NAME:

75 MINUTES; HAND IN YOUR 1 SHEET OF NOTES WITH THE EXAM; ASK FOR EXTRA PAPER IF NEEDED. MAKE (AND STATE) ANY REASONABLE ASSUMPTIONS NECESSARY TO GET AN ANSWER IN ADDITION TO THOSE GIVEN. CHECKING WHETHER THE ANSWER MAKES SENSE MAY HELP YOU EARN PARTIAL CREDIT IF YOU WENT WRONG SOMEWHERE.

PROBLEMS 1-4 (60 pts total): Use blank paper to solve problems 1 through 4 which all pertain to the same large industrial source described below.

Environment: Big city, cloudy winter night
Inversion at 400m above ground
Wind speed at 10 m above ground = 3.5 m/s
T = 270 K, P = 1 atm, C = 15 $\mu g/m^3$ immediately upwind of NOx source
First-order decay reaction for NOx with k = 0.005 s^{-1}
Emissions: An emission source is located at x = 0m and y = 0m, with characteristics: Q = 10,000 m^3/s, C of NOx = 1000 $\mu g/m^3$, h = 90m, Δh = 10m
Receptor: Located at x = 1400m, y = 100m, z = 0m

IF YOU CAN'T SOLVE PROBLEM 1, ASSUME *stability = D, width = 400m, height = 400m, flow = 10^6 m^3/s*

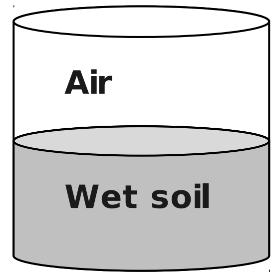
PROBLEM 1a: Find the atmospheric stability class A-F.
PROBLEM 1b: Estimate the width of the CV, assuming it equals the edge to edge width of the NOx source plume at the receptor.
PROBLEM 1c: Estimate the height of the CV, based on the problem statement.
PROBLEM 1d: Estimate the flow rate (m^3/s) and mean velocity (m/s) of wind entering the CV.

PROBLEM 2: Determine NOx concentration at the receptor in $\mu g/m^3$ using a steady 0D material balance approach based on the CV dimensions you found in Problem 1.

PROBLEM 3: Determine NOx concentration at the receptor in $\mu g/m^3$ using the Gaussian plume model. To account for NOx reaction, multiply your final result by the factor $\exp(-kx/u_H)$.

PROBLEM 4: Compare your NOx concentrations for problems 2 and 3 and explain why they differ and whether they make sense. Explain which approach is the best.

PROBLEM 5 (30 pts)



Problem scenario: On a construction site, benzene is spilled onto bare soil that has some water puddles. Benzene (C_6H_6) is found in gasoline and in solvents, and is a hazardous chemical that is both volatile and adsorbent.

Potentially useful information:

a. Ambient T = 20 degC; air P = 1 atm; soil density = 1.75 kg/L
b. Benzene data and relevant reactions: MW of benzene = 78 g/mol

$$C_6H_6(\text{aq}) \Leftrightarrow C_6H_6(\text{g}) \quad K = 4.31\ \frac{\text{atm}}{M}$$

$$C_6H_6(\text{aq}) \Leftrightarrow C_6H_6(\text{ads}) \quad K = 1014\ \frac{\text{mg/kg soil}}{M}$$

c. Control volume data: Air volume = 1000 L, Soil volume = 100 L, Water volume = 10 L

For simplicity, use this notation: $[C_6H_6(g)] = C_g$, $[C_6H_6(aq)] = C_{aq}$, *and* $[C_6H_6(ads)] = C_{ads}$

(a) What are the assumptions of the equilibrium chemistry approach?

(b) If the amount of benzene spilled into the 100 L soil CV is 100 moles and there was no benzene in the study area before the spill, determine the equilibrium concentrations and mole amounts of benzene in the air, in the soil, and in the water.

PROBLEM 6 (10 pts):
Concisely describe how the construction of a suburb in some part of Long Island that was previously forest would affect the following steps in the hydrological cycle: (a) Evaporation; (b) Infiltration; (c) Runoff; (d) Seepage (groundwater flow).

