Geosciences and Engineering, Vol. 10, No. 15 (2022), pp. 80–95.
https://doi.org/10.33030/geosciences.2022.15.080

A REVIEW ON ROLE OF GEOSYNTHETIC CLAY LINERS IN CONTAMINATED SITE REMEDIATION

Hasan Eteraf[1], Tamás Madarász[2], Amir Mosallaei[3],
Balázs Kovács[4], Viktória Mikita[5]

[1]*University of Miskolc, hghassan@uni-miskolc.hu,* https://orcod.gov/0000-0001-5730-445X
[2]*University of Miskolc, hgmt@uni-miskolc.hu,* https://orcid.gov/0000-0002-3291-1605
[3]*Budapest University of Technology and Economics, amir.mosallaei@epito.bme.hu*
https://orcid.gov/0000-0002-3291-1605
[4]*University of Miskolc, kovacs.balazs@gama-geo.hu,* https://orcid.gov/0000-0002-3594-7355
[5]*University of Miskolc, gmv@uni-miskolc.hu,* https://orcid.gov/0009-0006-9303-1368

Abstract: Many environmental disasters occurred in the past due to site contamination caused by leakage of leachate to surround soil, surface water and ground water aquifer. The main concern is focused on the contamination potential due to migration of the leachate produced from the waste disposal or storage sites into the soil and underlying layers. Leachate quality, quantity and properties are directly relevant to waste management methods, environment conditions and waste characteristics, as well as the process of landfill processing, and the leachate may be the major source of various pollutants and emissions Problems associated with the cleanup sites have shown that remediation technologies need to be developed that are feasible, fast, and deployable in a wide range of physical settings. Using an effective landfill liner is a common way of preventing the movement of pollutants (with gas or leachate) from landfill sites or contaminated sites (e.g. brownfields, fuel stations, accidental spills, etc.). In this study different types of Geosynthetic clay liners were reviewed and they were compared in aspects of hydraulic conductivity, strength, material and chemical to improve GCL design to optimum.

Keywords: *GCL, Liner, leachate, Landfill, Hydraulic Conductivity*

1. INTRODUCTION

Many environmental disasters occurred in the past due to site contamination caused by leakage of leachate to surround soil, surface water and ground water aquifer. The main concern is focused on the contamination potential due to migration of the leachate produced from the waste disposal or storage sites into the soil and underlying layers. [1]

The characteristics of the leachate also depend on the pretreatment of the solid waste such as segregation of recyclable material like plastics, paper, metals, glass, etc, shredding and/or bailing of the waste. the characteristics of landfill leachate vary over time and also they are different from one landfill to another. Many factors effect on the leachate compound such as types of wastes deposited, composition of wastes, moisture content, the particle size, the degree of compaction, the hydrology of the site and the climate. [1]

In response to spreading need to take environmental pollution into consideration, many remediation technologies have been developed to treat soil, leachate, wastewater, and groundwater contaminated by various pollutants. [2] The main goals of sustainable waste management are to protect human health and the environment and to reduce the number of natural resources consumed. [3] A particular contaminated site may require a combination of procedures to allow the optimum remediation for the prevailing conditions. Biological, physical, and chemical technologies may be used in conjunction with one another to reduce the contamination to a safe and acceptable level. [2]

There are numbers of soil remediation approaches such as: soil washing, soil vapor extraction, soil processing, soil flushing, solidification / stabilization, asphalt batching, vitrification, biopiles, phytoremediation, bioslurry systems, bioventing, encapsulation, aeration, thermal desorption. There are, on the other hand, various groundwater remediation methods such as: air sparging, groundwater injection and treatment technology, passive/reactive treatment walls, bioslurping, ultraviolet oxidation treatment, biosparging, groundwater drainage wells, horizontal well technology, natural attenuation. [2]

Problems associated with the cleanup sites have shown that remediation technologies need to be developed that are feasible, fast, and deployable in a wide range of physical settings. [2] Using an effective landfill liner is a common way of preventing the movement of pollutants (with gas or leachate) from landfill sites or contaminated sites (e.g. brownfields, fuel stations, accidental spills, etc.). 'Liner' is an identifier layers of materials performed before waste is collected to cover or line the surface of the waste disposal sites. [5]

2. LEACHATE

Throughout the waste disposal process, a managed disposal procedure is unavoidable, either for the disposal of actual waste or of materials remaining during the treatment phase or, if necessary, if the main phase cannot be carried out for a period of time due to failure, malfunction, remediation or other causes. Landfill is a main municipal solid waste disposal facility in most countries, some of which are still on the least developed category and face a linear rise in municipal solid waste and problems with waste management. [24]

The construction of an engineered sanitary landfill is certainly quite capital intensive. Having an overview of the performance of landfill sites demands experience and understanding of the characteristics of the landfill waste as well as the operating activities at the landfill site. [23]

Increased resource consumption results in large quantities of solid waste from different forms of manufacturing and domestic operations, which pose a major threat to human health and the environment. [25]

Leachate quality, quantity and properties are directly relevant to waste management methods, environment conditions and waste characteristics, as well as the process of landfill processing, and the leachate may be the major source of various pollutants and emissions. [26]

Chemical reactions such as biodegradation, adsorption, hydrolysis, dissolution, dilution, partitioning and precipitation are among the most important factors influencing the consistency of the leachate. [27]

