Paper Number:
DOE/MC/30127-97/C0753

Title:
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Contract Number:
DE-FC21-93MC30127

Conference:
Advanced Coal-Fired Power Systems '96 Review Meeting

Conference Location:
Morgantown, West Virginia

Conference Dates:
July 16-18, 1996

Conference Sponsor:
U.S. DOE, Morgantown Energy Technology Center

Disclaimer

Conference Proceedings - Power Systems '96
U.S. DOE (METC) July 16-18, 1996

The Impact of Leachate From Clean Coal Technology Waste on the Stability of Clay and Synthetic Liners

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ABSTRACT

This project was developed to provide design criteria for landfill disposal sites used for sludges such as those generated using the Clean Coal Technologies (CCT) tested at the Public Service Company of Colorado's Arapahoe Power Plant. The CCT wastes used were produced at the Arapahoe Plant Unit No.4 that was equipped with the integrated dry NO_x/SO_2 emissions control system installed under the Clean Coal Technology (CCT) Program. The investigation emphasized the potential impact of clean coal technology materials (sodium and calcium injection systems, and urea injection) on the permeability and stability characteristics of clay liner materials and the stability of synthetic liner materials.

Flexible-wall permeameters were used to determine the hydraulic conductivities (HC) of the clay liner materials impacted by various compactive conditions. Tests were conducted using the waste materials overlying the clay liner materials under wet/dry cycles, freeze/thaw cycles, and over 120-day periods.

The impact of CCT materials on the characteristics of the clay liner materials studied in this project was minimal. The HC measurements of the waste/clay liner systems were similar to the water/clay liner systems. HC decreased for clay liners compacted at moisture levels slightly higher than optimum (standard Procter) and increased for liners compacted at moisture levels lower than optimum (standard Procter). Although some

swelling was evident in the sodium materials, the sludge materials did not have a negative impact on the integrity of the liners over 120-day tests. Wet/dry cycles tended to result in lower HC, while freeze/thaw cycles substantially increased HC for the liners tested.

Tests were also conducted to assess the compatibility of synthetic liner materials with the CCT by-products. The test program was conducted using methods specified and/or referenced in EPA, SW 846-Method 9090 with some modifications. Compatibility evaluations were made using high-density polyethylene (HDPE), very low-density polyethylene (VDPE), and polyvinyl chloride (PVC) synthetic liner materials treated with baseline fly ash materials (no CCT used), sodium injection materials, calcium injection materials, and materials generated from the sodium injection/urea injection/low NO_x burner control system. The synthetic liner materials were subjected to a 50:50 ratio of sludge to water for periods to 120 days at room temperature (23°C). At the end of each equilibration period, the liner materials were tested using mechanical engineering techniques and weight losses due to volatiles and extractables.

Sustained increment changes in the measured physical properties of the materials over time were not observed. Some abrupt changes in strength were found at several times during the testing period. However, these aberrations seemed more indicative of isolated changes in the conditioning methods or test procedures and could be related to flaws or changes in the materials related to manufacturing conditions. After 120 days of conditioning, none of the measured physical properties varied significantly from those for the untreated liner materials. This was true for all samples regardless of the conditioning solution used.

The volatiles and extractables tests for the HDPE and VDPE materials indicated that the waste materials had little influence on their overall structure. However, the extractables data suggest that PVC liner material might decompose in the waste environments evaluated. The PVC liner material reacted similarly for all treatments with about a 30% weight loss.

Introduction

Landfills commonly used for disposal of solid wastes pose a potential threat to surface and groundwater quality. The major concern is that the leachates form the waste may contain elements that are detrimental to the quality of the waters for their designated uses. Clay liners are usually used in landfills often in combination with synthetic liner materials to help assure the prevention of the movement of leachate from the disposal site. It is important to determine the compatibility of both the clay liner material and the synthetic liner material to the specific waste prior to prescribing a suitable liner system for a specific application.

Clay liners are often used in landfills to contain and attenuate the leachate from solid waste materials. The suitability of soil materials for liner use is usually based on permeability criteria (Brown and Anderson, 1980). However, other considerations relative to chemical-physical relationships often determine whether a clay liner is compatible to a specific type of waste. These relationships must be evaluated in detail before an appropriate liner can be prescribed for a specific landfill.

Problems often found with clay liners are related to volume shrinkage's (Hettiaratchi et al., 1988). Shrinkage's in compacted liners often result from increases in salt concentrations in the solutions within the clay liner (Green et al., 1983). Also, the impact of acidic and alkaline solutions on the dissolution of the clay minerals present in the clay liner materials results in increased permeability's for similar reasons (Peterson and Krupka, 1981). The presence of certain organic compounds in the leachates are sometimes associated with increased permeability's (Green, et al., 1983).

