

Full Length Research Paper

Phosphate transport variation in sand column

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Groundwater pollution by human activities has been reported severally. Movement of leachate is identified as a major process of the phenomenon. Analytical work to replicate the process has been partially successful in soils. The objective therefore was to investigate the one dimensional (1-D) transport of phosphate at the side and centre of a sand column, verify and calibrate the model derived. Phosphate of known concentration was applied to the saturated sand column. A rainfall simulator located 45 cm above the column was showered over the soil. Samples were collected from drum outlets piped from the sides and centre of the column and analyzed at time intervals of 15, 30, 45, and 60 min. The rate of movement of phosphate with respect to depth in the soil were 0.045, 0.018, 0.013 and 0.013 ppm/cm at the side of the soil column while the rates at the centre were 0.036, 0.021, 0.014 and 0.001 ppm/cm at 15, 30, 45, and 60 min respectively. The model verified with experimental data showed predicted transport was in close agreement with experimental values with coefficient of correlation (r) ranging from 0.86 to 0.98. The amount of phosphate retained on the soil is higher at the centre than at the side of the soil column. The concentration of phosphate in the leachate generally decreased with depth and time.

Key words: Phosphate transport, column experiment, model, side flow, centre flow.

INTRODUCTION

Pollutants that contaminate groundwater may also be responsible for surface water contamination. Contaminants can migrate through soils and end up in ground water over time for example, pesticides, fertilizer, road salt, toxic substances from mining sites and used motor oil. It is also possible for untreated waste from septic tanks (which is common in Nigeria) and toxic chemicals from underground storage tanks to contaminate ground water (Asiwaju-Bello, 2004; Benka-Coker and Bafer, 1999). Displacement studies are important tools for understanding transport of solutes through soil. These provide insight about contaminant transport processes such as diffusion, dispersion, sorption, retardation and transformation (Shuckla et al., 2002; Shuckla et al., 2003; Fityus et al., 1999). Non-linear phosphate transport model with two consecutive reactions have been presented. It is believed that molecular

diffusion controls transport in low permeability materials, and diffusion through clays has been extensively studied in the laboratory. However, field scale studies have been more limited because diffusion occurs over long time scales. In the limited field studies that are reported, vertical transport was monitored in only a few locations and thus there was no assessment of the spatial variability of contaminant concentrations.

Long-term tritium transport through field scale compacted liner assumed that tritium transport was one dimensional in the vertical direction, findings showed no significant horizontal variability (Notodarmojo et al., 1999; Naseri et al., 2011; Ryden et al., 2006; Gerritse, 1993; Toupiol et al., 2002). The objectives of this study therefore were to investigate the one dimensional solute transport equation at the centre and side for single layer sand column, calibrate, and verify derived model.

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THEORY

1-D Contaminant transport

The convective-dispersion transport equation (CDE) remains the foundation on which most analyses of solute transport in porous media have been based. The 1-D non-steady equation for contaminant transport in a homogeneous soil with two consecutive reactions was derived by Notodarmojo et al. (19991) as

$$\frac{\partial C}{\partial t} = \frac{D_v}{R} \frac{\partial^2 C}{\partial z^2} - \frac{V}{R} \frac{\partial C}{\partial z} - \frac{K}{R} C^n m t^{m-1} \quad (1)$$

Where D_v is the hydrodynamic dispersion coefficient (cm^2/day); V is the average pore water velocity (cm/day); C is the solute concentration ($\mu\text{g}/\text{cm}^3$); t is the time of flow (days); K represents a constant (as presented in Equation 3) while m and n are the constants which indicate dependence of sorption on time and concentration respectively. The parameter R called retardation factor is expressed as

$$R = 1 + K t_n^m C^{n-1} \quad (2)$$

$$\text{Where } K = \frac{k_d}{\theta} \rho \quad (3)$$

The symbol ρ represents the bulk density, k_d is the partition coefficient while θ is the volumetric water content.

