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Sealing and Volume Change Behaviour of Gellan Gum amended Granular Bentonite under Extreme Chemical Loading for Landfill Applications

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Abstract. Geosynththetic clay liners (GCLs) having granular bentonite (GB) are widely used as lining system in waste containment facilities. Significant increase of several folds in hydraulic conductivity has been observed by several researchers in presence of high concentration salt solutions in leachate due to lose in osmotic potential. The second generation GCLs having polymer amended bentonites are being explored for liner applications under extreme salt environment by several researchers. A biopolymer, gellan gum was explored in this study to use as amendment of the GB present in GCLs to improve its sealing ability. The liner system is also subjected to the mechanical stresses due to the waste load. The performance of liner under the influence of chemical and mechanical loading needs to be understood before using them for long term. In this study, the GB and gellan gum amended GB was compacted at a density of 1.2 Mg/m^3. The sealing and volume change behavior of these samples were evaluated with different commonly available salts (i.e. NaCl, and KCl) in leachate. The results showed the influence of pore fluids, gellan gum amendment on sealing and volume change behaviour. Mechanism influencing the sealing and volume change behaviour will be presented.

Keywords: GCLs, Gellan Gum, Granular Bentonite; Sealing behavior; Salts, Loadings.

1 Introduction

Leachate from the municipal solid, industrial, and demolition waste contains several contaminants including inorganic cations, heavy metals, ammonia, pesticides, pharmaceuticals, dyes, and several other emerging contaminants. These contaminants migrate to the groundwater sources and pollute it (Yadav and Singh, 202). Leachate of rubber industry, coal combustion residual products, construction and demolition waste, and electroplating industry contains high concentration of sodium and potassium (Das and Bharat, 2021; Chen et al., 2018). Engineered landfills are used to encapsulate the waste and prevents its spread to the environment. Landfill consists of leachate collection system, clay liner, groundwater monitoring system, daily cover, and final cover system as shown in Figure 1. Bentonite clays are used as a barrier material to attenuate the spread of the contaminates. Bentonites are used due to its high swelling ability, low hydraulic conductivity, high specific surface area, self-sealing ability, low diffusion and high sorption ability (Benson et al., 1994; Chen et al., 2016; Bharat and Das, 2017; Kaufhold et al., 2015). Geosynthetic clay liners (GCLs) having a 5-7 mm thick bentonite layer sandwiched between woven and non-woven geotextiles are used as engineered barrier. GCLs has several advantages over the conventional compacted clay liner. GCLs are easier to transport and install, has limited thickness, produces very less dust during installation process. GCLs contains bentonite in granular form as it is primary product during processing of bentonite and improved workability in granular form. The granular bentonite (GB) contains several macro-voids, and these macro-voids closes upon hydration due to the development of osmotic pressure between individual particles. The process of the filling of macro-voids is called self-sealing of the GB and time required for sealing of voids is known as sealing time.

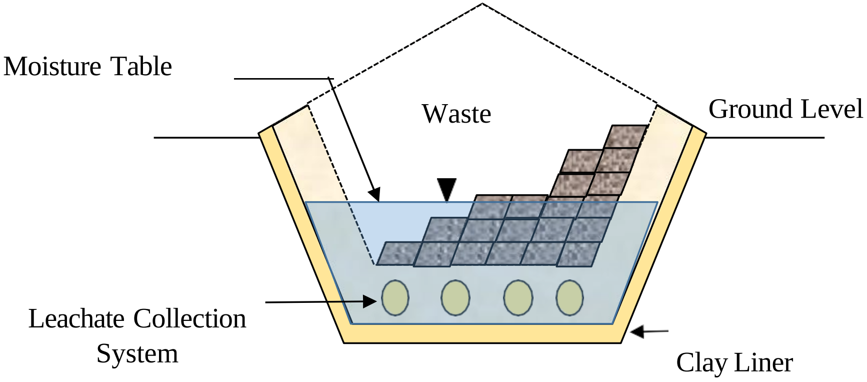


Fig. 1. Schematic diagram for landfill with various components

The development of the repulsive pressure leads to the reduction in the hydraulic conductivity of the GB. The saturated GCL has a hydraulic conductivity lower than 10^{-9} m/sec; diffusion becomes the dominant contaminant transport mechanism in such cases (Lee and Shackelford, 2005; Das and Bharat, 2021; Yadav and Bharat, 2022). Initial degree of hydration of the GCL influences the hydraulic performance. The GCL remains un-hydrated before exposure to the chemical environment. The GB loses its sealing ability upon permeation with high ionic solutions due to loss in its osmotic potential. The presence of macro-voids due to non-swelling nature of GB allows the migration of the contaminants through it.

