CHEMICAL COMPATIBILITY OF GCLs WITH COAL COMBUSTION RESIDUALS (CCRs)

INTRODUCTION

In the wake of the coal ash impoundment failure near Kingston, Tennessee in December 2008, there has been increased attention given to containment systems for coal combustion residuals (CCRs). In June 2010, the USEPA proposed new rules requiring composite liner systems (geomembrane liners placed over a layer of compacted clay soil) for CCR disposal facilities. A common composite liner design involves the use of a geosynthetic clay liner (GCL) underneath the geomembrane, in place of the compacted clay layer. A question that arises related to GCLs in CCR applications is chemical compatibility. Liquids containing high levels of dissolved calcium or magnesium, or those with high ionic strength, can reduce the amount of bentonite swelling, resulting in increased GCL hydraulic conductivity. Before CCR chemistry and compatibility with GCLs can be addressed, a review of the types of CCRs is necessary.

CCRs are generated during power generation processes, and can include fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) residuals. Fly ash is a very fine, non-combustible residue carried in stack gases from boiler units and collected by flue gas cleaning equipment. Bottom ash and boiler slag are heavier ash particles that cannot be carried by the gas, and fall to the bottom of the boiler. FGD residual is produced in flue gas scrubbers as part of the process that removes sulfur dioxide (SO_2) from stack gases. FGD systems can be either "wet" or "dry". In wet FGD systems, which are by far the most common in large, coal-fired utility boilers, slurried limestone or lime added downstream of the particulate removal device reacts with the gaseous SO_2 to produce calcium sulfite ($CaSO_3$). Many wet scrubber systems include a forced oxidation step that converts the calcium sulfite to calcium sulfate ($CaSO_4$). Because the sulfate material is in an aqueous slurry, it forms the hydrate, $CaSO_4 \cdot 2H_2O$ (gypsum). Dry FGD systems are installed upstream of the particulate removal device, and produce a mixture of reaction products ($CaSO_3$ and $CaSO_4$), along with fly ash and the unreacted sorbent, lime. These different CCRs are either managed separately, or more commonly, are mixed together and co-managed.

EPRI CCR LEACHATE DATABASE

An excellent reference on CCR leachate characteristics is available from the Electric Power Research Institute (EPRI), in a report from 2006 entitled, "Characterization of Field Leachates at Coal Combustion Product Management Sites." As part of this study, researchers analyzed field leachate samples collected from 33 different coal combustion management facilities in 15 states. The sites were located primarily in the Eastern and Midwestern US, where coal-fired power plants predominate. The objective of the study was to evaluate leachate samples associated with a range of coal types, combustion systems, and management methods. The study found that the chemical constituents in a given CCR waste stream and their leachability can vary by coal type and combustion/collection process. Major constituents included sulfates, calcium, magnesium, and sodium. CCR leachates associated with subbituminous and lignite coals tend to be sodium-rich, and have higher ionic strength compared with leachates associated with bituminous coal. Concentrations of most constituents

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are generally highest in FGD leachate, then in ash landfill leachate, and then in ash impoundment samples. In general, most CCR leachates are moderately to strongly alkaline regardless of coal type or process.

CHEMICAL COMPATIBILITY ASSESSMENT

The topic of GCL chemical compatibility has been the subject of much study in recent years, with several important references available in the literature. One of these references, Kolstad et al (2004/2006) from the University of Wisconsin at Madison (see TR-254), presents a model that conservatively estimates the hydraulic conductivity of a GCL when it is permeated with an inorganic leachate. Two key leachate characteristics are the ionic strength and the ratio of monovalent-to-divalent cations (RMD). Using this tool, a chemical compatibility evaluation was performed using the major cation concentrations (calcium, magnesium, sodium, and potassium) in the EPRI (2006) report. This evaluation is presented in Table 1, and summarized below:

- **Overall Database.** The overall database (77 samples) showed a wide range of ionic strength and RMD values, resulting in a wide range of predicted GCL hydraulic conductivity values, between 1.8×10^{-10} and 3.1×10^{-6} cm/s, with a geometric mean value of 2.8×10^{-9} cm/s. However, the highest hydraulic conductivity and ionic strength values were associated with one specific FGD site, as discussed below. Over 96% of the samples corresponded to expected hydraulic conductivity values less than 10^{-7} cm/s, and over 90% of the samples corresponded to expected GCL hydraulic conductivity values less than 10^{-8} cm/s.

- **Fly Ash.** Fly ash leachates (39 samples) showed low ionic strength (< 0.2 M), resulting in relatively low predicted GCL hydraulic conductivity values, between 1.8×10^{-10} and 8.3×10^{-9} cm/s, with a geometric mean of 2.5×10^{-9} cm/s.

- **Fly Ash/Bottom Ash Mixtures.** Fly ash/bottom ash leachates (24 samples) also showed low ionic strength (< 0.2 M), resulting in predicted GCL hydraulic conductivity values between 4.5×10^{-10} and 5.3×10^{-9} cm/sec. The geometric mean value was 2.4×10^{-9} cm/s.

