NEW LIGHTER, LONGER GCLS FOR MINING APPLICATIONS

TAILINGS AND MINE WASTE 2020

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Outline

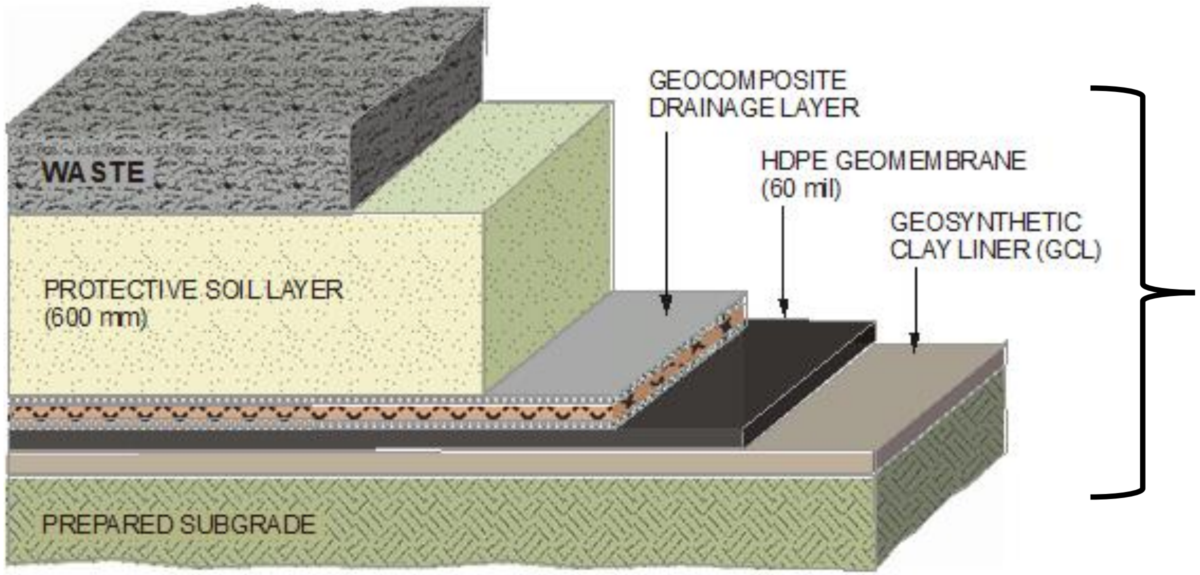
- Traditional GCL Design and Hydraulic Performance
- Mining Leachate Chemistry
- Polymer Modified GCL Design
- Polymer Modified GCL Testing:
  - Index Testing:
    - Free Swell
    - Fluid Loss
  - Performance Testing:
    - Hydraulic Performance
    - Geotechnical Properties

GCLs in Mining Applications

Heap Leach Pads

Tailings Ponds

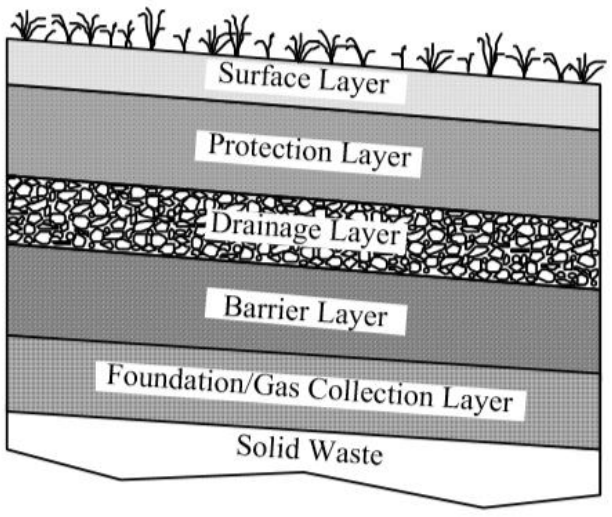
Caps / Closures



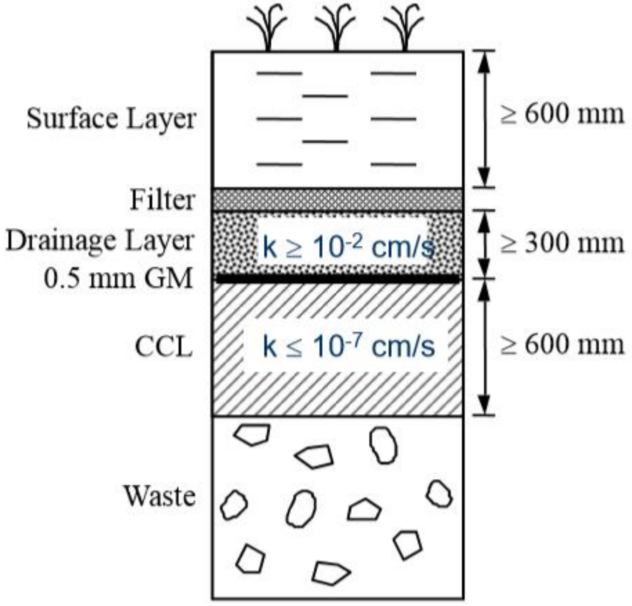
Alternative Composite Liner Systems

- Faster Installation (Less Build $)
- Engineered Quality (Less Lab $)
- Better Retention (Higher Profit $)

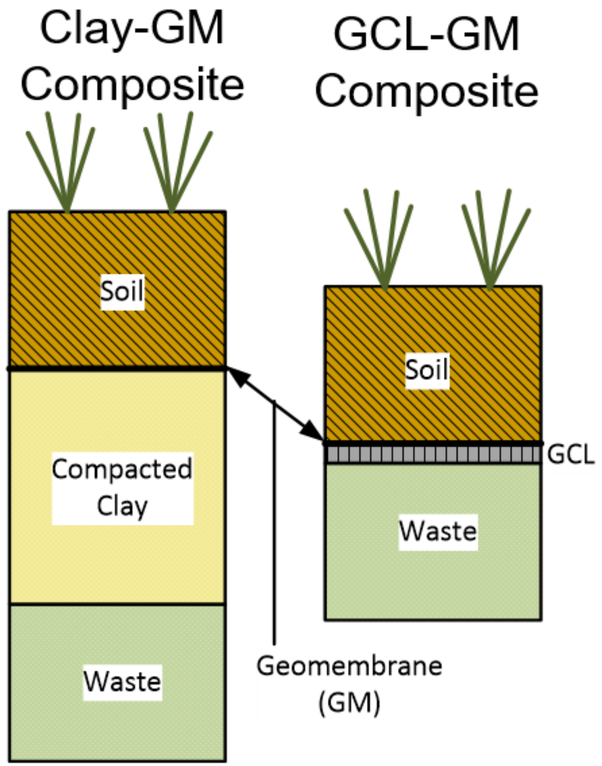
GCLs in Cover Systems



Components



Minimum Subtitle C



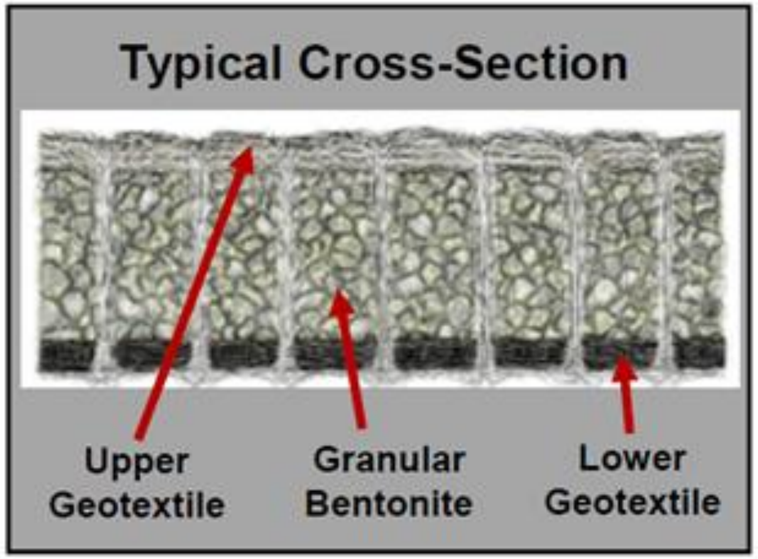
- Leakage rate is controlled by the hydraulic properties of the barrier layer (and defects)
- GCL covers are easier to install and require less earth movement

Koerner, R. M. and Daniel, D. D., “Technical Equivalency Assessment of GCLs to CCLs,” Proceedings, 7th GRI Seminar, Geosynthetic Liner Systems: Innovations Concerns and Designs, Drexel University, Philadelphia, Pennsylvania, 1993.

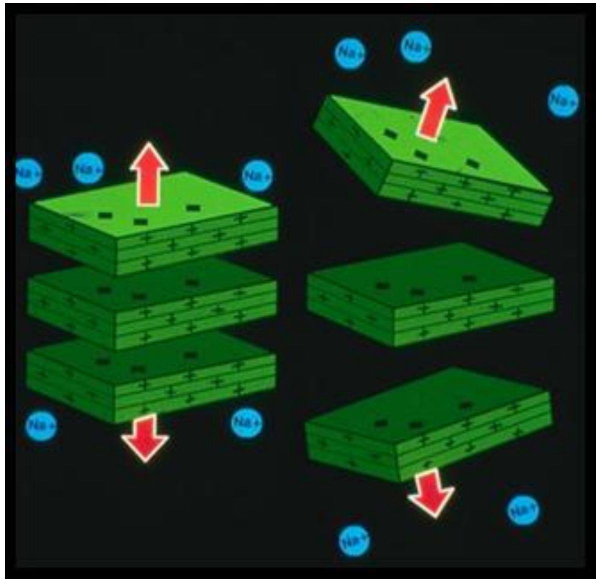
Benson, C.H., Albright, W.H, Roesler, A.C., Abichou, T. "Evaluation of final cover performance: Field data from the Alternative Cover Assessment Program (ACAP)" WM '02 Conference, Tucson, Arizona, 2002.

GCL Design

- Sodium bentonite granules hydrate and swell to form a gel
- Hydrated gel must be maintained to retain low hydraulic conductivity (k)
- k ~3-5x10^{-9} cm/sec
- Environmental factors such as pH, electrolyte concentration and type can reduce swelling & gelling of the bentonite
- Higher quality bentonites yield better hydraulic performance

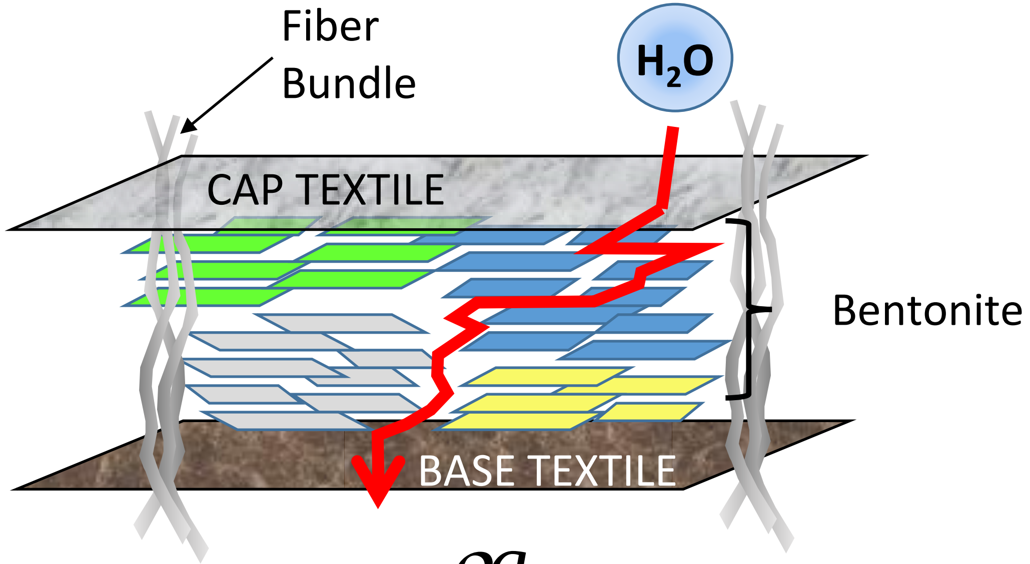


Bentonite Swelling



C. Benson : Geosynthetic Clay Liners in Waste Containment Applications: Part II – Hydraulic and Chemical Compatibility Performance of GCLs in Landfill Cover Systems, Geo-Institute, ASCE Knowledge and Learning (2014)

