Improving the swell index and fluid loss methods for compatibility testing of bentonites

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Introduction

Geosynthetic clay liners (GCLs) are now a common feature of environmental lining systems in landfills, leach-heap pads, impoundments, irrigation canals and aesthetic ponds. The ASTM standard method (ASTM D5891-02) for fluid loss (FL) is an adaptation from the older American Petroleum Institute methods (API Specification 13A; API Specification 13B) for determining gel strength of bentonite and drilling mud suspensions. While the method provides an index to assist with evaluating water retention characteristics of a bentonite filter cake when deposited at elevated pressure from suspension, in its current form it is a qualitative test only (Rosin-Paumier et al., 2010). Such guidance is required to adapt the test for testing compatibility of the bentonite component of GCLs to leachates from landfills, mineral processing, or subsurface waters more typically encountered in field conditions (Chung and Daniel, 2008). Likewise, the ASTM standard method (ASTM D5890-06) for swell index (SI) provides an operator-dependent qualitative result suitable only for bentonite swelling in good quality water. We report here modified FL and SI values, along with flux and permeability of the filtrate and gel strength and effective porosity of the filter cake obtained on up to 5 M aqueous NaCl. We show that both modified methods can be semi-quantitative and are well-suited to compatibility testing of bentonite in saline leachates, can be used to differentiate between high quality bentonites and are potentially useful as tests for ‘fit-for-purpose’ products.

Materials and Methods

To indicate the generality of the tests, we chose three bentonites, two of which are commonly used in GCLs in Australasia (Table 1), and a range of aqueous NaCl concentrations. Samples of each bentonite were assessed for quantitative mineralogy and cation exchange capacity. Bentonites A and C are natural sodium bentonites whereas bentonite B is a sodium activated magnesium bentonite. All bentonites are composed of finely divided particles with smectite (montmorillonite) dominating the finest size fractions. The three bentonites typically have SI values in excess of 24 ml/2g in deionised water as well as FL values < 15 mL in deionised water, index values which are currently accepted by the GCL industry in Australia.

All specifications of the original ASTM methods were followed, the exception being that for ASTM D5891-02 we used a gravimetric determination of filtrate flux and, for both methods, we used solutions with up to 5 M NaCl to react with the bentonites. Pre-weighed vessels were used to collect filtrate after 7.5 and 30 minutes under 690 kPa (100 psi) applied pressure through hardened, ash-less filter paper. After 30 minutes, the filter press was disassembled and the thickness, wet mass and dry mass of the filter cake was determined. These parameters were sufficient to enable determination of filtrate volume, fluid loss, filtrate flux, permeability, permittivity and a variety of measures associated with the filter cake for example gravimetric water content, gel strength, effective porosity and effective void ratio. All values reported are for duplicate tests. For the SI tests, we ensured that the 2 g of powdered (un-sieved) sample was deposited onto the top of solutions in100 mL graduated cylinders within a 2-hr time frame and then determined the swell volume after standing undisturbed for 24 hr at 20^{o}C.

Table 1. Mineralogical and chemical properties of the bentonites studied.

Bentonite	Smectite content of Bulk (%)	<0.2 µm Smectite content (% of bulk)	Smectite Content of <0.2 µm (%)	CEC – MB-TSPP$ (cmol/kg)	% Na on CEC (ESP) (%)
A	81	56	100	104	60
B	72	52	98	85	83
C	84	57	100	92	65

$The methylene blue (MB) CEC tests were conducted on bulk materials (at CSIRO Land and Water) following the tetra-sodium pyrophosphate (TSPP) pre-treatment method of Wang et al. (1996).

Results and Discussion

Figure 1 shows the changes in SI measured as a function of NaCl concentration. While some differences in the SI were still observed at low (≤0.25 M) concentrations of NaCl, it is clear that the SI test is insufficiently robust to differentiate potential differences in bentonite performance to higher soluble salt concentrations.

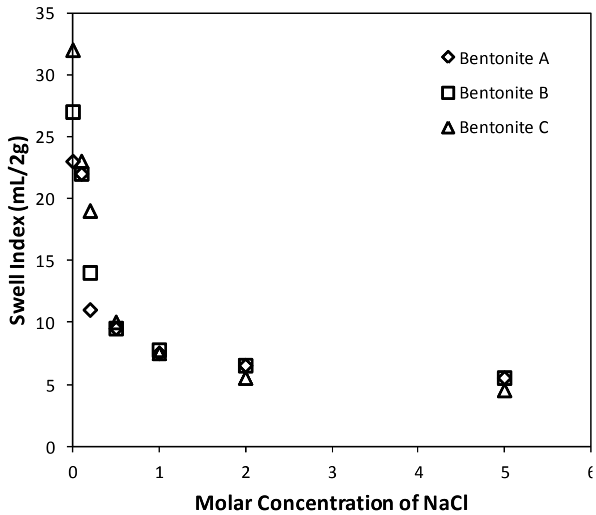

Fig. 1. SI in aqueous NaCl.

