittivity could be attributed to the lower viscosity of the fluid at higher temperatures. Finally, adding a cationic polymer up to the amount of 2% by mass to the bentonite resulted in almost two orders of magnitude decrease in the permittivity of the GCLs that were permeated with 0.5 M $MgCl_2$ solution. In conclusion, cationic polymer-treated GCLs might be used effectively in waste containment facilities by both decreasing the permittivity and increasing the swell index of the GCLs.

Keywords: Cationic polymer; Geosynthetic clay liner; Heap leach pad; Hydraulic performance; Landfill; Tailing dam; Temperature

1. INTRODUCTION

A geosynthetic clay liner (GCL) consists of a thin layer of bentonite that is sandwiched between two layers of geotextiles. The thickness of a GCL varies within the range of 5-10 mm (Budihardjo et al., 2012). The geotextile components of a GCL could be woven or nonwoven. These geotextile layers stick together to form a composite material by adhesives, needle punching or stitch bonding. Due to its low hydraulic conductivity, a GCL is placed over soils as a leachate barrier. Permeability coefficient (k) of a GCL is generally within the range of 10^{-12}-10^{-10} m/s (Bouazza, 2002). When a GCL is placed along a slope, its shear strength becomes crucial. Shear strength of a GCL is maintained by either stitchbonding or needlepunching. By these reinforcement methods, the GCL gains extra resistance against shearing (Budihardjo et al., 2012).

1.1. Various GCL Applications

1.1.1. Solid Waste Landfill Containment

In landfill applications, GCLs are used as bottom liners for waste and leachate containments as shown in Figure 1. For most cases, a GCL is used with a geomembrane layer to form a geocomposite liner in hazardous and municipal solid waste landfill applications. A municipal solid waste landfill is generally formed by a single composite liner composed of a leachate collection and removal system with a geomembrane overlying either a GCL or compacted clay liner (CCL). On the other hand, a hazardous waste landfill generally consists of a double liner system with two geomembranes placed over both GCL and CCL (Geosynthetic Materials Association, 2010).

Fig. 1. GCL Placement in a Solid Waste Landfill (Geosynthetic Materials Association, 2010)

1.1.2. Mining Applications

Heap leach pads and mine tailing dams are the most common examples for mining application areas in which GCL is used. Extraction processes and recycling facilities involving chemical solutions are governed by considering secondary containment ponds that are named as mine tailing dams (Geosynthetic Materials Association, 2010). Geomembranes and GCLs are placed over the bottom and along the slopes of the heap leach pads as can be seen in Figure 2.

Fig. 2. GCL Placement in a Heap Leach Pad (Geosynthetic Materials Association, 2010)

Recovering metals from low-grade ores is maintained in heap leach pads. Geomembranes and GCLs placed over the surface of the leach pads prevent the loss of the chemical solutions containing valuable metals while protecting the underlying soils and groundwater from contamination. By using geomembranes and GCLs in heap leach pads, surface water run-off and rainwater intrusion might be prevented. The weather conditions might cause the requirement of a capping system over a heap leach pad after completion of the mining activities (Geosynthetic Materials Association, 2010).

1.1.3. Caps and Closures

Geomembrane and GCL closure systems are used as landfill caps to prevent fluid migration into the landfill by preventing the seepage of fluids from the collected wastes to the landfill surface. The cap is also used to trap and vent the gases generated during decomposition of organic wastes. Furthermore, the landfill might be expanded vertically by the use of caps and landfill capacity could be enlarged (Geosynthetic Materials Association, 2010). The cap also enables an efficient and safe restoration and revegetation area by fully encapsulating the wastes as shown in Figure 3.

Fig. 3. GCL Placement as a Landfill Cap in a Closure System (Geosynthetic Materials Association, 2010)

1.1.4. *Coal Ash Storage Sites*

Geomembranes and GCLs are also used as liners in some coal ash storage sites as shown in Figure 4. Geosynthetic drain pipes are often used to dewater the coal ash slurry by allowing the coal ash to be recycled in the manufacture of other products such as gypsum (Geosynthetic Materials Association, 2010).

Fig. 4. GCL Placement in a Coal Ash Storage Site (Geosynthetic Materials Association, 2010)

1.1.5. *Surface Impoundments (Pond Liners)*

The conservation of surface water in ponds covered by GCLs reduces the demand on groundwater. Generally, a geomembrane layer is used over the GCL in order to minimize water seepage as can be seen in Figure 5. GCLs used in pond liners are preferred for agricultural and aquacultural purposes as well as for decorative purposes in amusement parks, golf courses and resorts (Geosynthetic Materials Association, 2010).

