3-15: 1~~0~~5
3-21: 10
3-22: 10
3-25: 10
3-29: 5
3-30: 10
4-10: 15
1: 15
2: 10
100

Chemical Engineering 4310
Fall Semester, 2005
Homework Assignment #2
Chapters 3and 4
(For return in marked box in hall of 2nd floor
Chemical Sciences by noon on Friday, September 29)

Work problems 3-15, 3-21, 3-22, 3-25, 3-29, 3-30 and 4-10 in the text

1. We want to evaluate the usage of nitrogen in the MTU Unit Operations laboratory. We are concerned that if a release of nitrogen occurs the oxygen level will be reduced below the 19.5% allowed by OSHA. The laboratory has a floor area of 4,800 ft^2 and a volume of 74,300 ft^3. The ventilation rate is 1 ft^3 /min for each ft^2 of laboratory floor space.
   a. In the past we used a gas cylinder to supply the nitrogen. This is a K-cylinder, with a volume of 1.76 ft^3. The nitrogen in a full cylinder is pressurized to 2,500 psig. Nitrogen behaves as an ideal gas under these conditions.
      Calculate the concentration of oxygen in the room if the cylinder fails catastrophically. Assume that the nitrogen released by the cylinder displaces the air in the lab.
      Is the oxygen concentration acceptable for this case?
   b. We currently supply nitrogen from a small nitrogen plant. The plant is capable of producing 19.3 SCFM of nitrogen. Estimate the concentration of oxygen in the lab due to this continuous release of nitrogen. Is this acceptable? What about the local concentration around the vicinity of the leak?

2. Spill containment should be provided when transporting chemicals in a laboratory.
   A 2-liter bottle of tetrahydrofuran (THF) (C_4H_8O) must be transported from a laboratory storage cabinet to a hood. If an accident occurs and the container is broken, the THF will form an evaporating pool resulting in a vapor concentration within the lab.
   Consider two accident scenarios:
   A. The THF is transferred without any containment. Assume that upon breakage of the container a pool of 1-cm depth is formed. Estimate the vapor concentration in the laboratory in ppm.
   B. The THF is transferred using a tray with dimensions of 15-cm x 15-cm. If the container breaks, a pool will form completely within the container. Estimate the vapor concentration in the laboratory in ppm.
   C. Compare the two values. Based on the equations, how does the vapor concentration scale with the area of the pool, i.e. linear, quadratic, etc? What recommendation can you make with respect to the size of the tray?

Assume that the temperature is 25°C and the pressure is 1atm. Also assume a ventilation rate of 0.5 m^3/s in the laboratory.

For THF the following properties are available:

MW:	72.12
Vapor Pressure:	114 mm Hg
Liquid density:	888 kg/m^3
TLV-TWA:	200 ppm

3-15 First, check TLV-TWA, using the same approach as 3-2. This gives 195.8 ppm, which is below the TLV-TWA. Then check TLV-C (300 ppm). This was not exceeded. Finally, check TLV-STEL (250 ppm). This was exceeded between 9-11 AM. The STEL is for 15 minutes only. Therefore, this work area is not in compliance, due to the TLV-STEL.

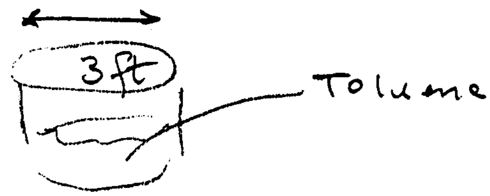
	Time	PPM	Exposed Min.	Exposed Hours	$\bar{C}$	$\bar{C}t$
	8:00	185				
	8:01	185	1	0.017	185	3.14
	9:17	240	76	1.27	212	269
	10:05	270	48	0.80	255	204
	11:22	230	77	1.28	250	320
*	12:00	197	38	0.633	213	135
	12:08	190				
*	1:00	154				
	1:06	150	6	0.10	152	15.2
	2:05	170	59	0.98	160	157
	3:09	165	64	1.07	167	179
	4:00	160	51	0.85	162	138
*	5:00	132	60	1.00	146	146
	5:05	130				

