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A Study on Porosity and Permeability of Saudi Soils

M.E. Dokla and M.H. Sayyouh

College of Engineering, King Saud University, Riyadh, Saudi Arabia

This work is concerned with studying the effect of overburden pressure on both porosity and permeability of samples from Saudi Soil. Experiments include the effect of temperature and presence of water on permeability. Consolidated and unconsolidated samples were used.

Both temperature and pressure had an effect on permeability of consolidated and unconsolidated soil samples. Increasing the pressure decreases liquid permeability of both consolidated and unconsolidated samples. Limestone samples showed a decrease in permeability while sandstone samples permeability increased with temperature increase.

Introduction

Permeability and porosity are very important rock characteristics. They determine both fluid storage capacity and easiness of fluid flow respectively. It has been taken that while porosity and permeability might be affected by the applied overburden pressure, they are not affected by changes in temperature. Recent studies, however, indicate that temperature might have a marked effect on absolute rock permeability [1–3]. Some of these investigators reported either a slight-to-moderate decrease in permeability, no change at all with increasing temperature, or an increase in some cases. All investigators indicated variable changes in permeability with overburden pressure, sometimes marked reductions were noticed. The effect of overburden on permeability depends greatly on the nature of formation. For unconsolidated formations the reduction is expected to be large, while for competent rocks the effect should be small. The conditions of surface soil in building areas in Saudi Arabia are such that the pores will normally be dry. The absence of liquid in the pores will result in low pore pressures. Lowering of pore pressure increases the confining stress on rock, causing it to compact. The compaction causes reduction of the effective pore diameters, resulting in a decreased permeability [4, 5]. This reduction will be greater in low-permeability than in high-permeability formations.

The gas permeability changes as the magnitude of water saturation changes. This work is concerned with studying the effect of temperature and pressure on porosity and permeability of some consolidated and unconsolidated Saudi soil samples.

Laboratory Measurements

Table 1 shows the properties of the different samples used in this study. Both consolidated limestone and sandstone soil samples were included. Unconsolidated soil samples of different properties were also used.

Porosity was measured by noticing the bulk volume of sample first and then saturating it under vacuum with the flowing fluid and noticing the

Table 1. Properties of Samples

Core Number	Core Type	Length (cm)	Diameter (cm)	Porosity (%)
LS1	Limestone	2.92	1.9	15.0
LS2	Limestone	2.36	1.9	17.6
LS3	Limestone	2.29	1.9	9.2
SS4	Sandstone	3.78	1.9	18.8
SOIL 1	Unconsolidated soil	3.82	1.83	25.2
SOIL 2	Unconsolidated soil	3.82	1.83	39.8
SOIL 3	Unconsolidated soil	7.34	3.80	19.7

The samples were collected from Riyadh area.

volume of the fluid that remains in the sample. Saturation was calculated by keeping a balance of the fluids entering and leaving the sample.

Gas permeability was measured by the RUSKA Gas Permeameter. This apparatus allows the flow of gas through the sample under different pressures. The gas flow rate is measured by a three scale flow meter.

The absolute permeability was calculated from the Darcy equation:

$$K = \frac{\mu \bar{Q} L}{A \Delta P}$$

where

$\bar{Q}$ = Average flow rate, cm^3/sec

L = Length of sample, cm

A = Sample cross-sectional area, cm^2

μ = Gas viscosity, cp

ΔP = Pressure drop, atm

Slippage effect, a phenomenon well known with respect to gas flow in small pores, causes gas permeability to depend upon the mean pressure. Because of this effect permeability has to be measured at several pressures. The gas permeability is then plotted versus the reciprocal mean pressure and extrapolated to zero on the horizontal axis to find the liquid permeability.

Liquid permeability was measured with a RUSKA liquid permeameter. A similar formula to the one given above was used in the calculations. The effect of temperature was introduced by heating both the water used and sample to the desired level.

In order to study the effect of compaction on permeability and porosity, the Hassler core holder was used. This apparatus allows the measurement of both absolute and relative permeability for a fluid in a sample under different overburden pressures.

