QUARTERLY PROGRESS REPORT 2

Title: Effects of Florida Leachates on Geosynthetic Clay Liners (GCLs)

Project Duration: December 1st, 2017 – October 30th , 2018
Investigators: Prof: Tarek Abichou, Ph.D. P.E. and Youneng Tang, Ph.D.
FAMU – FSU Dept. of Civil and Env. Eng.

PROJECT WEB SITE:
https://www.eng.famu.fsu.edu/~abichou/MSWI%20GCL%20FL%20Project.html

Present Goals:

The main objective of this study is to test the resistance of conventional GCLs from different vendors to synthetic permeant solutions and aggressive leachates from MSW, MSW+ASH, MSW- I landfills and CCPP landfills from Florida and possibly other states in the USA. Further, the intent is to identify conditions where these GCLs might not be adequate (such as negative gradient landfills and fluctuating groundwater table). On the GCLs, conventional tests were utilized (Swell Index, Atterberg limits, 1D Swell Test, hydraulic conductivity). The synthetic permeant solutions and aggressive leachates underwent chemical characterization such as ratio of monovalent and divalent cations (RMD), ionic strength (IC), electrical conductivity (EC), and pH.

Work accomplished during this reporting on 5/1/2018:

Presents Achievements

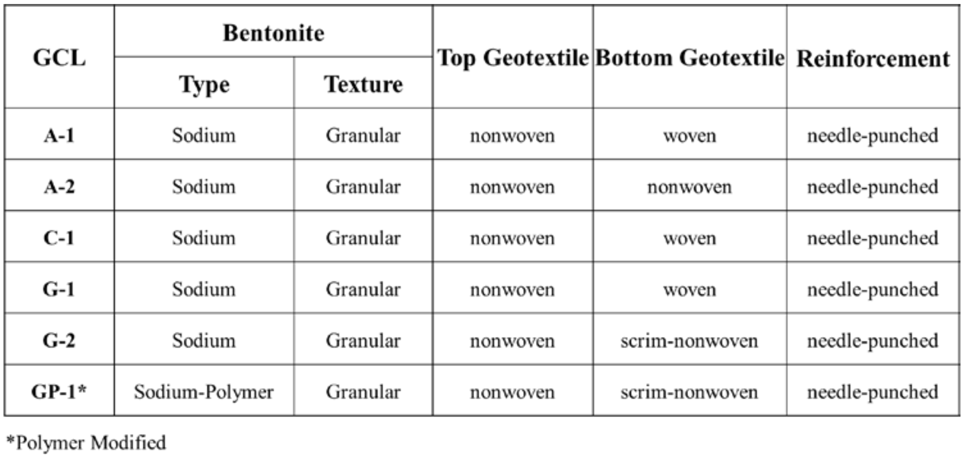
On February 2th, 2018, we received comments and feedback from TAG members on the present achievements and goals of the project that influenced our progressive advancement of the current GCL study. Feedback was also received regarding the determination of the physical properties, characteristics, and grain size distribution of vendor conventional and polymer modified GCLs. More lab testing was performed such as Atterberg limits, swell index, one-dimensional swell, and permeability (hydraulic conductivity) testing. Also, the synthetic permeant solutions and aggressive leachates underwent chemical characterization such as ratio of monovalent and divalent cations (RMD), ionic strength (IC), electrical conductivity (EC), and pH. All testing procedures are conducted in accordance with the American Standardized Testing Manuals (ASTM). Before the next TAG meeting, we would like to have few direct shear tests and cation exchange tests completed on the GCLs. Our future work is to analyze the results obtained from lab testing and form conclusions, so we can formulate a paper and showcase the work we have completed on GCLs.

Next, we will showcase some of the work accomplished during this reporting period:

1. **GCL Properties and Characterization of Conventional and Polymer Modified**

Six types of GCLs (exactly five conventional and one polymer modified) have been received so far from three different vendors and we expect to receive more in the future. The manufacturer specified properties for these GCLS were found to be similar. The physical properties of the bentonite and geotextile in used in the finished GCLs are summarized in Table 1, and their hydraulic properties in Table 2.

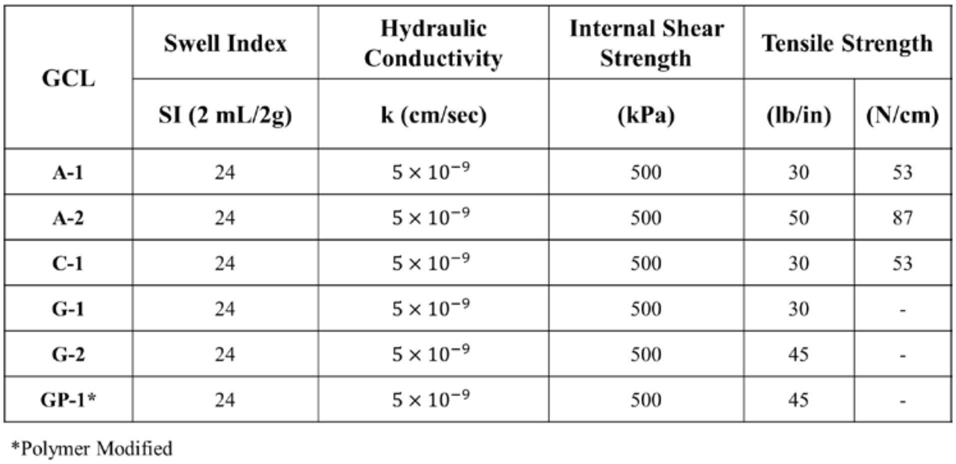
Table 1. Manufacturer GCL physical properties



