HYDROGEOLOGICAL TRANSPORT PHENOMENA

Final Exam **02/02/2005**

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1. A series of batch experiments have been carried out to study the sorption of phosphorous to a glacial outwash. Nine suspensions were prepared in nine different flasks, each containing 10 gm of the sediment and 100 mL of water with dissolved disodium phosphate in concentrations ranging from 0.85 mg/L to 14.6 mg/L. The flasks were shaken for 4 days on an autoshaker. The samples were then filtered and the filtrate (i.e. water) was analyzed for phosphate. The initial and the corresponding equilibrium concentrations of phosphate for the flasks are given in the table below.

Initial conc. (mg/L)	0.85	1.95	3.25	3.85	5.65	7.1	9.8	12.4	14.6
Equilibrium conc. (mg/L)	0.75	1.25	2.05	2.45	3.85	5.1	7.5	10.0	12.1

It was known that the sediments already had some adsorbed phosphate in their natural state. Thus, a solution of HCl was used to extract the adsorbed phosphate and it was found that the amount of phosphorus sorbed to the sediment prior to the test was 16 μg/g.

a. Plot the adsorption isotherm (s vs C) for the phosphate and observe the form of the curve.
b. What kind of isotherm does it suggest? Give the corresponding adsorption formula and calculate the adsorption parameters. *(each part 15 points)*

2. In a column experiment, four different solutes are injected at a rate of 200 ml/hr for 20 hours. Solute # l is conservative, solute # 2 undergoes equilibrium adsorption, solute # 3 adsorbs kinetically, and solute # 4 does not adsorb but undergoes decay. The column diameter is 10 cm and its length is 1 m. The soil porosity is 30 % and its dispersivity is 1 cm. From earlier measurements, distribution coefficient for solutes # 2 and 3 is found to be 0.333 L/kg. The soil bulk density is 1800 kg/m^3. The decay rate coefficient for solute # 4 is measured to be 0.1 hr^{-1}. The breakthrough curve for solute # 1 at a location x from the inlet is given by

$$C = \frac{1}{2} C_0 \operatorname{erfc}\left(\frac{x - vt}{2\sqrt{Dt}} \right)$$

a. Plot the normalized breakthrough curves for solute # 1 at x = 50 cm. Note that 5 to 6 points for the curve would be enough. *(10 points)*
b. Give the solution for solutes # 2 and # 4 based on equation 1 and plot the corresponding curves on the same graph as for solute # 1. Note that 5 points for each curve would be enough. *(10 points)*
c. If the kinetic rate coefficient for solute # 3 is 0.1 hr^{-1}, give a qualitative plot of its breakthrough curve on the same graph as those above. Draw another qualitative breakthrough curve for α = 10 hr^{-1}. Justify your answers. *(7 points)*
d. After 100 hours, how much of any of the solutes #1, 2, or 4 has remained in the column (either in the water or adsorbed)? *(3 points)*

3. A drinking water production well is operating in a homogeneous unconfined aquifer. At a distance of 100 m from the well, a municipal sewer starts to leak into the groundwater at a rate of 1 m^3/d. The leaking sewage water is contaminated with enteroviruses at a concentration of 200 viruses per liter. The abstraction rate from the well is about 210 m^3/hr. The aquifer is 10 m thick and is fully penetrated by the well. Its porosity is 31.8% and longitudinal dispersivity is estimated to be 1 m. If we neglect transversal dispersivity, governing equations for groundwater flow and transport in cylindrical coordinates are given as:

$$\frac{\partial}{\partial r}(rv) = 0 \quad \text{(steady-state flow)} \qquad [1]$$

$$\frac{\partial C}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}(rvC) = \frac{1}{r}\frac{\partial}{\partial r}\left(rD_r \frac{\partial C}{\partial r}\right) - r_{att} + r_{det} - r_{decay}^{l} \qquad [2]$$

$$\rho^b \frac{\partial s}{\partial t} = r_{att} - r_{det} - r_{decay}^{s} \qquad [3]$$

a. May we assume that dispersion is negligible? You must justify your answer with the aid of a quantitative argument. *(5 points)*

b. Because the leakage of the sewer has been going on for a long time, we may assume that the virus transport is steady state. Furthermore, assume that dispersion is negligible and that attachment, detachment, and decay may be modeled as first order processes. With these assumptions, equations [1] – [3] can be simplified drastically. Simplify the equations and combine them to reduce them to equations that can be integrated. Note that in a cylindrical coordinate, the flow towards the well has a negative sign. *(2 points)*

c. Solve the resulting equation for C and calculate the concentration of viruses in the discharge pipe of the well (the pipe that leaves the well). The values for attachment, detachment, and decay rate coefficients are: k_{att} = 0.05 day^{-1}, k_{det}= 10^{-3}day^{-1} μ_l = 0.01day^{-1}, and μ_s = 0.1 day^{-1}. If needed, use the relation: LN (X)=2.3*LOG(X). *(18 points)*

d. The maximum concentration level in drinking water is 2 viruses per 10000 m^3 of water. Is the allowable concentration in the produced groundwater exceeded? If yes, how far away should the leakage be in order not to cause a problem for the produced groundwater quality? At that distance, what would be the residence time of any viruses entering the groundwater? *(5 points)*

Tables of Error Function and Complementary Error Function
$\left(erfc(-\beta) = 2 - erfc(\beta)\right)$

β	erf (β)	erfc (β)
0	0	1.0
0.05	0.056372	0.943628
0.1	0.112463	0.887537
0.15	0.167996	0.832004
0.2	0.222703	0.777297
0.25	0.276326	0.723674
0.3	0.328627	0.671373
0.35	0.379382	0.620618
0.4	0.428392	0.571608
0.45	0.475482	0.524518
0.5	0.520500	0.479500
0.55	0.563323	0.436677
0.6	0.603856	0.396144
0.65	0.642029	0.357971
0.7	0.677801	0.322199
0.75	0.711156	0.288844
0.8	0.742101	0.257899
0.05	0.770668	0.229332
0.9	0.796908	0.203092
0.95	0.820891	0.179109
1.0	0.842701	0.157299
1.1	0.880205	0.119795
1.2	0.910314	0.089686
1.3	0.934008	0.065992
1.4	0.952285	0.047715
1.5	0.966105	0.033895
1.6	0.976348	0.023652
1.7	0.983790	0.016210
1.0	0.989091	0.010909
1.9	0.992790	0.007210
2.0	0.995322	0.004678
2.1	0.997021	0.002979
2.2	0.998137	0.001863
2.3	0.998857	0.001143
2.4	0.999311	0.000689
2.5	0.999593	0.000407
2.6	0.999764	0.000236
2.7	0.999866	0.000134
2.8	0.999925	0.000075
2.9	0.999959	0.000041
3.0	0.999978	0.000022