Assumptions for derivation of 1-D contaminant transport in soil

Let single layer represent a homogeneous soil column containing only sand of specific depth. Let it also be assumed that

1. The contaminant undergoes both sorption and desorption
2. The flow is one dimensional in a semi-infinite column length.
3. The contaminant solution is well mixed at the top boundary ($z=0$).
4. Initially ($t=0$), there is no sorbed or liquid phase contaminant in the column.
5. Sorption and desorption are described by the relationship

$$S = k_d C^n t^m \quad (4)$$

For linear sorption isotherm, $m=0$ and $n=1$. This implies that

$$S = k_d C \quad (5)$$

The initial and boundary conditions are:

$$C = S = 0 \text{ at } t = 0 \forall z \quad (7)$$

$$C = C_0 \text{ at } z = 0 \forall t \quad (8)$$

$$\frac{dC}{dt} \rightarrow 0 \text{ at } z \rightarrow \infty \quad (9)$$

The analytical solution to the solute transport equation for a concentration-type inlet boundary condition and semi-infinite column is

$$\frac{C(z,t)}{C_0} = \frac{1}{2} \operatorname{erfc} \left(\frac{Rz - Vt}{2(DRt)^{\frac{1}{2}}} \right) + \frac{1}{2} \exp \left(\frac{Vz}{D} \right) \operatorname{erfc} \left(\frac{Rz + Vt}{2(DRt)^{\frac{1}{2}}} \right) \quad (10)$$

These values of R , V and D used in this study are presented in Table 1.

Hypothesis testing

This is to test if the value of P , the population coefficient of correlation is sufficiently different from zero in order to decide whether predicted concentration C_p and the experimental concentration C_e are correlated. Reject the null hypothesis if 't' obtained from equation 13 designated as t_t is greater than t critical (t_c) obtained from the t -distribution table at level of significance, $\alpha = 5\% = 0.025$ for a 2-tailed test.

Null hypothesis (H_0): There is no significant relationship between C_p and C_e .

$$H_0: P = 0 \quad (11)$$

Alternative hypothesis (H_1): There is significant relationship between C_p and C_e .

$$H_1: P \neq 0 \quad (12)$$

The test statistics is given by

$$|t| = \left| \frac{r - p}{\sqrt{1 - r^2}} (\sqrt{n - 2}) \right| \quad (13)$$

Where

r = Coefficient of correlation of sample

n = sample size

p = population coefficient of correlation

C_p = predicted concentration from model

Table 1. Soil properties and contaminant transport coefficients.

Particular	Characteristic
Passing No 200 sieve (75 μ m)	57%
Liquid limit, Plastic limit and P.I	Non plastic
Group index	Nil
Passing No 40 sieve(0.425 mm)	42.38%
Passing No 10 sieve (2 mm)	99.4%
Moisture content	20.5%
Bulk density	1.2 g/cm ³
Permeability coefficient	9.57E-3 cm/s
Specific gravity	2.95
Porosity	0.407
Retardation factor	1.007
Partition coefficient	0.0024
Ave. pore water velocity	1 cm/day
Hydrodynamic dispersion coefficient D	111 cm ² /day

C_e = experimental concentration from laboratory.

