PERFORMANCE ASSESSMENT OF A FLUE GAS DESULFURIZATION MATERIAL AT A LINED POND FACILITY

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Abstract

A broad overview of the technical feasibility of using stabilized Flue Gas Desulfurization (FGD) product as a raw material for the construction of low permeability liners is presented. To demonstrate the practicality of using FGD material as a hydraulic barrier, a full-scale pond was designed and built on property owned by The Ohio State University. The facility, using lime-enriched FGD as the primary liner, was constructed in the summer of 1997 at the Western Branch of the Ohio Agricultural Research and Development Center near South Charleston in Clark County. The full-scale facility was monitored to study the leaching characteristics of the FGD liner. An evaluation of the performance of the facility is presented in terms of measurements of the permeability of the field-compacted FGD liner as well as the quality of the leachate. FGD materials can be compacted in the field using traditional construction equipment and the hydraulic barrier can be made comparable to one made from clay. First year monitoring of the full-scale facility has shown that: (a) the permeability coefficient of the field compacted liner is in the 10^{-7} cm/sec range, and (b) the quality of the leachate flowing through the FGD-liner generally meets the National Primary Drinking Water Regulations.

Introduction

Increasing restrictions on sulfur dioxide (SO_2) emissions from coal-fired plants have led utilities to design a number of methods to remove SO_2 from the flue gases before releasing them to the atmosphere. Lime is commonly used as the SO_2 scrubbing agent. The solid product produced is commonly referred to as Flue Gas Desulfurization (FGD) material. It mainly consists of varying amounts of sulfates and/or sulfites of a chemical reagent, unreacted reagent, fly ash, and water.

Ohio generates approximately 4 to 6 million tons of FGD material annually. In the past, the FGD material had generally been treated as a waste and consequently landfilled. Increasing costs of landfilling as well as the scarcity of landfill space have led utilities to look into the re-use of FGD material. Researchers at The Ohio State University have recently completed a comprehensive study of the land application of FGD materials.[1-3]

Laboratory Tests

Laboratory evaluation of the hydraulic conductivity and strength characteristics of lime enriched FGD materials have been presented by Butalia and Wolfe.[4] Table 1 shows some of the laboratory test results presented by Butalia and Wolfe and some additional tests that were conducted on compacted FGD samples. Two laboratory samples (66-34-5 and 66-34-8) were prepared in the laboratory by mixing fly ash (FA) and filter cake (FC) in approximately 2:1 ratio (dry weight basis). Samples 66-34-5 and 66-34-8 had lime contents (dry weight basis) of 5% and 8%, respectively. The moisture contents listed for the laboratory mixed samples are the optimum moisture contents so as to achieve maximum dry density (as per ASTM D-698-91[5]). The CON(AEP)-5%L and CON(AEP)-8%L samples were obtained from American Electric Power's (AEP) Conesville power plant near Coshocton, Ohio, while the GAV(AEP)-4%L and GAV(AEP)-8%L samples were obtained from AEP's Gavin plant near Gallipolis, Ohio. These samples were prepared at the respective power plants instead of being mixed in the laboratory. 4%L and 5%L denote the lime percentage on a dry weight basis as estimated by the plant operators. The CON and GAV samples were compacted using standard proctor test guidelines[5] at as received moisture contents. It can be observed from Table 1 that moisture contents of the samples received from the power plants were higher than the optimum moisture contents obtained in the laboratory. Consequently, the dry densities obtained by compacting these samples were lower than the maximum dry densities obtained from the laboratory mixed samples. However, the coefficient of permeability, which was measured as a function of curing time (7,28,60 and 90 days), using a falling head test[6], is lower for the plant mixed samples than for the laboratory samples. For the plant mixed samples, the permeability values are in the 10^{-7} to 10^{-8} cm/sec range at 28 days of curing. Samples with higher lime contents resulted in lower coefficients of permeability as well as higher unconfined compressive strengths. From Table 1, it can be observed that the permeability and strength characteristics of FGD materials generated at the Conesville and Gavin plants are similar. The 8% lime samples have the lowest permeability values that come close to 10^{-8} cm/sec. It can be concluded from Table 1 that FGD material can be compacted in the laboratory using standard soil testing procedures to obtain permeability coefficients that are in the 10^{-7} to 10^{-8} cm/sec range, which is lower than the 1×10^{-7} cm/sec value typically recommended by the U.S. Environmental Protection Agency for constructing liners for waste containment facilities.[7]

Full Scale FGD-Lined Facility

Since permeability is likely to be a function of the construction process, the field validation of the properties obtained in the laboratory is an important part of the documentation process. The design, construction, and monitoring of a full-scale testing facility, to evaluate the performance of a field-compacted FGD liner, is presented in this section.