GCL	Bentonite		Top Geotextile	Bottom Geotextile	Reinforcement
	Type	Texture			
A-1	Sodium	Granular	nonwoven	woven	needle-punched
A-2	Sodium	Granular	nonwoven	nonwoven	needle-punched
C-1	Sodium	Granular	nonwoven	woven	needle-punched
G-1	Sodium	Granular	nonwoven	woven	needle-punched
G-2	Sodium	Granular	nonwoven	scrim-nonwoven	needle-punched
GP-1*	Sodium-Polymer	Granular	nonwoven	scrim-nonwoven	needle-punched

*Polymer Modified

Table 2. Manufacturer GCL hydraulic and strength properties



GCL	Swell Index	Hydraulic Conductivity	Internal Shear Strength	Tensile Strength	
	SI (2 mL/2g)	k (cm/sec)	(kPa)	(lb/in)	(N/cm)
A-1	24	5×10^{-9}	500	30	53
A-2	24	5×10^{-9}	500	50	87
C-1	24	5×10^{-9}	500	30	53
G-1	24	5×10^{-9}	500	30	-
G-2	24	5×10^{-9}	500	45	-
GP-1*	24	5×10^{-9}	500	45	-

*Polymer Modified

Present Results

Because the aggregate-size distribution of the bentonite used in the GCL may have an influence on the hydraulic conductivity of the GCL, the various GCLs were further characterize by performed aggregate-size distribution on only the dry bentonite aggregates used in the GCLs following the specifications of ASTM E 112. The bentonite was extracted from the various types of GCLs; both conventional GCLs (with natural sodium bentonite) and polymer modified GCL (with polymer modified bentonite). Figure 1 shows the aggregates-size distribution curves for the various GCLs. In addition, the dry bentonite aggregates from each GCL were classified in accordance with the Unified Soil Classification System (ASTMD 2487) to be clayey sand (SC).

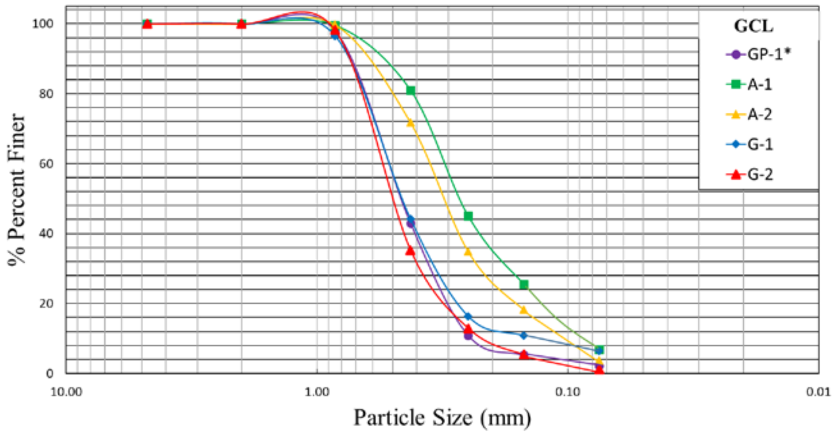


Figure 1: Grain size distribution for bentonite in GCL from different vendors

2. Chemical Characterization of Synthetic Permeant Solutions

In line with the goals of the current study, we have successfully collected leachate and ash samples from different landfill at different locations in Florida. The aim is to create synthetic leachates which will be representative of each type of landfill in Florida, that is MSW, MSW+ASH and MSW-I landfills. We are currently running all the necessary tests and analysis to achieve this goal. Meanwhile, synthetic leachates have also been created using sodium (Na) and calcium (Ca) salts as well as humic acid (HA). The chemical composition and characteristics using appropriate analytical instruments along with standard pH and EC Probes. Table 3 and 4 provides the summary of the chemical composition and characteristics of these permeant solutions.

Table 3. Chemical characteristics of salt solutions

Permeant		Chemical Characteristics							
	Concentration	Ca (mM)	Mg (mM)	Na (mM)	K (mM)	EC (µS/cm)	RMD (M^1/2)	Ionic strength (M)	pH
$CaCl_2$	2.5 mM	17.72	0.01	0.04	0.00	616	0.0004	0.01	6.94
	5 mM	4.99	0.00	0.26	0.08	1160	0.0048	0.02	6.68
	10 mM	7.98	0.01	0.36	0.01	1935	0.0041	0.03	6.52
	20 mM	10.38	0.00	0.26	0.08	4037	0.0033	0.07	6.45
	50 mM	52.90	0.01	0.14	0.02	10773	0.0007	0.18	6.64
	100 mM	84.34	0.02	0.21	0.02	24960	0.0008	0.42	6.10
	150 mM	119.77	0.03	0.24	0.03	32000	0.0008	0.54	6.38
	200 mM	174.16	0.04	0.29	0.05	44370	0.0008	0.74	6.35
NaCl	2.5 mM	0.05	0.01	2.18	0.01	322	0.2799	0.01	6.95
	5 mM	0.04	0.01	8.42	0.01	622	1.18	0.01	6.94
	10 mM	0.07	0.01	19.83	0.02	1219	2.23	0.02	6.80
	20 mM	0.05	0.01	23.97	0.02	2407	3.09	0.04	6.69
	50 mM	0.05	0.01	106.57	0.04	5130	14.55	0.09	6.96
	100 mM	0.04	0.00	137.02	0.11	9963	21.27	0.17	6.76
	150 mM	0.02	0.00	122.66	0.16	14640	24.47	0.25	6.81
	200 mM	0.02	0.00	210.09	0.14	19040	53.02	0.32	6.48
	350mM	0.41	0.00	411.05	3.58	32333	20.43	0.54	6.52
	500mM	0.26	0.00	680.74	3.49	45167	42.27	0.76	6.65

