

Evaluation of Effect of Chemicals on Hydraulic Properties of Sand – Bentonite Mixtures

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Abstract: The main purpose of this research is evaluation of effect of chemicals on permeability of sand- bentonite mixtures. The coefficients of permeability of sand- bentonite mixtures in water, solutions of sodium and calcium chlorides, sodium hydroxide, acetic acid, methanol and carbon tetrachloride were calculated using parameters obtained in 1- D consolidation test and Terzaghi's theory. At each void ratio permeability of samples in water is the lowest and that for carbon tetrachloride is the highest. For all fluids the permeability index C_k is decreased as the percentage of sand is increased. The largest C_k belongs to the samples tested in water and the smallest C_k belongs to the samples tested in carbon tetrachloride.

Keywords: Bentonite, consolidation, permeability, sand

1. INTRODUCTION

Terzaghi (1925) emphasized the effect of nonuniformity of voids on permeability of clay and general dependence of permeability on void ratio.

The effect of fluids other than water on permeability of clay soils was studied by many researchers decades ago. Also, recently because of environmental problems in the world, this subject again is being addressed in literatures (e.g Bowders and Daniel, 1987; Graham et al. 2001; Jo et al. 2001; Soule and Burns, 2001).

Macey (1942) measured permeability of clay soils in non-polar solutions. He reported that the permeability of clay in benzene was 100000 and 1000000 times larger than that in water.

Grace (1953) showed that dispersion is the main reason for the decrease in permeability in some electrolytes. He pointed out the importance of the reorientation of particles during consolidation test and its effect on the permeability.

Michaels and Lin (1954) showed that permeability of kaolinite decreased significantly with increase in polarity of permeant. They recognized that the most important factor controlling permeability of kaolinite is the degree of dispersion of soil in initial suspension.

Mesri and Olson (1971) tested clay minerals kaolinite, illite and montmorillonite in different permeants. They concluded that mechanical factors such as size, shape and orientation of clay particles were the main reasons for decrease in permeability in water from kaolinite to montmorillonite. The smaller size, more platy shape and more parallel orientation of particles of montmorillonite cause lower permeability for this clay mineral in water as compared with kaolinite and illite. They also showed that the permeability of these clay minerals in non-polar carbon tetrachloride at a constant void ratio was the same. They pointed out that the main reason for this observation was no interaction of non-polar carbon tetrachloride with clay particles and consequently aggregation of clay particles.

In the abovementioned researches, permeant and pore fluids were the same. More recently studies were directed in order to evaluate the effect of chemicals as permeant on the coefficient of permeability of clay liners with water as pore fluid. Uppot and Stephenson (1989) tested permeability of kaolinite and manganese montmorillonite samples against organic fluids acetic acid, anelene, methanol and gezolene as permeant. Tests were performed under pressure in flexible wall permeameter. Permeation of acetic acid and methanol into samples of montmorillonite first caused a decrease and then a two to three times increase in initial permeability, whereas for kaolinite no change in initial permeability was observed. Gasolene and anelene were not able to penetrate into samples of montmorillonite and initial permeability of kaolinite samples were decreased by 400 times.

Brown and Anderson (1983) tested permeability of compacted samples of kaolinite, illite and smectite in a permeameter with rigid wall against acetic acid, acetone, ethyle, methanol, anelene, gasoline and heptane as permeant. They reported increase in permeability of all the samples tested against anelene, gasoline and heptane by 10 to 100 times. Increase in permeability in acetic acid, methanol, acetone and ethyl was 50 to 1000 times. One of the important reason for considerable differences between these results and the results obtained by Uppot and Stephenson could be the performance of the tests under high pressure in the latter. The effective pressure which normally acts on clay liners is relatively low and therefore the results of tests performed by Brown and Anderson are closer to a more actual field condition.

Past and present studies show that the most important factor controlling the permeability of clay soils is aggregation of clay particles which affect the size and shape of the pores.

Bentonite has been suggested as material to be used in clay liners and cut off. In order to reduce crack potential of clay liners use of sand in bentonite has been suggested (Salehi, 2001). Hydraulic conductivity of sand – bentonite mixtures in water has been reported (Sivapullaiah et al, 2000).

