

Study on the Effect of Desiccation Cracks on the Hydraulic Conductivity of Geosynthetic Clay Liner

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ABSTRACT

Due to the rapid growth of the world population, the increased output of solid waste material is considered an important environmental issue. The poisoning of groundwater by landfill leachate poses a threat to all living things. The liner system in landfills is crucial for preventing leachate pollution of the surrounding ground. The geosynthetic clay liner (GCL) is a man-made approach for preventing dangerous pollution and protecting groundwater. In various landfill projects, geosynthetic clay liners (GCL) exist routinely utilized like hydraulic barriers which help in separating pollutants from the neighboring environment by reducing leachate escape. GCLs are frequently subjected to temperature variations before garbage is deposited in landfills, which might compromise the liner's hydraulic characteristics. The hydraulic conductivity of a Geosynthetic based clay liner may be affected by both fissures in the clay liner and the complicated content of leachates. The influence of desiccation cracks with sunshine exposure upon the flow characteristics of Geosynthetic clay liners is investigated in this study. As the penetrating liquid, tap water is being used.

Keywords: *Geosynthetic clay liner (GCL), Bentonite, hydraulic conductivity, and desiccation crack.*

INTRODUCTION

Geosynthetics have already been efficiently confining fluids, whether liquids or gases, thereby ensuring environmental protection for decades[1, 2]. Geotechnical engineering gave rise to its utilization, but with the advanced materials and variants on the original fundamental geosynthetics, they have grown considerably[3, 4]. This research focuses on geosynthetic clay liners (GCLs) and also in what way they communicate and interrelate, as well as how interaction improves their ability. GCLs work like single liners (similar to potable ponds) and a composite liner (as in some covers)[5, 6]. The bentonite provides the principal obstacle to fluid movement through a GCL[7, 8]. When properly hydrated, bentonite (usually sodium bentonite) has a low permeability to liquids and gases, which is especially important for gases. The GCL is frequently expected to rehydrate adequately from the nearby soil, and it frequently does. However, other elements influence a GCL's hydration and dehydration that are not fully understood. In particular, essential designs must take into account the relationship between the GCL as well as its environmental elements (including meteorological variables). This holds for GCLs that are employed as a solitary liner or as a component of a hybrid liner[9, 10]. There seem to be serious advances in the creation of geosynthetic liners, as well as in identifying the aspects that influence its field success and should therefore be taken into account during design and implementation.

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However, despite ignorance or carelessness, provides a widespread belief that a geomembrane liner system (GMB) either or both GCL may operate. There is too much reliance on folk law from the twentieth century and not sufficient solid engineering relies on twenty-first-era expertise. While the focus is generally made on assuring suitable constituents whenever seen in separation, the researcher believes that liners as a component of a physical-environmental system are currently receiving too little attention. This includes the liner's physical and hydraulic communication well with components in it, and the materials' time-related changes. A liner is exposed to temperature, as well as stresses/strains similar o part of a physical-environmental system as the scheme ages [6, 11-13].

Various researches symbolize the impact of effluents and cracks, which works on hydraulic conductivity of compressed clay liners [5, 11, 14, 15], montmorillonite mixes [16, 17], and GCLs [18, 19] still directed over the last twenty years. The hydraulic behavior of acceptable soil particles is affected via the interface among opening solutions as well as minerals in general. Natural clay's hydraulic conductivity is unaffected by inorganic salt [20]. Researchers also discovered that when osmolarity increased, hydraulic conductivity raised intended for clay having such a high liquid limit and elevated for clay using such a relatively lower border [21]. According to test results, the hydraulic conductivity of an acidic waste solution declines over time[22]. Pure organic chemicals typically significantly improve the hydraulic conductivity of clay particles, while mixed organic substances have few impacts [23]. It is also investigated and found that the compacted bentonite-sand mixtures and discovered that overall chemical composition had some impact on the structure of bentonite constricted within the sand frameworks [24] and also the biological, physical, and chemical links in compacted silt-bentonite mixes affect leachate percolation is also reported[17, 25].

The application of bentonite to different types of soil is a regularly used way to achieve the hydraulic heating value required by international rules (k 110-9 m/s)[26-28]. Bentonite's high swelling-shrinkage capacity may cause increased desiccation cracks in clay liners[29-31]. More research is needed into the self-healing capability and hydraulic efficacy of bentonite-modified clay which possess impacts of crackings and leachate. This study focus on the influence of desiccation cracks with sunshine exposure upon the flow characteristics of Geosynthetic clay liners having objectives of this work includes the following: (1) evaluate the influence of simulated effluents upon the hydraulic conductivity of clay soil, (2) evaluate the influence of desiccation cracks mostly on hydraulic conductivity of bentonite-soil and bentonite-revised clay, and (3) to study the conjoint effect of effluents and crackings upon this hydraulic conductivity.

