

CHAPTER FIVE

5.1 Assume volume additivity

$$\text{Av. density (Eq. 5.1-1): } \frac{1}{\bar{\rho}} = \frac{0.400}{\underset{\substack{\uparrow \\ \rho_O}}{0.703 \text{ kg/L}}} + \frac{0.600}{\underset{\substack{\uparrow \\ \rho_D}}{0.730 \text{ kg/L}}} \Rightarrow \bar{\rho} = 0.719 \text{ kg/L}$$

$$\text{a. } \underset{\substack{\uparrow \\ \text{mass of tank} \\ \text{at time } t}}{\dot{m}} = \dot{m}t + \underset{\substack{\uparrow \\ \text{mass of} \\ \text{empty tank}}}{m_0} \Rightarrow \dot{m} = \frac{(250 - 150)\text{kg}}{(10 - 3)\text{min}} = 14.28 \text{ kg/min} \quad (\dot{m} = \text{mass flow rate of liquid})$$

$$\Rightarrow \dot{V}(\text{L/min}) = \frac{\dot{m}(\text{kg/min})}{\bar{\rho}(\text{kg/L})} \Rightarrow \dot{V} = \frac{14.28 \text{ kg}}{\text{min}} \left| \frac{1 \text{ L}}{0.719 \text{ kg}} \right| = \underline{\underline{19.9 \text{ L/min}}}$$

$$\text{b. } m_0 = m(t) - \dot{m}t = 150 - 14.28(3) = \underline{\underline{107 \text{ kg}}}$$

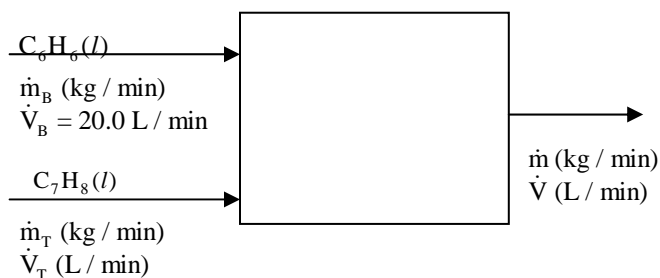
$$\text{5.2 } \underline{\text{void volume of bed:}} \quad 100 \text{ cm}^3 - (233.5 - 184)\text{cm}^3 = 50.5 \text{ cm}^3$$

$$\underline{\text{porosity:}} \quad 50.5 \text{ cm}^3 \text{ void} / 184 \text{ cm}^3 \text{ total} = \underline{\underline{0.274 \text{ cm}^3 \text{ void/cm}^3 \text{ total}}}$$

$$\underline{\text{bulk density:}} \quad 600 \text{ g} / 184 \text{ cm}^3 = \underline{\underline{3.26 \text{ g/cm}^3}}$$

$$\underline{\text{absolute density:}} \quad 600 \text{ g} / (184 - 50.5)\text{cm}^3 = \underline{\underline{4.49 \text{ g/cm}^3}}$$

5.3



$$\dot{V} = \frac{\Delta V}{\Delta t} = \frac{\pi D^2}{4} \frac{\Delta h}{\Delta t} = \frac{\pi (5.5 \text{ m})^2}{4} \left| \frac{0.15 \text{ m}}{60 \text{ min}} \right| = 0.0594 \text{ m}^3 / \text{min}$$

Assume additive volumes

$$\dot{V}_T = \dot{V} - \dot{V}_B = (59.4 - 20.0) \text{ L/min} = \underline{\underline{39.4 \text{ L/min}}}$$

$$\dot{m} = \rho_B \cdot \dot{V}_B + \rho_T \cdot \dot{V}_T = \frac{0.879 \text{ kg}}{\text{L}} \left| \frac{20.0 \text{ L}}{\text{min}} \right| + \frac{0.866 \text{ kg}}{\text{L}} \left| \frac{39.4 \text{ L}}{\text{min}} \right| = 51.7 \text{ kg/min}$$

$$x_B = \frac{\dot{m}_B}{\dot{m}} = \frac{(0.879 \text{ kg/L})(20.0 \text{ L/min})}{(51.7 \text{ kg/min})} = \underline{\underline{0.34 \text{ kg B/kg}}}$$

$$5.4 \quad \text{a.} \quad \left. \begin{array}{l} P_1 = P_0 + \rho_{sl} g h_1 \\ P_2 = P_0 + \rho_{sl} g h_2 \\ h = h_1 - h_2 \end{array} \right\} \Rightarrow \Delta P = P_1 - P_2 = \rho_{sl} \left(\frac{\text{kg}}{\text{m}^3} \right) g \left(\frac{\text{m}}{\text{s}^2} \right) h(\text{m}) \left(\frac{1 \text{ N}}{1 \frac{\text{kg} \cdot \text{m}}{\text{s}^2}} \right) \left(\frac{1 \text{ Pa}}{1 \frac{\text{N}}{\text{m}^2}} \right) = \underline{\underline{\rho_{sl} g h}}$$

$$\text{b.} \quad \frac{1}{\rho_{sl}} = \frac{x_c}{\rho_c} + \frac{(1-x_c)}{\rho_l} \Rightarrow \text{check units!}$$

$$\frac{1}{\text{kg slurry / L slurry}} = \frac{\text{kg crystals / kg slurry}}{\text{kg crystals / L crystals}} + \frac{\text{kg liquid / kg slurry}}{\text{kg liquid / L liquid}}$$

$$\frac{\text{L slurry}}{\text{kg slurry}} = \frac{\text{L crystals}}{\text{kg slurry}} + \frac{\text{L liquid}}{\text{kg slurry}} = \frac{\text{L slurry}}{\text{kg slurry}}$$

$$\text{c. i.)} \quad \rho_{sl} = \frac{\Delta P}{g h} = \frac{2775}{(9.8066)(0.200)} = \underline{\underline{1415 \text{ kg / m}^3}}$$

$$\text{ii.)} \quad \frac{1}{\rho_{sl}} = \frac{x_c}{\rho_c} + \frac{(1-x_c)}{\rho_l} \Rightarrow x_c \left(\frac{1}{\rho_c} - \frac{1}{\rho_l} \right) = \left(\frac{1}{\rho_{sl}} - \frac{1}{\rho_l} \right)$$

$$x_c = \frac{\left(\frac{1}{1415 \text{ kg / m}^3} - \frac{1}{1.2(1000 \text{ kg / m}^3)} \right)}{\left(\frac{1}{2.3(1000 \text{ kg / m}^3)} - \frac{1}{1.2(1000 \text{ kg / m}^3)} \right)} = \underline{\underline{0.316 \text{ kg crystals / kg slurry}}}$$

$$\text{iii.)} \quad V_{sl} = \frac{m_{sl}}{\rho_{sl}} = \frac{175 \text{ kg}}{1415 \text{ kg / m}^3} \left| \frac{1000 \text{ L}}{\text{m}^3} \right| = \underline{\underline{123.8 \text{ L}}}$$

$$\text{iv.)} \quad m_c = x_c m_{sl} = (0.316 \text{ kg crystals / kg slurry})(175 \text{ kg slurry}) = \underline{\underline{55.3 \text{ kg crystals}}}$$

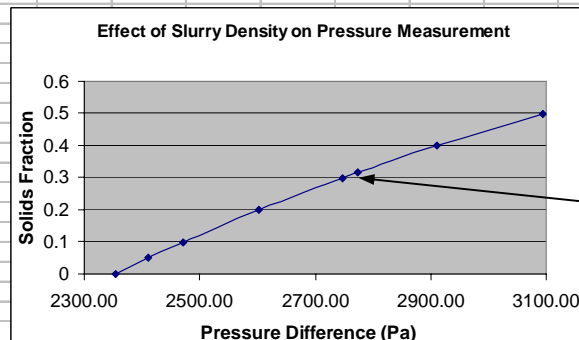
$$\text{v.)} \quad m_{\text{CuSO}_4} = \frac{55.3 \text{ kg CuSO}_4 \cdot 5\text{H}_2\text{O}}{249 \text{ kg}} \left| \frac{1 \text{ kmol}}{1 \text{ kmol CuSO}_4 \cdot 5\text{H}_2\text{O}} \right| \frac{159.6 \text{ kg}}{1 \text{ kmol}} = \underline{\underline{35.4 \text{ kg CuSO}_4}}$$

$$\text{vi.)} \quad m_l = (1-x_c)m_{sl} = (0.684 \text{ kg liquid / kg slurry})(175 \text{ kg slurry}) = \underline{\underline{120 \text{ kg liquid solution}}}$$

$$\text{vii.)} \quad V_l = \frac{m_l}{\rho_l} = \frac{120 \text{ kg}}{(1.2)(1000 \text{ kg / m}^3)} \left| \frac{1000 \text{ L}}{\text{m}^3} \right| = \underline{\underline{100 \text{ L}}}$$

d.

h(m)	0.2								
$\rho_l(\text{kg/m}^3)$	1200								
$\rho_c(\text{kg/m}^3)$	2300								
$\Delta P(\text{Pa})$	2353.58	2411.24	2471.80	2602.52	2747.84	2772.61	2910.35	3093.28	
x_c	0	0.05	0.1	0.2	0.3	0.316	0.4	0.5	
$\rho_{sl}(\text{kg/m}^3)$	1200.00	1229.40	1260.27	1326.92	1401.02	1413.64	1483.87	1577.14	



$\Delta P = 2775, \rho = 0.316$

5.4 (cont'd)

e. Basis: 1 kg slurry $\Rightarrow x_c(\text{kg crystals}), V_c(\text{m}^3 \text{ crystals}) = \frac{x_c(\text{kg crystals})}{\rho_c(\text{kg} / \text{m}^3)}$

$$(1 - x_c)(\text{kg liquid}), V_l(\text{m}^3 \text{ liquid}) = \frac{(1 - x_c)(\text{kg liquid})}{\rho_l(\text{kg} / \text{m}^3)}$$

$$\rho_{sl} = \frac{1 \text{ kg}}{(V_c + V_l)(\text{m}^3)} = \frac{1}{\frac{x_c}{\rho_c} + \frac{(1 - x_c)}{\rho_l}}$$