In the present study the coefficient of permeability of sand- bentonite mixtures as a function of void ratio and type of permeant are tested and mechanisms controlling the permeability of the mixtures are evaluated.

2. PROCEDURE AND ANALYSIS

Procedure and analysis are explained more completely in Lorestani (2003). In Summary, Laboratory samples of bentonite with different sand content (Sieve No. 80-200) at high water or fluid content near liquid limit were mixed with water and solutions of sodium and calcium chloride, sodium hydroxide, acetic acid, methanol and carbon tetrachloride with physical properties shown in Table 1. These chemicals were selected because they have wide different dielectric constant so when they are mixed with soil they cause different degree of particle aggregation. Then samples were placed into consolidation metal ring (50 mm ID and 20mm Ht.) and were consolidated under pressures in the range of 10 to 1240 kPa until

Table 1 Physical properties of liquids used

Permeants	Density (g/cm ³)	Viscosity (g/s.cm)	Dielectric constant
Distilled water (H ₂ O)	1.	0.98	80.1
Sodium chloride solution (NaCl)	-	-	-
Calcium Chloride solution (CaCl ₂)	-	-	-
Sodium Hydroxide solution (NaOH)	-	-	-
Acetic acid (CH ₃ COOH)	1.05	1.28	6.15
Methanol (CH ₃ OH)	0.42	1.15	32.63
Carbon tetrachloride (CCl ₄)	1.25	1.04	2.24

the end of primary obtained according to Taylor's method. The results of consolidation tests thus obtained were used to calculate the coefficient of permeability at each void ratio. The coefficient of permeability was calculated by fitting the Terzaghi theory of consolidation to settlement – time observation and obtaining the coefficient of consolidation as follows:

$$C_v = 0.2 H^2/t_{50} \quad (1)$$

$$k = \gamma \cdot C_v \cdot m_v \quad (2)$$

in which C_v =coefficient of consolidation, H = maximum drainage distance, m_v =coefficient of volume compressibility, t_{50} =time required for 50% consolidation, γ =unit weight of water or chemical, and k =coefficient of permeability.

It should be noted that this method of determination of the coefficient of permeability has been used by many researchers and comparing with direct measurement lower values in the range of 5 to 20% difference is obtained in water [(e.g. Mesri and Olson (1971); Mesri and Cepeda Diaz (1987) and Mesri et al (1994)].

A limited number of direct measurements of permeability using rigid wall permeameter and falling head method were performed on bentonite samples with methanol and carbon tetrachloride as permeant.

Liquid limit tests using water and all other solutions were performed and the results are shown in Table 2. It is necessary to note that all the samples in organic solutions of acetic acid, methanol and carbon tetrachloride showed a nonplastic behavior.

3. RESULTS

3.1 Liquid limit

The results of liquid limit tests on sand-bentonite mixtures with different liquids are shown in Table 2. Following points from these results are noted:

Liquid limit of bentonite with zero percent sand in distilled water is highest and it decreases as expected with the percent of sand, the concentration of electrolyte and the valency of cation are increased. The tendency for development of double layer is decreased as the concentration of electrolyte or the valency of cation is increased. For example, for bi-valence calcium as compared with mono-valence sodium a lower number of ions is required to balance the negative charged clay particle surface and therefore, a less amount of water is required for hydration and development of double layer.

The effect of the concentration of electrolyte and the valency of cation on liquid limits of mixtures is decreased as the percentage of sand is increased.

As it was mentioned before, samples prepared with organic chemicals shown to be non plastic. Another word soil particle in these chemicals become aggregated and act like sand particles without any plasticity. The molecules of these chemicals are nonpolar which is indicated by a lower dielectric constant as compared with molecules of water (Table 1).

