HYDROGEOLOGICAL TRANSPORT PHENOMENA

Final Exam **27/01/2017**

You are allowed to use only the Summary Lecture Notes and Analytical Solutions Handout.
Give all relevant formulas, steps of computations, and units. Make sure to account properly for units of different variables when making calculations. Whenever applicable, round off calculated values.
Start solving the problem you feel most confident about knowing its solution first.
Use an approximate value for the universal gas constant: R=8.3 J/moleK

1. Consider steady-state flow in a column experiment at a rate of 200 ml/hr. The column diameter is 9 cm and its length is 90 cm. The soil porosity is 35 % and its dispersivity is 1 cm. At a given instant, four different solutes are added to the inflow for the duration of 10 hours. The flow continues after the injection of solutes is stopped. Solute #1 is conservative, solute # 2 undergoes equilibrium adsorption, solute # 3 does not adsorb but undergoes decay, and solute # 4 undergoes both adsorption and decay. From earlier measurements, distribution coefficient, KD, for solutes # 2 and 4 is found to be 0.205 L/kg. The soil dry bulk density is 1700 kg/m3. The decay rate coefficient, λ, for solutes # 3 & # 4 is measured to be 0.1 hr^{-1}.

a. Give a qualitative plot of the normalized breakthrough curves for all four solutes at x = 45 cm. You don't need to calculate the error function. *(10 points)*
b. After 100 hours, how much (qualitatively) of any of the solutes would remain in the column (either in the water or adsorbed)? You must justify your answer in each case *(5 points)*

2. At an industrial plant, it is discovered that an abandoned underground storage tank has lost its content as a result of rapture. The tank was holding saltwater containing an unknown amount of a decaying and adsorbing solute. Also, the salt concentration of the solution and the time of rupture are unknown. The contents were released fast below groundwater table and had quickly spread over the whole depth of the aquifer, which has a saturated thickness of only 3 m. The contaminated aquifer consists of a homogeneous sandy soil. The half-life time of solute was measured to be 1000 days. From existing boreholes, it is determined that the direction of the groundwater flow is from west to east. The slope of the groundwater table is 0.1 cm/m. Hydraulic conductivity is determined by means of slug tests and has a uniform value of 12 m/day.
A number of observation boreholes are constructed downstream of the spill point. They've been sampled regularly and analyzed for determining the concentration of salt and the radioactive solute. The peak concentrations are measured in two boreholes that lie along a more-or-less straight line passing through the location of the storage tank. Borehole A is 5 m and borehole B is 9 m away from the tank. The measured peak concentration values and the standard deviations for salt are given in the following table (for convenience, assume that each month has 30 days):

Borehole	Borehole distance to the source (m)	Date	Peak conc. of salt (mg/L)	Longitudinal standard deviation (cm)
A	5	20/06/1996	10.6	200
B	9	30/09/1996	5.9	268

a. Calculate Darcy velocity, the real flow velocity, and porosity. *(7 points)*
b. Determine the (approximate) date of tank rupture. *(3 points)*
c. Calculate the longitudinal dispersivity of the aquifer and then estimate the transversal dispersivity using a rule of thumb (you need only one of the data points) *(5 points)*
d. Calculate the total mass of salt that was in the tank (you need only one of the data points). *(10 points)*
e. The peak concentration of the radioactive solute in the groundwater was measured to be 100 ppb in borehole A on 25/09/1996. Calculate the distribution coefficient of the solute. *(5 points)*
f. Calculate the total mass of the radioactive solute that was in the tank. *(10 points)*

Hint: You may model the pollution as an instantaneous line source in a 2D infinite domain.

3. In an experiment, a solvent is prepared by mixing 5 mL of TCE and 5 mL of Benzene.
a) Calculate the mole fraction of each component in the solvent. . *(5 points)*
This solvent is then thoroughly mixed with 20 mL of water and 50 grams of dry sand in a container with a total of volume of 83 mL (so, the rest is air). The container is closed and equilibrium is allowed to be reached.
b) Determine through calculations whether any Benzene remains in the solvent after equilibrium is reached. Calculate the remaining mass of Benzene. *(15 points)*

Component	Mass density (kg/m^3)	Molecular Wt. ($g.mole^{-1}$)	Vapor pressure (Pa)	*Solubility* (mg/L)	*Distribution Coeff. (L/kg)*
TCE	1,460	131	7,800	1100	0.65
Benzene	876	78	1200	1800	0.85

4. This problem is based on a real laboratory experiment (modified for the purpose of this question). Consider a column of 20 cm long and 6cm in diameter. The column was filled with homogeneous sand with a porosity of 30%. A valve at the top of the column was connected to a balloon in order to keep the air pressure atmospheric. The lower 5 cm of the sand was saturated with water containing TCE at a concentration of 550 mg/L. The concentration was kept constant by slow flow of water horizontally through the sand. Assume that the upper 15 cm of sand is completely dry, filled with stagnant air. See the figure below. For material properties of TCE, see the table above.
a) Obviously TCE volatilizes into the air phase and diffuses upwards. Calculate the equilibrium partial pressure of TCE that will be reached in the air phase of the dry sand (i.e., after a long time). *(5 points)*
b) Write the governing equation and initial and boundary conditions for diffusion of TCE within the air phase and give the (approximate) analytical solution for its concentration. *(10 points)*
c) Calculate the approximate time at which the partial pressure everywhere in the air phase of the column reaches 97% of maximum value. The molecular diffusion coefficient in the air is 0.15 cm^2/s. Assume a value of 1.5 for tortuosity of sand. *(10 points)*
(Hint: with the presence of the balloon, the air phase may be approximated as a semi-infinite domain).