Design of Facility

The full-scale facility was constructed to addresses two critical questions that will need to be answered about the behavior of stabilized FGD products constructed in the field, i.e., What is the permeability of a compacted engineered liner of known thickness and density? and What is the quality of the water that flows through the FGD liner?

The facility was designed and constructed at The Ohio State University's Ohio Agricultural Research and Development Center (OARDC) Western Branch in South Charleston (Clark County), Ohio. This site was chosen over other university sites because it had an abundance of clay onsite that was suitable for use as a secondary or outer liner to contain the primary FGD liner. The OARDC Western Branch is a swine and agronomic research facility and, hence, it was decided to build a livestock manure storage facility that could be used by the center for storing swine manure after the completion of this research. The facility was designed for a capacity of approximately 150,000 ft^3 to provide six months storage for all liquid wastes from the swine onsite. A double-layered design was chosen with compacted FGD as the primary inner liner and the onsite clay as the secondary outer liner. A leachate system was placed between the primary FGD liner and secondary clay liner to collect in a sump any water passing through the FGD fill. The sump was designed so that it could be used to collect leachate samples with ease and for conducting field permeability tests on the pond.

The facility is essentially rectangular in shape with overall dimensions of approximately 144 feet by 250 feet (including 8-foot wide berms), as shown in Figure 1. Three sides of the pond were constructed at 3:1 slope and the fourth (east) side slope at 7:1. The east side slope was designed to be less steep so as to allow for easy access to the pond bottom during and after construction. Cross-sections AA and BB which are presented as Figures 2 and 3, respectively, show the final elevations of the facility. As seen in Figures 2 and 3, the pond is 9 feet deep with a liquid freeboard of 2 feet. A berm of minimum 8-foot top width was added around the periphery of the pond to minimize the inflow of surface water. The natural clay at the site provided an outer liner that was at least 5 feet thick. The leachate collection system, which consisted of corrugated high-density polyethylene (HDPE) perforated pipes (with socks) and protected against crushing using #57 washed river gravel, was placed over the re-compacted clay. The bottom of the pond was then covered with 9 inches of sand. On top of the sand layer, an 18-inch thick layer of compacted FGD material was placed. A plan view of the leachate collection system is shown in Figure 4. A typical detail of the perforated pipe embedded in the sand layer is shown in Figure 5.

Construction of Facility

Excavation of the site began on July 30, 1997, and the re-compaction of onsite clay to form the secondary liner was completed on August 7, 1997. A sheepsfoot roller was used to compact the onsite clay (Figure 6). A geofabric was spread over the secondary liner. The leachate system was then placed over the secondary liner (Figure 7) and covered with sand (Figure 8). A layer of geofabric was laid over the sand layer. Lime-enriched FGD material was delivered by truck from American Electric Power's Conesville Station near Coshocton, Ohio (Figure 9) to the site at a rate of approximately 600 tons per day. Placement and compaction of FGD in 4-6 inch lifts were accomplished using two dozers and one sheepsfoot roller (figures 10 and 11). The site was smooth rolled before completion of the project (Figure 12).

Approximately 2,700 tons of lime-enriched FGD material was used in the construction of the primary liner. The moisture content of the FGD material received at the site during construction ranged from 49% to 62%, while the proctor dry density varied between 9.6 and 11.6 kN/m^3.

Wet weather during the liner placement resulted in several delays but construction at the site was completed by August 26, 1997. Filling of the pond with water began on September 12, 1997, and was completed on September 23, 1997. Figure 13 is a photograph of the partially filled facility. The pond was filled with water up to a depth of approximately 9 feet as shown in Figure 14.

Monitoring of Facility

The facility was used to store water for the first year. In August/September of 1998, some of the water was replaced with swine manure and the facility was monitored for at least another year. The monitoring program consists of two main activities:

1. *Field Permeability Testing:* Full-scale permeability tests on the facility are being conducted by lowering the water level in the sump to create a head difference across the FGD liner. The amount of time taken to increase the water in the sump to specific levels is observed. Knowing the thickness of the FGD liner and its plan view area, the effective permeability of the field compacted FGD-lined facility is calculated (Figure 15). The permeability data obtained from the full-scale pond tests is being compared with: a) laboratory tests conducted on laboratory compacted samples collected during pond construction; b) laboratory tests conducted on field compacted samples cored from test pads installed at the site; and c) field permeability tests (Boutwell) conducted on the test pads.
2. *Water Quality Monitoring Program:* Testing of water samples from the pond, the sump, and a well about 1,000 feet from the site is being carried out on a regular basis. The water quality analysis is being performed by the Chemical Analysis Laboratory of The Ohio State University's School of Natural Resources at OARDC in Wooster. Tests conducted on the water samples include pH, electrical conductivity, alkalinity, acidity, total dissolved solids, 24 elements by Inductively Coupled Plasma (ICP) Emission Spectrometry Mineral Analysis, 4 anions using Ion Chromatography (IC) Analysis, and ammonia as well as nitrogen by Micro-Kjeldahl Distillation. The effect of FGD on the quality of the water that does flow through the liner is being evaluated by comparing the results obtained from the pond and sump samples.

