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TO STUDY EFFECT OF SALT SOLUTION ON PERMEABILITY OF SOILS

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Abstract*— Since soils consists of discrete particles, the void spaces between the particles are interconnected and may be viewed as a highly complex and intricate network of irregular tubes. The flow through soils is based on conventional experiment performed by Darcy who acquainted experimentally determined constant called coefficient of permeability. This constant is obviously reflective of the permeability of a certain medium to a certain fluid, and it depends on the properties of both the porous medium and pervade fluid. For the penetrable medium it is the size of the channels in the void network that is of key importance, and this depends on the representative grain size diameter, the gradation factor delineating the shape of grain size distribution curve, the shape factor of the grains and the porosity of the medium. Among the fluid properties viscosity and density of fluids are of key importance. In the present study, permeability measurements were taken using sands of different sizes as the pervade mediums. The pervade fluids that were employed were pure water (tap water) and salt (NaCl) solutions of different concentrations (5g/l to 71g/l). Six different sands S1 to S6 were used which were classified on the basis of their increasing representative sizes 0.12mm,0.15mm,0.18mm,0.20mm,0.22mm and 0.25mm respectively. To rule out the effects due to temperature differences and fluid flow duration through sands, the permeability results were standardized at 20°C and the discharge readings were taken after two hours of the establishment of steady conditions respectively. It was observed that the permeability increased with increase in the concentration of salt solution. Also effect on the density, viscosity and dielectric constant were also analyzed.

Keywords:Permeability, Salt Solution,Dielectric Constant, Viscosity,Sand

I.INTRODUCTION

In this present work, variation of hydraulic conductivity with change in the concentration of salt solution and detergent solution is immediated. First of all six types of sands were favored for permeability studies. All these sands were then subjected to permeability tests using pure water as the permeating fluid. It was observed that all the sands were comparatively well graded but having different sizes. So, the sands were classified in the increasing order of their representative size (D_{10}). The sands were named from S1 to S6. All these sands were then themed to permeability tests using pure water as the pervade fluid. The permeability for each sand was resoluted as it was observed that the permeability assorted directly with the square of the D_{10} for the sands. The effect of density, dielectric constant, viscosity and surface tension were also analyzed.After the completion of the tests using pure water as permeant, laboratory tests were done on the same sands but using salt solution as the permeant. The concentration of the solution was gradually increased from 0g/l to 71g/l. The tests were carried out using seven different concentrations of the salt solution. The results were analyzed and it was observed that the permeability increased with the increase in the concentration of the salt solution. Further a archetypal was progressived to presage the permeability of a particular sand for a particular concentration of the salt solution. The archetypal was developed using the results obtained for five types of sands and the permeability results of S6 were used to validate the model. The results were acceptable

II. EXPERIMENTAL INVESTIGATIONS

2.1 MATERIALS USED

2.1.1 Sand

For the purpose of present study, six local sands were used. The sands were collected from different parts and were analyzed at geotechnical lab in NIT Srinagar. The sands were sieved and their nomenclature is based on their increasing representative sizes (representative size is the size below which 10% of the material is finer). S1 had a representative size of 0.12mm followed by S2, S3, S4, S5 and S6 having representative sizes of 0.15mm, 0.18mm, 0.20mm, 0.22mm, and 0.25mm respectively.

2.1.2 Fluids

Water, salt solutions of different concentrations and detergent solutions of different concentrations were used as the permeating fluids. Salt solutions were prepared by dissolving a fixed mass of salt in a particular volume of water. The concentration of solutions ranged from 5g/l to 71g/l. Precautions were taken to keep the solution in suspension by constant stirring.

III. EXPERIMENTAL PROCEDURE

1) The top flange of the main cylinder was removed and the cylinder was cleaned from inside. Then a wire mesh of opening 0.1mm was placed on the bottom grid of the cylinder to prevent the movement of the material through the outlet.
2) A fixed mass of the selected sand was measured. In my study I used a mass of 1000g for each and every test.
3) A small quantity of water was added to the sand before filling the cylinder to avoid the segregation of the particles while filling.
4) After filling the material into the cylinder another wire mesh was placed at the top of it and pea gravel was placed over this mesh to prevent the direct impact of water on the mass.
5) The top flange will be placed on the cylinder with washer in between and tightened to make it air tight.
6) The permeant was then allowed to pass through the sample and the flow will be adjusted by the stop cocks provided at the inlet and the outlet.
7) The permeant was then allowed to pass for about 2 hours until steady flow conditions will be attained. The steady conditions were attained when the head in the piezometers remains constant.
8) The pinch cocks were opened and the level pipes were connected to the pinch cocks to give the piezo-metric head at different points along the length of the sample.
9) After the steady conditions have been attained, the measuring flask is used to measure the amount of water collected in some time interval‘t’. Also the corresponding heads in the piezometers will be noted.
10) The permeability was then calculated as