Nowadays, several polymers are utilized for amendment of GB to overcome this disadvantage in high ionic environment. Sodium-carboxymethylcellulose (Na-CMC), glycerol carbonate, polypylene carbonate, acrylic acids etc. are explored for amendedment by several researchers (Onikata et al., 1996; Di Emidio et al., 2010; Scalia et al, 2014; Fehervari et al., 2016). Polymers used in composite with bentonite forms hydrogel upon hydration (Tian et al., 2016). The polymers and the clay particles interacts with electrostatic interactions, hydrogen bonding, cation bridging mechanisms. The present study explored a biopolymer, gellan gum (GL) as an amendment material to the GB to address this environmental concern.

Moreover, the GCLs are subjected to the mechanical stresses due to the weight of the waste in the landfill. The expected weight of the waste ranges from 20 kPa during initial stage to the 400 kPa at closure of the landfill. The volume change of the liner system is important as leachate collection system is place on liner system and collapse of liner can cause distress situation in the pipes of the leachate collection system. The influence of the mechanical loading conditions on the sealing and volume change behavior is important and need to be studied.

2 Materials and Methods

2.1 Granular Bentonite

The GB used in the present work was exhumed from the GCL. The physical, and surface properties of GB was presented in the tabular form from the earlier works of the authors (Yadav and Bharat, 2022).

Table 1. Table captions should be placed above the tables.

Property	Value
Specific gravity	2.78
Liquid limit, w_L	658
Plastic limit, w_P	48
Specific surface area	648
Cation exchange capacity	152.67

2.2 Gellan Gum

A biopolymer, gellen gum (GL) was used in the current study. The GL was procured from the Sigma-Aldrich. The GL was mixed in dry form to the GB for making the sample. The sodium and potassium solutions were utilized as pore-fluid in the work.

2.3 Permeation Experiment

The permeation experiment was performed with oedometer set-up as shown in Fig. 2. The set-up was fabricated using solid rod with 53 mm diameter to accommodate 10 mm thick sample of GL modified GB. Porous stones of 5 mm thickness were placed on the either side of the sample. A filter paper was also placed between the porous stone and GB sample. The set-up was placed on the loading assemble, and it was connected to the dial-gauge from top of the sample to measure the changes in the volume. The sample was also connected to the burette with the pore fluid. A mechanical load of 20 kPa wasplaced on the loading assembly to simulate the weight of the waste. Further, permeation experiment was started by opening the valve of the burette and changes in the height of the burette was monitored with time.

The value of the hydraulic head and dial gauge were continuously monitored until constant values were found for at 24 hours' interval. The permeation rates are indicative of the sealing ability of the GB. The hydraulic permeation rate slower than the $1*10^{-9}$

represents the complete sealing of the macro-voids and time required to achieve the sealing is known as sealing time. The permeation tests were performed under high ionic strength of NaCl and KCl with lower expected mechanical load condition.

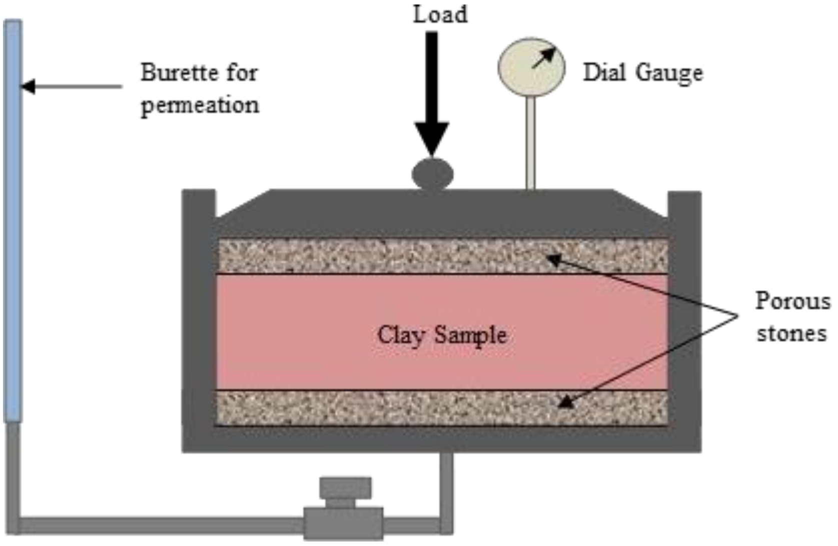


Fig. 2: Schematic diagram for the permeation set-up under loading conditions

3 Results and Discussion

The temporal variations of hydraulic infiltration rates for GB and gellan gum amended GB were presented in Figure 3. Fig. 3(a) shows permeation rates through GB and GB amended with GL with distilled water as pore fluid under 20 kPa mechanical load. The permeation rate was found to be higher initially during start of the experiment which further decreases with time and achieved the hydraulic permeation rate lower than the limiting value in 200 minutes and 1000 minutes for GBGL and GB, respectively. The GL amended GB achieved the equilibrium value of hydraulic permeation rate in 6000-7000 minutes, while GB achieved it in 10000 minutes. The equilibrium value was found to be in order of 10^{-11} m/sec for GB-GL and 10^{-10} m/sec for GB.