There are a number of variables that determine the effect of waste leachate on the long-term stability of a clay liner material. The primary variables include clay mineralogy, texture, surface chemistry considerations, the physical nature of the materials, and the chemistry of the waste leachate. Increased in salt concentrations can result in double layer collapse or less interaction between clay particles and resulting decreases in repulsive forces (Bohn et al., 1985). A decrease in repulsive forces causes the materials to flocculate reducing the effective stress in the liner which results in a volume shrinkage (Hettiaratchi et al., 1988). The mineralogy of the clay and the specific elements present in the solution associated with the clay will determine the amount of shrinkage that will result from double layer collapse. The 2:1 layer clay minerals such as montmorillinite have a much greater tendency for swelling and shrinking than the 1:1 clay types such as kaolinite. In addition, monovalent elements like sodium that have a very large hydrated radius have the potential to cause swelling, while divalent elements such as calcium have a tendency to reduce double layer expansion. Therefore, materials that have high-swelling montmorillonite clay minerals with sodium as the dominant element should be avoided. Elements such as calcium can displace the sodium and cause the double layers to collapse. this type of reaction resulted in a large amount of shrinkage in studies done by Hettiaratchi et al. (1988) with permeant solutions containing calcium. These authors suggested that clay liner materials should be conditioned with calcium solutions during the compaction stage to prevent shrinkage and cracking due to double layer collapse. However, it should be noted that if the salt concentration is increased to high levels (high electrical conductivity or EC) due to leachate migrating into the clay liner, no matter which cation is present, double layer collapse could occur resulting in the formation of cracks.

Shrinkage of clay liners can also be caused by the influence of organic compounds on the electrical double layer. The low dielectric constant of organic compounds relative to water reduces the influence of the surface charge, promoting flocculation of clay particles causing cracking of clay liners (Green et al., 1983). However, the amount of organic compounds seems to determine the degree of impact that the clay liners experience. Daniel et al. (1988) found that solutions containing low levels of organic compound did not cause shrinkage of clay liner materials. Therefore, it is apparent that most situations will require testing for compatibility between the specific wastes and the clay liner material to be used at the disposal site.

The load on the clay liner associated with the waste will also impact the effective stress experienced by the clay liner. Changes in effective stress with time may be an important factor relative to the long-term stability of a clay liner.

SPECIFIC PROBLEM

Wastes generated from CCT's have much different physical and chemical characteristics than the wastes generated from conventional power plants. As noted previously, the various wastes generated from implementation of CCT have significantly different impacts on the permeability of clay liners (Koegler et al., 1991). Also, the active lifetime of a compacted clay liner is generally assessed through permeability or saturated hydraulic conductivity and effective porosity measurements. Such assessments, however, do not take into account the influence of waste leachate chemical composition or the effects of alternating wetting and drying, and freezing and thawing cycles on leachate transport through clay liners. These "weathering" cycles need to be considered in the compatibility of a certain type of clay liner material with the waste being generated. Without good compatibility information, serious mistakes might be made that impact the environment and the consumer through environmental clean-up costs.

Flexible membrane liner compatibility studies have been conducted using clean coal technology (CCT) wastes by Koegler et al. (1991). These tests were done using fly ash/sludge materials that were generated from a number of power plants that represented desulfurization technologies such as spray dryer, atmospheric fluidized bed combustors (AFBC), limestone injection and sodium injection. These researchers looked at 20 synthetic membrane liners of various types from different venders. The findings indicated that water slurries of the wastes tested are chemically incompatible with some of the synthetic membrane liners tested. They also found that variations between synthetic liners of the same type, but obtained from different vendors, were significant. Therefore, it is recommended that before a liner is selected for a specific installation, compatibility tests using the actual waste material and liner samples form specific vendors should be completed.

OBJECTIVES

The purpose of this research was to investigate the potential impact of clean coal technology solid wastes on the permeability and attenuation characteristics of clay liner materials and on the integrity of synthetic membranes.

EXPERIMENTAL PLAN

The test program included three clay liner materials representing different overall characteristics. The liner materials represent two landfill sites located in Colorado and one site currently being used in California. Four waste materials generated at the Arapahoe Power Plant during the Clean Coal Technology testing program were used in the testing. The CCT materials used in this study include: materials collected during baseline operations without the applications of the CCT; the sodium injection materials; the calcium injection materials; and the materials generated from the sodium/urea injection/low NO_X *control system. This paper will address the general aspects of the research findings.*

Flexible-wall permeameters were used to determine the hydraulic conductivities (HC) of the clay liner materials impacted by various compactive conditions, confining pressures, *gradients, effective stresses and solution chemistry conditions. In addition, tests were conducted using the waste materials overlying the clay liner materials under wet/dry cycles, freeze/thaw cycles, and over long time periods. Dry cycles were conducted by allowing the liner materials to air dry to a point near field capacity (-1/3 bar matric potential), and did not represent an oven-dry condition.*

Clay liner and fly ash materials were tested using compacted cyclinders, 6-inches long and 4-inches in diameter. The tests were conducted at densities based on moisture/density relationships as described in ASTM D698. Clay liner material/fly ash simulations were done using 2 inches of clay liner material overlain by 2 inches of fly ash materials. The hydraulic conductivities of the various materials were determined using ASTM D5084-90.