$$k = \frac{0.221V}{th}$$

Where, ‘V’ is volume in ml,‘t’ is time in seconds, ‘h’ is head difference in cm and ‘k’ is the coefficient of permeability in cm/s

11) Step 9 is repeated two more times and the corresponding permeabilities were calculated. The final permeability value was taken as the mean of the three permeability values.
12) The temperature of flowing water was noted to get permeability at standard temperature of 20°C.

IV. RESULTS AND DISCUSSIONS

4.1 PERMEABILITY OF SANDS

Permeability tests were carried for all types of sands with pure water as permeating fluid, followed by the permeability tests with salt solution as permeating fluid. The permeabilities were calculated at four different discharges and the average results are put in this work. The permeabilitiues were calculated at different temperatures and have been standardized at 20°C. The permeabilities were calculated by using Darcy’s law .

$$Q=kiA$$

Where, Q is discharge, k is coefficient of permeability, i is hydraulic gradient, and A is the area of cross section of the soil specimen.
Flow is said to be laminar if permeability remains constant with increase in hydraulic gradient. Also Darcy’s law holds good as long as 30% of the material is below 2.54 cm which is hardly neglected in my study.
The permeabilities are tabulated in table 1 and table.2

TABLE 1. PERMEABILITIES OF SIX SAND TYPES WITH TAP WATER AS PERMEATING FLUID.

Sand Type	e	K (T=20°C)	F	$K_{(e=0.2)}$
S1	0.195603	0.001093	0.00626	0.00117
S2	0.187184	0.002763	0.005524	0.00335
S3	0.178764	0.003778	0.004846	0.005223
S4	0.195603	0.006738	0.00626	0.007212
S5	0.187184	0.008171	0.005524	0.00991
S6	0.187184	0.010436	0.005524	0.012657

Where,
e is void ratio, and
F is void ratio factor given by

$$F = \frac{e^3}{1+e}$$

The graph plotted between coefficient of permeability when water is used as the permeant and the square of the representative size (D_{10}) fits into a straight line

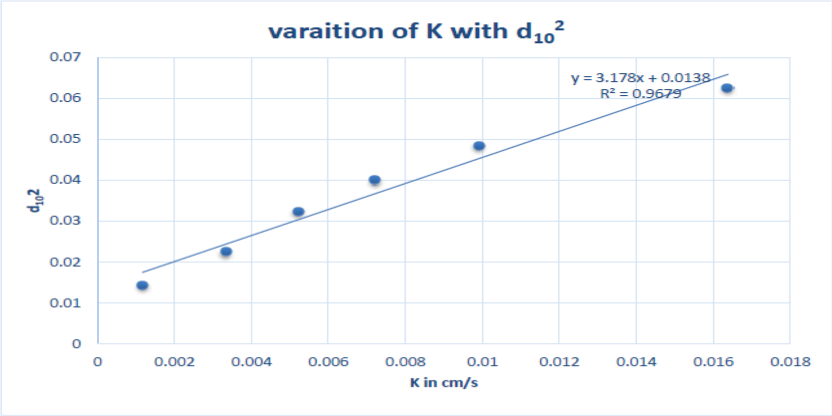

Fig 1.Variation of coefficient of permeability with D_{10}^2 of the test sands with water as permeating fluid.

TABLE 2. PERMEABILITIES OF SELECTED SANDS WITH SALT SOLUTIONS OF DIFFERENT CONCENTRATIONS AS PERMEATING FLUID.