The form and concentration of the pollutants in the leachate depends on the manner of disposal, along with the composition of the waste, and on the isolation of the waste prior to its final disposal. [28]

The lack of sufficient landfill infrastructure, such as liner, leachate storage and treatment systems, raises the risk for soil, groundwater and surface water pollution. [29]

In most situations, landfill leachate is composed of organic matter, inorganic chemicals and toxic substances. [31]

Hazardous substances in municipal solid waste (MSW) are identified in the form of paints, mercury-containing waste, batteries, vehicle maintenance materials and many other diffuse products. [30]

Solid waste disposal services, such as open dumps, landfills, sanitary landfills or incinerators, are a primary source of metals released into the environment. In addition, there is a greater risk of groundwater pollution in areas near landfill sites; this is due to the fact that most landfills and disposal facilities release a large amount of leachate into their surroundings. There are varying degrees of effects on human health and the environment depending on the form of landfill and its management. [22]

Principal leachate collection systems can have service lives that vary from less than a decade to more than a century, depending on design specifics, waste features and mode of operation. The use of liners is one of the most inexpensive ways to monitor and avoid contamination of the ground. Field tests and theoretical calculations indicate that composite liners are considerably stronger than single liners when it comes to preventing landfill leakage. Composite liners containing a geomembrane (GM) over a geosynthetic clay liner (GCL) resulted in considerably less leakage than those containing a compacted clay liner (CCL). High-density polyethylene (HDPE) GMs provide an excellent diffusive ion barrier. However, some organic compounds which are readily diffused through HDPE GMs and a combination of GM and a sufficient thickness of liner and attenuation layer are needed to regulate the effect at negligible rates. [11]

3. GCLs

During the last decade, structural engineers and environmental authorities have shown increasing interest in the use of geosynthetic clay liners (GCLs) as an alternative to compacted clays in over systems or, in some situations, bottom liners in waste containment facilities, as they also have very low hydraulic conductivity to water (kw < 10^{-10} m / s) and fairly low cost. In addition to environmental uses such as liner or solid waste storage systems, GCLs are also used as environmental barriers in transport facilities (road and rail) and geotechnical uses such as reducing contamination of subsurface layers from chemical leaks and drainage of road accidents. GCLs are also used as secondary liners for underground storage tanks of fuel to protect groundwater resources and are used as main liners for canals, reservoirs or surface impoundments. [6]

Containment measures can be classified as follows:

1. Bottom liners or barriers
2. Cover or cap liners
3. Vertical side barriers or cut-off walls

- The bottom liners are typically associated with the overlying drainage layer and the underlying low-permeable layer, often referred to as the geological barrier. A stable soil from a geotechnical point of view, ideal for base and building and not prone to subsidence, would be the geological barrier below and adjacent to the waste disposal site. Bottom barriers must sustain the mass of waste and should be almost impermeable in order to prevent leachate from spreading to the ecosystem. Most regulations therefore allow a low permeability of < 10^{-8}–10^{-9}/ s.
- Cover or cap liners shield waste or polluted land from rainwater penetration, gas emission and erosion. The main goals of the landfill cover are as follows:
  - minimizing water infiltration
  - preventing emission of mainly volatile pollutants
  - preventing erosion by water and wind
  - increasing the evaporation rate
  - re-cultivation and integration of the landfill into the regional landscape.
- Vertical side barriers or cut-off walls regulate lateral water flows (infiltration of groundwater or outflow of leachate) in landfills and contaminated areas. Material changes within the cut-off walls can be preceded by the same processes that affect the compacted clay liners: desiccation, freeze/thaw, chemical incompatibility, and excessive deformation.

Clay is most commonly used in containment systems to control the flow of water, leachate and gas to and from waste disposal sites. The compacted clay layer (CCL) can be used either individually or as a part of a lining system with an overlay of synthetic high-density polyethylene (HDPE) membrane (geomembrane) and a drainage layer. The combination of a CCL with a geomembrane is often referred to as a composite liner. The CCL, usually with a thickness of 0.5–1.0 m or more, can be substituted by a manufactured geosynthetic clay liner (GCL), which is a thin layer of low permeable substance (e.g. clay, bentonite) covered by geotextiles and/or geomembranes that are held together by Needling, sewing and/or synthetic adhesives. [5, 12]

The types of geotextiles which are used with the various material, vary significantly in their manufacturing style (e.g. woven slit film, needle punched nonwoven, spun, heat bonded nonwovens, etc.) and in their mass per unit area [e.g. ranging from 85 g/m2 to 1000 g/m2]. The thickness of GCL is usually 4–6 mm. GCLs are shipped to the site at a moisture level ranging from 5 to 23 per cent based on the local humidity. [12]

Geosynthetic clay liners (GCLs) have gained popularity as a replacement for compacted clay liners in cover systems and composite bottom liners. These are also used as environmental barriers in transport facilities or reservoirs and as single liners for canals, ponds or surface impoundments. As a result, they are intensively studied, in particular with regard to their hydraulic and diffusion properties, chemical stability, mechanical behaviour, endurance and gas migration. [6]

Through this study GCL were reviewed from different point of view in different aspect. The priority was evaluation of hydraulic conductivity as it is the most important factor of GCL performance.