The test program included compatibility evaluations for 3 types of synthetic liner materials including: (1) high-density polyethylene (HDPE); (3) very low density polyethylene (VDPE); and (3) polyvinyl chloride (PVC);. The synthetic liners were immersed in the leachate environment associated with 4 waste materials generated at the Arapahoe Power Plant during the CCT testing program as noted previously. The synthetic liners were subjected to the fly ash materials for periods of 30, 60, 90, and 120 days. The 50:50 ratio of sludge to water used in this study deviates from the EPA Method 9090 which requires a 5 to 15% solids solution. This procedure was modified because the pH values associated with the dilute system specified in Method 9090 were 2 pH units lower than the pH of the 50% solids solution. In addition, the pH of the 50% solution compared well to the pH of the saturated pastes of the sludge materials used in the study. The studies were done at room temperature (23° C). Comparisons of measurements of the synthetic material's physical properties, taken before and after contact with the leachates from the fly ash materials, were used to evaluate the compatibility of the liner with the waste over time. Testing included physical tests, tensile strength properties, and changes in volatile and extractable components of the materials.

The mechanical testing was performed using the guidelines of EPA Method 9090 with the exception of the puncture test which was done using ASTM D4833. As directed by EPA Method 9090, the tensile properties method was specified as ASTM D638. The modulus of elasticity was measured for the HDPE and VDPE materials per ASTM D882, Method A. Tear strength was measured per ASTM D1004. The punch strength test method used was specified in ASTM D4833. The change in volatile and extractable weights presented on a percentage basis was done using methods specified in SW 870 Appendix III-D and Appendix III-E. Volatile losses provide indications of the amount of water absorbed into the liner. Large amounts of absorption show a degradation of the liner. A decrease in liner extractions as compared to the material before testing, provides an indication of the components leached from the liner during exposure to a waste.

RESULTS

Clay Liner Material Evaluations

In general, the impact of CCT wastes on the characteristics of the clay liner materials studied in this project was minimal. As shown in Table 1, the HC measurements decreased for clay liners compacted at moisture levels slightly higher than optimum (standard Procter) and increased for liners compacted at moisture levels lower than optimum (standard Procter). The HC measurements of the waste/clay liner system reacted very similar to the water/clay liner systems. Although some swelling was evident in the sodium waste materials, the sludge materials did not have a negative impact on the integrity of the liners over the 120-day tests (Figure 1). The column did not show any signs of cracking and the hydraulic conductivity decreased with time. Some initial dispersion of clays resulting in plugging of pores maybe responsible for the gradual reduction in HC. The potential swelling and shrinkage due to the high sodium or sodic condition followed by the impact of high salt concentrations on the electronic double layer, did not occur. This clay chemistry phenomena was expected to have a negative impact on the integrity of the clay liner materials.

Table 1. Hydraulic Conductivity Evaluations for the Clay Liner Material at Various Water Content/Density Conditions.

	cm/s
H.C. at Std Dry	2.0E-05
H.C. at Std Opt.	4.0E-09
H.C. at Std Wet	2.0E-09
H.C. at Mod Dry	2.0E-08
H.C. at Mod Opt.	7.5E-09
H.C. at Mod Wet	1.3E-09

The HC values for the 120-day test of the clay liner materials contacted with calcium injection waste are presented in Figure 2. Shrinkage of the clay liner materials due to high electrical conductivity levels was expected to potentially cause cracking of the clay liner. However, cracking was not apparent and the HC values stabilized within several weeks indicating that the clay liner remained stable.

Wet/dry cycles did not have a major impact on the HC of the clay liner materials with time. The impact of wet/dry cycles on the system with sodium-injection fly ash overlaying a clay liner is shown in Figure 3. The decline of HC values with time resemble closely the trend shown in Figure 1 for a liner not impacted with wet/dry cycles.

The influence of freeze/thaw cycles on the HC values of a clay liner impacted with a calcium injection fly ash is shown in Figure 4. The initial HC values resemble those shown in Figure 2 for the calcium fly ash overlaying the clay liner. However, each freeze/thaw cycle substantially increases HC values for the system above the previous equilibration HC level. These results suggest that during the initial development and use of a disposal site, freezing conditions could result in the failure of the clay liner system.

