# National Exams May 2017

## 04-Geol-B1 Contaminant Hydrogeology

**Duration: 3 hours**

**Notes:**

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is an OPEN BOOK EXAM.
   Any non-communicating calculator is permitted.

3. FIVE (5) questions constitute a complete exam paper.

4. Each question is of equal value.

5. Most questions require an answer in essay format. Clarity and organization of the answer are important. Please show your work.

6. Unless otherwise specified, use water density = 998 kg/m$^3$, water viscosity = 0.001 kg/m-sec, g = 9.81 m/s$^2$, 1 atm = 101300 Pa, and
   R = 8.314 Pa-m$^3$/gmol-K = 0.082 atm-L/mol-K.

**Marking Scheme:**

| | | | |
|---|---|---|---|
| **1.** | (a) 12 marks; | (b) 5 marks; | (c) 3 marks |
| **2.** | (a) 3 marks; | (b) 3 marks; | (c) 7 marks; (d) 7 marks |
| **3.** | (a) 4 marks; | (b) 9 marks; | (c) 7 marks |
| **4.** | (a) 9 marks; | (b) 3 marks; | (c) 8 marks |
| **5.** | (a) 6 marks; | (b) 5 marks; | (c) 9 marks |

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**Question 1**

**a)** State if the following statements are **True (T)** or **False (F)**: **(12 marks)**

1) ____ Mechanical dispersion does not occur in stationary ground water.
2) ____ The coefficient of hydrodynamic dispersion increases with increasing values of the dispersivity or diffusion coefficient.
3) ____ Darcy's Law cannot be used for unsaturated flow.
4) ____ Coarse-grained soils can act as barriers to water flow.
5) ____ Diffusion of contaminants in water-saturated soils is always insignificant relative to mechanical dispersion.
6) ____ Reducing the interfacial tension between two fluids in a porous medium will also reduce measured capillary pressure, if the fluid saturations do not change.
7) ____ Geothermal energy is a good source of energy to heat homes in North America but not practical for cooling.
8) ____ In a porous media system that contains both air and water if the air saturation decreases the relative permeability of the air phase will increase.
9) ____ Excavation and disposal is the best option for remediation for any situation.
10) ____ Biodegradation of hydrocarbons always requires oxygen as electron donor.
11) ____ Nutrients, air, and acclimated microbes are always used in biopiles.
12) ____ Water pressure in any unsaturated soil will always be less than air pressure.

**b)** Explain how tritium can be used in hydrogeological investigations. In reference to the use of oxygen and hydrogen isotopes what is meant by the "meteoric water line"? **(5 marks)**

**c)** The approximate coefficient of molecular diffusion for $Cl^-$ in water is $2 \times 10^{-5}$ $cm^2/s$. Estimate its effective value in a saturated porous medium having a porosity of 0.3 and tortuosity of 1.22. **(3 marks)**

## Question 2

a) List six types of sources of groundwater contamination. **(3 marks)**

b) Determine the time required for 99 % of a chemical to hydrolyze in water assuming a hydrolysis rate coefficient of 0.001 $day^{-1}$. **(3 marks)**

c) At a contaminated site the concentration of benzene dissolved in groundwater at the water table was 260 µg/L. Determine the equilibrium partial pressure in the adjacent soil gas. The Henry's law constant for the partitioning reaction of benzene is 5.5 x $10^{-3}$ atm-$m^3$/mol and the molecular weight of benzene is 78.1 g/mol. If benzene was present as the pure liquid having a vapour pressure of 0.1 atm, what would the partial pressure be? **(7 marks)**

d) A leaking underground storage tank released 1000 gal of gasoline (density approximately 0.9 g/mL and approximately 1% benzene) to the subsurface. After one year, the resulting dissolved benzene plume is 100 ft long, 50 ft wide, and 10 ft deep. The average benzene concentration of the plume is 0.1 mg/L, and the porosity of the aquifer is 0.3. If no hydrocarbon is lost from volatilization or biodegradation, and there is no sorption of benzene to the soil how much of the original release is in the dissolved phase, and how much is in the NAPL phase? **(7 marks)**

## Question 3

a) The groundwater in a confined aquifer travels with a linear velocity of 16 cm/day. Determine the transport velocity of an organic contaminant having a $K_d$ of 6.6 mL/g in the medium with porosity of 0.37 and solids density of 2.64 g/$cm^3$. **(4 marks)**

b) In a laboratory column experiment some non-contaminated soil, collected from a field site, has been placed in a 6 cm diameter and 110 cm long column. The soil has a porosity of 0.36, a bulk density of 1.85 g/$cm^3$ and a $f_{oc}$ of 1.5%. Water containing 50 mg/L of PCE (PCE Henry constant, H = 0.008 atm-$m^3$/mol; $\log K_{ow}$ = 2.88 at 20 °C; $\log K_{OC} = -0.21 + \log K_{OW}$) has been added to the column at a rate of 0.35 L/hour. Determine the concentration of PCE in the effluent from the column after 3 days if the soil column dispersivity is 0.06 m and PCE effective diffusion coefficient is $10^{-10}$ $m^2$/sec. Assume linear adsorption of PCE to the soil. **(9 marks)**

c) PCE in **3b** was determined to be undergoing first order decay due to biodegradation from indigenous microorganisms present in the soil. Recalculate your answer to **3b** considering the first order decay with a first order decay rate of 0.09 $day^{-1}$. **(7 marks)**

