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EFFECT OF FLOW VELOCITY ON LONGITUDINAL DISPERSIVITY VALUE EVALUATED USING DARCY COLUMN

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ABSTRACT

A study was conducted to determine solute transport parameters at a laboratory scale with variation in flow velocity through sand columns. For this purpose, a Darcy apparatus was fabricated in laboratory and experiment was performed with different flow velocities (1.76 and 6.27 cm^3/sec). Bulk density of sand (1.4575 g/cm^3), length of sand column (36 cm), volume of sand column (1385.44 cm^3), constant head of water on sand column (10 cm) and water filled porosity (45%) weremaintained for each set of experimentation. Experimental Breakthrough curves were drawn and the longitudinal dispersivity values were evaluated using the standard formulation.Longitudinal dispersivity values for the two sets were 10.32 and 4.35 cm, respectively. Results of the study clearly indicated that the longitudinal dispersivity values decreased with increase in flow velocity through sand columns.

KEY WORDS
Groundwater contamination
Longitudinal Dispersivity
Darcy Apparatus

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INTRODUCTION

Water is the basic unit of life. More or less, all Indian cities depend on underlying groundwater as the main drinking source. Groundwater contamination sources are many, and vary both in space and time. Daisy *et al*. (2008) studied fluoride in groundwater in Amber tehsil of Jaipur district. The analytical results revealed that Fluorideconcentration varies from 0.91 to 4.20 mg/L which should be less than 1.5 mg/L for standard drinking water.Pulak *et al*.(2010)also found high concentration(1.3 to 20.9 mg/L) of fluoride in groundwater in 6out of the total 43 sampled tube wells in Birbhum district of West Bengal, India.Thus, groundwater quality needs to be maintained at a sufficiently high standard to minimize treatment requirement. However, the prediction of the effects on groundwater levels and groundwater quality is not a trivial exercise.Inorder to predict the medium and long term responses of urban aquifers due to the contamination inserted, laboratory/ on-field studies based models are required to predict the contaminant dispersion. Prediction necessitates a quantitative understanding and description of the processes that govern solute transport. Hydrodynamic dispersion is one of such processes, which depends upon the aquifer parameter named longitudinal dispersivity.

Longitudinal dispersivity is evaluated in the field or in laboratory.Since longitudinal dispersivity is a one-dimensional parameter, flow distance is chosen as an appropriate scale of measurement. For a laboratory experiment, flow distance is generally determined by measuring the length of the horizontally oriented core through which the tracer travelled(Schulze-Makuch, 1996); for a field tracer test, by determining the distance between the injection and the withdrawal well (D'Alessandro *et al*.1997); and for a computer simulation, by the horizontal flow distance between a ground water source and a sink. Mallants *et al*. (2000) investigated the spatial variability in the tracer velocity and dispersivity in a shallow sandy aquifer in northern Belgium. He found that the average longitudinal dispersivity corresponding to a travel distance of 10 m was equal to 0.2 m.

Longitudinal dispersivity had been frequently shown to increase with the scale of measurement (Pickens and Grisak, 1981, Gelhar *et al*., 1985, Neuman, 1990, Schulze-Makuch and Cherkauer, 1997, Neumanand Federico, 2003), owing to many independent processes, including advection, local dispersion and diffusion, the non-stationary nature of hydraulic conductivity fields, and sampling bias. Singh (2006) proposed a simple method and an optimization method for explicit estimation of specific dispersivity and injected mass from an ideal breakthrough curve (BTC) due to an instantaneous injection of a solute using a derivative based technique in which the analytical derivatives are derived. Vashisht andShakya (2007) studied the mixing and movement of both fresh and saline water along with length of the interface zone depends upon the longitudinal dispersivity of the aquifer.Straface and Biase (2013)also presented several approaches to deduce the longitudinal dispersivity in a sand column during experiments of tracer tests by measuring the output fluid concentration and the self-potential signals in the electrodes inserted into the sand.

It is clear that the longitudinal dispersivity changes with the scale of the medium. But, whether this aquifer parameter varies in a fixed pattern in relation with the variation in flow velocity through the aquifer is not yet evaluated. Keeping above philosophy in mind, study was undertaken to fabricate Darcy apparatus in the laboratory, and to evaluate and analyse longitudinal dispersivity values with different flow velocities through Darcy column under constant head conditions.

