A bentonite product with saline-sodic resistance

Will P Gates[1], Matt Gardam[2], Warren Hornsey[3], Daniel Gibbs[4], John Buckley[5]

[1]SmecTech, 24 Chapel Road, Moorabbin VIC 3189; will.gates@monash.edu
[2] Arumpo bentonite Pty Ltd, 35a Deakin Ave, Mildura, Vic 3502 mattg@arumpo.com.au
[3]TRI Australasia, Pty Ltd, Unit 12/45 Township Drive, Burleigh Heads, QLD 4225 whornsey@tri-env.com
[4] Geosynthetic Centre of Excellence, 11 Production Ave, Molendinar, QLD 4214 d.gibbs@geofabrics.com.au
[5]Geofabrics Australasia Pty Ltd, 11 Production Ave, Molendinar, QLD 4214 j.buckley@geofabrics.com.au

Abstract

The rapid advent of coal seam gas exploration and production presents some risks to Australian surface and ground water quality. Of particular concern are the handling, intermittent storage and disposal of saline-sodic brines, such as from coal seam gas production, which can adversely impact on the hydraulic performance of clay-based barrier systems. Two new bentonite products were evaluated for their hydraulic performance to saline and saline-sodic brines and found to have remarkable fluid loss and permeability characteristics.

Key Words: Coal seam gas, geosynthetic clay liners, hydraulic barriers, hydraulic conductivity, fluid loss, swell index

Introduction

Australian mineral and energy exploration industries produce enormous volumes of highly saline liquid wastes annually – in 2010 environmental costs associated with handling and disposal of these liquids exceeded \$250M (Australian Bureau or Statistics). With the advent of coal seam gas (CSG) exploration and production, this value is expected to raise many-fold in the near future. Due to the high saline-sodic chemistries of CSG waters, their above ground containment poses long-term threats to Australian ground and surface waters. Regulatory authorities increasingly require that impoundments be lined with composite liner systems comprised of a geomembrane (GM) primary barrier and one or more low permeable mineral layers to minimise transport of aqueous leachates into the surrounding groundwater. The composite liner system has proven to be the most effective way of minimising leakage rates to values up to several orders of magnitude less than the individual components alone (Bonaparte et. al., 1989). The mineral liners must maintain a hydraulic conductivity lower than the design value for the projected contaminating lifespan of the waste containment facility. While design criteria exist (e.g. Victoria EPA) for application in municipal solid waste landfills (i.e. less aggressive environment), clayey soil based liner lifetime expectancies are unknown in these environments and estimates are usually unsubstantiated by rigorous investigations.

The scarcity of suitable and economical clayey soils for traditional liners throughout CSG localities in Australia has resulted in an increased use of geosynthetic clay liners (GCLs) to promote environmental containment of CSG process waters because of their ready availability, technical equivalence and ease of deployment compared to traditional clayey liners. GCLs are manufactured products composed of ~5-10 mm of processed sodium bentonite sealed between two synthetic geotextiles held together by needle-punching or stitch bonding. Bentonite is processed (e.g., sodium beneficiated) to impart favourable sealing characteristics and GCLs are usually combined with a GM to form a composite liner. While providing suitable protection against transport of low salinity waters (Kolstad et al., 2004, Jo et al., 2004, 2005), interaction of GCLs with saline leachates (generally >0.3 M) results in increased potential for hydraulic incompatibility (Lange et al., 2009), enabling leachates to contaminate underlying sediments and groundwater if they are used as single liners or where primary physical barriers (GM) have failed. Thus, CSG discharge waters have constituted, and continue to constitute, a significant threat to Australian groundwater and ecosystems.

These issues require hydraulic barrier systems capable of functioning under geochemical conditions that are generally adverse to containment. The purpose of this study therefore, was to develop a suitably modified bentonite which could withstand excessive high saline-sodic conditions typical of CSG applications.

