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Transport of organic contaminants and geotechnical properties of fine-grained soils

Transport de contaminants organiques et propriétés géotechniques de sols fins

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SYNOPSIS An evaluation of the transport of acetone and phenol in hydraulic conductivity tests with compacted kaolinite indicated longitudinal dispersion coefficients of the order of 10^{-6} cm²/sec. It was observed that changes in hydraulic conductivity of compacted kaolinite with organic fluids are strongly affected by the effective stresses. Such changes could qualitatively be estimated from the change in index properties of the soils with a specific contaminant. Index Properties of Na- and Ca-montmorillonite and Georgia kaolinite with various organic contaminants showed that these active clays are highly affected by variations in the dielectric constant of the pore fluid while the pH of the organic contaminant was observed to influence the index properties of Georgia kaolinite.

INTRODUCTION

Among various different methods of waste containment, the most economical is placement in shallow waste disposal facilities where compacted fine-grained soil liners are used to retard the transport of the contaminants. Apart from the inorganic constituents of wastes, a majority consists of organic material and fluids. These contaminants together with the infiltrating water generate the leachates which are then transported through the liner under field gradients.

This study presents the effects of the transport of organic contaminants on geotechnical properties of fine-grained soils as evidenced from hydraulic conductivity tests and index properties of fine-grained soils with organic fluids. The implication of the observed behavior on hazardous waste disposal and contaminant transport are also discussed.

CONTAMINANT TRANSPORT

Expressions representing the movement of chemical species and a fluid in a porous medium may be obtained by the principles of the conservation of mass (Gillham and Cherry, 1982). If the velocity of flow is constant and the diffusion in the solid phase is orders of magnitude less than the one in the bulk solution and the flow is incompressible, isotropic and one-dimensional, and further if the adsorption of chemicals on the clay surfaces dominate the reactions in the medium, conservation of mass requires,

$$R \frac{\partial C}{\partial t} = D_L \frac{\partial^2 C}{\partial x^2} - v_x \frac{\partial C}{\partial x} \quad (1)$$

where R is the retardation coefficient which denotes the relative velocity of the reaction

constituents, v_x , with respect to the bulk flow, v_x , D_L = longitudinal dispersion coefficient, and C = concentration of chemicals. Data from laboratory experiments identify the principal parameters affecting the longitudinal dispersion as,

$$\frac{D_L}{D_0} = \alpha + \beta P_e \quad (2a)$$

$$P_e = \frac{v_x d}{D_0} \quad (2b)$$

where D_0 = diffusion in the bulk solution, d = mean pore diameter, α and β are constants. Solution of equation 1 for common boundary conditions in laboratory hydraulic conductivity tests with a contaminant are presented by Hashimoto, et al. (1964).

Assuming that the velocity of flow in fine-grained soils under field gradients range between 10^{-5} to 10^{-8} cm/sec, the mean pore diameter to be 10^{-2} to 10^{-4} cm, and the diffusion coefficients in the bulk solution to be 10^{-5} to 10^{-6} cm²/sec (Freeze and Cherry, 1979), Peclet numbers for insitu conditions are far less than 1.0. Experimental data suggest that for this range of Peclet number, D_L/D_0 ratio ranges between 0.6 to 1.0 (Perkins and Johnston, 1963) implying that longitudinal dispersion is mainly due to the diffusion of the chemical in bulk solution.

EXPERIMENTAL INVESTIGATION

The effect of the transport of organic contam-

inants on hydraulic conductivity of compacted soils is studied in flexible wall permeameters. The permeameters consisted of a set of triaxial cells where provisions were taken to maintain continuous backpressure (Acar, et al., 1984). The constant head is maintained by marriotte bottles and the gradient is continuously monitored by pressure transducers. All couplings and tubings were made of teflon to avoid adsorption and corrosion. Georgia kaolinite and a Ca-montmorillonite are chosen for permeation studies. Samples are first saturated with 0.01 N CaSO_4 solution and permeated with organic fluids. Since index properties of fine-grained soils with a specific molding fluid would give a qualitative indication of possible changes to be expected in their geotechnical properties, a separate study was initiated to investigate the effect of various organic contaminants on the index properties of the clay minerals used in the permeation study. A Na-montmorillonite was also added to this list. Tables I and II present the characteristics of the organic fluids and the clay minerals used in this study.