Results of First Year Monitoring

The full-scale FGD-lined facility was monitored for field permeability and water quality on a regular basis. Table 2 shows the effective coefficients of permeability obtained from full-scale permeability tests (Figure 15) conducted after the pond was filled with water. The permeability coefficients were calculated using the bottom area of the pond as the effective leaching area for the FGD-liner. The permeability coefficient values listed in Table 2 are the average of several test readings that were measured at each curing time. The full-scale permeability of the facility was evaluated to be 9.1×10^{-7} cm/sec at a curing time of one month. The permeability coefficient has continued to reduce over time and has stabilized at approximately 4×10^{-7} cm/sec. The actual area over which water flows through the FGD-liner is greater than the bottom area of the pond. Hence the full-scale permeability values presented in Table 2 should be taken to be an upper bound to the actual permeability of the field compacted FGD liner. Figure 16 shows the time history comparison of the full-scale permeability test values with averaged permeability coefficients obtained from a) laboratory tests on laboratory compacted samples, b) field tests (Boutwell) conducted on test pads, and c) laboratory tests conducted on samples cored from test pads. All the test procedures showed decreasing permeability with increasing curing time. It was observed that the laboratory compacted samples had permeability coefficients which were an order of magnitude lower than the full-scale testing values. Permeability values obtained from Boutwell tests and cored samples tested in the laboratory were in close agreement with each other but were one to three orders of magnitude higher than the full-scale tests. The test pad sample permeability values (Boutwell tests and cored sample testing) indicated a large scatter in the data. The permeability coefficients varied from 10^{-4} to 10^{-6} cm/sec with average permeabilities in range of 10^{-5} cm/sec.

Water quality monitoring of the site was conducted by collecting water samples from the pond, sump, and a vicinity well. The first baseline water samples were collected on September 12, 1997 before any water was added to the facility. Only well and sump samples were collected. After the pond had been filled with water on September 23, 1997, water samples were collected from the pond, sump, and well on a regular basis. All samples were tested for several constituents and properties including pH, electrical conductivity, alkalinity, acidity, total dissolved solids, aluminum, arsenic, boron, barium, calcium, cadmium, chromium, copper, iron, potassium, magnesium, manganese, sodium, nickel, phosphorous, lead, sulfur, selenium, silica, silver, vanadium, zinc, chloride, phosphate, sulfate, nitrate, ammonia, and nitrogen.

Table 3 lists the measured concentration levels of some the above listed elements. It is observed that concentration of barium, cadmium, and copper are much lower than the National Primary Drinking Water Regulation (NPDWR) limit. Arsenic concentration levels are also lower than the NPDWR limit. Immediately after the pond was filled, the level of chromium recorded was 0.125 mg/l. We believe that this was the result of relatively high levels of chromium in the source water. However, the sump samples have consistently shown lower chromium concentrations than the pond samples. We will continue to monitor chromium levels in the pond and sump since preliminary data indicate that there may be some absorption of the chromium by the FGD material. All measurements for chromium, which were made after the pond was filled with water, show low concentration levels compared to the NPDWR limit. The nitrate concentration level in the sump only slightly exceeded the NPDWR limit when the facility was first filled with water. Beyond the filling of the pond, the nitrate concentration levels were much lower than the NPDWR limit.