- **FGD Waste.** Flue gas desulfurization (FGD) leachates (5 samples) showed the highest ionic strengths (up to 0.42 M) and the highest magnesium and sodium concentrations (approximately 5,000 mg/L), resulting in predicted GCL hydraulic conductivity values between 6.1×10^{-9} and 3.1×10^{-6} cm/s. The geometric mean value was 5.3×10^{-8} cm/s. The highest hydraulic conductivity value was associated with a leachate sample collected from an FGD impoundment where sluice water was recirculated, resulting in a highly concentrated leachate.

- **FGD/Fly Ash/Bottom Ash Mixtures.** Facilities with blends of FGD waste and ash (8 samples), showed much lower ionic strengths (<0.13 M) than FGD waste alone, resulting in predicted GCL hydraulic conductivity values between 3.4×10^{-9} and 1.2×10^{-8} cm/s. The geometric mean value was 8.7×10^{-9} cm/s.

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Please note that another site-specific consideration is confining pressure. The hydraulic conductivity values predicted above assume a confining pressure of 2.9 psi (representing less than 5 feet of waste or soil cover). Certain applications, such as landfill bottom liners and heap leach pads, involve up to several hundred feet of waste, resulting in high compressive loads on the liner systems. Petrov et al (1997) showed that higher confining pressures will decrease bentonite porosity, and tend to decrease GCL permeability. TR-321 shows that higher confining pressures will improve hydraulic conductivity even when the GCL is permeated with aggressive calcium (5,000 mg/L) solutions.

COMPARISON WITH PAST CHEMICAL COMPATIBILITY RESULTS

The GCL hydraulic conductivity values predicted by the Kolstad model appear to be consistent with past laboratory testing results. Attachment A is a report by RMT, Inc., titled "Hydraulic Conductivity Compatibility Testing of Geosynthetic Clay Liner and Ash Leachate". Eight hydraulic conductivity tests were performed under four different hydration conditions to model potential field conditions. Leachate was derived from a Western fly ash which was chosen as the most conservative ash due to its high calcium content. The final hydraulic conductivity of the GCLs ranged from 5×10^{-10} to 1×10^{-9} cm/s, on the same order of magnitude as the Kolstad predictions for fly ash leachates.

COMPARISON OF CCR LEACHATE WITH MSW LANDFILL LEACHATE

The University of Wisconsin at Madison prepared a comparison of the CCR leachate data in the EPRI report to a large database of leachate concentrations from various municipal solid waste (MSW) landfills (see graph in Attachment B). A comparison of the CCR and MSW leachate chemistry indicates that CCR leachate is typically equivalent to or weaker than MSW landfill leachate, which has already been demonstrated to be compatible with GCLs (see TR-254 and TR-316).

CONCLUSIONS

A review of a large database (77 samples) of CCR leachate chemistry from 33 different sites shows that CCR leachate is generally compatible with GCLs. Over 96% of the samples in the database corresponded to expected hydraulic conductivity values less than 10^{-7} cm/s, and more than 90% of the samples corresponded to expected GCL hydraulic conductivity values less than 10^{-8} cm/s. Several GCL compatibility tests performed with fly ash leachates by RMT, Inc. confirmed low long-term hydraulic conductivity values, consistent with predicted values. Additionally, a comparison of CCR leachate and MSW leachate indicates that CCR leachate is typically equivalent to or weaker than MSW landfill leachate, which has already been demonstrated to be compatible with GCLs.

Some FGD leachates, specifically those where sluice water is recirculated to produce highly concentrated solutions, may pose GCL compatibility issues, and should be evaluated further during the project design stage. As discussed in TR-345, CETCO follows a tiered approach for chemical compatibility testing. Tier I consists of a simple review of existing analytical data, followed by Tier II bentonite screening tests (ASTM D6141) and Tier III long-term hydraulic conductivity tests (ASTM D6766). If a particular site leachate is found to pose compatibility problems with standard bentonite, CETCO can identify possible polymer amendments for further evaluation. Polymer-amended bentonites have been successfully used on selected past projects involving aggressive waste streams. Please contact CETCO Technical Services for additional information.

REFERENCES

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TABLE 1
SUMMARY OF CCR LEACHATE CHEMISTRIES AND PREDICTED GCL HYDRAULIC CONDUCTIVITIES

Major Cations[A]	**Units**	**All Leachates (77 samples)**			**Fly Ash (39 samples)**		
		Min	Max	Geomean	Min	Max	Geomean
Calcium	mg/L	2.22	730	91.6	2.22	681	70.9
Magnesium	mg/L	0.05	5810	8.3	0.05	236	5.4
Potassium	mg/L	2.2	609	27.0	2.2	219	20.1
Sodium	mg/L	3.8	4630	86.8	3.8	3410	47.7
Specific Conductance[A]	µS/cm	174	26140	1635	178	12800	1162
pH	--	4.3	12.0	8.3	4.3	11.5	8.0
Ionic Strength[B]	M	0.003	0.418	0.027	0.003	0.205	0.019
RMD[C]	$M^{1/2}$	0.01	8.18	0.087	0.01	8.18	0.06
GCL K [C,D,E]	cm/sec	1.8E-10	3.1E-06	**2.8E-09**	1.8E-10	8.3E-09	**2.5E-09**

