Organic Fluid Effects on the Permeability Of Soil-Bentonite Slurry Walls

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ABSTRACT

The past and present disposal of hazardous and toxic wastes in the subsurface environment has resulted in the extensive application of soil-bentonite slurry trench cutoff wall technology for the containment and control of these wastes. The reliable performance of these waste containment systems mandates an understanding of the interaction between the wastes and the permeability of the soil-bentonite backfill used in slurry trench cutoff walls. This paper presents the results of a study funded by the USEPA investigating the effect of organic fluids on the permeability of soil-bentonite backfill.

A laboratory investigation was conducted to obtain results of long-term permeability effects on soil-bentonite as a barrier, using as examples of hazardous wastes, four organic fluids, acetone, carbontetrachloride and acetic acid, and aniline. Cracking pattern tests were conducted to permit a rapid assessment of effects of organic fluid upon the permeability of the soil-bentonite backfill. Effect of organic fluid concentration was also studied.

Whereas results indicated that permeation with concentrated organic fluids increased permeability by at least one order of magnitude, dilute solutions had a significantly less detrimental effect upon the permeability of the soil-bentonite backfill. Cracking pattern tests correlated with the long-term permeability tests, suggesting the usefulness of this test as a rapid assessment tool in evaluating the effect of contaminants upon the permeability of soil-bentonite backfill.

INTRODUCTION

The past and present disposal of hazardous and toxic wastes in the subsurface environment has resulted in the extensive application of soil-bentonite slurry trench cutoff wall technology for the containment and control of chemical migration.[1] The reliable performance of these waste containment systems requires an understanding of the interaction between the wastes and the permeability of the soil-bentonite backfill used in slurry trench cutoff walls. Although much has been published regarding investigations of clay liner-waste interactions, little information has been available regarding soil-bentonite-waste interactions. In this paper, the authors present the results of a study investigating the effect of selected organic fluids on the permeability of soil-bentonite backfill.

A laboratory investigation was conducted utilizing triaxial cell permeameters specifically designed and constructed to conduct long-term permeability tests with a wide range of chemical permeants. Described in this paper are the results of long-term permeability testing with three organic fluids (carbontetrachloride, acetic acid, and aniline). The effect of organic fluid concentration was also studied.

The studies demonstrated that permeation with concentrated organic fluids caused an increase in permeability of at least one order of magnitude. Dilute (solubilized) solutions of the same fluid had a significantly less detrimental effect upon the permeability of the soil-bentonite backfill. The results of standard cracking pattern testing correlated with the long-term permeability test suggesting the usefulness of this test as a rapid assessment tool in evaluating the effect of contaminants upon the permeability of soil-bentonite backfill.

PREVIOUS STUDIES

Much has been written regarding the design of soil-bentonite slurry trench cutoff walls for conventional groundwater controls.[2,3,4] The widespread application of slurry trench cutoff wall technology for pollution migration control requires an understanding of the influence of contaminants and leachates upon the permeability of soil-bentonite. However, little information regarding soil-bentonite waste compatibility is presently available. For example, a recent handbook[5] providing guidance regarding the use of slurry walls for the control of subsurface pollutants discusses the effect of groundwater contaminants in the permeability of cutoff walls. Close review of this document, however, reveals that the test results discussed relate to bentonite-waste or clay liner-waste interactions. At the time of the handbook's preparation, published information on soil-bentonite backfill-waste interactions, as presented herein, was not available.

THEORETICAL BACKGROUND

It has been shown that clay particles, made up of tetrahedral and octahedral sheets, often carry a net negative charge as a result of isomorphous substitutions of certain cations within the sheet structure. When the clay is in the presence of water, these compensating cations have a tendency to diffuse away from the layer surface. The understanding of the ion distribution relative to the layer surface in the clay mineral is based upon work from colloidal chemistry. Although there are several models of how ion distribution in the diffuse ion layer can be analyzed, the most common model used in geotechnical engineering is the Gouy-Chapman model.