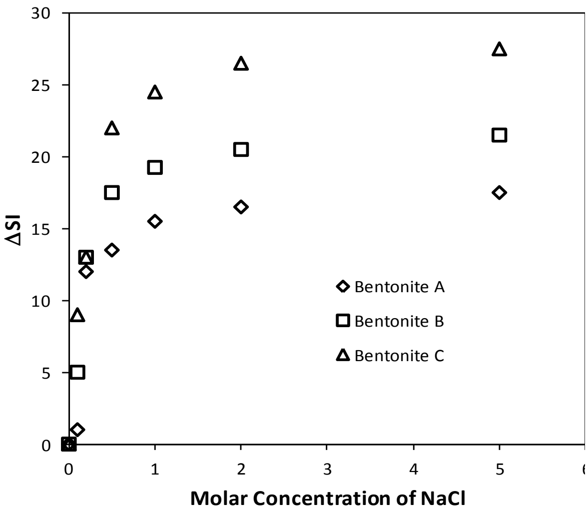

Fig. 2. ΔSI in aqueous NaCl.

In general, bentonites which yield high SI values according to ASTM D5890-06 show a greater loss of swell volume when exposed to saline water. We thus normalised the SI values by taking the difference between SI in deionised water and SI in each NaCl solution. The resulting ΔSI values are plotted against NaCl concentration (Figure 2) and show differentiation in the swelling behaviour of the three bentonites. One might reasonably assume that bentonites with large ΔSI values should be expected to have lower "performance" than bentonites with low ΔSI values.

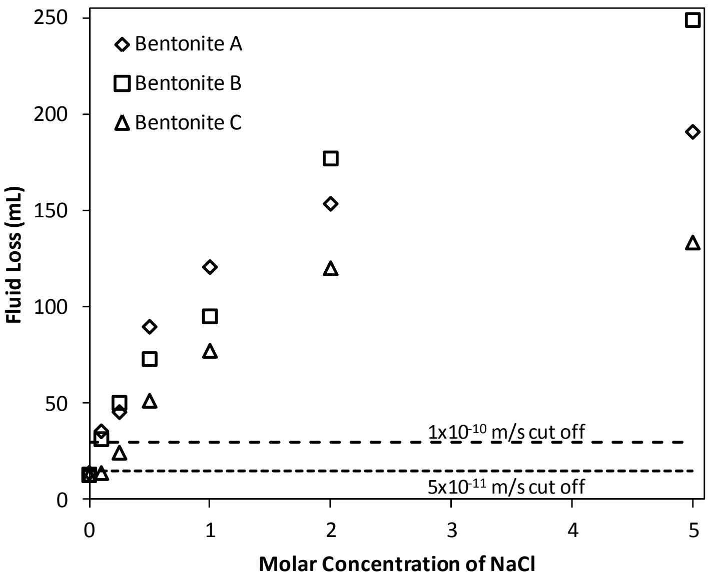

Fig. 3. FL values as a function of aqueous NaCl concentration. Cut off lines refer to 15 mL (…) and 30 mL FL (- - -).

Bentonite C showed the greatest range of ΔSI of the three bentonites, yielding ΔSI values ~10 mL greater than bentonite A. Increasing NaCl concentrations resulted in predictably greater FL, but also measurable differences between the three bentonites (Figure 3). All three bentonites yielded FL values <15 mL in DI water, but these increased above ~50 mL in 0.5M NaCl for bentonites A and B, but remained below 30 mL for bentonite C. Note that this is in contrast to expectations that a greater ΔSI would potentially return higher FL. In addition to higher FL values, bentonites A and B showed greater variability in FL compared to Bentonite C.

Table 2 shows the results of various calculations made on measurements from the fluid loss test. Bentonite C has the highest gravimetric water content (GWC) in filtrates of ≤0.25M NaCl, but values for this parameter are comparable to the other bentonites with higher NaCl concentration. The filter cake of bentonite C was consistently thinner and the overall change in thickness was about half that of either bentonite A or B. Thus, the gel strength of bentonite C was about 2x that of bentonites A and B. Both the effective void ratio and effective porosity of the three bentonites were similar. Total filtrate fluxes of all three bentonites responded to increased NaCl concentration in a similar manner, and were within the same order of magnitude, although bentonite C had lower total flux values. The 30 minute total flux values were used to calculate the saturated hydraulic conductivity (k) of the filter cake, taking into account the filter cake thickness (converted to m), diameter of the filter cell (0.076 m) and 70.4 m H_2O (conversion of kPa to m H_2O) applied static head (following Chung and Daniel, 2008). The k values for all three bentonites remained below $1x10^{-9}$ m/s up to 0.5 M NaCl, and for bentonites A and B, increased by 3-4.5 times that value at 5 M NaCl. Within measurement error, however, bentonite C maintained permeability at or below $1x10^{-9}$ m/s in 5 M NaCl, indicating exceptional performance as a natural sodium bentonite. Bentonite A had lower permeability than bentonite B at ≥2M NaCl, but similar values at lower salt levels. While the permittivity (ψ) changed by only an order of magnitude across the entire concentration range of NaCl used, bentonite C out-performed bentonites A and B by 2-3 times in any NaCl filtrate.