GIVEN INFORMATION

$1\ m^3 = 1000$ L, 1 mg = 10^{-3} g, 1 μg = 10^{-6} g

T(degK) = T(degC) + 273.15, 1 atm = 101325 Pa

$$\mathrm{MW}_i = \frac{\text{mass i}}{\text{mols i}} = \sum_{k=1,K} n_k \mathrm{AW}_k, \quad \mathrm{FW} = \sum_{k=1,K} y_i \mathrm{MW}_i$$

PV=nRT where R=0.08206 L atm mol^{-1} K^{-1}

$$\rho_{air} = \frac{\text{mass air}}{\text{volume air}} = \frac{n_{air} \times MW_{air}}{V_{air}} = \frac{n_{air}}{V_{air}} \times MW_{air} = \frac{P}{RT} \times MW_{air}$$

$$M_i = \frac{\text{mols i}}{\text{L m}} = \frac{\text{mass}_i / \mathrm{MW}_i}{V_w} = \frac{m_i}{\mathrm{MW}_i}, \quad y_i = \frac{\text{mols i}}{\text{mols t}} \approx \frac{\text{mass}_i / MW_i}{\rho_m \times V_m / MW_m} \text{ and } \sum_{i=1,I} y_i = 1$$

$$\mathrm{P}_i = y_i \mathrm{P} \qquad \text{and} \qquad \sum_{i=1,I} P_i = P$$

AW of elements in g/mol: 1 for H, 12 for C, 14 for N, 16 for O, 31 for P, 32 for S

Density of pure water at 1 atm and 4°C = 1000 kg/m^3

$$\frac{d}{dt}\int_{cv} \rho\, d\forall = -\int_{cs} \rho\, V(A)\cdot n\, dA \qquad \text{and} \qquad \frac{d}{dt}\int_{cv} \rho\, d\forall = \frac{dm}{dt}$$

$$\int_{cs} \rho\, V(A)\cdot n\, dA = -\int_{cs,in} \rho\, V(A)\, dA + \int_{cs,out} \rho\, V(A)\, dA = \sum_{cs,in} \rho\, \bar{V} A - \sum_{cs,out} \rho\, \bar{V} A = \sum_{cs,in} \dot{m} - \sum_{cs,out} \dot{m}$$

Eqn 6.33 $R_i = \pm \sum_{j=1,J} \left[k_j \forall \left(\prod_{h=1,H} C_{i,h} \right) \right]$ **and Eqn 6.34** $K = \dfrac{\prod_{h=1,H \text{ products}} [C_{i,h}]^{c^*}}{\prod_{h=1,H \text{ reactants}} [C_{i,h}]^{c^*}}$

Eqn 6.35 $K = 10^{-pK}$ **and Eqn 6.41** $\sum_{i=1,I} n_{i,j^*} = \sum_{i=1,I} n_{i,j^o}$

Eqn 6.23 $\mathrm{HA_{aq}} \Leftrightarrow H^+_{\mathrm{aq}} + \mathrm{A}^-_{\mathrm{aq}}$ **and Eqn 6.24** $A_a B_{b_s} \Leftrightarrow \mathrm{aA}^+_{\mathrm{aq}} + \mathrm{bB}^-_{\mathrm{aq}}$

Eqn 6.25 $A_{\mathrm{aq}} \Leftrightarrow A_{\mathrm{ads}}$ **or** $A_g \Leftrightarrow A_{\mathrm{ads}}$ **and Eqn 6.26** $A_a B_{b_{(\mathrm{aq})}} \Leftrightarrow A_a B_{b_{(g)}}$

Eqn 7.1 $P_1 + \rho g\, z_1 + \dfrac{\rho V_1^2}{2} = P_2 + \rho g\, z_2 + \dfrac{\rho V_2^2}{2}$ **Eqn 7.8** $E = A \times EF \times (1 - ER/100)$

Eqn 7.2 $V(z) = V(z_{\mathrm{ref}}) \left(\dfrac{z}{z_{\mathrm{ref}}} \right)^p$ **and Eqn 7.3** $Q = \int_A V(A)\, \mathrm{dA} = \dfrac{Y\ V(z_{\mathrm{ref}})}{z_{\mathrm{ref}}^p} \left(\dfrac{Z^{p+1}}{p+1} \right)$