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MATERIALS AND PROPERTIES

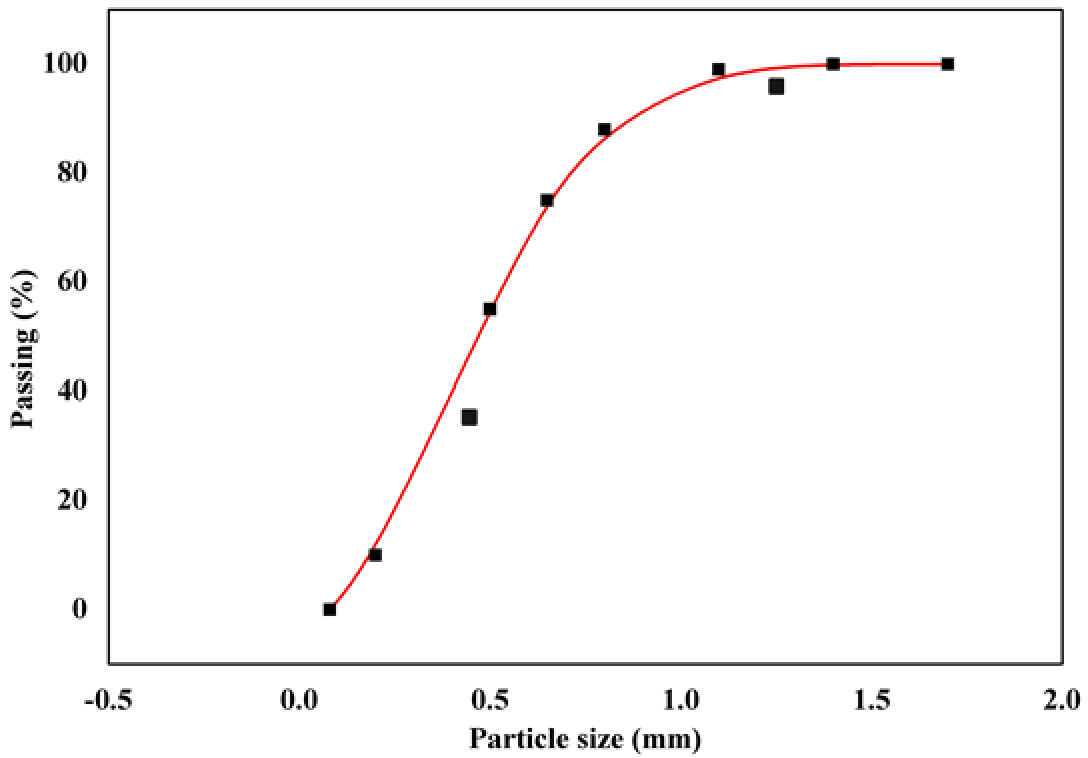

Figure -1. Particle size distribution curve

Figure 2. Images of a) Soil, b) Geotextile c) Bentonite clay powder.

Soil

The particle size distrubtion curve Figure-1 obtained from seview analaysis was exhibites that the soil is sandy with homogenious in nature. The geotechnical parameters of the soil were assessed using soil samples collected from the dumpsite, shown in Figure 2.(a) Soil, b) Geotextile, c) Bentonite clay powder.

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Geotextile

The laboratory determines the geotextile's qualities such as mass per unit area, thickness, and puncture resistance, as shown in Figure 2(b).

Bentonite clay

The properties of bentonite clay used for the project are given in Table 1 and Figure 2(c) shows its image.

Table 1. Properties of materials sample.

	Properties	Valuve
Soil Samples	Gravel	0.25%
	Core Sand	0.11%
	Meadium Sand	21.16%
	Fine sand	69.64%
	Silt-Clay	0.75%
	D10	0.11%
	Cu	1.86
	Cc	1.07
	Specfic gravity	2.470
	Water contant	9.09%
Geo- Textile	Mass/Unit Area	84.44g/m^2
	Thickness	0.35mm
	Punctureresistance	30mm
Clay	Liquid limit	31.15%
	Plastic limit	76.2%
	Plasticity index	233.8

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Glue gun sticks

Glue gun sticks are used to prevent side leakages. They are applied to the interior area of the pipe to hold the geotextile tightly and prevent leakage through it and Table 1 represents the properties of all materials used for testing.

Hydraulic conductivity test

A hydraulic conductivity test should be performed for investigating the effect of desiccation cracks on the hydraulic conductivity of Geosynthetic clay liner (GCL). The experimental model setup for doing the hydraulic conductivity test is depicted in Figures 3.

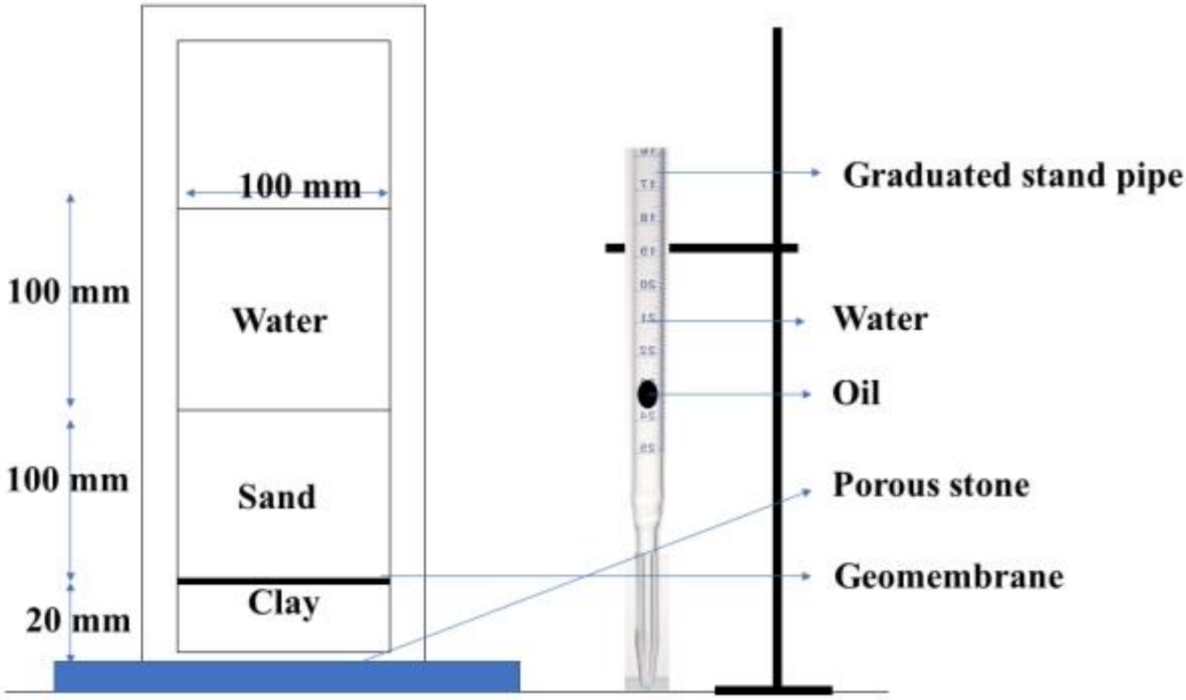

Figure 3. Experimental model set up

For the hydraulic conductivity test, tap water is used as the permeating liquid. The soil sample's hydraulic conductivity is determined. Different quantities of clay soil combination should be prepared, and tests should be conducted on each percentage to determine the best one. The appropriate clay-soil mixture is then exposed to sunlight for the required periods, yielding hydraulic conductivity values. Here, GCLs with a 50mm defective geotextile damage hole are used. They are exposed to sunshine to detect the impact of desiccation cracks. The ability to cure oneself is also examined. The schematic representation model setup is shown in the picture. A layer of clay-soil mixture in a proper proportion is applied to the bottom. The geotextile is securely fastened above the clay-soil mixture. Glue sticks are used to prevent side leaks. It is covered with soil above the geotextile. Above it, a hydraulic head is maintained. As a result, water percolates through this and can be retrieved via the outlet tube linked to the pipe. To prevent evaporation, one or two drops of oil are put above the water gathered in the tube.

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RESULT AND DISCUSSION

The results from the present study are tabulated below and the results from the hydraulic conductivity test are discussed to find out their effect on the hydraulic performance of Geosynthetic Clay Liners (GCLs).