Table 2 Liquid limits of mixtures

% Sand	0	50	70	90
Permeant				
Distilled water (H ₂ O)	95.3	57.5	36.7	21.2
Sodium chloride solution (NaCl)	78.8	48.9	33.1	20.7
Calcium Chloride solution (CaCl ₂)	85.9	52.3	34.3	20.9
Base solution (NaOH)	83.2	51.7	34.8	20.9
Acetic acid (CH ₃ COOH)	NP	NP	NP	NP
Methanol (CH ₃ OH)	NP	NP	NP	NP
Carbon tetrachloride (CCl ₄)	NP	NP	NP	NP

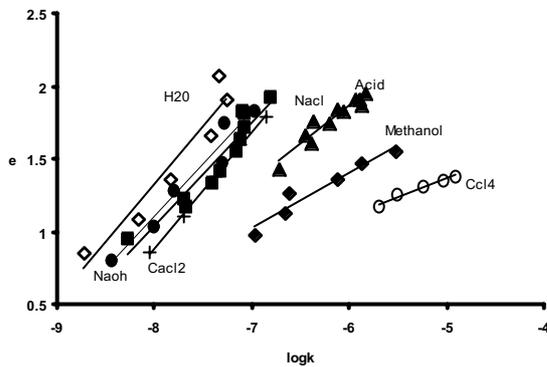


Fig. 1 e-logk for bentonite in different permeant.

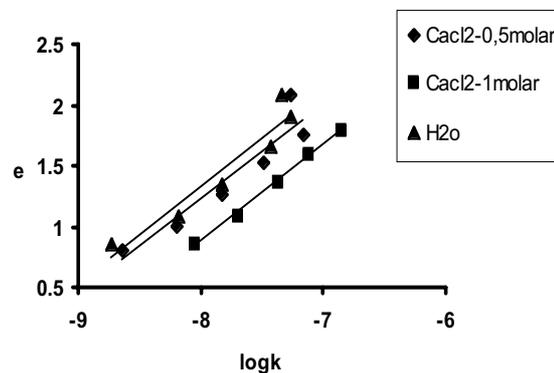


Fig.2 Effect of concentration of electrolyte on e-logk for bentonite.

3.2.Calculated Permeability

3.2.1Bentonite

In Figs. 1 and 2 the coefficient of permeability of bentonite samples in water and solutions of sodium and calcium chloride, sodium hydroxide, acetic acid, methanol and carbon tetrachloride as a function of void ratio is shown. From these results following points are indicated:

1. At each void ratio the permeability of samples in water is the lowest and that for carbon tetrachloride is the highest. In distilled water, soil particles show a dispersed character and mechanical factors such as fineness of particles and tortuous nature of pores lowers the permeability of soil. On the other hand, in nonpolar carbon tetrachloride soil particles have an aggregated nature which means that soil particles stick to each other and form larger particles and therefore less tortuous shape of pores leads to a larger permeability of soil.
2. At each void ratio, permeability of pure bentonite in methanol and acetic acid is lower than that in carbon tetrachloride and larger than that in water (Fig. 1). However, the permeability at each void ratio in methanol with dielectric constant of 32.6 is larger than that in acetic acid with dielectric

constant of 6.2. Higher dielectric constant means that molecules of methanol are more polar than those of acetic acid and therefore, more interaction between soil particles and methanol occurs. For this reason the permeability in methanol actually should be lower than in acetic acid. One explanation for this behavior may be that some chemical reactions between acetic acid and soil particles may have prohibited aggregation of soil particles and therefore lowered the permeability. This behavior has also been reported by Peterson and Gee (1984) for clay liners in acidic environment.

3.2.2 Sand – Bentonite Mixtures

Mixtures of bentonite with 50 and 90% sand with water and different chemical liquids were tested in consolidation. At different void ratio the coefficient of permeability were calculated. The results are shown in Fig. 3 through Fig 10. Following points with regard to these results are noted:

For all liquids the permeability index, C_k ($C_k = \Delta e / \Delta \log k$) is decreased as the percentage of sand is increased. This means that as the percentage of sand is increased, with a little change in void ratio a large decrease in permeability occurs. This behavior is more pronounced for the samples

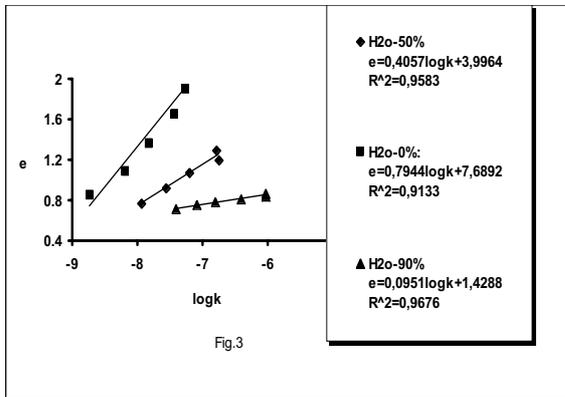


Fig.3 e-logk for sand – bentonite mixtures with different sand content in water.