Results and Discussion

Gas permeability was measured for four consolidated samples with and without water saturation. The results are shown in Table 2. It can be seen that the presence of water saturation reduces the gas permeability of the samples although this water saturation is immobile. It is also worth to note that samples number 1, 2, and 3 which are limestone samples are

Table 2. Liquid and Gas Permeability vs. Water Saturation for Different Consolidated Cores

Core Number	Liquid Permeability (md)	Gas Permeability (md)	Water Saturation (% PV)
LS1	—	7.0	0.0
LS2	—	7.6	0.0
LS3	—	4.0	0.0
SS4	—	760	0.0
LS1	—	4.0	33.7
LS2	—	66.9	13.8
LS3	—	3.64	40.7
LS1	5.3	—	100.0
LS2	41.5	—	100.0
LS3	3.86	—	100.0
SS4	166.0	—	100.0

The samples were collected from Riyadh area.

very tight and have low permeability compared to the sandstone sample number 4. The immobile water saturation increases as the permeability decreases. Liquid permeabilities for the mentioned samples are also shown. Water saturation was considered immobile when no more water came out of the sample at high enough pressure differential.

Two soil samples were used as shown in Table 3. Here both liquid and gas permeability are presented. The difference between the two permeabilities of each sample is quite marked. This may be attributed to the reaction between liquid and soil, which results in reducing samples' pore space.

In order to show the effect of the mean pressure on gas permeability measurements both LS2 and SOIL 1 samples were used. Figures 1 and 2 are plots of the gas permeability vs. the reciprocal of the mean pressure. A linear relation was obtained and the intersection of the lines with vertical coordinate gives the permeability at infinite mean pressure which is the liquid permeability. The liquid permeabilities obtained from these figures are very close to the measured values.

Table 3. Liquid and Gas Permeabilities for Different Unconsolidated Cores

Core Number	Liquid Permeability (md)	Gas Permeability at Mean Pressure = 0.25 atm (md)
SOIL 1	73.0	1914.0
SOIL 2	9.0	64.0
SOIL 3	1.0	—

The samples were collected from Riyadh area.

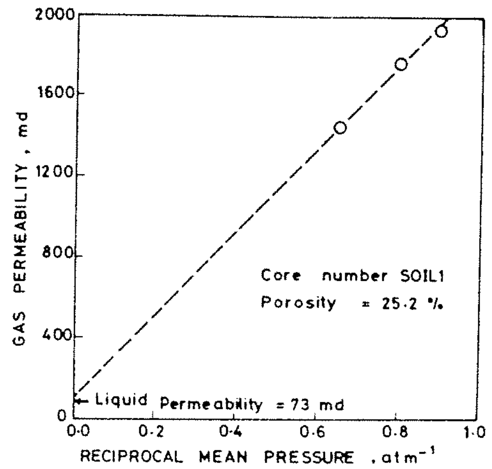

Fig. 1: Gas Permeability vs. Reciprocal Mean Pressure for Core No. SOIL 1.

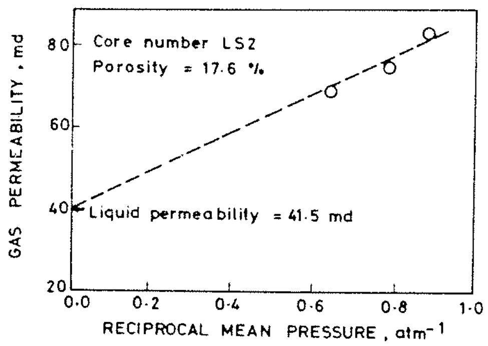

Fig. 2: Gas Permeability vs. Reciprocal Mean Pressure for Core No. LS2.