Table 4. Chemical characteristics of calcium salt and humic acid solutions

Permeant solutions	Chemical Characteristics							
	Ca (mM)	Mg (mM)	Na (mM)	K (mM)	pH	EC (µS/cm)	IC (mM)	RMD ($mM^{1/2}$)
5 mM CaCl2 + 100 mg/L HA	2	0.009	0.148	0.016	6.8	1310	20	0.107
10 mM CaCl2 + 100 mg/L	5	0.013	0.162	0.019	6.7	2587	41	0.084
20 mM CaCl2+ 100 mg/L HA	10	0.016	0.191	0.051	6.9	4170	67	0.077
50 mM CaCl2+ 100 mg/L HA	24	0.025	0.287	0.042	6.3	10070	161	0.067
100 mM CaCl2+ 100 mg/L HA	45	0.025	0.384	0.490	6.4	18747	300	0.130

3. Atterberg limits testing

In accordance with ASTM D 4318, Atterberg limit tests were performed on bentonite extracted from the various GCLs to determine their liquid limits (LL) and plastic limits (PL). Figure 1 and 2 shows some of our undergraduate students conducting these tests. The bentonite extracted from the various types of GCLs for the test. Natural sodium bentonite (Na-B) from the conventional GCLs and polymer modified bentonite (PM-B) from the polymer modified GCLs.

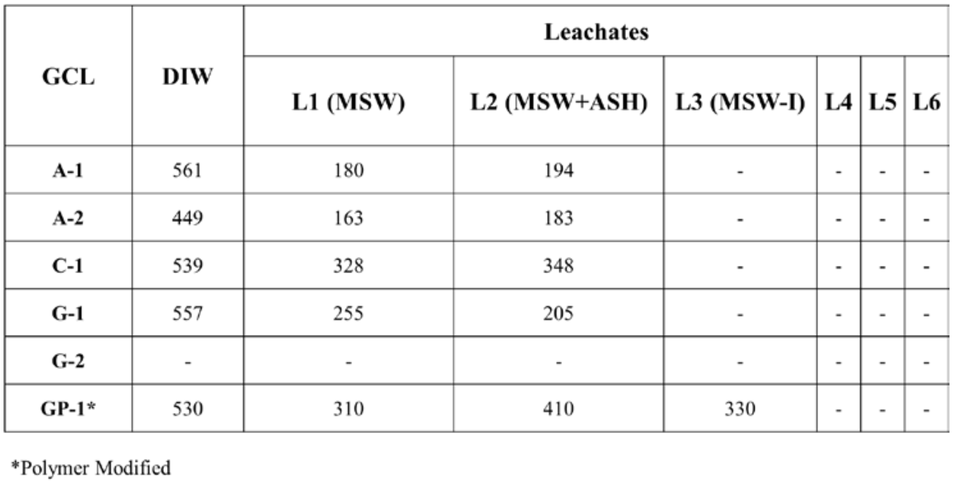
Figure 2: Liquid Limits Testing conducted by Nora & Tristan

Figure 3: Plastic limits testing conducted by Alyssa

Present Results

The Atterberg limit tests were conducted using deionized water (DIW) and different leachates. The results of the LL test (given in Table 5) indicates that for all the sample (both Na-B and PM-B) there was a significant decrease in the LL when the test was performed with the leachates as compared to deionized water (DI) water as shown Figure 4.

Table 5. Liquid limit test performed on vendor conventional GCLs with various permeant solutions



GCL	DIW	Leachates					
		L1 (MSW)	L2 (MSW+ASH)	L3 (MSW-I)	L4	L5	L6
A-1	561	180	194	-	-	-	-
A-2	449	163	183	-	-	-	-
C-1	539	328	348	-	-	-	-
G-1	557	255	205	-	-	-	-
G-2	-	-	-	-	-	-	-
GP-1*	530	310	410	330	-	-	-

*Polymer Modified

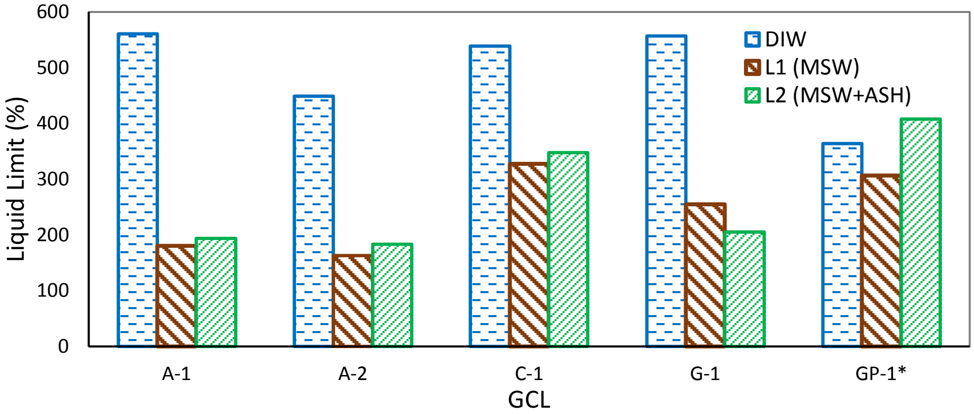


Figure 4. Liquid limit test performed on vendor conventional GCLs with various permeant solutions

The influence of Ca and Na on the liquid limit of the vendor Na-B and PM-B was also investigated. The results are tabulated in Table 6. The concentration of the Na solution was increased to 500 mM to match the ionic stnerght of the 200 mM Ca solution for comparision purposes. From the result we see that the for both Na-B and PM-B the Na salt solution didn't have any significant impact on the lqid limit until the Na conccentraitons were about 100 mM. With the Ca solution however the impact is immediate. Generally in higher salt (Na/Ca) concentrations the liquid limit of the PM-B was higher than that of Na-B. Liquid limits of the PM-B and Na-B with solution ionic stenreght is shown in Figure 5. A trendline has also been fitted to indicite show how the liquid limits decereaes with increasing ionic strenght of salt solution. More LL and PL tests are currently being done on the various vendor GCLs with various aggressive landfill leachates as well as synthetic leachates.