$\Sigma = 1566$

* Interpolated

1566/8 = 195.8 ppm

3 - 21. Solution



a) The evaporation rate is established using Eq 3-12

$$Q_m = \frac{M K A P^{SAT}}{R_g T_L}$$

Determine K with Eq 3-18

$$K = K_o \left(\frac{M_o}{M} \right)^{1/3} = \left(0.83 \ \frac{cm}{s}\right)\left(\frac{18}{92.13}\right)^{1/3}$$

$$= 0.482 \ cm/s$$

$$= \left(0.482 \ \frac{cm}{s}\right)\left(\frac{1 \ in.}{2.54 \ cm}\right)\left(\frac{1 \ ft}{12 \ in}\right)$$

$$= 0.0158 \ ft/s$$

$$A = \frac{\pi d^2}{4} = \frac{(3.14)(3 \ ft)^2}{4} = 7.06 \ ft^2$$

$$T_L = 85 \ °F = 545 \ °R = 303 \ °K$$

Determine P^{SAT} via

$$\ln P^{SAT} = 16.0137 - \frac{3096.52}{303 - 53.67} = 3.594$$

$$P^{SAT} = 36.39 \ mm \ Hg = 0.0479 \ atm = 0.704 \ psia$$

$$\therefore \ Q_m = \frac{(92.13 \ Lb_m/Lb \ mol)(0.0158 \ ft/s)(60 s/min)(7.06 \ ft^2)(0.704 \ psia)}{(10.73 \ psia \ ft^3/Lb \ mol \ °R)(545 \ °R)}$$

$$Q_m = 0.0742 \ Lb_m/min$$

3-21 Continued

Initial mass of toluene:

$$= (42\ gal)\left(0.1337\ \frac{ft^3}{gal}\right)(0.866)(62.4\ Lb_m/ft^3)$$

$$= 303.4\ Lb_m$$

$$\text{Time to evaporate} = \frac{303.4\ Lb_m}{0.0742\ Lb_m/min}$$

$$= 4090\ min = 68.1\ hrs.$$

b) Use Eq. 3-14 to determine the concentration:

$$C_{ppm} = \frac{K A P^{SAT}}{k Q_v P} 10^6$$

$$C_{ppm} = \frac{(0.0158\ ft/s)(60\ s/min)(7.06\ ft^2)(0.704\ psia)}{k\,(1000\ ft^3/min)(14.7\ psia)} \times 10^6$$

$$= \frac{321}{k} \quad \text{for } 0.1 < k < 0.5$$

Concentration range is: 641 ppm to 3210 ppm

All greater than the TLV.

3-22 The required ventilation rate is composed of two components: the rate for benzene and the rate for toluene.

Toluene: (TLV = 50 ppm from Table 2-8)

$$Q_m = \left(\frac{2\ \text{pts}}{\text{hr}}\right)\left(\frac{1\ \text{gal}}{8\ \text{pts}}\right)\left(62.4\ \frac{\text{Lbm}}{\text{ft}^3}\right)(0.866)\left(\frac{1\ \text{hr}}{60\ \text{min}}\right)\left(0.1337\ \frac{\text{ft}^3}{\text{gal}}\right)$$

$$Q_m = 0.0301\ \frac{\text{Lbm}}{\text{min}} = 1.80\ \frac{\text{Lbm}}{\text{hr}}$$

$$Q_v = \frac{Q_m R_g T (10^6)}{k\, C_{ppm}\, P M}$$

$$= \frac{(0.0301\ \text{Lbm/min})\left(10.73\ \frac{\text{psia ft}^3}{\text{Lb mol }^\circ\text{R}}\right)(540\ ^\circ\text{R})}{(0.1)(50)(14.7\ \text{psi})\left(92.13\ \frac{\text{Lbm}}{\text{Lb mol}}\right)(10^{-6})}$$

$$= 2.58 \times 10^4\ \text{ft}^3/\text{min}$$

Benzene: (TLV = 10 ppm from Table 2-8)

$$Q_m = \left(\frac{1\ \text{pt}}{8\ \text{hr}}\right)\left(\frac{1\ \text{gal}}{8\ \text{pts}}\right)\left(62.4\ \frac{\text{Lbm}}{\text{ft}^3}\right)(0.8794)\left(\frac{1\ \text{hr}}{60\ \text{min}}\right)\left(0.1337\ \frac{\text{ft}^3}{\text{gal}}\right)$$

$$= 0.00191\ \text{Lbm/min} = 0.115\ \text{Lbm/hr}$$

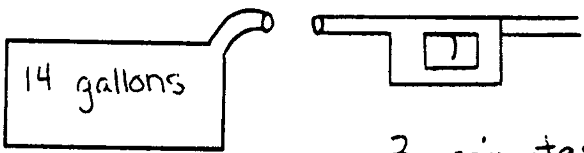
$$Q_v = \frac{(0.00191)(10.73)(540)(10^6)}{(0.1)(10.0)(14.7)(78.11)} = 96{,}400\ \text{ft}^3/\text{min}$$