From the equation describing the diffuse ion layer thickness, Lambe[6] has presented a list of variables in the soil-water system which affect the diffuse ion layer and the colloidal stability. These variables include electrolyte concentration, ion valance, dielectric constant, temperature, size of the hydrated ion, pH and anion adsorption. It has been shown that a reduction in the diffuse ion layer thickness reduces the interparticle repulsion forces and thus increases the tendency toward a more flocculated or aggregated soil structure. The effect of changes in the value of any of the parameters in the Gouy-Chapman model on the diffuse layer thickness (and consequently the accompanying soil structure tendency) is shown in Table 1.[7]

In a previous study, the findings of various researchers were reviewed on a case-by-case basis and the results were examined for compatibility with those results predicted by the Gouy-Chapman model. In most cases, the clay behavior due to changes in pore fluid composition was consistent with the changes predicted by the Gouy-Chapman model.[7] The conclusion drawn was that the Gouy-Chapman model is useful as a predictive tool to qualitatively study the influence of pore fluid on clay behavior. It must be pointed out that additional studies of the effects of hazardous wastes on clays from the physiochemical standpoint are required in virtually all areas. It is cautioned, however, that other phenomena (such as dissolution of the soil structure) may govern the clay response under certain chemistry conditions.

Table 1
Effect of Pore Fluid Parameters on Double Layer Thickness and Soil Structure Tendency

Pore Fluid Parameter	Change in Pore Fluid Parameter	Change in Double Layer Thickness	Change in Soil Structure Tendency
Electrolyte Concentration	Increase Decrease	Decrease Increase	Flocculated Dispersed
Ion Valence	Increase Decrease	Decrease Increase	Flocculated Dispersed
Dielectric Constant	Increase Decrease	Increase Decrease	Dispersed Flocculated
Temperature	Increase Decrease	Increase Decrease	Dispersed Flocculated
Size of Hydrated Ion	Increase Decrease	Increase Decrease	Dispersed Flocculated
pH	Increase Decrease	Increase Decrease	Dispersed Flocculated
Anion Adsorption	Increase Decrease	Increase Decrease	Dispersed Flocculated

EQUIPMENT AND PROCEDURES

As indicated by reviews of previous studies conducted by others, determination of the influence of organic fluids upon the permeability of soil-bentonite backfill requires test equipment and procedures beyond those which are presently standard. As a result of this need, the interaction between the organic fluids and the soil-bentonite response was considered in the equipment development. It was also necessary to consider compatibility between the test equipment and permeants. Further, a method of modeling the state of stress of the soil-bentonite backfill relative to field conditions was incorporated into the test technique to arrive at a system able to determine the effects of organic fluids upon the permeability of soil-bentonite backfill.

To accomplish these investigations, a triaxial cell (flexible wall) permeameter system was developed. The triaxial cell permeameter testing system developed by these studies has three major components: (1) the control panel, (2) the permeameter board and (3) the triaxial cell. The triaxial cell for studies such as this must be compatible with the wide range of permeants to be functional. The logical choice for such material compatibility is the use of Teflon® for the ultimate in compatibility between hazard and toxic permeants and the equipment. However, due to the flexibility of Teflon, it is not usually possible to maintain the high pressures required to provide backpressure saturation and permit a wide range of total and effective stresses. The structural rigidity of aluminum or steel is therefore necessary to provide rigidity for the triaxial equipment. This dichotomy of goals was satisfied through the specially designed and fabricated triaxial cells shown schematically in Figure 1. These cells not only optimize the use of stainless steel or aluminum to provide adequate rigidity, but also provide ultimate compatibility through the use of Teflon® at all points in which the permeameter is in contact with the permeant.