Table 6. Results of the Liquid limit test with salt solutions

Permeant		Na-B (Ben ST)	PM-B (CAR)
	Concentration		
	DI water	465	530
NaCl	5 mM	595	602
	10 mM	530	565
	20 mM	565	541
	50 mM		478
	100 mM	420	443
	200 mM	263	380
	500 mM		200
$CaCl_2$	5 mM	460	465
	10 mM	387.5	360
	20 mM	365	415
	50 mM	230	170
	100 mM	150	200
	200mM	115	145

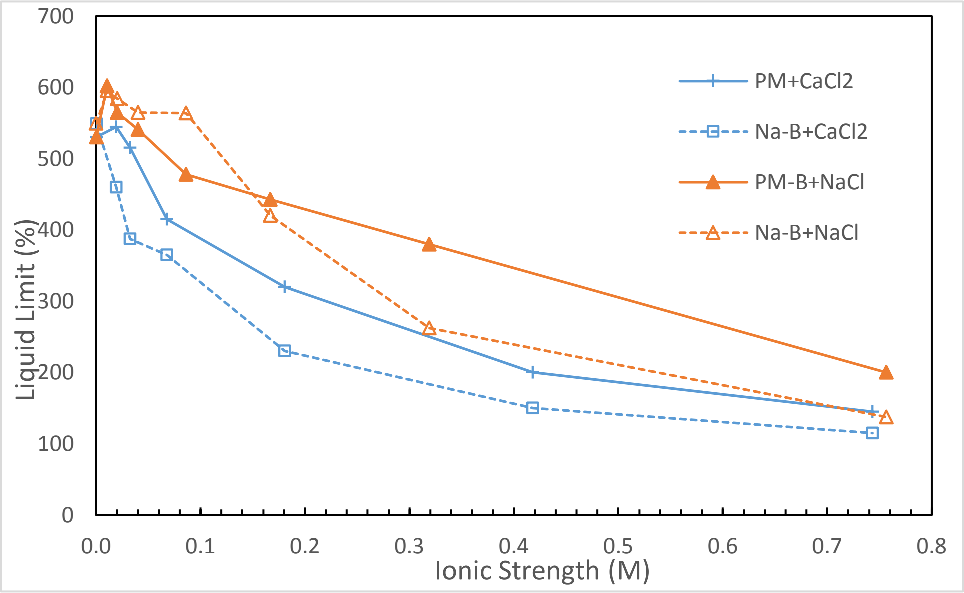


Figure 5. Liquid limits of Na-B and PM-B against ionic strength

4. Swell index test

A quick assessment of the hydraulic conductivity of GCL can be made using the swelling capacity of its constituent bentonite. In accordance with ASTM D 5980, the swell index test was used to determine the free swelling capacity (under zero normal stress) of the bentonite extracted from the various types of GCLs (both conventional and polymer modified). Figure 6 shows the undergraduate students performing the swell index tests. Researchers and manufacturers have recommended a minimum swell index of 24 mL per 2.0 g of bentonite.

Figure 6: Swell index test conducted by Alyssa & Avery

Present Results

The results of the tests are tabulated in Table 7. It was observed that for the Na-B as well as the PM-B, swell volume reduced substantially when introduced to the MSW, MSW+ ASH and the MSW-I leachates (see Figure 7).

Table 7. Swell index tests performed on bentonite from Vendor Conventional and Polymer Modified GCLs with various landfill leachates in comparison with DIW

GCL	DIW	Leachates					
		L1 (MSW)	L2 (MSW+ASH)	L3 (MSW-I)	L4	L5	L6
A-1	34	8	11	10	-	-	-
A-2	34	11	9	10	-	-	-
C-1	29	12	16	11	-	-	-
G-1	29	10	10	8	-	-	-
G-2	-	-	-	-	-	-	-
GP-1*	27	11	12	12	-	-	-

*Polymer Modified

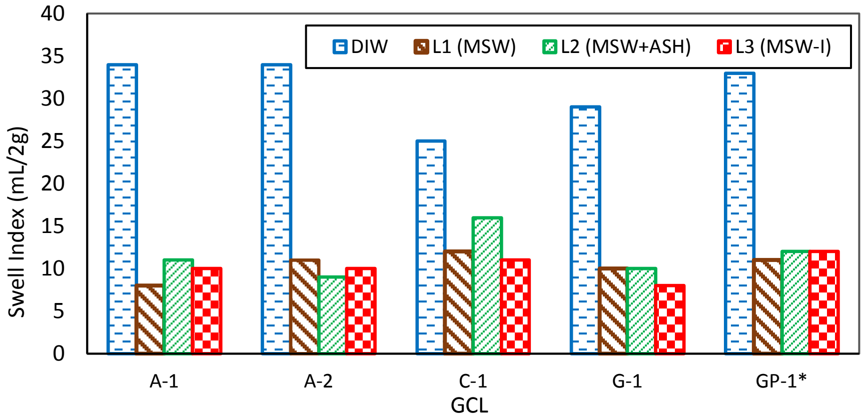


Figure 7. Swell index tests performed vendor Na-B and PM-B with various landfill leachates in comparison with DIW