Salt Conc. / Sand type	0 g/l	5g/l	8.5g/l	20g/l	35.5g/l	50g/l	71g/l
S1	0.0011	0.002	0.0028	0.003	0.0048	0.0052	0.0058
S2	0.0033	0.0047	0.00544	0.0067	0.0085	0.009	0.011
S3	0.005	0.0059	0.0063	0.0072	0.0107	0.0118	0.0140
S4	00072	0.0088	0.107	0.0118	0.0126	0.0136	0.0174
S5	0.0112	0.0119	0.0127	0.016	0.0202	0.022	0.024

4.2 Variation of permeability with salt concentration

The concentration of salt in the salt solution was increased from 0 to 7.1 g/l and the corresponding changes in the permeability were observed. It was observed that the permeability increased with increase in the concentration, however the increase ws not same for different sands. The permeability vs concentration of NaCl in the solution for five types of sands is shown in the figures 2 to 6. The different concentrations used in the study are 0g/l, 5g/l, 8.5g/l, 20g/l, 35.5g/l, 50g/l and 71 g/l. The permeability values have been standardised at 20°C. The variation of permeability of salt solutions as suggested by many researchers has been found to be time dependent. All the readings have been taken after two hours of the establishment of steady conditions.

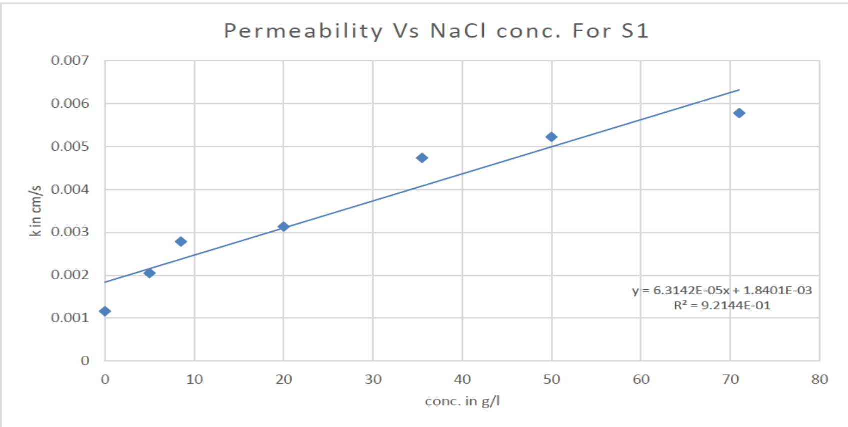

Fig 2. Varaition of permeability of sand 1 with change in salt concentration

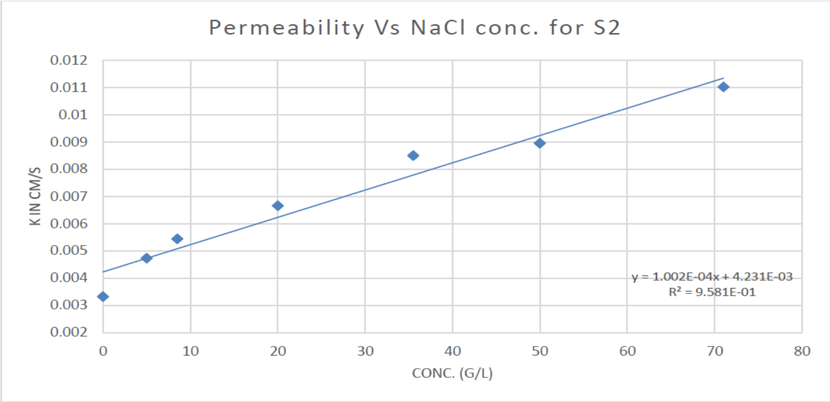

Fig 3. Varaition of permeability of sand 2 with change in salt concentration

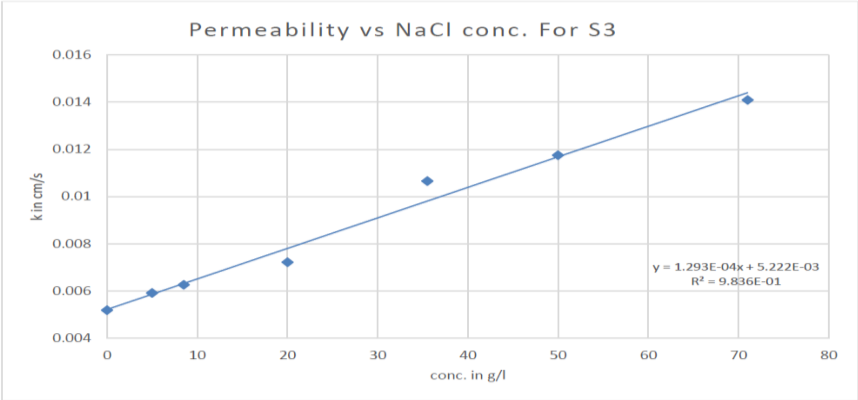

Fig 4. Variation of permeability of sand 3 with change in salt concentration

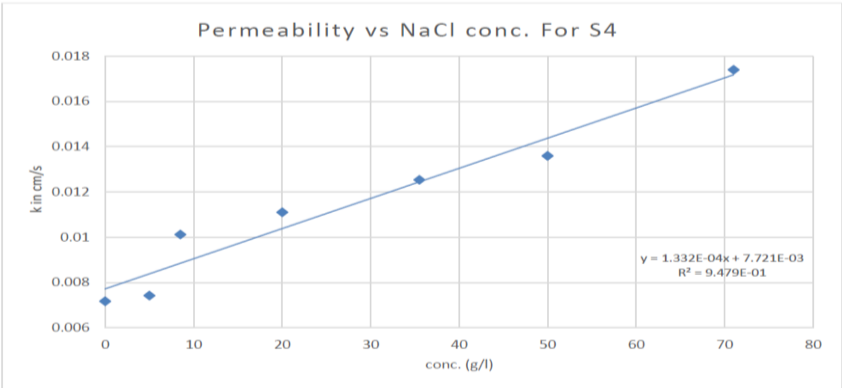

Fig 5. Variation of permeability of sand 4 with change in salt concentration

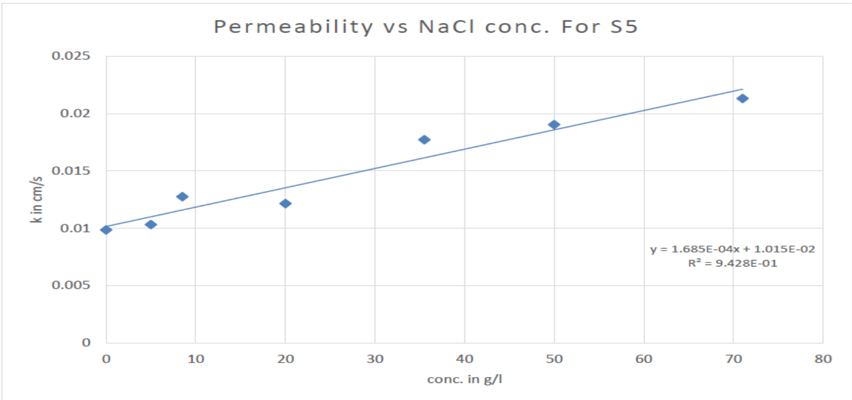