Selection of suitable proportion of clay-soil mixture

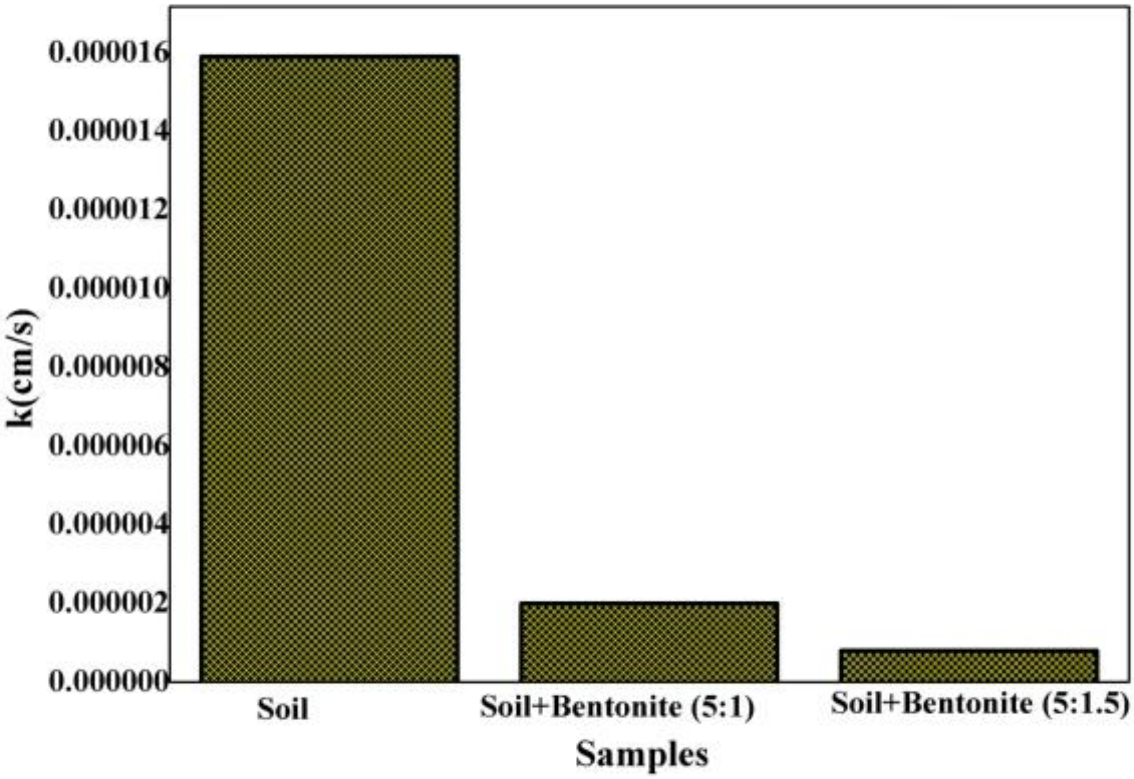

Figure 4. Hydraulic conductivity of selected sample.

The hydraulic conductivity test was accomplished over the soil sample, given in Figure 4. The hydraulic conductivity of different proportions of clay soil mixture are measured and suitable proportions were found. The result obtained from the test were tabulated in Table 2 given below.

Table 2. Hydraulic conductivity test

Sl no	Type of sample	Permeating liquid	K(cm/s)		
1	Soil sample	Tap water	1.406×10^{-5}	1.718×10^{-5}	1.640×10^{-5}

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2	Soil + bentonite clay (5:1)	Tap water	1.315×10^{-6}	1.644×10^{-6}	2.769×10^{-6}
3	Soil + bentonite clay (5:1.5)	Tap water	4.166×10^{-7}	2.777×10^{-7}	5.55×10^{-7}

Therefore, the suitable proportion of soil-bentonite mixture selected for doing the project is 5:1.5 which has a permeability value at a range of 10^{-7} cm/s. The graph below shows the hydraulic conductivity versus the type of sample selected.

Permeability due to sunlight exposure of soil-bentonite mixture

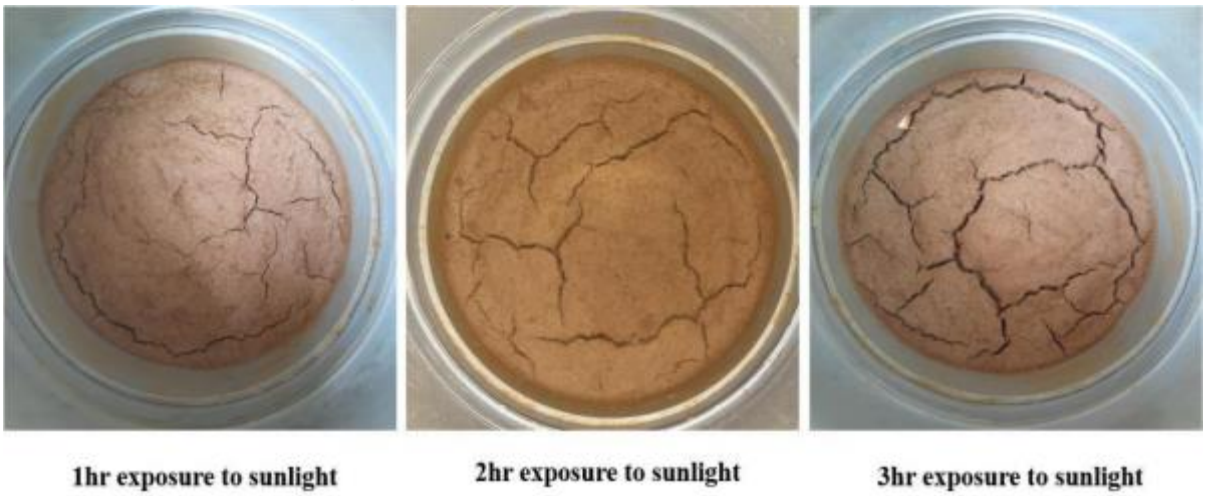

Figure 5. Crack patterns

Soil-bentonite clay mixture in the proportion of 5:1.5 are subjected to sunlight exposure for 1hr, 2hr, and 3hr and are placed for taking the permeability value. Clay-soil mixture when exposed to sunlight it was noticed that desiccation cracks are formed on the clay-soil mixture and when the time of exposure to sunlight increases the formation of desiccation cracks also increased. Figure 5 shows the crack patterns formed by the sunlight exposure and more cracks are formed for the sample with 3-hour sunlight exposure.

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On analyzing the permeability values, it is observed that sunlight exposure is a factor that affects hydraulic conductivity. Hydraulic conductivity values increased for the soil-bentonite mixture when subjected to sunlight exposure, as given in Table 3.