Present Results

Swell index tests were also conducted using Na and Ca salt solutions with varying solution concentrations. The results are shown in Figure 8. As was expected the swell index for both the Na-B and PM-B was significantly high in Na solution than in the Ca solutions up to a solution concentration of about 200mM. The Na solution did not have any significant influence of the free swell of the PM-B until the concentration was more than 150mM. The most significant observation was that at low concentrations of the Ca solution the Na-B swelled more than PM-B. Above concentration of 50Mm However, the swell index of the PM-B was a little over that of the Na-B. To see where the swell index of the PM-B cross over to exceed that of the Na-B, swell index testing was perform using 350mM and 500mM Na solutions. The 500mM was used to match the ionic strength of the 200mM solution (both had an ionic strength of approximately 0.74M). The results indicate that the above ionic strength of 0.4 M for Na solution the PM-B swell approximately 2ml/2g higher than that of Na-B (see Figure 9).

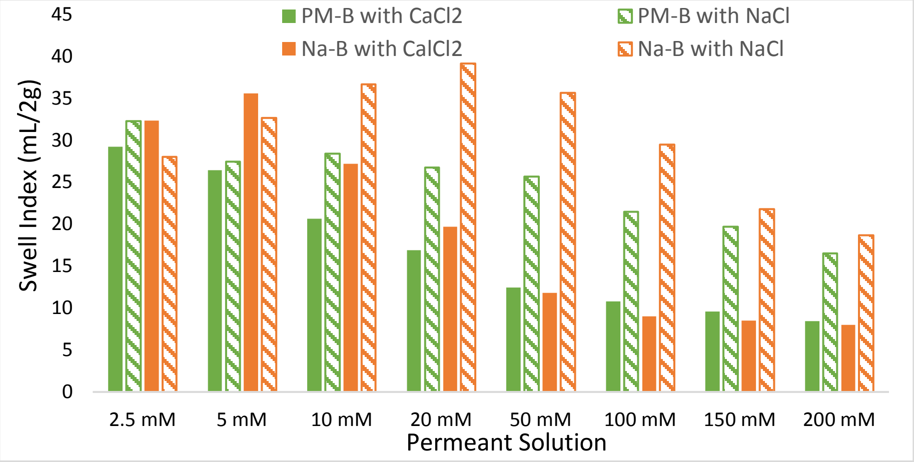


Figure 8. Swell index tests performed on vendor Na-B (Ben. ST) and PM-B (CAR) with salt solutions

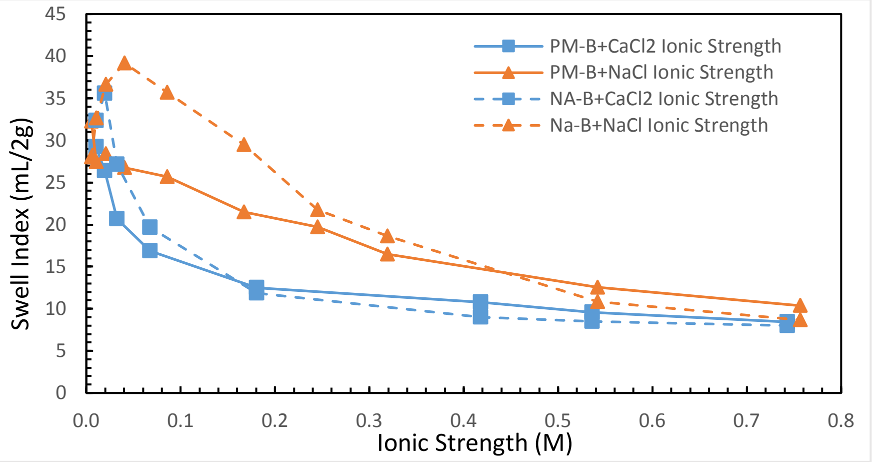


Figure 9. Swell index of vendor Na-B and PM-B against ionic strength of salt solutions

The effect of humic acid (HA) on the swelling index was also investigated. First, 100 mg/L of HA and varying concentrations (5mM to 200mM) of Ca solution were prepared. Then swell index testing of Na-B and PM-B were performed. The results are shown in Figure 10. The results indicate that the swell index of the Na-B reduced significantly when HA was added to the Ca solutions. However, for the PM-B the addition of HA to the Ca solution rise (up to 10 mL/2g) in the swell index. To point it out, some of the HA and Ca precipitated out of the solution (see Figure 11a) HA+Ca mix. This is typical of Ca due to its low solubility. Analysis of the HA+Ca solution confirmed that there was significant reduction of the Ca concentration in all the HA+Ca solution due to precipitation. A plot of the swell index verse the measured Ca concentration is given in Figure 12. The precipitation of some HA+CA however does not explain the significant variations in the swell index due to the addition of HA. It important to mention here, that HA alone did not have any impact on the swell index of the Na-B (results not shown here).