(A) Source: EPRI (2006), "Characterization of Field Leachates at Coal Combustion Product Management Sites".
(B) Estimated from Specific Conductance (SC), using Snoeyink and Jenkins (1980).
(C) Calculated using Kolstad et al (2004), assuming K with deionized water = 9E-10 cm/sec.
(D) At 3 psi confining pressure. Increased confining pressure will result in lower K values (Petrov et al, 1997).
(E) Excludes results outside Kolstad range (RMD > 2), which yield abnormally low K values (<1E-10 cm/sec).

TABLE 1
SUMMARY OF CCR LEACHATE CHEMISTRIES AND PREDICTED GCL HYDRAULIC CONDUCTIVITIES

Major Cations[A]	**Units**	**Fly Ash/Bottom Ash (24 samples)**			**FGD (5 samples)**		
		Min	Max	Geomean	Min	Max	Geomean
Calcium	mg/L	2.5	392	56.2	524	600	566.3
Magnesium	mg/L	0.05	188	9.3	23	5810	506.2
Potassium	mg/L	3.6	277	14.8	20	500	104.0
Sodium	mg/L	6	837	72.8	606	4630	1554.1
Specific Conductance[A]	μS/cm	174	5100	1123	4800	26140	12061
pH	--	6.0	11.8	8.5	6.2	9.0	7.5
Ionic Strength[B]	M	0.003	0.082	0.019	0.077	0.418	0.193
RMD[C]	$M^{1/2}$	0.01	2.19	0.09	0.11	0.64	0.31
GCL K [C,D,E]	cm/sec	4.5E-10	5.3E-09	**2.4E-09**	6.1E-09	3.1E-06	**5.3E-08**

TABLE 1
SUMMARY OF CCR LEACHATE CHEMISTRIES AND PREDICTED GCL HYDRAULIC CONDUCTIVITIES

Major Cations[A]	**Units**	**FGD, Fly Ash, Bottom Ash (8 samples)**		
		Min	Max	Geomean
Calcium	mg/L	234	730	559.7
Magnesium	mg/L	0.05	10	2.8
Potassium	mg/L	30	609	347.3
Sodium	mg/L	141	2310	340.2
Specific Conductance[A]	μS/cm	2190	11560	5901
pH	--	7.8	12.0	9.9
Ionic Strength[B]	M	0.035	0.185	0.094
RMD[C]	$M^{1/2}$	0.07	1.43	0.22
GCL K [C,D,E]	cm/sec	3.4E-09	1.2E-08	**8.7E-09**

ATTACHMENT A
HYDRAULIC CONDUCTIVITY COMPATIBILITY TESTING OF GEOSYNTHETIC CLAY LINER AND ASH LEACHATE (RMT)

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HYDRAULIC CONDUCTIVITY COMPATIBILITY TESTING OF GEOSYNTHETIC CLAY LINER AND ASH LEACHATE

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HYDRAULIC CONDUCTIVITY COMPATIBILITY TESTING OF GEOSYNTHETIC CLAY LINER AND ASH LEACHATE

By: Peter D. Creamer[1], P.E.

ABSTRACT

Landfill owners and engineers are investigating alternatives to a natural clay liner. One such alternative is a geosynthetic clay liner (GCL). In certain areas of the country, natural sources for liner-quality clay are scarce, and therefore not economically feasible. A power utility company located in northwestern Wisconsin is in the feasibility stage of permitting a landfill with a GCL/geomembrane composite liner. This particular power company uses western coal to produce electricity, which typically has a higher calcium content than other coal sources. The calcium may result in an ion exchange with the sodium bentonite in the GCL. Thus, as part of the permitting process, the Wisconsin Department of Natural Resources required that the GCL be tested for compatibility with the ash leachate (*i.e.*, its effect on hydraulic conductivity).

The ash leachate for the compatibility test was generated in the laboratory to simulate the proposed disposal operations. Eight hydraulic conductivity tests were performed under four different hydration conditions to model the potential field conditions. The hydraulic conductivity was measured by the falling head method in a flexible-wall permeameter. The method used generally follows the ASTM D 5084 standard with some minor modifications. The leachate was tested for chemical composition before and after the test to determine the effect of the leachate on the bentonite.

This paper will present the results of the GCL hydraulic conductivity testing and discuss the effects of the ash leachate on the GCL.

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INTRODUCTION

Geosynthetic clay liners (GCLs) are increasingly used as hydraulic barrier layers in bottom liner systems for landfills where suitable clay is unavailable, except in Wisconsin. To date, the Wisconsin Department of Natural Resources (WDNR) has not permitted the use of GCLs in lieu of clay for bottom liner systems. And only recently has the WDNR permitted the use of a GCL to replace the clay component of a composite final cover system.