5.5 Assume $P_{\text{atm}} = 1 \text{ atm}$

$$P\hat{V} = RT \Rightarrow \hat{V} = \frac{0.08206 \text{ m}^3 \cdot \text{atm}}{\text{kmol} \cdot \text{K}} \left| \frac{313.2 \text{ K}}{4.0 \text{ atm}} \right| \frac{1 \text{ kmol}}{10^3 \text{ mol}} = \underline{\underline{0.0064 \text{ m}^3/\text{mol}}}$$

$$\rho = \frac{1 \text{ mol}}{0.0064 \text{ m}^3 \text{ air}} \left| \frac{29.0 \text{ g}}{\text{mol}} \right| \frac{1 \text{ kg}}{10^3 \text{ g}} = \underline{\underline{4.5 \text{ kg}/\text{m}^3}}$$

5.6 a. $V = \frac{nRT}{P} = \frac{1.00 \text{ mol}}{P} \left| \frac{0.08206 \text{ L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \right| \frac{373.2 \text{ K}}{10 \text{ atm}} = \underline{\underline{3.06 \text{ L}}}$

b. $\% \text{ error} = \frac{(3.06\text{L} - 2.8\text{L})}{2.8\text{L}} \times 100\% = \underline{\underline{9.3\%}}$

5.7 Assume $P_{\text{atm}} = 1.013 \text{ bar}$

a.

$$PV = nRT \Rightarrow n = \frac{(10 + 1.013)\text{bar}}{(25 + 273.2)\text{K}} \left| \frac{20.0 \text{ m}^3}{0.08314 \text{ m}^3 \cdot \text{bar}} \right| \frac{\text{kmol} \cdot \text{K}}{28.02 \text{ kg N}_2} = \underline{\underline{249 \text{ kg N}_2}}$$

b. $\frac{PV}{P_s V_s} = \frac{nRT}{n_s R T_s} \Rightarrow n = V \cdot \frac{T_s}{T} \cdot \frac{P}{P_s} \cdot \frac{n_s}{V_s}$

$$n = \frac{20.0 \text{ m}^3}{298.2\text{K}} \left| \frac{273\text{K}}{1.013 \text{ bar}} \right| \frac{(10 + 1.013)\text{bar}}{22.415 \text{ m}^3(\text{STP})} \left| \frac{1 \text{ kmol}}{28.02 \text{ kg N}_2} \right| = \underline{\underline{249 \text{ kg N}_2}}$$

5.8 a. $R = \frac{P_s V_s}{n_s T_s} = \frac{1 \text{ atm}}{1 \text{ kmol}} \left| \frac{22.415 \text{ m}^3}{273 \text{ K}} \right| = \underline{\underline{8.21 \times 10^{-2} \frac{\text{atm} \cdot \text{m}^3}{\text{kmol} \cdot \text{K}}}}$

b. $R = \frac{P_s V_s}{n_s T_s} = \frac{1 \text{ atm}}{1 \text{ lb - mole}} \left| \frac{760 \text{ torr}}{1 \text{ atm}} \right| \frac{359.05 \text{ ft}^3}{492 \text{ }^\circ\text{R}} = \underline{\underline{555 \frac{\text{torr} \cdot \text{ft}^3}{\text{lb - mole} \cdot \text{ }^\circ\text{R}}}}$

$$5.9 \quad P = 1 \text{ atm} + \frac{10 \text{ cm H}_2\text{O}}{10^2 \text{ cm}} \left| \frac{1 \text{ m}}{10.333 \text{ m H}_2\text{O}} \right| = 1.01 \text{ atm}$$

$$T = 25^\circ \text{C} = 298.2 \text{ K}, \quad \dot{V} = \frac{2.0 \text{ m}^3}{5 \text{ min}} = 0.40 \text{ m}^3/\text{min} = 400 \text{ L/min}$$

$$\dot{m} = \dot{n}(\text{mol/min}) \cdot \text{MW}(\text{g/mol})$$

$$\text{a.} \quad \dot{m} = \frac{P\dot{V}}{RT} \cdot \text{MW} = \frac{1.01 \text{ atm}}{0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}}} \left| \frac{400 \frac{\text{L}}{\text{min}}}{298.2 \text{ K}} \right| \left| \frac{28.02 \frac{\text{g}}{\text{mol}}}{1} \right| = \underline{\underline{458 \text{ g/min}}}$$

$$\text{b.} \quad \dot{m} = \frac{400 \frac{\text{L}}{\text{min}}}{298.2 \text{ K}} \left| \frac{273 \text{ K}}{22.4 \text{ L(STP)}} \right| \left| \frac{1 \text{ mol}}{28.02 \frac{\text{g}}{\text{mol}}} \right| = \underline{\underline{458 \text{ g/min}}}$$

$$5.10 \quad \underline{\text{Assume ideal gas behavior:}} \quad u \left(\frac{\text{m}}{\text{s}} \right) = \frac{\dot{V}(\text{m}^3/\text{s})}{A(\text{m}^2)} = \frac{\dot{n}RT/P}{\pi D^2/4} \Rightarrow \frac{u_2}{u_1} = \frac{\dot{n}R}{\dot{n}R} \cdot \frac{T_2}{T_1} \cdot \frac{P_1}{P_2} \cdot \frac{D_1^2}{D_2^2}$$

$$u_2 = u_1 \frac{T_2 P_1 D_1^2}{T_1 P_2 D_2^2} = \frac{60.0 \text{ m}}{\text{sec}} \left| \frac{333.2 \text{ K}}{300.2 \text{ K}} \right| \left| \frac{(1.80 + 1.013) \text{ bar}}{(1.53 + 1.013) \text{ bar}} \right| \left| \frac{(7.50 \text{ cm})^2}{(5.00 \text{ cm})^2} \right| = \underline{\underline{165 \text{ m/sec}}}$$

$$5.11 \quad \underline{\text{Assume ideal gas behavior:}} \quad n = \frac{PV}{RT} = \frac{(1.00 + 1.00) \text{ atm}}{0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}}} \left| \frac{5 \text{ L}}{300 \text{ K}} \right| = 0.406 \text{ mol}$$

$$\text{MW} = 13.0 \text{ g}/0.406 \text{ mol} = 32.0 \text{ g/mol} \Rightarrow \underline{\underline{\text{Oxygen}}}$$

$$5.12 \quad \underline{\text{Assume ideal gas behavior:}} \quad \text{Say } m_t = \text{mass of tank}, \quad n_g = \text{mol of gas in tank}$$

$$\left. \begin{array}{l} \text{N}_2: \quad 37.289 \text{ g} = m_t + n_g(28.02 \text{ g/mol}) \\ \text{CO}_2: \quad 37.440 \text{ g} = m_t + n_g(44.1 \text{ g/mol}) \end{array} \right\} \Rightarrow \begin{array}{l} n_g = 0.009391 \text{ mol} \\ m_t = 37.0256 \text{ g} \end{array}$$

$$\text{unknown: } \text{MW} = \frac{(37.062 - 37.0256) \text{ g}}{0.009391 \text{ mol}} = \underline{\underline{3.9 \text{ g/mol} \Rightarrow \text{Helium}}}$$

$$5.13 \quad \text{a.} \quad \dot{V}_{\text{std}} [\text{cm}^3(\text{STP})/\text{min}] = \frac{\Delta V \text{ liters}}{\Delta t \text{ min}} \left| \frac{273 \text{ K}}{296.2 \text{ K}} \right| \left| \frac{763 \text{ mm Hg}}{760 \text{ mm Hg}} \right| \left| \frac{10^3 \text{ cm}^3}{1 \text{ L}} \right| = 925.3 \frac{\Delta V}{\Delta t}$$

$$\left. \begin{array}{c} \phi \\ 5.0 \\ 9.0 \\ 12.0 \end{array} \right\} \frac{\dot{V}_{\text{std}} [\text{cm}^3(\text{STP})/\text{min}]}{139} \left\{ \begin{array}{l} \text{straight line plot} \\ \downarrow \\ \phi = 0.031 \dot{V}_{\text{std}} + 0.93 \end{array} \right.$$

$$\text{b.} \quad \dot{V}_{\text{std}} = \frac{0.010 \text{ mol N}_2}{\text{min}} \left| \frac{22.4 \text{ liters(STP)}}{1 \text{ mole}} \right| \left| \frac{10^3 \text{ cm}^3}{1 \text{ L}} \right| = 224 \text{ cm}^3 / \text{min}$$

$$\phi = 0.031(224 \text{ cm}^3 / \text{min}) + 0.93 = \underline{\underline{7.9}}$$

5.14 Assume ideal gas behavior $\rho(\text{kg/L}) = \frac{n(\text{kmol})M(\text{kg/kmol})}{V(\text{L})} \stackrel{\frac{n}{V} = \frac{P}{RT}}{=} \frac{PM}{RT}$

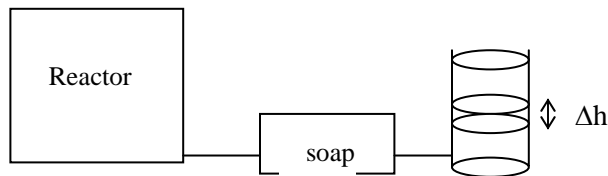
$$V_2(\text{cm}^3/\text{s}) = V_1(\text{cm}^3/\text{s}) \cdot \left(\frac{\rho_1}{\rho_2} \right)^{1/2} = V_1 [P_1 M_1 T_2 / P_2 M_2 T_1]^{1/2}$$

a. $V_{\text{H}_2} = 350 \frac{\text{cm}^3}{\text{s}} \left[\frac{758 \text{ mm Hg}}{1800 \text{ mm Hg}} \left| \frac{28.02 \text{ g/mol}}{2.02 \text{ g/mol}} \right| \frac{323.2 \text{ K}}{298.2 \text{ K}} \right]^{1/2} = \underline{\underline{881 \text{ cm}^3/\text{s}}}$

b. $\bar{M} = 0.25M_{\text{CH}_4} + 0.75M_{\text{C}_3\text{H}_8} = (0.25)(16.05) + (0.75)(44.11) = 37.10 \text{ g/mol}$

$$V_g = 350 \frac{\text{cm}^3}{\text{s}} \left[\frac{(758)(28.02)(323.2)}{(1800)(37.10)(298.2)} \right]^{1/2} = \underline{\underline{205 \text{ cm}^3/\text{s}}}$$

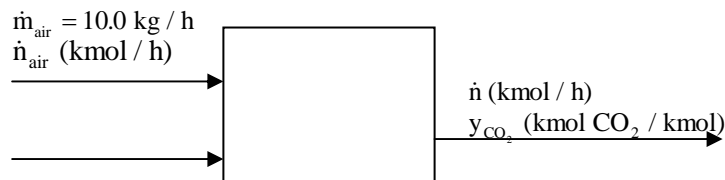
5.15 a.