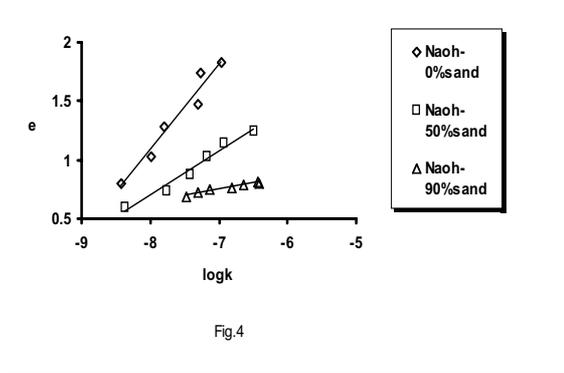


Fig. 4 e-logk for sand – bentonite mixtures in sodium hydroxide.

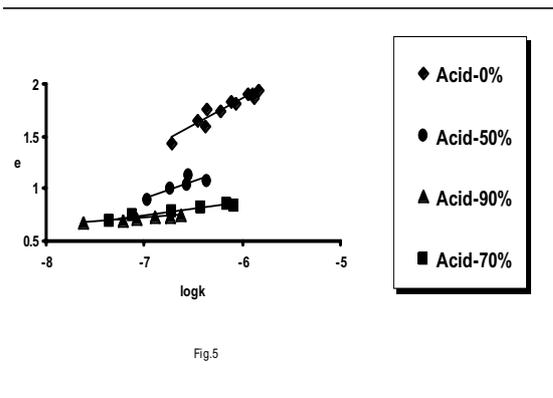


Fig. 5 e-logk for sand – bentonite mixtures in acetic acid..

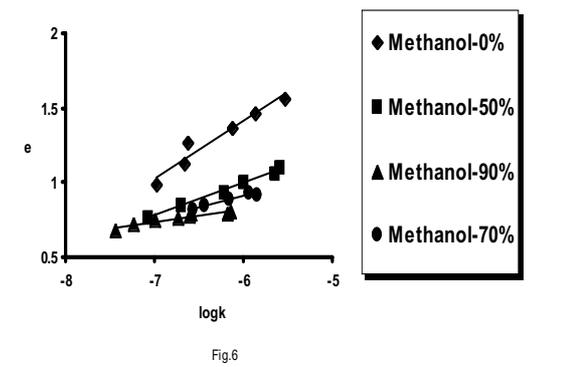


Fig. 6 e-logk for sand – bentonite mixtures in methanol..

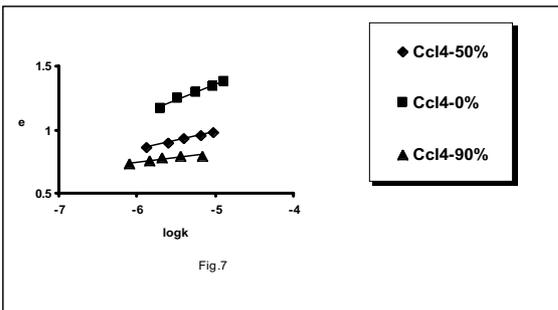


Fig. 7 e-logk for sand – bentonite mixtures in carbon tetrachloride.

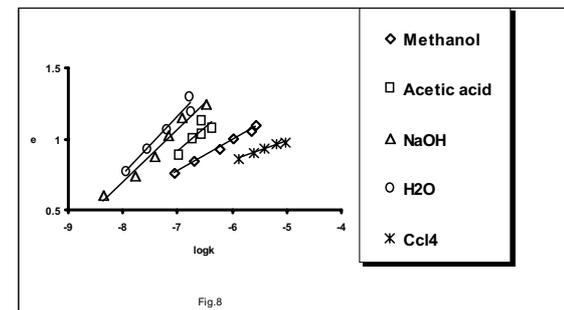


Fig. 8 e-logk for sand – bentonite (50-50) in different permeant.