The effect of temperature on permeability was investigated for both consolidated and unconsolidated soil samples. Figures 3 through 7 are plots of liquid permeability as function of temperature. Figures 3 and 4 are for limestone samples and they show that liquid permeability is markedly affected by

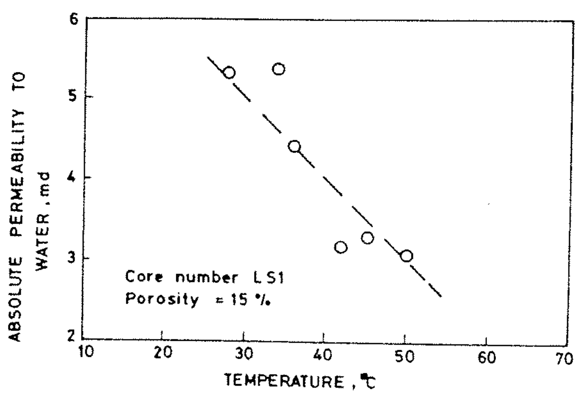

Fig. 3: Liquid Permeability vs. Temperature for Core No. LS1.

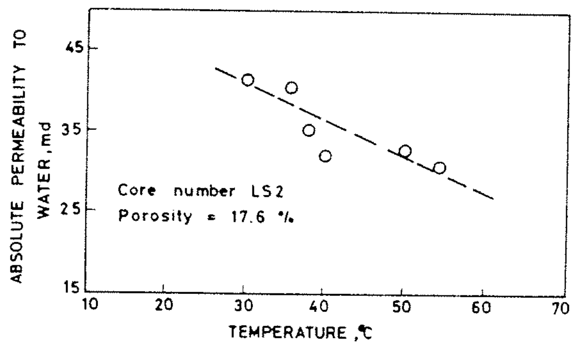

Fig. 4: Liquid Permeability vs. Temperature for Core No. LS2.

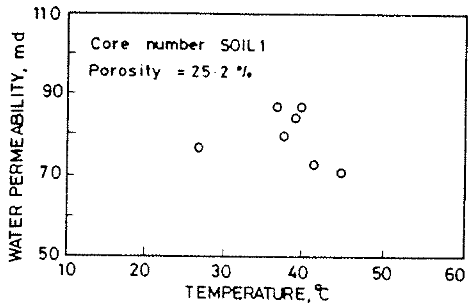

Fig. 5: Liquid Permeability vs. Temperature for Sample SOIL 1.

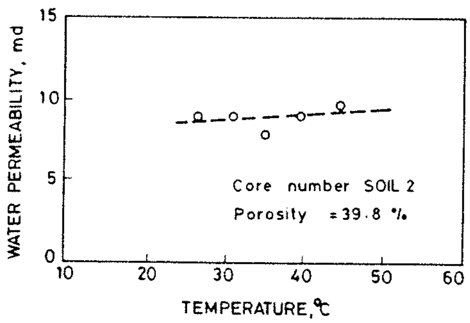

Fig. 6: Liquid Permeability vs. Temperature for Core SOIL 2.

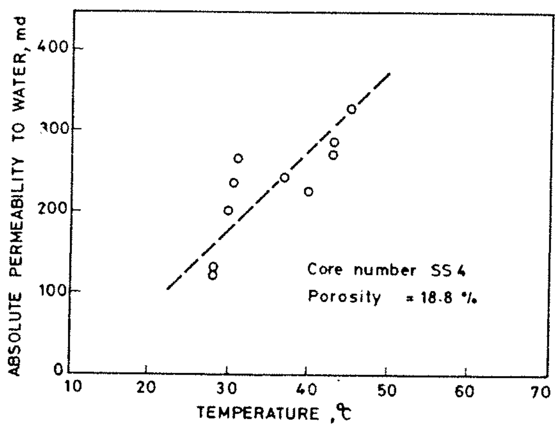

Fig. 7: Liquid Permeability vs. Temperature for Core No. SS4.