4. STRENGTH

In the refurbishment process for aged small earth dams, the sloping main zone is usually built as a water barrier on the upstream side of the bodies by using cohesion impermeable soil. However, these soils are not always accessible at dam sites and their supplying is also problematic. The installation of geosynthetic clay liners (GCLs) was suggested as one of the alternative approaches for the construction of a sloping core region. GCLs are commonly used in waste disposal facilities and are considered to be impermeable materials for small earth dams. Nevertheless, design criteria have not yet been formed as there are few studies on the mechanical characteristics of GCLs in small earth dams. Specifically, the shear strength parameters of the internal bentonite layer of GCLs during the earthquake must be studied. [7]

Ross & Fox presents the results of full-scale research to further investigate possible GCL damage factors in earth dam retrofit applications in seismically active areas. In particular, (a) investigate whether shear displacements may reduce the magnitude of GCL overlap during earthquakes; (b) explore the impact of gravel particles on GCL thickness at the localized point of contact; and (c) examine the implications of accidental exposure of exposed GCL to short-term precipitation in terms of moisture content and effects during subsequent compacting; The results of these experiments show that no changes were observed in the GCL panel even under extreme shaking. Although gravel particles have been observed to reduce the thickness of the GCL to 2.2 millimetres locally, no plowing of the particle into the GCL has occurred due to a lack of shear displacement at the interface, resulting in no localized internal erosion through the barrier. In addition, hydration of GCL panels during construction due to surface wetting has been found to result in less hydration than post-construction. These findings show that while each of the three GCL damage factors cannot be ruled out to be relevant in operation, the performance of the GCL retrofitted earth dam tested was adequate under even extreme earthquake level 2 shaking and indicates that the retrofitting of small earth dams with GCLs is a promising strategy to optimize their static and seismic resistance. [13]

The design standard for small earth dams using GCLs is not known as there are few research on their mechanical features. Throughout Shigemoto's analysis, cyclic direct shear tests were performed on the internal bentonite layer of needle punched GCL in order to investigate the mechanical characteristics of GCLs laid in reservoirs during earthquakes. Tests were conducted under standard stress of 25 kPa, taking into account the low confining pressure in embankments and the shear displacement amplitude of 0.5, 1.0, 3.0 and 5.0 mm. The shear strength was observed to decrease with the amount of test cycles due to the fracturing of the needle-punching and the removal of the needle from the geotextiles. In addition, the results showed that the amount of decrease in shear strength expanded as the amplitude grew. [7]

There are few researches on the shear strength performance of the GCLs under dynamic loading. Lai et al. (1998) conducted stress regulated cyclic simple shear tests on the internal bentonite layer of GCL which is supported by geomembrane without needles-punching in hydrated and without moisture conditions. [7]

Tests show that small displacement amplitudes ($\Delta a \leq 10$ mm) had little to no impact on the post-cyclic static shear strength for GMX / GCL interface. Larger displacement amplitudes resulted in a decrease in post-cyclic static strength until a displacement amplitude of 20 mm was achieved, after which there was no further decrease in shear strength of the interface with increasing displacement amplitude. The mode of failure depended on the rate of cyclic shearing. Larger displacement amplitudes ($\Delta a = 30$ mm) needed faster shearing and led in interface failures for all normal stresses, whereas smaller amplitudes needed slower shearing and partial internal shearing to complete internal failures of the GCL. [13]

In another research, the post-cyclic static shear response of the GMX/GCL interface were examined. Each post-cyclic static test was carried out at a displacement rate of $R = 1$ mm/min. For $\Delta a < 15$ mm, the peak shear stress was not affected, and corresponded to the peak shear stress of the monotonic test completed with no previous cyclic testing. For $\Delta a \geq 15$ mm, the peak strength was greatly reduced. [21]

A waste containment facility liner or cover system must not only have a good hydraulic / gas barrier, but must also be structurally strong during all steps of the project (i.e. while construction, during and after waste storage). For this purpose, the determination of stability is a vital consideration for design engineering. [6]

Shan and Daniel (1991), Stark and Eid (1996), Gilbert et al. (1996), Eid and Stark (1997), and Fox et al. (1998a) provided a detailed collection of findings on the internal strength of unreinforced GCLs and reinforced GCLs. Peak shear strengths for non-reinforced GCL products were found to be similar to those for bentonite in aspect of having very low shear strength. This is the reason why it is not generally prescribed for slopes of more than 10H : 1V (Frobel, 1996; Richardson, 1997). At the other side, reinforced GCLs possess a higher internal peak strength due to the presence of fibers. Reinforced GCL strength behavior has also been shown to rely on fiber resistance and bentonite shear strength. When the fibers are pulled out and/or ripped at large displacements, bentonite can continue to absorb residual force. It should be noted that despite the internal failure of reinforced (needle punched) GCLs could happened in the laboratory, no known instances of slope failures can be attributed to internal shear failure of reinforced GCLs. [6]

A group of laboratory experiments were carried out to investigate the geomechanical and geoenvironmental properties of sepiolite alone, zeolite alone, sepiolite–zeolite soil mixtures as control content.

The rise in applied compaction energy greatly improved the unconfined compressive strengths (qu) of all soil mixtures. In comparison, all soil mixtures prepared at an optimum 5 per cent dry side and an optimum 5 per cent wet side got the highest and lowest qu values, respectively.