Fig. 5. GCL Placement in a Surface Impoundment (Geosynthetic Materials Association, 2010)

1.1.6. *Canal Liners*

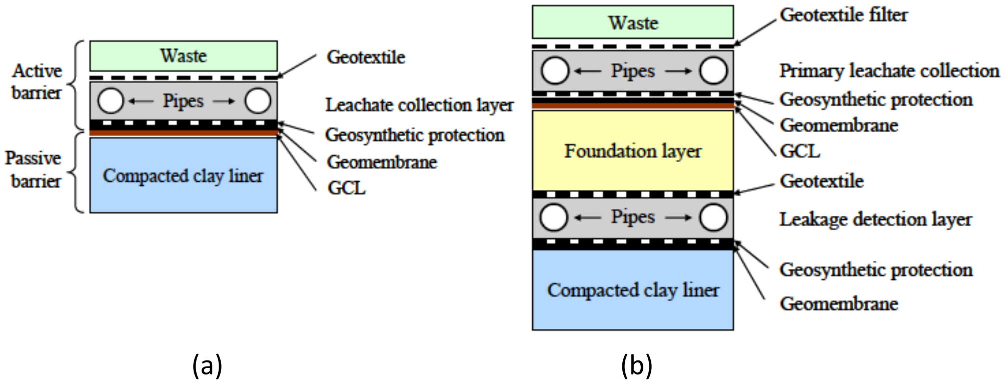
Water is very valuable as a resource in arid or semi-arid climates for agricultural purposes. Besides, seepage from irrigation canals and waterways is a costly problem. By using geomembranes and GCLs, water-loss might be minimized and crop productivity might be maximized in irriganiton canals as shown in Figure 6. Geomembranes and GCLs can be economically employed. Geomembranes and GCLs are effective alternatives to concrete, asphalt or CCLs by reducing the seepage through unlined irrigation canals or waterways and by repairing poorly performing existing linings or those that are rapidly deteriorating (Geosynthetic Materials Association, 2010).

Fig. 6. GCL Placement as a Canal Liner in an Irrigation Canal (Geosynthetic Materials Association, 2010)

1.2. Lining Systems in Mining Applications

1.2.1. *Landfills*

Landfills are designed as either a single or a double composite liner as shown in Figures 7a and 7b. A single composite liner is composed of the collected waste, geotextile layer, leachate collection layer with pipes, geotextile, geomembrane, GCL and CCL from top to bottom whereas a double composite liner consists of geotextile, leakage detection layer with pipes, geotextile, geomembrane, CCL, all beneath the foundation layer in addition to the collected waste, geotextile filter, primary leachate collection layer, geotextile protection, geomembrane and GCL from top to bottom, as the same components listed for the single composite liner (Rowe, 2005; Barroso and Lopes, 2007). A secondary drainage named as leakage detection layer is placed between the primary and secondary liners for a double composite liner as can be seen in Figure 7b. This drainage system is formed either by granular soils or by geonets. With this leakage detection layer, the system controls the leachate that permeats through the primary liner system (Rowe, 2005). Double composite liners are mainly used in hazardous landfills and the thickness of the landfill for hazardous waste has to be greater than 5 m whereas that of the landfill for non-hazardous waste has to be designed with a thickness of at least 1 m (Touze-Foltz et al., 2008). Furthermore, a landfill has to be constructed by considering that the permeability coefficient (k) of the landfill is not higher than 10^{-9} m/s (Guyonnet et al., 2007).



(a) (b)

Fig. 7. Landfill Composite Liner Systems: (*a*) Single; (*b*) Double (Rowe, 2005; Barroso and Lopes, 2007)