GCL Hydraulic Conductivity



$$K = k\frac{\rho g}{\mu}$$

K = Hydraulic conductivity
k = intrinsic permeability
ρ= pore fluid density
g = gravitational acceleration
μ = fluid viscosity

Hydraulic conductivity (K) depends on:

1) **Fluid properties:**
   - Viscosity of fluid
   - Density of fluid
2) **Force of gravity**
3) **Intrinsic permeability**

Intrinsic permeability (k) depends on:

1) Amount of fluid (saturation)

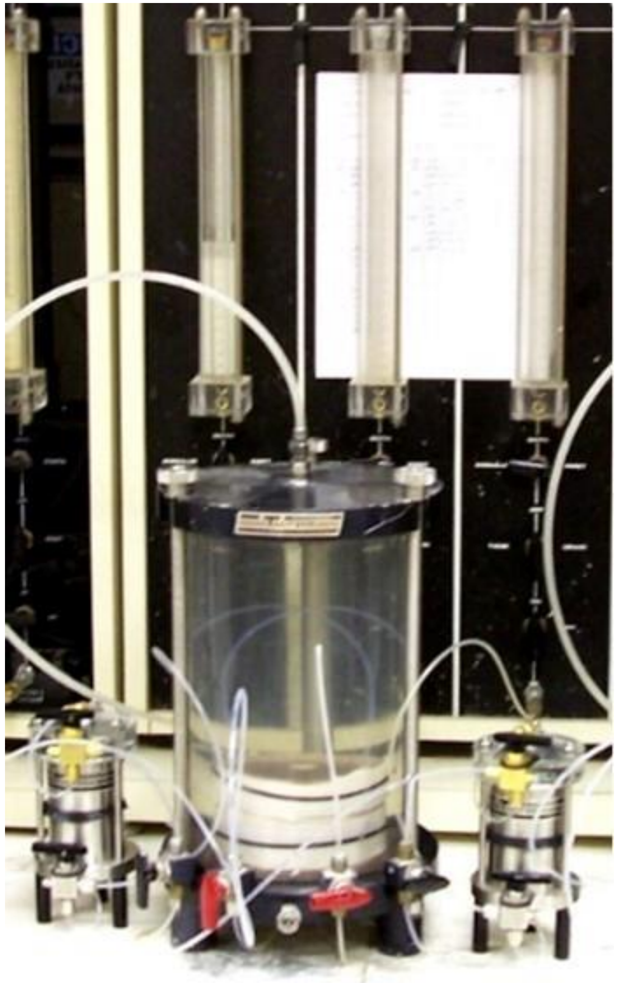
2) Clay properties:
- Clay grain size
- Surface characteristics of clay
- Impurities within matrix
- Interfacial area of impurities

3) Flow channels:
- Pore size distribution
- Pore shape
- Tortuosity (connectivity)
- Porosity

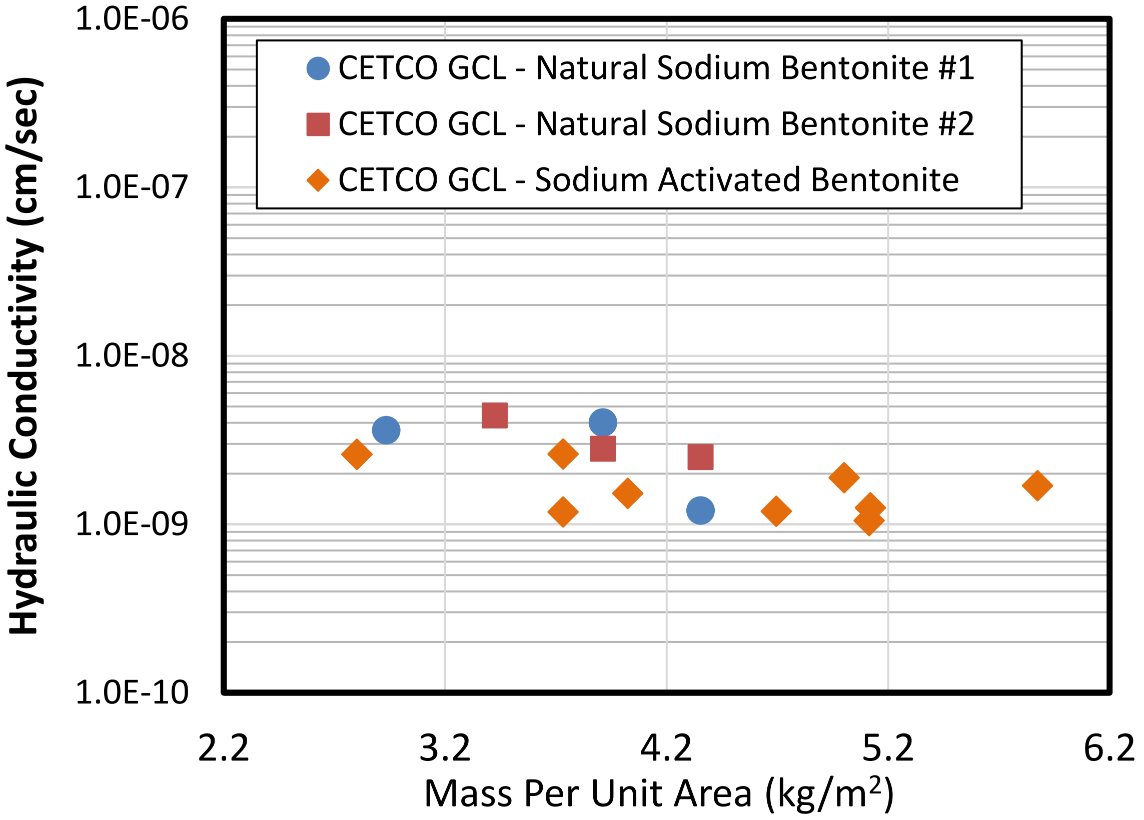
Hydraulic Conductivity Testing

- Hydraulic testing method:
  - ASTM D6766: Scenario 2, Method C:
    - ❑Prehydrated with leachate for 48 hrs
    - ❑Falling head / Rising Tail
  - Hydraulic gradient of 150
  - Effective confining stress of ~34.5 kPa
  - Leachate introduced and collected by bladder accumulators
- Leachate testing / effluent monitoring
  - Electrical conductivity (EC)
  - Inductively couple plasma (ICP) – cations
  - pH