Materials and Methods

Four bentonites from Australia and overseas (Table 1) were tested for their ability to withstand saline-sodic leachates using ASTM standard methods for fluid loss (ASTM D5891), swell index (ASTM D5890) and saturated hydraulic conductivity (ASTM D5887 & ASTM D6766). Arumpo bentonite underwent two different non-disclosed beneficiations and modifications (ABM1 and ABM2). All tests were carried out using potentially incompatible leachates. Leachates included artificial seawater (ASTM D1141), 0.3 M, 1 M and 2 M NaCl and a CSG surrogate consisting of 20% soluble sodium salts (2:1:1 $NaCl:NaHCO_3:Na_2CO_3$). The brines typically had pH in the range 9.1 – 9.2 and electrical conductivity ~145-155 mS/cm. All leachates were either made in-house (for fluid loss and swell index) or purchased as certified products (hydraulic conductivity tests). Saturated hydraulic conductivity tests, using flexible-walled triaxial permeameters (at TRI Australasia), were performed on ABM1 in synthetic seawater (~0.6 M) and 1 M NaCl, and on ABM2 in 2 M NaCl and 20% saline-sodic brine. Some tests were conducted with the sample initially pre-hydrated with deionised water and other tests were conducted by directly hydrating the dry bentonite product with the leachate. Dry clay powder was lightly packed into the triaxial cell with carrier and cover geotextiles to mimic a GCL. All tests were taken to chemical equilibrium, which resulted in only 1-3 pore volumes of flow.

Results and Discussion

Table 1 compares the four other bentonite products, which have been used in GCLs. All samples had low swell index (SI) and high fluid loss (FL). The resulting cake thickness combined with the filtrate flux returned calculated (Gates et al., 2011) saturated hydraulic conductivity (k_{calc}) values of 8 x 10^{-10} m/s or greater, which is equivalent to a constant head of water moving 25 mm or more per year. Thus the expected service life of un-modified bentonites used in GCLs against CSG brines is not expected to exceed one year.

Table 1. Bentonite sources and testing results on as-received bentonites with 20% saline-sodic CSG brine surrogate. k_{calc} calculated hydraulic conductivity from the FL tests.

Bentonite	Source	SI (mL/2g)	FL (mL)	Filter cake (mm)	k_{calc}^* (m/s)
CSK	Asia	4.0	103	4.0	8.2 x 10^{-10}
TAU	Australia	4.0	118	3.7	8.2 x 10^{-10}
EAU	Australia	5.0	97	5.9	1.3 x 10^{-9}
ESA	South Africa	5.5	106	4.3	8.7 x 10^{-10}

Table 2 displays the results of the ABM products with the same 20% saline-sodic brines as well as in 0.3 M and 2.0 M NaCl.

Table 2. ABM sample results on 0.3M, 2 M NaCl and 20% saline-sodic CSG brine surrogate. k_{calc} calculated hydraulic conductivity from the FL tests.

Arumpo Product	Leachate	SI (mL/2g)	FL (mL)	Filter cake (mm)	k_{calc} (m/s)
ABM1	0.3 M NaCl	8	17.4	2.4	7.6 x 10^{-11}
	(s.d. n=3)	-	(0.5)	-	(1.7 x 10^{-12})
ABM1	20% brine	8.5	40.2	4.7	3.2 x 10^{-10}
	(s.d. n=8)	(0.1)	(2.8)	(0.3)	(1.4 x 10^{-11})
ABM2	2 M NaCl	8	22.7	4.6	2.1 x 10^{-10}
	(s.d. n=4)	-	(0.8)	(0.6)	(3.7 x 10^{-11})
ABM2	20% brine	9	21.8	4.5	1.7 x 10^{-10}
	(s.d. n=4)	-	(2.3)	(0.4)	(2.3 x 10^{-11})

Note that SI values for ABM products in 20% brine (Table 2) are double that of the other un-modified bentonites (Table 1), and the FL values are ~2.5x and 5x less for, respectively, ABM1 and ABM2, compared to the unmodified bentonites. The resulting k_{calc} values are of a similar magnitude lower as well for the ABM products in 20% saline-sodic brine. ABM1 performed well in 0.3 M NaCl and ABM2 performed adequately in 2 M NaCl. These latter solutions were trialled to determine the effect of ionic strength without elevated pH. The results indicate that ABM1 is limited in its ability to withstand strongly saline-sodic leachates compared to ABM2 (e.g. FL is 2x), but should perform well at lower ionic strengths, even at neutral pH. ABM2 appears to perform well in strongly saline and saline-sodic leachates.

