Chemical Compatibility of Geosynthetic Clay Liners to Aggressive Bauxite Liquor

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Abstract

Experiments were conducted to evaluate the effect of an aggressive bauxite liquor on the hydraulic conductivity of geosynthetic clay liners (GCLs) used for composite liners in disposal facilities for red mud from aluminum refining. Tests were conducted on two sodium-bentonite (Na-B) GCL and one bentonite-polymer (B-P) composite GCL. The Na-B GCLs contained powdered or granular bentonite. The B-P GCL contained a mixture of granular NaB and dry water-soluble polymer. All GCLs were prehydrated to 100% water content with a 2500 mg/L NaCl solution prior to permeation. The Na-B GCL with granular bentonite was permeable to bauxite liquor (5.0×10^{-10} m/s), whereas the Na-B GCL with powdered bentonite maintained low hydraulic conductivity (1.8×10^{-11} m/s). Hydraulic conductivity of the B-P GCL was very low initially (1×10^{-12} m/s), but increased over time to 1.3×10^{-10} m/s as polymer was eluted from the pore space. Clogging of fine pores by precipitates is hypothesized as the mechanism for the low hydraulic conductivity of the Na-B GCL with powdered bentonite. The findings indicate that GCLs used for composite liners in disposal facilities for residuals from aluminum refining can have very different hydraulic conductivity depending on the characteristics of the bentonite or bentonite-polymer mixture in the GCL. Construction specifications should ensure that the GCL that is installed is chemically compatible with the liquid to be contained.

Keywords: Geosynthetic clay liner, bauxite liquor, hydraulic conductivity.

1. Introduction

Geosynthetic clay liners (GCLs) are factory-manufactured clay barriers consisting of a layer of sodium-bentonite (Na-B) clay sandwiched between two geotextiles [1-3]. GCLs are widely used in waste containment facilities to limit leakage due to their low hydraulic conductivity to water (typically < 10^{-10} m/s) and ease of installation [1-3]. The low hydraulic conductivity is due primarily to osmotic swelling of Na-B, which creates narrow and tortuous flow paths [1]. However, the propensity for osmotic swelling, and the hydraulic conductivity, are affected strongly by the chemistry of the liquid to be contained [4-6]. GCLs permeated with more aggressive leachates (higher ionic strength and/or a predominance of polyvalent cations) can be orders of magnitude more permeable than GCLs permeated with deionized (DI) or tap water due to lower osmotic swelling of the Na-B in the leachate [2-8].

Benson et al. [9] evaluated hydraulic conductivity of two conventional Na-B GCLs to a bauxite liquor from an aluminum refining operation with pH 12.2 and ionic strength of 774 mM. One GCL contained granular bentonite and the other powdered bentonite. Both GCLs had low hydraulic conductivity (~10^{-11} m/s) to tap water. When permeated with bauxite liquor, the hydraulic conductivity of the GCL containing granular bentonite was 1.8×10^{-8} m/s, whereas the hydraulic conductivity of the GCL with powdered bentonite was 2.5×10^{-12} m/s. The high hydraulic conductivity of the GCL with granular NaB was attributed to compression of osmotic swell by the bauxite liquor, resulting in large intergranular flow paths. Low hydraulic conductivity of the GCL with powdered bentonite was attributed to precipitation of aluminum complexes in the fine pores of the bentonite powder.

This paper describes outcomes of tests conducted to evaluate the hydraulic conductivity of three commercially available GCLs being considered for a composite liner in a disposal facility for aluminum refining that will contain very aggressive bauxite liquor (pH 14.3, electric conductivity of 19.5 S/m). Tests were conducted on three different GCLs: two conventional Na-B GCLs (granular bentonite, powdered bentonite) and one bentonite-polymer (B-P) composite GCL.

2. Method and Materials

2.1. Geosynthetic Clay Liner

Physical properties of the GCLs are summarized in Table 1, with Na-BG corresponding to the GCL with granular bentonite, Na-BP to the GCL with powdered bentonite, and B-P for the GCL with a B-P composite. Both geotextiles on the GCLs were polypropylene, with the upper nonwoven and the lower woven. The geotextiles were bonded by needlepunching. Polymer loading in the B-P GCL was determined using the loss on ignition method.