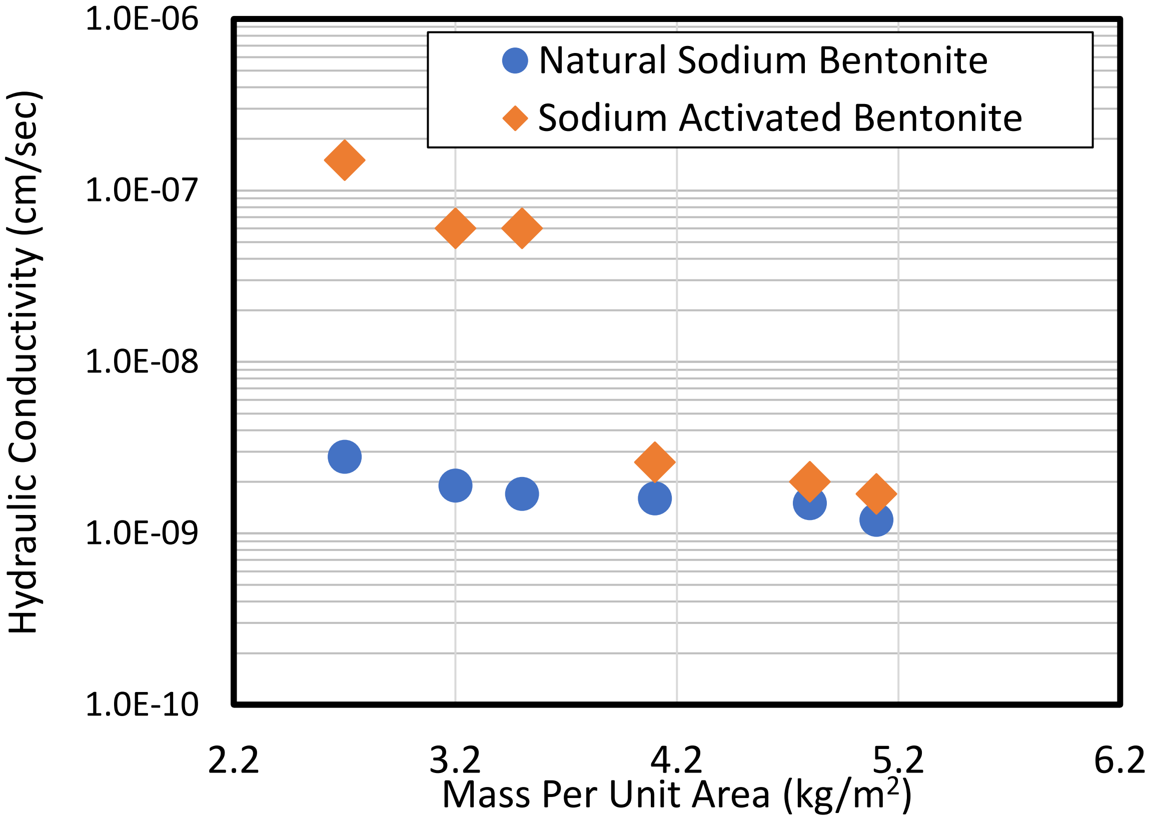
Falling Headwater / Rising Tail



Influence of Clay Quality and MPU on Hydraulic Performance



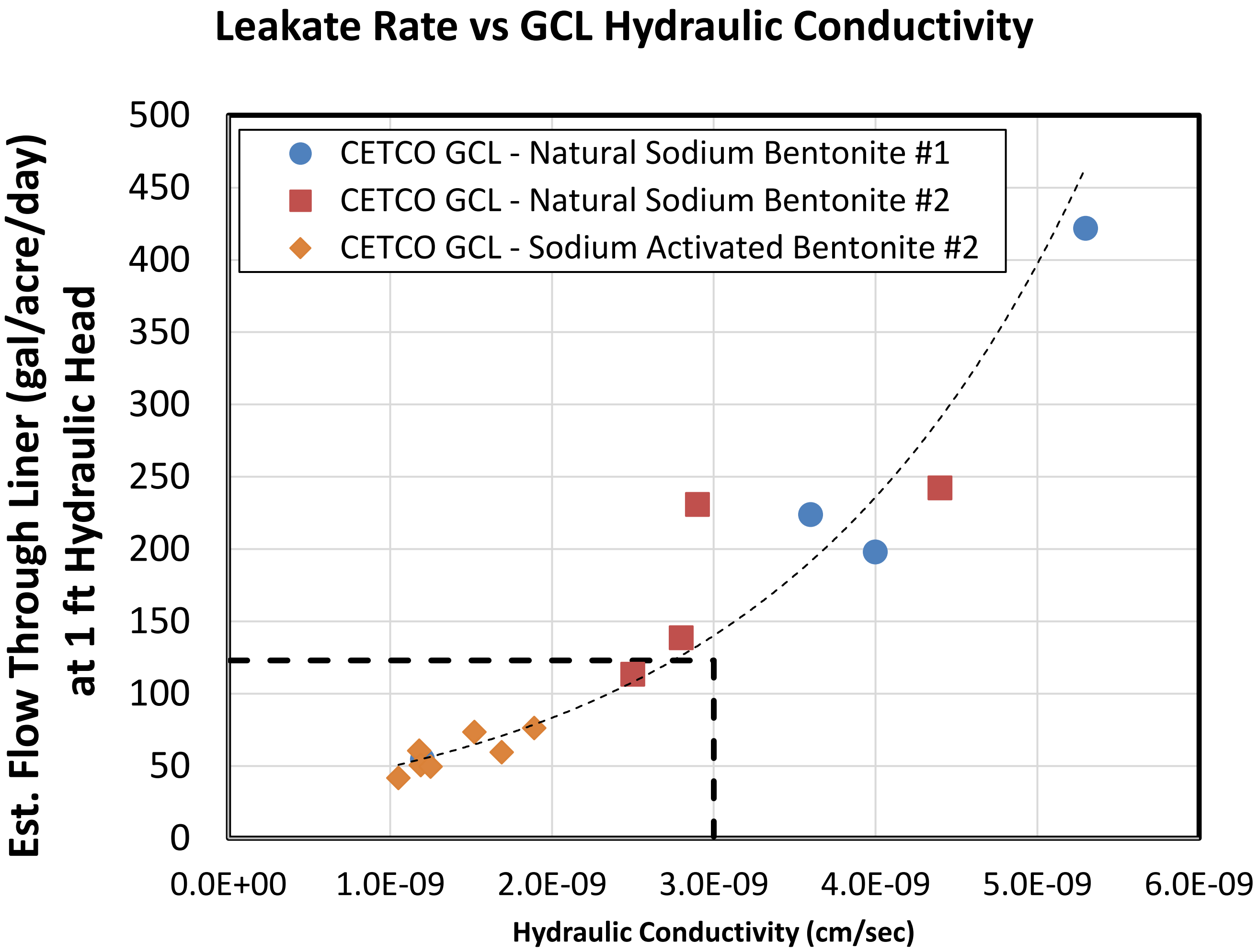
*CETCO Internal Data



**K.P. von Maubeuge, Investigation of bentonite requirements for geosynthetic clay barriers. *Clay Geosynthetic Barriers, 2002*

- Most producers specify hydraulic conductivity < $5x10^{-9}$ cm/sec
- Most GCLs are produced with a minimum of 3.7 kg/m^2 (some agencies require higher MPUs)
- Mass per unit area does not significantly influence hydraulic conductivity (It will influence leakage rates)
- Evidence that clay & GCL quality parameters may influence hydraulic conductivity at low mass per unit area

Typical CCL / GCL Leakage Rates

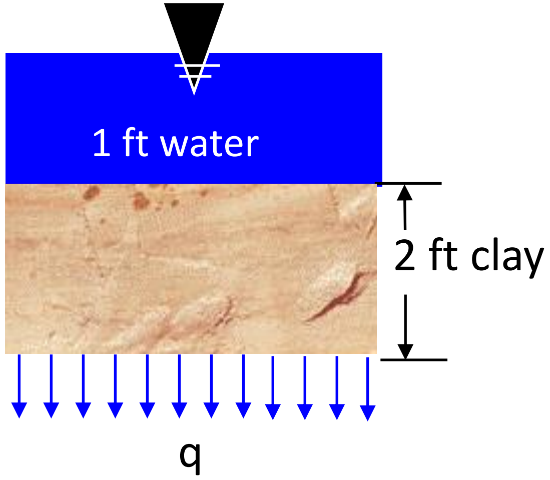


Clay (2 ft thick, 1 ft head)

q = k * i

q = 10^{-7} cm/sec * ((1+2)/2)

q = 138 gal/acre/day

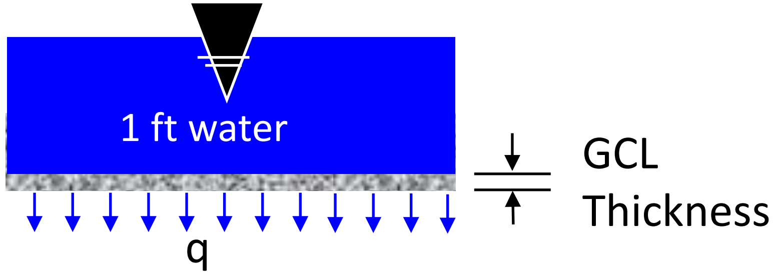


GCL (0.7 cm thick, 1 ft head)

q = k * i

q = 3.0 x 10^{-9} cm/sec * ((1ft+0.023ft)/0.023ft)

q = 123 gal/acre/day

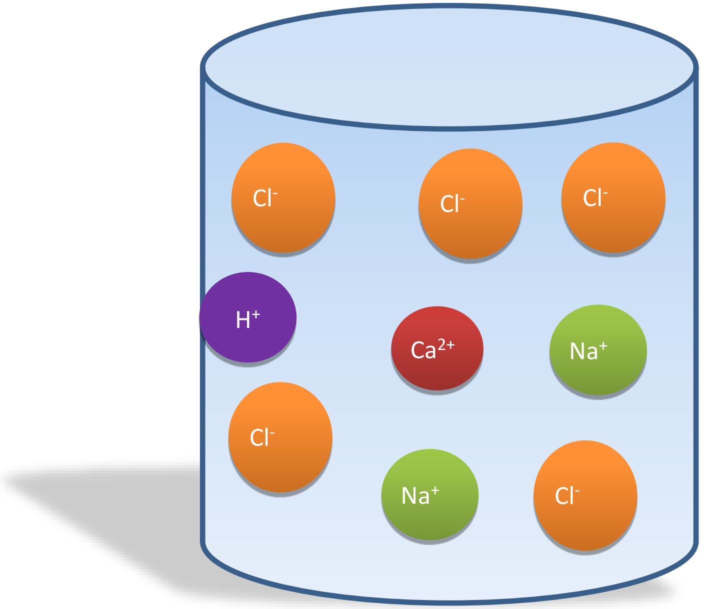


Water Chemistry: Ionic Strength, RMD and pH

Ionic Strength:

$$I = \frac{1}{2}\sum_i c_i \times z_i^{\ 2}$$

Where:
c = concentration of ion
z = charge of ion
[ ] = concentration in moles/liter



Ratio of Monovalent to Divalent Ions:

$$RMD = \frac{\left[Na^{+} + K^{+} + NH_4^{+}\right]}{\sqrt{\left[Ca^{2+} + Mg^{2+} + Al^{3+} + etc.\right]}}$$

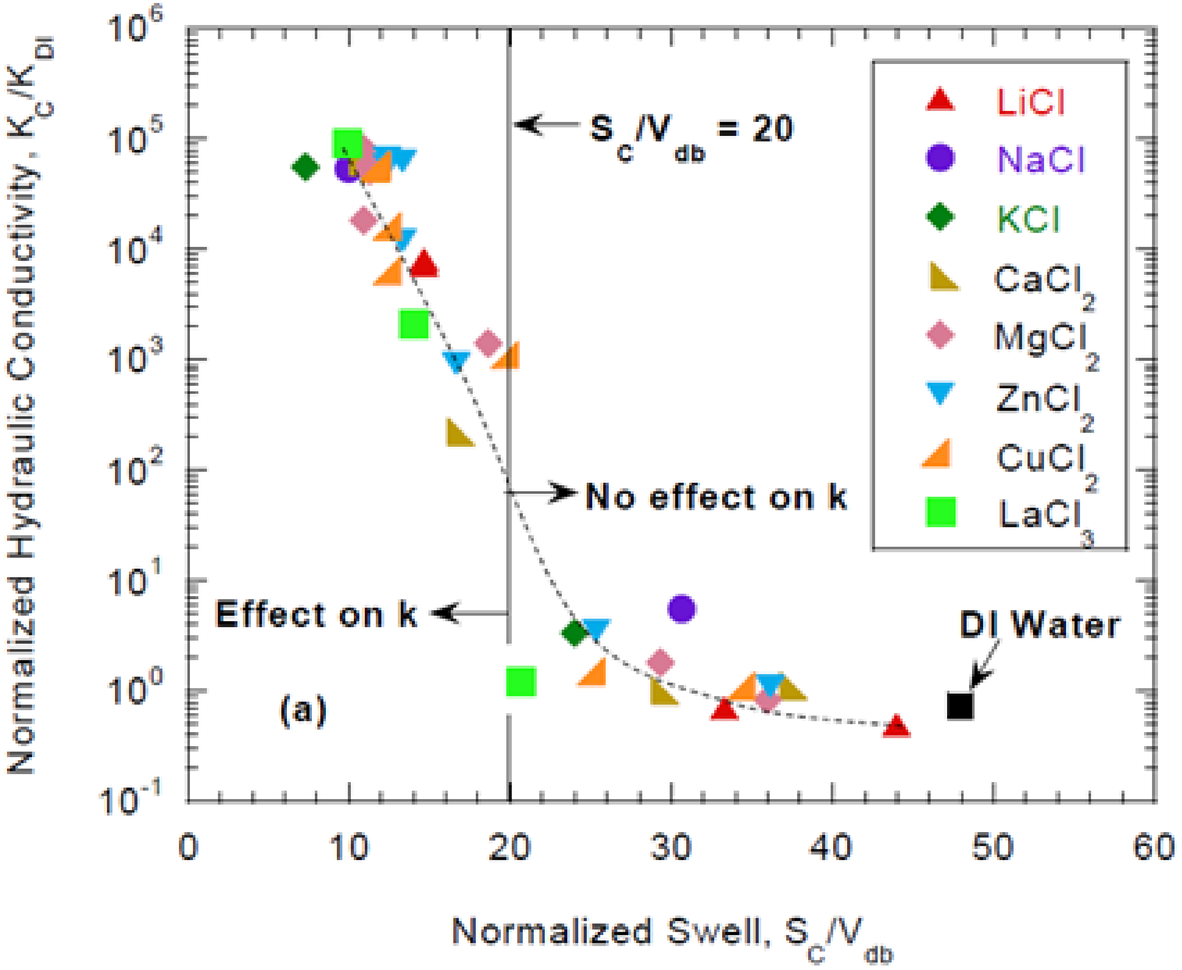
pH = $-\log_{10}[H^+]$

Scalia et al (2012) Shackelford et al. (2000), Jo et al. (2001), Kolstad et al. (2004), Jo et al. (2004), Jo et al. (2005), and Lee and Shackelford (2005)

Typical Leachate Chemistry Ranges

Application	pH Range	RMD	[I]
Low pH Applications			
Nickel (laderites)	< 1	0.2	< 7.3
Copper (sulfides)	1.5 - 2	0.01	0.6 – 2
High pH Applications			
Gold/Silver	9.5 - 11	0.2-1.0	0.07-0.6
Aluminum	11.5 - 12.5	1.8	0.01 - 4
Other Applications			
	pH	RMD	[I]
Coal Combustion Storage	6 - 8	0.01 – 8.0	0.05 - 1.3
Frac Water Storage	6 - 8	1.8	>0.7
Caps / Closures	6 - 8	<0.7	<0.03

Free Swell and Hydraulic Conductivity



- Strong monotonic relationship independent of cation species
- Free swell per D5890 is a good indicator of chemical compatibility (for traditional GCLs)