1.2.2. Heap Leach Pads

Heap leach facilities are used as part of the mining process to extract metal from ore and have been used for the recovery of gold, copper, silver and other metals and non-metals. A heap leach pad is generally lined with a natural or a geosynthetic material in order to maintain environmental containment of the ores and leach solutions (Renken et al., 2005). The barrier in a heap leach pad is usually composed of a single or a double composite system with a leakage collection layer as shown in Figures 8a and 8b. Single composite liner systems consist of a geomembrane placed over a GCL or CCL (Pries and Westhus, 2014). The geomembrane layers used in heap leach pads are generally made of HDPE or LDPE. HDPE and LDPE geomembranes are proved to be suitable for containment of corrosive acid rock drainage and metal leaching products by providing long periods, at least 20 years of usage. Single composite liner systems are commonly preferred in areas that experience hydraulic heads lower than 1 m (Touze-Foltz et al., 2008). From bottom to top, a single composite liner system is composed of the existing foundation (subgrade), GCL or CCL, geomembrane, geotextile layer that is placed for protection, mineral drainage layer including solution collection and air injection pipes as shown in Figure 8a (Lupo, 2006). On the other hand, double composite liner systems are composed of two geomembrane liners separated by a leakage collection layer as shown in Figure 8b. The lower secondary geomembrane is placed over a GCL or a CCL like the placement of the geomembrane in a single composite liner system. Over the upper geomembrane layer, geotextile layer for protection and then, the mineral drainage layer including the piping is placed (Lupo, 2006).

A double composite liner system is preferred in the areas where high hydraulic heads might exist. Single geomembrane liners are usually used for copper leach pads whereas composite liners are preferred for gold and silver leach pads (Breitenbach and Smith, 2006).

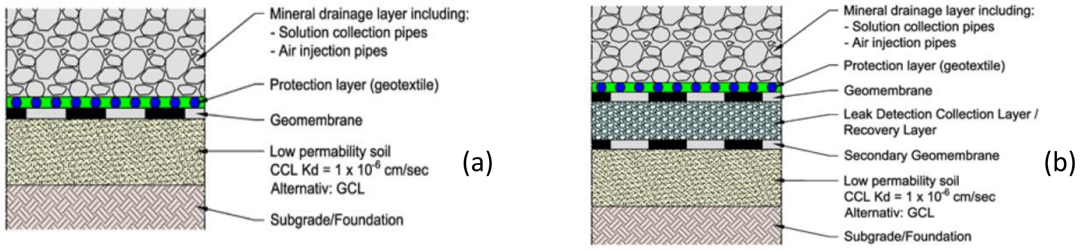


Fig. 8. Heap Leach Pad Composite Liner Systems: (*a*) Single; (*b*) Double (Lupo, 2006)

Due to the improvements in ore processing techniques and the rising demand for metals and non-metals, some heap leach pads possess an area greater than 10 km^2 having ore heights higher than 180 m over the lined base. The performance of the liner system is dependent on the interaction between different parameters such as foundation settlements, interface shear strength, geomembrane strength, gradations of the liner bedding soil and overliner material (Touze-Foltz et al., 2008).

1.2.3. Tailing Storage Facilities

Tailing storage facilities or mine tailing dams are structures that are constructed to impound waste materials (tailings) resulting from mineral processing activities as shown in Figure 9. If the tailings contain substances that might have a negative effect on the environment, the tailing dam has to be lined with GCL in order to minimize the permeation of the leachates into the ground. The barrier systems including GCL in mine tailing dams are generally constructed as single composite liner systems. In these facilities, double composite liner systems are not preferred due to the hydraulic properties of the tailings. Moreover, a single composite liner system can be effectively used even at hydraulic heads greater than 100 m due to the fact that the tailings usually form a low permeable layer at the base of the tailing dam above the liner system. Permeability coefficient (k) of consolidated tailings is commonly within the range of 10^{-6}-10^{-10} m/s and rarely lower than 10^{-10} m/s (Vick, 1983). By having a low permeability coefficient, the consolidated tailings have the capability to minimize seepage from the facility. The single composite liner system in mine tailing dams is composed of a geomembrane layer placed over GCL or CCL. Additionally, a drainage layer might also be placed over the geocomposite to increase the consolidation process of the tailings or to provide internal drainage for the tailing dam. Some of the main factors that have significant effects on the design of the liner system are foundation settlements, environmental considerations and possible expansion of the upstream, centreline or downstream construction of the tailing dam (Touze-Foltz et al., 2008).

Fig. 9. GCL Placement in a Mine Tailing Dam (GDT Lining, 2017)

2. EXPERIMENTAL PROGRAM

GCL behavior in environments having high temperature has been a crucial concern for geotechnical and environmental engineers. In mining applications, GCLs are commonly in contact with solid wastes or leachates that might possess a high percentage of organic and chemical substances. Organic particles of a waste that are collected in a landfill, heap leach pad or mine tailing dam decompose biologically and due to this decomposition, heat is generated (Rowe, 2005). The temperature of the wastes or leachates might rise up to 60 °C because of the biodegradation of the organic particles (Rowe and Islam, 2009). Moreover, the leachates collected in waste containment areas may range from aggressive acidic fluids to aqueous solutions that have the capability to deteriorate the hydraulic properties of the barrier material. In order to improve the hydraulic capability of the liner placed in waste containment areas, adding various types of polymers to the bentonite component of the GCL could be an efficient solution.