## Question 4

a) A tanker truck spills a load of water contaminated with salt in a long swath along a ditch that is above an aquifer and perpendicular to the direction of groundwater flow (Darcy velocity = 0.09 m/day) in the aquifer (porosity of 0.37, longitudinal dispersivity of 26 m, salt effective diffusion coefficient of $1.1 \times 10^{-10}$ $m^2/s$). The water quickly infiltrates the aquifer and provides an instantaneous pulse input of chloride (1000 kg of chloride) into the aquifer. If the transport can be considered one-dimensional, determine the maximum concentration of chloride in the aquifer after 110 days, and the location of this concentration. Also determine the concentration of chloride 50 m from the ditch after 110 days. **(9 marks)**

b) A capillary tube of radius 0.25 mm is inserted into a beaker of water. If the air-water interfacial tension is 72 dynes/cm, determine height of the water in the tube. Assume water is completely wetting to the tube material. **(3 marks)**

c) The depth of the water table at a site is 4 m from the ground surface. The capillary pressure and saturation relationship of the soil at the site is best fit by a Brooks-Corey curve with $\lambda = 2.75$, $\Psi_d = 0.43$ m, $S_{wr} = 0.15$, $S_m = 1.0$. The soil has a porosity of 0.37. Determine the moisture content and relative humidity in the soil at the ground surface if the hydraulic head gradient in the vadose zone is at a uniform value of 0.1 (hydraulic head lower at the water table than at the ground surface) and the temperature is 10 °C. **(8 marks)**

## Question 5

a) Briefly discuss three principal components required for the development of a conceptual site model. **(6 marks)**

b) Comment on the contaminant types that bioremediation is well suited for and the optimum conditions under which in-situ bioremediation works. **(5 marks)**

c) An underground storage tank at an industrial facility leaked approximately 100,000 litres of gasoline over a five-year period into a shallow sandy aquifer. An aggressive program of product recovery collected approximately 40,000 liters of free product. i) Explain what potential problems could occur by simply leaving the residually-saturated fraction of the spill in the ground. ii) What are the feasible alternatives for removing this remaining volume of gasoline? **(9 marks)**

TABLE G.2 The Error Functions

| X | erf(X) | erfc(X) |
|---|---|---|
| 0.00 | 0.000000 | 1.000000 |
| 0.05 | 0.056372 | 0.943628 |
| 0.10 | 0.112463 | 0.887537 |
| 0.15 | 0.167996 | 0.832044 |
| 0.20 | 0.222703 | 0.777297 |
| 0.25 | 0.276326 | 0.723674 |
| 0.30 | 0.328627 | 0.671373 |
| 0.35 | 0.379382 | 0.620618 |
| 0.40 | 0.428392 | 0.571608 |
| 0.45 | 0.475482 | 0.524518 |
| 0.50 | 0.520500 | 0.479500 |
| 0.55 | 0.563323 | 0.436677 |
| 0.60 | 0.603856 | 0.396144 |
| 0.65 | 0.642029 | 0.357971 |
| 0.70 | 0.677801 | 0.322199 |
| 0.75 | 0.711156 | 0.288844 |
| 0.80 | 0.742101 | 0.257899 |
| 0.85 | 0.770668 | 0.229332 |
| 0.90 | 0.796908 | 0.203092 |
| 0.95 | 0.820891 | 0.179109 |
| 1.00 | 0.842701 | 0.157299 |
| 1.10 | 0.880205 | 0.119795 |
| 1.20 | 0.910314 | 0.089686 |
| 1.30 | 0.934008 | 0.065992 |
| 1.40 | 0.952285 | 0.047715 |
| 1.50 | 0.966105 | 0.033895 |
| 1.60 | 0.976348 | 0.023652 |
| 1.70 | 0.983790 | 0.016210 |
| 1.80 | 0.989091 | 0.010909 |
| 1.90 | 0.992790 | 0.007210 |
| 2.00 | 0.995322 | 0.004678 |
| 2.10 | 0.997021 | 0.002979 |
| 2.20 | 0.998137 | 0.001863 |
| 2.30 | 0.998857 | 0.001143 |
| 2.40 | 0.999311 | 0.000689 |
| 2.50 | 0.999593 | 0.000407 |
| 2.60 | 0.999764 | 0.000236 |
| 2.70 | 0.999866 | 0.000134 |
| 2.80 | 0.999925 | 0.000075 |
| 2.90 | 0.999959 | 0.000041 |
| 3.00 | 0.999978 | 0.000022 |