For municipal waste landfills, the current Wisconsin solid waste regulations (NR500) require a liner to be constructed with 4 feet of compacted clay and a 60-mil HDPE geomembrane. For industrial landfills, the liner is to consist of 5 feet of compacted clay.

A power utility company located in northwestern Wisconsin planning a 32-acre, 3 million-cubic yard ash disposal landfill expansion retained RMT, Inc., to assist them in permitting the facility. Given the scarce supply of liner quality clay in this area of Wisconsin, RMT began considering the possibility of using a GCL overlain by a geomembrane.

The first consideration was to see how economically feasible it would be to use a GCL/geomembrane composite liner and cap in lieu of a 5-foot-thick clay liner and 2-foot-thick clay cap. The results of the economic analysis showed that by implementing the GCL liner and final cover designs, the utility will save between $1.4 million and $9.5 million depending on the location of the clay borrow site.

With this information in hand, the utility instructed RMT to begin discussions with the WDNR regarding the feasibility of using a GCL instead of compacted clay. RMT prepared a list of GCL-related technical issues and documentation to support its use. After the initial presentation to the WDNR, the WDNR agreed to consider the use of a GCL as part of the composite liner system, provided RMT could satisfactorily demonstrate that the GCL would be compatible with the ash leachate and that the GCL would be stable on the long 3:1 perimeter sideslopes.

A detailed GCL testing plan was prepared and submitted to the WDNR for approval. The testing plan included hydraulic conductivity compatibility testing and direct shear interface friction testing.

The remaining sections of this paper present the hydraulic conductivity compatibility testing plan, leachate generation, hydraulic conductivity testing procedures, and test results. The direct shear testing is beyond the scope of this paper.

GCL COMPATIBILITY TESTING PLAN

This particular power utility burns primarily western coal to generate electricity at their power generating stations. Western coal has a higher calcium content than other coal sources. Studies by Ruhl and Daniels (1997) and Egloffstein (1997) indicate that sodium cations exchange with calcium cations. Thus, a sodium bentonite GCL, if exposed to high concentrations of calcium, may lose some of its swelling capacity, which in turn may lead to an increase in the GCL's hydraulic conductivity.

Given the potential for ion exchange and the calcium content in the ash, the WDNR requested that hydraulic conductivity testing using representative ash leachate as the permeant be conducted to determine if the GCL will be compatible and maintain a low hydraulic conductivity. A testing plan was prepared and submitted to the WDNR for approval prior to initiating the testing.

The testing plan called for a series of falling-head hydraulic conductivity tests to be performed. Ash leachate and water were used as the permeants for the testing to measure the effect, if any, of the leachate on the GCL. As mentioned above, the chemical content of the permeant may affect how the bentonite within the GCL will hydrate, which then affects the hydraulic conductivity. Water was included as a permeant to serve as a baseline to compare with the results of the tests for the leachate permeant.

The design maximum hydraulic conductivity was set at $5x10^{-9}$ cm/s, which is equivalent to 4 feet of $1x10^{-7}$ cm/s compacted clay and the value reported by the GCL manufacturer. Test results below this value were to be considered acceptable.

As reported by Ruhl and Daniel (1997), the condition of hydration also affects the hydraulic conductivity of the GCL. From this paper, GCLs that were not initially hydrated (i.e., prehydrated) with water typically had higher hydraulic conductivity values when permeated with various leachates. Exposure of the GCL to the leachate prior to initiating the permeation process also affected the hydraulic conductivity. Therefore, hydraulic conductivity testing of the GCL for this project was conducted under non-prehydrated conditions, with and without 48-hour exposure of the permeant, and prehydrated conditions, using ash leachate and water as the permeants.

The GCL hydraulic conductivity testing plan includes the following tests:

- Two tests for prehydrated GCLs permeated with water (with 48-hour exposure to water prior to initiating the permeation process)
- Two tests for nonprehydrated GCLs, with 48-hour exposure to the ash leachate, prior to initiating the permeation process
- Two tests for prehydrated GCLs with 48 hour exposure to water, prior to initiating the ash leachate permeation process
- Two tests for nonprehydrated GCLs permeated with ash leachate (no pre-exposure to leachate)

LEACHATE GENERATION

The fly ash leachate was generated at RMT's applied chemistry laboratory using dry fly ash from one of the power utility's generating stations that burns 100 percent western coal. As mentioned above, western coal has a higher calcium content than other coal types. Leachates having high concentration of multivalent cations, such as calcium, have shown in some studies to increase the hydraulic conductivity of GCL's; therefore, the western coal fly ash leachate was assumed to be the most conservative choice.

The leachate was developed after performing a preliminary fly ash study to determine the amount of fly ash required to generate the needed quantity of leachate to perform the hydraulic conductivity tests. Deionized water was mixed with the dry fly ash at an approximate moisture content of 75+ percent (weight of water/weight of solids) for 18 to 24 hours, per the SPLP extraction technique. After the slurry solids had settled, the remaining liquid was decanted off. The decanted liquid and additional deionized water (equivalent to that retained by the ash) were mixed with new fly ash at the same 75+ percent moisture content. Five rounds of mixing were conducted to achieve the in-field conditions. This leachate generation process is designed to simulate the ash sluicing process proposed for use by the power utility at the landfill.