Sepiolite itself has yielded the highest qu values. Furthermore, the qu values were significantly risen with the addition of sepiolite to the zeolite soil. In addition, rising the sepiolite content, caused a significantly decrease in hydraulic conductivity value of soil mixtures due to high activity, high clay content, plasticity index and high specific surface area. [4]

5. MATERIAL

Landfill bottom liners are typically made of natural clay soils due to their high strength and low hydraulic conductivity characteristics. However, in recent years it has become increasingly difficult to find locally available clay soils that meet the essential engineering characteristics. [4]

Nevertheless, in previous years it has become more difficult to find locally accessible natural soil that satisfies the engineering properties described above. Scientists are now searching for alternate materials that can be used as liners in urban waste disposal sites. Recent studies have suggested replacing natural clay soils with soil likehood geomaterials such as sand-bentonite mixtures, foundry sand, fly ash, wood ash and tire rubber. [4]

Although these materials generally fulfilled the engineering properties required to be used in liner constructions, issues relating to their mechanical and environmental compatibility have been identified. [4]

Low hydraulic conductivity is typically met by CCL, which also includes smectites. Because wet clay content is often very difficult to handle and dry clay is very prone to cracking, sand and clay mixtures (often bentonite) are used as bottom liners (Grantham and Robinson, 1988; Cancelli et al., 1994; Ebina et al., 2004). In this case, the hydraulic conductivity depends heavily on the content of the clay. A higher hydraulic conductivity was determined for Ca-type rather than Na-type clays. A combination of bentonite and zeolite also resulted in higher hydraulic conductivity in comparison to sand-bentonite mixtures (O¨ren et al., 2011). [5]

If expansive clays are mixed with fly ash-an industrial waste- the density of mixture increases that leads to a reduction in hydraulic conductivity. Fly ash-stabilized expansive clay may therefore also be suggested as an advanced clay liner material. It is therefore important to research the different physical and engineering characteristics of this new clay liner material. Liquid limit (LL) and free swell index are important factors to be reviewed for this clay liner material. The hydraulic conductivity of this new clay liner material refers to the amount of the fly ash in the mixture. Viana et al. presents experimental results gained on hydraulic conductivity (k) of fly ash stabilized expansive clay liner at varying levels of fly ash and solute concentration of transmit fluid. Tests were conducted with (DIW), $CaCl_2$, NaCl and KCl deionized water as permeating fluids. Fly ash content varied as 0, 10, 20 and 30 per cent by weight of expansive clay used in admixtures and the concentration of solute varied as 5 mM (milli molar), 10, 20, 50, 100 and 500. Rising amount of fly ash, solute concentration and kinematic viscosity, caused a decrease in Hydraulic conductivity (k). So it seems that Parameters such as solute concentration and kinematic viscosity of permeating fluids also affect the hydraulic conductivity of clay liners. [15]

For example, Edil et al. (1992) and Palmer et al. (2000) indicated that the use of fly ash in liner construction is practical. However, the field ash compaction process can be complicated and may result in higher hydraulic conductivity and lower stiffness (Palmer et al., 2000). In fact, fly ash itself contains a large amount of heavy metals, which is an unavoidable hazard for the environment. Sand – bentonite mixtures and foundry sand provided a reasonable level of stiffness and hydraulic conductivity with pure deoinized water influent solutions. Nevertheless, the hydraulic conductivity of these soils improved dramatically with the use of chemical influent solutions. [4]

Karunaratne et al. conducted laboratory research to explore the practical feasibility of combining alternative materials with bentonite to generate Modified low-cost GCLs. The alternative materials used were sand, clay and tire grain. Direct shear, consolidation and expansion tests were conducted on bentonite mixtures with differing percentages in the mass of the alternative material. Ramp tests and expansion tests were also performed on alternative GCLs produced with these types of mixtures. The findings obtained have shown that the presence of alternative materials in bentonite has improved the shear strength and permeability of the mixture and reduced its potential of expansion. Tests on bentonite-tire grain mixtures indicate that alternative GCLs developed with this form of mixture can be used in less critical barrier systems (especially under high stress levels) and as liner/protective layers below geomembranes, thus having better usage for waste tires in terms of environmental. Hydraulic conductivity and consolidation behavior of bentonite-kaolinite mixtures have been analyzed. It was found that at least 30% bentonite was needed in the mixture to achieve the same decreasing coefficient of consolidation tendency with pressure as seen by pure bentonite. The 50 : 50 bentonite : kaolinite (50 : 50 B: K) ratio failed in approximately the same hydraulic conductivity, k, as pure bentonite; The hydraulic conductivity tests were performed using pure water, 0.25 M calcium chloride, 0.1 M hydrochloric acid, and 0.1 M sodium hydroxide. With the calcium chloride permeant, the hydraulic conductivity of the mixture was observed to be in the range of 10^{-10}m/s, while the hydrochloric acid and sodium hydroxide permeants yielded values of approximately 10^{-11}m/s. The idea of using a mixture of bentonite-kaolinite (B : K) instead of pure bentonite with a jute geotextile as the foundation of a clay liner in a landfill is discussed exploring the potential use of kaolinite to replace the percentage of bentonite used in landfill and liner systems was the goal of one of performed research. [16]