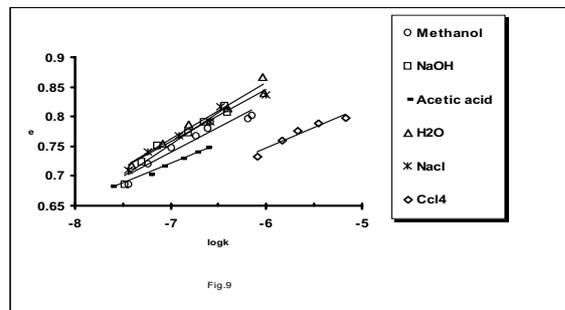


Fig. 9 e-logk for sand – bentonite (90-10) in different permeant.

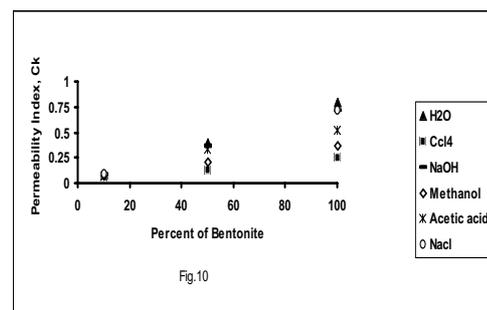


Fig. 10 Permeability index (Ck) against percentage of bentonite for different permeant.

tested in water and less pronounced for samples tested in other liquids. For example, for bentonite samples tested in water C_k decreased from about 0.8 for zero percent sand to about 0.1 for 90 percent sand.

As it is shown in Fig.10 the largest C_k belongs to the samples tested in distilled water and the smallest C_k belongs to the samples tested in carbon tetrachloride from 0.25 for zero percent sand to about 0.07 for 90 percent sand, and for other chemicals the value of C_k is between.

3.3.Measured Permeability

In the first phase of the research explained in previous sections, permeability of sand – bentonite mixtures in water and other liquids when pore fluid and permeant are the same was evaluated. In this phase the permeability of mixtures were calculated using the data obtained in consolidation tests performed in which the samples were prepared and consolidated in the presence of water or the respected liquids.

In the second phase of the research the evaluation of the permeability of sand – bentonite mixtures in water as pore fluid and other chemical as permeant was intended using the same procedure described above. However, because it was expected that during the loading consolidation of the respected sample would be due to extraction of water from the pores regardless of the nature of the cell liquid and thus the permeability obtained would not be affected. Therefore, in order to facilitate the entry of the cell fluid through the samples and to observe a change in permeability, it was decided to load – unload and reload the samples. However, after a limited number of tests with the modified procedure and with acetic acid as cell fluid no notable change in permeability was observed. It is concluded that in order to observe the possible change in permeability of samples prepared with

water as pore fluid and other chemical as permeant one must uses direct measurement of permeability. In the following section the results of three such tests on samples of bentonite at water content of about 98-100% ($e = 3.0-3.3$) with water as pore fluid and methanol and carbon tetrachloride as permeant is shown and discussed.

In these tests after the samples were prepared and placed in the rigid wall mold, falling head permeability test using water as permeant was conducted for 120-200 hours. After this period the water in the burette and in the reservoir above the sample was replaced with methanol or carbon tetrachloride and tests were continued using these chemicals as permeant for another 75-300 hours. The relationship between the quantities of flow entering the samples against the time is shown in Figs. 11, 12, and 13. A linear relationship between the quantity of flow and the time is established in which an increase in the slope of the line is observed after the permeant was changed from water to methanol or carbon tetrachloride indicating an increase in permeability. Table 3 compares the permeability of bentonite before and after introduction of the chemical through the samples. The increase in the permeability of the samples after permeating methanol is only 50% and that for the sample permeated with carbon tetrachloride is 900 % before a rapid increase in the rate of flow was observed in 74 hours after carbon tetrachloride was added. Examining this sample after dismantling the test showed large continuous cracks through the sample indicating direct flow path through the sample at the end of the test.