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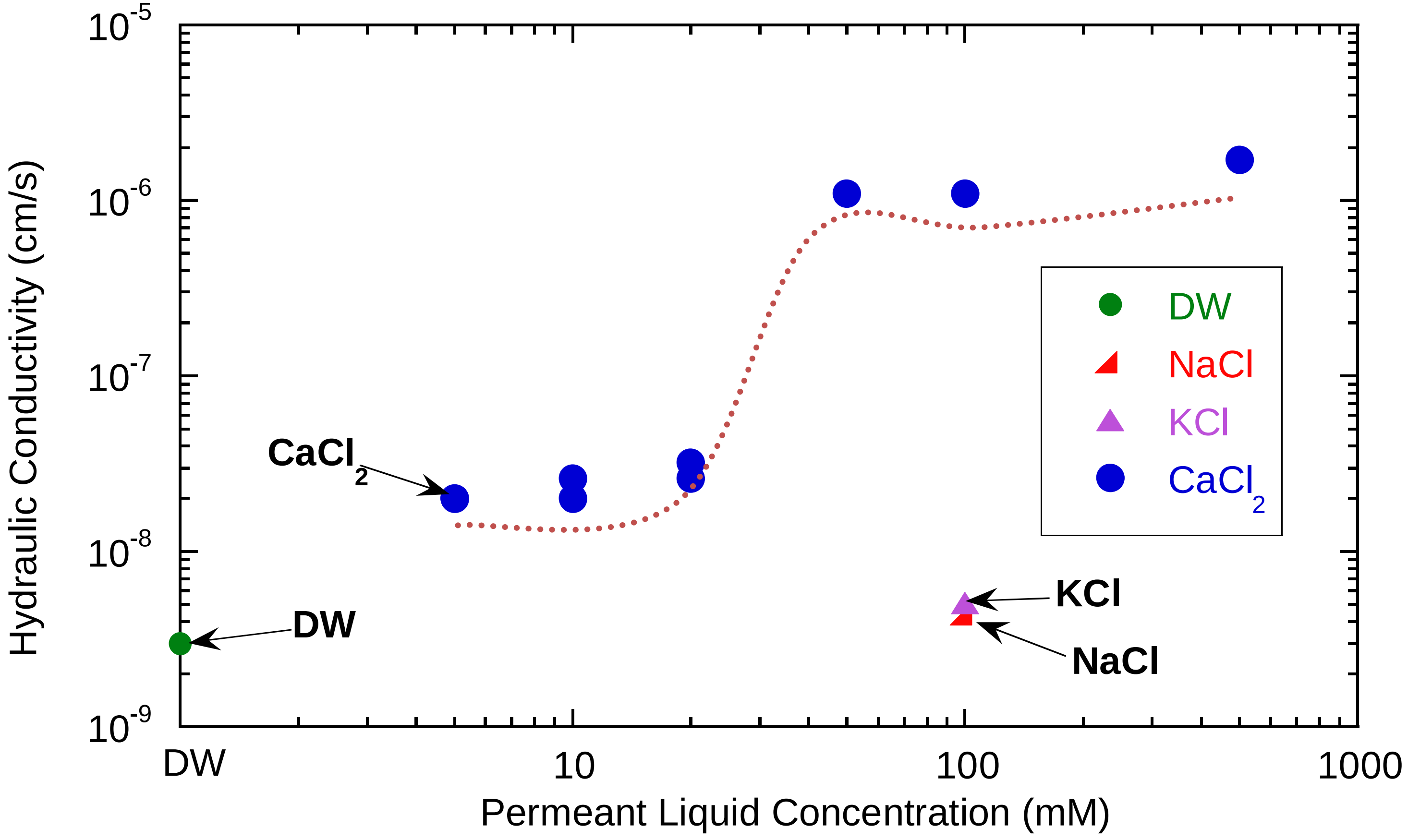
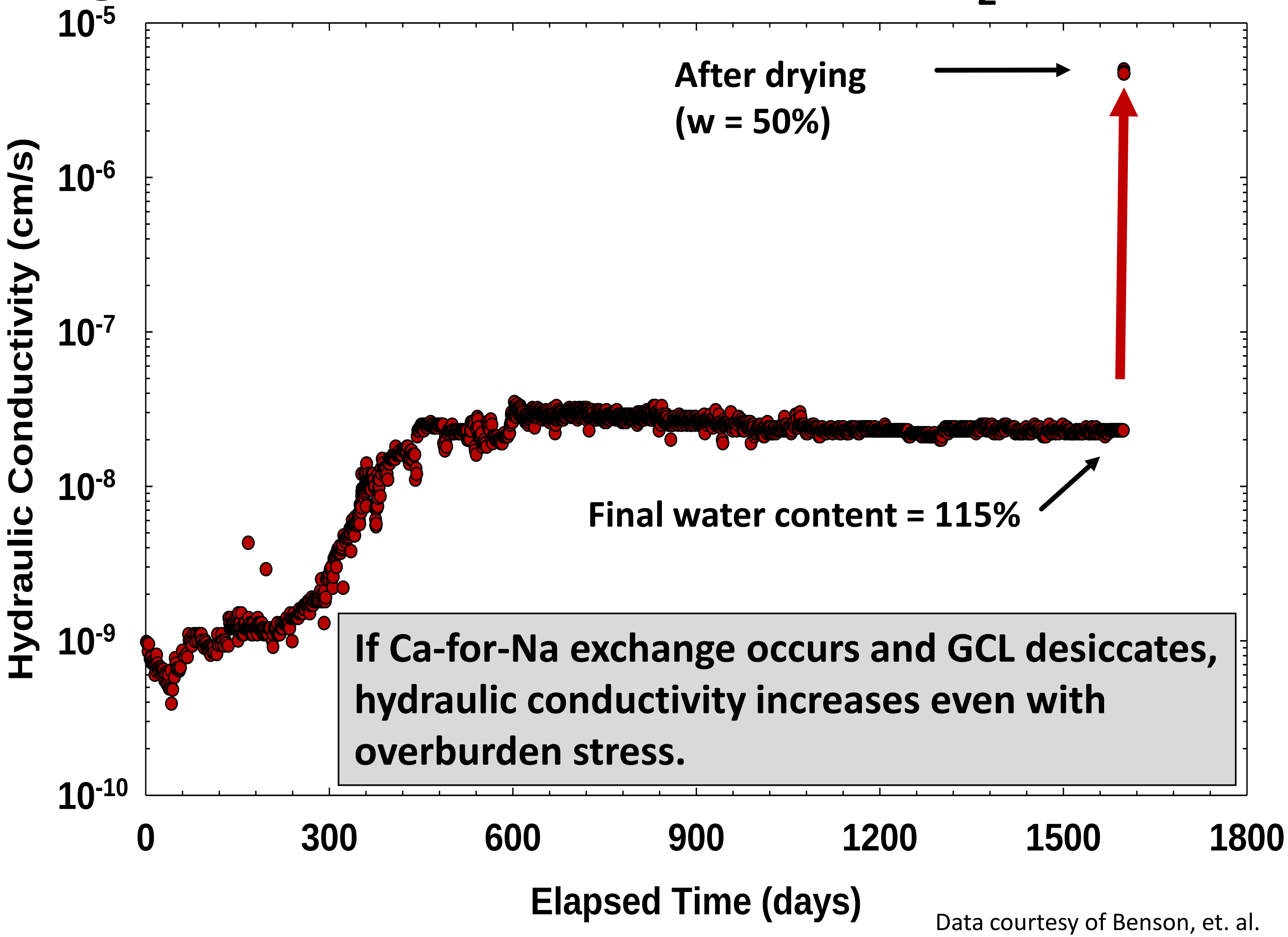
Hydraulic Conductivity: Influence of Ion Concentration & Valence

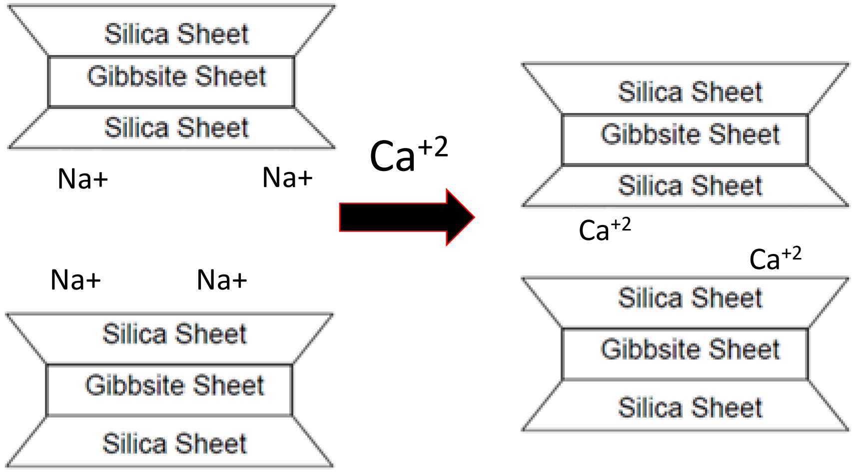


Dilute solutions, divalent cations – 10x
Strong solutions, divalent cations – 1000x
Modest monovalent solutions -- no effect on K.

Data courtesy of Benson, et. al.

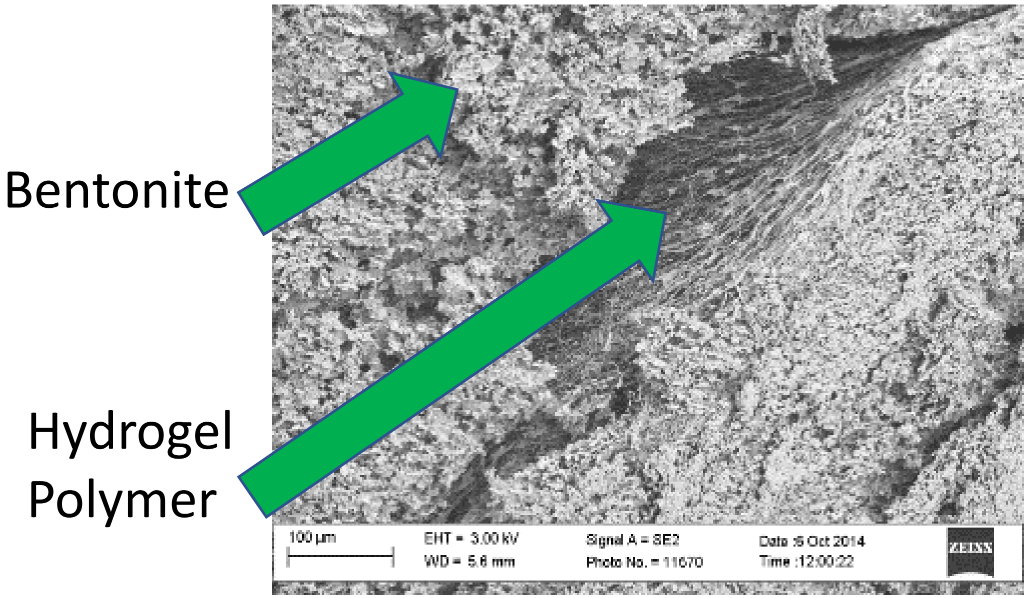
Long-Term Permeation with Dilute $CaCl_2$ Solutions





Data courtesy of Benson, et. al.