Red mud is a waste material produced by the Bayer Process commonly used in the manufacturing of alumina from bauxite. Approximately 35% to 40% per ton of bauxite processed with the Bayer Procedure ends up as red mud waste. According to disposal issues, contamination has a detrimental effect on the environment. Exploring the various reuses of red mud waste is necessity to find a proper solution of this environmental issue. Tian et al.'s research evaluates the effects of red mud on unconfined compressive strength, hydraulic conductivity and swelling of compacted clay liners as a hydraulic barrier. The findings of the study indicate that compacted clay samples including red mud and cement-based mud additives had a high compressive strength and decreased the values of hydraulic conductivity and swelling in comparison to natural clay. It is therefore demonstrated that red mud and cement-red mud materials can be used successfully in geotechnical applications for the stabilization of clay liners. [17, 18]

6. CHEMICAL

Synthetic and natural municipal solid waste (MSW) leachate permeation affects the hydraulic conductivity and exchange complex of geosynthetic clay liners (GCLs). A number of laboratory experiments were carried out to analyze the geomechanical and geoenvironmental properties of sepiolite alone, zeolite alone, sepiolite–zeolite soil mixtures and Eskisehir clay as control material. Sepiolite did not have a noticeable effect on the pH of the effluent solutions even though it had approximately 23 per cent CaO material. On the other hand, the increase in sepiolite content lowered the electrical conductivity (EC) of sepiolite – zeolite soil mixture wastewater solutions. Column leaching experiments showed that sepiolite clay had a greater impact on adsorption ability of landfill liners. adsorption levels of Pb^{2+}, Cu^{2+}, and Zn^{2+} rose with the sepiolite material. On the other hand, temperature had a major effect on the adsorption of metals. for example, Steel adsorption at 35 °C was 375 times greater than steel adsorption at 5 °C. [4]

The effect of temperature on the hydraulic conductivity values with bentonite swelling is elucidated using the NaCl solutions, not deionized water used in previous studies, because the swelling capacity of bentonite in deionized water is so large that changes in hydraulic conductivity are negligible even at an elevated temperature. The free swell in the 60 °C NaCl solution is larger than that in the 20 °C NaCl solution. Although previous studies have suggested that the intrinsic permeability is smaller for the 60 °C NaCl permeation than for the 20 °C NaCl permeation, the measured intrinsic permeability values of GCLs are $5.9 * 10^{-18}$ m^2 for the 20 °C NaCl permeation and $2.5 * 10^{-17}$m2 for the 60 °C NaCl permeation. Consequently, the intrinsic permeability increases with temperature, and the relationships between the free swell and the hydraulic conductivity reported in previous studies are not applicable to the elevated temperature condition. [8]

The problem of cation exchange-induced changes in hydraulic conductivity for sodium bentonite GCLs has received considerable attention recently (Dobras and Elzeas, 1993; James et al., 1997; Melchior, 1997; Lin and Benson, 2000). This focus is due to the fact that an increase in GCL hydraulic conductivity (one to two orders of magnitude) has been observed in contact with calcium-rich soils or calcium solutions. Such findings refer to GCLs which are subjected to low compressive pressures (<20 kPa) as usual of landfill cover systems. It is expected that at high compressive pressures such as those found in the bottom liners of the landfills, no adverse impact will be found. (Daniel, 2000). [6]

Results of confined swell, consolidation, and hydraulic conductivity tests on the needle-punched geosynthetic clay liner (GCL) are stated. Effects of permeant [purified water, aqueous single-salt solutions with concentrations between 0.01 and 2.0 M NaCl and industrial municipal solid waste (MSW) leachate], static confining tension, hydrating medium and degree of bentonite hydration at the time of applying confined stress are tested. Increases in permeant salt concentration and declines in the severity of the container tension induced an increase in hydraulic conductivity. High concentrations of salt in hydrating fluids have been shown to increase hydraulic conductivity. GCLs with 0.6 M and 2.0 M NaCl solutions were more permeable than GCLs hydrated with water at first. The impact of bentonite hydration degree at the time of application of the confining stress was demonstrating the hydraulic advantages of maximizing overloaded stress prior to GCL hydration. Tests conducted using synthetic MSW leachate produced findings equivalent to those obtained with aqueous salt solutions between 0.2 and 0.8 M NaCl. [10]

Bentonite is a natural clay mineral commonly used in the mining and solid waste disposal industry, e.g. as a soil mixture for the installation of seepage barriers or as a part of geosynthetic clay liners (GCLs) to have low hydraulic conductivity. However, the deterioration of bentonites usually happens when permeated with acidic solutions, such as those used in mining applications, which may affect the physical characteristics and, in general, the hydraulic performance of geosynthetic clay liners. In Petrov et al. research, properties such as Atterberg limits, free swell index, and fluid loss of three specimens of bentonites with various concentrations of sulphuric acid solutions were calculated. Such features were shown to deteriorate even with low (0.015 M) sulfuric acid solutions; higher concentrations (up to 1 M) resulted in greater degradation. X-ray diffraction and infrared spectroscopy have been used to track shifts in bentonites after interactions with acid solutions. Acid leachate typically results in the overall deterioration of the hydraulic utilization of geosynthetic clay liners and, potentially, of any bentonite-soil mixture. [9]