Table 3. Permeability of soil-bentonite mixture due to sunlight exposure

Time of sunlight Exposure (hr)	**K(cm/s)**		
	1hr	**2hr**	**3hr**
1hr	2.341×10^{-5}	1.402×10^{-5}	1.040×10^{-5}
2hr	2.810×10^{-5}	1.401×10^{-5}	1.091×10^{-5}
3hr	4.061×10^{-5}	2.108×10^{-5}	1.425×10^{-5}

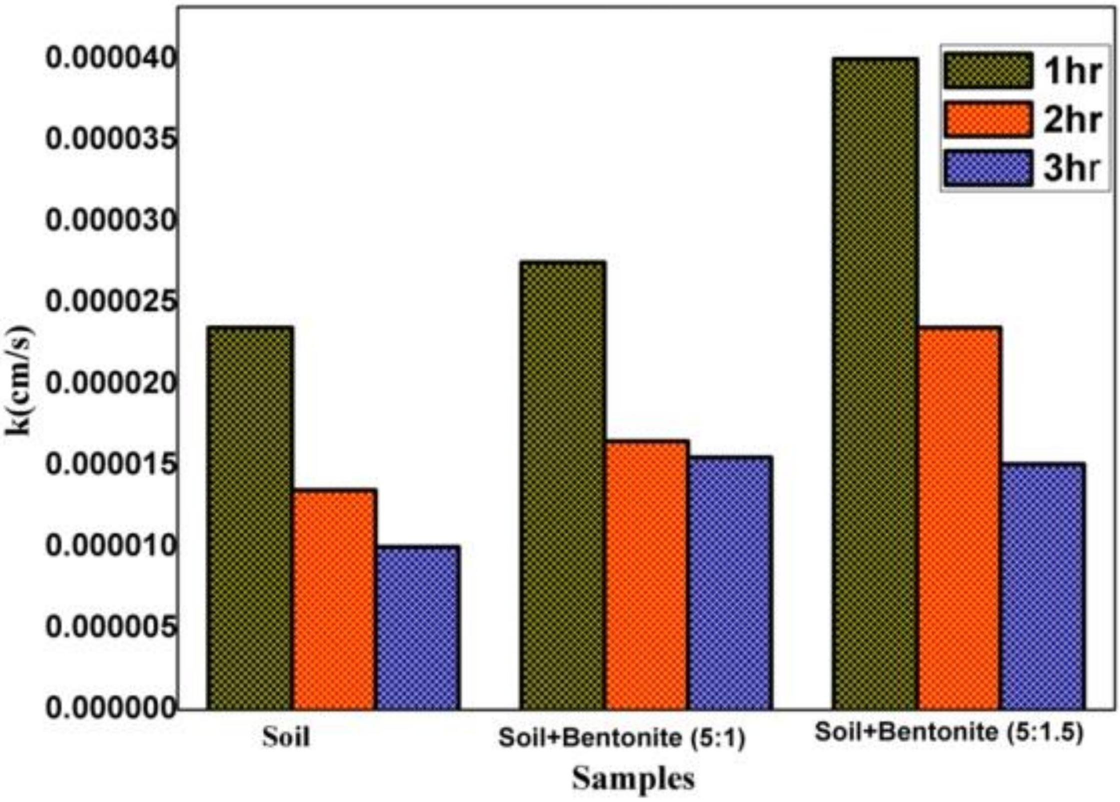

Figure 6. Hydraulic conductivity values at varying hours of sunlight exposure.

Figure 6 is the graph showing the permeability due to sunlight exposure to the soil-bentonite mixture and showed that the maximum hydraulic conductivity is seen for the sample with 3-hour sunlight exposure.

Permeability of gcls with 50mm defected geotextile due to sunlight exposure

Karthika Sari, et al. (2013) discovered that when tap water is utilized as the permeating liquid, a broken hole up to 30mm can self-heal. A 50mm damage hole is used in this investigation to evaluate the self-healing capabilities. The effect of percentage area defective on the hydraulic conductivity of Geosynthetic clay liners was investigated using a 50mm damage hole geotextile. As a result, the defective geotextile with the pipe diameter is positioned correctly over through the soil-bentonite mixture. To avoid side leaks, glue sticks are put to the sides of the pipe to secure the geotextile to the inner side. Figure 6 depicts a GCL model with a 50mm damage hole that is suitably positioned just above the clay-soil mixture. For 1 hour, 2 hours, and 3 hours, these specimens are subjected to sunshine. The measurements are collected to calculate hydraulic conductivity. The hydraulic calculated results of GCL with 50mm defective geotextile indicate that k is in the 10-7 cm/s region. The graph of hydraulic conductivity vs time of sunshine treatment of GCL due to direct sunlight is shown in Figure 7 and Table 4 shows the values of permeability due to sunlight exposure of soil bentonite mixture with 50mm defected geotextile. The hydraulic conductivity increases as the time spent in direct sunshine increases.

Table 4. Permeability due to sunlight exposure of soil bentonite mixture with 50mm defected geotextile

Time of sunlight exposure (hr)	**K(cm/s)**		
	1day	**2days**	**3days**
1hr	2.603×10^{-7}	1.718×10^{-7}	1.423×10^{-7}
2hr	3.645×10^{-7}	2.187×10^{-7}	1.701×10^{-7}
3hr	4.791×10^{-7}	3.020×10^{-7}	2.326×10^{-7}

It indicates that even a small damaged hole can increase the leakage rate and it cannot be self-healed. The effect of sunlight exposure plays a major role in the hydraulic performance of geosynthetic clay liners.