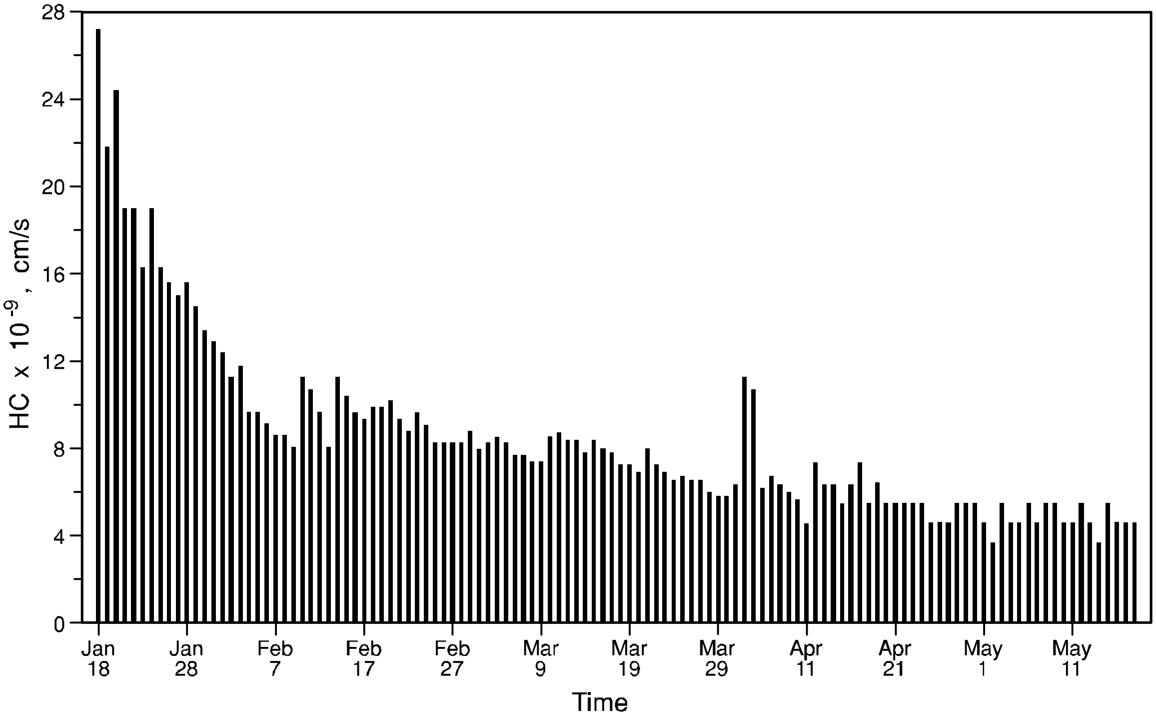

Figure 1. Long-term hydraulic conductivity values for a clay liner impacted by sodium injection fly ash leachate.

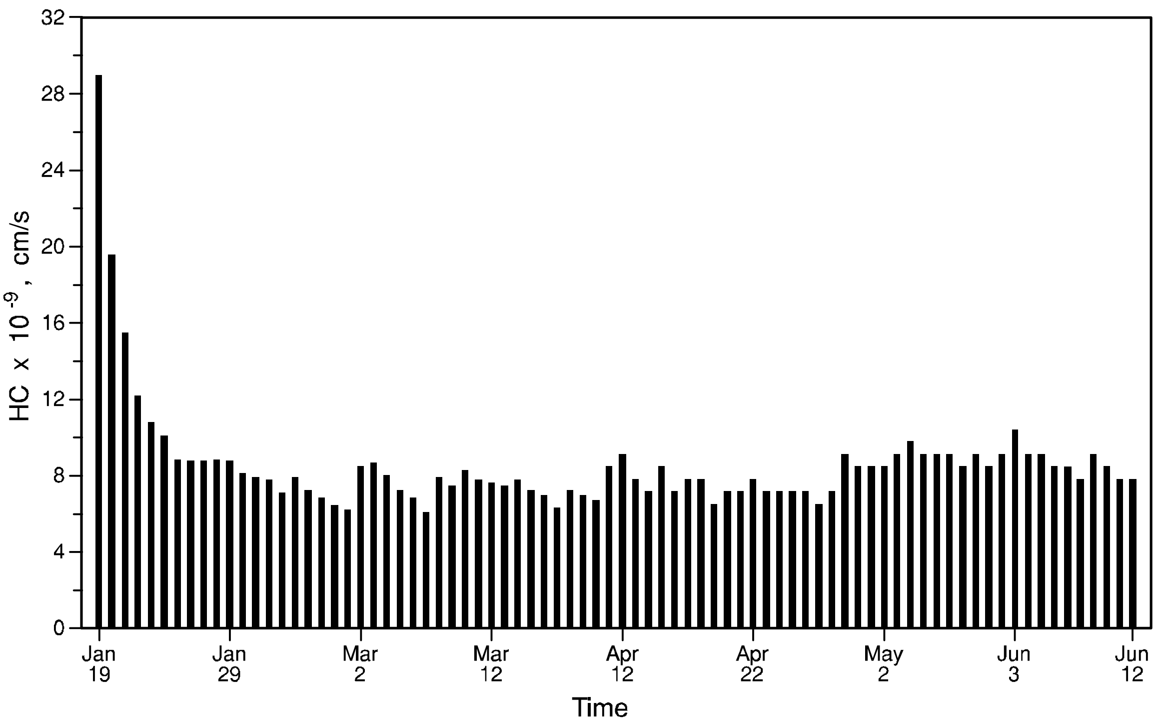

Figure 2. Long-term hydraulic conductivity values for a clay liner material overlain by calcium injection fly ash.