It can be observed from Table 3 that the pH of the well sample has been decreasing slightly according to seasonal groundwater variations. The pH of the pond sample was within the Ohio Secondary Maximum Contaminant Level (OSMCL). The pH of the sump water rose sharply to 12.0 on filling the facility with water and has been dropping since then. The last pH level reading for the sump was 9.1, which is within the OSMCL range of 7.0 to 10.5. The dissolved aluminum concentrations in the sump samples increased significantly during the filling of the pond. However soon after filling the facility, the aluminum concentrations dropped significantly and have stabilized at approximately four times the National Secondary Drinking Water Regulation (NSDWR) limit. The aluminum concentrations in the pond are approximately twice the NSDWR limit. Iron levels for the pond and sump samples have always been lower than the NSDWR limit. Sulfate levels have generally been within the NSDWR limit. The NSDWR limit for silver was exceeded slightly in the sump during the filling of the pond but since then the measured levels have decreased significantly and are currently much lower than the recommended regulation limit. Zinc concentration levels are also much lower than the NSDWR limit. On filling the pond, the chloride concentration in the sump increased to about four times the NSDWR limit, but has decreased since then to a level much lower than the regulation limit. Phosphate level in the sump increased on filling of the facility with water but reduced quickly and no measurable concentrations have been detected in the last 5 months. Boron, elevated levels of which can be phytotoxic to plant growth, generally had lower concentration levels in the sump than the pond. As with chromium, we will be monitoring this element to see if this trend is continued for a long enough period of time to indicate the possibility that boron is being trapped in the FGD liner.

Conclusions

Lime-enriched FGD material can be compacted in the laboratory to achieve permeability values lower than those generally recommended for lining waste containment facilities. A full-scale FGD-lined pond facility was constructed at The Ohio State University to study the permeability and leachate characteristics of a field-compacted FGD liner. First year monitoring of the facility has shown that: a) the full-scale permeability of the field-compacted FGD liner is in the 10^{-7} cm/sec range, which is typical of compacted clays; b) the full-scale permeability testing method is the most reliable; c) results of field permeability tests (e.g., Boutwell test) on test pads have large scatter in the data; d) quality of the leachate that flowed through the field-compacted FGD liner generally meets the NPDWR limits; and e) some constituents (e.g., chromium and boron) may be absorbed by the FGD material as water leaches through it. The water in the pond was replaced with swine manure beginning in August/September 1998 and the facility will be monitored for at least one more year.

Acknowledgments

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Table 1. Laboratory Compacted FGD Samples

Sample	Moisture Content (%)	Dry Density (kN/m^3)	Coefficient of Permeability (cm/sec)				q_u (psi)
			7 day	28 day	60 day	90 day	90 day
66-34-5 (FA-FC-L)	27	12.4	3.6 x10^{-5}	3.2 x10^{-6}	1.5 x10^{-6}	1.4 x10^{-6}	242
66-34-8 (FA-FC-L)	32	12.2	1.4 x10^{-5}	1.2 x10^{-6}	1.3 x10^{-7}	4.8 x10^{-8}	343
CON(AEP)-5%L	48	11.1	2.6 x10^{-6}	3.6 x10^{-7}	3.2 x10^{-7}	2.6 x10^{-7}	240
CON(AEP)-8%L	42	11.9	1.3 x10^{-6}	6.1 x10^{-8}	3.4 x10^{-8}	3.0 x10^{-8}	629
GAV(AEP)-4%L	51	10.8	2.2 x10^{-6}	2.2 x10^{-7}	1.5 x10^{-7}	1.7 x10^{-7}	371
GAV(AEP)-8%L	39	12.5	1.6 x10^{-6}	1.2 x10^{-7}	2.0 x10^{-8}	1.0 x10^{-8}	607

FA: Fly Ash
AEP: American Electric Power
FC: Filter Cake
CON: Conesville Plant
L: Lime
GAV: Gavin Plant

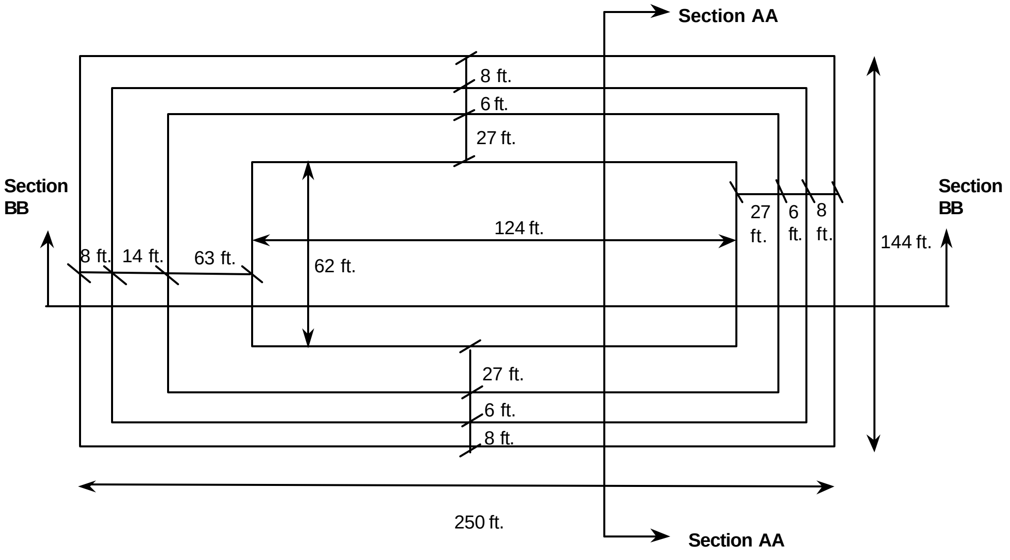


Figure 1.