Total Ventilation Rate

$$Q_v = 2.58 \times 10^4 + 9.64 \times 10^4\ \text{ft}^3/\text{min}$$

$$= 122{,}500\ \text{ft}^3/\text{min} = 7.35 \times 10^6\ \text{ft}^3/\text{hr}$$

3-25



3 minutes to fill

$M = 94$ $\quad P^{SAT}$ @ 77°F = 4.8 psia

$Q_v = 3000\ ft^3/min$

Equation 3-24 applies:

$$C_{ppm} = \frac{P^{SAT}}{K Q_v P} \left(\Phi r_f V_c + KA \right) \times 10^6$$

Since we don't know the area of the filling tube, assume $\Phi r_f V_c \gg KA$ (normally a good assumption). Then:

$$C_{ppm} = \frac{P^{SAT} \Phi r_f V}{K Q_v P} \times 10^6$$

Assume splash filling, $\Phi = 1.0$

$$r_f = \frac{1}{3\ min} = .33/min$$

$$V_c = (14\ gal)\left(\frac{.1337\ ft^3}{gal}\right) = 1.87\ ft^3$$

let k be a parameter

$$P = 14.7\ psia$$

$$C_{ppm} = \frac{(4.6\ psia)(1.0)(.33/min)(1.87\ ft^3)(10^6)}{(k)(3060\ ft^3/min)(14.7\ psia)}$$

$$C_{ppm} = \frac{64.4}{k}$$

Since k ranges from 0.1 to 0.5, $129 \le C_{ppm} \le 644$

For average ventilation, and $0 \le C_{ppm} \le 500$,

so

$$C_{ppm} = \frac{64.4}{1/5} = \underline{322\ ppm} > \text{TLV of } 300\ ppm$$

3-29

A good control velocity is 100-125 fpm.

For 100 fpm:

$$Q_v = LW\bar{u}$$

$$= (4\ ft)(3\ ft)(100\ ft/min) = 120\ ft^3/min$$

3-30

Assume well-mixed behavior in the hood. Then equation 3-9 applies:

$$Q_v = \frac{Q_m R_g T}{k C_{ppm} PM} \times 10^6$$

For a concentration of 12.5% by volume

$$C_{ppm} = \left(\frac{12.5}{100}\right)\left(10^6\right) = 1.25 \times 10^5$$

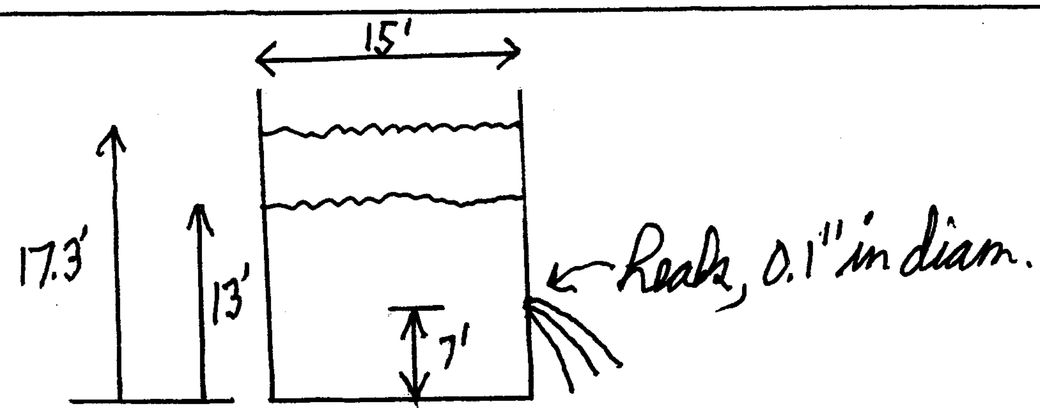
Then:

$$Q_v = \frac{(5.3 \text{ lbm/hr})(1 \text{ hr}/60 \text{ min})(10.73 \text{ psia-ft}^3/\text{lbmole-}^\circ\text{R})(530^\circ\text{R})}{(k)(1.25\times10^5)(14.7 \text{ psia})(131.4 \text{ lbm/lbmole})(10^{-6})}$$

$$= 2.08 \text{ ft}^3/\text{min}$$ (Assume $k \simeq 1$, well mixed)

$$\bar{u} = \frac{Q_v}{LW} = \frac{2.08 \text{ ft}^3/\text{min}}{(4 \text{ ft})(3 \text{ ft})} = \underline{.17 \text{ ft/min}}$$ (Achieved w/ 10 fpm)