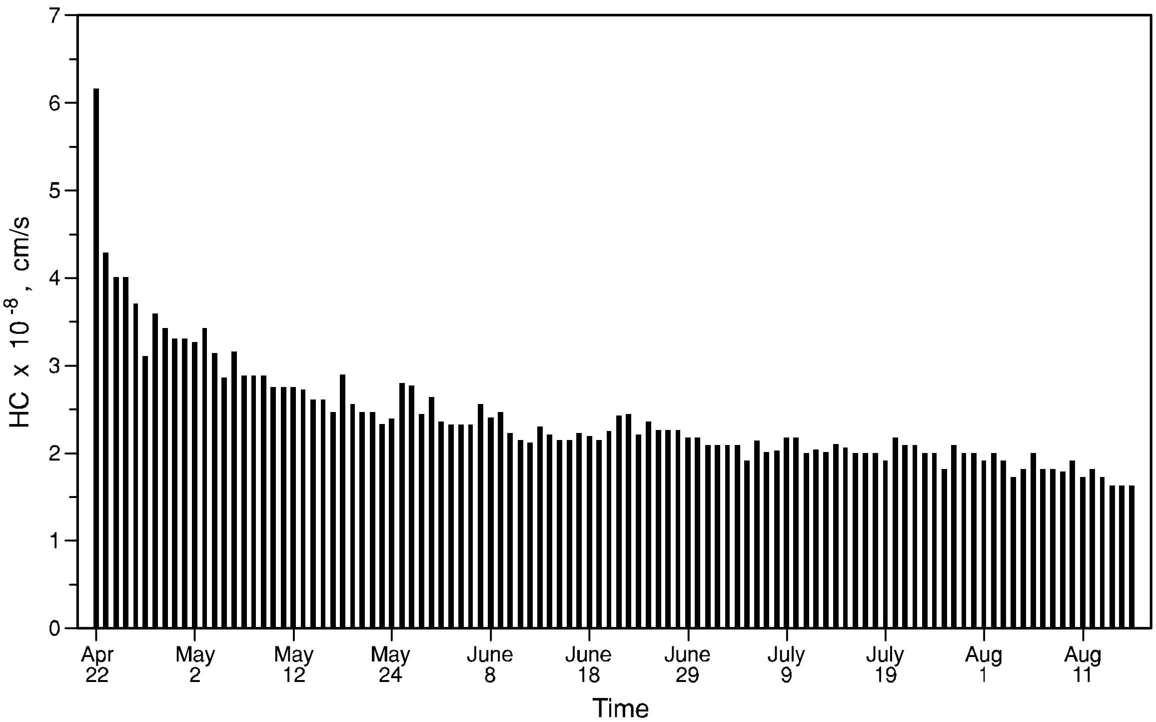

Figure 3. Hydraulic conductivity values for a clay liner material impacted by leachate from sodium injection fly ash under-going wet/dry cycles.

Synthetic Liner Evaluations

<u>*Mechanical Testing*</u>

The punch strength test data for the HDPE, VDPE and PVC materials are shown in Figure 5. This is the only property that permits direct comparison across the three materials tested, since the test was performed identically for each material type and at the same crosshead speed as required by the testing methods. The information demonstrates that the materials have much different capabilities to resist puncture. The heavy, thicker HDPE has the strongest punch strength as compared to the VDPE and the PVC materials. The PVC material which is slightly thicker and stiffer has more strength than the VDPE which is a very low density polyethylene material. However, it is apparent that the influence of the various wastes on the integrity of the synthetic liner materials is not significant. This was also found to be true for the tear strength with grain and stress at 100% elongation with grain (Figures 6 and 7). The HDPE had high tear strength as compared to the VDPE and the PVC which have comparable tear strength. However, the stress at 100% elongation with grain for the PVC material (untreated and treated) was the same as the HDPE material, and both had higher stress strength than the VDPE material. This information provides an indication that the HDPE, VDPE and PVC materials have the overall strength capabilities after 120 days of treatment with the various wastes as the untreated liner materials have. The HDPE material has higher strength as compared to the VDPE and PVC materials. However, the strength characteristics of the VDPE and PVC materials are not compromised by the waste materials.