ANALYSIS OF RESULTS

The analytical or experimental results of equation 1 are often presented as a plot of the change in concentration of the effluent with respect to the input concentration versus the number of pore volumes permeated. Figure 1 presents such a plot for acetone and phenol permeated through kaolinite compacted at the wet of optimum water content. Theore-

tical solution of equation 2 for constant flux boundary conditions is also depicted. The experimental results indicate that the longitudinal dispersion coefficient for acetone and phenol in compacted kaolinite would be in the order of $10^{-6} \text{ cm}^2/\text{sec}$. Batch adsorption tests with acetone and phenol did not indicate any significant adsorption of these chemicals on kaolinite implying retardation coefficients of 1.0.

As observed from the theoretical curves in Figure 1, as the rate of flow increases with respect to the longitudinal dispersion coefficient, the transport of the contaminant is mainly controlled by the rate of flow of the bulk solution. An increase in the rate of

TABLE II
Characteristics of Clay Minerals

Characteristic	K	Ca-M	Na-M
Composition (%)			
Kaolinite (K)	96	-	-
Illite	4	1	-
Ca-Mont (Ca-M)	-	99	-
Na-Mont (Na-M)	-	-	100
Index Properties			
Liquid Limit (%)	64	88	425
Plastic Limit (%)	34	54	58
Activity	0.32	2.8	4.5

TABLE I
Characteristics of Organic Fluids

Compound	pH	ϵ	HC	S
Water	7.0	80.4	-	-
E. Glycol	6.4	38.7	-	-
Nitrobenzene	3.9	35.7	H,T,S,P	1.9
Ethanol		13.1	-	∞
Acetone	6.8	20.7	T	∞
Phenol	3.5	13.1	H,T,S,P	86.3
Aniline	9.9	6.9	T,S	34.0
Xylene	5.6	2.5	T,S	0.2
T. Chloro-ethylene	5.6	2.3	H,T,S,P	0.02
Benzene	5.7	2.3	H,T,S,P	1.77
CCl_4	4.0	2.2	H,T,S,P	0.77
Heptane	5.4	1.9	-	0.03

ϵ - Dielectric constant (20°C)

HC - Hazard Classification (USEPA, 1977)

H - acute hazardous P - priority compound

T - toxic

S - section 311 compound

S - Solubility (gm/l) (25°C)

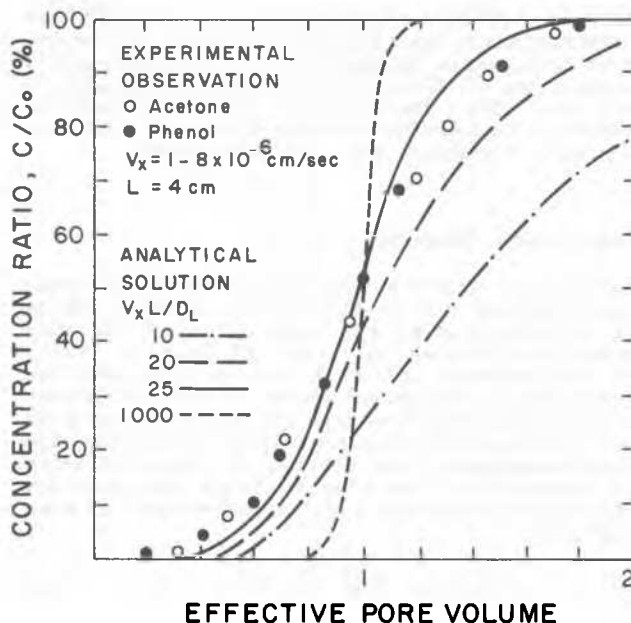


Fig. 1. Breakthrough of acetone and phenol in compacted kaolinite

flow can be initiated either by increases in the hydraulic gradient or the hydraulic conductivity. Although the field gradients vary within 1-10, it is not uncommon to have 2-3 orders of magnitude change in hydraulic conductivity of fine-grained soils due to fabric changes initiated by the movement of contaminants (Michaels and Lin, 1954). Furthermore, any fabric change will also initiate a volume change and in cases where the soil liner is subjected to differential volume changes, tension cracks might develop which would further increase the rate of flow. Consequently, in order to assess the structural integrity of compacted soil liner, it becomes necessary to estimate the possible fabric changes with a specific leachate.