b. $\dot{n}_{\text{CO}_2} = \frac{P\dot{V}}{RT} \Rightarrow \dot{V} = \frac{\pi R^2 \Delta h}{\Delta t} = \frac{\pi (0.012 \text{ m}^2)^2}{4} \left| \frac{1.2 \text{ m}}{7.4 \text{ s}} \right| \frac{60 \text{ s}}{\text{min}} = 1.1 \times 10^{-3} \text{ m}^3 / \text{min}$

$$\dot{n}_{\text{CO}_2} = \frac{755 \text{ mm Hg}}{0.08206 \frac{\text{m}^3 \cdot \text{atm}}{\text{kmol} \cdot \text{K}}} \left| \frac{1 \text{ atm}}{760 \text{ mm Hg}} \right| \left| \frac{1.1 \times 10^{-3} \text{ m}^3 / \text{min}}{300 \text{ K}} \right| \left| \frac{1000 \text{ mol}}{1 \text{ kmol}} \right| = \underline{\underline{0.044 \text{ mol/min}}}$$

5.16



$$\begin{aligned} \dot{V}_{\text{CO}_2} &= 20.0 \text{ m}^3 / \text{h} \\ \dot{n}_{\text{CO}_2} &(\text{kmol} / \text{h}) \\ 150^\circ \text{C}, 1.5 \text{ bar} \end{aligned}$$

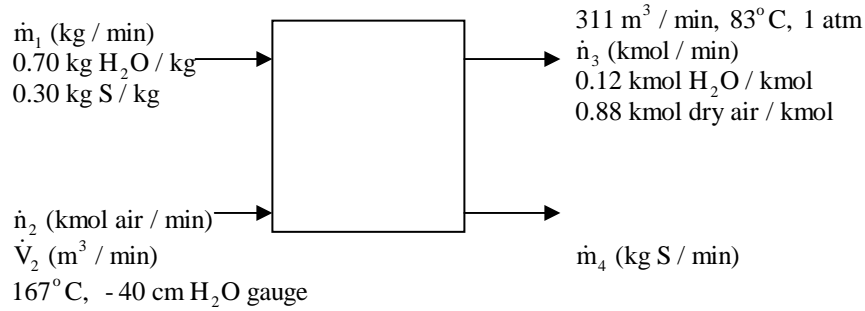
Assume ideal gas behavior

$$\dot{n}_{\text{air}} = \frac{10.0 \text{ kg}}{\text{h}} \left| \frac{1 \text{ kmol}}{29.0 \text{ kg air}} \right| = 0.345 \text{ kmol air} / \text{h}$$

$$\dot{n}_{\text{CO}_2} = \frac{P\dot{V}}{RT} = \frac{1.5 \text{ bar}}{8.314 \frac{\text{m}^3 \cdot \text{kPa}}{\text{kmol} \cdot \text{K}}} \left| \frac{100 \text{ kPa}}{1 \text{ bar}} \right| \left| \frac{20.0 \text{ m}^3 / \text{h}}{423.2 \text{ K}} \right| = 0.853 \text{ kmol CO}_2 / \text{h}$$

$$y_{\text{CO}_2} \times 100\% = \frac{0.853 \text{ kmol CO}_2 / \text{h}}{(0.853 \text{ kmol CO}_2 / \text{h} + 0.345 \text{ kmol air} / \text{h})} \times 100\% = \underline{\underline{71.2\%}}$$

5.17 Basis: Given flow rates of outlet gas. Assume ideal gas behavior



$$\text{a. } \dot{n}_3 = \frac{1 \text{ atm}}{356.2 \text{ K}} \left| \frac{311 \text{ m}^3}{\text{min}} \right| \frac{\text{kmol} \cdot \text{K}}{0.08206 \text{ m}^3 \cdot \text{atm}} = 10.64 \text{ kmol/min}$$

$$\text{H}_2\text{O balance: } 0.70 \dot{m}_1 = \frac{10.64 \text{ kmol}}{\text{min}} \left| \frac{0.12 \text{ kmol H}_2\text{O}}{\text{kmol}} \right| \frac{18.02 \text{ kg}}{\text{kmol}}$$

$$\Rightarrow \dot{m}_1 = 32.9 \text{ kg/min milk}$$

$$\text{S(solids) balance: } 0.30(32.9 \text{ kg/min}) = \dot{m}_4 \Rightarrow \underline{\underline{\dot{m}_4 = 9.6 \text{ kg S/min}}}$$

$$\text{Dry air balance: } \dot{n}_2 = 0.88(10.64 \text{ kmol/min}) \Rightarrow \dot{n}_2 = 9.36 \text{ kmol/min air}$$

$$\dot{V}_2 = \frac{9.36 \text{ kmol}}{\text{min}} \left| \frac{0.08206 \text{ m}^3 \cdot \text{atm}}{\text{kmol} \cdot \text{K}} \right| \frac{440 \text{ K}}{(1033 - 40) \text{ cm H}_2\text{O}} \left| \frac{1033 \text{ cm H}_2\text{O}}{1 \text{ atm}} \right|$$

$$= \underline{\underline{352 \text{ m}^3 \text{ air/min}}}$$

$$u_{\text{air}} (\text{m/min}) = \frac{\dot{V}_{\text{air}} (\text{m}^3/\text{s})}{A (\text{m}^2)} = \frac{352 \text{ m}^3}{\text{min}} \left| \frac{1 \text{ min}}{60 \text{ s}} \right| \frac{1}{\pi/4 \cdot (6 \text{ m})^2} = \underline{\underline{0.21 \text{ m/s}}}$$

b. If the velocity of the air is too high, the powdered milk would be blown out of the reactor by the air instead of falling to the conveyor belt.

$$\text{5.18 } SG_{\text{CO}_2} = \frac{\rho_{\text{CO}_2}}{\rho_{\text{air}}} = \frac{\frac{PM_{\text{CO}_2}}{RT}}{\frac{PM_{\text{air}}}{RT}} = \frac{M_{\text{CO}_2}}{M_{\text{air}}} = \frac{44 \text{ kg/kmol}}{29 \text{ kg/kmol}} = \underline{\underline{1.52}}$$

$$\text{5.19 a. } x_{\text{CO}_2} = 0.75 \quad x_{\text{air}} = 1 - 0.75 = 0.25$$

$$\text{Since air is 21\% O}_2, \quad x_{\text{O}_2} = (0.25)(0.21) = 0.0525 = \underline{\underline{5.25 \text{ mole\% O}_2}}$$

$$\text{b. } m_{\text{CO}_2} = n \cdot x_{\text{CO}_2} \cdot M_{\text{CO}_2} = \frac{1 \text{ atm}}{0.08206 \frac{\text{m}^3 \cdot \text{atm}}{\text{kmol} \cdot \text{K}}} \left| \frac{(2 \times 1.5 \times 3) \text{ m}^3}{298.2 \text{ K}} \right| \frac{0.75 \text{ kmol CO}_2}{\text{kmol}} \left| \frac{44.01 \text{ kg CO}_2}{\text{kmol CO}_2} \right| = \underline{\underline{12 \text{ kg}}}$$

More needs to escape from the cylinder since the room is not sealed.

5.19 (cont'd)

- c. With the room closed off all weekend and the valve to the liquid cylinder leaking, if a person entered the room and closed the door, over a period of time the person could die of asphyxiation. Measures that would reduce hazards are:
1. Change the lock so the door can always be opened from the inside without a key.
 2. Provide ventilation that keeps air flowing through the room.
 3. Install a gas monitor that sets off an alarm once the mole% reaches a certain amount.
 4. Install safety valves on the cylinder in case of leaks.

$$5.20 \quad n_{\text{CO}_2} = \frac{15.7 \text{ kg}}{44.01 \text{ kg}} \left| \frac{1 \text{ kmol}}{1 \text{ kmol}} \right| = 0.357 \text{ kmol CO}_2$$

Assume ideal gas behavior, negligible temperature change ($T = 19^\circ\text{C} = 292.2\text{K}$)

$$\text{a.} \quad \frac{P_1 V}{P_2 V} = \frac{n_1 RT}{(n_1 + 0.357)RT} \Rightarrow \frac{n_1}{n_1 + 0.357} = \frac{P_1}{P_2} = \frac{102 \text{ kPa}}{3.27 \times 10^3 \text{ kPa}}$$

$$\Rightarrow n_1 = \underline{\underline{0.0115 \text{ kmol air in tank}}}$$

$$\text{b.} \quad V_{\text{tank}} = \frac{n_1 RT}{P_1} = \frac{0.0115 \text{ kmol}}{102 \text{ kPa}} \left| \frac{292.2 \text{ K}}{102 \text{ kPa}} \right| \left| \frac{8.314 \text{ m}^3 \cdot \text{kPa}}{\text{kmol} \cdot \text{K}} \right| \left| \frac{10^3 \text{ L}}{\text{m}^3} \right| = 274 \text{ L}$$

$$\rho_f = \frac{15700 \text{ g CO}_2 + 11.5 \text{ mol air} \cdot (29.0 \text{ g air} / \text{mol})}{274 \text{ L}} = \underline{\underline{58.5 \text{ g} / \text{L}}}$$

- c. CO_2 sublimates \Rightarrow large volume change due to phase change \Rightarrow rapid pressure rise.
Sublimation causes temperature drop; afterwards, T gradually rises back to room temperature, increase in T at constant $V \Rightarrow$ slow pressure rise.