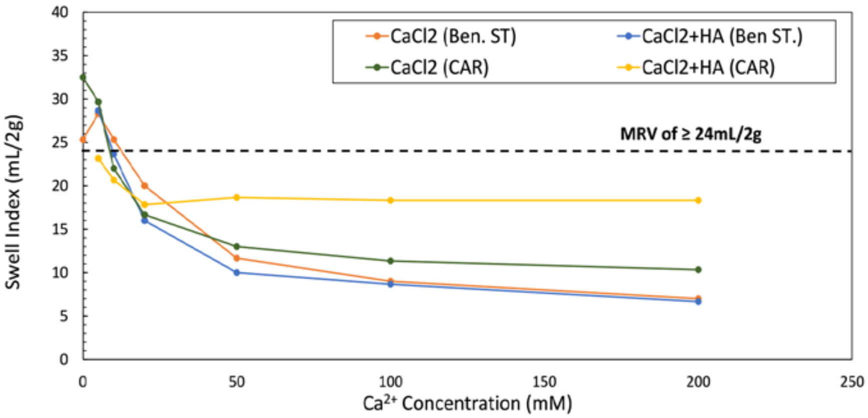


Figure 10: Effects of Ha with Ca salt on swell index of vendor Na-B and PM-B

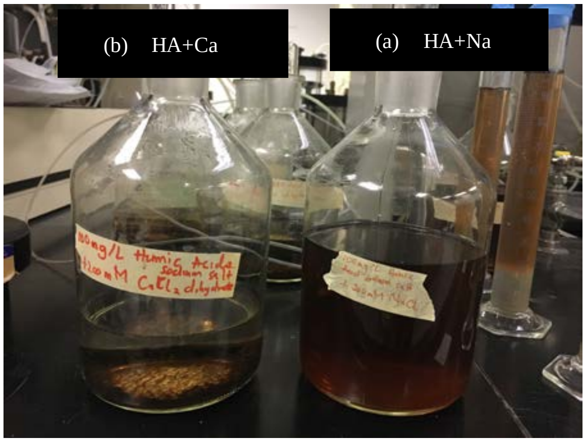


Figure 11. Humic Acid + Salt solutions

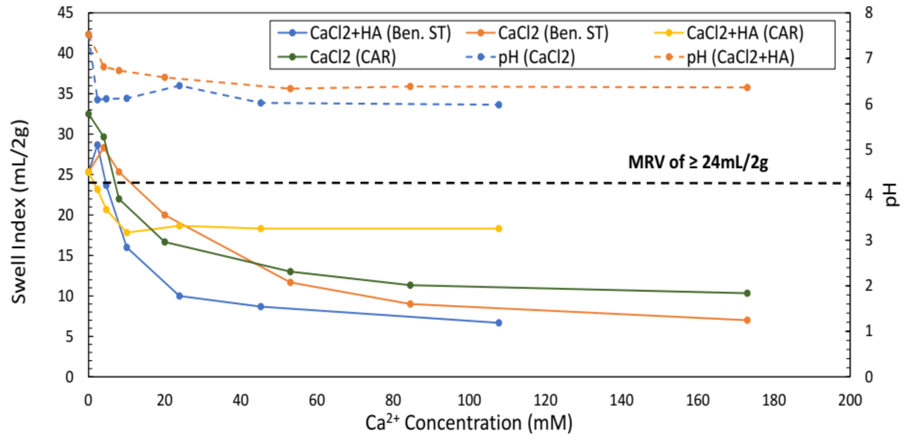


Figure 12. Effects of HA with Ca salt on swell index of vendor Na-B and PM-B against measured concentrations of Ca

One possible explain for the results is rooted in the behavior of humic substances, the mechanism under which are interact with clay minerals as well as their behavior in electrolyte solutions. The effect of the electrolyte type of the swell index of the Na-B was also investigated to get more insight to better understand the effect of the HA the Na-B swelling. Similar solutions of 100mg/L of HA plus 5mM to 100Mm of Na salt were made. As was expected, there was no precipitation in the case of the HA+Na mixture (see Figure 11). Swell test results showed that, HA had a more severe impact on the swell index of Na-B with a Na electrolyte background as compared with Ca as shown in Figure 13. Swell index test using different landfill leachates and synthetic leachates are still being performed.

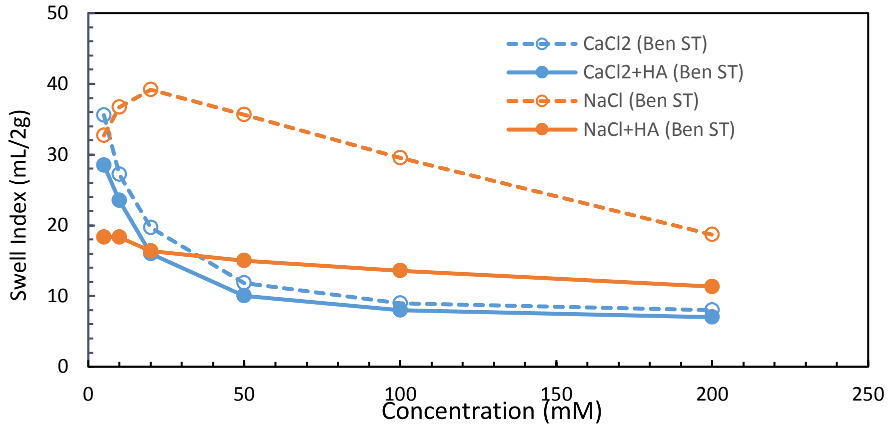


Figure 13. Influence of HA with different electrolytes on the swell index of Na-B

5. One-Dimensional Swell Test

The effects of various landfill leachates on the swelling capacity of the various GCLs were also investigated by performing a one-dimensional (1-D) swell test on bulk GCL samples. The setup of the 1-D swell test is show in Figure 14. The test procedure is as follows; a 100 mm diameter sample of GCL was cut and placed in a ring of similar diameter into a pan. To simulate the overburden stress from topsoil of a landfill, a normal stress of 20kPa is applied to the GCL. A dial gauge was then installed on top of the sample to measure the vertical displacement of the GCL during swelling. After that, 500 mL of the permeant solution is poured into the pan to hydrate the GCL sample. The swelling of the sample is monitored throughout the test until there is no more vertical displacement in the sample.