Conclusions

Modification to the ASTM fluid loss and swell index tests increase their semi-quantitative usefulness when evaluating bentonite performance in saline leachates. The modifications enable differentiation between the performances of high quality bentonites, commonly used in GCL applications, when reacted with non-standard leachates, such as those of elevated ionic strength due to increased salinity.

Acknowledgements

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Table 2. Properties of the bentonite and filter cake determined from the modified Fluid Loss test as a function of NaCl concentration. Estimated error is 10-15%.

	NaCl concentration (mole/L)						
	Nil	**0.10**	**0.25**	**0.5**	**1.0**	**2.0**	**5.0**
A /GWC (g/g)	10.6	6.6	4.9	4.0	3.2	2.6	2.1
B /GWC (g/g)	10.4	8.4	6.3	4.6	3.3	2.6	1.9
C /GWC (g/g)	16.5	11.0	6.6	4.5	4.2	2.8	2.3
A /T (mm)	3.29	4.30	4.85	5.37	6.23	8.83	9.63
B /T (mm)	3.25	4.61	5.19	6.21	6.94	8.81	10.1
C /T (mm)	2.30	3.29	3.04	3.07	3.70	5.16	5.65
A / GS (g/g/mm)	3.2	1.5	1.0	0.75	0.53	0.30	0.22
B / GS (g/g/mm)	3.2	1.8	1.2	0.74	0.48	0.29	0.18
C / GS (g/g/mm)	7.2	3.4	2.2	1.4	1.2	0.53	0.40
A / e_{eff}	24.4	14.5	11.3	7.96	5.46	4.36	3.77
B / e_{eff}	28.9	16.8	13.7	8.80	5.69	4.51	4.27
C / e_{eff}	20.3	17.2	14.8	8.44	6.37	4.18	3.66
A / η_{eff}	0.96	0.93	0.91	0.89	0.84	0.81	0.79
B / η_{eff}	0.97	0.94	0.93	0.90	0.85	0.82	0.81
C / η_{eff}	0.95	0.94	0.94	0.89	0.86	0.81	0.78
A /Q ($m^3/m^2/s$)	$1.8x10^{-6}$	$4.5x10^{-6}$	$5.2x10^{-6}$	$1.0x10^{-5}$	$1.4x10^{-5}$	$2.0x10^{-5}$	$3.5x10^{-5}$
B /Q ($m^3/m^2/s$)	$1.6x10^{-6}$	$3.9x10^{-6}$	$6.4x10^{-6}$	$1.0x10^{-5}$	$1.3x10^{-5}$	$2.4x10^{-5}$	$3.4x10^{-5}$
C /Q ($m^3/m^2/s$)	$1.5x10^{-6}$	$1.9x10^{-6}$	$3.0x10^{-6}$	$6.4x10^{-6}$	$1.0x10^{-5}$	$1.5x10^{-5}$	$1.6x10^{-5}$
A /k (m/s)	$7.4x10^{-11}$	$2.4x10^{-10}$	$3.2x10^{-10}$	$7.2x10^{-10}$	$1.1x10^{-9}$	$2.3x10^{-9}$	$3.1x10^{-9}$
B /k (m/s)	$6.4x10^{-11}$	$2.3x10^{-10}$	$4.2x10^{-10}$	$8.1x10^{-10}$	$1.1x10^{-9}$	$2.7x10^{-9}$	$4.4x10^{-9}$
C /k (m/s)	$4.9x10^{-11}$	$8.2x10^{-10}$	$1.2x10^{-10}$	$2.6x10^{-10}$	$4.8x10^{-10}$	$1.1x10^{-9}$	$1.2x10^{-9}$
A /ψ (1/s)	$2.6x10^{-14}$	$6.8x10^{-14}$	$7.3x10^{-14}$	$1.6x10^{-13}$	$1.9x10^{-13}$	$3.1x10^{-13}$	$3.7x10^{-13}$
B /ψ (1/s)	$2.0x10^{-14}$	$5.0x10^{-14}$	$8.1x10^{-14}$	$1.3x10^{-13}$	$1.6x10^{-13}$	$3.0x10^{-13}$	$4.4x10^{-13}$
C /ψ (1/s)	$2.1x10^{-14}$	$2.5x10^{-14}$	$4.0x10^{-14}$	$8.5x10^{-13}$	$1.3x10^{-13}$	$2.1x10^{-13}$	$2.2x10^{-13}$

Definitions: GWC = gravimetric water content; T = Filter cake thickness; GS = gel strength; e_{eff} = effective void ratio; η_{eff} =effective porosity; Q = flux; k = permeability; ψ = permittivity.

Notes