5.21 At point of entry, $P_1 = (10 \text{ ft H}_2\text{O})(29.9 \text{ in. Hg}/33.9 \text{ ft H}_2\text{O}) + 28.3 \text{ in. Hg} = 37.1 \text{ in. Hg}$.
At surface, $P_2 = 28.3 \text{ in. Hg}$, $V_2 =$ bubble volume at entry

$$\text{Mean Slurry Density: } \frac{1}{\rho_{\text{sl}}} = \frac{x_{\text{solid}}}{\rho_{\text{solid}}} + \frac{x_{\text{solution}}}{\rho_{\text{solution}}} = \frac{0.20}{(1.2)(1.00 \text{ g} / \text{cm}^3)} + \frac{0.80}{(1.00 \text{ g} / \text{cm}^3)}$$

$$= 0.967 \frac{\text{cm}^3}{\text{g}} \Rightarrow \rho_{\text{sl}} = \frac{1.03 \text{ g}}{\text{cm}^3} \left| \frac{2.20 \text{ lb}}{1000 \text{ g}} \right| \left| \frac{5 \times 10^{-4} \text{ ton}}{1 \text{ lb}} \right| \left| \frac{10^6 \text{ cm}^3}{264.17 \text{ gal}} \right| = 4.3 \times 10^{-3} \text{ ton} / \text{gal}$$

$$\text{a.} \quad \frac{300 \text{ ton}}{\text{hr}} \left| \frac{\text{gal}}{4.3 \times 10^{-3} \text{ ton}} \right| \left| \frac{40.0 \text{ ft}^3 (\text{STP})}{1000 \text{ gal}} \right| \left| \frac{534.7^\circ \text{R}}{492^\circ \text{R}} \right| \left| \frac{29.9 \text{ in Hg}}{37.1 \text{ in Hg}} \right| = \underline{\underline{2440 \text{ ft}^3 / \text{hr}}}$$

$$\text{b.} \quad \frac{P_2 V_2}{P_1 V_1} = \frac{nRT}{nRT} \Rightarrow \frac{V_2}{V_1} = \frac{P_1}{P_2} \Rightarrow \frac{\frac{4}{3} \pi \left(\frac{D_2}{2}\right)^3}{\frac{4}{3} \pi \left(\frac{D_1}{2}\right)^3} = \frac{37.1}{28.3} \Rightarrow D_2^3 = 1.31 D_1^3 \stackrel{D_1 = 2 \text{ mm}}{=} \Rightarrow D_2 = 2.2 \text{ mm}$$

$$\% \text{ change} = \frac{(2.2 - 2.0) \text{ mm}}{2.0 \text{ mm}} \times 100 = \underline{\underline{10\%}}$$

5.22 Let B = benzene

n_1, n_2, n_3 = moles in the container when the sample is collected, after the helium is added, and after the gas is fed to the GC.

n_{inj} = moles of gas injected

n_B, n_{air}, n_{He} = moles of benzene and air in the container and moles of helium added

n_{BGC}, m_{BGC} = moles, g of benzene in the GC

y_B = mole fraction of benzene in room air

- a.** $P_1 V_1 = n_1 R T_1$ (1 \equiv condition when sample was taken): $P_1 = 99 \text{ kPa}$, $T_1 = 306 \text{ K}$

$$n_1 = \frac{99 \text{ kPa}}{101.3 \frac{\text{kPa}}{\text{atm}}} \left| \frac{2 \text{ L}}{306 \text{ K}} \right| \left| \frac{\text{mol} \cdot \text{K}}{.08206 \text{ L} \cdot \text{atm}} \right| = 0.078 \text{ mol} = n_{air} + n_B$$

- $P_2 V_2 = n_2 R T_2$ (2 \equiv condition when charged with He): $P_2 = 500 \text{ kPa}$, $T_2 = 306 \text{ K}$

$$n_2 = \frac{500 \text{ kPa}}{101.3 \frac{\text{kPa}}{\text{atm}}} \left| \frac{2 \text{ L}}{306 \text{ K}} \right| \left| \frac{\text{mol} \cdot \text{K}}{.08206 \text{ L} \cdot \text{atm}} \right| = 0.393 \text{ mol} = n_{air} + n_B + n_{He}$$

- $P_3 V_3 = n_3 R T_3$ (3 \equiv final condition in lab): $P_3 = 400 \text{ kPa}$, $T_3 = 296 \text{ K}$

$$n_3 = \frac{400 \text{ kPa}}{101.3 \frac{\text{kPa}}{\text{atm}}} \left| \frac{2 \text{ L}}{296 \text{ K}} \right| \left| \frac{\text{mol} \cdot \text{K}}{.08206 \text{ L} \cdot \text{atm}} \right| = 0.325 \text{ mol} = (n_{air} + n_B + n_{He}) - n_{inj}$$

$$n_{inj} = n_2 - n_3 = 0.068 \text{ mol}$$

$$n_B = n_{BGC} \times \frac{n_2}{n_{inj}} = \frac{0.393 \text{ mol}}{0.068 \text{ mol}} \left| \frac{m_{BGC}(\text{g B})}{78.0 \text{ g}} \right| \left| \frac{1 \text{ mol}}{78.0 \text{ g}} \right| = 0.0741 \cdot m_{BGC}$$

$$y_B(\text{ppm}) = \frac{n_B}{n_1} \times 10^6 = \frac{0.0741 \cdot m_{BGC}}{0.078} \times 10^6 = 0.950 \times 10^6 \cdot m_{BGC}$$

$$\left. \begin{array}{l} 9 \text{ am: } y_B = (0.950 \times 10^6)(0.656 \times 10^{-6}) = \underline{\underline{0.623 \text{ ppm}}} \\ 1 \text{ pm: } y_B = (0.950 \times 10^6)(0.788 \times 10^{-6}) = \underline{\underline{0.749 \text{ ppm}}} \\ 5 \text{ pm: } y_B = (0.950 \times 10^6)(0.910 \times 10^{-6}) = \underline{\underline{0.864 \text{ ppm}}} \end{array} \right\} \text{The avg. is below the PEL}$$

- b.** Helium is used as a carrier gas for the gas chromatograph, and to pressurize the container so gas will flow into the GC sample chamber. Waiting a day allows the gases to mix sufficiently and to reach thermal equilibrium.
- c.** (i) It is very difficult to have a completely evacuated sample cylinder; the sample may be dilute to begin with. (ii) The sample was taken on Monday after 2 days of inactivity at the plant. A reading should be taken on Friday. (iii) Helium used for the carrier gas is less dense than the benzene and air; therefore, the sample injected in the GC may be He-rich depending on where the sample was taken from the cylinder. (iv) The benzene may not be uniformly distributed in the laboratory. In some areas the benzene concentration could be well above the PEL.

5.23 Volume of balloon = $\frac{4}{3}\pi(10\text{ m})^3 = 4189\text{ m}^3$

Moles of gas in balloon

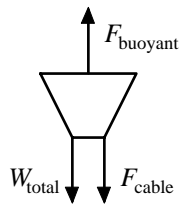
$$n(\text{kmol}) = \frac{4189\text{ m}^3}{22.4\text{ m}^3(\text{STP})} \cdot \frac{492^\circ\text{R}}{535^\circ\text{R}} \cdot \frac{3\text{ atm}}{1\text{ atm}} \cdot \frac{1\text{ kmol}}{22.4\text{ m}^3(\text{STP})} = 515.9\text{ kmol}$$

a. He in balloon:

$$m = (515.9\text{ kmol}) \cdot (4.003\text{ kg/kmol}) = \underline{\underline{2065\text{ kg He}}}$$

$$m_g = \frac{2065\text{ kg}}{1\text{ kg} \cdot \text{m} / \text{s}^2} \cdot \frac{9.807\text{ m}}{\text{s}^2} \cdot \frac{1\text{ N}}{1\text{ kg} \cdot \text{m} / \text{s}^2} = \underline{\underline{20,250\text{ N}}}$$

b. $\left(\frac{P_{\text{gas in balloon}}}{P_{\text{air displaced}}} \right) V = \frac{n_{\text{gas}} RT}{n_{\text{air}} RT} \Rightarrow n_{\text{air}} = \frac{P_{\text{air}}}{P_{\text{gas}}} \cdot n_{\text{gas}} = \frac{1\text{ atm}}{3\text{ atm}} \cdot 515.9\text{ kmol} = 172.0\text{ kmol}$



$$F_{\text{buoyant}} = W_{\text{air displaced}} = \frac{172.0\text{ kmol}}{1\text{ kmol}} \cdot \frac{29.0\text{ kg}}{1\text{ kmol}} \cdot \frac{9.807\text{ m}}{\text{s}^2} \cdot \frac{1\text{ N}}{1\text{ kg} \cdot \text{m} / \text{s}^2} = 48,920\text{ N}$$

Since balloon is stationary, $\sum F_i = 0$

$$F_{\text{cable}} = F_{\text{buoyant}} - W_{\text{total}} = 48920\text{ N} - \frac{(2065 + 150)\text{ kg}}{1\text{ kg} \cdot \text{m} / \text{s}^2} \cdot \frac{9.807\text{ m}}{\text{s}^2} \cdot \frac{1\text{ N}}{1\text{ kg} \cdot \text{m} / \text{s}^2} = \underline{\underline{27,200\text{ N}}}$$

c. When cable is released, $F_{\text{net}}(\uparrow) = 27200\text{ N} = M_{\text{tot}} a$

$$\Rightarrow a = \frac{27200\text{ N}}{(2065 + 150)\text{ kg}} \cdot \frac{1\text{ kg} \cdot \text{m} / \text{s}^2}{\text{N}} = \underline{\underline{12.3\text{ m/s}^2}}$$

d. When mass of displaced air equals mass of balloon + helium the balloon stops rising. Need to know how density of air varies with altitude.

e. The balloon expands, displacing more air \Rightarrow buoyant force increases \Rightarrow balloon rises until decrease in air density at higher altitudes compensates for added volume.