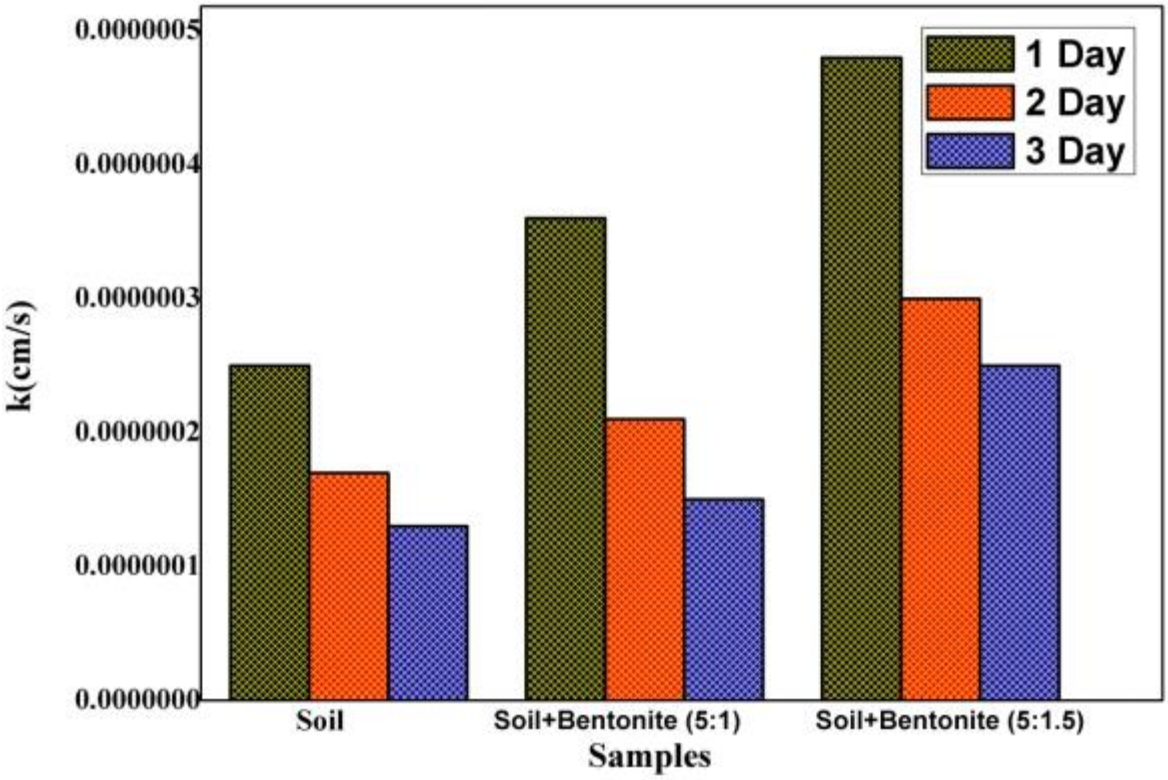

Figure 7. Hydraulic conductivity or permeability values at varys number of days sunlight exposure.

Permeability of gcl with 50mm defected geotextile before sunlight exposure

Permeability of GCL with 50mm damage hole before sunlight exposure is taken and the k value gives the range of 10^{-8} cm/s. Also shows that the size of the hole cannot be self-healed. Figure 8 and Table 5 represent the changes in hydraulic conductivity of GCL without exposure to sunlight.

Table 5. Permeability value of GCL before sunlight exposure

Time	K (cm/s)
1 day	$5.207X\ 10^{-8}$
2 days	$2.603X10^{-8}$
3 days	$2.603X10^{-8}$

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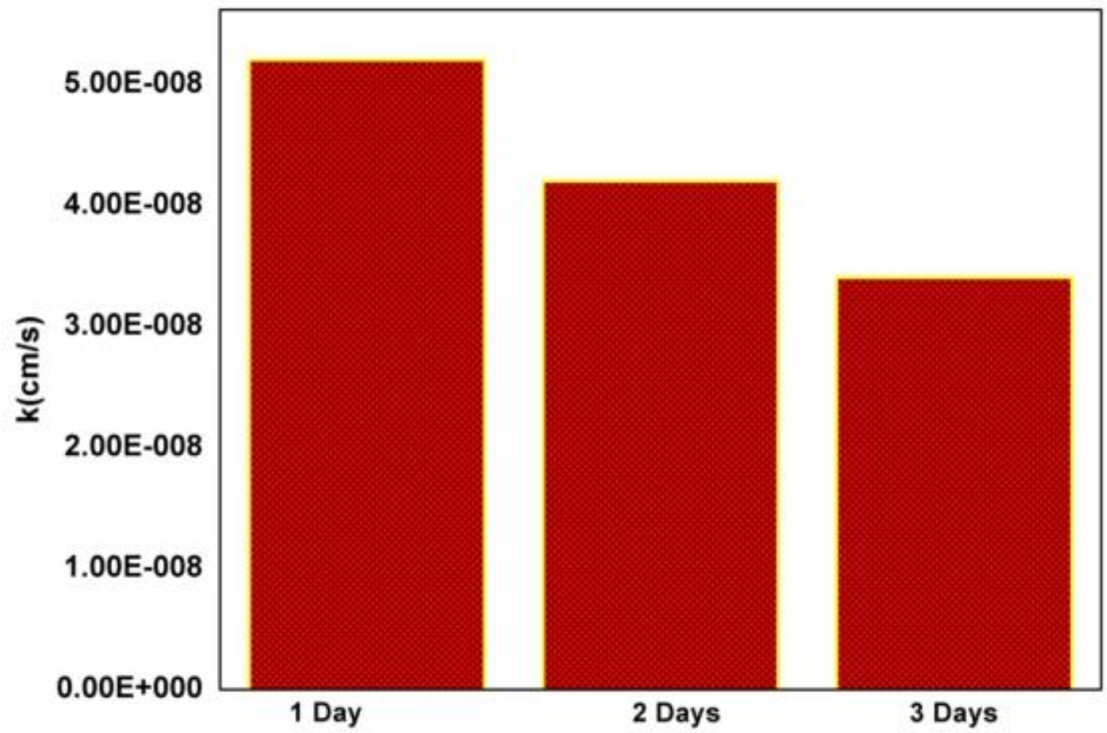

Figure 8. Hydraulic conductivity values without sunlight exposure.

Comparison between hydraulic conductivity of clay-soil mixture and gcl due to sunlight exposure

When the measurements of the clay-soil mixture and GCL are compared as a function of sunshine exposure, the clay-soil mixture has a higher permittivity than the GCL. Figures 9, 10, and 11 demonstrate hydraulic conductivity versus sample type (clay-soil mixture and GCL) after 1 hour, 2 hours, and 3 hours of solar exposure, respectively.