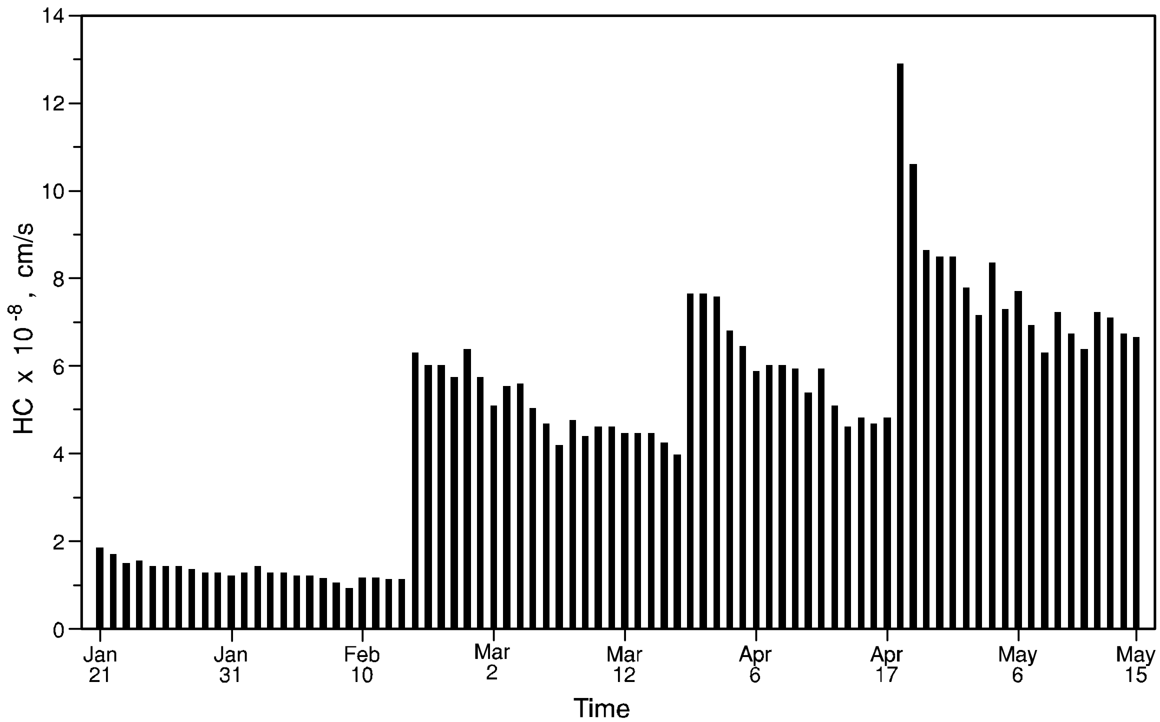

Figure 4. The influence of freeze/thaw cycles on the HC values of a clay liner impacted by solution extracted from calcium injection fly ash.