5.24 Assume ideal gas behavior, $P_{\text{atm}} = 1\text{ atm}$

a. $P_N V_N = P_c V_c \Rightarrow V_c = \frac{P_N V_N}{P_c} = \frac{5.7\text{ atm}}{9.5\text{ atm}} \cdot \frac{400\text{ m}^3/\text{h}}{1} = \underline{\underline{240\text{ m}^3/\text{h}}}$

b. Mass flow rate before diversion:

$$\frac{400\text{ m}^3}{\text{h}} \cdot \frac{273\text{ K}}{303\text{ K}} \cdot \frac{5.7\text{ atm}}{1\text{ atm}} \cdot \frac{1\text{ kmol}}{22.4\text{ m}^3(\text{STP})} \cdot \frac{44.09\text{ kg}}{\text{kmol}} = 4043 \frac{\text{kg C}_3\text{H}_6}{\text{h}}$$

5.24 (cont'd)

Monthly revenue:

$$(4043 \text{ kg/h})(24 \text{ h/day})(30 \text{ days/month})(\$0.60/\text{kg}) = \underline{\underline{\$1,747,000/\text{month}}}$$

c. Mass flow rate at Noxious plant after diversion:

$$\frac{400 \text{ m}^3}{\text{hr}} \left| \frac{273 \text{ K}}{303 \text{ K}} \right| \left| \frac{2.8 \text{ atm}}{1 \text{ atm}} \right| \left| \frac{1 \text{ kmol}}{22.4 \text{ m}^3} \right| \left| \frac{44.09 \text{ kg}}{\text{kmol}} \right| = 1986 \text{ kg/hr}$$

$$\underline{\text{Propane diverted}} = (4043 - 1986) \text{ kg/h} = \underline{\underline{2057 \text{ kg/h}}}$$

5.25 a. $P_{\text{He}} = y_{\text{He}} \cdot P = 0.35 \cdot (2.00 \text{ atm}) = \underline{\underline{0.70 \text{ atm}}}$

$$P_{\text{CH}_4} = y_{\text{CH}_4} \cdot P = 0.20 \cdot (2.00 \text{ atm}) = \underline{\underline{0.40 \text{ atm}}}$$

$$P_{\text{N}_2} = y_{\text{N}_2} \cdot P = 0.45 \cdot (2.00 \text{ atm}) = \underline{\underline{0.90 \text{ atm}}}$$

b. Assume 1.00 mole gas

$$\left. \begin{array}{l} 0.35 \text{ mol He} \left(\frac{4.004 \text{ g}}{\text{mol}} \right) = 1.40 \text{ g He} \\ 0.20 \text{ mol CH}_4 \left(\frac{16.05 \text{ g}}{\text{mol}} \right) = 3.21 \text{ g CH}_4 \\ 0.45 \text{ mol N}_2 \left(\frac{28.02 \text{ g}}{\text{mol}} \right) = 12.61 \text{ g N}_2 \end{array} \right\} 17.22 \text{ g} \Rightarrow \text{mass fraction CH}_4 = \frac{3.21 \text{ g}}{17.22 \text{ g}} = \underline{\underline{0.186}}$$

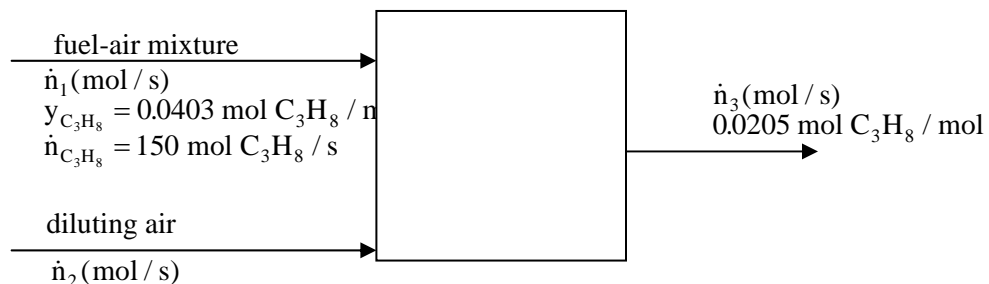
c. $\overline{\text{MW}} = \frac{\text{g of gas}}{\text{mol}} = \underline{\underline{17.2 \text{ g/mol}}}$

d. $\rho_{\text{gas}} = \frac{m}{V} = \frac{n(\overline{\text{MW}})}{V} = \frac{P(\overline{\text{MW}})}{RT} = \frac{(2.00 \text{ atm})(17.2 \text{ kg/kmol})}{(0.08206 \frac{\text{m}^3 \cdot \text{atm}}{\text{kmol} \cdot \text{K}})(363.2 \text{ K})} = \underline{\underline{1.15 \text{ kg/m}^3}}$

5.26 a. It is safer to release a mixture that is too lean to ignite.

If a mixture that is rich is released in the atmosphere, it can diffuse in the air and the C_3H_8 mole fraction can drop below the UFL, thereby producing a fire hazard.

b.



$$\dot{n}_1 = \frac{150 \text{ mol C}_3\text{H}_8}{\text{s}} \left| \frac{\text{mol}}{0.0403 \text{ mol C}_3\text{H}_8} \right| = 3722 \text{ mol/s}$$

Propane balance: $150 = 0.0205 \cdot \dot{n}_3 \Rightarrow \dot{n}_3 = 7317 \text{ mol/s}$

5.26 (cont'd)

Total mole balance: $\dot{n}_1 + \dot{n}_2 = \dot{n}_3 \Rightarrow \dot{n}_2 = 7317 - 3722 = 3595 \text{ mol air / s}$

c. $\dot{n}_2 = 1.3(\dot{n}_2)_{\min} = 4674 \text{ mol / s}$

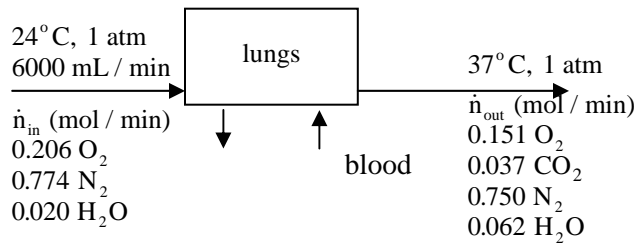
$$\left. \begin{aligned} \dot{V}_2 &= \frac{4674 \text{ mol / s}}{\left| \frac{8.314 \text{ m}^3 \cdot \text{Pa}}{\text{mol} \cdot \text{K}} \right| \frac{398.2 \text{ K}}{131,000 \text{ Pa}}} = 118 \text{ m}^3 / \text{s} \\ \dot{V}_1 &= \frac{3722 \text{ mol}}{\text{s}} \left| \frac{8.314 \text{ m}^3 \cdot \text{Pa}}{\text{mol} \cdot \text{K}} \right| \frac{298.2 \text{ K}}{110000 \text{ Pa}} = 83.9 \text{ m}^3 / \text{s} \end{aligned} \right\} \frac{\dot{V}_2}{\dot{V}_1} = 1.41 \frac{\text{m}^3 \text{ diluting air}}{\text{m}^3 \text{ fuel gas}}$$

$$y_2 = \frac{150 \text{ mol / s}}{\dot{n}_1 + \dot{n}_2} = \frac{150 \text{ mol / s}}{(3722 \text{ mol / s} + 4674 \text{ mol / s})} \times 100\% = \underline{\underline{1.8\%}}$$

d. The incoming propane mixture could be higher than 4.03%.

If $\dot{n}_2 = (\dot{n}_2)_{\min}$, fluctuations in the air flow rate would lead to temporary explosive conditions.

5.27 Basis: (12 breaths/min)(500 mL air inhaled/breath) = 6000 mL inhaled/min



a. $\dot{n}_{\text{in}} = \frac{6000 \text{ mL}}{\text{min}} \left| \frac{1 \text{ L}}{10^3 \text{ mL}} \right| \frac{273 \text{ K}}{297 \text{ K}} \left| \frac{1 \text{ mol}}{22.4 \text{ L (STP)}} \right| = 0.246 \text{ mol/min}$

N₂ balance: $(0.774)(0.246) = 0.750\dot{n}_{\text{out}} \Rightarrow \dot{n}_{\text{out}} = 0.254 \text{ mol exhaled/min}$

O₂ transferred to blood: $[(0.246)(0.206) - (0.254)(0.151)](\text{mol O}_2/\text{min})[32.0 \text{ g/mol}]$
 $= \underline{\underline{0.394 \text{ g O}_2/\text{min}}}$

CO₂ transferred from blood: $[(0.254)(0.037)](\text{mol CO}_2/\text{min})[44.01 \text{ g/mol}]$
 $= \underline{\underline{0.414 \text{ g CO}_2/\text{min}}}$

H₂O transferred from blood:

$$[(0.254)(0.062) - (0.246)(0.020)](\text{mol H}_2\text{O/min})[18.02 \text{ g/mol}]$$

$$= \underline{\underline{0.195 \text{ g H}_2\text{O/min}}}$$

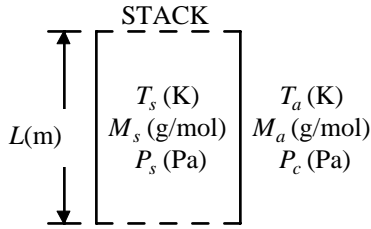
5.27 (cont'd)

$$\frac{PV_{in}}{PV_{out}} = \frac{n_{in}RT_{in}}{n_{out}RT_{out}}$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = \left(\frac{n_{out}}{n_{in}} \right) \left(\frac{T_{out}}{T_{in}} \right) = \left(\frac{0.254 \text{ mol/min}}{0.246 \text{ mol/min}} \right) \left(\frac{310\text{K}}{297\text{K}} \right) = \underline{\underline{1.078 \text{ mL exhaled/ml inhaled}}}$$

b. $(0.414 \text{ g CO}_2 \text{ lost/min}) + (0.195 \text{ g H}_2\text{O lost/min}) - (0.394 \text{ g O}_2 \text{ gained/min}) = \underline{\underline{0.215 \text{ g/min}}}$

5.28



Ideal gas: $\rho = \frac{PM}{RT}$

a. $D = (\rho g L)_{\text{combust.}} - (\rho g L)_{\text{stack}} = \frac{P_a M_a}{RT_a} g L - \frac{P_a M_s}{RT_s} g L = \frac{P_a g L}{R} \left[\frac{M_a}{T_a} - \frac{M_s}{T_s} \right]$

b. $M_s = (0.18)(44.1) + (0.02)(32.0) + (0.80)(28.0) = 31.0 \text{ g/mol}$, $T_s = 655\text{K}$,
 $P_a = 755 \text{ mm Hg}$

$M_a = 29.0 \text{ g/mol}$, $T_a = 294\text{K}$, $L = 53 \text{ m}$

$$D = \frac{755 \text{ mm Hg}}{760 \text{ mm Hg}} \left| \frac{1 \text{ atm}}{760 \text{ mm Hg}} \right| \left| \frac{53.0 \text{ m}}{1 \text{ m}} \right| \left| \frac{9.807 \text{ m/s}^2}{1 \text{ m/s}^2} \right| \left| \frac{\text{kmol} \cdot \text{K}}{0.08206 \text{ m}^3 \cdot \text{atm}} \right|$$

$$\times \left[\frac{29.0 \text{ kg/kmol}}{294\text{K}} - \frac{31.0 \text{ kg/kmol}}{655\text{K}} \right] \times \left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) = \frac{323 \text{ N}}{\text{m}^2} \left| \frac{1033 \text{ cm H}_2\text{O}}{1.013 \times 10^5 \text{ N/m}^2} \right|$$

$$= \underline{\underline{3.3 \text{ cm H}_2\text{O}}}$$

5.29 a. $\rho = \frac{P(\text{MW})}{RT} \xrightarrow{\text{MW}_{\text{CCl}_2\text{O}} = 98.91 \text{ g/mol}} \frac{\rho_{\text{CCl}_2\text{O}}}{\rho_{\text{air}}} = \frac{98.91}{29.0} = 3.41$