Polymer Modified GCLs (PMGs)

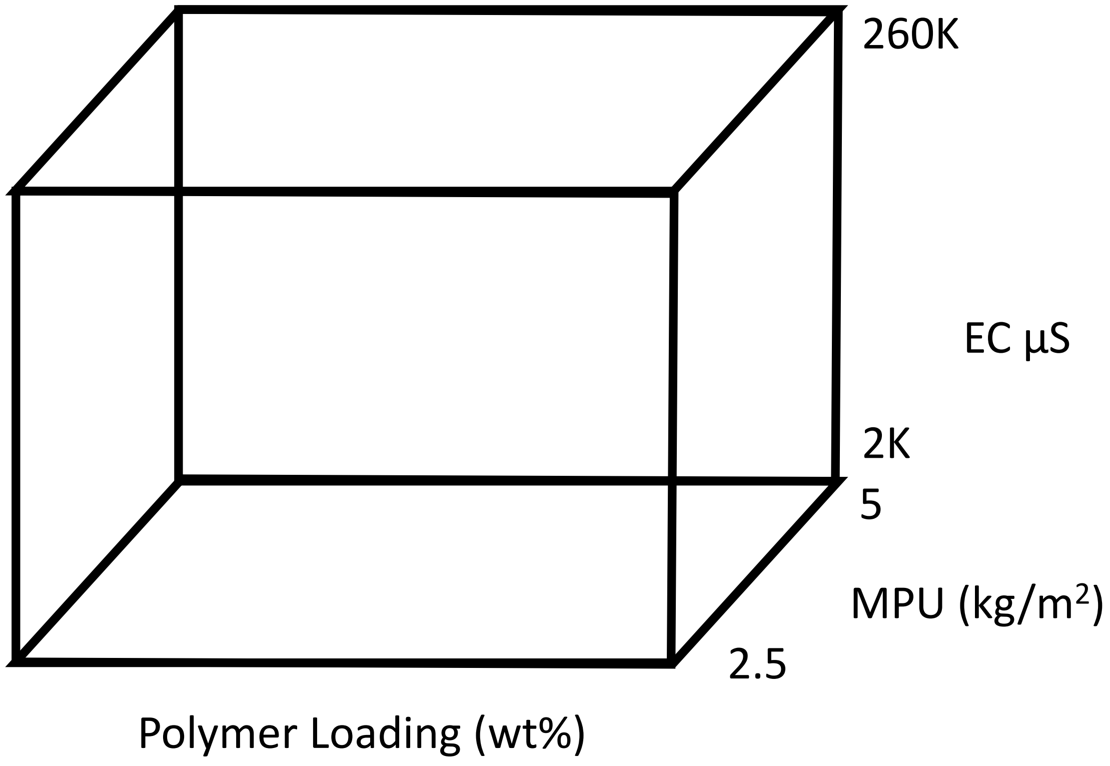


Typical PMG Composition:

- Typically <10% polymer addition
- Polymer type tailored to the specific application
- Range of different types available:
  - High pH: red mud, CKD, trona ponds
  - High saline/chloride: CCR, frac-ponds, brine evaporation
  - Low pH: Phosphate mining, copper, nickel, uranium etc.

Picture courtesy of Benson, Tan et. al.

Polymer Modified GCLS for Permeability Testing:



Experimental Design:

- Polymer loading (wt%): 2, 4, 6, 8, 10, 12 wt%
- Mass per unit area (kg/m^2): 2.5 and 5.0

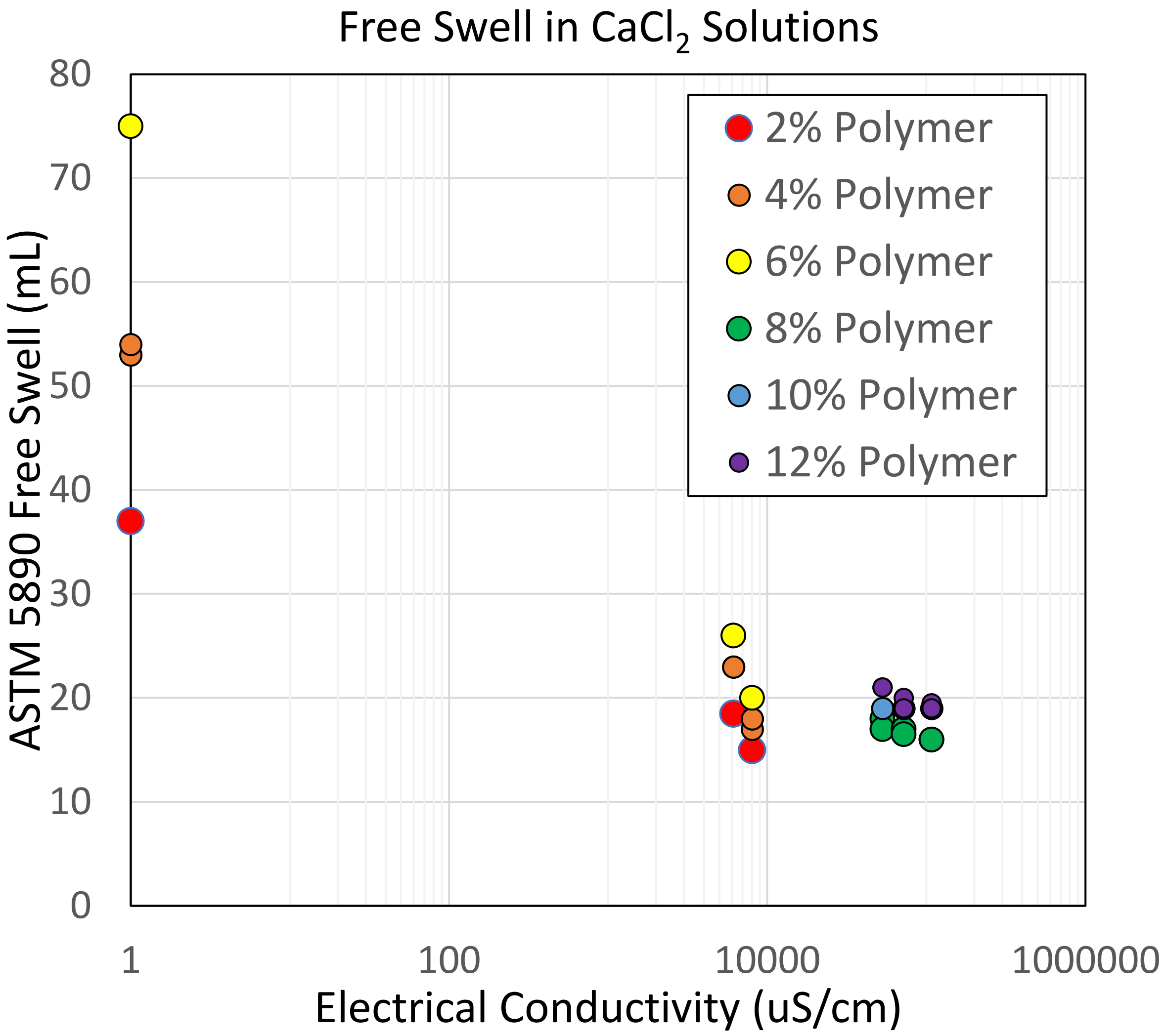
Index Testing:

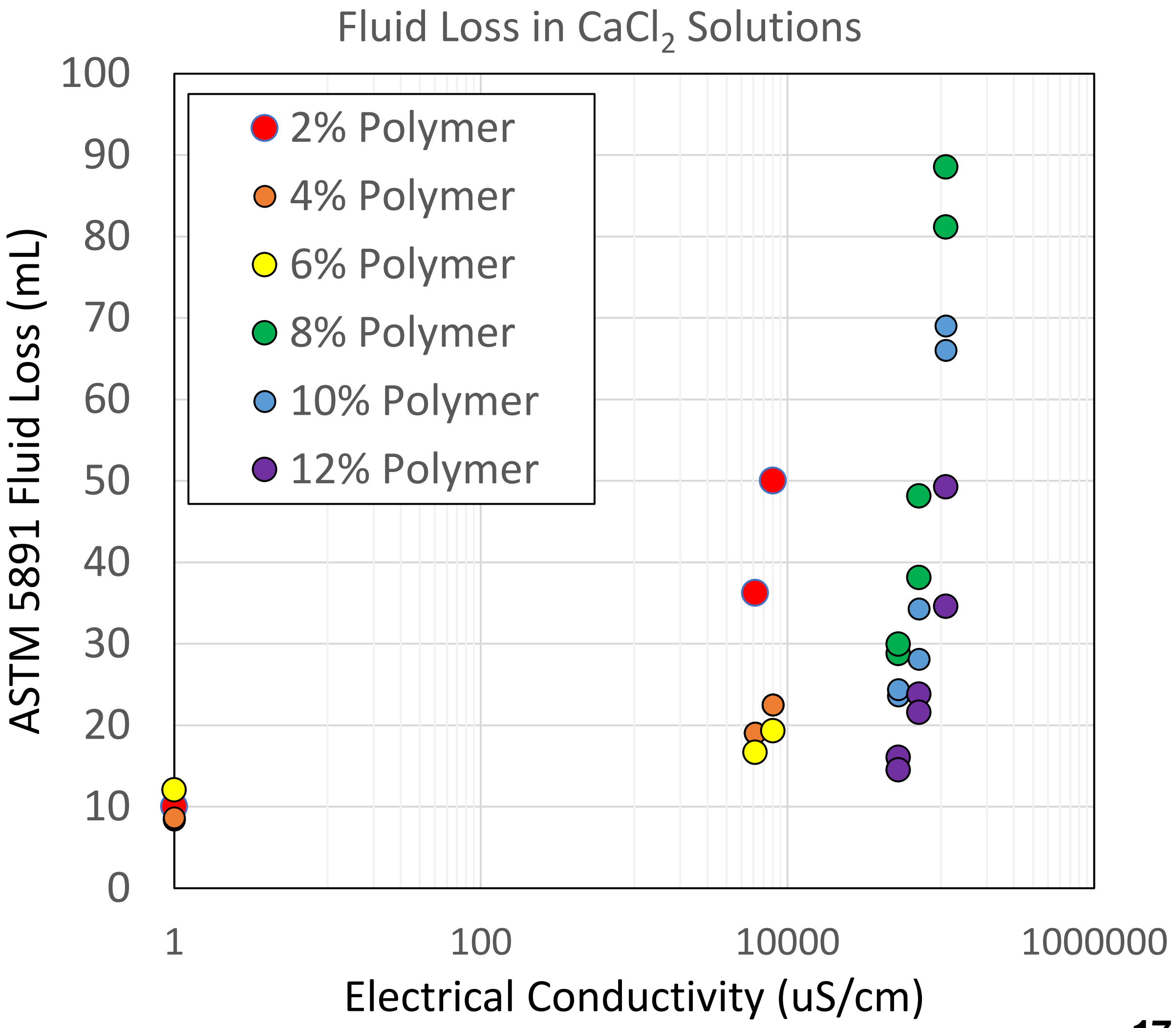
- Free swell (ASTM D5890)
- Fluid loss (ASTM D5891)

Performance Testing:

- Hydraulic conductivity (ASTM D6766)
- Internal peel (ASTM D6496)
- Direct Interfacial shear (ASTM D6243)