In this experimental program, triaxial hydraulic conductivity and free swell tests were performed on an unreinforced GCL in order to investigate the effect of temperature of the leachates collected in a mine application, on the hydraulic properties of the GCL. For this reason, the temperature of the permeation fluid was chosen as 20°C and 40°C respectively and 0.5 M $MgCl_2$ solution was used as the permeation fluid that represented an aggressive leachate. Furthermore, deionized water was also used in order to evaluate the effects of 0.5 M $MgCl_2$ solution on the hydraulic capability of the GCL. Besides the temperature considerations, cationic polymer treatment was investigated in both of the triaxial hydraulic conductivity and free swell tests by adding an amount of 1% and 2% cationic polymer by mass to the bentonite and polymer mixture in the GCL.

2.1. Materials

The GCL used in the experiments consisted of granular Na bentonite layer sandwiched between a woven geotextile and a nonwoven geotextile without any reinforcement as can be seen in Figure 10. The moisture content and the mass/unit area of the bentonite were measured as 14% and 4800 gr/m^2 respectively. The bentonite had a specific gravity of 2.69, liquid limit of 640% and a plastic limit of 28%.

The woven geotextile component of the GCL was a polypropylene, slit-film geotextile having a mass/unit area of 100 gr/m^2 and an apparent opening size of 0.4 mm whereas the nonwoven geotextile component of the GCL was a polypropylene, staple fiber, needle-punched geotextile with a mass/unit area of 250 gr/m^2 and an apparent opening size of 0.2 mm.

Fig. 10. GCL Specimen having 100 mm Diameter (Nonwoven Side Up)

First, woven and nonwoven geotextiles having a diameter of 100 mm were cut separately from geotextile rolls and 37.7 gr oven-dried granular Na bentonite was added on the nonwoven geotextile in order to satisfy the mass/unit area of the bentonite as 4800 gr/m^2. Afterwards, the granular Na bentonite was wetted homogenously with deionized water in order to enhance its bonding to the geotextiles. In the end, the woven geotextile having a diameter of 100 mm was placed over the wetted bentonite without any reinforcement (Ozhan and Guler, 2013).

The polymer added to the GCL was chosen as a powdered polymer that consisted of approximately 11 times more soluble cations than soluble anions in terms of mass. 1% and 2% cationic polymer amounts in terms of dry mass was added to the bentonite-polymer mixture respectively. Afterwards, the mixture was taken in a polyethylene bottle and the mixture was shaken by for five minutes and remained in the bottle for almost 24 hours in order to obtain a homogenous structure (Razakamanantsoa et al. 2012). Finally, the polymer-treated GCLs were manufactured similarly with the GCLs that were assembled without polymer treatment.

2.2. Test Procedures

2.2.1. Triaxial Hydraulic Conductivity Tests

Constant-head triaxial hydraulic conductivity tests were performed on the GCLs placed in flexible-wall permeameters (ASTM D6766, 2012). Permittivity (Ψ) of the GCLs was measured during and at the end of the tests. Permittivity (Ψ) was calculated as follows:

$$\Psi = \frac{\Delta Q}{A \cdot \Delta h \cdot \Delta t} \tag{1}$$

Where Ψ (1/s) was permittivity, ΔQ (cm^3) was the average of inflow and outflow for a specific time interval, A (cm^2) was the cross-sectional area of the GCL, Δh (cm) was the hydraulic head difference acting on the GCL and Δt (s) was the time interval over which the flow ΔQ occured.

From bottom to top, triaxial permeability test setup was composed of a rigid bottom cap, porous stone, filter paper, GCL specimen, filter paper, porous stone and a rigid top cap as can be seen in Figure 11. A latex membrane was wrapped around the GCL specimen and o-rings were fixed to the latex membrane in order to prevent side leakage. Then, the permeameter cell was filled with 0.5 M $MgCl_2$ solution or deionized water (ASTM D6766, 2012).