Phosgene, which is 3.41 times more dense than air, will displace air near the ground.

b. $V_{\text{tube}} = \frac{\pi(D_{in})^2 L}{4} = \frac{\pi}{4} [0.635 \text{ cm} - 2(0.0559 \text{ cm})]^2 (15.0 \text{ cm}) = 3.22 \text{ cm}^3$

$$m_{\text{CCl}_2\text{O}} = V_{\text{tube}} \cdot \rho_{\text{CCl}_2\text{O}} = \frac{3.22 \text{ cm}^3}{10^3 \text{ cm}^3} \left| \frac{1 \text{ L}}{10^3 \text{ cm}^3} \right| \left| \frac{1 \text{ atm}}{0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}}} \right| \left| \frac{98.91 \text{ g/mol}}{296.2 \text{ K}} \right| = \underline{\underline{0.0131 \text{ g}}}$$

c. $n_{\text{CCl}_2\text{O(l)}} = \frac{3.22 \text{ cm}^3}{1.37 \times 1.000 \text{ g}} \left| \frac{1.37 \times 1.000 \text{ g}}{\text{cm}^3} \right| \left| \frac{\text{mol}}{98.91 \text{ g}} \right| = 0.0446 \text{ mol CCl}_2\text{O}$

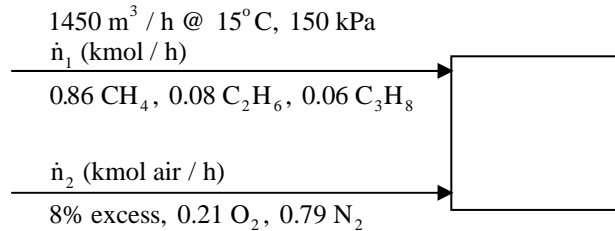
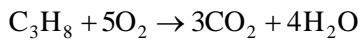
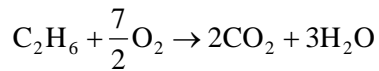
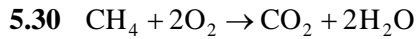
5.29 (cont'd)

$$n_{\text{air}} = \frac{PV}{RT} = \frac{1 \text{ atm}}{296.2 \text{ K}} \left| \frac{2200 \text{ ft}^3}{296.2 \text{ K}} \right| \left| \frac{28.317 \text{ L}}{\text{ft}^3} \right| \left| \frac{\text{mol} \cdot \text{K}}{.08206 \text{ L} \cdot \text{atm}} \right| = 2563 \text{ mol air}$$

$$\frac{n_{\text{CCl}_2\text{O}}}{n_{\text{air}}} = \frac{0.0446}{2563} = \underline{\underline{17.4 \times 10^{-6}}} = \underline{\underline{17.4 \text{ ppm}}}$$

The level of phosgene in the room exceeded the safe level by a factor of more than 100. Even if the phosgene were below the safe level, there would be an unsafe level near the floor since phosgene is denser than air, and the concentration would be much higher in the vicinity of the leak.

- d. Pete's biggest mistake was working with a highly toxic substance with no supervision or guidance from an experienced safety officer. He also should have been working under a hood and should have worn a gas mask.



$$\dot{n}_1 = \frac{1450 \text{ m}^3}{\text{h}} \left| \frac{273.2 \text{ K}}{288.2 \text{ K}} \right| \left| \frac{(101.3 + 150) \text{ kPa}}{101.3 \text{ kPa}} \right| \left| \frac{1 \text{ kmol}}{22.4 \text{ m}^3(\text{STP})} \right| = 152 \text{ kmol/h}$$

Theoretical O₂:

$$\frac{152 \text{ kmol}}{\text{h}} \left[0.86 \left(\frac{2 \text{ kmol O}_2}{\text{kmol CH}_4} \right) + 0.08 \left(\frac{3.5 \text{ kmol O}_2}{\text{kmol C}_2\text{H}_6} \right) + 0.06 \left(\frac{5 \text{ kmol O}_2}{\text{kmol C}_3\text{H}_8} \right) \right] = 349.6 \text{ kmol/h O}_2$$

$$\text{Air flow: } \dot{V}_{\text{air}} = \frac{1.08(349.6) \text{ kmol O}_2}{\text{h}} \left| \frac{1 \text{ kmol Air}}{0.21 \text{ kmol O}_2} \right| \left| \frac{22.4 \text{ m}^3(\text{STP})}{\text{kmol}} \right| = \underline{\underline{4.0 \times 10^4 \text{ m}^3(\text{STP})/\text{h}}}$$

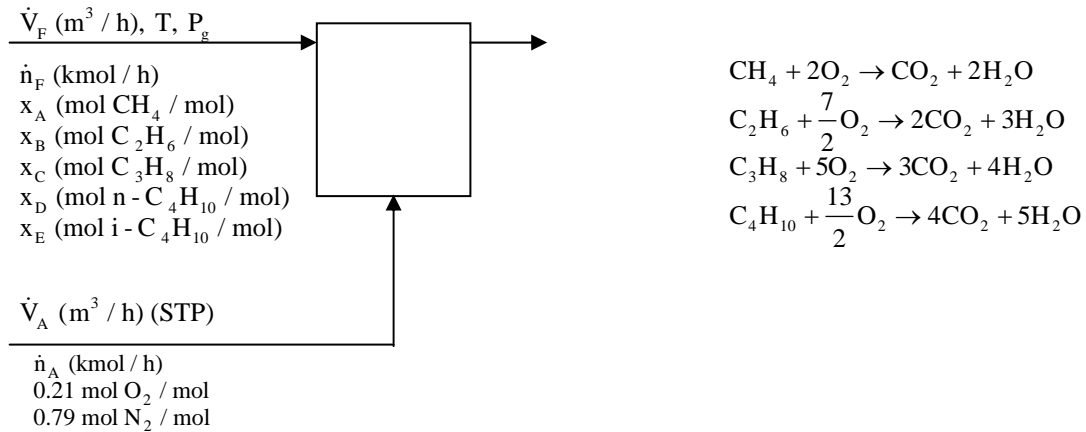
5.31 Calibration formulas

$$(T = 25.0; R_T = 14), (T = 35.0, R_T = 27) \Rightarrow T(^{\circ}\text{C}) = 0.77R_T + 14.2$$

$$(P_g = 0; R_p = 0), (P_g = 20.0, R_r = 6) \Rightarrow P_{\text{gauge}}(\text{kPa}) = 3.33R_p$$

$$(\dot{V}_F = 0; R_p = 0), (\dot{V}_F = 2.0 \times 10^3, R_F = 10) \Rightarrow \dot{V}_F(\text{m}^3/\text{h}) = 200R_F$$

$$(\dot{V}_A = 0; R_A = 0), (\dot{V}_A = 1.0 \times 10^5, R_A = 25) \Rightarrow \dot{V}_A(\text{m}^3/\text{h}) = 4000R_A$$



$$\dot{n}_F = \frac{\dot{V}_F(\text{m}^3/\text{h})}{(T + 273.2)\text{K}} \cdot \frac{(P_g + 101.3)\text{kPa}}{101.3\text{kPa}} \cdot \frac{1\text{ kmol}}{22.4\text{ m}^3(\text{STP})}$$

$$= \frac{0.12031 \dot{V}_F (P_g + 101.3)}{(T + 273)} \left(\frac{\text{kmol}}{\text{h}} \right)$$

Theoretical O_2 :

$$(\dot{n}_{\text{O}_2})_{\text{Th}} = \dot{n}_F (2x_A + 3.5x_B + 5x_C + 6.5(x_D + x_E)) \text{ kmol O}_2 \text{ req./h}$$

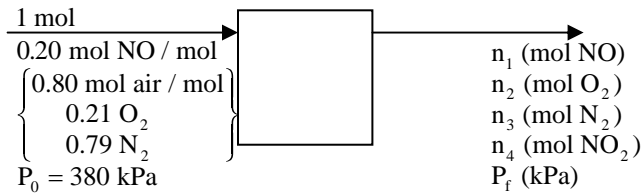
$$\text{Air feed: } \dot{n}_A = \frac{(\dot{n}_{\text{O}_2})_{\text{Th}} \text{ kmol O}_2 \text{ req.}}{\text{h}} \cdot \frac{1 \text{ kmol air}}{0.21 \text{ kmol O}_2} \cdot \frac{(1 + P_x/100) \text{ kmol feed}}{1 \text{ kmol req.}}$$

$$= 4.762 \left(1 + \frac{P_x}{100} \right) (\dot{n}_{\text{O}_2})_{\text{Th}}$$

$$\dot{V}_A = [\dot{n}_A (\text{kmol air/h})] (22.4 \text{ m}^3 (\text{STP})/\text{kmol}) = 22.4 \dot{n}_A [\text{m}^3 (\text{STP})/\text{h}]$$

RT	TQ	Rp	Pg(kPa)	Rf	xa	xb	xc	xd	xe	PX(%)	rF	nO2 th	nA	Vf(m³/h)	Va(m³/h)	Pa
23.1	32.0	7.5	25.0	7.25	0.81	0.08	0.05	0.04	0.02	15	72.2	183.47	1004.74	1450	22506.2	5.63
7.5	20.0	19.3	64.3	5.8	0.58	0.31	0.06	0.05	0.00	23	78.9	226.4	1325.8	1160	29697.8	7.42
46.5	50.0	15.8	52.6	2.45	0.00	0.00	0.65	0.25	0.10	33	28.1	155.2	983.1	490	22022.3	5.51
21	30.4	3	10.0	6	0.02	0.4	0.35	0.1	0.13	15	53.0	248.1	1358.9	1200	30439.2	7.6
23	31.9	4	13.3	7	0.45	0.12	0.23	0.16	0.04	15	63.3	238.7	1307.3	1400	29283.4	7.3
25	33.5	5	16.7	9	0.5	0.3	0.1	0.04	0.06	15	83.4	266.7	1460.8	1800	32721.2	8.2
27	35.0	6	20.0	10	0.5	0.3	0.1	0.04	0.06	15	94.8	303.2	1660.6	2000	37196.7	9.3