Index Testing in $CaCl_2$ Solutions





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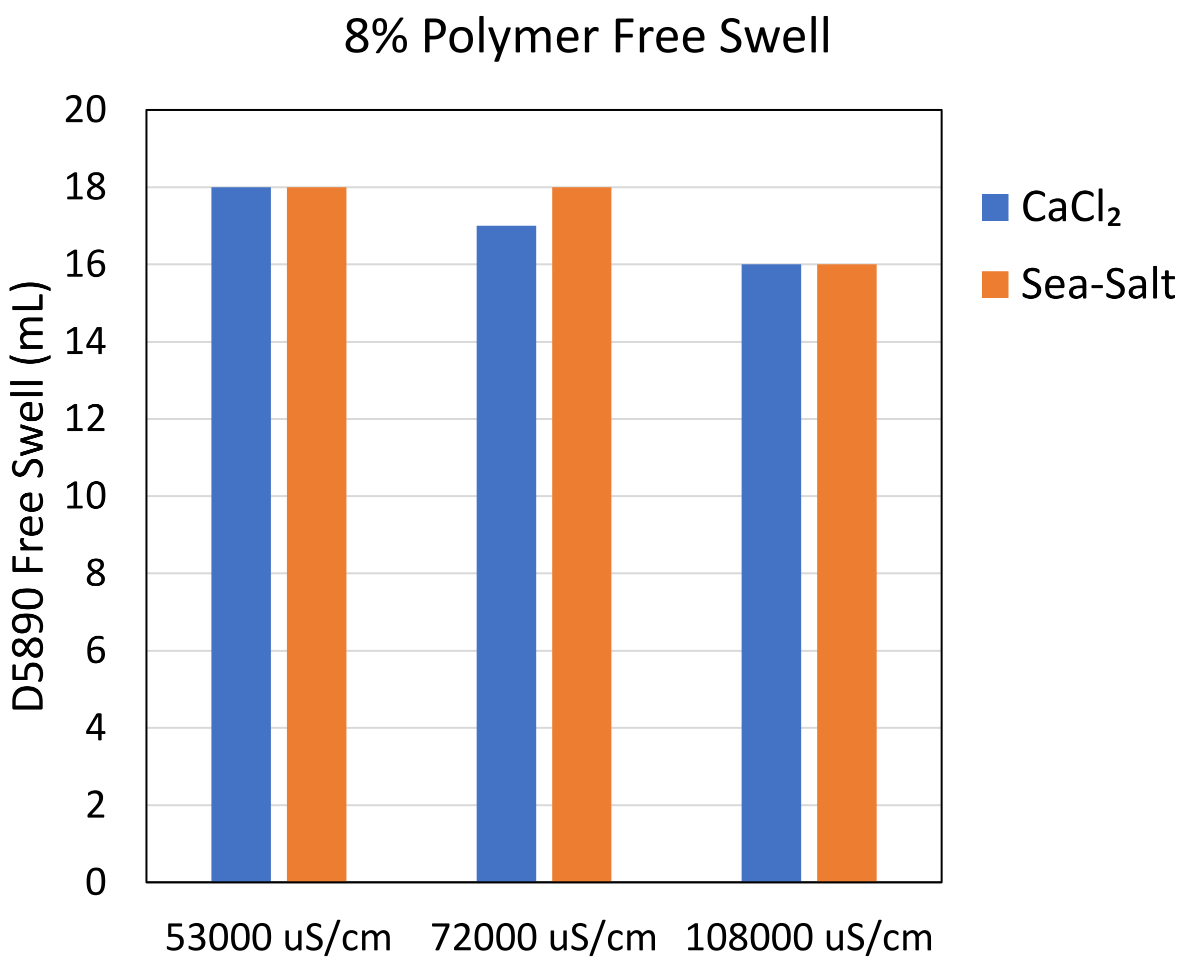
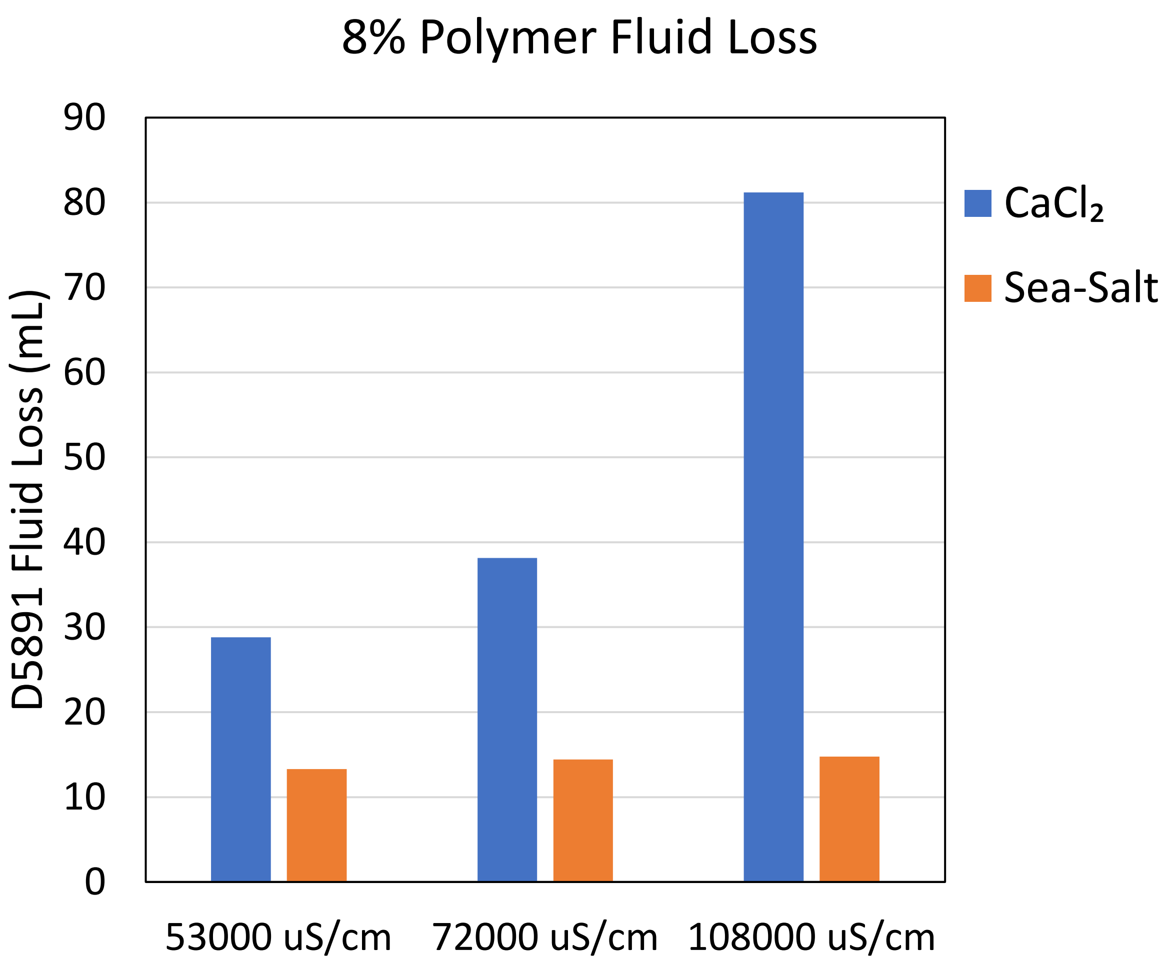
Index Testing in $CaCl_2$ vs Seawater Solutions



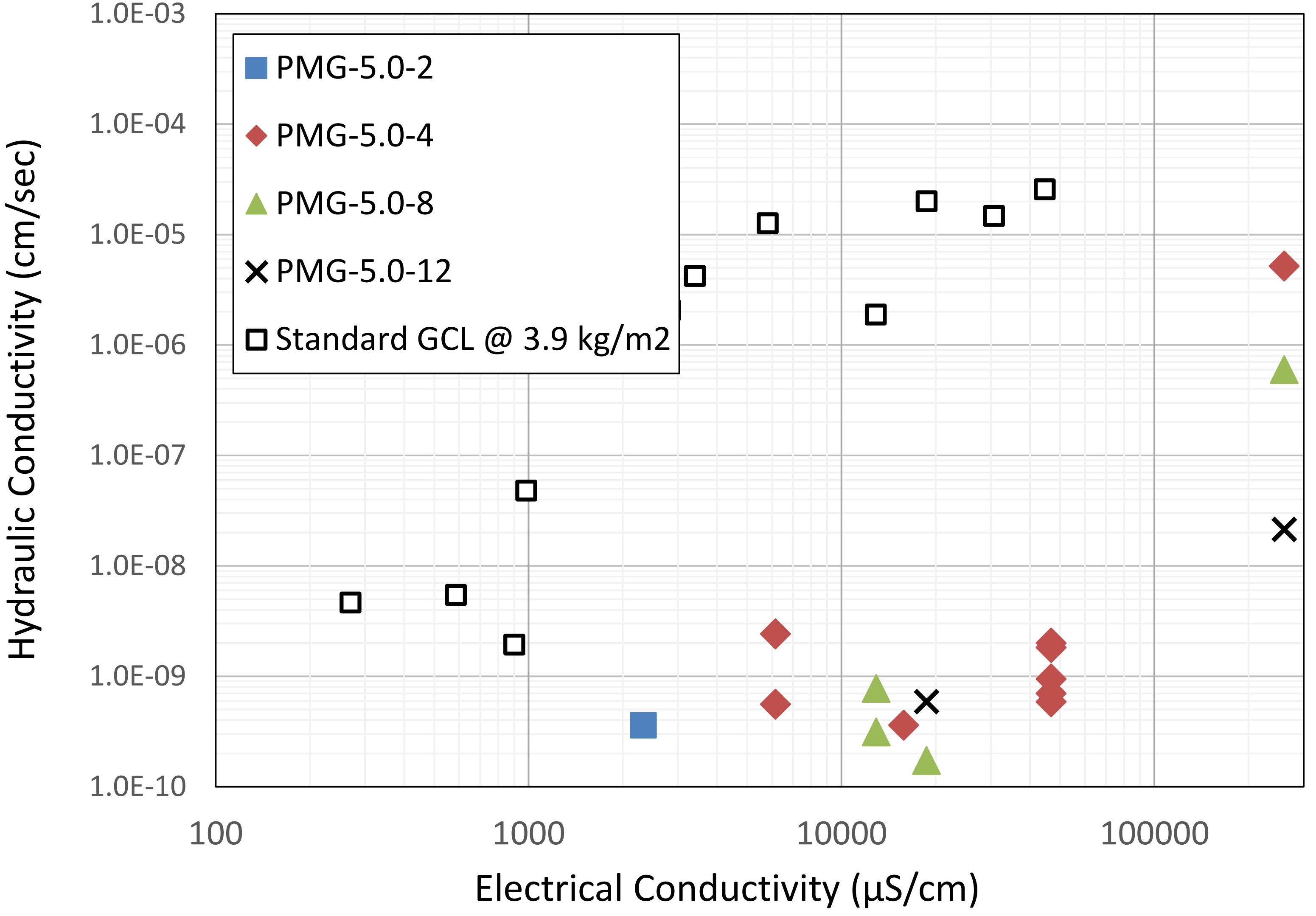


Leachates for Permeability Testing

Permeant Type	Permeant pH	Permeant EC (µS/cm)	Permeant Ionic Strength by ICP (M)	Permeant RMD by ICP (M^0.5)
0.005 M $CaCl_2$	6.5	1200		-
0.01 M $CaCl_2$	6.5	2330		-
0.03 M $CaCl_2$	6.3	6150	0.09	-
0.07M $CaCl_2$	6.7	12920	0.21	-
0.1 M $CaCl_2$	6.9	18700	0.3	-
Coal Ash Leachate #1	8.5	2884	0.02	0.18
Coal Ash Leachate #2	10.9	2492	0.06	0.05
Coal Ash Leachate #3	11	46800	1.05	4.76
Mining Leachate #1	6.8	15800	0.21	0.704
Mining Leachate #2	8.8	260000	4.8	6.3