Eqns 7.12 and 7.15: $\Delta h = 2.6 \left(\dfrac{F}{u_h S} \right)^{1/3}$ **(stable);** $\Delta h = 1.6 \dfrac{F^{1/3}\, x_f^{1/3}}{u_h}$ **(neutral/unstable)**

Eqn 7.13 $F = g r^2 v_s \left(1 - \dfrac{T_a}{T_s} \right)$**, Eqn 7.14** $S = \dfrac{g}{T_a} \left(\dfrac{dT_a}{dz} + 0.01 \dfrac{\mathrm{K}}{\mathrm{m}} \right)$**,**

Eqn 7.16 $x_f = 120\,F^{0.4}\ for\ F \geq 55$
$= 50\,F^{5/8}\ for\ F < 55$

Eqn 7.17 $H = h + \Delta h$ **Eqn 7.18** $x_L = \left(\frac{0.47(L-H)-f}{c}\right)^{1/d}$ **Eqn 7.19** $E_i = Qm_i$

Eqn 7.21 $\sigma_y = a\ x^{0.894}$ with x in km and **Eqn 7.22** $\sigma_z = c\ x^d + f$ with x in km

Eqn 7.23 $C(x,y,0) = \frac{E}{\pi u_H \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]\ for\ x < 2x_L$

Eqn 7.24 $C(x,y,0) = \frac{E}{\sqrt{2\pi}\, u \sigma_y L}\ for\ x \geq 2x_L\ and\ |y| \leq 3\sigma_y$ **Eqn 7.25** $C^{total}_{x,y,0} = C_u + C^{plume}_{x,y,0}$

Atmospheric stability class		Value of exponent p in Equation 7.2 Rough terrain	Smooth terrain
A	Very unstable	0.15	0.09
B	Moderately unstable	0.15	0.09
C	Slightly unstable	0.20	0.12
D	Neutral	0.25	0.15
E	Slightly stable	0.40	0.24
F	Stable	0.60	0.36

	Actual temperature lapse rate range (deg K/100m)
A	dT/dz < -1.9 degC/100m
B	-1.9 ≤ dT/dz < -1.7
C	-1.7 ≤ dT/dz < -1.5
D	-1.5 ≤ dT/dz < -0.5
E	-0.5 ≤ dT/dz < 0
F	0 ≤ dT/dz

Atmospheric Stability Classifications

Surface Windspeed[a] (m/s)	Day Solar Insolation Strong[b]	Moderate[c]	Slight[d]	Night Cloudiness[e] Cloudy (≥4/8)	Clear (≤3/8)
<2	A	A–B[f]	B	E	F
2–3	A–B	B	C	E	F
3–5	B	B–C	C	D	E
5–6	C	C–D	D	D	D
>6	C	D	D	D	D

[a]Surface wind speed is measured at 10 m above the ground.
[b]Corresponds to clear summer day with sun higher than 60° above the horizon.
[c]Corresponds to a summer day with a few broken clouds, or a clear day with sun 35–60° above the horizon.
[d]Corresponds to a fall afternoon, or a cloudy summer day, or clear summer day with the sun 15–35° above the horizon.
[e]Cloudiness is defined as the fraction of sky covered by clouds.
[f]For A–B, B–C, or C–D conditions, average the values obtained for each.
Note: A, Very unstable; B, moderately unstable; C, slightly unstable; D, neutral; E, slightly stable; F, stable. Regardless of windspeed, class D should be assumed for overcast conditions, day or night.

Stability	a	$x \leq 1$ km c	d	f	$x \geq 1$ km c	d	f
A	213	440.8	1.941	9.27	459.7	2.094	−9.6
B	156	106.6	1.149	3.3	108.2	1.098	2.0
C	104	61.0	0.911	0	61.0	0.911	0
D	68	33.2	0.725	−1.7	44.5	0.516	−13.0
E	50.5	22.8	0.678	−1.3	55.4	0.305	−34.0
F	34	14.35	0.740	−0.35	62.6	0.180	−48.6

Note: The computed values of σ will be in meters when x is given in kilometers.