The permeability board was designed, constructed and tested to satisfy the objectives and constraints required to monitor the permeation of soil-bentonite backfill with organic fluids. The permeability board (Fig. 2) was designed to allow permeants to be changed and inflow-outflow riser pipes to be filled/emptied without changing the state of stress on the sample. Finally, a control panel was developed to control the backpressure gradient and confining stress required for the testing. Additional details regarding equipment and procedur for this permeability test are described elsewhere.[4]

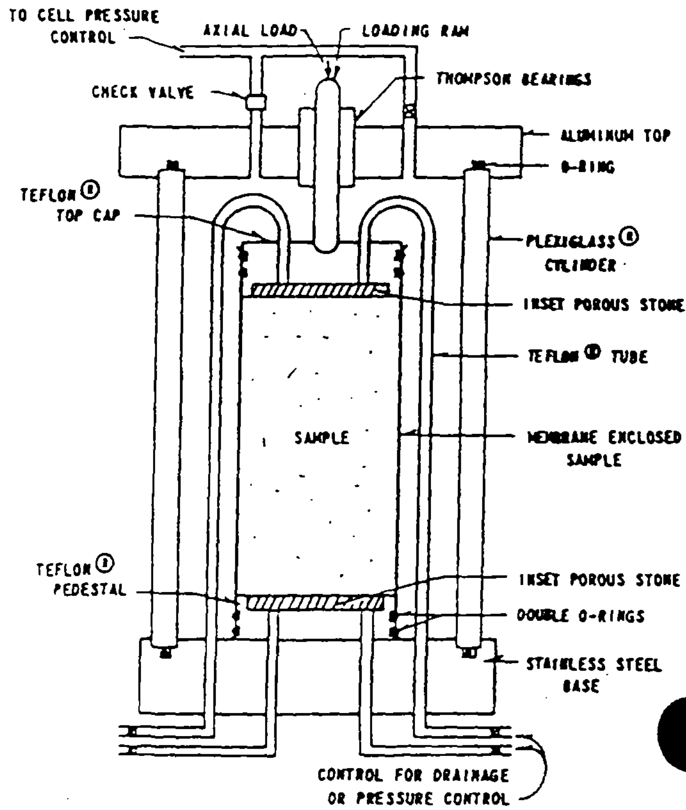

Figure 1
Lehigh Triaxial Cell Schematic

Procedures for sample preparation primarily involve those activities required to prepare low permeability samples of soil-bentonite which would represent a typical mix design for a slurry trench cutoff wall. These procedures were developed to be consistent with procedures which would be used during actual construction of a slurry trench cutoff wall. The base granular material utilized with the bentonite was a New Jersey Bar Sand obtained in bulk and used throughout the testing program.

After selecting the appropriate sample size, stabilized soil-bentonite slurry was added. To arrive at a sufficient bentonite content to result in a low permeability mix (i.e., less than 1×10^{-7} cm/sec), additional dry powder bentonite was added. Soil-bentonite slurry was prepared by mixing tap water and powdered bentonite to arrive at approximately 6% slurry by weight. The bentonite was allowed to fully hydrate so that the slurry properties were stabilized. Stabilization of slurry properties was determined by a stabilized Marsh viscosity of 40 sec.[5] The resultant laboratory sample was therefore representative of that which would be prepared for a soil-bentonite cutoff wall in a similar sandy material (such as the source area of the sands of the New Jersey coastal plain physiographic province).

Because the resulting samples are considered remolded samples, it was necessary to mold them into the desired dimensions for permeability testing. In this case, a sample diameter of 7.1 cm by a sample length of 14.2 cm was used. The 7.1 cm diameter is a standard triaxial cell diameter for which porous stones and triaxial cell membranes can be obtained. Membranes were placed within a mold and a vacuum was applied to pull the membrane tightly back against the