MATERIALS AND METHODS

Sand was collected from the field beside University Clinic at Federal University of Technology Owerri, Nigeria. A 56 cm diameter by 88 cm length cylindrical steel tank was constructed with outlet pipes of 19 mm from the centre and sides of the tank. It was perforated at the base with 6 mm drilling bits covering a surface area of 352 cm. The tank was filled with sand and compacted. A 500 μ g/ml of phosphate stock solution was prepared by dissolving 1.097 g of dry KH_2PO_4 and making up to mark in a 500 ml volumetric flask. A one horsepower pump with a flow rate of 3300 L/h which was connected to a water tank was started and water was gently sprinkled evenly over the soil to saturate it using a rainfall simulator (shower head) located 45 cm centrally above the tank. The sprinkling of water continued until water came out from all outlets. The pump was stopped and 500 μ g/ml of phosphate solution was added evenly to the surface of the soil. The stopwatch was started as rainfall simulation continued. Care was taken that the soil surface was covered at all times with water without spilling. Phosphate samples were collected at time intervals of 15, 30, 45 and 60 min from all outlets. The concentrations of phosphate in these samples were determined. For colorimetric determination of phosphate, spectrophotometric method of analysis was employed (APHA, 1999). A sample containing 2 ml of phosphate was treated with 2 ml of 1.5% Ammonium molybdate solution, 5ml of de-ionized water and 1 ml of 0.1% stannous chloride. The resulting sky blue coloration was measured using a spectrophotometer at wavelength (λ) of 660 nm. The concentration of standard sample and their corresponding absorbance were determined. The standard concentrations were then plotted against absorbance. The absorbances for test samples were read off from the spectrophotometer. The concentrations for the test samples were derived from the graph of standard concentration against absorbance.

RESULTS AND DISCUSSION

Table 1 shows the properties and the 1-D transport

coefficient of the soil studied. The soil is A-1b, medium brown, very gravelly coarse sand based on AASTO classification (Das, 1999). Figures 1 to 8 show the experimental (C_e) and predicted (C_p) transport of phosphate in 15, 30, 45 and 60 min from the side and centre of the tank. The coefficient of correlation ranges from 0.86 to 0.98 respectively (Table 2). This is an indication of good agreement between experiment and model (Nwaogazie, 1999). The discrepancies between C_p and C_e in Figures 1 to 8 can be attributed to the assumptions adopted in the model which are simplification of very complex laboratory phenomenon, inaccuracies of instrumentation and possibly data processing error (Serrano, 2002). The model predicted was lower than experimental values (Toupiol et al., 2002).

The amount of phosphate in the leachate through the side of the sand column decreased at a rate of 0.045 ppm/cm in 15 min, 0.018 ppm/cm in 30 min and remained fairly constant at a rate of 0.013 ppm/cm in 45 and 60 min respectively. This implies that contaminants in soil travel fast initially and decreases with time probably due to saturation of the soil pore spaces. The amount of phosphate in leachate through the centre of the sand column decreased at a rate of 0.036 ppm/cm in 15 min, 0.021 ppm/cm in 30 min, 0.014 ppm/cm in 45 min to 0.001 ppm/cm in 60 min. The concentration of phosphate in the leachate generally decreased with depth and time. The rate of decrease in phosphate in the leachate is higher at the centre than the side of the side of the sand column. This shows that the soil may not be uniform with respect to porosity and sizes of particles (Saxena and Jarvis, 1995). The predicted (C_p) and experimental (C_e) phosphate concentrations at 15, 30, 45, and 60 min were in close agreement. Table 2 shows the correlation coefficient and t-test for predicted and experimental concentrations in the soil column. The t (computed) is

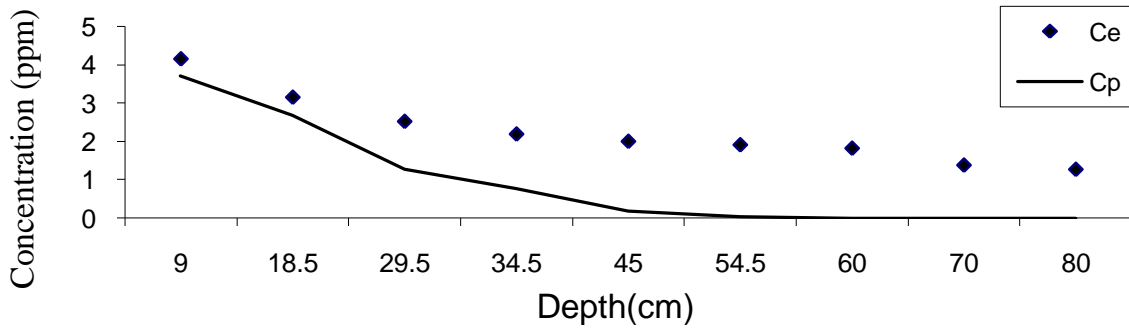


Figure 1. Sidewall flow in 15 min for Phosphate in sand column.