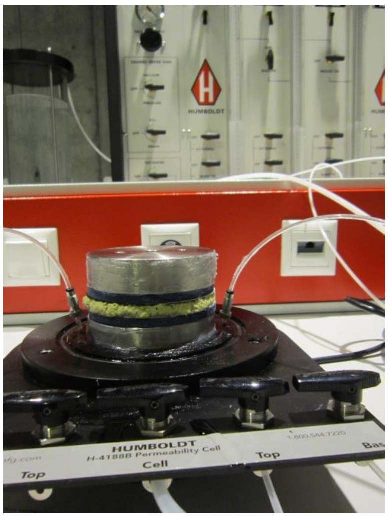


Fig. 11. Triaxial Hydraulic Conductivity Test Configuration

The hydraulic head acting on the GCL was chosen as 30 cm due to the fact that the maximum leachate level could not be greater than 30 cm in a landfill (Weber and Zornberg, 2005). After saturation and consolidation were maintained, permeation through the GCL from bottom to top was initiated by taking the cell pressure, influent pressure and effluent pressure as 550 kPa, 530 kPa and 527 kPa respectively (ASTM D6766, 2012). Flow through the GCLs that were permeated with deionized water was almost constant during the hydraulic conductivity tests. Because of this, measuring permittivity continued only 6-7 days. Contrarily, it took longer time to measure constant permittivity values for the GCLs permeated with 0.5 M $MgCl_2$ solution due to the termination of cation exchange between the ions of the bentonite and the divalent ions of the aqueous solution. Permittivity became almost constant 14-16 days after permeation was initiated.

The temperature of the permeation fluid was set to the desired value by placing the permeameter cells and the plastic tubes in water tanks with heaters as shown in Figure 12. The water tanks that were made of stainless steel, were filled with the permeation fluids and afterwards, the temperature of the fluid that permeated through the plastic tubes and the fluid in the permeameter cells was set to 20^oC and 40^oC by programming the heater of the water tanks to the desired temperature values.

The GCLs were designated according to the amount of cationic polymer (1P for 1% cationic polymer or 2P for 2% cationic polymer), the permeation fluid (0.5MC for 0.5 M $MgCl_2$ solution or DW for deionized water), and the temperature of the permeation fluid (20 for 20^oC and 40 for 40^oC). For example, a GCL having an amount of 1% cationic polymer by mass that was permeated with 0.5 M $MgCl_2$ solution at 40^oC was designated as GCL-1P-0.5MC-40.

Fig. 12. Permeameter Cells in Water Tanks

2.2.2. Free Swell Tests

Free swell tests were conducted as outlined in ASTM D5890 (2011). Cationic polymer-treated bentonite specimens were prepared by measuring the mass of the polymer as 1% and 2% in the bentonite-polymer mixture (Razakamanantsoa et al. 2012). After pouring all of the bentonite or bentonite-polymer mixture into the burrette filled with the permeation fluid, the swell index was measured after 24 hours for the bentonite specimens without polymer treatment and after 72 hours for the bentonite specimens with polymer treatment due to the longer period for the swelling of polymer-treated bentonite specimens (ASTM D5890, 2011). Moreover, liquid paraffin was added to the permeation fluid at 40^{o}C in order to prevent evaporation due to the higher temperature.

The same water tanks as used for triaxial hydraulic conductivity tests were also used for free swell tests in order to set the permeation fluid temperature at 20^{o}C and 40^{o}C. The cylindrical burrettes were placed in the water tanks that were filled with the permeation fluid as can be seen in Figure 13.

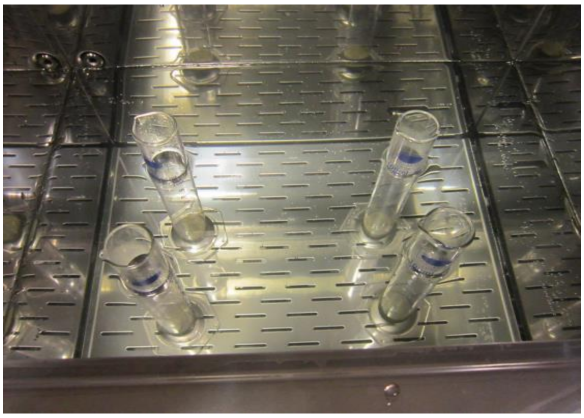


Fig. 13. Cylindrical Burrettes in Water Tanks for Free Swell Test

3. RESULTS AND DISCUSSION

In Table 1, the results of both triaxial hydraulic conductivity and free swell tests were listed. According to the triaxial hydraulic conductivity and free swell test results, both permittivity and swell index increased as the temperature of the permeation fluid increased from 20^{o}C to 40^{o}C. Moreover, adding cationic polymer to the GCL improved the hydraulic barrier capability of the GCL by both increasing the swell index and decreasing the permittivity as can be seen in Table 1.