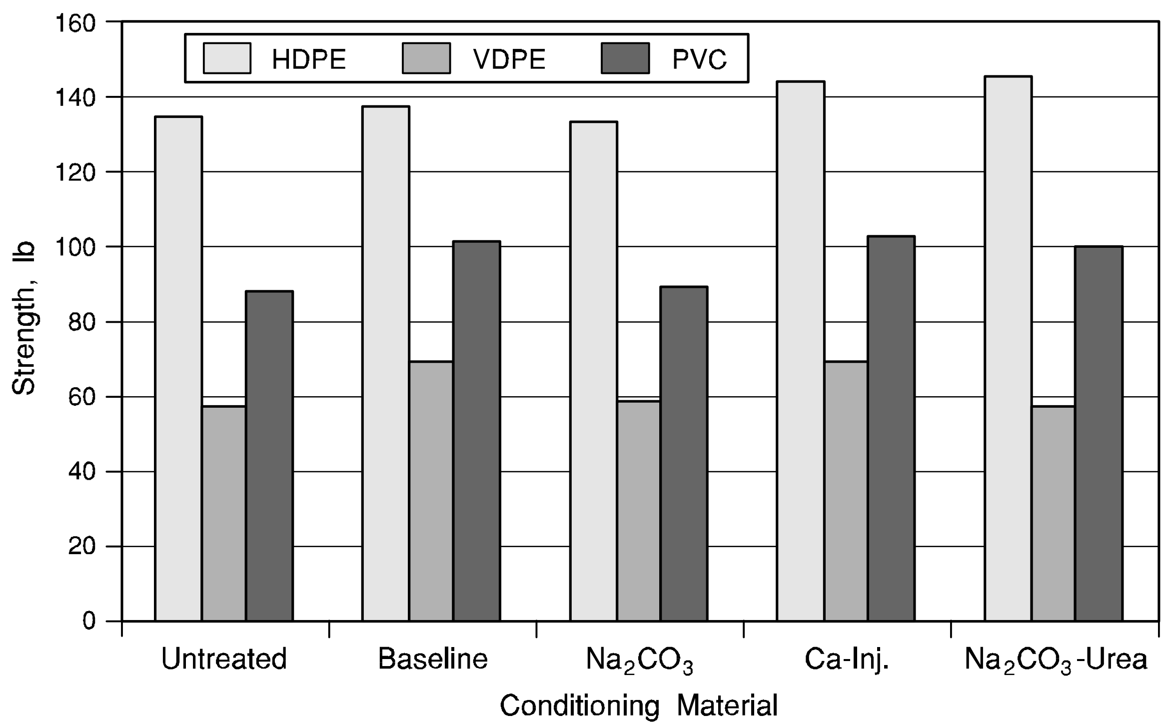

Figure 5. Punch Strength after 120 days of Conditioning

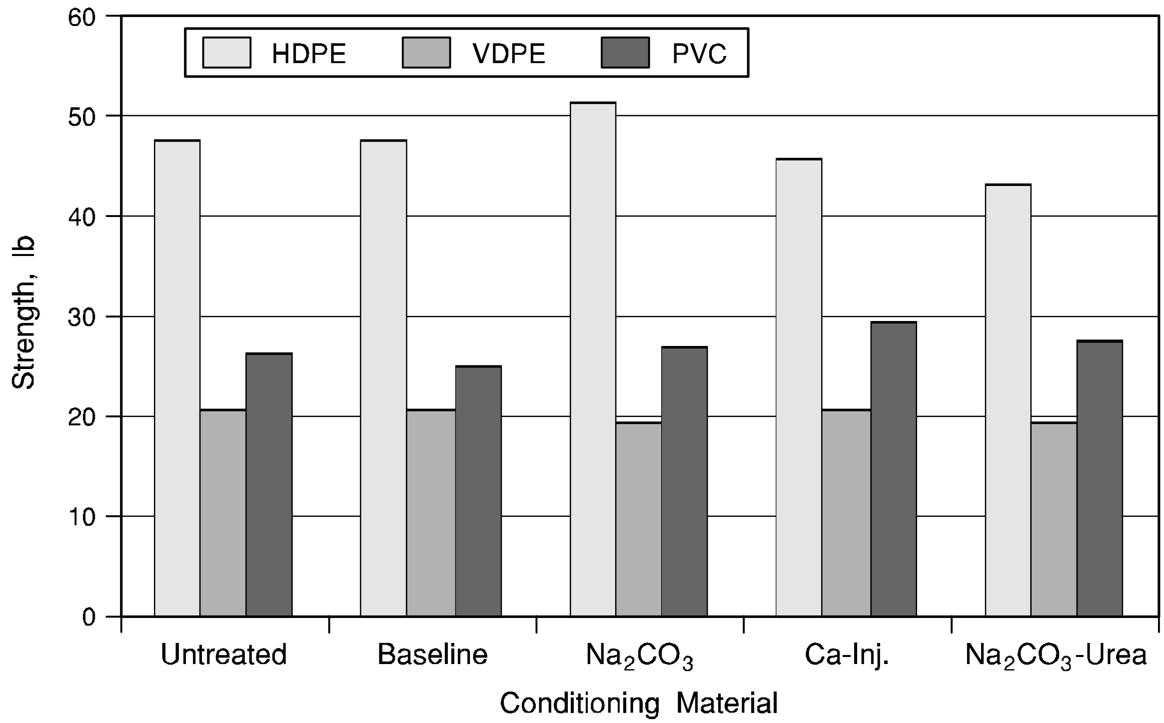

Figure 6. Tear Strength with Grain after 120 days of Conditioning

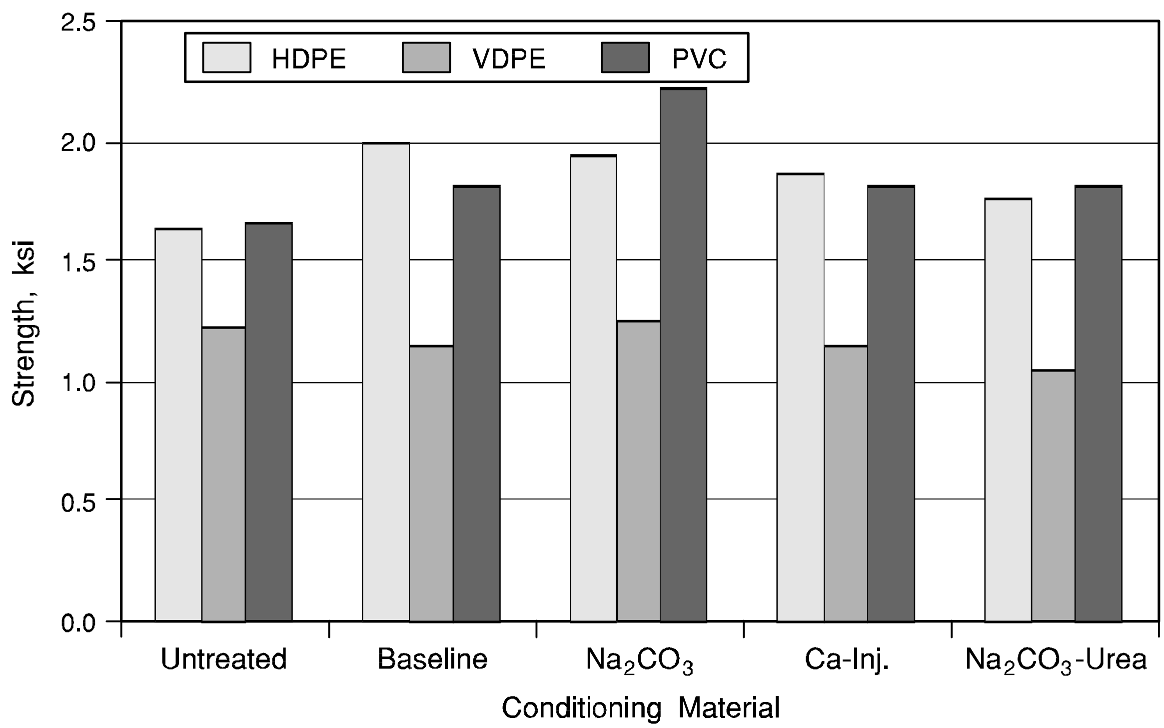

Figure 7. Stress at 100% Elongation with Grain after 120 days of Conditioning

Volatiles and Extractables Tests

Volatiles

An increase in volatile losses is an indication of water absorption into the liner materials. The percentage volatiles present in the liner samples after exposure to the sludge materials are presented in Table 2. The volatile loses associated with the PVC material are similar after a 120 day period of conditioning in the baseline, Na_2CO_3, and the Na_2CO_3-Urea sludge materials. The volatile loses associated with the Ca injection waste treatment appear to be higher. However, volatile loses for all the treated materials were rather small with the largest loss found to be about 0.25%.

Table 2. Weight Losses Due to Volatiles andExtractables

Membrane/Treatment	Volatiles, % Wt. Loss	Extractables, % Wt. Loss
PVC-Baseline	0.19	30.76
PVC-Na_2CO_3 Inj.	0.20	30.19
PVC-Na_2CO_3 Inj.	0.20	30.33
PVC-Na_2CO_3-Urea Inj.	0.20	30.21
PVC-Ca Inj.	0.26	30.36
HDPE-Baseline	0.14	0.34
HDPE-Na_2CO_3 Inj.	0.08	0.53
HDPE-Na_2CO_3 Inj.	0.10	0.61
HDPE-Na_2CO_3-Urea Inj.	0.08	0.53
HDPE-Ca Inj.	-0.01	0.60
VDPE-Baseline	0.07	1.31
VDPE-Na_2CO_3 Inj.	0.07	1.23
VDPE-Na_2CO_3-Urea Inj.	0.16	1.12
VDPE-Na_2CO_3-Urea Inj.	0.13	1.06
VDPE-Ca Inj.	0.05	1.38

For the HDPE liner materials, the influence of the sludge generated under baseline conditions had a weight loss of 0.14% which was higher than the CCT sludge treatments. The treatments using Na_2CO_3 and Na_2CO_3-Urea sludges resulted in volatile loses of about 0.1% and 0.08%, respectively, and the Ca injection material gained 0.01% weight after 120 days of treatment. This data demonstrate that the water absorption into the HDPE liner materials is very limited.

The VDPE liner material also tended not to absorb much water. The liner treated with Ca-injection, Na_2CO_3, and baseline materials lost about equal amounts of weight at about 0.06%. The liner treated with Na_2CO_3 had a volatile loss of about 0.16% which is significantly higher than the loses resulting from treatment with the other wastes used.

Extractables