Eight commercially available geosynthetic clay liners (GCLs) permeated with a leachate characteristic of low-level radioactive waste (LLW) disposal facilities managed by the U.S. Department of Energy (DOE) were tested for hydraulic conductivity. Two GCLs (CS and GS) contained conventional sodium bentonite (Na-B). The rest formed a combination of bentonite – polymer (CPL, CPH, GPL1, GPL2 and GPH) or bentonite – polymer composite (BPC). All GCLs (except GPL2 and GPH) were specifically permeated with two synthetic LLW leachates that were essentially equal, except that one had no radionuclides (non-radioactive synthetic leachate or NSL) and the other had radionuclides (radioactive synthetic leachate or RSL). The hydraulic conductivity of RSL and NSL were equivalent. In the case of CS and GS GCLs, the hydraulic conductivity steadily rose by 5–25 because the divalent cations in the leachate substituted the original sodium cations bound to bentonite. CPL, GPL1, and GPL2 GCLs with low polymer loading (1.2–3.3 per cent) had hydraulic conductivity comparable to conventional GCLs. At the other side, hydraulic conductivity of CPH, GPH and BPC GCLs with high polymer loading ($\geq$5 per cent) to RSL or NSL was equal or lower than hydraulic conductivity to deionized water. Leachate permeation reduced the bentonite swell index in all GCLs. [19]

Bradshaw et al. assessed the usage index properties such as liquid limit, sedimentation volume and swell index of bentonite hydrated with chemical solutions as a substitute measurement to see the influence of chemical solutions on the hydraulic conductivity of two GCLs. One GCL included higher quality bentonite HQB and the other one has lower quality bentonite LQB. Calcium chloride $CaCl_2$ solutions have been used for the research system as such solutions are known to improve the hydraulic conductivity of GCLs. In general, a rise in the concentration of $CaCl_2$ resulted in a reduction in the liquid limit LL, sedimentation volume SV, or swell index SI, and a rise in the hydraulic conductivity k of the GCL. Little to no change in an index property, however, did not automatically mean there was no change in k, and major changes in an index property appeared without significant changes in k. [20]

In Xaypanya et al. study, the effect of synthetic salt solutions on the consistency and compressibility behaviours of compacted clay at various concentrations was evaluated. Two forms of inorganic salts $MnSO_4$ and $FeCl_3$ are used at various concentrations of 2 percent, 5 percent and 10 percent. The Clay used was CL-clay (kaolinite). The result indicates that the consistency limits increased while the concentration of salts increased. although the compression index (Cc) decreased by rising the concentration from 2% to 5%, after that the Cc became almost unchanged. The swelling index (Cs) continues to increase steadily as the concentration of MnSO4 rises but it tends to decrease with risen in concentration of $FeCl_3$. [22]

7. CONCLUSION

In this study, GCLs performance were evaluated as a liner in landfill in aspect of Hydraulic conductivity, strength, swell index, etc. also the influence of leachate characteristic on hydraulic conductivity of GCL were reviewed. There is often a lack of clay supply at the site and a need for improved hydraulic conductivity in some projects, and cost efficiency may be the project's goal. Depends on the type of project, using an alternative material as a substitution can be a good solution in all the cases listed. Discussion and comparison of previous studies on this topic has the following outcome:

- Most regulations require GCLs to have low permeability of less than $10^{-9}\ \frac{m}{s}$
- Although Using fly ash as an additive cause decrease in hydraulic conductivity, it contains heavy metals which can be dangerous for environment.
- Sand–bentonite mixtures and foundry sand are a good choice because of their low hydraulic conductivity as barrier material in GCL. But their hydraulic conductivity would be increased in the situation of using chemical permeant (not pure water), so it does not make sense to use it.
- Red mud addition increases GCL efficiency by reducing hydraulic conductivity. It also causes increase in strength.
- The mixture of bentonite with tire grain has low hydraulic conductivity and is a suitable substitution material in GCl.
- Hydraulic conductivity depends on content of the clay deeply. Clay including Ca has higher hydraulic conductivity than Na-type clay. Bentonite-zeolite combination also has higher hydraulic conductivity than sand bentonite combination.
- Using sepiolite and zeolite in GCL will increase its shear strength. However, the presence of these two materials, especially sepiolite, has a major effect on the reduction of hydraulic conductivity.
- Hydraulic conductivity also relies on permeant fluid pH. Increasing pH can contribute to hydraulic conductivity increase.
- hydraulic conductivity depends on solute concentration and kinematic viscosity of permeating fluids
- Hydraulic conductivity of GCL against of salt solution is more than pure water. the diverge of acid fluid permeant ($8 * 10^{-11}$) with pure water ($3.14 * 10^{-11}$) is more than alkaline fluid permeant ($2.5 * 10^{-11}$) with pure water. So, the hydraulic conductivity of salt solution is more than pure water, like as acidic one.
- The presence of radioactive content in permeated fluid does not impact hydraulic conductivity of GCL. Significant raise in polymer amount of GCLs leads to increase in hydraulic conductivity.
- Non-reinforced GCL is not suggested for high-rate slopes due to their low shear strength.

