Key

Fall 2005
CEE 432/532 Fate and Transport of Pollutants
Midterm #2 (Time 120 minutes)

Instructions

Write your Name - NOW.

Please turn in your exam after 90 minutes.

Each subpart of a particular problem may or may not be independent. For example, you may need correct answer of (ii) to get correct answer of (iii).

In order to get partial credit, you must show your work/calculations.

Most questions require that you calculate answers in specified units, please read the problem carefully.

1. A stream has a channel area of 0.3 m^2 (1 m wide and 0.3 m deep) and a discharge of 360 ~~m^3/day~~ m^3/hr. For a tracer test, 2.5 gm of Rhodamine dye are suddenly introduced at point A in the channel at time t = 0. The spatial variance of the dye associated with the maximum concentration is 0.9 m^2.

(i) Point B is located 50 m downstream of A. The time for maximum concentration of dye to appear at point B (in minutes) is most nearly:

(A) 0.046
→ (B) 2.5
(C) 1.25
(D) none of the above

$Q = \frac{360 m^3}{hr} = 0.1\ m^3/sec$, $V = \frac{0.1}{0.3} = 0.33\ m/sec$

$\tau_B = \frac{50 m}{0.33 \frac{m}{sec}} = 151.51\ sec$

$= 2.5\ min$

(ii) The one-dimensional dispersion coefficient associated with the stream (in m^2/sec) is most nearly:

→ (A) 3.0 x 10^{-3}
(B) 2.67 x 10^{-3}
(C) 5.34 x 10^{-3}
(D) 10.8 x 10^{-3}

$D_L = \frac{\sigma^2}{2t} = \frac{(0.9)}{2 * 151.51}$

$= 2.97 \times 10^{-3}\ \frac{m^2}{sec}$

(iii) The maximum concentration of dye at point B (in gm/m^3) is most nearly:

(A) 1.31
(B) 2.62
(C) 2.97
→ (D) 3.7

$M = mass/x\text{-sectional area} = 2.5/0.3$

$= 8.33\ gm/m^2$

$C_{max} = M/\sqrt{4\pi D_L t} = 8.33/\sqrt{(4\pi * 2.97 \times 10^{-3} * 151.51)}$

$= 3.50\ gm/m^3$

(iv) The advective flux of dye (gm/m^2-sec) is most nearly:

(A) 3.7
→ (B) 1.22
(C) 0.61
(D) 0.30

Advective flux $= CV$

$= 3.7\ \frac{gm}{m^3} * 0.33\ \frac{m}{sec}$

$= 1.22\ \frac{gm}{m^2\text{-}sec}$

(l) Conc. of benzene $= \dfrac{23,625,000}{2,345,682}$

$= 10.07 \ \dfrac{mg}{L}$

$\dfrac{\pi}{4}(145)^2 * d = \dfrac{2,345,682 \ L}{3.78 \ \frac{L}{gal} * 7.48 \ \frac{gal}{ft^3}}$

$= 82,961 \ ft^3$

$\Rightarrow d = 5.02 \ ft$

Ans. 5 ft and 10 mg/L

hr

2. Using methane as a tracer, the gas exchange co-efficient for a pond (diameter of 145 ft and a water depth of 3 ft) is estimated to be 12 cm/~~sec~~. ~~A~~ quarter million gallons of industrial wastewater containing 25 ppm of benzene (C_6H_6) is discharged into the pond.

(ii) The final pond depth (in ft) and the concentration of benzene (in mg/L) are most nearly:

Volume $= \frac{\pi}{4}(145)^2 * 3 * 7.48$ gal/ft^3 $= 370,551$ gal

(A) 10 and 10, respectively.
(B) 5 and 5, respectively
→ (C) 5 and 10, respectively
(D) 10 and 5, respectively

Total vol $= 370,551 + 250,000 = 620,551$ gal $* 3.78 \frac{L}{gal}$ $= 2,345,568$ L

Amount of benzene $= 250,000 * 3.78 * 25 = 23,625,000$ mg

(ii) The gas exchange co-efficient for benzene (in cm/hr) is most nearly:

(A) 58
→ (B) 5.4
(C) 4.5
(D) 2.4

$$\frac{k_b}{k_m} = \frac{\sqrt{MW_m}}{\sqrt{MW_b}} \Rightarrow k_b = k_m * \frac{\sqrt{16}}{\sqrt{78}} = 12 * \sqrt{\frac{16}{78}}$$