The leachate was tested for the following parameters before and after the hydraulic conductivity testing:

- Aluminum
- Boron
- Calcium
- Iron
- Magnesium
- Manganese
- Potassium
- Sodium
- Alkalinity
- Chloride
- pH

The results of the tests were compared, to further evaluate the effect of the leachate on the bentonite.

HYDRAULIC CONDUCTIVITY TESTING PROCEDURES

Eight falling-head hydraulic conductivity tests were performed in flexible wall permeameters to document the performance of the GCL. The testing was performed in accordance with the test method described in ASTM D5084, with some modifications to account for the unique size and composition of the GCL. A schematic diagram of the test setup is shown on Figure 1.

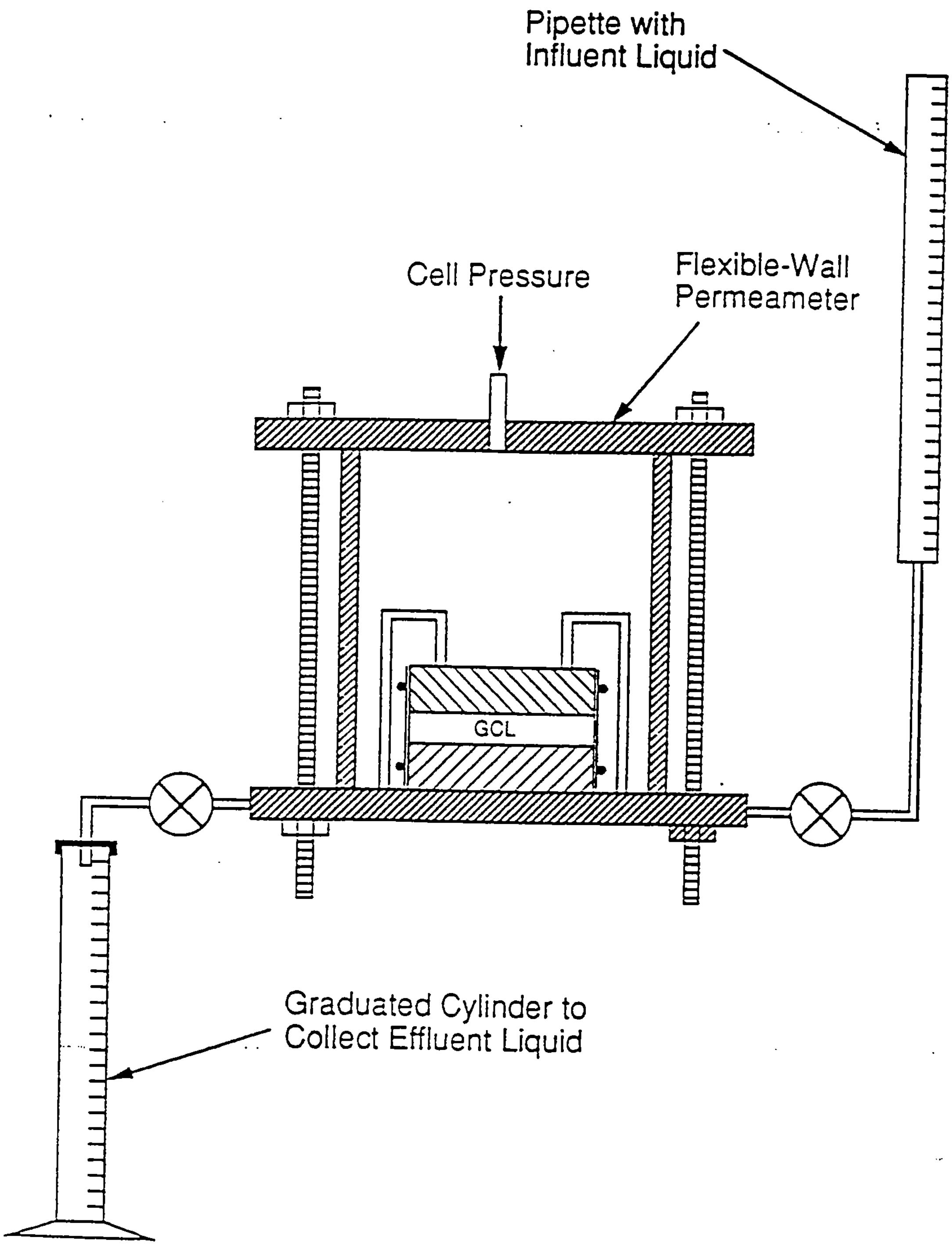


Figure 1 - Schematic Diagram of Permeameter Setup
(from Ruhl and Daniel, 1997)

The GCL product used in this testing was Bentomat® DN manufactured by CETCO. Manufacturer's literature for this product is included in Attachment 1.