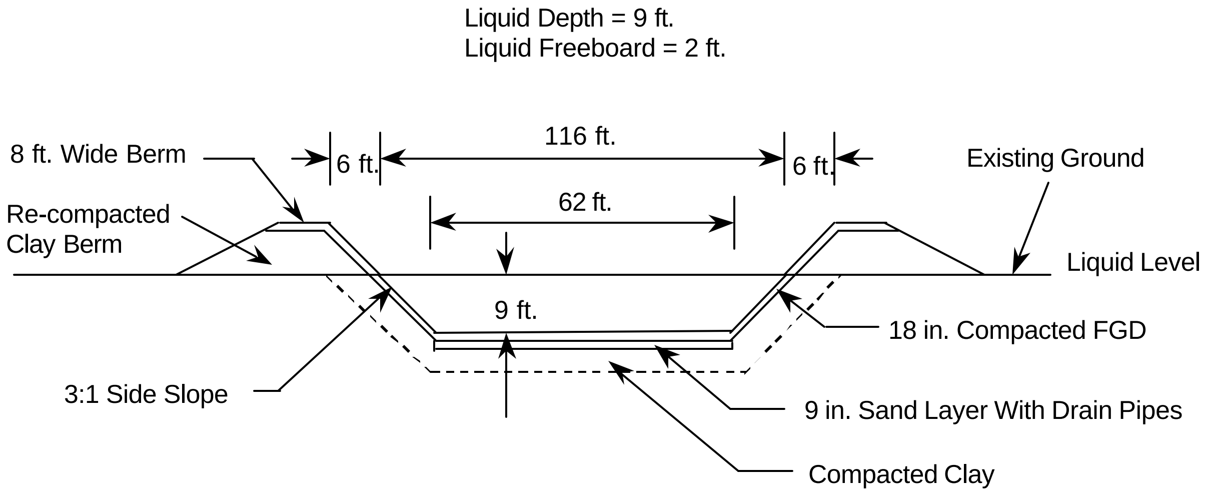


Figure 2. Section AA -- Plan View of Facility.

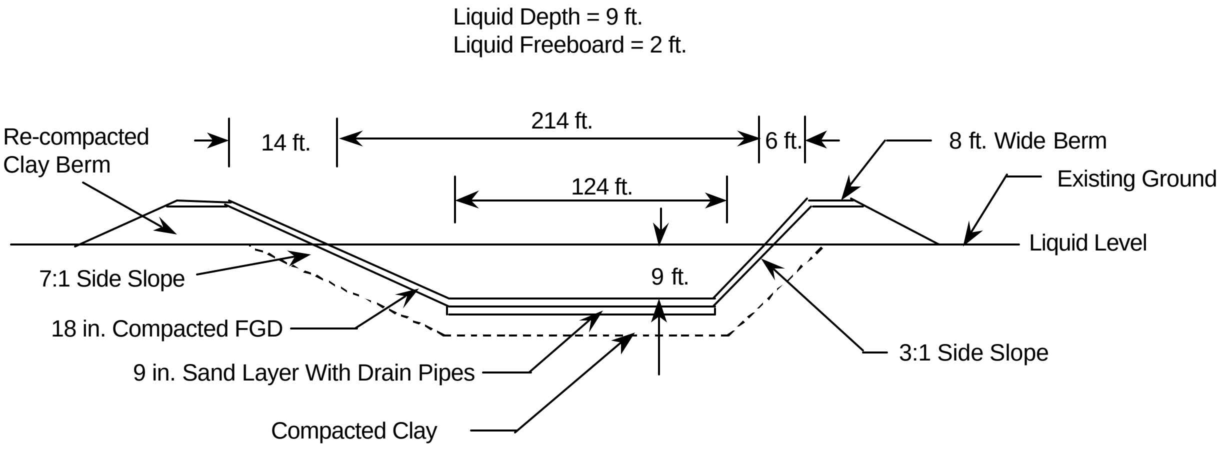


Figure 3. Section BB.