$= 5.4$ cm/hr

(iii) The total benzene flux to the atmosphere (in gm/hr) is most nearly:

Flux $J = 5.4 \frac{cm}{hr} * \frac{10\ mg}{L} * \frac{L}{1000\ cm^3} = 0.054 \frac{mg}{cm^2\text{-}hr}$

(A) 0.89
(B) 5.71
→ (C) 830
(D) 1,054

Total flux $= 0.054 \frac{mg}{cm^2\text{-}hr} * \left[\frac{\pi}{4}(145)^2 * (30.48)^2\right] * \frac{1}{1000}$

$= 828$ gm/hr

(iv) If volatilization is the only removal mechanism from the pond, the benzene concentration in the pond after ~~one~~ two week (in ppb) is most nearly:

(A) 3.6
(B) 5.4
→ (C) 23
(D) 168

Use (1-19)

$$\left(\frac{dm}{dt}\right)_{ben} = k_{ben} C_{ben} * A = J \cdot A$$

Dividing both side by volume

$$\frac{dC_{ben}}{dt} = k_{ben} C_{ben} \cdot \frac{1}{depth}$$

First order: $k = k_{ben} \cdot \frac{1}{depth} = \frac{5.4\ cm}{hr} * \frac{1}{10\ ft} * \frac{3.28\ ft}{m} \cdot \frac{1\ m}{100\ cm}$

$= 0.0177\ hr^{-1}$

Then $= C_o e^{-kt} = 10 e^{-(0.0177 * 168 * 2)}$

$= 0.026 \frac{mg}{L} = 26.1$ ppb.

See Sln to Asn #6
Example 2-6

O_2

$$\frac{10 \text{ mg } O_2}{L} * \frac{25 \text{ L}}{1} * \frac{1 \text{ gm}}{1000 \text{ mg}} * \frac{1 \text{ mol}}{32 \text{ g } O_2} = 7.8 \times 10^{-3} \text{ mol}$$

Organic = 0.23 mol

O_2 = 7.8×10^{-3} mol

1 mole organic ≡ 1 mole O_2

→ anaerobic

(ii) zero

(iii) $0.23 - (7.8 \times 10^{-3}) = 0.222$ mole organic

$$\frac{1}{4} CH_2O + \frac{1}{5} NO_3^- + \frac{1}{5} H^+ \rightarrow \frac{1}{10} N_2 + \frac{1}{4} CO_2 + \frac{7}{20} H_2O$$

$$\frac{2 \text{ mg } NO_3}{L} * \frac{25 \text{ L}}{1} * \frac{1 \text{ gm}}{1000 \text{ mg}} * \frac{1 \text{ mole } NO_3^-}{62 \text{ gm } NO_3} = 8.06 \times 10^{-4} \text{ mole}$$

organic consumed $= \left(\frac{5}{4}\right) * 8.06 \times 10^{-4}$

$= 1 \times 10^{-3}$ mole

organic remaining $= 0.222 - 1 \times 10^{-3} = 0.221$ mole

$$\frac{1}{4} CH_2O + \frac{1}{8} SO_4^{-2} + \frac{1}{8} H^+ \rightarrow \frac{1}{8} HS^- + \frac{1}{4} CO_2 + \frac{1}{4} H_2O$$

$$SO_4^{-2} = \frac{15 \text{ mg } SO_4}{L} * \frac{25 \text{ L}}{1} * \frac{1 \text{ gm}}{1000 \text{ mg}} * \frac{1 \text{ mole } SO_4^{-2}}{96 \text{ gm } SO_4}$$

$= 3.9 \times 10^{-3}$ mole SO_4^{-2}

organic consumed $= 2 * (3.9 \times 10^{-3}) = 7.8 \times 10^{-3}$ mole

Remaining = 0.213 mole

3. A 10 gm (dry weight) mouse is accidentally bottled in a 25-liter jug of spring water that initially contains 10 mg/L of dissolved oxygen. Assume that 70% of the mouse's dry weight is CH_2O.

The jug also contains 2 ppm of NO_3^- and 15 ppm of SO_4^{-2}.

(i) Which of the following statement is correct?