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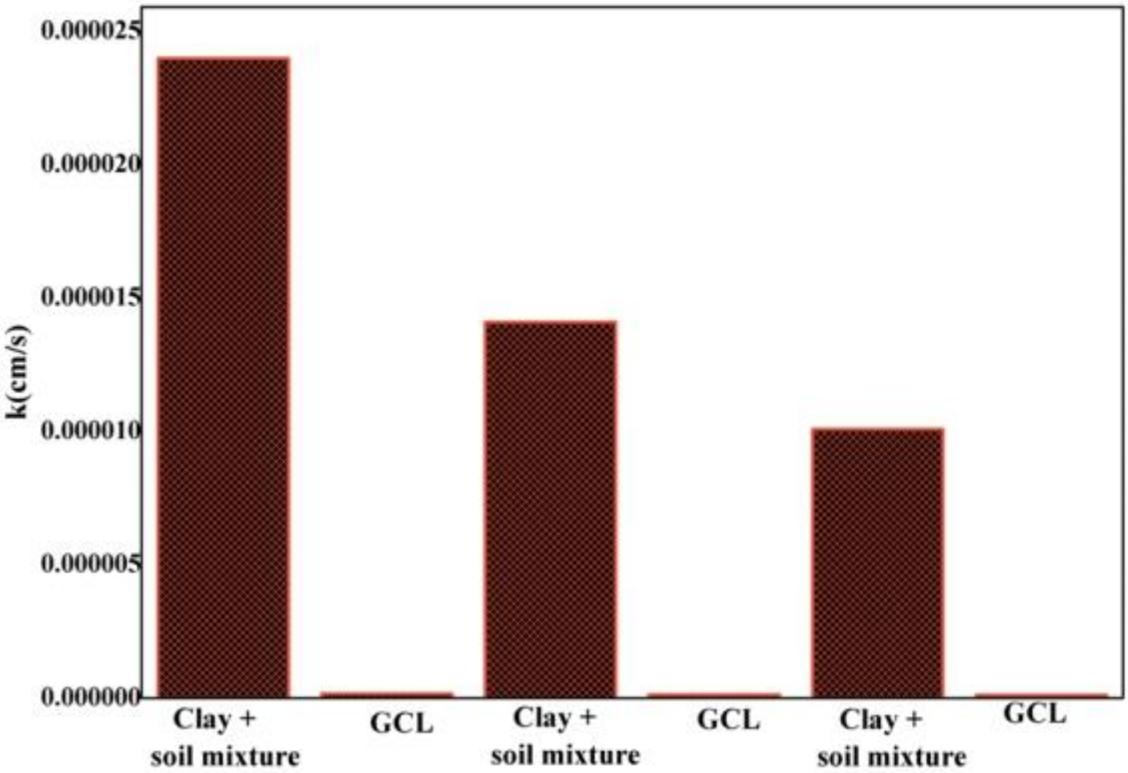

Figure 9. Hydraulic conductivity values of clay-soil mixture and GCL sample at 1-hour sunlight exposure.

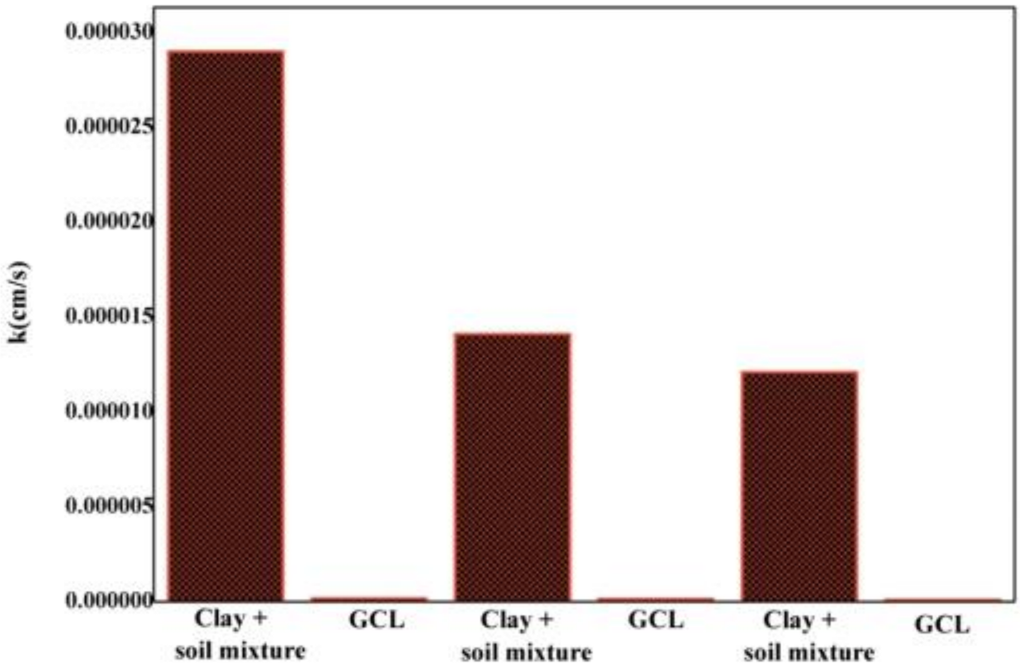

Figure 10. Hydraulic conductivity values of clay-soil mixture and GCL sample at 2-hour sunlight exposure

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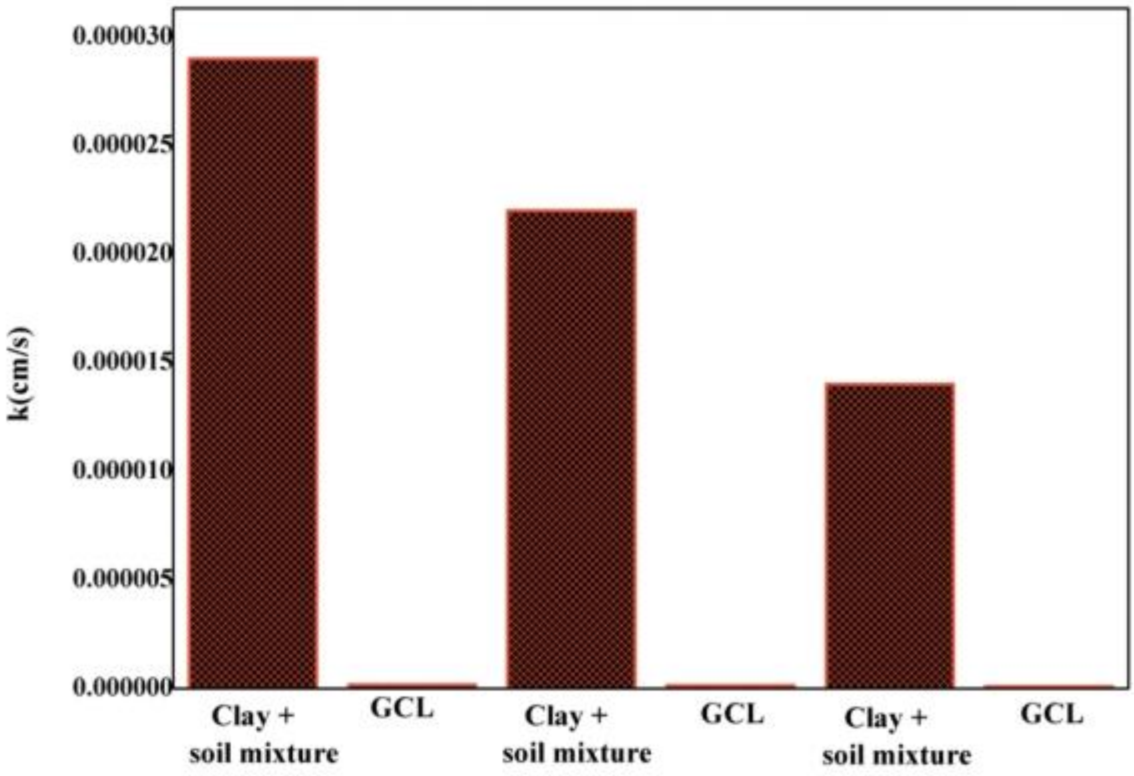