The samples were 4 inches in diameter and were cut from a manufacturer-supplied roll sample. The pressure difference across each sample was approximately 2 psi. The confining pressure was 35 kPa, which is equivalent to the weight of the leachate drainage layer and 10 feet of moisture-conditioned fly ash.

The minimum test termination criterion was when the average hydraulic conductivity reading over an 8-hour period showed no significant variation from 75 percent to 125 percent of the average reading, and no significant upward or downward trend in the flow. Ultimately, six of the eight tests were terminated after 4 weeks. The two tests with the highest hydraulic conductivity were continued for another 14 weeks to evaluate long-term effects on the performance of the GCL.

TEST RESULTS

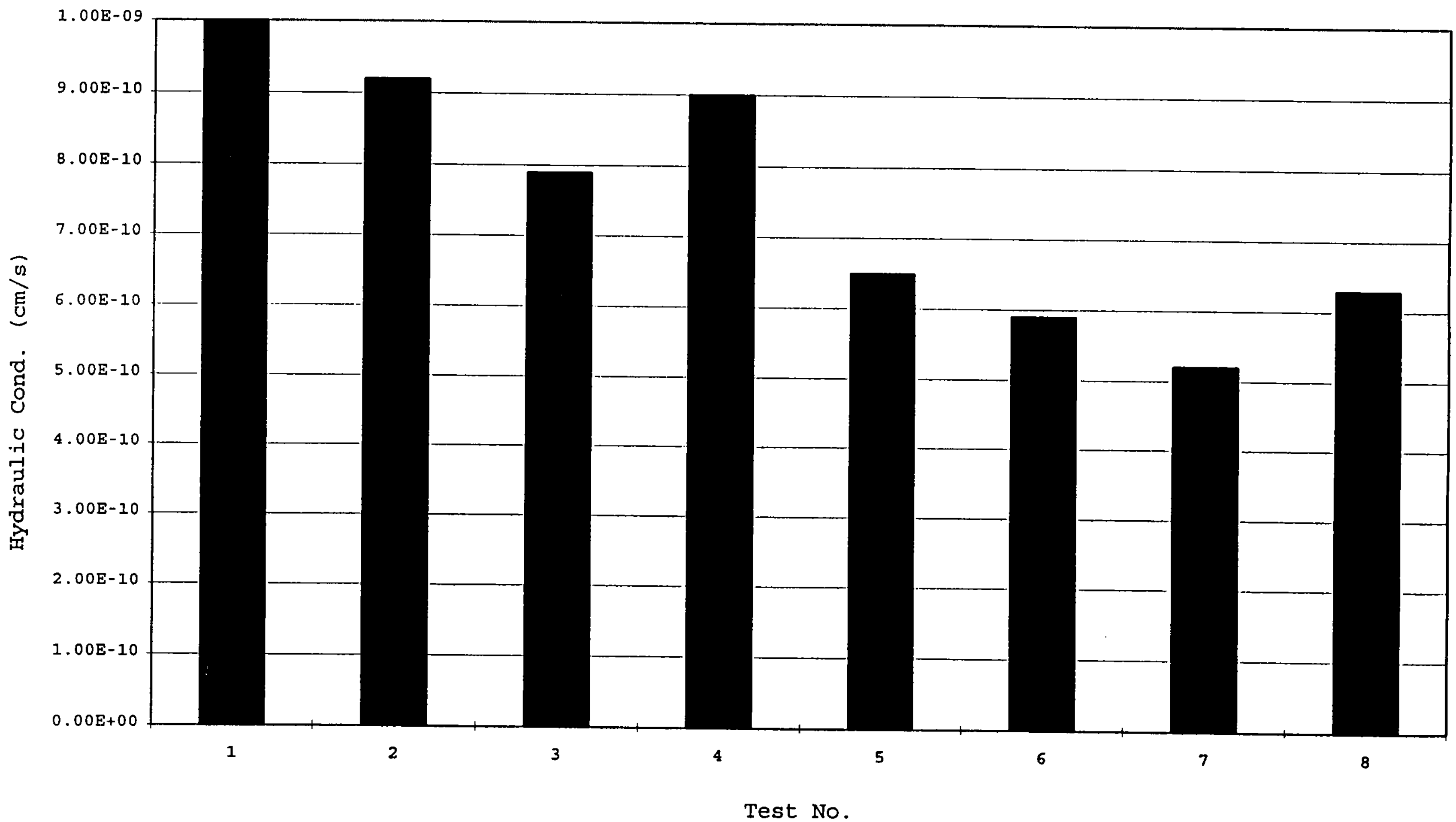
The final hydraulic conductivity for each test is listed in Table 1. The results were all within one-half order of magnitude ranging from $1x10^{-9}$ cm/s to $5x10^{-10}$ cm/s. These results on shown graphically on Figure 2. All of the tests were less than the design maximum hydraulic conductivity of $5x10^{-9}$ cm/s.