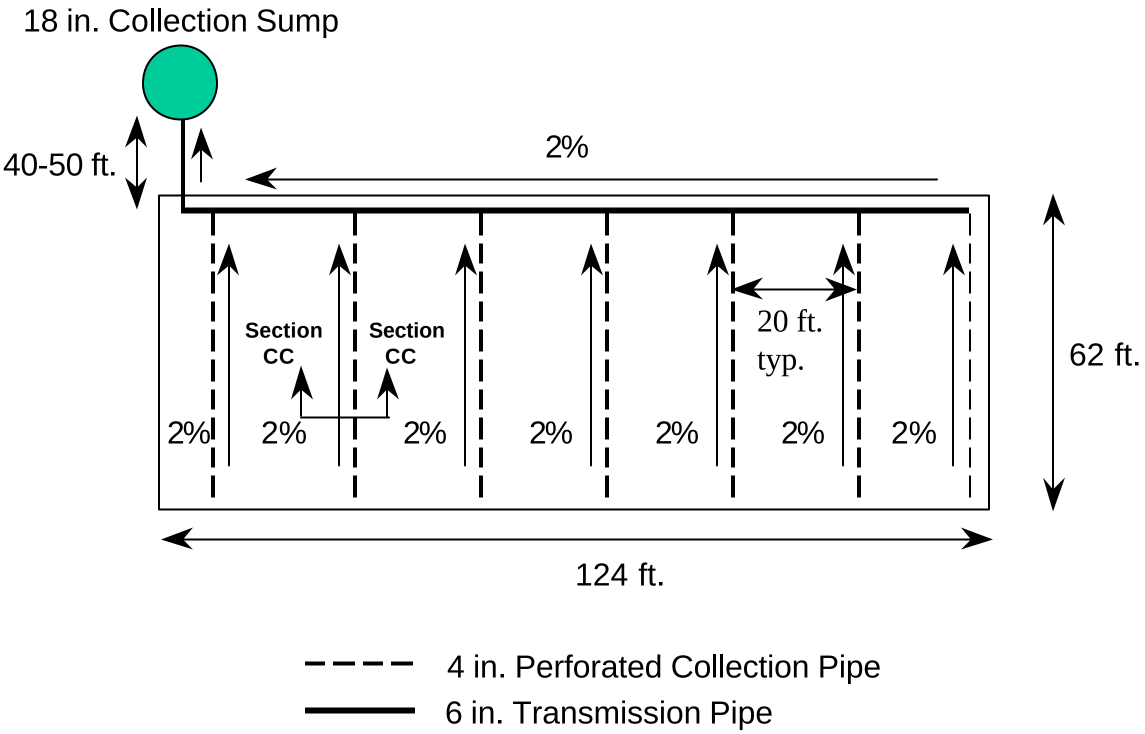


Figure 4. Leachate Collection System Layout.

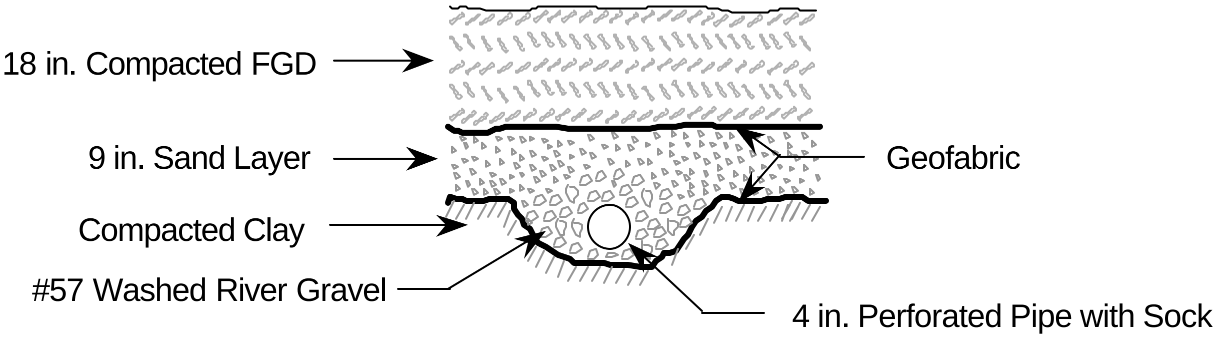


Figure 5. Section CC.

Figure 6. Compaction of Onsite Clay.