5.32 $\text{NO} + \frac{1}{2}\text{O}_2 \rightleftharpoons \text{NO}_2$



a. Basis: 1.0 mol feed

90% NO conversion: $n_1 = 0.10(0.20) = 0.020 \text{ mol NO} \Rightarrow \text{NO reacted} = 0.18 \text{ mol}$

$$\text{O}_2 \text{ balance: } n_2 = 0.80(0.21) - \frac{0.18 \text{ mol NO}}{1 \text{ mol NO}} \left| \frac{0.5 \text{ mol O}_2}{\text{mol NO}} \right| = 0.0780 \text{ mol O}_2$$

$$\text{N}_2 \text{ balance: } n_3 = 0.80(0.79) = 0.632 \text{ mol N}_2$$

$$n_4 = \frac{0.18 \text{ mol NO}}{1 \text{ mol NO}} \left| \frac{1 \text{ mol NO}_2}{1 \text{ mol NO}} \right| = 0.18 \text{ mol NO}_2 \Rightarrow n_f = n_1 + n_2 + n_3 + n_4 = 0.91 \text{ mol}$$

$$y_{\text{NO}} = \frac{0.020 \text{ mol NO}}{0.91 \text{ mol}} = 0.022 \frac{\text{mol NO}}{\text{mol}}$$

$$y_{\text{O}_2} = 0.086 \frac{\text{mol O}_2}{\text{mol}} \quad y_{\text{N}_2} = 0.695 \frac{\text{mol N}_2}{\text{mol}} \quad y_{\text{NO}_2} = 0.198 \frac{\text{mol NO}_2}{\text{mol}}$$

$$\frac{P_f V}{P_0 V} = \frac{n_f RT}{n_0 RT} \Rightarrow P_f = P_0 \frac{n_f}{n_0} = 380 \text{ kPa} \left(\frac{0.91 \text{ mol}}{1 \text{ mol}} \right) = \underline{\underline{346 \text{ kPa}}}$$

b. $n_f = n_0 \frac{P_f}{P_0} = (1 \text{ mol}) \frac{360 \text{ kPa}}{380 \text{ kPa}} = 0.95 \text{ mol}$

$$n_i = n_{i0} + \nu_i \xi$$

$$\Downarrow$$

$$n_1 (\text{mol NO}) = 0.20 - \xi$$

$$n_2 (\text{mol O}_2) = (0.21)(0.80) - 0.5\xi$$

$$n_3 (\text{mol N}_2) = (0.79)(0.80)$$

$$n_4 (\text{mol NO}_2) = \xi$$

$$n_f = 1 - 0.5\xi = 0.95 \Rightarrow \xi = \underline{\underline{0.10}}$$

$$\Rightarrow n_1 = 0.10 \text{ mol NO}, n_2 = 0.118 \text{ mol O}_2, n_3 = 0.632 \text{ mol N}_2,$$

$$n_4 = 0.10 \text{ mol NO}_2 \Rightarrow y_{\text{NO}} = 0.105, y_{\text{O}_2} = 0.124, y_{\text{N}_2} = 0.665, y_{\text{NO}_2} = 0.105$$

$$\text{NO conversion} = \frac{(0.20 - n_1)}{0.20} \times 100\% = \underline{\underline{50\%}}$$

$$P (\text{atm}) = \frac{360 \text{ kPa}}{101.3 \frac{\text{kPa}}{\text{atm}}} = 3.55 \text{ atm}$$

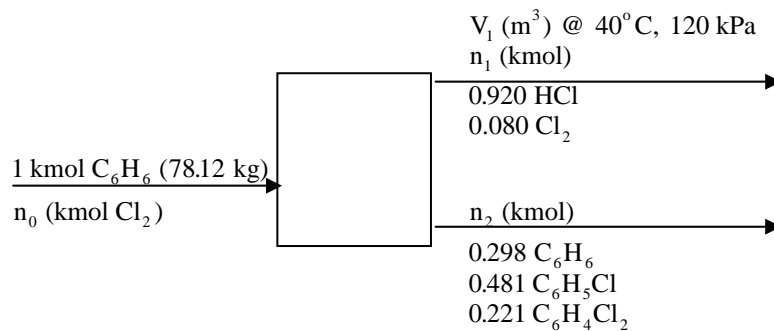
$$K_p = \frac{(y_{\text{NO}_2} P)}{(y_{\text{NO}} P)(y_{\text{O}_2} P)^{0.5}} = \frac{(y_{\text{NO}_2})}{(y_{\text{NO}})(y_{\text{O}_2})^{0.5} P^{0.5}} = \frac{0.105}{(0.105)(0.124)^{0.5} (3.55)^{0.5}} = \underline{\underline{1.51 \text{ atm}^{\frac{1}{2}}}}$$

5.33

Liquid composition:

$$\begin{array}{rcl}
 100 \text{ kg liquid} \Rightarrow \left. \begin{array}{l} \frac{49.2 \text{ kg M}}{112.6 \text{ kg}} \left| \frac{1 \text{ kmol}}{112.6 \text{ kg}} = 0.437 \text{ kmol M} \right. \\ \frac{29.6 \text{ kg D}}{147.0 \text{ kg}} \left| \frac{1 \text{ kmol}}{147.0 \text{ kg}} = 0.201 \text{ kmol D} \right. \\ \frac{21.2 \text{ kg B}}{78.12 \text{ kg}} \left| \frac{1 \text{ kmol}}{78.12 \text{ kg}} = 0.271 \text{ kmol B} \right. \end{array} \right\} \Rightarrow \begin{array}{l} 0.481 \text{ kmol M / kmol} \\ 0.221 \text{ kmol D / kmol} \\ 0.298 \text{ kmol B / kmol} \end{array} \\
 \hline
 0.909 \text{ kmol}
 \end{array}$$

a. Basis: 1 kmol C₆H₆ fed



$$\begin{aligned}
 \text{C balance: } \frac{1 \text{ kmol C}_6\text{H}_6}{1 \text{ kmol C}_6\text{H}_6} \left| \frac{6 \text{ kmol C}}{1 \text{ kmol C}_6\text{H}_6} \right. &= n_2 [0.298 \times 6 + 0.481 \times 6 + 0.221 \times 6] \\
 \Rightarrow n_2 &= 1.00 \text{ kmol}
 \end{aligned}$$

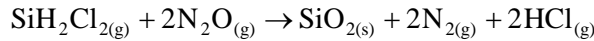
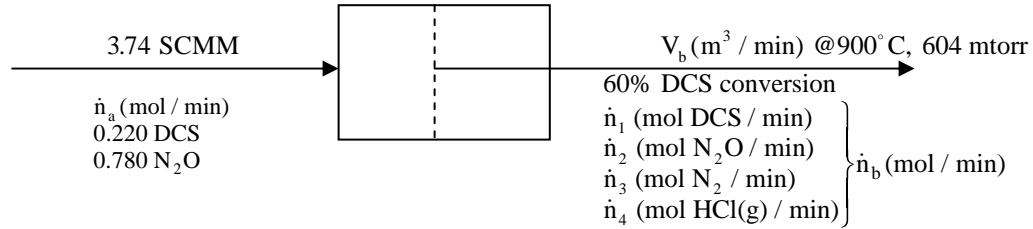
$$\begin{aligned}
 \text{H balance: } \frac{1 \text{ kmol C}_6\text{H}_6}{1 \text{ kmol C}_6\text{H}_6} \left| \frac{6 \text{ kmol H}}{1 \text{ kmol C}_6\text{H}_6} \right. &= n_1 (0.920)(1) \\
 + n_2 [0.298 \times 6 + 0.481 \times 5 + 0.221 \times 4] &\Rightarrow n_1 = 1.00 \text{ kmol}
 \end{aligned}$$

$$\begin{aligned}
 V_1 &= \frac{n_1 RT}{P} = \frac{1.00 \text{ kmol}}{120 \text{ kPa}} \left| \frac{101.3 \text{ kPa}}{1 \text{ atm}} \right| \left| \frac{0.08206 \text{ m}^3 \cdot \text{atm}}{\text{kmol} \cdot \text{K}} \right| \frac{313.2 \text{ K}}{1} = 21.7 \text{ m}^3 \\
 \Rightarrow \frac{V_1}{m_B} &= \frac{21.7 \text{ m}^3}{78.12 \text{ kg B}} = \underline{\underline{0.278 \text{ m}^3 / \text{kg B}}}
 \end{aligned}$$

$$\begin{aligned}
 \text{b. } \dot{V}_{\text{gas}} (\text{m}^3 / \text{s}) &= u (\text{m} / \text{s}) \cdot A (\text{m}^2) = u \cdot \frac{\pi d^2}{4} \Rightarrow d^2 = \frac{4 \cdot \dot{V}_{\text{gas}}}{\pi \cdot u} \\
 d^2 &= \frac{4 \dot{m}_{B0} (\text{kg B})}{\text{min}} \left| \frac{0.278 \text{ m}^3}{\text{kg B}} \right| \left| \frac{\text{s}}{\pi (10) \text{ m}} \right| \left| \frac{1 \text{ min}}{60 \text{ s}} \right| \left| \frac{10^4 \text{ cm}^2}{\text{m}^2} \right| = 5.90 \dot{m}_{B0} (\text{cm}^2) \\
 \Rightarrow d (\text{cm}) &= \underline{\underline{2.43 \cdot (\dot{m}_{B0})^{\frac{1}{2}}}}
 \end{aligned}$$

c. Decreased use of chlorinated products, especially solvents.