Fig 6. Variation of permeability of sand 5 with change in salt concentration

It is clear from the above graphs that the value of permeability increases with increase in the concentration of the salt solution. It is evident that the permeability of S1 increases by a factor of about 4 which decreases as we move from S1 to S6. However it is clearly observable that there is a definite increase in the coefficient of permeability. Also it can be seen from the graphs 2 to 6 that the variation follows nearly a linear trend which means the permeability increases linearly with increase in the concentration of the permeating fluid.The increase in the permeability can be attributed to the fact that the soil minerals might undergo large interlayer shrinkage in contact with certain chemicals. This is accompanied by enormous loss in diffuse double layer (DDL) thickness, potential cracking, and increase in hydraulic conductivity values**.**The permeability of a soil to a particular fluid is directly proportional to the density and inversely proportional to the viscosity of the fluid.

$$K = c\frac{\rho}{\mu}$$

Where,
ρ is density of the fluid, and μ is coefficient of viscosity.
If a graph is plotted between concentration and the factor ρ/μ we see that it is a decreasing function as such the permeability should decrease with increase in the concentration. But the results are totally opposite. A research paper by Muniram Budhu et al. suggested that an additional fluid property, dielectric constant has an inverse relationship with the permeability. So we can modify above equation by adding the term of dielectric constant.

$$K = \frac{\rho}{\epsilon\mu}$$

Where, ϵ is dielectric constant of the solution.