The increase in the coefficient of permeability of bentonite obtained in direct measurement when water used as pore fluid and methanol and carbon tetrachloride as permeant are compared at the same void ratio

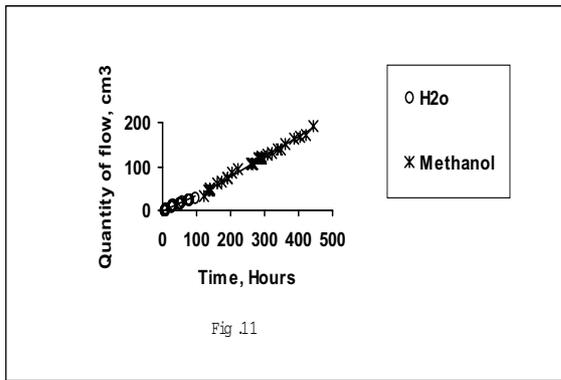


Fig.11 Quantity of flow against time for bentonite in distilled water and then in methanol.

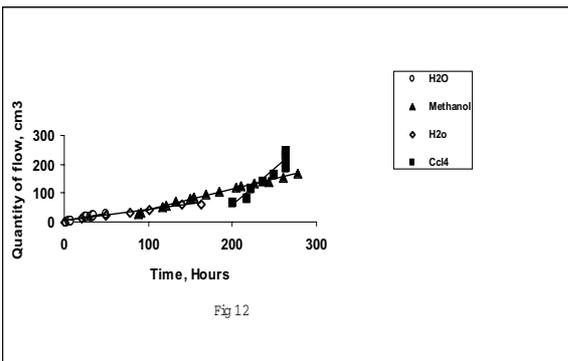


Fig.12 Quantity of flow against time for bentonite in tap water and then in methanol.

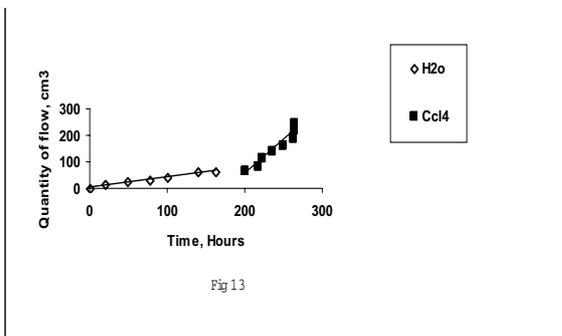


Fig. 13 Quantity of flow against time for bentonite in distilled water and then in carbon tetrachloride.

with those calculated when methanol and carbon tetrachloride used both as pore fluid and as permeant in Tables 4 and 5. The latter were calculated assuming a linear extrapolation from e-log k relationships at void ratios of 3.1 and 3.2 respectively. As it is shown the increase in permeability of bentonite in water is very much larger when water is completely replaced with any of chemicals than that when water used as pore

Table 3 Measured permeability of bentonite before and after Introducing chemicals

Permeant	K_{before} , cm/sec.	K_{after} , cm/sec.
Tap water/Methanol	5.5×10^{-7}	7.6×10^{-7}
Distilled water/Methanol	3.8×10^{-7}	5.4×10^{-7}
Distilled water/CCl4	4.2×10^{-6}	4.5×10^{-5}

Table 4 Comparison of the increase in k for Methanol

Type	k_{water} , cm/sec.	k_{methanol} , cm/sec.	$k_{\text{methanol}}/k_{\text{water}}$
Calculated	1.6×10^{-6}	2.5×10^{-2}	15852
Measured	3.8×10^{-7}	5.4×10^{-7}	1.5

Table 5 Comparison of the increase in k for Carbon tetrachloride

Type	k_{water} , cm/sec.	K_{CCl4} , cm/sec.	$K_{\text{CCl4}}/k_{\text{water}}$
Calculated	2.2×10^{-6}	158	7.3×10^7
Measured	4.5×10^{-7}	4.2×10^{-6}	9.3

fluid and chemicals as permeant. When water is used as pore fluid and later the permeant is changed to chemical, apparently all of the water around soil particles is not replaced during flow and complete aggregation of bentonite particles in this case does not occur.