(i) $\frac{1}{4} CH_2O + \frac{1}{4} O_2 \rightarrow \frac{1}{4} CO_2 + \frac{1}{4} H_2O$

$CH_2O = \frac{0.7 \text{ gm } CH_2O}{1 \text{ gm mouse}} * \frac{1 \text{ mole } CH_2O}{30 \text{ gm } CH_2O} = 0.23$

(A) The environment in the jar will be aerobic.
(B) Amount of oxygen is sufficient to oxidize the organic matter.
→ (C) The environment in the jar will be anaerobic.
(D) One mole of CH_2O require one-quarter mole of oxygen.

(ii) The amount of oxygen (in moles) remaining in the bottle is most nearly:

(A) 7.8×10^{-3}
→ (B) zero
(C) 0.225
(D) none of the above.

(iii) The amount of sulfate present in the jug (in moles) is most nearly:

(A) 8.1×10^{-4}
→ (B) zero
(C) 0.225
→ (D) 3.9×10^{-3}.

(iv) The amount of organic matter (in moles) remaining in the bottle is most nearly:

(A) 8.1×10^{-4}
(B) zero
→ (C) 0.225
(D) 4.09×10^{-3}.

4. A disgruntled postal worker dumps a liquid culture of Anthrax into a straight unlined earth canal 1,000 m upstream of the intake pipe for the municipal water works; 10^{11} organisms are introduced into the river which has a cross section and hydraulic radius of 0.6 m^2 and 0.2 m, respectively.

(i) Assuming a slope of 0.00055, the stream velocity (in m/sec) is most nearly:

→ (A) 0.35
(B) 0.53
(C) 0.80
(D) 1.76

$R = 0.2\ m = 0.2 * 100 * \frac{1}{30.48} = 0.65\ ft.$

$V = \frac{1.49}{n} R^{2/3} S^{1/2} = \frac{1.49}{0.02} (0.65)^{2/3} (0.00055)^{1/2}$

$= 1.3\ ft/sec = 1.3 * \frac{1}{3.28}$

$= 0.4\ m/sec$

(ii) Assuming no decay of the culture with time and the longitudinal dispersion coefficient is 0.1 m^2/sec, the maximum concentration of organisms (in organisms/m^3) expected at the plant is most nearly:

(A) 1.1×10^{11}
(B) 2.1×10^{10}
→ (C) 3.1×10^{9}
(D) 4.1×10^{8}

$\tau = \frac{1000\ m}{0.4\ m/sec} = 2500\ sec$

$C_{max} = \frac{M}{\sqrt{4\pi D_L \tau}} = \frac{10^{11}/0.6}{\sqrt{4\pi * 0.1 * 2500}}$

$= 2.97 \times 10^{9}\ orgs/m^3$

(iii) The width of organism cloud at the intake (in m) constituting 68% of the organism mass is most nearly:

(A) 84
→ (B) 42
(C) 21
(D) none of the above.

$\sigma = \sqrt{2 D_L \tau} = \sqrt{2 * 0.1 * 2500}$

$= 22.36\ m$

$68\% \approx 2\sigma = 44.72\ m$

(iv) If the organisms have a 10-hr half life in the river, the maximum concentration of organisms (in organisms/m^3) expected at the plant is most nearly:

(A) 1.0×10^{11}
(B) 2.0×10^{10}
→ (C) 3.0×10^{9}
(D) 4.0×10^{8}

$k = (0.693/\tau_{1/2}) * \frac{1}{3600} = 1.9 \times 10^{-5}\ sec^{-1}$

Using results of (ii)

$C_{max} = \frac{M}{\sqrt{4\pi D_L \tau}} \cdot e^{-kt}$

$= (2.97 \times 10^{9}) * e^{-(1.9 \times 10^{-5}) * 2500}$

$= 2.83 \times 10^{9}\ orgs/m^3$

⇒ no change

(iii) Propane travel time

$$1500\ m - 200\ m = 1300\ m$$

$$\tau = \frac{1300\ m}{0.4\ m/sec} = 3{,}250\ sec$$

Using first-order loss rate

$$\frac{75}{52} = e^{-K * 3250}$$

$$\Rightarrow k = 1.12 \times 10^{-4}\ sec^{-1}$$

$$\frac{k_r}{k_{propane}} = \sqrt{\frac{\sqrt{MW_{prop}}}{\sqrt{MW_{oxygen}}}}$$

$$\Rightarrow k_r = k_{propane} \sqrt{\frac{\sqrt{44}}{\sqrt{32}}}$$

$$= 1.12 \times 10^{-4} \sqrt{\frac{\sqrt{44}}{\sqrt{32}}} = 1.2 \times 10^{-4}\ sec^{-1}$$