- Although reinforced GCLs' failure is possible due to theoretical science, but it has never occurred in reality up to now.
- Needle-punch in GCL play a significant role in strength of it. fracturing of the needle-punching and the removal of the needle from the geo-textile during earthquake occurred result in decrease of shear strength.
- In both low and high normal stresses, small displacement amplitudes ($\Delta a \leq 10$ mm) has a neglectable effect on shear strength. whereas, larger displacements cause more decrease in shear strength.
- A further advantage of GCL is the adsorption of heavy metals. It is noteworthy to bear in mind that the temperature produced as a result of chemical and biological landfill processes has a major influence on heavy metal adsorption. By increasing in temperature, more heavy metals will be adsorbed.
- Several parameters affect GCL efficiency that their impact are not predictable because of dissimilar influence in different condition, For example The effect of leachate characteristics on swell index of liner and also Effect of temperature on hydraulic conductivity of GCL are not predictable.

After all, Using GCL as a liner in waste disposal is one of the best ways if not the best way to prevent leachate migration into environment and also they are a wise choice to use in case that resistance of liner is required. Choosing the type of GCL and its material depends on intent of the project and its applicability but having low hydraulic conductivity should be considered anyway. using a substitute material in GCL can improve its performance, however the optimoum amount of substitute material should be taken into consideration. Using more than optimum content can cause side effect. For example, the optimum amount of kaolinite is 50% In bentonite-kaolanite mixture and using more than 70% of it, cause increase in hydraulic conductivity.

ACKNOWLEDGEMENT

The described article/presentation/ study was carried out as part of the GINOP-2.3.2-15-2016- 00031 "Innovative solutions for sustainable groundwater resource management" project implemented in the framework of the Szechenyi 2020 program. The realization of this project is supported by the European Union, co-financed by the European Social Fund and the European Structural and Investment Funds.

REFERENCES

[1] Kumar, D. and Alappat, B.J. (2005). Evaluating leachate contamination potential of landfill sites using leachate pollution index. *Clean Technologies and Envi-ronmental Policy*, 7 (3), pp. 190–197. http://doi.org/10.1007/s10098-004-0269-4

[2] Khan, F.I., Husain, T. and Hejazi, R. (2004). An overview and analysis of site remediation technologies. *Journal of environmental management*, 71 (2), pp. 95–122, https://doi.org/10.1016/j.jenvman.2004.02.003.

[3] Allesch, A. and Brunner, P.H. (2014). Assessment methods for solid waste management: A literature review. *Waste Management & Research*, 32 (6), pp. 461–473, https://doi.org/10.1177%2F0734242X14535653.

[4] Guney, Y., Cetin, B., Aydilek, A. H., Tanyu, B. F. and Koparal, S. (2014). Utilization of sepiolite materials as a bottom liner material in solid waste landfills. *Waste management*, 34 (1), pp. 112–124. https://doi.org/10.1016/j.wasman.2013.10.008

[5] Wagner, J. F. (2013). Clay liners and waste disposal. In *Developments in Clay Science*, Vol. 5, Elsevier, pp. 663–676. https://doi.org/10.1016/B978-0-08-098259-5.00023-8

[6] Bouazza, A. (2002). Geosynthetic clay liners. *Geotextiles and Geomembranes*, 20 (1), pp. 3–17, https://doi.org/10.1016/S0266-1144(01)00025-5.

[7] Shigemoto, R., Sawada, Y., Maki, R. and Kawabata, T. (2018). Shear Strength Characteristics of Internal Bentonite Layer of Needle-Punched GCL Used in Small Earth Dams under Cyclic Loading. In *Geotechnical Earthquake Engineering and Soil Dynamics V: Slope Stability and Landslides, Laboratory Testing, and In Situ Testing*, pp. 365–372. VA: American Society of Civil Engineers, Reston, https://doi.org/10.1061/9780784481486.038.

[8] Ishimori, H. and Katsumi, T. (2012). Temperature effects on the swelling capacity and barrier performance of geosynthetic clay liners permeated with sodium chloride solutions. *Geotextiles and Geomembranes*, 33, pp. 25–33. https://doi.org/10.1016/j.geotexmem.2012.02.005

[9] Petrov, R. J. and Rowe, R. K. (1997). Geosynthetic clay liner (GCL)-chemical compatibility by hydraulic conductivity testing and factors impacting its performance. *Canadian Geotechnical Journal*, 34 (6), pp. 863–885. https://doi.org/10.1139/t97-055

[10] Rowe, R. K. (2005). Long-term performance of contaminant barrier systems. *Geotechnique*, 55 (9), pp. 631–678, https://doi.org/10.1680/geot.2005.55.9.631.

[11] Daniel, D. E. and Koerner, R. M. (1993). Quality assurance and quality control for waste containment facilities. Risk Reduction Engineering Laboratory, Office of Research and Development, US Environmental Protection Agency. https://nepis.epa.gov/

[12] Sawada, Y., Nakazawa, H., Take, W. A. and Kawabata, T. (2019). Full scale investigation of GCL damage mechanisms in small earth dam retrofit applications under earthquake loading. Geotextiles and Geomembranes, 47 (4), pp. 502–513, https://doi.org/10.1016/j.geotexmem.2019.03.001.