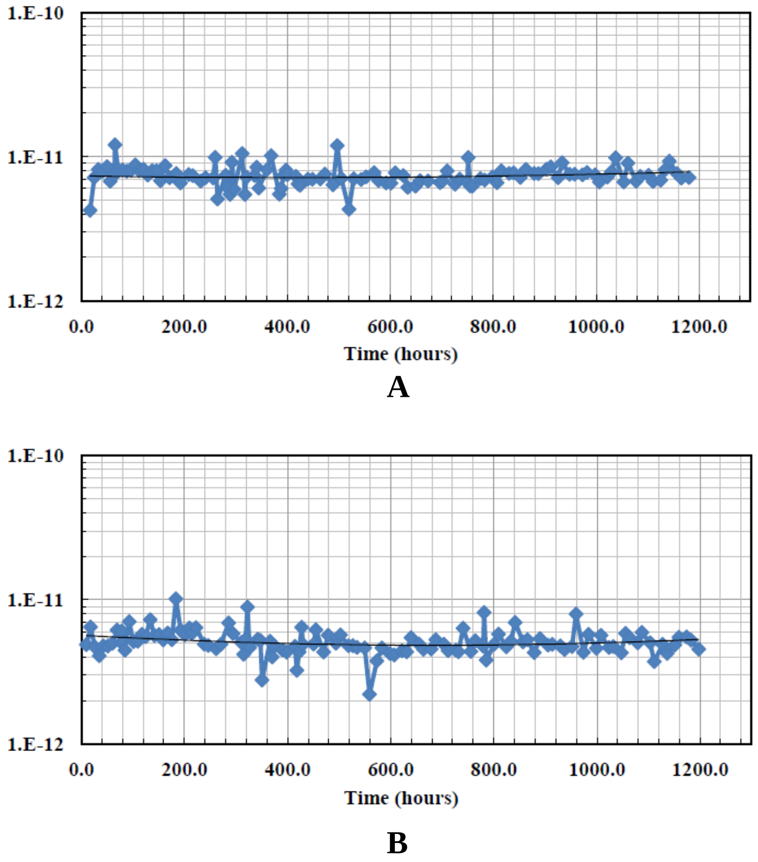

Figure 1. Saturated hydraulic conductivity of ABM2 in 20% brine; A) non pre-hydrated, B) prehydrated in deionised water.

The results of the triaxial hydraulic conductivity ($k_{triaxial}$) tests (Figure 1, Table 3) reveal that both products are highly effective hydraulic barriers against high ionic strength saline-sodic leachates, at least in the short term. Comparisons indicate that the $k_{triaxial}$ values are 2 to 25 x lower than corresponding k_{calc} determined from the fluid loss measurements. These results confirm earlier FL tests (Gates et al, 2011) showing it is a useful compatibility test for bentonites in high ionic strength leachates.

Table 3. Triaxial hydraulic conductivity tests on ABM products in various saline and saline-sodic leachates and under conditions of pre-hydration (with deionised water) and no pre-hydration.

Product	leachate	hydration method	$k_{triaxial}$ (m/s)
ABM1	Seawater	no pre-hydration	3.1×10^{-11}
		pre-hydrated with deionised water	1.1×10^{-11}
	1 M NaCl	no pre-hydration	1.9×10^{-11}
		pre-hydrated with deionised water	1.1×10^{-11}
ABM2	2 M NaCl	no pre-hydration	3.3×10^{-11}
		pre-hydrated with deionised water	2.0×10^{-11}
	20% brine	no pre-hydration	7.3×10^{-12}
		pre-hydrated with deionised water	5.1×10^{-12}

Conclusions

Two new Arumpo bentonite products were observed to have remarkable hydraulic performance properties to saline-sodic leachates compared to bentonites typically used in GCLs in Australia. The swell index were double, the fluid loss values were 2.5 – 5x lower and the saturated hydraulic conductivity values, calculated from fluid loss fluxes, were a similar magnitude lower for the ABM1 and ABM2 products. Pre-hydration of the ABM products in de-ionised water had a minimal, but positive, effect on the saturated hydraulic conductivity, as measured using triaxial permeamters, indicating that the ABM products are resistant to the detrimental effects of the high ionic strength of saline-sodic leachates, at least in the short term. Further tests are required to validate these results over longer time periods and larger flow volumes.

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