Table 1. Experimental Test Results

GCL Designation	Swell Index (ml/2g)	Permittivity (1/s)
GCL-0.5MC-20	3	$5{,}7X10^{-6}$
GCL-1P-0.5MC-20	5,5	$4{,}1X10^{-7}$
GCL-2P-0.5MC-20	7	$4X10^{-7}$
GCL-0.5MC-40	3,5	$3{,}3X10^{-5}$
GCL-1P-0.5MC-40	7,5	$1{,}4X10^{-6}$
GCL-2P-0.5MC-40	9	$9{,}2X10^{-7}$
GCL-DW-20	24	$8{,}7X10^{-9}$
GCL-1P-DW-20	27	$2{,}4X10^{-9}$
GCL-2P-DW-20	28	$7{,}8X10^{-10}$
GCL-DW-40	26	$9{,}6X10^{-9}$
GCL-1P-DW-40	28,5	$3X10^{-9}$
GCL-2P-DW-40	29	$8{,}2X10^{-10}$

Permittivity versus time graphs of the GCLs permeated with 0.5 M $MgCl_2$ solution at 20°C were shown in Figure 14. As time passed, permittivity increased up to 1-2 orders of magnitude due to the ion exchange process between the cations in 0.5 M $MgCl_2$ solution and the cations in the bentonite. After the ion exchange process was completed, almost constant permittivity values were measured as can be seen in Figure 14. At the end of the tests, permittivity of GCL-0.5MC-20 was measured as $5.7x10^{-6}$ 1/s whereas both GCL-1P-0.5MC-20, and GCL-2P-0.5MC-20 had a permittivity almost one order of magnitude smaller than that of GCL-0.5MC-20. As shown in Figure 14, adding 2% cationic polymer to the GCL did not improve the hydraulic properties when compared to the permittivity of the GCL having 1% cationic polymer.

Similar behavior in terms of permittivity was obtained for the GCLs tested with 0.5 M $MgCl_2$ solution at 40°C when compared to that at 20°C as shown in Figure 15. Again, permittivity increased due to the ion exchange and at the end of the tests, GCL-0.5MC-40 had a permittivity of $3.3x10^{-5}$ 1/s. When 1% cationic polymer was added to the GCL, permittivity decreased with an amount of approximately 1.2 orders of magnitude. 2% cationic polymer treatment improved the hydraulic capability by decreasing the permittivity with only an amount of almost 0.1 order of magnitude.

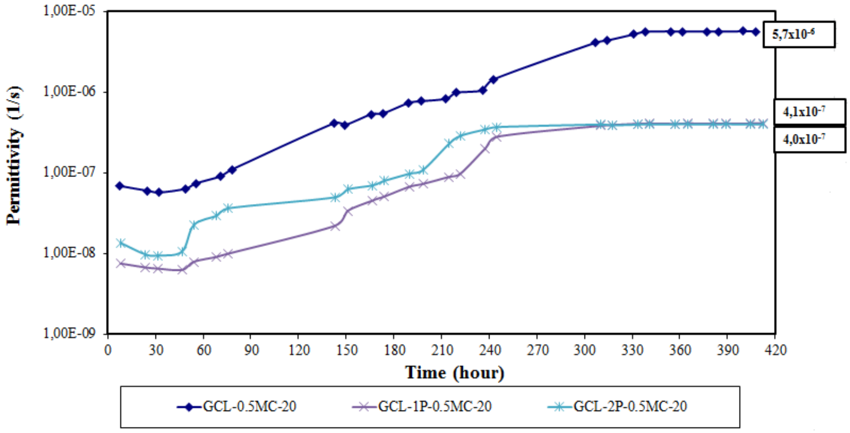


Fig. 14. Permittivity versus Time Graphs for the GCLs Permeated with 0.5 $MgCl_2$ Solution at 20^{o}C

When Figure 14 and Figure 15 were compared, it might be concluded that as the temperature of 0.5 M $MgCl_2$ solution increased from 20°C to 40°C, permittivity of the GCL also increased within the range of 0.5-0.7 order of magnitude.