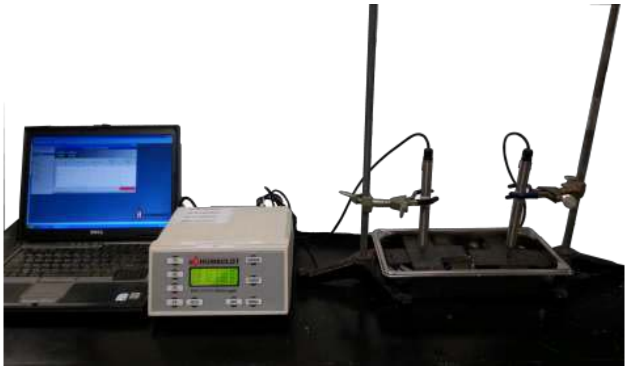


Figure 14: 1-D Swell test setup to measure GCL vertical swelling

Present Results

From Figure 15, it can be shown the rate of swelling was rapid in the first 24 hours for the test with DIW. In the case of DIW for all the GCL samples (conventional GCLs) the maximum displacement was attained after 72 hours. With MSW leachate however, there was an initial rapid rate of swell within the first few hours, but the swelling ceased abruptly after that. In the general was considerably high swelling in the sample hydrated with DIW than those hydrated with MSW leachate. 1-D swell test with different landfill leachates as well as synthetical leachates will be performed in the future.

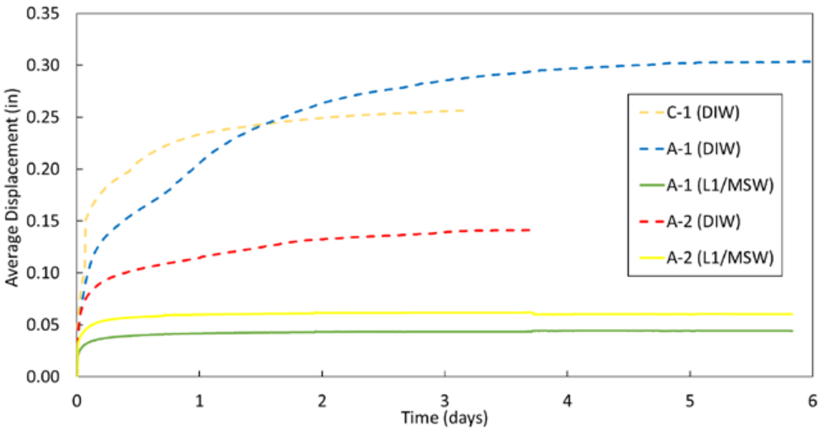


Figure 15: 1-D Swell tests performed on vendor conventional GCLs

6. Hydraulic Conductivity Test

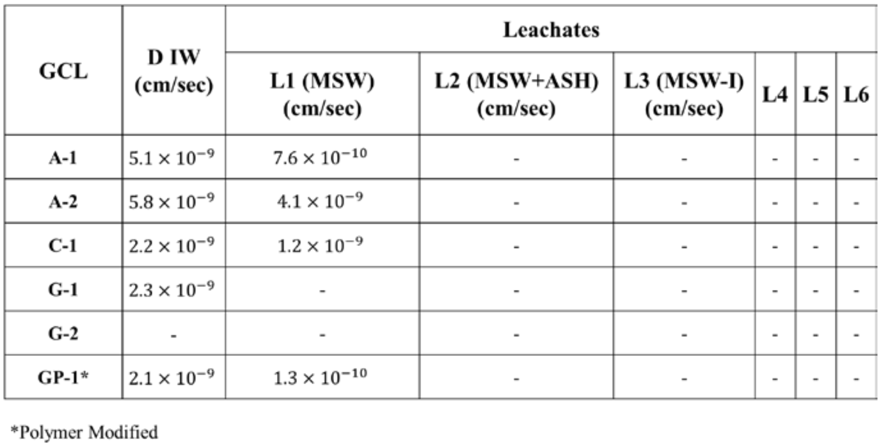
The hydraulic conductivity of the various GCLs when permeated with different permeant fluid were determined using the flexible wall permeameter in accordance with ASTM 5887. The setup for the test is shown in Figure 16. The hydraulic conductivity tests were conducted using the falling-head constant tail pressure method. The all sample were both hydrated and permeated with the same solution.

Figure 16: Flexible wall permeameter test setup to measure hydraulic conductivity

Present Results

The results of the tests which are summarized in Table 8 indicate that the hydraulic conductivity of both the conventional and polymer modified GCL when permeated with MSW leachate were within the vicinity of 10^{-9} to 10^{-10} (also see Figure 17). Due to polymer elution we have experience clogging of the effluent tube of flexible wall permeameter several times when running the hydraulic conductivity test on the PM GCLs (see Figure 18). This make running the hydraulic conductivity test on PM GCLs using the flexible wall permanent take unreasonable too long to complete and requires several flushing of the tubes during the test. Therefore, we plan to build a rigid wall permeameter which will be fitted with bigger effluent tubes which will ensure the smooth running of future hydraulic conductivity tests on the various PM GCLs. More hydraulic conductivity tests will be performed using different landfill and synthetic leachates.