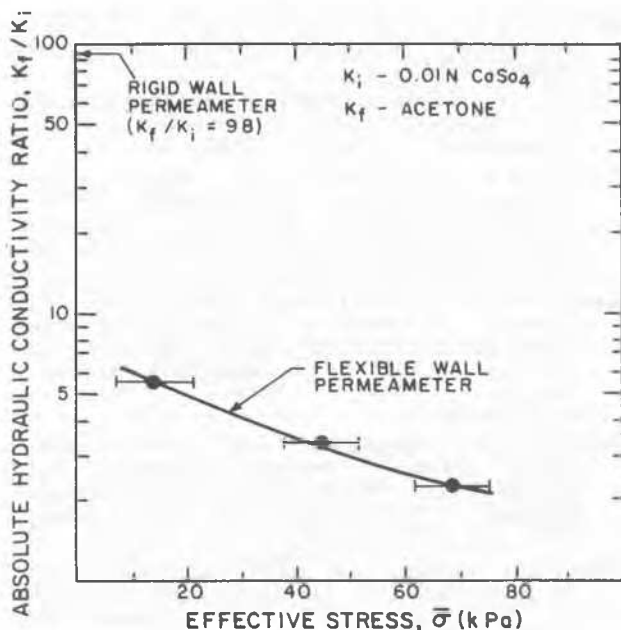


Fig. 2. The effect of effective stresses and testing scheme on hydraulic conductivity of compacted kaolinite to pure acetone

Figure 2 presents the change in absolute hydraulic conductivity of compacted kaolinite with pure acetone after saturation with 0.01 N CaSO_4 solution. It is observed that effective stresses have a major influence in the changes recorded with flexible wall permeameters. Since samples compacted in rigid wall permeameters are also subjected to effective stresses of unknown magnitude, the dramatic increase in hydraulic conductivity with such a testing scheme was attributed to side leakages due to decreases in the volume of the sample with acetone permeation (Acar, et al., 1984).

Considering the variables that affect the forces of interaction in fine-grained soils, an increase in hydraulic conductivity would imply a decrease in the repulsive forces resulting in a flocculated fabric and vice versa. The liquid limit of a fine-grained soil with a specific leachate could be used as

a qualitative indication of the changes in the thickness of the diffuse double layer or the repulsive forces. The change in the liquid limit of the two smectite minerals with the organic fluids given in Table 1 are presented in Figure 3. In the case of montmorillonites, it is observed that the dielectric constant has a major influence on the index properties. These clays became non-plastic for fluids with dielectric constants of less than 30. Figure 4 indicates that kaolinite does not show the expected trend with dielectric constant. It is observed that different organic fluids induce different responses in index properties of kaolinite. This mineral was non-plastic to acetone and to contaminants with dielectric constants of less than three. Nitrobenzene, phenol and carbontetrachloride with low pH values resulted in high liquid limit values. These variable responses could mainly be attributed to the positive charges at the broken edges of this mineral. In fact, a low pH would tend to dissociate the OH^- groups on the edges of the particles resulting in higher liquid limits (Genevois, 1977). However, it should also be noted that the decrease in index properties of this mineral with organic contaminants, when compared with that of water, is not as drastic as the highly active montmorillonites.

