CEV 426 Environmental Remediation
Spring 2015
MIDTERM EXAM
12.04.2015
(60 minutes)

Student ID# :
Name :

Please read and sign the below statement:

I have read and understood the exam conduct rules of the Department of Environmental Engineering before starting my exam.

Signature:

Question 1 (8%)
Match the term on the left with the appropriate definition on the right.

Terms
Remediation engineering
NAPL
Water table
Partition coefficient

Definitions
A geologic unit that can store and transmit water at rates fast enough to supply reasonable amounts to wells.
The ratio of the concentrations of a chemical in two different phases under equilibrium conditions.
The surface at which pore water pressure in a porous medium is equal to atmospheric pressure.
The amount of water that can be transmitted horizontally by the entire saturated thickness of the aquifer under a hydraulic gradient of one.
Non-aqueous phase liquid.
The concentration of a chemical dissolved in water when that water is both in contact and at equilibrium with the pure chemical.
The development and implementation of strategies to clean up (remediate) the environment by removing the hazardous contamination.
A measure of the effect of the shape of the flowpath followed by water molecules in a porous media.

Question 2 (6%)
List 3 different groundwater contamination sources that you consider to be important.

The Complementary Error Function

TABLE 3-4 The Complementary Error Function[a]

x	erfc(x)	x	erfc(x)
0	1.0		
0.05	0.943628	1.1	0.119795
0.1	0.887537	1.2	0.089686
0.15	0.832004	1.3	0.065992
0.2	0.777297	1.4	0.047715
0.25	0.723674	1.5	0.033895
0.3	0.671373	1.6	0.023652
0.35	0.620618	1.7	0.016210
0.4	0.571608	1.8	0.010909
0.45	0.524518	1.9	0.007210
0.5	0.479500	2.0	0.004678
0.55	0.436677	2.1	0.002979
0.6	0.396144	2.2	0.001863
0.65	0.357971	2.3	0.001143
0.7	0.322199	2.4	0.000689
0.75	0.288844	2.5	0.000407
0.8	0.257899	2.6	0.000236
0.85	0.229332	2.7	0.000134
0.9	0.203092	2.8	0.000075
0.95	0.179109	2.9	0.000041
1.0	0.157299	3.0	0.000022

$$\mathrm{erfc}(x) = 1 - (2/\sqrt{\pi})\int_0^x e^{-\epsilon^2} d\epsilon$$
$$\mathrm{erfc}(-x) = 2 - \mathrm{erfc}(x)$$

[a] Adapted from Freeze and Cherry (1979).

Question 3 (16%)
A child went into a site and played with dirt contaminated with benzene. During his stay at the site he inhaled 2 m^3 of air containing 10 ppbV of benzene and ingested a mouthful (~5 cm^3) of soil containing 3 mg/kg of benzene. Calculate and compare the amount of exposure by the two routes (ingestion and inhalation).
Assume the bulk density of soil is 1.8 g/cm^3.
(You may assume that molar volume of gases at the site conditions is 24.05 L.)

Question 4 (16%)
The subsurface of a site is contaminated with tetrachloroethylene (PCE). A recent soil vapor survey indicates that the soil vapor contained 9 mg/L of PCE.

a. Estimate the PCE concentration in the soil moisture.
b. Estimate the PCE concentration adsorbed on the soil solids.

The soil contains 1% of organic carbon. Assume the adsorption follows a linear model.
This relationship can be used to estimate K_{oc} (L/kg): $K_{oc} = 0.63\ K_{ow}$

Question 5 (24%)

A column experiment is set up in the laboratory. Sand is packed into a cylindrical column, 1.5 m in length and 10 cm in diameter; water flows through the column with a seepage velocity of 1 m/hr. Porosity is 0.3. Five miligrams of salt are injected into the column (a pulse injection). Hydrodynamic dispersion coefficient is estimated to be 5×10^{-4} m^2/hr.

a. What will be the concentration of salt after an hour at a distance 0.9 m down the column?
b. After an hour, where (at what distance down the column) will you see the maximum salt concentration? What is this maximum concentration?
c. If you used a non-conservative tracer with a first-order decay coefficient of 0.1 hr^{-1}, what will the concentration of this tracer be after an hour at a distance 0.9 m down the column? Assume the tracer is not sorbed onto the sand.