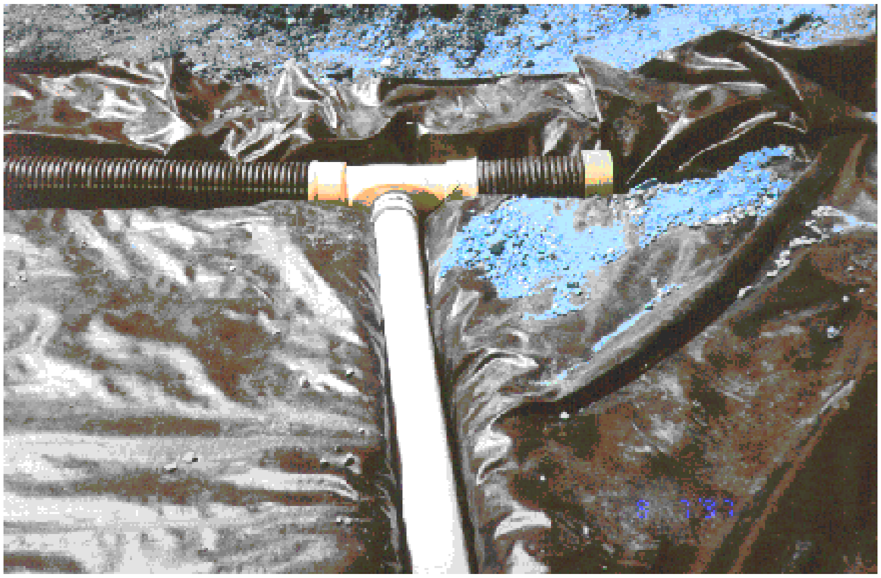


Figure 7. Typical Leachate System Collection.

Figure 8. Spreading of Sand.

Figure 9. Truck Unloading FGD.

Figure 10. Spreading the FGD.

Figure 11. Compacting FGD on a Side Slope.

Figure 12. Final Smooth Rolling of FGD..

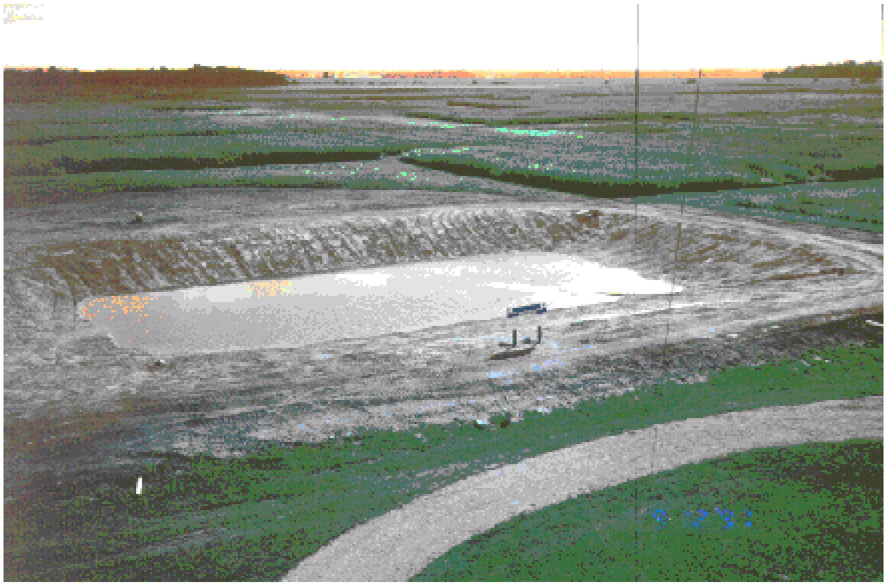
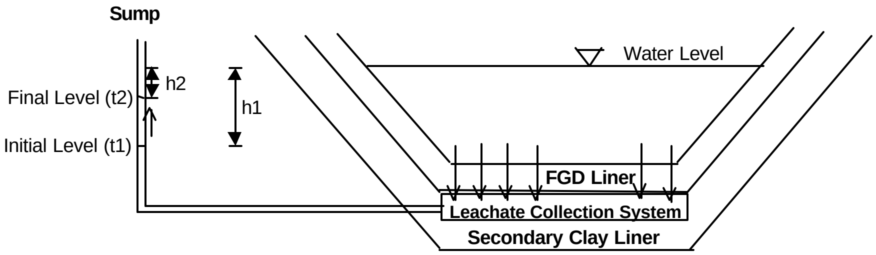


Figure 13. Facility Being Filled With Water.

Figure 14. Facility Filled With Water.



$$k = \frac{L}{(t2 - t1)} \frac{a}{A} \ln\left(\frac{h1}{h2}\right)$$

L = Thickness of FGD liner
a = Area of sump
A = Effective area of FGD liner

Figure 15. Full Scale Permeability Test.