Figure 11. Hydraulic conductivity values of clay-soil mixture and GCL sample at 3-hour sunlight exposure

Comparison between hydraulic conductivity of gcl with sunlight exposure and GCL without sunlight exposure (normal GCL)

When the hydraulic conductivity measurements of GCL with and without sunshine exposure are compared, it is obvious that GCL with sunlight exposure has higher permeability than normal GCL. Figure 12 indicates that the desiccation cracks possess a substantial impact on GCL hydraulic efficiency. The permeability increases as the desiccation crack development grow.

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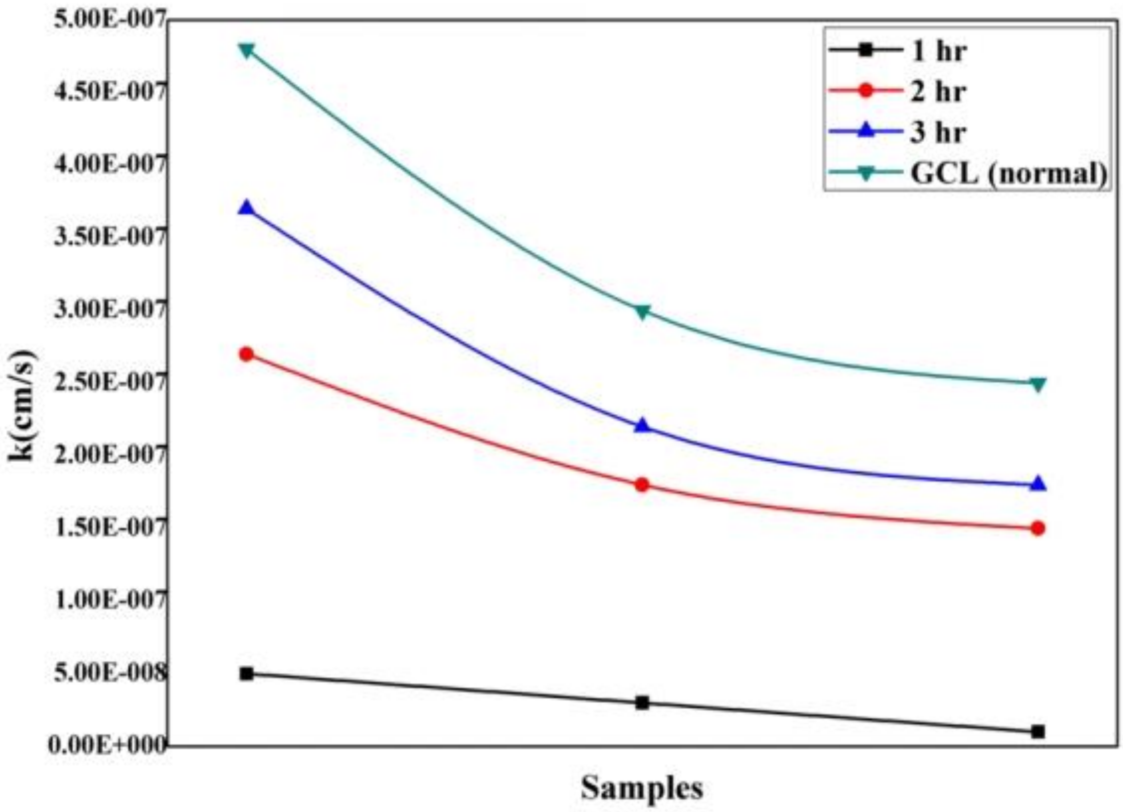

Figure 12. Comparison of hydraulic conductivity values obtained at varying exposure time.

CONCLUSIONS

The geotextile possesses the self-healing potential which was investigated in this research using a 50mm damage hole. The hydraulic conductivity test revealed that the defective geotextile could not self-heal. As a result, the percentage of area defective has a significant impact on the hydraulic conductivity of GCLs. The hydraulic conductivity of the GCL reduced after 1hr, 2hr, and 3hr of sunlight exposure when compared to the clay-soil mixture. The inclusion of geotextile atop the clay-soil mixture causes the permeability value to drop. The hydraulic conductivity rate rises as the number of desiccation fractures grow, according to the outcome of the hydraulic conductivity test. Desiccation fractures have a big impact on hydraulic conductivity since they can't heal entirely. To summarise, our research demonstrates that desiccation fractures are a significant factor affecting the hydraulic performance of geosynthetic clay liners (GCLs).

FUTURE SCOPE OF THE STUDY

It is possible to investigate the growth of desiccation cracks after prolonged sunshine exposure and determine their permeability. The effect of introducing a broken hole anywhere on geotextile and its hydraulic conductivity can be investigated in a future investigation. The influence of nominal thickness on the GCL’s hydraulic conductivity could be investigated by

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varying the clay-soil specimen thickness while keeping all other parameters constant. The effect of the hydraulic head on their hydraulic conductivity can also be studied by adjusting the hydraulic head while keeping all other parameters constant.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request

Funding Statement

Not applicable

Conflict of intrest

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References

[1] Tanasă, F., Nechifor, M., Ignat, M. E., & Teacă, C. A. (2022). Geotextiles—A Versatile Tool for Environmental Sensitive Applications in Geotechnical Engineering. Textiles, 2(2), 189-208.

[2] Zanzinger, H., Koerner, R. M., & Gartung, E. (Eds.). (2022). Clay geosynthetic barriers. CRC Press.

[3] Basu, D., & Lee, M. (2021). Sustainability considerations in geosynthetic applications. In ICE Handbook of Geosynthetic Engineering: Geosynthetics and their applications (pp. 427-457). ICE Publishing.

[4] Bathurst, R. Tomorrow with Geosynthetics: A Cost Effective Building Construction Material.

[5] Hou, J., Teng, Y., Bao, S., Li, H., & Liu, L. (2022). Evaluation of the Hydraulic Conductivity of Geosynthetic Clay Liners. Clays and Clay Minerals, 1-14.