A decrease in weight loss due to liner extractables is an indication that liner components are leached from the liner due to exposure to a waste. The weight loss associated with liner materials is presented in Table 2. The PVC liner material reacted similarly for all treatments with about a 30% weight loss due to extractables. The HDPE and VDPE liner materials reacted much differently as the extractable loses for the HDPE were about 0.5% for each treatment and the loses for the VDPE materials varied from about 1.06% for the Na_2CO_3-Urea material to about 1.38% for the Ca injection fly ash. These data suggest that PVC liner material might decompose relatively rapid in the waste environments evaluated.

CONCLUSIONS

The impact of CCT materials on the characteristics of the clay liner materials studied in this project was minimal. The HC measurements of the waste/clay liner systems were similar to the water/clay liner systems. HC decreased for clay liners compacted at moisture levels slightly higher than optimum (standard Procter) and increased for liners compacted at moisture levels lower than optimum (standard Procter). Although some swelling was evident in the sodium materials, the sludge materials did not have a negative impact on the integrity of the liners over 120-day tests. Wet/dry cycles tended to result in lower HC, while freeze/thaw cycles substantially increased HC for the liners tested.

Sustained increment changes in the measured physical properties of the materials over time were not observed. Some abrupt changes in strength were found at several times during the testing period. However, these aberrations seemed more indicative of isolated changes in the conditioning methods or test procedures and could be related to flaws or changes in the materials related to manufacturing conditions. After 120 days of conditioning, none of the measured physical properties varied significantly form those for the untreated liner materials. This was true for all samples regardless of the conditioning solution used. It is apparent from the results of this study, that the HDPE liner material would be expected to perform better than the VDPE and PVC liner materials due to its higher strength characteristics.

The volatiles and extractables tests for the HDPE and VDPE materials indicated that the waste materials had little influence on their overall structure. However, the extractables data suggest that PVC liner material might decompose in the waste environments evaluated. The PVC liner material reacted similarly for all treatments with about a 30% weight loss.

ACKNOWLEDGMENTS

This paper was prepared with the support of the U.S. Department of Energy, Morgantown Energy Technology Center, Cooperative Agreement No. DE-FC21-93MC30127 and the Public Service Company of Colorado. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of the DOE or the Public Service Company of Colorado.

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