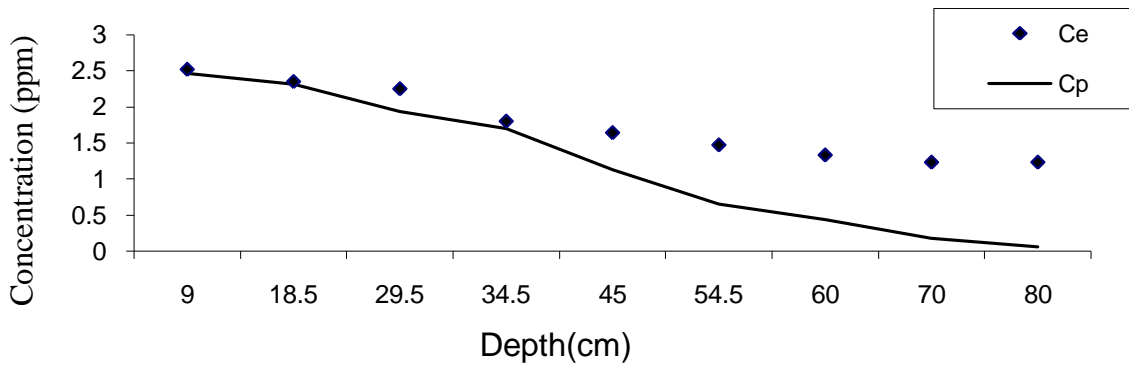


Figure 2. Sidewall flow in 30 min for Phosphate in sand column.

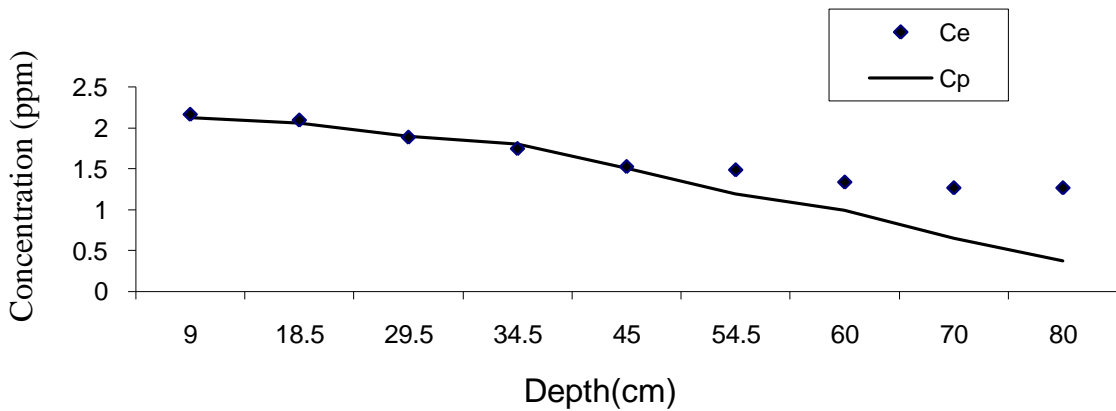


Figure 3. Sidewall flow in 45 min for phosphate in sand column.

greater than t (critical); therefore the null hypothesis was rejected. There was therefore a significant relationship between the predicted and experimental concentration values.