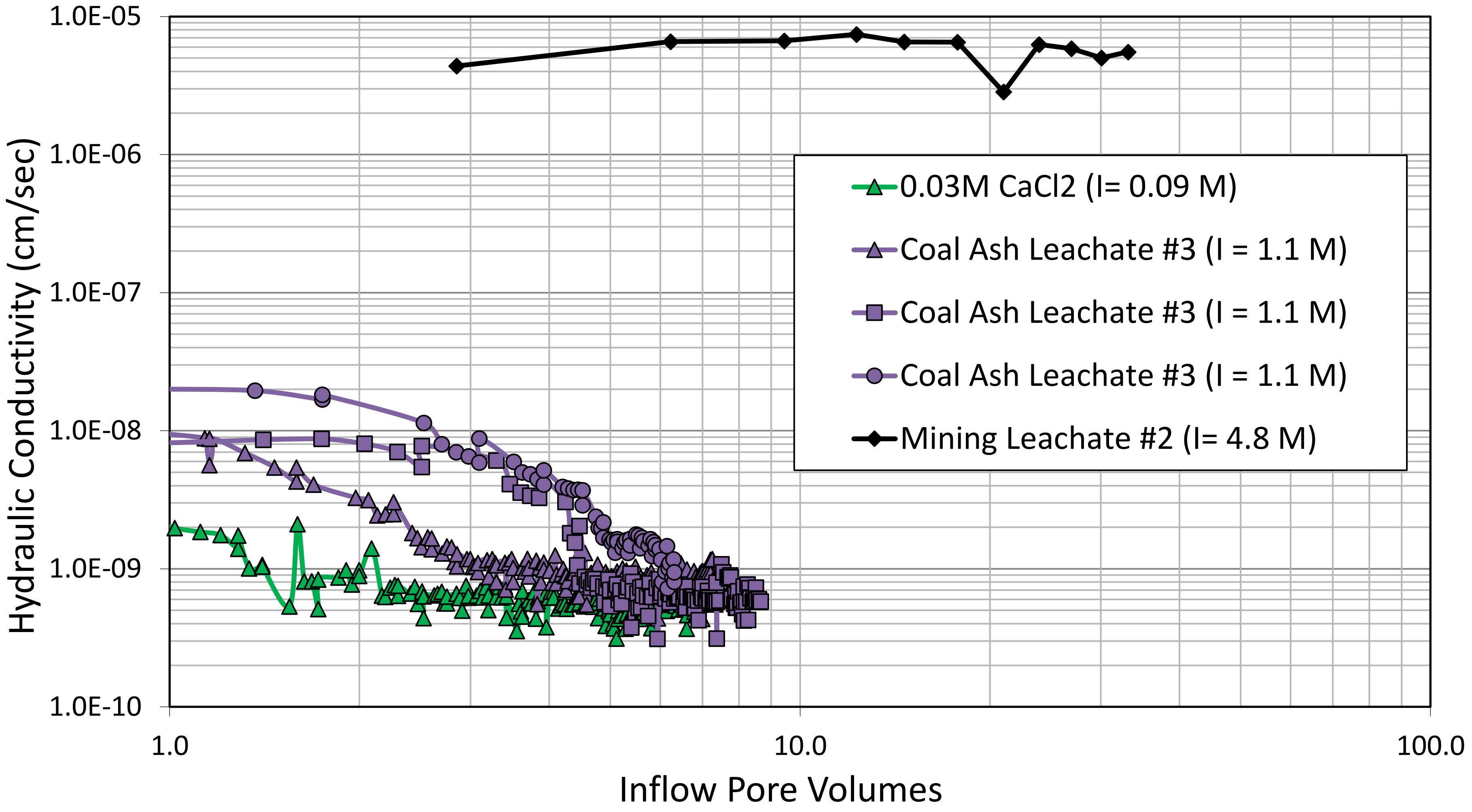
Pre-hydration and testing with the same leachate

Permeability Testing: 5 kg/m²

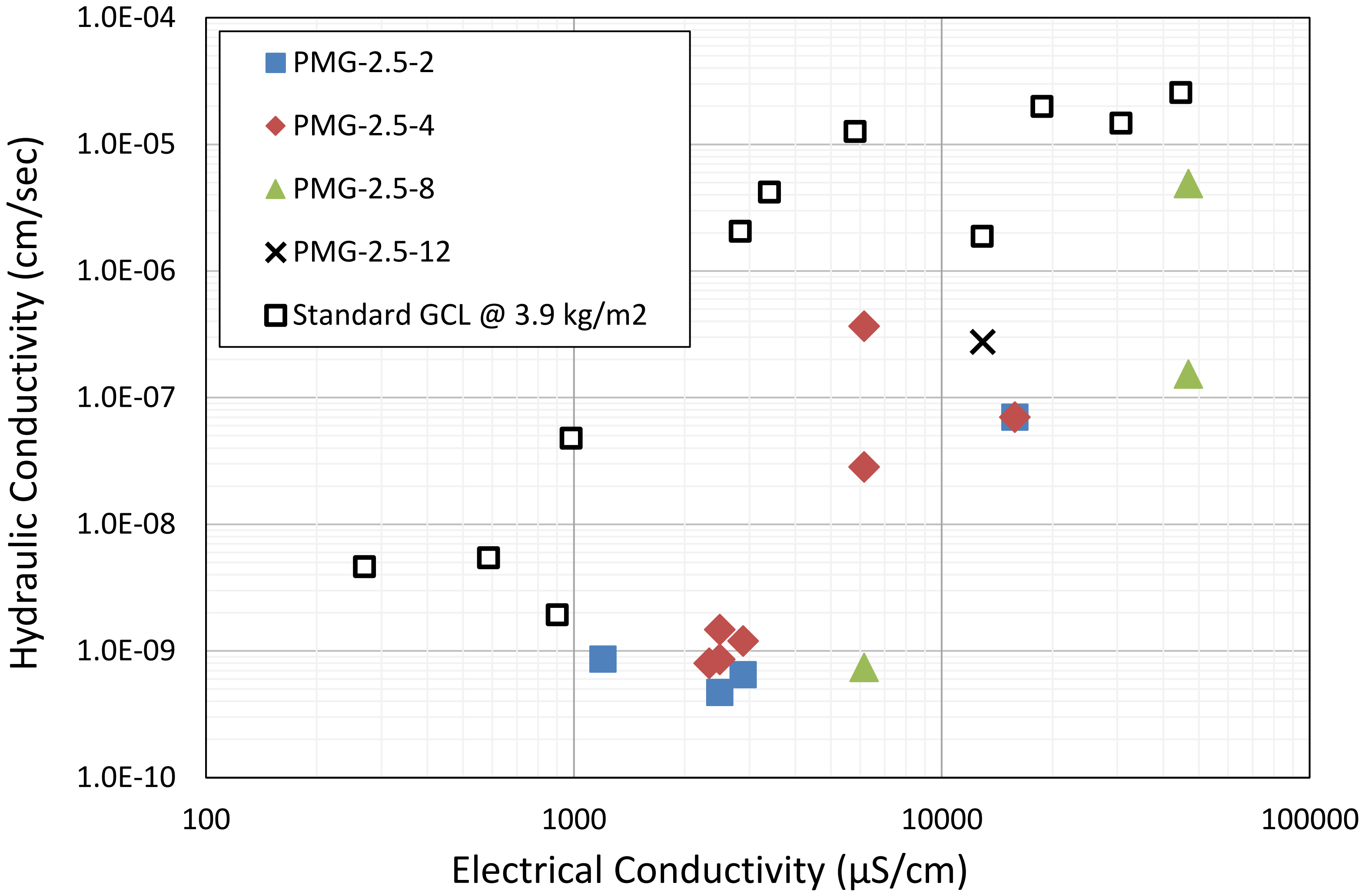


Permeant Type	Permeant EC (µS/cm)
0.005 M $CaCl_2$	1200
0.01 M $CaCl_2$	2330
0.03 M $CaCl_2$	6150
0.07M $CaCl_2$	12920
0.1 M $CaCl_2$	18700
Coal Ash Leachate #1	2884
Coal Ash Leachate #2	2492
Coal Ash Leachate #3	46800
Mining Leachate #1	15800
Mining Leachate #2	260000

Permeability Testing: 4 wt% Polymer - 5 kg/m²



Permeability Testing: 2.5 kg/m^2



Permeant Type	Permeant EC (µS/cm)
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0.01 M $CaCl_2$	2330
0.03 M $CaCl_2$	6150
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0.1 M $CaCl_2$	18700
Coal Ash Leachate #1	2884
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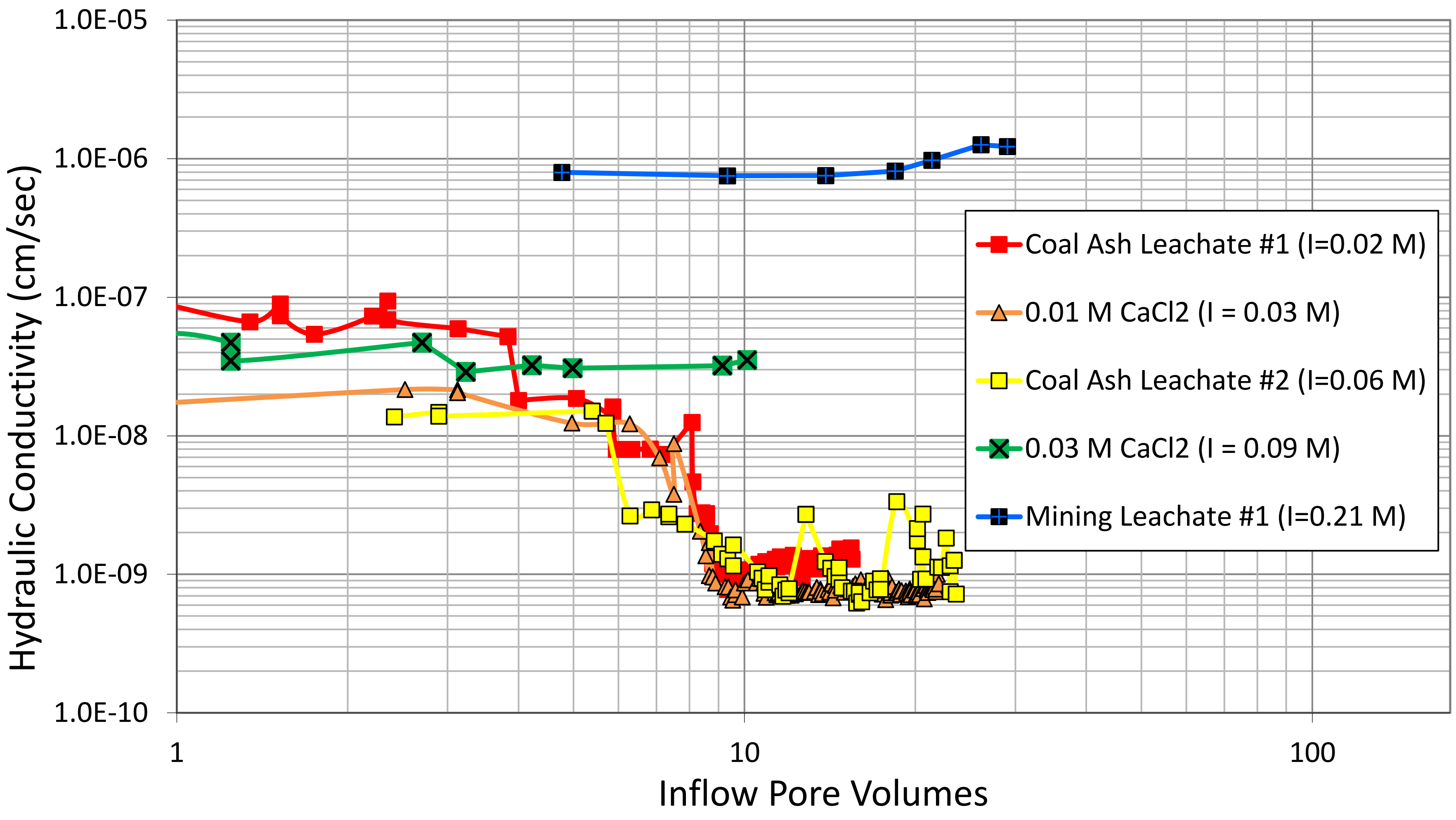
Coal Ash Leachate #3	46800
Mining Leachate #1	15800
Mining Leachate #2	260000