MATERIALS AND METHODS

Development of experimental setup

The experimental setup in laboratory was developed based upon Darcy law basic theory as shown in Figure 1. The setup was made of steel pipe having diameter 7.00 cm with 48.50 cm length. The steel pipe was joined with the steel base of thickness 3.0 mm with the help of arc welding.

A steel pipe of 1.6 cm diameter and 20cm length was fixed at the base to act as outlet. Flow control tap was joined with this steel outlet with the help of a flexible plastic pipe. At the base of the column, nylon mesh having diameter equal to internal diameter of the column was fixed to trap any sand particle.Sand particles were thoroughly washed to remove any silt content present, which other wise interferes with tracer front. After placing 1 cm sand layer in the column, slight compaction was done to achieve density equivalent to real field situations. This step was repeated until the sand column was formed.

Evaluation of the longitudinal dispersivity

Longitudinal dispersivity of the porous medium was evaluated from experimental breakthrough curve equation (Kirkham and Powers, 1971)as:

$$\frac{C\,(x\,,t)}{C_0}=\frac{1}{2}\left[\operatorname{erf}_c\left\{\frac{1-p}{2\left(\frac{a_L\,p}{L}\right)^{\frac{1}{2}}}\right\}+e^{\frac{L}{a_L}}\operatorname{erf}_c\left\{\frac{1+p}{2\left(\frac{a_L\,p}{L}\right)^{\frac{1}{2}}}\right\}\right] \quad ..\ (1)$$

Where, $a_L$is longitudinal dispersivity; $p=\frac{Vt}{L}$ and is called pore volume; erf_c is the complementary error function; *V* is the velocity of flow; *L* is the length of the porous media; *t* is the time; *C* is the concentration of the solute in the effluent and C_0 is the initial concentration of the solute in the displacing fluid.

For evaluating the a_L, equation (1) was differentiated with respect to pore volume *p* and was evaluated at $p=1$ as:

$$\left.\frac{d\,(C/C_0)}{dp}\right|_{p=1}=\left(\frac{L}{4\pi a_L}\right)^{\frac{1}{2}} \quad ...\ (2)$$

Taking S_l,the slope of the experimental breakthrough curve at $p=1$, equation (2) was written as equation (3) which wasthe final solution for evaluating longitudinal dispersivity.

$$a_L=\frac{L}{4pS_l^2} \quad ...\ (3)$$

Observations and calculations

Before starting the experiment with first sand column, it was allowed to saturate from the bottom by placing the Darcy column in water tub. Sodium chloride (NaCl) solution was used as a tracer (C_0). Another nylon mesh was placed on the top of the sand column to avoid disturbances to column while pouring chloride solution. Chloride (*Cl*) was selected as appropriate anion for study, because of its non-interaction with the sand matrix and its simplicity in detection. Initial head above the sand column was fixed equal to 10 cm for every set of experiment. Effluent samples were collected in measuring flasks for every consecutive minute, until the complete depth of the chloride solution present on top of the sand column passed through outlet. After each experiment, warm water was passed through the sand column for making it free from any chloride ions. Net working length of sand column was measured after the completion of each set of the experiment. It was done purposely because, during the experimentation, due to continuous flow through the column, it attained the minimum possible length under its own weight. Concentration of chloride in the effluent samples was determined by EC meter.

From pre-defined weight of sand column, average bulk density of the sand column was evaluated. Considering the particle density of the aquifer sand to be 2.65 gcm^{-3}, water filled porosity*n* of the column was determined using the relation as:

$$\text{Porosity}\,(\%)=\left[1-\frac{\text{Bulk density}}{\text{Particle density}}\right]\times 100 \quad ...\ (4)$$

Average velocity of flow v_d through the sand column was determined using the relation as:

$$\text{Av. velocity of flow, } v_d=\frac{\text{Av. flow rate through the sand column (cm}^3\text{/sec)}}{\text{Cross - sectional area of the column (cm}^2)} \quad ..\ (5)$$

The average pore velocity was given by $V=\frac{v_d}{n}$. Using relation $p=\frac{Vt}{L}$, pore volumes passed through the sand column with respect to time were evaluated. Relative concentration ratios for the respective time periods were also evaluated, which were used for drawing the experimental breakthrough curve.