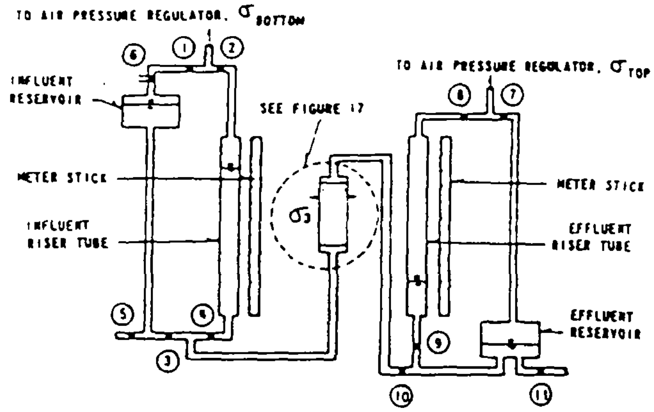

Figure 2
Lehigh Control Panel Schematic

Legend:

Valve	Valve Name/Function—Material
1	Influent Reservoir Pressure Control Valve—Brass
2.	Influent Riser Tube Pressure Control Valve—Brass
3	Influent Riser Tube Fill Valve—Teflon®
4	Influent Riser Tube By-Pass Valve—Teflon®
5	Influent Reservoir Drain Valve—Teflon®
6	Influent Reservoir Pressure Relief Valve (Three-Way)—Brass
7	Effluent Reservoir Pressure Control Valve—Brass
8	Effluent Riser Tube Pressure Control Valve—Brass
9	Effluent Riser Tube Drain Valve—Teflon®
10	Effluent Riser Tube By-Pass Valve—Teflon®
11	Effluent Reservoir Drain Valve—Teflon®

mold. The prepared sample was then placed within a sample mold while the mold was setting on the bottom pedestal. Once a sample was placed in the mold, the top platen was placed over the sample. Filter paper was placed on the porous stones to minimize plugging and loss of fines during testing. The membrane was secured in place by two O-rings. The double O-ring arrangement to seal the membrane around the pedestal was further aided by the O ring grooves cut into the triaxial cell platens.

During sample setup, the material was weighed before and after filling the material into the mold, allowing the total unit weight of the material to be determined. Moisture contents were measured to permit a calculation of dry density of materials placed in the mold. After completing sample setup, a vacuum was applied through the permeability board via the control panel. This vacuum was applied for a period of 24 to 72 hr to initially consolidate the sample. Consolidation was necessary because the samples have a very low shear strength, i.e., a 10 to 15 cm slump. After initial vacuum consolidation, the split-ring mold was removed and the samples had enough inherent rigidity (strength) to stand by themselves while the remainder of the triaxial cells were assembled. With the samples still under vacuum, the remaining portion of the triaxial cell was assembled and filled with water. Upon complete assembly of the cell, the cell pressure was then applied. For these studies, a constant average effective stress of 207 kPa (30 psi) was utilized throughout the investigation to minimize the number of parameters affecting the results of the study. This effective stress is typical of that expected in a slurry trench cutoff wall at a depth between 11 m and 14 m. After application of the cell pressure, backpressure was applied to ensure saturation. This was done by incrementally increasing the cell and platen pressures to maintain a constant effective stress of 207 kPa. The backpressure utilized for these studies was 345 kPa.

Sample permeation was begun by employing deaired tap water permeant used as the original pore fluid for sample preparation. This step was done to establish the steady state permeation rate prior to the introduction of the pore fluid under investigation.

Permeation was begun by elevating the pressure at the bottom platen via the control panel to induce the gradient that caused upward flow through the sample. Upward flow aids in the flushing of any trapped air, although this is unlikely since the backpressure has been utilized. The permeability can therefore be calculated using Darcy's Law based upon head differences, sample length, observed flow rate and the area of the sample. Recognizing the unsteady-state nature of the initial seepage data, it was nonetheless decided to calculate permeability using the recorded data. Therefore, the coefficient of permeability was calculated from the start of the test. Typical gradients utilized with these studies were approximately 100. Permeation of the water was allowed to continue until steady state equilibrium was reached. The pore fluid under investigation was then added.

TEST RESULTS

Utilizing the equipment and procedures just described, the following section of the paper presents the results of long-term pore fluid exchange testing utilizing organic fluids. These organic fluids were aniline, representative of an organic base; acetic acid, representative of organic acids; and carbontetrachloride, representative of a neutral nonpolar organic fluid.