4-10



Turpentine, $\rho = 55\ lb_m/ft^3$

a.) Compute volume spilled by change in liquid level

$$V_{SPILL} = V_1 - V_2 = \frac{\pi D_T^2}{4}(h_1 - h_2)$$

$$= \frac{(3.14)(15\ ft)^2}{4}(17.3\ ft - 13\ ft)$$

$$= 759\ ft^3 = 5680\ \text{gallons}$$

b.) Determine max. spill rate from Equation 4-12

$$Q_m = \rho A C_0 \sqrt{2\left(\frac{g_c P_g}{\rho} + g h_L\right)}$$

Assume $C_0 = 0.61$

$$A = \frac{\pi d^2}{4} = \frac{(3.14)(0.1\ in)^2}{4}\left(\frac{1\ ft^2}{144\ in^2}\right) = 5.45 \times 10^{-5}\ ft^2$$

$P_g = 0$ psig

h_L = initial liquid height above hole $= 17.3 - 7$

$= 10.3\ ft$

Substituting

$$Q_m = \left(55 \frac{lb_m}{ft^3}\right)(5.45 \times 10^{-5} ft^2)(0.61) \times$$

$$\sqrt{(2)(32.17 ft/s^2)(10.3 ft)}$$

$$= 0.0471\ lb_m/sec = 2.82\ lb_m/min = 169\ lb_m/hr.$$

c.) Use Equation 4-18 to determine time required for level to drop to 13' above bottom.

$$h_L^o = 17.3 ft - 7 ft = 10.3 \text{ ft above leak}$$

$$h_L = 13 ft - 7 ft = 6.0 \text{ ft above leak}$$

$$A_t = \frac{\pi d^2}{4} = \frac{(3.14)(15 ft)^2}{4} = 176.6 ft^2$$

For this case $P_g = 0$ and

$$h_L = h_L^o - C_o\left(\frac{A}{A_T}\right)\sqrt{2g h_L^o}\, t + \frac{g}{2}\left(\frac{C_o A}{A_t} t\right)^2$$

Substituting

$$6.0 ft = 10.3 ft - (0.61)\left(\frac{5.45 \times 10^{-5} ft^2}{176.6 ft^2}\right) \times$$

$$\sqrt{(2)(32.17 ft/sec^2)(10.3 ft)}\, t$$

$$+ \left(\frac{32.17 ft/sec^2}{2}\right)\left[\frac{(0.61)(5.45 \times 10^{-5} ft^2)}{176.6 ft^2} t\right]^2$$

$5.700 \times 10^{-13} t^2 - 4.846 \times 10^{-6} t + 4.3 = 0$

Solve for t

Two roots

$t = 1.01 \times 10^6$ sec, 7.50×10^6 sec

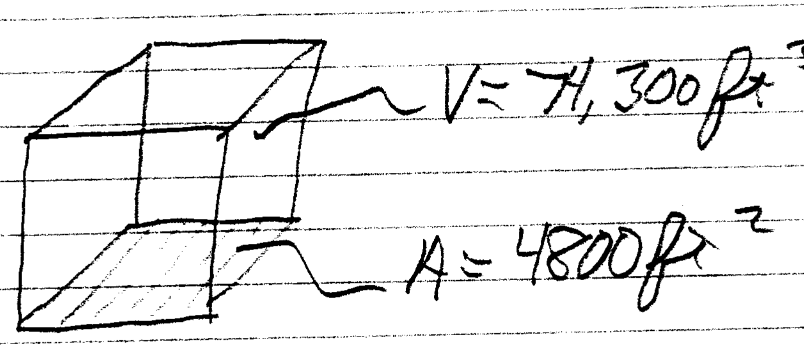
$= 281$ hours, 2082 hours

281 hours is correct answer. This is 11.7 days.