Test numbers 3 and 8 were run for a total of 18 weeks. The final hydraulic conductivity of these two tests actually decreased slightly from their initial results ($1.6x10^{-9}$ cm/s and $1.3x10^{-9}$ cm/s, respectively) after 4 weeks of testing.

The analytical data for the synthetic leachate, before and after hydraulic conductivity testing, are listed in Table 2. Prior to submittal for analysis, leachate effluent from the hydraulic conductivity testing was diluted to account for limited sample volumes. Subsamples for aluminum, boron, calcium, magnesium, potassium, alkalinity, and chloride were diluted by a factor of 10. A subsample for sodium was diluted by a factor of 100.

TEST #	CONDITION			HYDRAULIC CONDUCTIVITY (cm/s)
	PERMEANT	EXPOSURE (48 hours)	PREHYDRATION	
1	Water	Water	Yes	1.0×10^{-9}
2	Water	Water	Yes	9.2×10^{-10}
3	Leachate	Leachate	No	7.9×10^{-10}
4	Leachate	Leachate	No	9.0×10^{-10}
5	Leachate	Water	Yes	6.5×10^{-10}
6	Leachate	Water	Yes	5.9×10^{-10}
7	Leachate	None	No	5.2×10^{-10}
8	Leachate	None	No	6.3×10^{-10}

Table 1 - Hydraulic Conductivity Compatibility Test Results



Hydraulic Conductivity Compatibility Testing

Figure 2

ANALYTE	UNITS	WATER			SYNTHETIC LEACHATE						
		TAP WATER BEFORE TESTING	AFTER HYDRAULIC CONDUCTIVITY TESTING		BEFORE TESTING	AFTER HYDRAULIC CONDUCTIVITY TESTING					
			TEST 1	TEST 2		TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8
Aluminum	mg/L	< 0.0099	1.2	9.9	7.8	1.0	2.1	0.9	0.52	0.72	< 0.23
Boron	mg/L	0.0067	3.5	4.5	9.7	11	16	5.5	8.9	6.8	10
Calcium	mg/L	60	29	100	97	13	9.1	54	200	80	35
Iron	mg/L	0.014	4.4	52	4.4	0.54	1.2	< 0.41	< 0.35	0.35	0.89
Magnesium	mg/L	31	45	53	2.5	0.42	1.8	33	60	31	19
Manganese	ug/L	1.1	84	3100	16	13	< 9.9	17	52	190	39
Potassium	mg/L	1.0	100	19	71	14	280	49	570	350	140
Sodium	mg/L	2.9	1700	960	1300	1,100	2300	1700	2400	2100	2,100
Alkalinity	mg/L	280	740	< 30	3900	980	1000	390	340	570	610
Chloride	mg/L	3.1	220	510	13	14	420	92	620	410	280
pH	su	NA	9.04	5.87	12.8	NA	9.18	8.55	8.23	NA	NA

Table 2 - Permeant Characterization and Analysis Results

Concentrations in the "as is" synthetic leachate (before hydraulic conductivity) were comparable to actual leachate previously sampled and tested by the power utility. So, the synthetic leachate was judged to be representative of actual conditions.

Ruhl and Daniel (1997) found that high levels of calcium can exchange with sodium in the bentonite and cause an increase in hydraulic conductivity. A calcium concentration of 97 mg/L was observed in the synthetic leachate, as compared to previously tested leachate calcium concentrations that ranged from 21.4 to 427 mg/L. The test results below address the significance of the calcium concentrations.

Concentrations of all of the analytes varied in each permutation, as well as within each set, suggesting that the chemistry of the bentonite is not consistent. For example, Test 1 and Test 2 were conducted with water as the permeant. The hydraulic conductivity was not significantly different between the tests, but the chemistry of the effluent was. Sodium concentrations were 1,700 and 960 mg/L. In some cases, analytes differed by an order of magnitude between the tests.

The primary concern is whether the concentration of calcium in the leachate can affect the hydraulic conductivity of the GCL. As described earlier, high calcium concentrations can theoretically replace the sodium in the bentonite and cause an increase in hydraulic conductivity. The laboratory test was designed to determine if calcium replaces sodium in the GCL. If this were occurring, then sodium levels would be elevated in the leachate following hydraulic conductivity testing (i.e., leachate that passed through the bentonite). Slightly higher sodium and potassium concentrations were observed in leachate effluents collected after hydraulic conductivity testing, but the difference does not appear to be significant.

It is also probable that the bentonite is naturally releasing sodium as indicated in Test 1 and Test 2 where the permeant was water. In these tests, the sodium levels are almost as high as in the synthetic leachate. Even though there are slight differences in sodium concentrations between the tests, no significant difference was observed in the hydraulic conductivity before and after contact with the leachate.

These data indicate that the chemistry varied within each test permutation, but the hydraulic conductivity was consistent within each test permutation, as well as between test permutations. The varying analyte concentrations suggest that the chemical composition of the bentonite was inconsistent, which was causing the varying concentrations in the leachate effluents.

