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 μg/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 μg/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.

Using Table 7.9, cloudy conditions at the given 10-m windspeed implies ***stability class D****.*

PROBLEM 1b: Estimate the width of the CV, assuming it equals the edge to edge width of the NOx source plume at the receptor.

From Eq. 7.21 and Table 7.14, at the receptor location $\sigma_y = a\,x^{0.894} = 68\,1.4^{0.894} = 92\,\mathrm{m}$.
We estimate the plume width as $6\sigma_y$ *or* ***552 m****.*

PROBLEM 1c: Estimate the height of the CV, based on the problem statement.

Is the plume affected by the inversion? From Eq. 7.18, we find that x_L *is 11.1 km >> x, suggesting that it isn't. Thus, the effective plume height is determined by*
$\sigma_z = c\,x^d + f = 44.5(1.4)^{0.516} - 13 = 40\,\mathrm{m}$ *and is the smaller of* $6\sigma_z$ *and* $3\sigma_z + H$, *so* ***220 m****.*

PROBLEM 1d: Estimate the flow rate (m^3/s) and mean velocity (m/s) of wind entering the CV.
Assuming a power law wind profile over the CV,

$$Q = \frac{Y\ v(z_{\mathrm{ref}})}{z_{\mathrm{ref}}^p}\left(\frac{Z^{p+1}}{p+1}\right) = \frac{(552\,m)(3.5\,m/s)}{(10\,m)^{0.25}}\frac{(220\,m)^{1.25}}{1.25} = 7.35\times10^5\,\mathrm{m^3\,s^{-1}}.$$

The mean velocity is

$$\bar{v} = \frac{Q}{A} = \frac{Q}{YZ} = \frac{v(z_{ref})}{p+1}\left(\frac{Z}{z_{ref}}\right)^p = 6.1\,\mathrm{m\,s^{-1}}.$$

PROBLEM 2: Determine NOx concentration at the receptor in g/m^3 using a <u>steady 0D</u> material balance approach.

Take our control volume to range from just before the source (x = 0) to the receptor (x = 1400 m) and with Y, Z determined by the plume extent at x = 1.4 km from problem 1. The 0-D assumption means that the NOx concentration is assumed to be identical throughout the plume; call this concentration C. NOx mass balance then gives:

$$XYZ\frac{dC}{dt}=0=Q(C_{upwind}-C)+Q_{source}C_{source}-kXYZC$$

$$\rightarrow C=\frac{Q_{source}C_{source}+Q\,C_{upwind}}{Q+kXYZ}=13.3\,\mu\mathrm{g\,m^{-3}}$$

PROBLEM 3: Determine NOx concentration at the receptor in g/m^3 using the Gaussian Plume model. Account for NOx reaction by multiplying your final result by the factor exp(-kx/u_H).

With the GPM we would use Eq. 7.23 to find the concentration due to the plume (neglecting reaction):

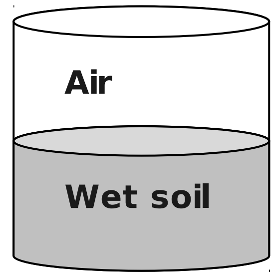
$$C(x,y,0)=\frac{E}{\pi u_H\sigma_y\sigma_z}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

We need u_H, which using the power law profile is 6.2 m/s. We then have C(1400, 100, 0) = 3.35 µg/m^3. Adding the background concentration, we have C_{tot}(1400, 100, 0) = 18.35 µg/m^3. Multiplying by the factor accounting for reaction gives us ***5.96 µg/m^3***.

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

The concentration estimated based on the two approaches differs by a factor of 2. They differ primarily because the 0-D mixing assumption has the concentration as constant through the entire plume control volume, while GPM is a 3-D model which accounts for the dilution of the plume further away from the source, so that concentrations are lower as x (and y) increase. Although the GPM may not be accurate either because transport and mixing is likely to be more complicated and because there may be other sources of NOx nearby that could affect the concentration, it is likely to be a better estimate than the 0-D model. The order of magnitude of the estimated concentrations make sense since they are consistent with each other and with the background concentration.

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

$$C_6H_{6\,(aq)} \Leftrightarrow C_6H_{6\,(g)} \quad K = 4.31\ \frac{\text{atm}}{M}$$

$$C_6H_{6\,(aq)} \Leftrightarrow C_6H_{6\,(ads)} \quad K = 1014\ \frac{\text{mg/kg soil}}{M}$$

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?

No flows of matter or energy in or out of the CV for long enough that chemical equilibrium is reached. No relevant reactions other than those given.

(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.

Mass balance:

$$100\,\text{mol} = C_g^* V_a + C_{aq}^* V_w + C_{ads}^* V_s$$

Chemical equilibrium (plus ideal gas law and given soil density):

$$C_g^* = \frac{4.31\,\text{atm}/\text{M}}{RT} C_{aq}^* = 0.179\, C_{aq}^*$$

$$C_{ads}^* = \frac{1.014\,\text{g}/\text{kg soil}}{\rho_{soil} \times MW_{benzene}} C_{aq}^* = 0.00743 C_{aq}^*$$

Substituting these into the first equation,

$$100\,\text{mol} = 190\,\text{L} \times C_{aq}^* \rightarrow C_{aq}^* = 0.527\, M$$

Putting this into the next two equations,

$$C_g^* = 0.0943\, M\,; C_s^* = 0.00391\, M$$

We can multiply by the volume of each medium to get molar amounts:

$$C_g^* V_a = 94.3\,\text{mol}; C_{aq}^* V_w = 5.27\,\text{mol}; C_{ads}^* V_s = 0.391\,\text{mol}.$$

Thus, while the equilibrium molar concentration is highest in the water phase, most of the benzene is in the gas phase because that is the largest part of the control volume.

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).

Evaporation: Vegetation transpires a lot of water; cutting down much of the vegetation would therefore reduce evaporation.
Infiltration: Paving over and compacting soil would reduce infiltration of water into the soil.
Runoff: Runoff would increase and reach higher peaks during storms because less water evaporates and because precipitation that falls on paved areas would go directly into sewers and then streams instead of percolating in the soil.
Seepage: Groundwater levels may be drawn down by pumping of groundwater for residential use and because recharge of infiltrated water is reduced. Flow patterns may change if the water table slope is modified.