Should decrease inspection time!

SOLUTION - Problem 1

1.)



a.) Cylinder volume = 1.76 ft³

Ideal gas law

$$P_1 V_1 = P_2 V_2$$

$$V_2 = V_1 \left(\frac{P_1}{P_2}\right) = (1.76\ ft^3)\left(\frac{2514.7\ psia}{14.7\ psia}\right)$$

$$= 301\ ft^3 \text{ of nitrogen.}$$

Total volume of air = 74,300 ft³

O_2 in initial volume = $(0.21)(74{,}300\ ft^3)$

$$= 15{,}600\ ft^3$$

The nitrogen displaces the air, so final volume of air is $74{,}300\ ft^3 - 301\ ft^3$

$$= 73999\ ft^3$$

Total O_2 left $= (0.21)(73999\ ft^3) = 15540\ ft^3$

$$\text{Vol. \% } O_2 \text{ after release} = \frac{15{,}540 \text{ ft}^3\ O_2}{74{,}300 \text{ ft}^3 \text{ total}} \times 100$$

$$= \underline{\underline{20.9\%}}$$

This is just a small decrease in O_2.
However, concentration near the cylinder may be much lower in O_2

D.) The ventilation rate is

$$Q_v = \left(\frac{1 \text{ ft}^3/\text{min}}{\text{ft}^2}\right)(4{,}800 \text{ ft}^2) \simeq 4{,}800 \text{ ft}^3/\text{min}$$

The release rate of nitrogen is 19.3 ft³/min

$$C = \frac{Q}{kQ_v} \times 100 = \frac{(19.3 \text{ ft}^3/\text{min})(100)}{k(4{,}800 \text{ ft}^3/\text{min})}$$

$$= \frac{0.402}{k} = \text{Vol. \% } N_2 \ \underline{\text{over}} \text{ ambient}$$

If $k = 0.1$, $C = 4.02$
$\therefore$ Total $N_2 = 79 + 4 = 83\%$
Total $O_2 = 100 - 83 = \underline{17\%\ O_2}$

If $k \approx 0.5$, $C = 0.804$
$\therefore$ Total $N_2 = 79 + 0.8 \simeq 79.8$
Total $O_2 = 100 - 79.8 = \underline{20.2\%\ O_2}$

- We might have a problem based on mixing.
- Concentrations of O_2 near the release will be lower.

SOLUTION - Problem 2

1.) THF ~ MW: 72.12

VP: 114 mm Hg

ρ : 888 kg/m^3

TWA: 200 ppm

A. Total spill - no containment

2 liter bottle = 0.002 m^3

Pool depth = 1 cm = 0.01 m

$V = Ah$

$$A = \frac{V}{h} = \frac{0.002\,m^3}{0.01\,m} = 0.2\,m^2$$

Use Equation (3-14) to estimate concentration

$$C_{ppm} = \frac{KAP^{sat}}{kQ_vP} \times 10^6 \qquad (3\text{-}14)$$

$$K = K_0\left(\frac{M_0}{M}\right)^{1/3} \qquad (3\text{-}18)$$

$$= (0.83\,cm/s)\left(\frac{18}{72.12}\right)^{1/3} = 0.52\,cm/s$$

$$= 0.0052\,m/s$$

$$p^{sat} \simeq \frac{114\,mmHg}{760\,mmHg/atm} \simeq 0.15\,atm$$

Substituting

$$C_{PPM} \simeq \frac{(0.0052\,m/s)(A\,m^2)(0.15\,atm)}{k\,(0.5\,m^3/s)(1\,atm)}$$

$$= \frac{1560\,A}{k} \quad A \equiv m^2$$

For $A = 0.2\,m^2$

$$C_{PPM} \simeq \frac{(1560)(0.2\,m^2)}{k} = \frac{312}{k}$$

$\therefore$ for $0.1 \le k \le 0.5$

$$\boxed{614 \le C_{PPM} \le 3120\ ppm}$$

b) Tray area $= (0.15\,m)(0.15\,m) = 0.0225\,m^2$

$$\therefore C_{PPM} \simeq \frac{(1560)(0.0225\,m^2)}{k} = \frac{35.1}{k}$$

$$\boxed{70.2 \le C_{PPM} \le 351\ ppm}$$

A lot less.

c.) Concentration is linear with area. Need to make tray as small as possible