(iv) Use (2-14)

$$L = \frac{w^2 V}{2 D_t}$$

$$= \frac{(3)^2 (0.4)}{2 * 2.44 \times 10^{-3}}$$

$$= 737\ m$$

is being investigated

5. The characteristics of a small river that is proposed to receive effluent from a new wastewater treatment plant. The width of this uniform river is 10 ft, depth is 1 ft, slope is 0.001, and the Manning's coefficient is 0.03. River velocity is thus 0.4 m/sec. To estimate the travel time and the dispersion properties, 50 gm of Rhodamine dye was injected at the site of the proposed outfall. Because the river is too wide to easily distribute the dye evenly across the channel, the dye was dumped near the bank and expected to spread out soon. A steady bubbling of propane, a gaseous tracer, into the river at this location was also started.

The concentration of Rhodamine was monitored at a distance 1 km downstream using a fluorometer. The data when converted to a spatial distribution at t = 2500 sec after dye release, show that 95% of mass lies between 800 m and 1200 m at t = 2500 sec.

The propane concentration measured was 75 μM at 200 m downstream of the outfall and 52 μM at 1,500 m.

(i) The variance associated with the dispersion of Rhodamine dye (in m) is most nearly:

(A) 2500
(B) 1200
(C) 800
→ (D) 95

95% ⇒ 1200 − 800 = 400 = 4σ

⇒ $\sigma = 100$ m

(ii) The longitudinal dispersion co-efficient for the reach of stream between the proposed outfall and the (Rhodamine dye) measurement location (in m²/sec) is most nearly:

(A) 200
(B) 20
→ (C) 2
(D) none of the above

$$D_L = \frac{\sigma^2}{2\tau} = \frac{100^2}{2 * 2500}$$

$= 2$ m²/sec

(iii) Assuming no dilution by lateral flow and surface renewal model is applicable, the reaeration co-efficient (in sec⁻¹) is most nearly:

(A) 1.4×10^{-4}
(B) 1.3×10^{-4}
→ (C) 1.2×10^{-4}
(D) 1.1×10^{-4}

opposite

(iii) Assuming a straight channel, the minimum distance (in m) one must go to collect a sample near shore that is representative of the entire channel cross section is most nearly:

(A) 250
(B) 500
→ (C) 750
(D) 1,000

Transverse mixing zone.

For straight channels. (2-16a)

$D_t = 0.15 * d * u^*$

(Eq 2-15) $u^* = \sqrt{g d S} = \sqrt{9.81 * 0.3 * 0.001}$

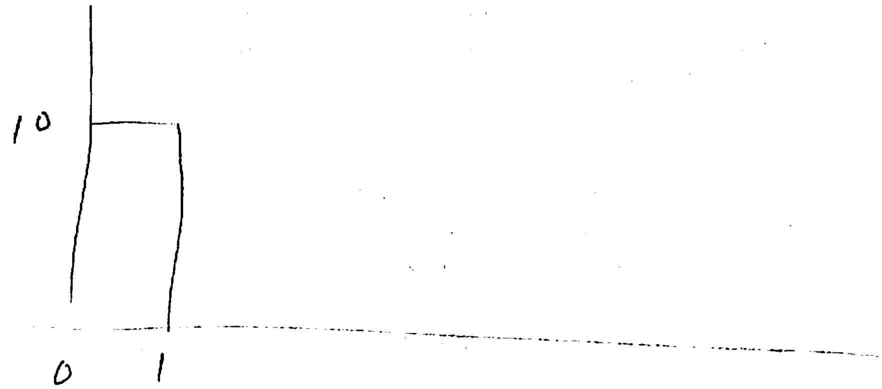
$= 0.054$ m/sec

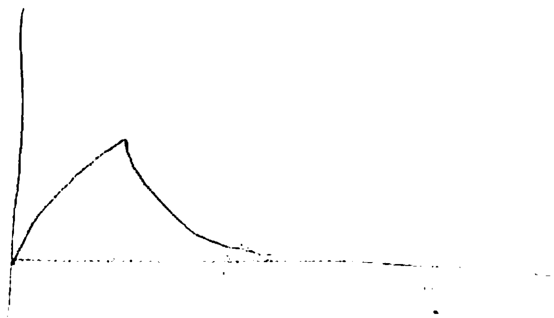
∴ $D_t = 0.15 * 0.3 * 0.054$

$= 2.44 \times 10^{-3}$ m²/sec

See Example 2-7

$$t_d = \frac{500}{\frac{100\ \text{gal}}{\text{day}}} = 5 \text{ days.}$$





(i) $$C_1 = C_0\left(1 - e^{-1/5}\right) = 10\left(1 - e^{-1/5}\right) = 1.81 \text{ mg/L}$$