The temporal variations of the hydraulic infiltration rates for GL amended GB, and alone GB with 0.5M NaCl as pore fluid was presented in Fig. 3(b). The permeation rate was found to be in 10^{-5} m/sec order of magnitude, which reduces further with time upon hydration with NaCl solution. The permeation rate of NaCl solution through GB and GL amended GB was not able to attain the limiting hydraulic permeation rate and it attains an equilibrium hydraulic permeation value in order of 10^{-7} m/sec for both GB and GB-GL. The reason for the higher permeation rate as compared to distilled water is reduction in the osmotic potential of GB due to high concentration NaCl. Moreover, the reduced osmotic repulsion was not sufficient to overcome the van der Waal forces of attraction between the particles. Due to insufficient repulsive forces, the granules could not break, which lead to the presence of the macro-voids in the GB.

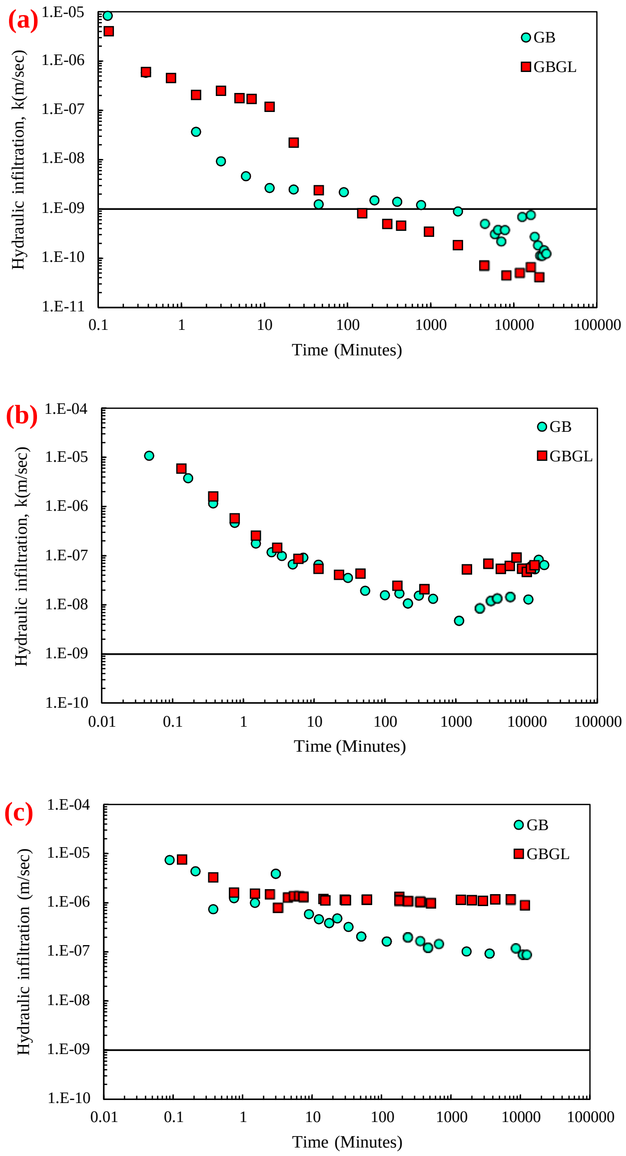


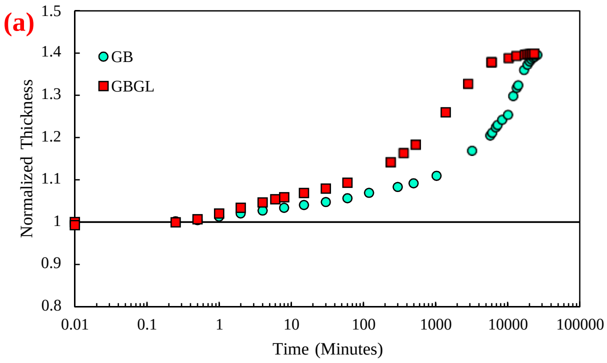
Fig. 3: Temporal variations of hydraulic infiltration rates of GB and gellan gum amended GB under 20 kPa mechanical loading with (a) Distilled water; (b) 0.5M NaCl; and 0.5M KCl

The temporal variations of the hydraulic permeation rates of the GL amended GB was presented in Fig. 3(c). The initial hydraulic permeation rate was found to be in order of 10^{-5} m/sec, which only reduced by one order of magnitude and achieved 10^{-6} m/sec as equilibrium hydraulic permeation rate. Moreover, the permeation rate reduced to two orders of magnitude and achieved 10^{-7} m/sec. The increase in the permeation rate of GL amended GB with KCl as compared to the distilled water is attributed to the poorly developed osmotic potential in presence of KCl. The insignificant development in osmotic potential does not overcome the van der Waal forces of attraction between the granules of GB and GB does not break into individual particles. The retention of GB in granule form lead to the presence of large number of macro-voids. These voids allowed the permeation of the pore-fluid very quickly. The performance of the biopolymer in salt environment was not found satisfactory.