RESULTS AND DISCUSSION

Experiment was carried out with two different flow velocities and all other settings (e.g. length of the sand column, constant head of water on column) were kept same for each set of experimentation as tabulated in Table 1.

After the experimentation,chloride concentrations for all the samples of the experiments were analyzed and presented against time in Tables 2 and 3. Incorporating the particle density of the sand 2.65 g/cm^3 and bulk density values from Table 1 in equation (4), water filled porosity *n* of the column was determined equal to 45 percent. Pore volumes (*p*) passed through the sand columns with respect to time, EC in effluent and C/C_0 ratios with respect to for two sets are presented in

Table 1 : Specifications ofthe two sets of the sand column

Properties	Set 1	Set 2
Length of sand column	36 cm	36 cm
Volume of the sand column	1385.44 cm^3	1385.44 cm^3
Weight of the sand column	2019 g	2019 g
Bulk density	1.4575 g/cm^3	1.4575 g/cm^3
Flow velocity	1.76 cm^3/s	6.27 cm^3/s
Water filled porosity	45%	45%

Table 2 : Change in tracer concentration with time from the initial value of 1550 μs (C_0) for the first set

Time (min)	EC in effluent (µS)C	C/C_0	Pore volume (*p*)
0.5	650	0.419	0.085
1.0	650	0.419	0.170
1.5	650	0.419	0.255
2.0	660	0.426	0.340
2.5	660	0.426	0.425
3.0	670	0.432	0.510
3.5	690	0.445	0.595
4.0	720	0.465	0.680
4.5	780	0.503	0.765
5.0	850	0.548	0.850
5.5	1100	0.710	0.935
6.0	1350	0.871	1.020
6.5	1400	0.903	1.105
7.0	1450	0.935	1.190
7.5	1470	0.948	1.275
8.0	1500	0.968	1.360
8.5	1500	0.968	1.445
9.0	1500	0.968	1.530
9.5	1500	0.968	1.615

Table 3 : Change in tracer concentration with time from the initial value of 1500 μs (C_0) for the second set

Time (min)	EC in effluent (µS)C	C/C_0	Pore volume (*p*)
0.3	620	0.413	0.151
0.5	630	0.420	0.302
0.8	650	0.433	0.453
1.0	870	0.550	0.603
1.3	1130	0.700	0.754
1.5	1360	0.800	0.905
1.8	1440	0.960	1.056
2.0	1460	0.973	1.207
2.3	1470	0.980	1.358
2.5	1480	0.987	1.508
2.8	1480	0.987	1.659
3.0	1480	0.987	1.810

Table 4 : Average flow rate and average velocity of flow through sand column for different sets

	Average flow rate measured at outlet (cm^3/sec)	Cross-sectional area of the column (cm^2)	Average velocity of flow through sand column, v_d (cm/sec)	Average pore velocity (*V*)
Set 1	1.76	38.48	0.0457	0.102
Set 2	6.27	38.48	0.1629	0.362

Table 5 : Slope of experimental breakthrough curves and longitudinal dispersivity values for the two sets of sand columns

	Flow Velocity(cm^3/s)	Slope of experimental Breakthrough curve at $P_v = 1$	Longitudinal dispersivity (cm)
Set 1	1.76	0.527	10.32
Set 2	6.27	0.943	4.35

Tables 2 and 3. Average flow rate, average velocity of flow (v_d) andaverage pore velocity (*V*) through the sand columns for the two sets are tabulated in Table 4. Then, Experimental Breakthrough curves were drawn by plotting pore volume values against C/C_0 values as shown in Fig 2&3. Also, slopes of the curves were evaluated at $P=1$ which were then incorporated in the equation (3) to determine longitudinal dispersivity values and are tabulated in Table 5 along with

Figure 1: Experimental setup

slope of Experimental Breakthrough curves at$P = 1$. Perusal of the Table 5 clearly indicates that the longitudinal dispersivity value decreases with increase in flow velocity through sand column.

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REFERENCES

Daisy, S., Ashutosh and Khan, T.I. 2008.Ground water fluoride content and water quality in Amber Tehsil of Jaipur District.*The Ecoscan*.**2(2):**265-67.