Conclusion

Understanding the transport of contaminants in soils is

the basis for protection of groundwater from pollution. Studies on the transport of leachate through single layer sandy soils were conducted in a laboratory column. The equation was calibrated using results from laboratory experiment. The movement of phosphate in the soil decreased at the rates of 0.045 ppm/cm, 0.018 ppm/cm, 0.013 ppm/cm, 0.013 ppm/cm at the side of the sand column while at the centre it decreased from 0.036 to 0.021

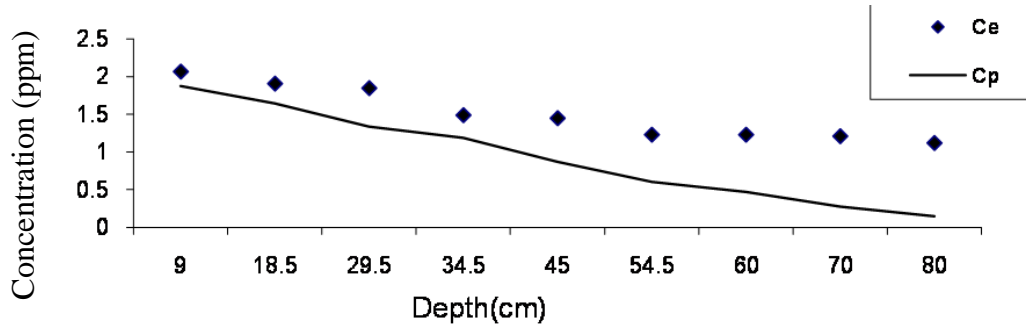


Figure 4. Sidewall flow in 60 min for Phosphate in sand column.

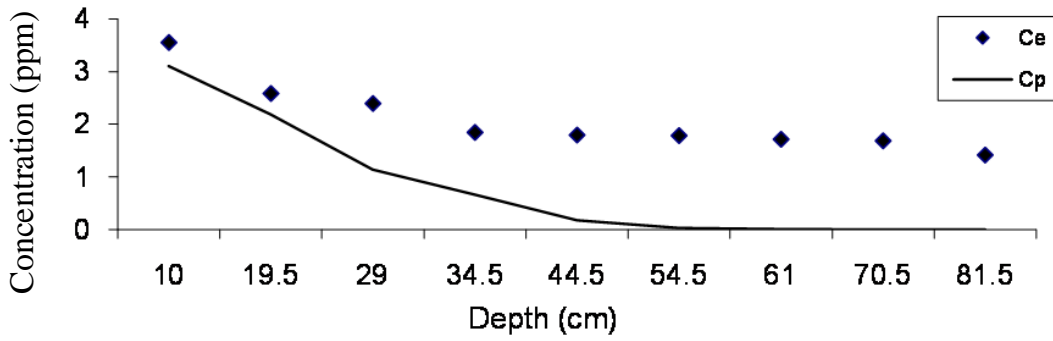


Figure 5. Centre flow in 15 min for Phosphate in sand column.

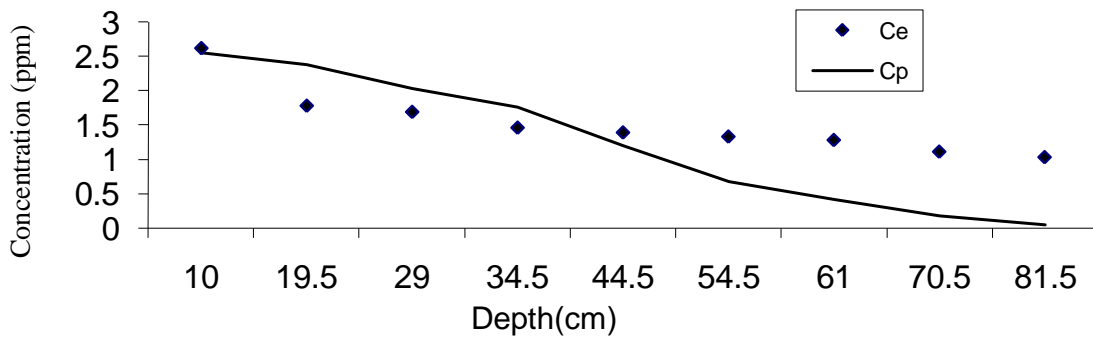


Figure 6. Centre flow in 30 min for Phosphate in sand column.