Table 1. Physical properties of GCLs used in study.

GCL	Initial Thickness (mm)	Polymer Loading (%)	Swell Index in DI water (mL/2.0 g)	Swell Index in Bauxite Liquor (mL/2.0 g)
Na-BG	3.8	—	26.0	5.5
Na-BP	4.4	—	26.5	6.0
B-P	4.1	5.1	26.5	5.5

Note: Swell index measured using ASTM D5890 [10] in DI water and bauxite liquor. Polymer loading determined using loss on ignition test per ASTM D7348 [11]

Granule size distributions for the bentonites in the GCLs are shown in Fig. 1. The Na-BG GCL has medium-fine sand-size granules, the Na-BP has fine sand to silt-size granules, and the B-P GCL has medium sand-size granules. The Na-BP has 53% of the bentonite granules finer than the No. 200 sieve (75 μm).

2.2. Bauxite Liquor

The bauxite liquor used in the testing program was obtained from an aluminum refinery. Analysis for elemental concentrations by inductively coupled plasma-optical emission spectroscopy (ICP-OES) showed that the predominant metals are Al (~107 mM) and Na (~1122 mM). The bauxite liquor has pH 14.3 and ionic strength of 2.05 M.

2.3. Prehydration

Prior to permeation, the GCL specimens were prehydrated to 100% water content by misting with a 2500 mg/L NaCl solution. Prehydration was anticipated to enhance chemical compatibility of the GCLs by inducing osmotic swelling of the bentonite and formation of a polymer hydrogel prior to contact with bauxite liquor [1].

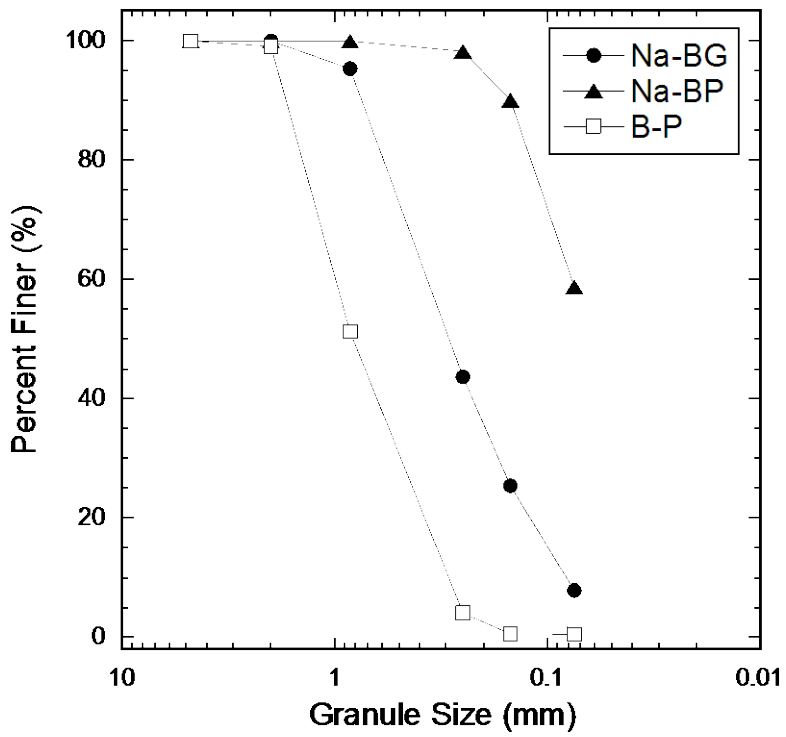

Figure 1. Granule size distributions of bentonites in GCLs used in this study.