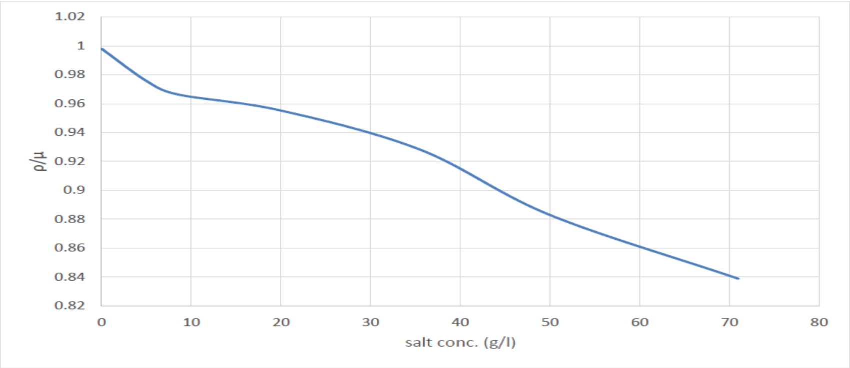

Fig 7. Varaition of ρ/μ with concentration of salt solution

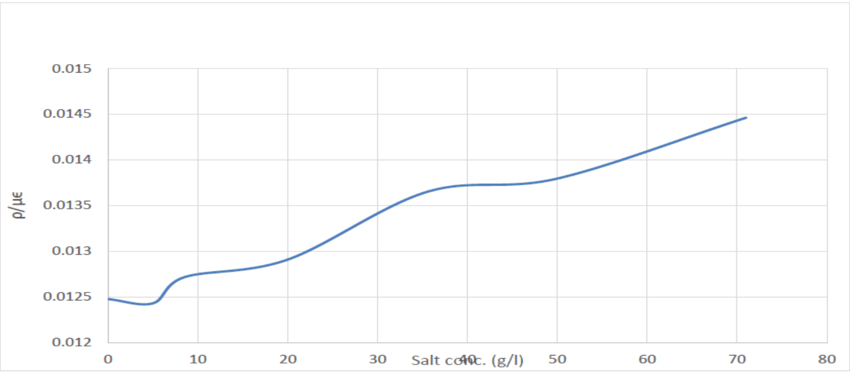

Fig 8. Variation of ρ/μϵ with concentration of salt solution

So it is evident from the figure that the decrease in the value of dielectric constant can be held a responsible factor for the increase in the value of permeability of soils to salt solutions.

4.3 Model development

As has been reported earlier (T.C Kenney et al.)that the prominent factor affecting the permeability is the representative size of the medium, in my study which has been found to be D_{10}, it is observed that the effect of the concentration of the salt decreases with increase in the representative grain size (d_{10}). The change in permeabilities of the sands with change in the salt concentration is tabulated in Table 3

TABLE 3. CHANGE IN THE PERMEABILITY OF SANDS FROM 0 TO 71G/L

Sand	**D_{10}**	**K/K_0**
S1	0.12	4.97
S2	0.15	3.33
S3	0.18	2.74
S4	0.20	2.45
S5	0.22	2.09

Where,
K is the permeability of sand when concentration of solution is 7.1g/l, and K_0 is the permeability of the sand to tap water
The best fit straight lines for the five types of sands are tabulated in table 4.

TABLE 4. BEST FIT LINEAR EQUATIONS FOR FIVE SAND TYPES

Sand Type	**D_{10}**	**Best fit linear equation**
S1	0.12	y = 6.314E-05x + 1.840E-03
S2	0.15	y = 6.314E-05x + 1.840E-03
S3	0.18	y = 1.293E-04x + 5.222E-03
S4	0.20	y = 1.332E-04x + 7.721E-03
S5	0.22	y = 1.685E-04x + 1.015E-02

So a model for the permeability studies can be developed as a straight line showing the variation of permeability with the concentration of salt solution as equation below

$$y=ax+b$$

y is the permeability, *x* is the concentration of salt solution and '*a*' and '*b*' are the parameters which depend on the representative size of the medium. Also the other parameters of the medium which influence the permeability like void ratio need to be controlled. In other words this model can be used for sands with different representative sizes but with same void ratio.
The values of a and b can be correlated with the representative size of the sands as is shown in the figures 9 and 10