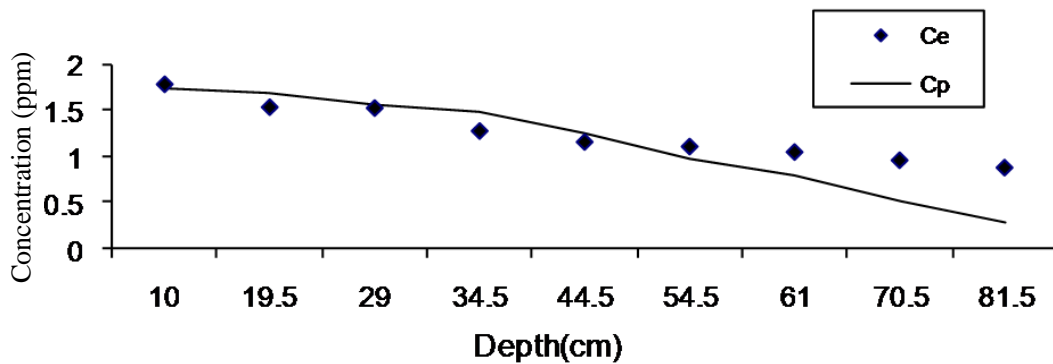


Figure 7. Centre flow in 45 min for Phosphate in sand column.

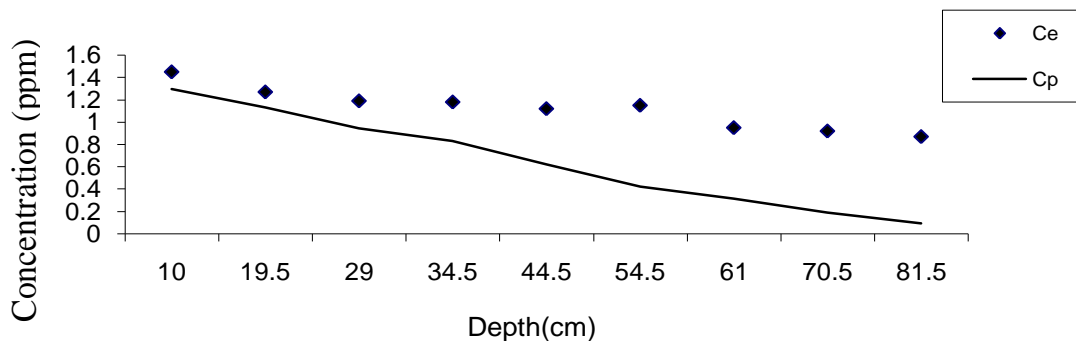


Figure 8. Centre flow in 60 min for Phosphate in sand column.

Table 2. Correlation coefficient and student t-test for model.

Flow	Time (min)	Test parameter			Regression equation
		$r_{(C_p/C_e)}$	$t_{\alpha/2}(\text{computed})$	$t_{\alpha/2}(\text{statistical table})$	
Side flow	15	0.97	10.60	2.36	$C_p=1.46C_e-1.33$
	30	0.98	13.00	2.36	$C_p=1.81C_e-1.97$
	45	0.94	7.30	2.36	$C_p=1.71C_e-1.41$
	60	0.97	10.60	2.36	$C_p=1.69C_e-1.6$
Centre flow	15	0.97	10.60	2.36	$C_p=1.46C_e-2.33$
	30	0.86	4.50	2.36	$C_p=1.81C_e-1.97$
	45	0.92	6.20	2.36	$C_p=1.71C_e-1.41$
	60	0.95	8.05	2.36	$C_p=1.69C_e-1.41$

ppm/cm, 0.014 to 0.001 ppm/cm at 15, 30, 45, and 60 min respectively. The 1-D contaminant transport through sandy soil shows that there is variation in transport of phosphate at the centre and side of the soil column. The predicted and experimental values of phosphate transport at the side and centre of the column were in close agreement with r values ranging from 0.86 to 0.98.

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