[13] Ross, J. D., Fox, P. J. and Olsta, J. T. (2011). Dynamic shear response of a geomembrane/geosynthetic clay liner interface. In *Geo-Frontiers 2011: Advances in Geotechnical Engineering*, pp. 2010–2020. https://doi.org/10.1061/41165(397)205

[14] Phanikumar, B. R. and Shankar, M. U. (2016). Studies on hydraulic conductivity of fly ash-stabilised expansive clay liners. *Geotechnical and Geological Engineering*, 34 (2), pp. 449–462, https://doi.org/10.1007/s10706-015-9956-7.

[15] Viana, P. M. F., Palmeira, E. M. and Viana, H. N. L. Evaluation on the Use of Alternative Materials in Geosynthetic Clay Liners. https://www.researchgate.net/publication/274080243_Evaluation_on_the_Use_of_Alternative_Materials_in_Geosynthetic_Clay_Liners.

[16] Karunaratne, G. P., Chew, S. H., Lee, S. L. and Sinha, A. N. (2001). Bentonite: kaolinite clay liner. *Geosynthetics International*, 8 (2), pp. 113–133. https://doi.org/10.1680/gein.8.0189

[17] Kalkan, E. (2006). Utilization of red mud as a stabilization material for the preparation of clay liners. Engineering geology, 87 (3–4), pp. 220–229. https://doi.org/10.1016/j.enggeo.2006.07.002

[18] Tian, K., Benson, C. H. and Likos, W. J. (2016). Hydraulic conductivity of geosynthetic clay liners to low-level radioactive waste leachate. *Journal of Geotechnical and Geoenvironmental Engineering*, 142 (8), p. 04016037. https://doi.org/10.1061/(ASCE)GT.1943-5606.0001495

[19] Lee, J. M., Shackelford, C. D., Benson, C. H., Jo, H. Y. and Edil, T. B. (2005). Correlating index properties and hydraulic conductivity of geosynthetic clay liners. *Journal of Geotechnical and Geoenvironmental Engineering*, 131 (11), pp. 1319–1329, https://doi.org/10.1061/(ASCE)1090-0241(2005)131:11(1319).

[20] Bradshaw, S. L. and Benson, C. H. (2014). Effect of municipal solid waste leachate on hydraulic conductivity and exchange complex of geosynthetic clay liners. Journal of Geotechnical and Geoenvironmental Engineering, 140 (4), p. 04013038, https://doi.org/10.1061/(ASCE)GT.1943-5606.0001050.

[21] Stern, A. N. (2009) 'Dynamic Shear Behavior of a Needle-Punched Geosynthetic Clay Liner/Geomembrane Interface at a High Normal Stress', p. 62. http://hdl.handle.net/1811/36959

[22] Xaypanya, P., Takemura, J., Chiemchaisri, C., Seingheng, H. and Tanchuling, M. A. N. (2018). Characterization of landfill leachates and sediments in major cities of Indochina Peninsular countries—Heavy metal partitioning in municipal solid waste leachate. Environments, 5 (6), p. 65. https://doi.org/10.3390/environments5060065

[23] Owusu-Nimo, F., Oduro-Kwarteng, S., Essandoh, H., Wayo, F. and Shamudeen, M. (2019). Characteristics and management of landfill solid waste in Kumasi, Ghana. Scientific African, p. e00052. https://doi.org/10.1016/j.sciaf.2019.e00052

[24] Pariatamby, A. and Tanaka, M. (2014). MSW Management in Asia and the Pacific Islands-Challenge and Strategic Solution. Environmental Science and Engineering, Springer: Singapore, https://doi.org/10.1007/978-981-4451-73-4.

[25] Ziadat, A. H. and Mott, H. (2005). Assessing solid waste recycling opportunities for closed campuses. *Management of Environmental Quality: An International Journal*, Vol. 16 No. 3, pp. 250–256. https://doi.org/10.1108/14777830510591679

[26] El-Fadel, M., Findikakis, A. N. and Leckie, J. O. (1997). Environmental impacts of solid waste landfilling. *Journal of environmental management*, 50 (1), pp. 1–25, https://doi.org/10.1006/jema.1995.0131.

[27] Kjeldsen, P., Barlaz, M. A., Rooker, A. P., Baun, A., Ledin, A. and Christensen, T. H. (2002). Present and long-term composition of MSW landfill leachate: a review. Critical reviews in environmental science and technology, 32 (4), pp. 297–336, https://doi.org/10.1080/10643380290813462.

[28] Ole, H., Lizzi, A. and Jette, B. H. (2000). *Leachate emission from landfill*. Final Report Swedish Environmental Protection Agency; Naturvårdsverket: Stockholm, Sweden. ISSN 1102-6944; TRN: SE0007199

[29] Kanmani, S. and Gandhimathi, R. (2013). Assessment of heavy metal contamination in soil due to leachate migration from an open dumping site. Applied Water Science, 3 (1), pp. 193–205, https://doi.org/10.1007/s13201-012-0072-z.

[30] Slack, R. J., Gronow, J. R. and Voulvoulis, N. (2005). Household hazardous waste in municipal landfills: contaminants in leachate. Science of the total environment, 337 (1–3), pp. 119–137. https://doi.org/10.1016/j.scitotenv.2004.07.002

[31] Umar, M., Aziz, H. A. and Yusoff, M. S. (2010). Variability of parameters involved in leachate pollution index and determination of LPI from four landfills in Malaysia. International Journal of Chemical Engineering, 2010. https://doi.org/10.1155/2010/747953