There exists several implications of the observed dramatic decreases in the consistency limits of active clay minerals with the organic contaminants. Presently, soils with high activities are used in order to ascertain the low permeability of the compacted soil liners. Fine-grained soils with high activities are associated with lower water permeabilities (Lambe, 1954). However, the above results indicate that the initial structure of these soils will be more sensitive to post-constructional changes in the pore fluid chemistry. Decreases in the dielectric constant of the pore fluid with the transport of the organic contaminant would depress the thickness of the diffuse double layer resulting in a decrease in the forces of repulsion in the system. As a consequence, there will be a restructuring of the fabric leading to a decrease in volume (Green, et al., 1981), increases in hydraulic conductivity (Michaels and Lin, 1954; Anderson, et al., 1980; Acar, et al., 1984), decrease in compressibility (Sridharan and Rao, 1974), and an increase or decrease in shear strength depending upon the dielectric constant of the medium (Ladd and Martin, 1967; Moore and Mitchell, 1974).

SUMMARY AND CONCLUSIONS

Hydraulic conductivity and index tests presented in this study lead to the following conclusions with regard to the effect of the transport of organic contaminants.

- (i) When acetone and phenol are permeated through kaolinite compacted at the wet of optimum water content, the longitudinal dispersion coefficient is found to be in the order of $10^{-6} \text{ cm}^2/\text{sec}$.

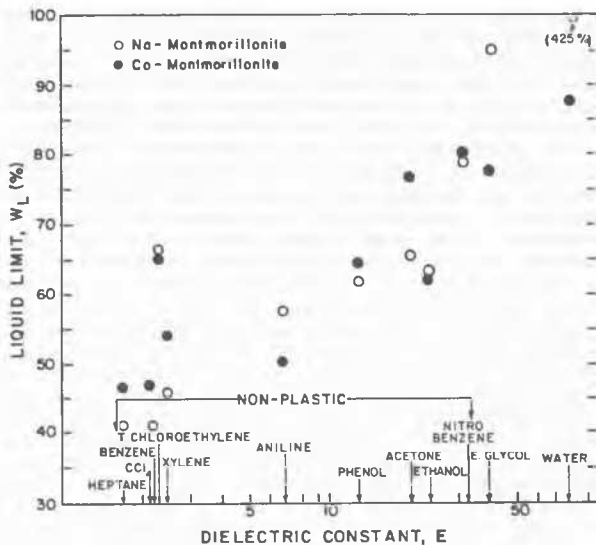


Fig. 3. The effect of dielectric constant on liquid limit of Na- and Ca-montmorillonite

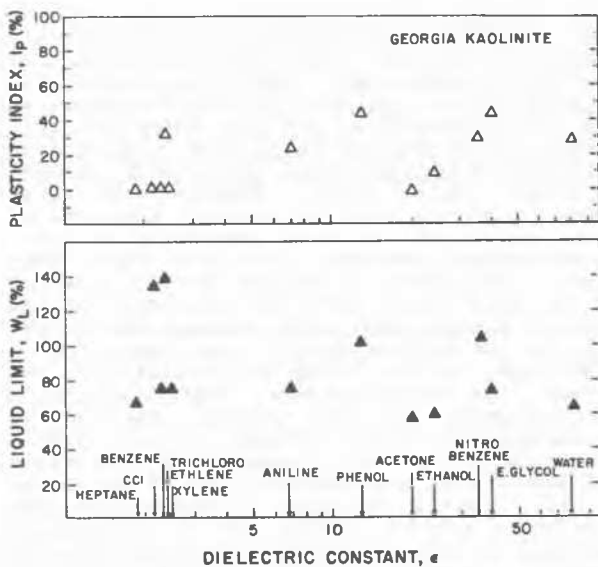


Fig. 4. Index properties of Georgia kaolinite with different organic fluids

not indicate such a trend. The pH of the solution is observed to be dominant on the index properties of kaolinite.

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- (ii) The testing scheme is a major consideration in assessment of the possible changes in hydraulic conductivity of fine-grained soils with an organic fluid. Changes in absolute hydraulic conductivity are observed to be highly affected by the applied effective stresses.
- (iii) Index properties of active montmorillonitic clays are highly affected by the variations in the dielectric constant of the pore fluid while, kaolinite does