Permeation With Aniline

Three permeability tests were conducted to evaluate the effect of aniline on the soil-bentonite backfill. Aniline concentrations included pure aniline, aniline at a concentration equal to the solubility limit of 30,000 mg/l and aniline at a concentration of 15,000 mg/l. Shown on Figure 3 are the results of a long-term permeability test utilizing aniline in pure form. The soil sample is described as a New Jersey Bar Sand and bentonite at 7% by weight. Note that the initial permeation with water yields a permeability of approximately 2×10^{-8} cm/sec. [redacted]

Since aniline is an organic base with low dielectric constant (6.9 at 20°C), it is predicted by the Gouy-Chapman model that the diffuse ion layer would be significantly reduced in response to permeation with a low dielectric material. This reduction in the diffuse ion layer and, hence, a shrinking (or reduction in interparticle basal plane spacing) would cause an increase in soil permeability. Conceptually, the clay materials are in a sand matrix and, in fully hydrated state, are effective in plugging the voids to the point that the Darcy permeability is relatively low. With a reduction in the diffuse ion layer and resultant shrinking of the particles, the clayey fraction is less effective in reducing soil permeability. Thus, a change in pore fluid utilizing low dielectric materials yields some predictable results consistent with the diffuse ion layer models.

Of equal importance to the permeability changes in response to pure organic fluids is the effect of organic fluids at lower concentrations. Hence, two additional tests were conducted using

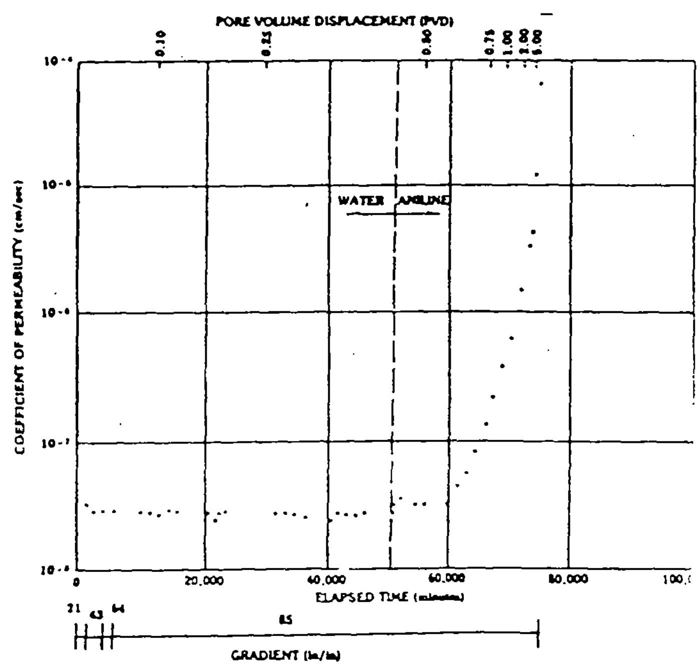

Figure 3
Permeability Test Results—Aniline (Concentrated)

solubilized aniline as a permeant. Figures 4 and 5 present the results of permeability testing utilizing aniline at 30,000 and 15,000 mg/l, respectively. As shown in these two figures, there is virtually no change in permeability after permeation of two or more pore volume displacements for test durations greater than 160,000 min (111 days).

Consideration of the change in pore fluid dielectric for these aqueous solutions using ideal fluid concepts indicates that there is a negligible difference in dielectric constant between the original pore water and the pore water at 30,000 or 15,000 mg/l of aniline. Therefore, the diffuse ion layer thickness model would indicate little change in the coefficient expected with permeation of aniline in solubilized form. This is consistent with the results shown. With these data, it is concluded that, although concentrated organic fluids will result in significant increases in laboratory permeability, permeability increases of aqueous solutions or organic fluids are considerably less.