Table 8. Hydraulic conductivity tests performed on vendor conventional GCLs with various permeant solutions



GCL	D IW (cm/sec)	Leachates					
		L1 (MSW) (cm/sec)	L2 (MSW+ASH) (cm/sec)	L3 (MSW-I) (cm/sec)	L4	L5	L6
A-1	5.1×10^{-9}	7.6×10^{-10}	-	-	-	-	-
A-2	5.8×10^{-9}	4.1×10^{-9}	-	-	-	-	-
C-1	2.2×10^{-9}	1.2×10^{-9}	-	-	-	-	-
G-1	2.3×10^{-9}	-	-	-	-	-	-
G-2	-	-	-	-	-	-	-
GP-1*	2.1×10^{-9}	1.3×10^{-10}	-	-	-	-	-

*Polymer Modified

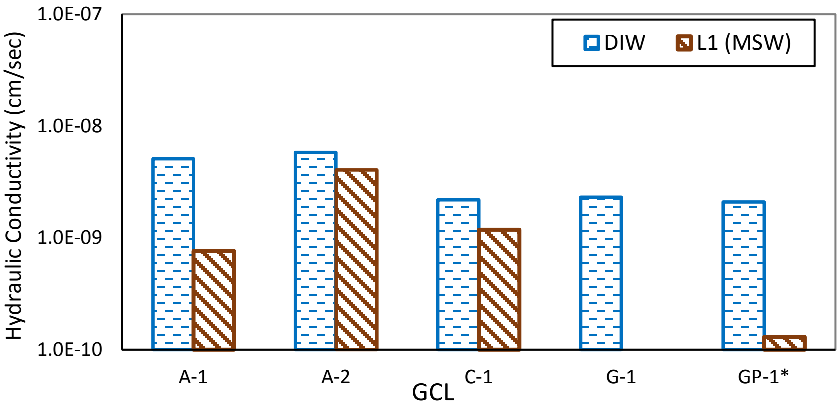


Figure 17. Hydraulic conductivity tests performed on vendor conventional GCLs with various permeant solutions

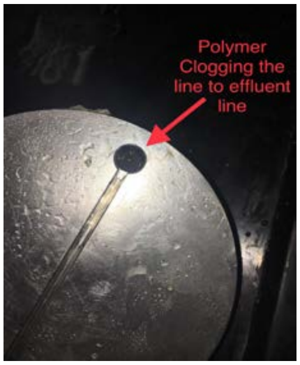


Figure 18. Clogging of effluent line in the cell of the flexible wall permeameter

Information Dissemination Activities: We are working on a Draft Paper to showcase the testing completed on the Geosynthetic Clay Liners.

Metrics:

1. List of graduate student or postdoctoral researchers **funded** by **THIS** Hinkley Center project

Last name, first name	Rank	Department	Professor	Institution
Bently Higgs		Civil & Environmental Engineering	Dr. Tarek Abichou	FAMU-FSU College of Engineering
Christian Wireko		Civil & Environmental Engineering	Dr. Tarek Abichou	FAMU-FSU College of Engineering
Dr. Liang Li		Civil & Environmental Engineering	Dr. Tarek Abichou & Dr. Youneng Tang	FAMU-FSU College of Engineering

2. List undergraduate researchers working on **THIS** Hinkley Center project

Past Undergraduate Researchers

- Name: Alyssa Schubert
  Department: Environmental Science
  Professor: Dr. Tarek Abichou, Ph.D, P.E.
  Institution: FAMU-FSU College of Engineering

- Name: Nora Sullivan
  Department: Environmental Science
  Professor: Dr. Tarek Abichou, Ph.D, P.E.
  Institution: FAMU-FSU College of Engineering

Present Undergraduate Researchers

- Name: David Carbajal
  Department: Civil and Environmental Engineering Professor: Dr. Tarek Abichou, Ph.D, P.E. Institution: FAMU-FSU College of Engineering

- Name: Tristan Wahl
  Department: Mechanical Engineering
  Professor: Dr. Tarek Abichou, Ph.D, P.E.
  Institution: FAMU-FSU College of Engineering
- Name: Avery VanRussel
  Department: Civil and Environmental Engineering Professor: Dr. Tarek Abichou, Ph.D, P.E. Institution: FAMU-FSU College of Engineering

3. List research publications resulting from **THIS** Hinkley Center project (use format for publications as outlined in Section 1.13 of this Report Guide).

4. List research presentations (as outlined in 1.13.6 of this Report Guide) resulting from **THIS** Hinkley Center project.
    - Most recently, there was a TAG meeting on February 2th, 2018.

5. List who has referenced or cited your publications from this project?
   .

6. How have the research results from **THIS** Hinkley Center project been leveraged to secure additional research funding?

7. How have the results from **THIS** Hinkley Center funded project been used (**not** will be used) by FDEP or other stakeholders? (1 paragraph maximum).

   With the current results obtained from testing completed on the geosynthetic materials, we hope to provide reliable data to showcase the good and bad qualities of these geosynthetic materials because landfills still generate and contain contaminants long after they are closed. Therefore, we hope that this Hinkley Center funded project would convince FDEP and stakeholders that there is a need to create more robust materials that will withstand exposure to harsh conditions of landfills for example leachate and elevated temperatures as a continual effort to protect our environment from harmful contaminants for future generations.

TAG members:

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TAG meetings:

- Tag Meeting #1 –
  Completed Date: Friday,

February 2th, 2018 Time:
10am to 12pm
Venue: FAMU-FSU College of Engineering
2525 Pottsdamer Street
Room A127