STP874-EB/Jul. 1985



# GENERAL DISCUSSION

*J. Daemen*[1] *(written discussion)*—Would any author comment on the possibilities of reducing test time requirements by some type of accelerated testing? What acceleration methods are available/reliable?

*D. Anderson,*[2] *W. Crawley,*[3] *and D. Zabcik*[4] *(closure)*—The main method used to decrease testing time has been to increase the hydraulic gradient by increasing the pressure head. Increased pressure may have one of the following effects:

1. It may decrease permeability by causing increased shear forces along pore walls, thereby causing an increase in particle migration and subsequent clogging of pores.
2. It may increase permeability if the migrating particles pipe out of the clay liner rather than clog the pores as just mentioned. Some would also argue that there is a threshold gradient below which flow will not occur in some smaller pores. In this case also, a higher gradient would result in a higher permeability.

Another way that has been suggested to shorten testing time is to increase the concentration of leachate constituents. This is, however, inadvisable because many of the effects constituents have on permeability are concentration dependent.

Other inadvisable methods for shortening time include increased temperature, decreased specimen thickness, and decreased clay content. It is necessary to pass at least two pore volumes of leachate through a barrier to establish how that leachate will affect permeability. With permeabilities less than $1 \times 10^{-7}$ cm s$^{-1}$ and hydraulic gradients no higher than 40, a test should be expected to last at least six months.

*Y. Acar*[5] *(closure)*—The API water loss test which we used in our experiments can be used to simulate the effects of salts on slurries. It is a short-term, 24-h test, which gives a good indication as to what the effect would be on bentonite.

*Wes Holtz*[6] *(written discussion)*—What is the effect of calcium ions when cement is added to sodium bentonite slurry mixes?

[1]University of Arizona, Tucson, AZ.

[2,3,4]K. W. Brown & Associates, Inc., College Station, TX 77840.

[5]Assistant professor, Department of Civil Engineering, Louisiana State University, Baton Rouge, LA 70803.

[6]Woodward-Clyde Consultants, Englewood, CO 80111.

*Y. Acar (closure)*—Calcium ions will replace sodium ions, causing a reduction in swelling of the bentonite and thus a drop in viscosity and an increase in water loss. Because the slurry thickens as a result of the addition of fines, the bentonite will not drop out of suspension, and, while the permeability of the filter cake increases, it does not become totally permeable. By adding sodium carbonate or a sodium phosphate, the effect can be reduced.

*A. I. Johnson*[7] *(written discussion)*—I have some concern that the effects of the temperature and the density of permeating fluids are not entering into calculations of the permeability reported from laboratory tests. Permeabilities frequently are not converted to a standard temperature, for example, and thus cannot be converted easily to field temperatures, such as that of the groundwater.

*S. R. Day*[8] *and D. E. Daniel*[9] *(closure)*—It is true that the hydraulic conductivity ($k$) is a function of both the fluid and the porous medium. Another measure of flow through porous media is often used in other disciplines known as the intrinsic or absolute permeability ($K$). These variables are related by the properties of the fluid.

$$k = \frac{K g \rho}{\mu} \tag{1}$$

where

$k$ = hydraulic conductivity (L/T),
$K$ = intrinsic permeability ($L^2$),
$\rho$ = density of the fluid ($M/L^3$),
$g$ = acceleration due to gravity ($L/T^2$), and
$\mu$ = dynamic viscosity of the fluid (M/LT).

It should be remembered that the temperature of interest is the temperature of the fluid flowing through the liner, not the air temperature.

It is possible to correct $k$ to a standard temperature (say 20°C) by forming the following ratio from Eq 1.

$$\frac{k_{20}}{k_T} = \frac{\rho_{20}\mu_{\mathrm{T}}}{\rho_{\mathrm{T}}\mu_{20}} \tag{2}$$

The magnitude of this correction for water is illustrated in the following table.

[7]Woodward-Clyde Consultants, Englewood, CO 80111.
[8]Civil engineer, GEOCON, Inc., Pittsburgh, PA 15235.
[9]Assistant professor, Department of Civil Engineering, University of Texas, Austin, TX 78712.

| Temperature, °C | $k_{20}/k_T$ |
|---|---|
| 0 | 1.78 |
| 20 | 1.00 |
| 40 | 0.66 |

The relative importance of this correction should be weighted against the relative accuracy of the total testing program.

In field testing clay liners with water, it is generally not practical to consider this relatively minor correction factor. Typically, there are other sources of error (for example, resolution, representative sampling, soil variability, etc.) that are more critical. When testing with permeants other than water it may be meaningful to convert to absolute permeability. An example of this use of absolute permeability can be found in this publication in the paper by Acar, Field, and Scott.

*Y. Acar (closure)*—We have not yet been successful enough to obtain a good agreement between the hydraulic conductivity measured in the laboratory and in the field. Differences of orders of magnitude are possible due to different fabric generated by the laboratory and field compaction schemes and the field macrofabric variations that are not accounted for in a laboratory compaction test. In fact, we have not yet established whether the microfabric generated in the field is comparable to the fabric in the laboratory. Consequently, although it is a lot more proper to report absolute values of hydraulic conductivity, such corrections are not expected to decrease the variation between laboratory and field values and hence would not justify the use of the laboratory values for *in situ* conditions.