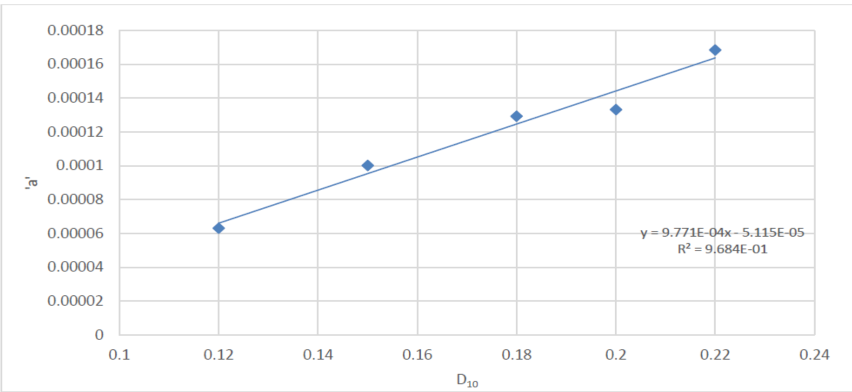

Fig 9. Variation of Parameter 'a' with D_{10}

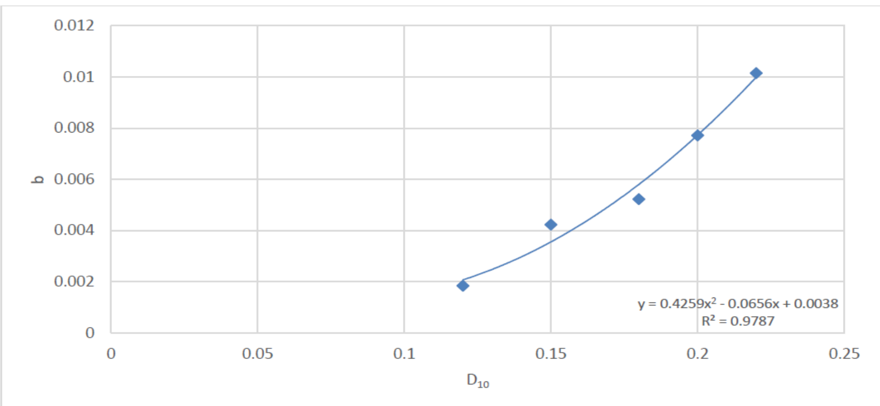

Fig 10. Variation of parameter 'b' with D_{10}

So, in general the relation of '*a*' and '*b*' with D_{10} can be expressed as

$$a=0.0009771D_{10}+0.00005115$$

And,

$$b=0.4259D_{10}^2-0.06556D_{10}+0.0038$$

Where, D_{10} is representative grain diameter or size below which 10% of soil material is finer.

4.4 Model validation

The permeability results of Sand 6 are used to check the validity of results obtained by using equation 5.5. The representative grain size of S6 is 0.25mm. Solving equations 5.6 and 5.7 we get the following values of '*a*' and '*b*'.

a = 0.0002954, and b = 0.01402

Inserting the above values in equation 5.5 we get the equation for S6 as

$$y=0.0002954x+0.01402$$

The validation of the model can be checked by comparing the results based on the model with those obtained experimentally. Fig 11 shows a comparison of values given by the model with that obtained experimentally. Error analysis of the results is done in the table 5.7.