Question 6 (30%)

The groundwater underneath a landfill is contaminated by landfill leachates containing 1,2-DCA. A recent groundwater monitoring in March 2015 indicated that 1,2-DCA have traveled 250 m down gradient.

Estimate:

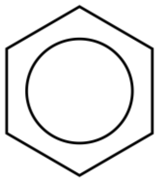
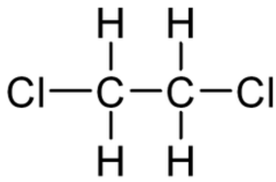
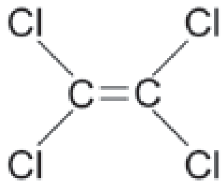
a. Retardation factor for 1,2-DCA in this aquifer.
b. The Darcy velocity of the groundwater.
c. The seepage velocity of the groundwater.
d. The velocity of plume migration.
e. The time when the 1,2-DCA plume first entered the aquifer.

The following data were obtained during the site assessment phase:

Aquifer porosity = 0.40
Aquifer hydraulic conductivity = 30 m/day
Groundwater gradient = 0.01
Bulk density of aquifer materials = 1.8 g/cm^3
Fraction of organic carbon of aquifer materials = 0.015
K_{ow} = 34 for 1,2-DCA
This relationship can be used to estimate K_{oc} (cm^3/g): $K_{oc} = 0.63\ K_{ow}$

Chemical Properties

Chemical	**Molecular weight (g/mole)**	**Henry's law constant (dimensionless)**	**log K_{ow}**
Benzene	78	0.24	2.13
1,2-Dicloroethane (1,2-DCA)	99	0.041	1.47
Tetrachloroethylene (PCE)	166	0.34	2.88

Benzene	**1,2-Dicloroethane (1,2-DCA)**	**Tetrachloroethylene (PCE)**
		

SOME EQUATIONS YOU MAY NEED:

Darcy's Law

$Q = -KA\dfrac{dh}{dl}$	Q : volumetric discharge (L^3/T) K : hydraulic conductivity (L/T) A : cross-sectional area (L^2) dh/dl : gradient of hydraulic head (L/L)

1-D Advective-Dispersive Transport Equation with First-Order Decay

Pulse Input	Continuous Input
$C(x,t) = \dfrac{M}{n\sqrt{4\pi D_L t}} e^{-(x-vt)^2/4D_L t} e^{-kt}$	$C(x,t) = \left(\dfrac{C_0}{2}\right)\mathrm{erfc}\left(\dfrac{x-vt}{2\sqrt{Dt}}\right)e^{-kt}$
C : Concentration (M/L^3) M : Mass input per unit area (M/L^2) x : Distance (L) D_L : Longitudinal Fickian transport coefficient (L^2/T) n : Porosity (L^3/L^3) t : Time (T) v : Seepage velocity (L/T) k : First-order decay rate coefficient (T^{-1})	C : Concentration (M/L^3) C_0 : Concentration at the source (M/L^2) x : Distance (L) D_L : Longitudinal Fickian transport coefficient (L^2/T) n : Porosity (L^3/L^3) t : Time (T) v : Seepage velocity (L/T) k : First-order decay rate coefficient (T^{-1})

Retardation

$R = 1 + K_d\dfrac{\rho_b}{n}$	R : Retardation factor $\left[(M/L^3)/(M/L^3)\right]$ K_d : Distribution coefficient (L^3/M) ρ_b : Bulk density (M/L^3) n : Porosity (L^3/L^3)