$$C_3 = C_0 e^{-2/5} = 1.81\, e^{-2/5} = 1.21 \text{ mg/L}$$

(iii)

$$C_6' = C_0\left(1 - e^{-1/5}\right) = 10\left(1 - e^{-1/5}\right) = 1.81 \text{ mg/L}$$

$$C_7' = C_0\, e^{-1/5} = 1.81\, e^{-1/5} = 1.48 \text{ mg/L}$$

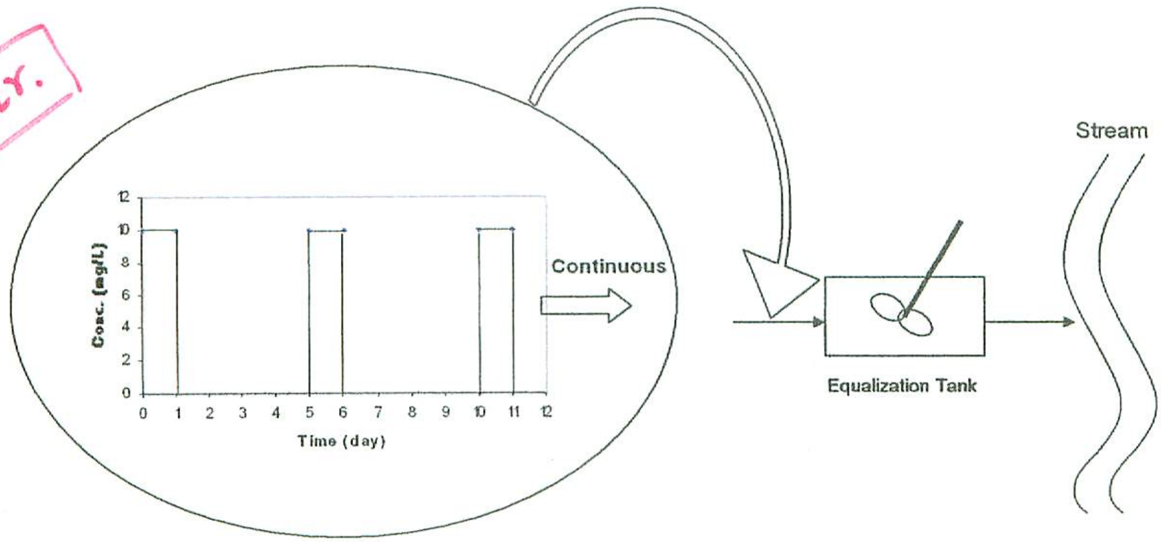
$$C_7'' = C_0\, e^{-6/5} = 1.81\, e^{-6/5} = 0.54 \text{ mg/L}$$

Total conc = $1.48 + 0.54 = 2.02$ mg/L

$$\begin{cases} C_6 = 11.81\left(1 - e^{-1/5}\right) = 2.14 \text{ mg/L} \\ C_7 = 2.14\, e^{-1/5} = 1.75 \text{ mg/L} \end{cases}$$

6. A 500 gallon (complete mix) equalization tank is used to dilute the concentration of a toxic compound before discharging into a receiving stream. The release of the compound into the waste stream (100 gpd) is intermittent (i.e., 10 mg/L for one day and then 0 mg/L for the next four days and so on). The concentration of the compound is also shown in the following graph:

no hr.



(i) The equalization basin effluent concentration at t = 3 day (in mg/L) is most nearly:

(A) 0.814
→ (B) 1.0
(C) 1.81
(D) 10.0

(ii) The equalization basin effluent concentration at t = 7 day (in mg/L) is most nearly:

(A) 0.45
(B) 0.81
(C) 1.60
→ (D) 1.95