Permeation With Carbontetrachloride

In a manner similar to the study described above, samples of soil-bentonite backfill were prepared using seven percent bentonite in a matrix of New Jersey Bar Sand. These samples were then permeated with a pure carbontetrachloride permeant. As shown in Figure 6, a rapid increase in permeability was observed. The permeability arose from an initial permeability of approximately 3×10^{-8} to approximately 2×10^{-6}. This is essentially an increase in permeability of two orders of magnitude. When permeated with carbontetrachloride in aqueous solutions at the solubility limit of 720 mg/l, essentially no increase in permeability was observed in Figure 7. As previously discussed, the dielectric of the aqueous solution would b essentially the same as the dielectric of the original pore fluid. N change in the diffuse ion layer or thickness or swelling would be e pected for these samples.

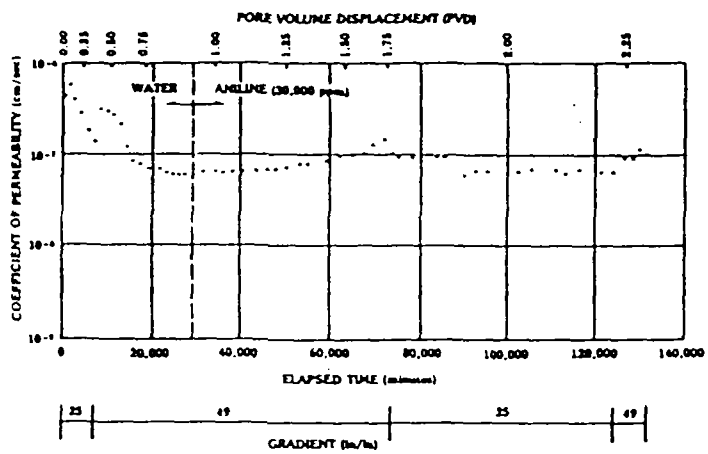

Figure 4
Permeability Test Results—Aniline (30,000 mg/l)

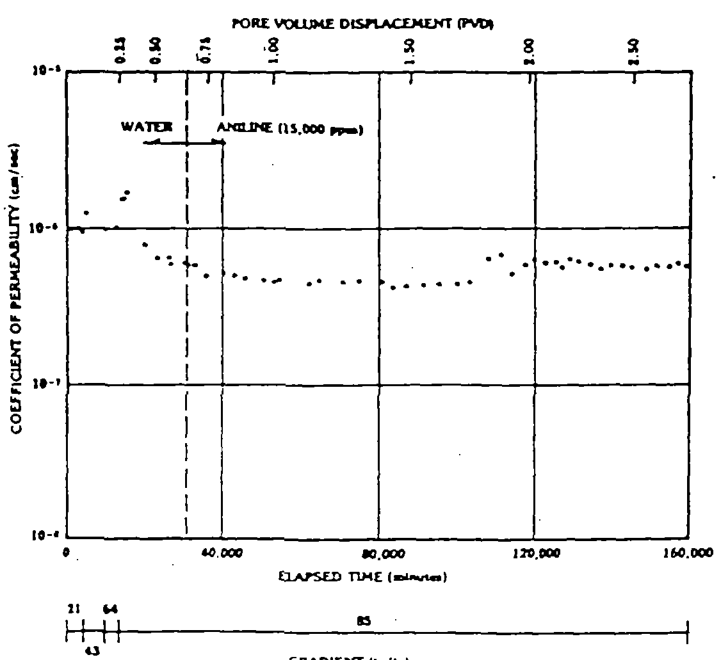

Figure 5
Permeability Test Results—Aniline (15,000 mg/l)

Permeability With Acetic Acid

To further investigate the effects of organic fluids upon the permeability of soil-bentonite backfill, a permeation test was conducted utilizing an organic acid. For these tests, an acetic acid was selected and prepared at a pH of one by dilution with tap water. Figure 8 presents the results of the long-term permeability testing utilizing acetic acid. After establishment of equilibrium with water, there was an initial rise in permeability upon permeation with acetic acid. Upon continued permeation of acetic acid, there was a steady increase in permeability.