The temporal variations of volume change in terms of the normalized thickness of GB and GL amended GB under 20 kPa mechanical stress with distilled water was plotted in Fig. 4(a). A slight collapse in the samples was observed upon application of mechanical loading initially. Further, samples started swelling due to the development of osmotic potential of GB particles. The large amount of swelling with equilibrium normalized thickness of 1.40 was observed with distilled water as pore-fluid.

The temporal variations of the volume change in terms of normalized thickness of GB and GL amended GB under 20 kPa mechanical stress with 0.5M NaCl as pore fluid were presented in Fig. 4(b). A collapse of 1-1.5% was observed initially upon application of the mechanical load. The samples started swelling upon inundation with the NaCl solution and achieved the original volume within 1 minute from the start of the experiments. The samples further swelled and achieved an equilibrium normalized thickness of 1.06 for GB-GL and 1.07 for alone GB. The equilibrium normalized thickness is much lower with NaCl as pore-fluid as compared to distilled water, which is attributed to the poor development of osmotic potential in case of NaCl.

The temporal variations of the volume change in terms of normalized thickness of GB and GL amended GB under 20 kPa mechanical loading with 0.5M KCl salt solution is presented in Fig. 4(c). A slight collapse of 1-1.5% was observed upon the application of mechanical loading. The GB-GL sample didn't swell significantly upon inundation with 0.5M KCl and it was not able to attain original volume even at equilibrium. While, alone GB sample swelled and achieved the original volume within 1 minute and achieved the normalized thickness of 1.05 at equilibrium. Due to the reduction in osmotic potential, the swelling potential of GB in high KCl environment is lost. The macro-voids present in GL amended GB also remain intact upon permeation with KCl as pore-fluid.



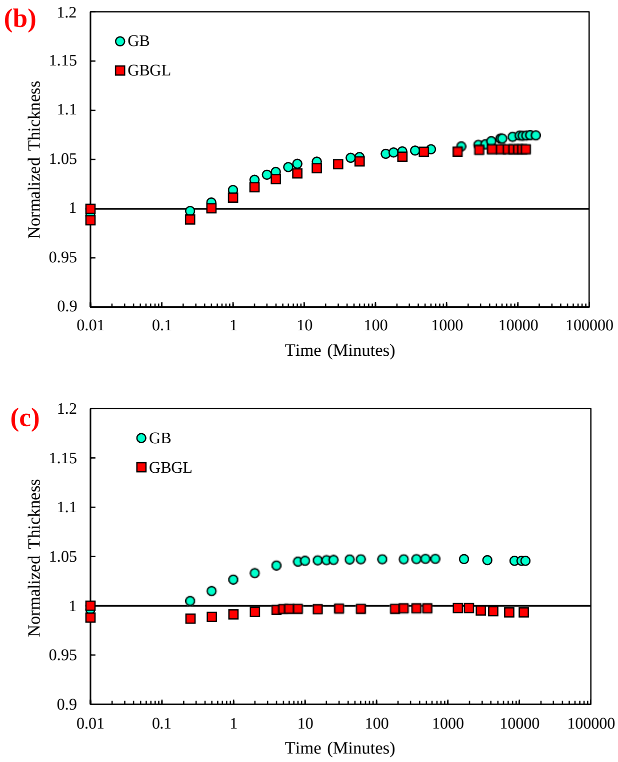


Fig. 4: Temporal variations of normalized thickness of GB and GL amended GB under 20 kPa mechanical stress with (a) distilled water; (b) 0.5 M NaCl; and (c) 0.5M KCl as pore-fluid

4 Conclusion

The present work was conducted to explore the possibilities to improve the sealing and volume change behavior of GB with a biopolymer, gellan gum. The study was conducted on the critical chemical (i.e. 0.5 M) and mechanical (20kPa) loading conditions. The following conclusions can be derived from this work:

The studied biopolymer, i.e. gellan gum failed to achieve the limiting value of the hydraulic permeation rate in presence of high concentration salt solution.

KCl salt solution has more influence on sealing and volume change of GB as compared to NaCl.

The hydration of GCL with distilled water is recommended before its exposure to the leachate in the field. The hydration of GB lead to the development of full osmotic potential and can arrest the migration of the contaminants.

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