2.4. Hydraulic Conductivity Tests

Hydraulic conductivity tests on GCL specimens were conducted in flexible-wall permeameters using the falling headwater and constant tailwater method described in ASTM D6766 [12]. The effective confining stress was 100 kPa and the hydraulic gradient was 125. Influent for the specimens was contained in 50 mL burettes sealed with parafilm to prevent evaporation and carbonation. Effluent was collected in 60-mL polyethylene bottles sealed with parafilm. Backpressure saturation was not applied to simulate the *in situ* condition and to avoid unrealistic changes in geochemistry.

Equilibrium was defined using the hydraulic and chemical equilibrium criteria in ASTM D6766 [12]. The criteria include no temporal trend in the hydraulic conductivity measurements, hydraulic conductivity falling within 25% of the mean for three consecutive measurements, incremental effluent volume (Q_{out}) within 25% of the incremental influent volume (Q_{in}) for at least 3 measurements, and the ratio Q_{out}/Q_{in} exhibiting no temporal trend. Chemical equilibrium was defined as the electrical conductivity and pH of the effluent (EC_{out} and pH_{out}) showing no temporal trend and falling within 10% of the electrical conductivity and pH of the influent (EC_{in} and pH_{in}).

3. Results and Discussion

One specimen of each GCL was permeated with bauxite liquor. Summary information from the tests is reported in Table 2. Pore volumes of flow (PVF) in Table 2 were computed using the final properties of each GCL specimen (e.g., thickness, diameter, mass, water content). The tests were conducted for 120 to 182 d. The Na-BG GCL permeated with bauxite liquor met the termination criteria in ASTM D6766 [12], whereas the Na-BP and B-P GCLs had not reached chemical equilibrium at termination. Time limitations for the testing program required that tests on the Na-BP and B-P GCLs be terminated before the termination criteria were satisfied.

Table 2. Hydraulic conductivity of GCLs permeated with bauxite liquor.

GCL	Test Duration (d)	Prehydration water content (%)	PVF	Hydraulic Conductivity (m/s)
Na-BG	182	100	38.3	5.0×10^{-10}
Na-BP	182	100	7.6	1.8×10^{-11}
B-P	120	100	6.5	1.3×10^{-10}

Hydraulic conductivity of the GCLs permeated with bauxite liquor is shown in Fig. 2 as a function of PVF. Hydraulic conductivity of the Na-BG GCL increased to approximately 5.0×10^{-10} m/s during the first 10 PVF and then levelled off for 38 PVF. In contrast, the hydraulic conductivity of Na-BP increased to 1.8×10^{-11} m/s during the first few PVF and then levelled off. Hydraulic conductivity of the B-P GCL increased from 1.0×10^{-12} m/s to 8.5×10^{-11} m/s during first 2 PVF, then decreased to approximately 2×10^{-11} due to polymer clogging the effluent line (Fig. 3). After removing the polymer from effluent tube, the hydraulic conductivity increased to 1.3×10^{-10} m/s.

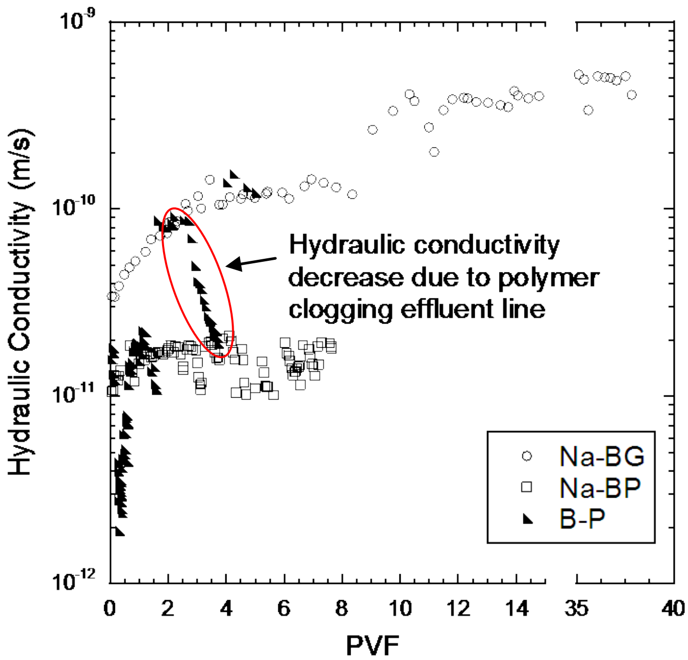

Figure 2. Hydraulic conductivity vs. pore volumes of flow for Na-BG, Na-BP, and B-P GCLs permeated with bauxite liquor.