4. CONCLUSIONS

Based on test results and analyses following conclusions are reached:

1. The permeability of sand – bentonite mixtures are the lowest in water and the highest in carbon tetrachloride and for other chemicals tested is between.
2. For all liquid the permeability index, C_k is decreased as the percentage of sand is increased and this change is the more pronounced for water.
3. The largest C_k belong to the samples tested in distilled water and smallest C_k belongs to the samples tested in carbon tetrachloride.
4. The change in permeability of bentonite when water used as pore fluid and chemicals as permeant are much less than when chemicals are used as both pore fluid and permeant.

5. It appears that for some organic chemicals such as carbon tetrachloride when replaced for water as permeant in direct measurement of permeability one should let enough time for reaction to occur before ending the test.

REFERENCES

- [1]. Brown, K. W. and Anderson, D. C. (1983) Effects of organic solvents on the permeability of clay soils, EPA-600/2-83-016, final reports, Solid and Hazardous Waste Res. Div., U.S. Environ. Protection Agency, Cincinnati, Ohio.
- [2]. Bowders, J. J. and Daniel, D.E. (1987), Hydraulic conductivity of compacted clay to dilute organic chemicals, *J. Geotech. Engrg., ASCE*, 113(12), 1432-1449.
- [3]. Grace, H. P. (1953), Resistance and compressibility of filter cakes, *Chem. Engrg Prog.* 49, 303-318, 367-377.
- [4]. Graham, J.; Yuen, K.; Goh, T. B.; Janzen, P.; and Sivakumar, V. (2001), Hydraulic conductivity and pore fluid chemistry in artificially weathered plastic clay, *Engineering Geology*, 60, 69-81.
- [5]. Jo, H. Y.; Katsumi, T.; Benson, C. H.; and Edil, T. B. (2001), Hydraulic conductivity and swelling of nonprehydrated GCLs permeated with single – species salt solutions, *J. of Geotech. and Geoenviron. Engr., ASCE* 127 (6), 557-567.
- [6]. Lorestani, M. (2003), Evaluation of hydraulic conductivity of sand – bentonite mixtures against different permeant, M.S. Thesis, Shahid Chamran Univ. Ahwaz, Iran.
- [7]. Macey, H.H. (1942), Clay-water relationship and internal mechanisms of drying, *Trans. Br. Ceram. Soc.* 41,73-121.
- [8]. Mesri, G. and Cepeda - Diaz, A. (1987), Permeability of shales. Proc. 8th Panamerican Conf. SMFE, Cartagena, Columbia, 89-100.
- [9]. Mesri, G., Feng, T. W., Ali, S., and Hayat, T. M. (1994), Permeability characteristics of soft clays, proc. Xiii ICSMFE, New Dehli, India.
- [10]. Mesri, G. and Olson, R. E. (1971), Mechanisms controlling the permeability of clays, clay minerals, vol. 19, pp151-158.
- [11]. Michaels, A.S. and Lin, C. S. (1954), The permeability of kaolinite, *Ind. Engrg chem.* 46, 1239-1246.
- [12]. Peterson, S. R., and Gee, G. W. (1984), Interactions between acidic solutions and clay liners: permeability and neutralization. *Hydraulic barriers in soil and rock: ASTM STP 874*, ASTM , Philadelphia, Pa., 229-245.
- [13]. Salehi, S. (2001) Evaluation of hydraulic conductivity and shrinkage potential of bentonite – sand mixtures, M.S. Thesis, Shahid Chamran Univ. Ahwaz, Iran.
- [14]. Sivapullaiah, P.V., and Sridharan, A., and Stalin, V. K. (2000). Hydraulic conductivity of bentonite – sand mixtures, *Canadian Geotechnical Journal* vol. 37, 406-413.
- [15]. Soule, N. M. and Burns, S. E. (2001), Effects of organic cation structure on behavior of organobentonite, *J. of Geotech. and Geoenviron. Engr., ASCE*, 127 (4), 363-370.
- [16]. Terzaghi, C. (1925), Determination of the permeability of clay, *Engrg. News Rec.* 95,832-836.
- [17]. Uppot J. O. and Anderson, D.C. (1989), Permeability of clays under organic permeants, *J. Geotechnical Engrg., ASCE*, 115(1), 115-131.