[6] Keerthana, S., & Arnepalli, D. N. (2022). Hydraulic Performance of Polymer-Modified Bentonites for Development of Modern Geosynthetic Clay Liners: A Review. International Journal of Geosynthetics and Ground Engineering, 8(2), 1-20.

[7] El-Zein, A., Airey, D., Yu, B., Esgandani, G. A., Proust, G., Dias-da-Costa, D., ... & Chen, S. (2021). Self-repair of cracks and defects in clay: a review of evidence, mechanisms, theories and nomenclature. Acta Geotechnica, 16(12), 3741-3760.

[8] Rimoldi, P., Shamrock, J., Kawalec, J., & Touze, N. (2021). Sustainable use of geosynthetics in dykes. Sustainability, 13(8), 4445.

[9] Salemi, N., Abtahi, S. M., Rowshanzamir, M., & Hejazi, S. M. (2018). Geosynthetic clay liners: effect of structural properties and additives on hydraulic performance and durability. Environmental earth sciences, 77(5), 1-13.

[10] Jongvivatsakul, P., Ramdit, T., Ngo, T. P., & Likitlersuang, S. (2018). Experimental investigation on mechanical properties of geosynthetic cementitious composite mat (GCCM). Construction and Building Materials, 166, 956-965.

[11] Wireko, C., Abichou, T., Tian, K., Zainab, B., & Zhang, Z. (2022). Effect of incineration ash leachates on the hydraulic conductivity of bentonite-polymer composite geosynthetic clay liners. Waste Management, 139, 25-38.

[12] Ören, A. H., Taşkesti, B., & Özdamar Kul, T. (2022). Evaluating the Hydration and Hydraulic Performance of a Geosynthetic Clay Liner (GCL) in Terms of Bentonite Mass per Unit Area. International Journal of Geosynthetics and Ground Engineering, 8(2), 1-11.

[13] Khan, M. K., Emidio, G. D., & Bezuijen, A. Hydraulic Performance of Alginate-Based Bentonite. In Geo-Congress 2022 (pp. 60-67).

[14] Gholikhany, M., & Badv, K. (2021). Effect of temperature on the hydraulic conductivity of compacted clayey soil and geosynthetic clay liner (GCL). Journal of Civil and Environmental Engineering.

[15] Zainab, B., Wireko, C., Li, D., Tian, K., & Abichou, T. (2021). Hydraulic conductivity of bentonite-polymer geosynthetic clay liners to coal combustion product leachates. Geotextiles and Geomembranes, 49(5), 1129-1138.

[16] Gupt, C. B., Bordoloi, S., Bhatlu, M. N., & Sekharan, S. (2022). Hydraulic conductivity variation in compacted bentonite–fly ash mixes under constant-volume and free-swelling flow conditions. Canadian Geotechnical Journal, 99(999), 1-18.

[17] Musso, T. B., Carlos, L., Parolo, M. E., Francisca, F. M., Pettinari, G., Giuliano, V., & Ruffato, M. (2022). Mudstones as Landfill Liner Material for Heavy Metal Removal: Equilibrium and Dynamic Sorption Study. Water, Air, & Soil Pollution, 233(4), 1-16.

[18] Norris, A., Aghazamani, N., Scalia, J., & Shackelford, C. D. (2022). Hydraulic Performance of Geosynthetic Clay Liners Comprising Anionic Polymer–Enhanced Bentonites. Journal of Geotechnical and Geoenvironmental Engineering, 148(6), 04022039.

[19] Lau, Z. C., Bouazza, A., & Gates, W. P. (2022). Influence of polymer enhancement on water uptake, retention and barrier performance of geosynthetic clay liners. Geotextiles and Geomembranes.

[20] Lo, I. M., & Liljestrand, H. M. (1996). Laboratory sorption and hydraulic conductivity tests: Evaluation of modified-clay materials. Waste management & research, 14(3), 297-310.

[21] Gul, C. B., Gullulu, M., Oral, B., Aydinlar, A., Oz, O., Budak, F., ... & Yurtkuran, M. (2008). Urinary IL-18: a marker of contrast-induced nephropathy following percutaneous coronary intervention?. Clinical biochemistry, 41(7-8), 544-547.

[22] He, J., Wang, Y., Li, Y., & Ruan, X. C. (2015). Effects of leachate infiltration and desiccation cracks on hydraulic conductivity of compacted clay. Water Science and Engineering, 8(2), 151-157.

[23] Bowders Jr, J. J., & Daniel, D. E. (1987). Hydraulic conductivity of compacted clay to dilute organic chemicals. Journal of Geotechnical Engineering, 113(12), 1432-1448.

[24] Sällfors, G., & Öberg-Högsta, A. L. (2002). Determination of hydraulic conductivity of sand-bentonite mixtures for engineering purposes. Geotechnical & Geological Engineering, 20(1), 65-80.

[25] Francisca, F. M., & Glatstein, D. A. (2010). Long term hydraulic conductivity of compacted soils permeated with landfill leachate. Applied Clay Science, 49(3), 187-193.

[26] Wardhana, I. W., Budihardjo, M. A., Istirokhatun, T., & Ikhlas, N. (2021, November). Desiccation cracks behaviour of leachate in bentonite-zeolite composite liner. In IOP Conference Series: Earth and Environmental Science (Vol. 894, No. 1, p. 012043). IOP Publishing.

 https://doi.org/10.37896/pd91.3/91339

[27] Cao, B., Chen, J., & Al-Tabbaa, A. (2021). Crack-resistant cement–bentonite cut-off wall materials incorporating superabsorbent polymers. Canadian Geotechnical Journal, 58(6), 800-810.

[28] Budihardjo, M. A., Syafrudin, S., Priyambada, I. B., & Ramadan, B. S. (2021). Hydraulic Stability of Fly Ash-Bentonite Mixtures in Landfill Containment System. Journal of Ecological Engineering, 22(7).

[29] Zhang, S. C., Li, K., Sun, K. M., & Wang, S. (2022). Impact of Initial Moisture Content on the Shrinkage-Swelling Behavior of Heishan Bentonite. KSCE Journal of Civil Engineering, 26(2), 550-555.

[30] He, Y., Lu, P. H., Ye, W. M., Chen, Y. G., & Zhang, K. N. (2022). Coupled chemo-hydro-mechanical effects on volume change behaviour of compacted bentonite used as buffer/backfill material in high-level radioactive waste repository. Journal of Nuclear Science and Technology, 1-25.

[31] Jadda, K., Injamala, S. K., & Bag, R. (2021). Hydro-mechanical Behavior of Glass Fiber Reinforced Clay Barriers. In Proceedings of the Indian Geotechnical Conference 2019 (pp. 145-156). Springer, Singapore.