Lower swelling of the bentonite in the Na-BG GCL is the primary factor responsible for the higher hydraulic conductivity of this GCL to bauxite liquor (e.g., 5.5 mL/2.0 g, Table 1). Jo et al. [4] report that conventional GCLs can maintain low hydraulic conductivity when the swell index exceeds 16 mL/2.0 g. Swell index of the powdered Na-B was also very low in bauxite liquor (6.0 mL/2.0 g). However, the Na-BP GCL maintained very low hydraulic conductivity to the bauxite liquor, most likely due to precipitation of aluminum complexes in the fine pores of the powdered bentonite, as observed in similar experiments described by Benson et al. [13].

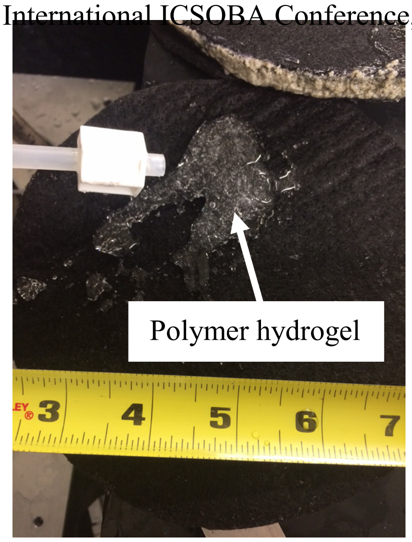

Figure 3. Removing polymer hydrogel clogging the effluent tube.

The initially low hydraulic conductivity of the B-P GCL is attributed to polymer clogging intergranular pores in the bentonite [3, 14]. The polymer forms a three-dimensional hydrogel structure that occupies the intergranular pore space when bentonite swelling is suppressed [2, 3], resulting in low hydraulic conductivity of GCL. However, during permeation, a sufficient mass of polymer was eluted, opening intergranular flow channels and resulting in higher hydraulic conductivity.

4. Conclusion

This study evaluated the hydraulic conductivity of three GCLs used in composite liners to contain bauxite liquor from aluminum refining. Three commercially available GCLs were evaluated - two with conventional sodium-bentonite (Na-B) and the other with a bentonite-polymer composite (B-P). One of the conventional GCLs contained granular bentonite and the other powdered bentonite. All three GCLs were prehydrated to 100% water content with 2500 mg/L NaCl solution prior to permeation.

Hydraulic conductivity of the Na-BG GCL containing granular bentonite increased immediately when permeated with bauxite liquor, with a final hydraulic conductivity of 5.0×10^{-10} m/s. The relatively high hydraulic conductivity of the Na-BG GCL to bauxite liquor is attributed to suppression of swell of the Na-B. In contrast, the Na-BP GCL with powdered bentonite had very low hydraulic conductivity (1.8×10^{-11} m/s) despite little swelling of the bentonite. The low hydraulic conductivity of the Na-BP GCL is attributed to precipitation of aluminum complexes in the fine pores of the powdered bentonite.

Hydraulic conductivity of the prehydrated B-P GCL to bauxite liquor initially was very low (1.0×10^{-12} m/s), but ultimately increased to 1.3×10^{-10} m/s. The low initial hydraulic conductivity of the B-P GCL is attributed to polymer hydrogel clogging intergranular pores that conduct flow in the Na-B GCL. The increase in hydraulic conductivity over time is attributed to polymer eluting from the pore space, resulting in larger intergranular pores to conduct flow.

The findings indicate that GCLs used for composite liners in disposal facilities for aluminum refining can have very different hydraulic conductivity depending on the characteristics of the bentonite or bentonite-polymer mixture in the GCL. Construction specifications should ensure that the GCL that is installed is chemically compatible with the liquor to be contained.

5. References

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