D'Alessandro, M., Mousty, F., Bidoglio, G., Guimera, J., Benet, I., Sanchez-Vila, X., Garcia-Gutierrez, M. and DeLlano, A.Y. 1997. Field tracer experiment in a low permeability fractured medium; results from El Berrocal site. *J. Contaminant Hydrology*.**26(1-4):** 189-201.

Gelhar, L. W., Mantoglou, A., Welty, C. and Rehfeldt, K. R. 1985. A review of field-scale physical solute transport processes in saturated and unsaturated porous media. Palo Alto, California: Electric Power Research Institute EPRI EA-4190 Project 2485–5.

Kirkham, D. and Powers, W. L. 1971. Advanced Soil Physics.New York Wiley-Interscience.

Mallants, D., Espino, A., Hoorick, M.V., Feyen, J., Vandenberghe, N. and Loy, W. 2000. Dispersivity estimates from a tracer experiment in a sandy aquifer. *Ground Water*.**38(2):**304-310.

Neuman, S. P. 1990. Universal scaling of hydraulic conductivities and dispersivities in geologic media.*Water Resources Research*. **26(8):** 1749-758.

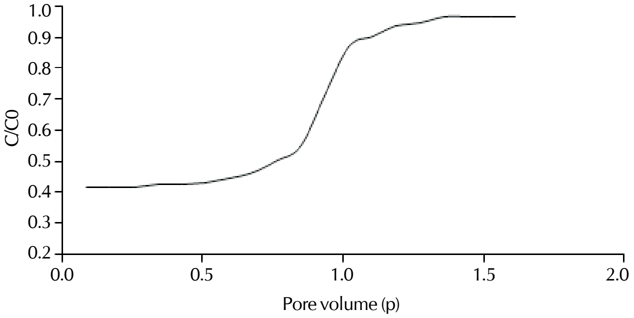

Figure 2: Experimental breakthrough curve for flow velocity of 1.76 cm^3/s

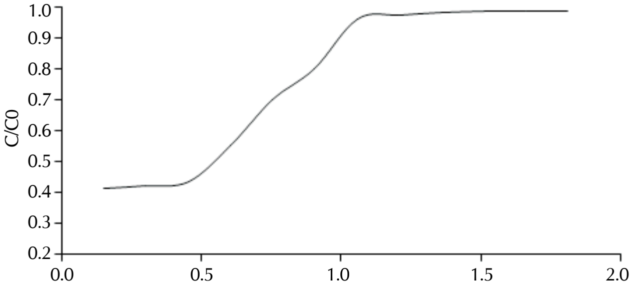

Figure 3: Experimental breakthrough curve for flow velocity of 6.27 cm^3/s

Neuman, S. P. and Federico, V. D. 2003. Multifaceted nature of hydrogeologic scaling and its interpretation.*Review of Geophysics*.**41(3):** 4.1-4.31.

Patra, P. K., Mandal, B. and Chakraborty,S. 2010. Hydrogeochemistry of fluoride rich groundwater inBirbhum district of West Bengal, India.*The Ecoscan*. **4(2and3)**:209-211.

Pickens, J. F. and Grisak, G. E. 1981. Scale-dependent dispersion in a stratified granular aquifer.*Water Resources Research*. **17(4):** 1191–1211.

Schulze-Makuch, D. 1996.Facies dependent scale behavior of hydraulic conductivity and longitudinal dispersivity in the carbonate aquifer of SE Wisconsin. Ph.D. diss., Department of Geological Sciences, University of Wisconsin–Milwaukee.

Schulze-Makuch, D. and Cherkauer, D. S. 1997. Method developed for extrapolating scale behavior. EOS, Transactions, American Geophysical Union.**78(1):**3.

Singh, S. K. 2006.Estimating dispersivity and injected mass from breakthrough curve due to instantaneous source.*J. Hydrology*. **329:** 685-691.

Straface, S. and Biase, M. D. 2013. Estimation of longitudinal dispersivity in a porous medium using self-potential signals. *J. Hydrology*. **505:** 163-171.

Vashisht, A. K. and Shakya, S. K. 2007. Evaluating longitudinal dispersivity in the laboratory.*Agricultural Engineering Today*. **31(2):** 1-5.