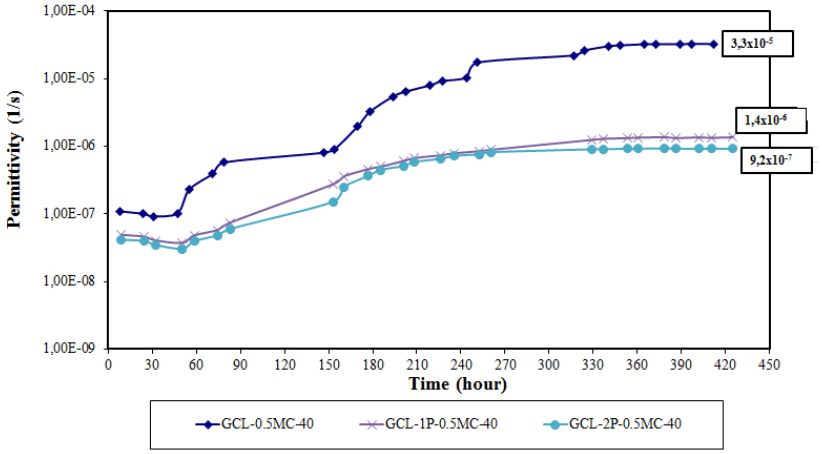


Fig. 15. Permittivity versus Time Graphs for the GCLs Permeated with 0.5 $MgCl_2$ Solution at 40^{o}C

However, permittivity behavior of the GCLs permeated with deionized water was not the same as that of the GCLs permeated with 0.5 M $MgCl_2$ solution as shown in Figures 16 and 17. Because there is no ion exchange between the ions of neutral deionized water and the cations of the bentonite, permittivity was almost constant from the start until the end of the tests. Permittivity of GCL-DW-20 was measured as $8.7x10^{-9}$ 1/s as can be seen in Figure 16. 1% cationic polymer treatment caused approximately 0.6 order of magnitude decrease in permittivity and then, adding 2% cationic polymer resulted in almost 0.4 order of magnitude permittivity decrease when compared to that of 1% cationic polymer treated GCL.

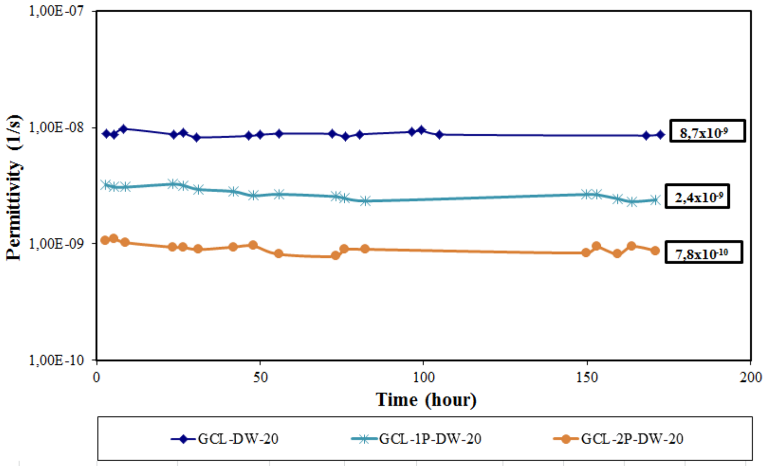


Fig. 16. Permittivity versus Time Graphs for the GCLs Permeated with Deionized Water at 20^0C

Permittivity of GCL-DW-40 was measured as 9.6×10^{-9} 1/s whereas GCL-1P-DW-40 and GCL-2P-DW-40 had a permittivity of 3×10^{-9} and 8.2×10^{-10} 1/s respectively. As shown in Figure 17, adding cationic polymer up to 2% enhanced the hydraulic capability of the GCL by decreasing its permittivity. Permittivity of the GCL treated with 2% cationic polymer was almost one order of magnitude smaller than that of the GCL without polymer treatment as can be seen in Figure 17.

For the GCLs permeated with deionized water, temperature increase did not deteriorate the permittivity as much as that of the GCLs permeated with 0.5 M $MgCl_2$ solution. Increase in the temperature of deionized water from 20°C to 40°C, resulted in an increase in the permittivity up to only 0.1 order of magnitude.