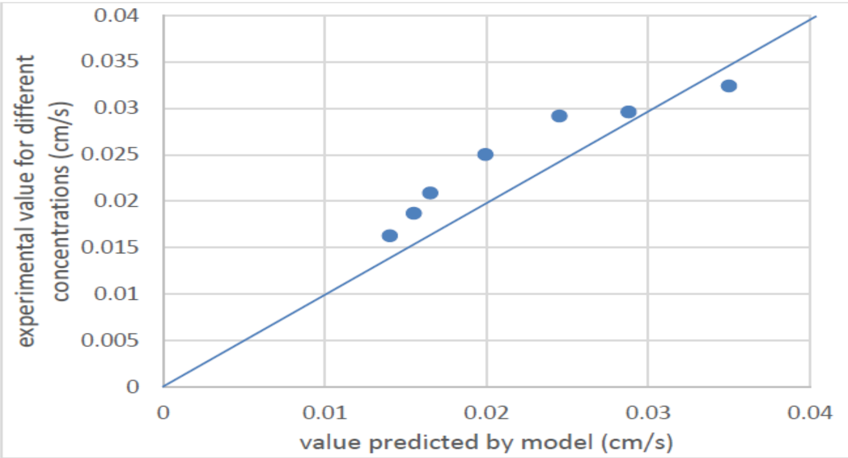

Fig 11. Comparison of model values with experimental values

TABLE 5. ERROR ANALYSIS OF RESULTS BASED ON MODEL

conc. (g/l)	Model value y	Experimental value yi	Error e	e^2	Y_i^2
0	0.01402	0.016282	-0.00226	5.11664E-06	0.000265
5	0.015497	0.0187	-0.0032	1.02592E-05	0.00035
8.5	0.016531	0.02088	-0.00435	1.89147E-05	0.000436
20	0.019928	0.025012	-0.00508	2.58471E-05	0.000626
35.5	0.024507	0.029156	-0.00465	2.1616E-05	0.00085
50	0.02879	0.029603	-0.00081	6.60969E-07	0.000876
71	0.034993	0.032395	0.002598	6.75168E-06	0.001049

The coefficient of determination, R^2 = 0.7

4.5 Variation of viscosity with salt concentration

The concentration of salt in the salt solution was increased from 0 to 71 g/l and the corresponding changes in the viscosity were observed. It was observed that the viscosity increased with increase in the concentration. The viscosity vs concentration of NaCl in the solution is shown in the figure 12. The different concentrations used in the study are 0g/l, 5g/l, 8.5g/l, 20g/l, 35.5g/l, 50g/l and 71 g/l.

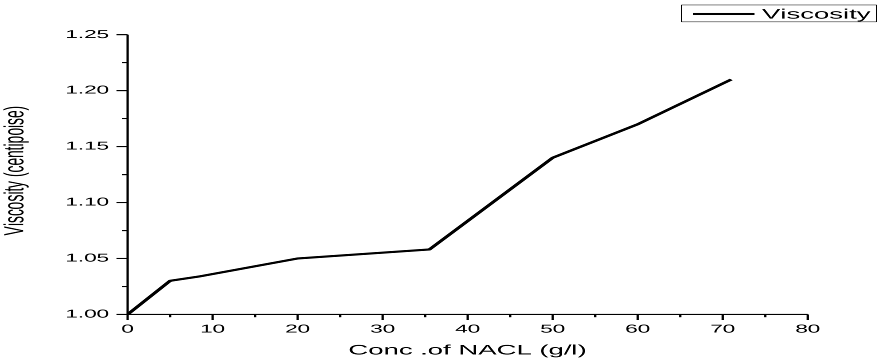

Fig 12 Varaition of viscosity of NaCl solution with change in concentration

V. CONCLUSIONS

A laboratory study was undertaken to examine the effect of nature of fluid on the coefficient of permeability of sands. From the results, analyses and observations presented, following conclusions are drawn,

- An increase in the value of D_{10} increases the value of coefficient of permeability with water as permeant from 0.001093 cm/s to 0.010436 cm/s. There is a straight line fit between the coefficient of permeability and the square of the representative size (D_{10}).
- There is a linear increase in the coefficient of permeability of sands with increase in the concentration of the salt solution. The variation of permeability for five types of sands with change in salt concentration from 0g/l to 71g/l is given below'
    - For S1 the permeability varies from 0.0011 cm/s to 0.0058 cm/s.
    - For S2 the permeability varies from 0.0033 cm/s to 0.011 cm/s.
    - For S3 the permeability varies from 0.005 cm/s to 0.0140 cm/s.
    - For S4 the permeability varies from 0.0072 cm/s to 0.0174 cm/s.
    - For S5 the permeability varies from 0.0112 cm/s to 0.024 cm/s.
    - By considering dielectric constant the value of permeability increases with increase in salt and detergent solutions. So if an embankment is constructed to damp that soil which contains acidic or basic solutions there would be lot of seepage.
    - Two models have been worked out that relate the coefficient of permeability with the concentration of salt solution and detergent solution respectively.

      For salt solutions,

$$k=aC+b$$

Where, $a=0.0009771D10+0.00005115$

And $b=0.4259D102-0.06556D10+0.0038$

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