Although the bentonite material differed chemically, it is apparent that the chemical composition of the bentonite is independent of the hydraulic conductivity, since significant hydraulic conductivity differences were not observed between permutations. The tests indicate no tendency for the fly ash leachate to degrade the hydraulic conductivity of the GCL.

CONCLUSIONS

This paper has presented the hydraulic conductivity compatibility testing program of a GCL and synthetically generated fly ash leachate. Eight hydraulic conductivity tests were set up and exposed to water and ash leachate under varying conditions of hydration. The results of all eight tests were less than the design maximum hydraulic conductivity of 5×10^{-9} cm/s.

These results are consistent with hydraulic conductivity results reported by Ruhl and Daniel (1997) for permeation with simulated fly ash leachate which indicate that the leachate will not negatively impact the GCL hydraulic conduction. Thus, the proposed GCL/geomembrane composite liner design will adequately protect public health, welfare, and the environment in accordance with the Wisconsin solid waste regulations at the same time will save the power utility millions of dollars in construction costs.

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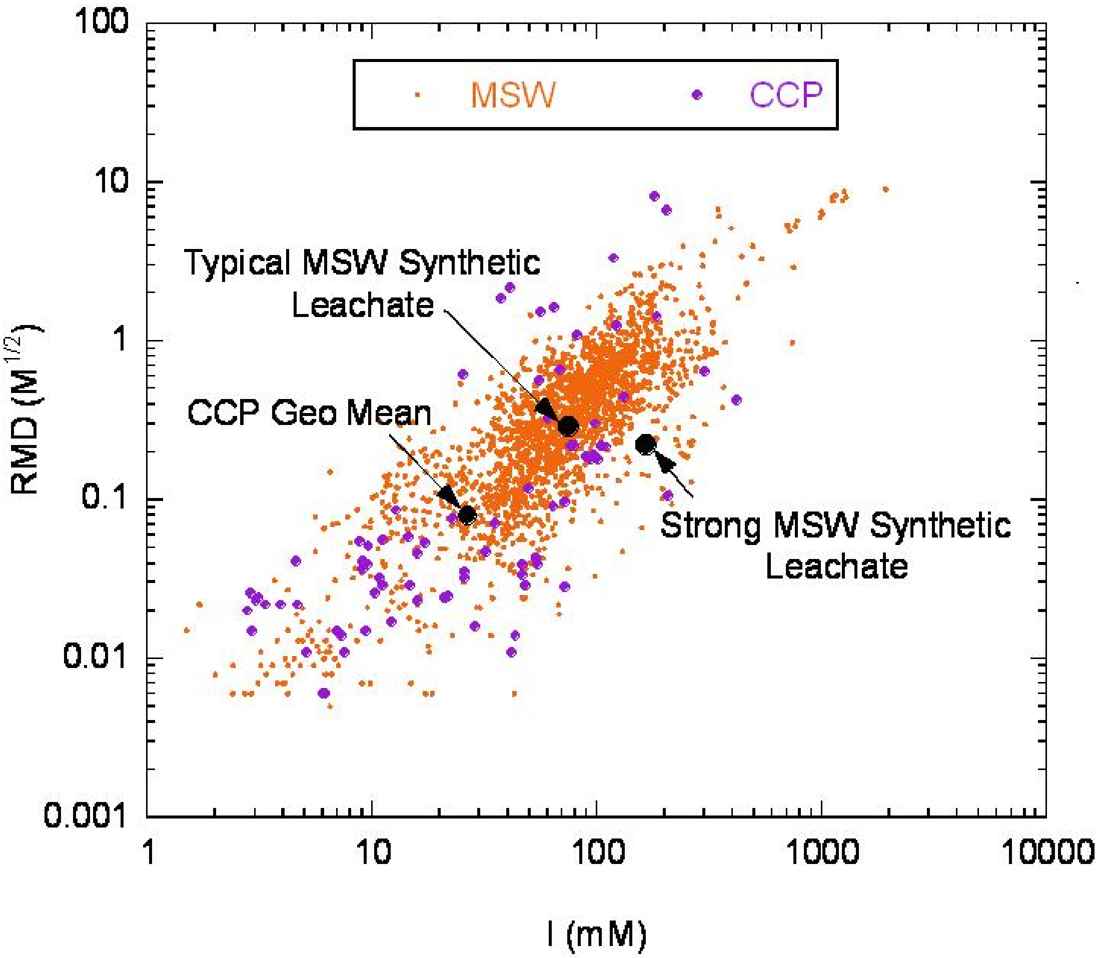
ATTACHMENT B

COMPARISON OF CCR LEACHATE (EPRI, 2006) WITH MUNICIPAL SOLID WASTE LANDFILL LEACHATE (UNIVERSITY OF WISCONSIN AT MADISON)

800.527.9948 Fax 847.851.1899



MSW
CCP
Typical MSW Synthetic Leachate
CCP Geo Mean
Strong MSW Synthetic Leachate
RMD (M^1/2)
I (mM)
100
10
1
0.1
0.01
0.001
1
10
100
1000
10000

TR-347
11/10