The initial rise in permeability can be explained by an examination of diffuse ion layer thickness changes. The acetic acid, having a low pH and a low dielectric constant, would be expected to reduce the diffuse ion layer thickness and cause a shrinking of the clay materials. This would result in an increase in permeability. Long-term permeation with this material, because of its low pH, resulted in dissolutioning of the material in the soil structure. Continued monitoring indicated that the pH did not decrease to the original value of one. It is evident that materials were being dissolved and causing continued permeability increases to occur.

DISCUSSION OF RESULTS

Presented in the previous sections of this paper were descriptions of the test equipment and protocols developed to determine the influence of hazardous and toxic fluids upon the permeability of soil-bentonite backfills. The results of permeability testing utilizin an organic acid, a neutral nonpolar organic fluid and an organic bas

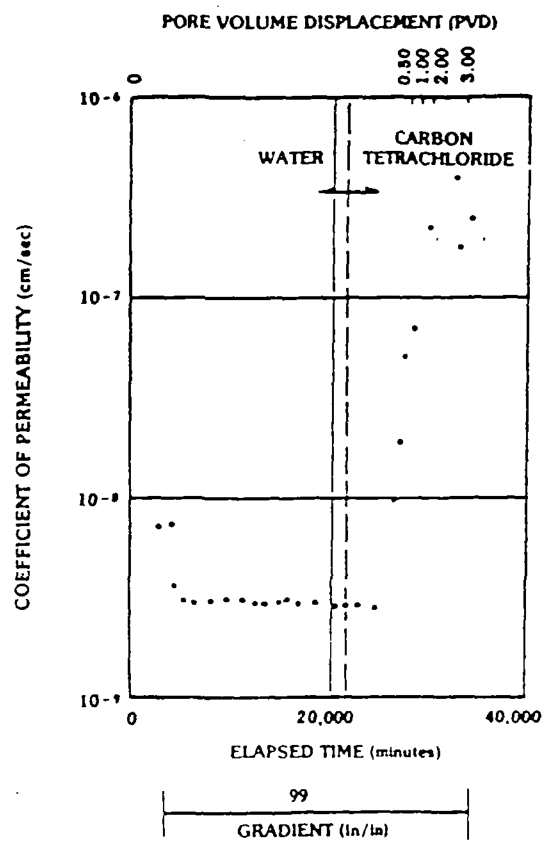

Figure 6
Permeability Test Results—Carbontetrachloride (Concentrated)

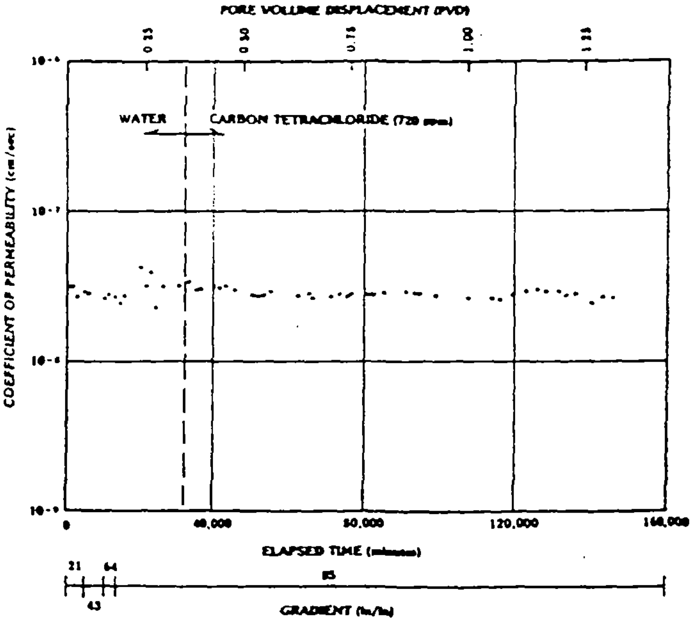

Figure 7
Permeability Test Results—Carbontetrachloride (720 mg/l)

led to several observations. It was observed that, in response to permeation with concentrated organic fluids, significant permeability increases occurred in the range of two to four orders of magnitude. It was further observed that when samples were permeated with aqueous solutions of these same organic fluids, no significant increase in permeability occurred. Permeation with acetic acid at a pH of one resulted in an initial permeability increase. Long-term permeation with the acetic acid permeant resulted in a further increase in the permeability.