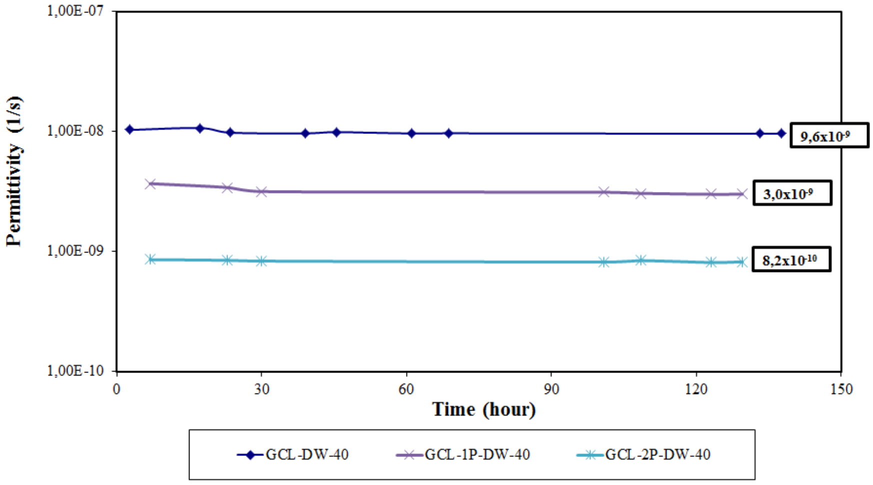


Fig. 17. Permittivity versus Time Graphs for the GCLs Permeated with Deionized Water at 40^0C

As a result, an increase in the temperature of a leachate that could be collected in a waste containment area due to the biodegradation of the organic substances in the leachate, would result in a considerable increase in the permittivity of the GCL. The increase in permittivity might be attributed to the decrease in viscosity of the leachate at higher temperatures. According to Rowe (1998), as the viscosity of a fluid decreased due to an increase in the temperature of the fluid, permeability of the fluid increased which deteriorated the hydraulic capability of the material that the fluid was in contact to.

Cationic polymer treatment improved the hydraulic conductivity even at higher temperatures of the permeation fluid. For 0.5 M $MgCl_2$ solution that could be used as an aggressive aqueous solution, permittivity decrease was even higher than one order of magnitude at both 20°C and 40°C. However, adding 1% amount of cationic polymer by mass was found to be enough to obtain a significant decrease in permittivity. There was no need to increase the polymer amount up to 2% in the GCL.

As can be seen in Table 1, both cationic polymer treatment and increasing the temperature of the permeation fluid from 20°C to 40°C caused the swell index of the GCL to increase gradually. Although the swell index values were comparably very low when the GCL was permeated with 0.5 M $MgCl_2$ solution instead of deionized water, almost the same amount of increase in the swelling capacity of the GCL was measured. However the increase in the swell index was not high enough to improve the hydraulic properties of the GCL when compared to the negative effect of the temperature increase on the permittivity of the GCL.

4. CONCLUSIONS

GCL is a liner material that is preferred to be placed as a barrier in both fresh water reservoirs and waste containment areas. Mining applications are significant examples for GCL usage in waste containment facilities. The three main applications of GCLs in mining industry are landfills, heap leach pads and tailing dams. In these structures, GCLs are generally used as a part of either a single or a double composite liner system.

Temperature problem related to the GCLs in mining applications is a serious concern due to the possible deterioration of the hydraulic capability of the GCLs. As the temperature of the leachate in a waste containment facility increases, hydraulic conductivity of the GCL may increase which can result in poor barrier function of the GCL as a liner material. In order to simulate temperature increase due to the decomposition of organic substances in a waste containment facility, 0.5 M $MgCl_2$ solution was used as the permeation liquid. This aqueous solution having a high molarity represented an aggressive leachate.

The results of the laboratory tests indicated that temperature increase caused both an increase in permittivity and swell index of the GCL when the GCL was permeated with either 0.5 M $MgCl_2$ solution or deionized water. Although the slight increase in swell index was an advantage in terms of hydraulic performance, the increase in permittivity was measured much higher than that of the swell index which deteriorated the hydraulic capability of the GCL as an overall performance.

As a precaution against the deterioration of the hydraulic performance of the GCL due to temperature increase, a cationic polymer up to an amount of 2% by mass was added to the GCL. The results of the laboratory tests indicated that cationic polymer treatment up to 1% caused a significant decrease, higher than one order of magnitude, in the permittivity of the GCL. Moreover, polymer addition up to 2% resulted in a slight but continuous increase in the swell index of the GCL.

Due to biological activities, temperature of the leachate collected in a waste containment facility generally increases. This temperature increase causes a declination in the hydraulic performance of the barrier material. According to both triaxial hydraulic conductivity and free swell test results, cationic polymer treatment enhanced the hydraulic capability of the GCL.

ACKNOWLEDGEMENTS

Experimental work of this study has been supported by TUBITAK (The Scientific and Technological Research Council of Turkey) under 3501-Career Development Program, Project #: 114M282, “Effects of Waste Water Temperature on the Hydraulic Performance of Polymer Treated and Untreated Geosynthetic Clay Liners”.

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