*S. A. Gill*[10] *and B. R. Christopher*[11] *(closure)*—Indeed, the effects of temperature and density of the permeating fluid should be entered into calculations, especially with permeating fluids other than water. On permeants such as solvents, drilling fluids, and even water that contains high quantities of contaminants, density determinations of the permeating fluids should be made. Ideally, tests should be performed in laboratories under controlled "standard" conditions. Unfortunately, standard conditions have not been defined for soil testing laboratories. It is felt that comparisons of results between laboratories would be more valid if tests were performed in more controlled environments as opposed to converting laboratory data to standard temperature. In our case study, all tests were performed in a temperature-controlled room maintained at 22±2°C (71±2°F). Under these conditions, temperature has an insignificant effect on test results.

*I. Johnson (closure)*—I appreciate the comments of the authors. The problem exists, however, that permeabilities are important to many problems be-

[10]Chief engineer, STS Consultants, Northbrook, IL 60062.
[11]STS Consultants, Northbrook, IL 60062.

sides that of leakage through clay liners at waste ponds or flow of relatively pure groundwater and the range of temperatures or densities related to those situations. Temperatures can be quite high when considering flow problems involved with solar ponds or geothermal energy, for example. I recommend that the permeabilities always be reported to a standard of 20°C. In any case, the least that should be done is to report the temperature of the permeant as used in the test. Permeabilities in my laboratory were performed in a constant temperature room, but I still reported the values at a standard temperature. Furthermore, density also can be an important factor when one considers the wide variety of fluids that are of interest to subsurface flow problems today. Because investigators in soil and rock problems have dealt for so many years primarily with the movement of relatively pure groundwater through the pores at a narrow range of temperatures, there is a tendency to forget the effects of viscosity (temperature) and density. There also is a tendency among investigators to automatically assume that something must be wrong with the laboratory test or sample when a difference between laboratory and field permeability data occurs. One should look at both methods for possible errors or difficulties, remembering that many factors also affect field tests.

*J. A. Mundell*[12] *(written discussion)*—(1) Many laboratory results have been shown on the effect of various permeants on the permeability of compacted clay. What effect does the state of compaction (molding moisture content, compaction energy) have on these effects? (2) Have the authors taken this into account in their studies? (3) Results presented at this symposium indicate that the results of various permeants on the permeability of lower plasticity silty clay may be much less than for highly plastic, bentonite clays. What are the authors' experiences with regard to this?

*Y. Acar (closure)*—(1) To this author's knowledge, no specific study exists that scrutinizes the effect of different permeants on the hydraulic conductivity of samples compacted at different molding water contents and compaction energies. However, when water is the permeant, the effect of such mechanical variables on hydraulic conductivity is well established. Studies by various investigators indicate that while the clay fabric is not very stable at the dry side of the optimum water content, hydraulic conductivity could be orders of magnitude greater than that obtained at the wet side of optimum water content. As a consequence, it is expected that soils compacted at or slightly above the optimum water content would offer the most stable fabric. As to the effect of compaction energy, previous experience with earth dams indicates that soils compacted at efforts greater than the standard compaction effort tend to be brittle in deformation behavior and more susceptible to desiccation cracking when subjected to any volume decreases. Consequently, standard Proctor efforts and optimum moisture contents were used in our studies.

(2) This author believes that it is necessary to restrict the activity of the soil used in the liners for shallow land waste disposal facilities where the postcon-

[12]Environmental research associate, Department of Civil Engineering, University of Notre Dame, Notre Dame, IN 46556.

structional pore fluid chemistry is expected to be significantly different than the initial molding fluid. Various results presented at this symposium emphasize the necessity to bring criteria that provide a control on not only the mechanical variables such as the compactive effort, the type of compaction, and the molding water content but also on the compositional variables such as the clod size, the activity of the soil, and the chemical characteristics of the leachate generated.

(3) High swelling bentonites will work very well to prevent the breakthrough of certain leachates such as those of municipal sanitary landfills. Strong leachates, like certain industrial ones, will have a more deleterious effect on these types of bentonites versus silty clay because the quantity of fines is much lower. Consequently, when there is a reduction in the size of the double layer, the porosity is increased and therefore the permeability also. This will not happen to any large degree with silty clays because the pores are filled with fines rather than with swollen clay particles. It is important that the materials are tested in the lab for compatibility with the leachate prior to installation. Bentonites are often much cheaper than such silty clays.

*C. Williams*[13] *(written discussion)*—The audience is led to believe that soil liners have few problems with most leachates. When are acids and bases a problem? The pH range? Organic comment rations? Soil types and mineralogy?

*D. Anderson,*[8] *W. Crawley,*[9] *and D. Zabcik*[10] *(closure)*—Dilute aqueous leachates with a near neutral pH have not been shown to affect the permeability of compacted clay liners or soil-bentonite mixtures. Both acids and bases may increase or decrease permeability as follows:

1. Dissolution of soil particles or soil binding agents by strong acids or bases will release particle fragments for migration.
2. If particle migration continues for an extended time, the pores will enlarge and, consequently, the permeability will increase.
3. If the pores are too small for passage of the migrating particles, the pores will become clogged and, consequently, the permeability will decrease.

Acids or bases can be a problem where the clay liner or slurry trench is adjacent to soils with pores large enough to allow for the migration of clay particles.

*Y. Acar (closure)*—Acids and bases are a problem for bentonite at a pH lower than 2 and higher than 11. Organic materials are a big problem if they are pure, which means they will compete with water, and if sinkers (higher specific gravity than water) are at a relatively high concentration (more than 20 ppm). For more information, check "General Classification of Wastes," IMCLAY Binder, International Minerals and Chemical Corp., Mundelein, Illinois (Industry Group). Acids and bases are also a problem if the soils contain such soluble minerals as gypsum, creating pore spaces upon dissolution.

[13]McBride-Ratcliffe & Associates, Houston, TX 77040.