The results of these permeability tests can be explained in light of the diffuse ion layer thickness model. For concentrated organic fluids, permeability increases would be finite. Given a base soil matrix, particularly one which has a high percentage of natural fines, the permeability increases would likely, as a upper bound, only increase to that permeability which would be measured in the base material prior to bentonite addition. Hence, the reduction in the size of the hydrated bontonite would result in a coefficient of permeability similar to or less than that material prior to the addition of the bentonite. In the cases observed herein, that upper limit of permeability degradation was not observed.

The results of this study led to several practical design applications of soil-bentonite backfill for slurry trench cutoff walls for pollution-migration control. First, since the maximum permeability would be expected to approach the permeability of the base soil, the selection of the gradation of the base soils is very important. A well-graded material consisting of coarse to fine sand and gravel with silts and low activity clays would result in a backfill for slurry trench cutoff walls for pollution migration control which would exhibit the least degradation in permeability in response to concentrated organic fluids. In this way, after permeation with concentrated or solubilized organic fluids, the change in permeability in response to this permeation would be minimized.

In the application of slurry trench cutoff walls for pollution-migration control, unless the wall is subjected to concentrated organic fluids, only limited degradation would be expected to occur based upon the test results reported herein. Hence, unless nonaqueous phase material is present, significant degradations in the slurry trench cutoff wall backfill would not be expected. Even under nonaqueous phase liquid conditions, the attacks on the wall would be localized and permeability increases would be expected to occur only to the limit of the permeability of the base soil prior to bentonite addition.

CONCLUSIONS

Soil-bentonite backfills were prepared and permeated with organic fluids at various concentrations. For concentrated carbontetrachloride and aniline, permeability increases of between two and four orders of magnitude were observed. However, when the same materials were used as permeants in aqueous form or concentrations equal to or less than their solubility limits, no appreciable increase in permeability was observed. The implication for slurry trench cutoff walls or pollution-migration control is that significant increases in permeability would not be expected due to permeation of solubilized organic fluids. Concentrated organic fluids would be expected to cause a permeability increase, limited by the permeability of the base soil.

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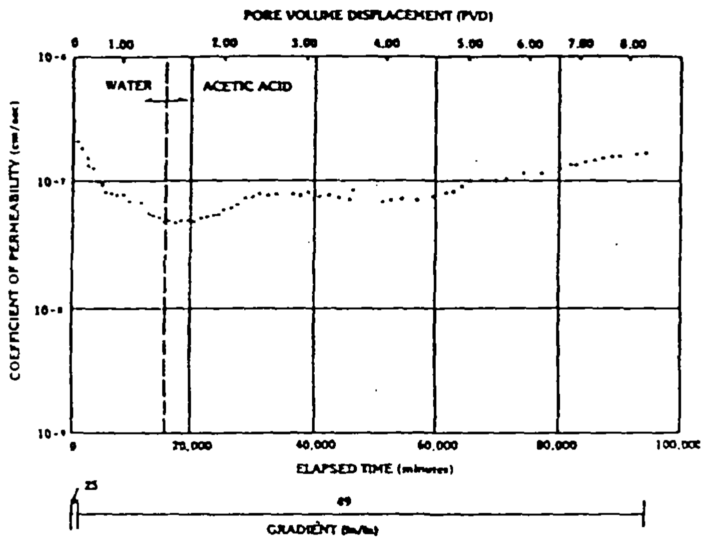

Figure 8
Permeability Test Results—Acetic Acid (pH 1 0)

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