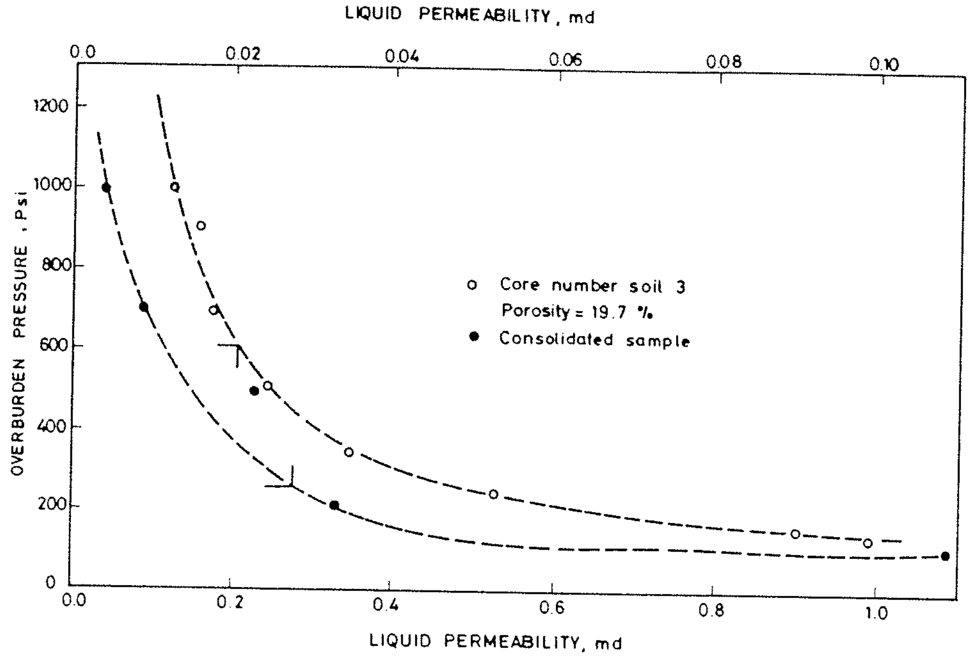

Fig. 8: Effect of Overburden Pressure on Liquid Permeability for Core No. SOIL 3 and Consolidated Sample.

temperature. Although the temperature range is limited to the expected surface values, the effect is clear. The permeability was reduced to about half its value when temperature was increased by about 30 °C. Figures 5 and 6 are for unconsolidated soil samples. Here the effect of temperature on permeability is not appreciable. Figure 7 is for sandstone sample 4. In this case permeability increases with temperature contrary to limestone samples. The nature of pore space in sandstone is different from that in limestone. In sandstone the pores are of the intergranular type and are expected to be more evenly distributed, while the pores in limestone are either of the intercrystalline type or in the form of fractures, such that the surface area per unit pore volume will be higher than that in sandstones. Limestone samples normally have some shale content. Shale adjusts itself to temperature by changing its molecular structure. Other authors [3, 6] have noticed this behaviour with samples having shale content.

The effect of overburden pressure on permeability of consolidated and unconsolidated samples was studied. A maximum of 1000 psi overburden pressure was used. The overburden pressure was applied through a core holder in which the sample is held in a rubber sleeve and pressure is applied on the outer surface of the sleeve. The results are shown on Fig. 8. The permeability of the unconsolidated soil sample was sensitive to pressure. A reduction of 9 times in permeability was obtained upon increasing overburden pressure from 150 to 1000 psi. The consolidated sample results followed the same manner.

Conclusions

1. Permeability of samples used was found to be a function of temperature. Limestone samples showed a decrease in permeability while sandstone samples showed an increase. Permeability of soil samples increased with temperature but at a small rate.

2. The presence of immobile water saturation in samples resulted in decreasing gas permeability.

3. Overburden pressure had a significant effect on the permeability of both consolidated and unconsolidated samples.

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دراسة على المسامية والنفاذية للتربة السعودية

محمود العوضي دقلة ومحمد حلمي صيوح

قسم هندسة النفط – كلية الهندسة – جامعة الملك سعود
الرياض ، المملكة العربية السعودية

تناول البحث موضوع تأثير ضغط التحمل على مسامية ونفاذية بعض العينات من التربة السعودية . وقد شملت التجارب كذلك دراسة تأثير الحرارة على النفاذية واستخدمت عينات متماسكة وغير متماسكة تتأثر بالتغير فى كل من الضغط والحرارة فقد انخفضت قيمة النفاذية لجميع العينات مع زيادة الضغط . كذلك فقد انخفضت نفاذية العينات الجيرية مع زيادة درجة الحرارة بينما ازدادت نفاذية العينات الرملية .