Permeability Testing: 4 wt% Polymer - 2.5 kg/m²



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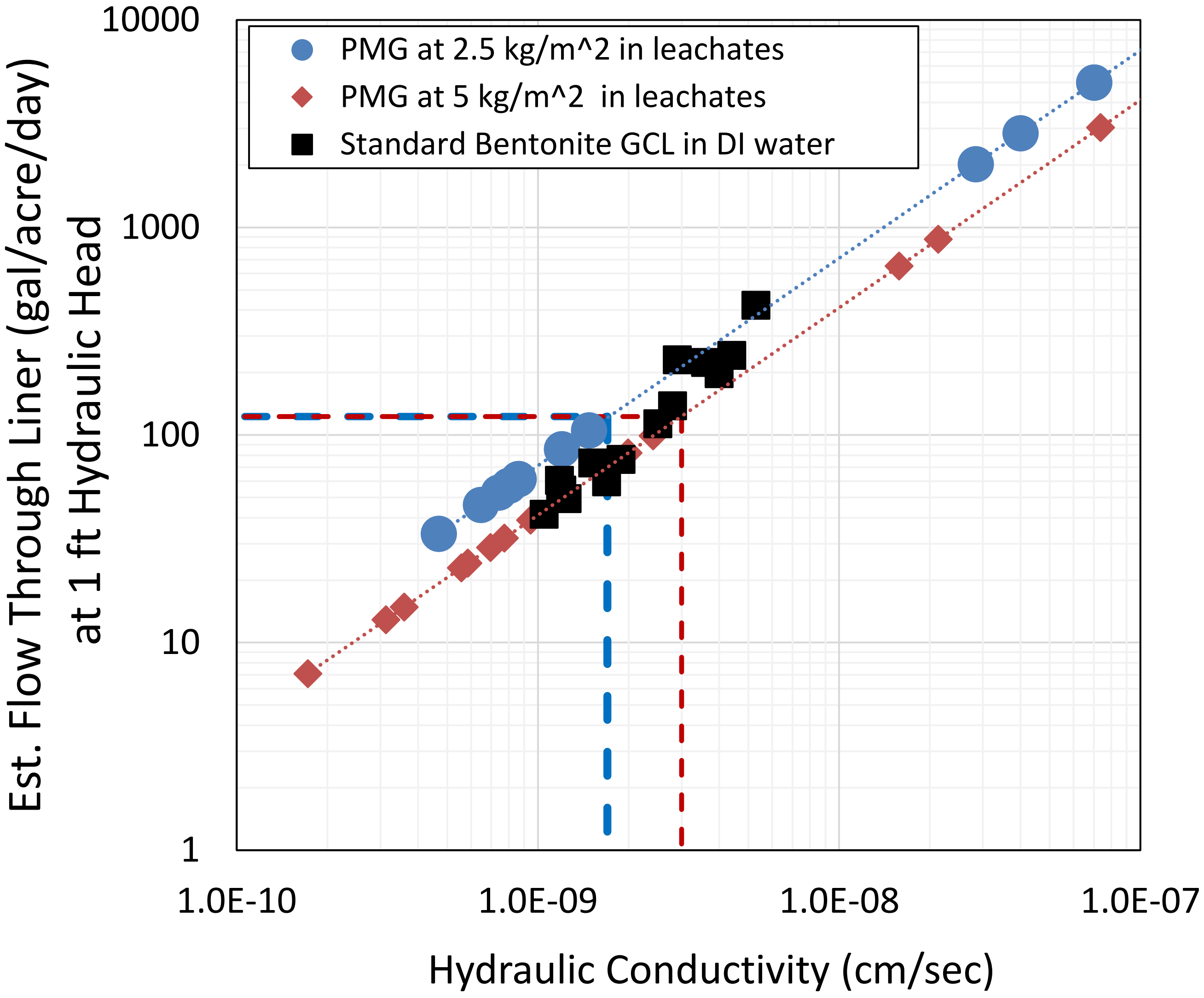
Estimated Leakage Rates



<u>PMG (0.7 cm thick, 1 ft head)</u>

$q = k * i$

$q = 3.0 \times 10^{-9}$ cm/sec * ((1ft+0.023ft)/0.023ft)

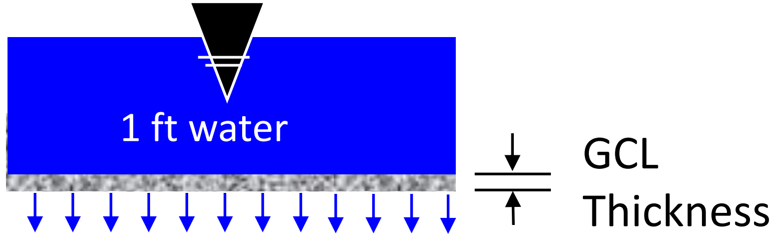
q = 123 gal/acre/day

<u>PMG (0.4 cm thick, 1 ft head)</u>

$q = k * i$

$q = 1.7 \times 10^{-9}$ cm/sec * ((1ft+0.013ft)/0.013ft)

q = 123 gal/acre/day

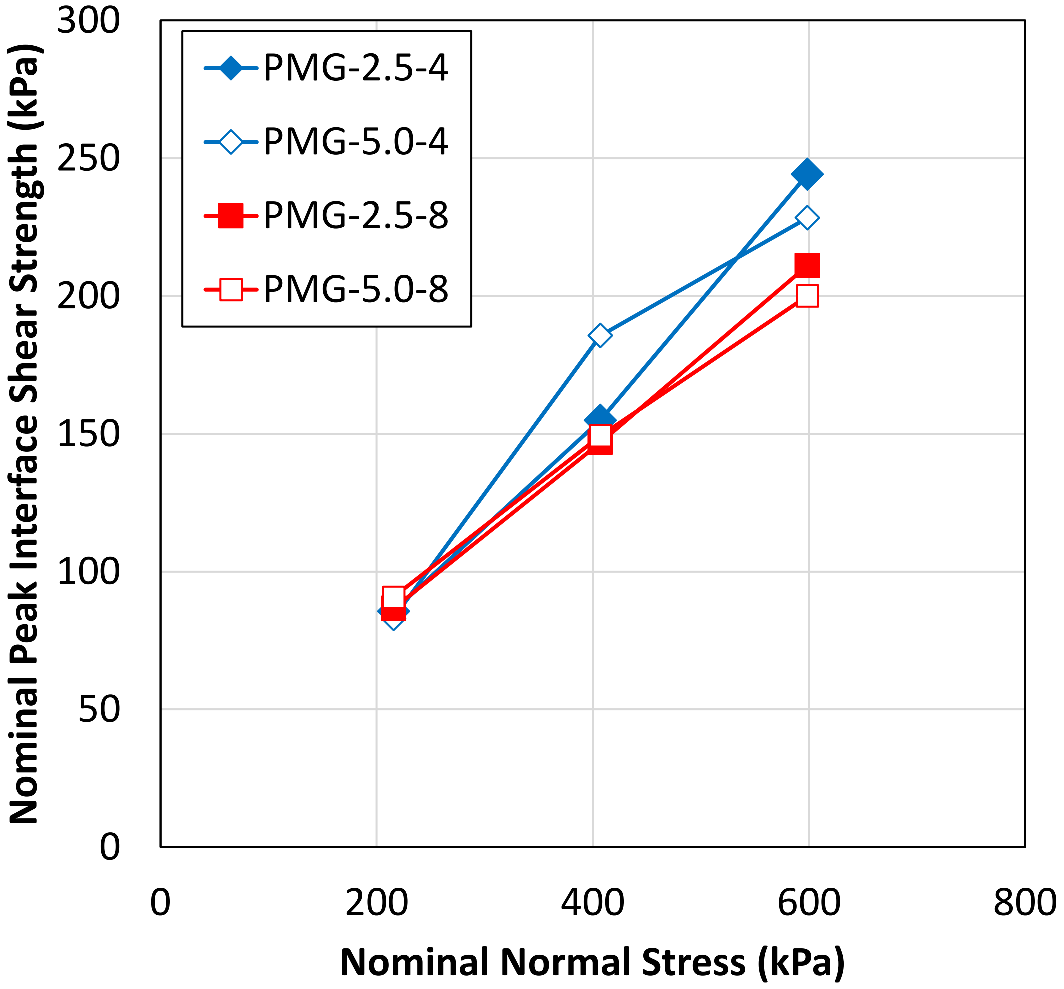


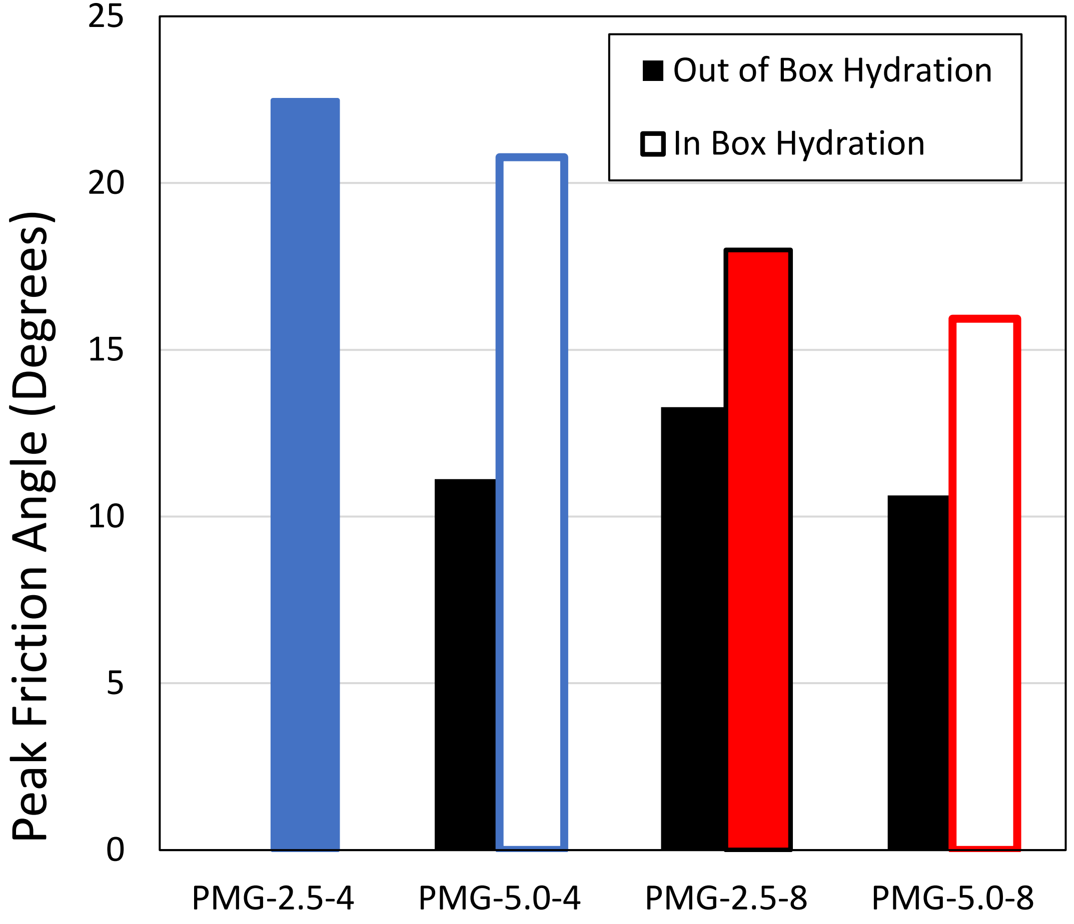
Interfacial Shear Testing Conditions

PMG	Normal Stress	Peak Shear Stress	Large Displacement Shear stress (In Box Hydration)	Peak Friction Angle (In Box Hydration)	Adhesion (In Box Hydration)	Avg Peel Strength
	(kPa)	(kPa)	(kPa)	(Degrees)	(kPa)	N/cm
PMG-2.5-4	215	86	68			
PMG-2.5-4	407	155	46	22.5	-6.9	26.6
PMG-2.5-4	599	244	152			
PMG-5.0-4	215	83	51			
PMG-5.0-4	407	186	110	20.8	11.3	21.4
PMG-5.0-4	599	228	86			
PMG-2.5-8	215	87	52			
PMG-2.5-8	407	147	91	18.0	16.0	21.9
PMG-2.5-8	599	211	112			
PMG-5.0-8	215	91	59			
PMG-5.0-8	407	149	85	15.9	30.5	21.2
PMG-5.0-8	599	200	108			

Testing performed against a spike textured geomembrane

Interfacial Shear Results





Out of box pre-hydration is not recommended

Conclusions

- New “U-Series” Resistex® Geosynthetic clay liners (PMGs) developed
- Intended for use in capping and base liner applications
- High swelling potential and sealing power vs range of leachate chemistries
- Polymer content can be tailored for a specific leachate
- Higher MPUs / polymer contents required for high strength leachates
- Lower MPU / polymer contents can be used for lower strength leachates
- High peel strength and interfacial shear strength

Thank You For Your Attention!

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