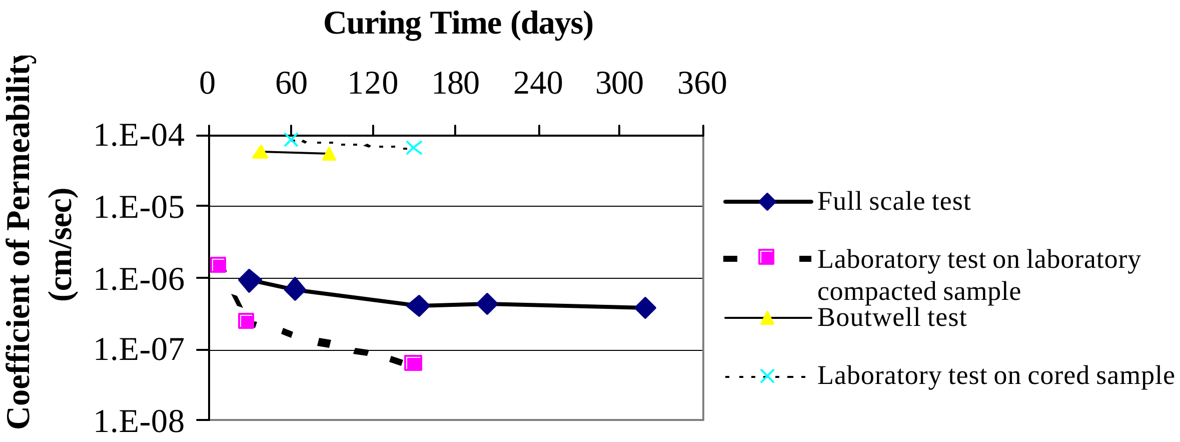


Figure 16. Comparison of Permeability Test Methods.

Table 2. Full Scale Permeability Tests.

Curing Time (days)	Coefficient of Permeability* (cm/sec)
31	9.1×10^{-7}
63	6.8×10^{-7}
153	4.1×10^{-7}
202	4.3×10^{-7}
317	3.8×10^{-7}

*Effective area of FGD liner = Bottom area of pond.

Table 3. Water Quality Monitoring.

	Regulation Limit	Measured Concentration Levels (mg/l except pH)											
Sample Location **Date Collected**		**Sump** **9/12/97**	**Well** **9/12/97**	**Sump** **9/28/97**	**Pond** **9/28/97**	**Well** **9/28/97**	**Sump** **1/26/98**	**Pond** **1/26/98**	**Well** **1/26/98**	**Sump** **3/16/98**	**Pond** **3/16/98**	**Sump** **7/9/98**	**Pond** **7/9/98**
pH	7.0-10.5***	7.94	8.25	12.05	8.39	8.62	11.23	7.85	7.96	11.28	7.57	9.12	8.22
Aluminum	0.05 to 0.2 mg/l**	0.157	0.248	5.505	0.713	0.151	1.033	0.489	<0.040	0.737	0.305	0.809	0.403
Arsenic	0.05 mg/l*	<0.035	<0.035	0.049	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
Boron	-	0.059	0.214	1.154	0.742	0.204	0.552	0.635	0.203	0.455	0.692	0.374	0.952
Barium	2.0 mg/l*	0.100	0.080	0.035	0.028	0.078	0.027	0.028	0.058	0.030	0.031	0.017	0.049
Cadmium	0.005 mg/l*	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.001	0.001	<0.001	<0.001	<0.001
Chromium	0.1 mg/l*	0.080	0.125	0.087	0.188	0.127	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.006
Copper	1.3 mg/l*	0.018	0.026	0.014	0.019	0.034	<0.004	<0.004	0.039	<0.004	<0.004	<0.004	<0.004
Iron	0.3 mg/l**	0.043	0.267	0.150	0.048	0.039	0.019	0.142	1.313	<0.006	0.016	<0.006	<0.006
Silver	0.1 mg/l**	<0.008	<0.008	0.104	0.012	0.008	0.044	0.018	0.010	0.028	0.018	<0.008	<0.008
Zinc	5.0 mg/l**	0.043	0.271	<0.005	<0.005	<0.005	0.009	<0.005	<0.005	<0.005	<0.005	0.531	0.623
Chloride	250 mg/l**	85.38	6.91	976.92	16.80	5.77	480.08	32.69	5.46	377.50	34.33	38.93	239.67
Phosphate	-	0.00	0.00	53.71	0.00	0.00	1.36	0.00	0.00	0.00	5.51	0.00	0.00
Sulfate	250 mg/l**	125.25	21.82	182.11	104.46	18.95	185.05	141.25	20.45	171.19	183.79	262.31	120.82
Nitrate	10 mg/l*	11.41	0.00	0.81	0.17	0.26	0.41	0.51	0.25	0.33	0.35	0.00	0.00

*** National Primary Drinking Water Regulation**
**** National Secondary Drinking Water Regulation**
***** Ohio Secondary Maximum Contaminant Level**

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