5.34



$$\text{a. } \dot{n}_a = \frac{3.74 \text{ m}^3 \text{ (STP)}}{\text{min}} \left| \frac{10^3 \text{ mol}}{22.4 \text{ m}^3 \text{ (STP)}} \right| = 167 \text{ mol / min}$$

$$60\% \text{ conversion: } \dot{n}_1 = (1 - 0.60) \left(\frac{0.220 \text{ mol DCS}}{\text{mol}} \right) (167 \text{ mol / min}) = 14.7 \text{ mol DCS / min}$$

$$\text{DCS reacted: } (0.60)(0.220)(167) \frac{\text{mol DCS}}{\text{min}} = 22.04 \text{ mol DCS reacted / min}$$

$$\begin{aligned} \text{N}_2\text{O balance: } \dot{n}_2 &= 0.780(167) \frac{\text{mol N}_2\text{O}}{\text{min}} \\ &\quad - \frac{22.04 \text{ mol DCS}}{\text{min}} \left| \frac{2 \text{ mol N}_2\text{O}}{\text{mol DCS}} \right| = 86.18 \text{ mol N}_2\text{O / min} \end{aligned}$$

$$\text{N}_2 \text{ balance: } \dot{n}_3 = \frac{22.04 \text{ mol DCS}}{\text{min}} \left| \frac{2 \text{ mol N}_2}{\text{mol DCS}} \right| = 44.08 \text{ mol N}_2 / \text{min}$$

$$\text{HCl balance: } \dot{n}_4 = \frac{22.04 \text{ mol DCS}}{\text{min}} \left| \frac{2 \text{ mol HCl}}{\text{mol DCS}} \right| = 44.08 \text{ mol HCl / min}$$

$$\dot{n}_B = \dot{n}_1 + \dot{n}_2 + \dot{n}_3 + \dot{n}_4 = 189 \text{ mol / min}$$

$$\Rightarrow \dot{V}_B = \frac{\dot{n}_B RT}{P} = \frac{189 \text{ mol}}{\text{min}} \left| \frac{62.36 \text{ L} \cdot \text{torr}}{\text{mol} \cdot \text{K}} \right| \left| \frac{0.001 \text{ m}^3}{\text{L}} \right| \left| \frac{1173 \text{ K}}{0.604 \text{ torr}} \right| = \underline{\underline{2.29 \times 10^4 \text{ m}^3 / \text{min}}}$$

$$\text{b. } p_{\text{DCS}} = x_{\text{DCS}} \cdot P = \frac{\dot{n}_1}{\dot{n}_B} P = \frac{14.7 \text{ mol DCS/min}}{189 \text{ mol/min}} \cdot 604 \text{ mtorr} = 47.0 \text{ mtorr}$$

$$p_{\text{N}_2\text{O}} = x_{\text{N}_2\text{O}} \cdot P = \frac{\dot{n}_2}{\dot{n}_B} P = \frac{86.2 \text{ mol N}_2\text{O/min}}{189 \text{ mol/min}} \cdot 604 \text{ mtorr} = 275.5 \text{ mtorr}$$

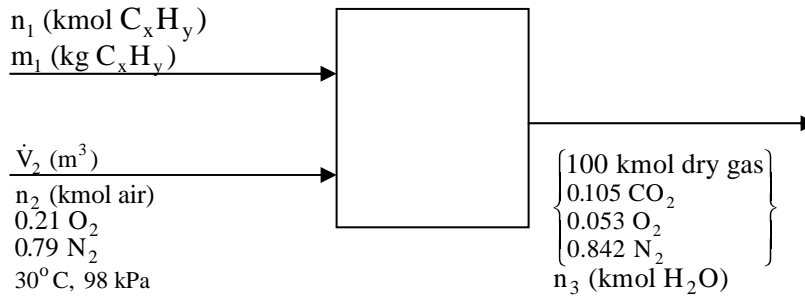
$$r = 3.16 \times 10^{-8} \cdot p_{\text{DCS}} \cdot p_{\text{N}_2\text{O}}^{0.65} = 3.16 \times 10^{-8} (47.0) (275.5)^{0.65} = 5.7 \times 10^{-5} \frac{\text{mol SiO}_2}{\text{m}^2 \cdot \text{s}}$$

$$\begin{aligned} \text{c. } h(\text{\AA}) &= r \cdot t \cdot \frac{\text{MW}}{\rho_{\text{SiO}_2}} = \frac{5.7 \times 10^{-5} \text{ mol SiO}_2}{\text{m}^2 \cdot \text{s}} \left| \frac{60 \text{ s}}{\text{min}} \right| \left| \frac{120 \text{ min}}{\text{min}} \right| \left| \frac{60.09 \text{ g/mol}}{2.25 \times 10^6 \text{ g/m}^3} \right| \left| \frac{10^{10} \text{\AA}}{1 \text{ m}} \right| \\ &= \underline{\underline{1.1 \times 10^5 \text{\AA}}} \end{aligned}$$

The films will be thicker closer to the entrance where the lower conversion yields higher p_{DCS} and $p_{\text{N}_2\text{O}}$ values, which in turn yields a higher deposition rate.

5.35

Basis: 100 kmol dry product gas



a. N₂ balance: $0.79n_2 = 0.842(100) \Rightarrow n_2 = 106.6 \text{ kmol air}$

O balance: $2(0.21n_2) = 100[2(0.105) + 2(0.053)] + n_3 \Rightarrow n_3 = 13.17 \text{ kmol H}_2\text{O}$

C balance:
$$\frac{n_1 (\text{kmol C}_x\text{H}_y)}{\left(\frac{\text{kmol C}_x\text{H}_y}{x (\text{kmol C})}\right)} = 100(0.105) \Rightarrow n_1 x = 10.5 \quad (1)$$

H balance:
$$n_1 y = 2n_3 \xrightarrow{n_3=13.17} n_1 y = 26.34 \quad (2)$$

Divide (2) by (1) $\Rightarrow \frac{y}{x} = \frac{26.34}{10.5} = \underline{\underline{2.51 \text{ mol H / mol C}}}$

O₂ fed: $0.21(106.6 \text{ kmol air}) = 22.4 \text{ kmol}$

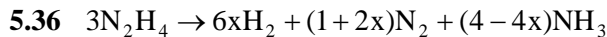
O₂ in excess = 5.3 kmol \Rightarrow Theoretical O₂ = (22.4 - 5.3) kmol = 17.1 kmol

% excess = $\frac{5.3 \text{ kmol O}_2}{17.1 \text{ kmol O}_2} \times 100\% = \underline{\underline{31\% \text{ excess air}}}$

b.
$$V_2 = \frac{106.6 \text{ kmol N}_2}{\text{kmol}} \left| \frac{22.4 \text{ m}^3 (\text{STP})}{\text{kmol}} \right| \left| \frac{101.3 \text{ kPa}}{98 \text{ kPa}} \right| \left| \frac{303 \text{ K}}{273 \text{ K}} \right| = 2740 \text{ m}^3$$

$$m_1 = \frac{n_1 x (\text{kmol C})}{\text{kmol}} \left| \frac{12.0 \text{ kg}}{\text{kmol}} \right| + \frac{n_1 y (\text{kmol H})}{\text{kmol}} \left| \frac{1.01 \text{ kg}}{\text{kmol}} \right| \xrightarrow[n_1 y = 26.34]{n_1 x = 10.5} m_1 = 152.6 \text{ kg}$$

$$\frac{V_2}{m_1} = \frac{2740 \text{ m}^3 \text{ air}}{152.6 \text{ kg fuel}} = \underline{\underline{18.0 \frac{\text{m}^3 \text{ air}}{\text{kg fuel}}}}$$



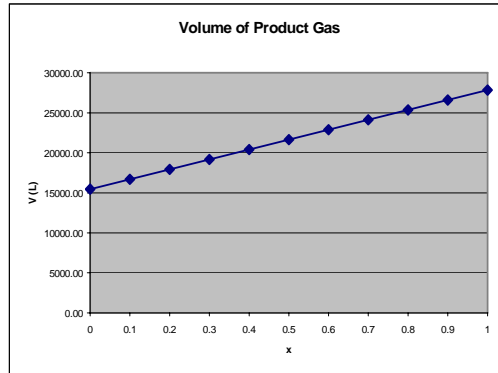
a. $0 \leq x \leq 1$

b.
$$n_{\text{N}_2\text{H}_4} = \frac{50 \text{ L}}{\text{L}} \left| \frac{0.82 \text{ kg}}{32.06 \text{ kg}} \right| \left| \frac{1 \text{ kmol}}{32.06 \text{ kg}} \right| = 1.28 \text{ kmol}$$

$$\begin{aligned} n_{\text{product}} &= 1.28 \text{ kmol N}_2\text{H}_4 \left[\frac{6x \text{ kmol H}_2}{3 \text{ kmol N}_2\text{H}_4} + \frac{(1+2x) \text{ kmol N}_2}{3 \text{ kmol N}_2\text{H}_4} + \frac{(4-4x) \text{ kmol NH}_3}{3 \text{ kmol N}_2\text{H}_4} \right] \\ &= \frac{1.28}{3} (6x + 1 + 2x + 4 - 4x) = 1.707x + 2.13 \text{ kmol} \end{aligned}$$

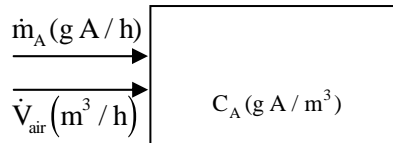
5.36 (cont'd)

x	n _{product}	V _p (L)
0	2.13	15447.92
0.1	2.30	16685.93
0.2	2.47	17923.94
0.3	2.64	19161.95
0.4	2.81	20399.96
0.5	2.98	21637.97
0.6	3.15	22875.98
0.7	3.32	24113.99
0.8	3.50	25352.00
0.9	3.67	26590.01
1	3.84	27828.02



- c. Hydrazine is a good propellant because as it decomposes generates a large number of moles and hence a large volume of gas.

5.37



- a. (i) Cap left off container of liquid A and it evaporates into room, (ii) valve leak in cylinder with A in it, (iii) pill of liquid A which evaporates into room, (iv) waste containing A poured into sink, A used as cleaning solvent.

$$\text{b. } \dot{m}_A \left(\frac{\text{kg A}}{\text{h}} \right)_{\text{in}} = \dot{m}_A \left(\frac{\text{kg A}}{\text{h}} \right)_{\text{out}} = \dot{V}_{\text{air}} \left(\frac{\text{m}^3}{\text{h}} \right) C_A \left(\frac{\text{kg A}}{\text{m}^3} \right)$$

$$\text{c. } y_A = \frac{\text{mol A}}{\text{mol air}} = \frac{C_A \left(\frac{\text{g A}}{\text{m}^3} \right) \cdot V}{M_A \left(\frac{\text{g A}}{\text{mol}} \right) \cdot n_{\text{air}}} \xrightarrow{C_A = \frac{\dot{m}_A}{k \cdot V_{\text{air}}}; n_{\text{air}} = \frac{PV}{RT}} y_A = \frac{\dot{m}_A}{k \cdot V_{\text{air}}} \frac{RT}{M_A P}$$

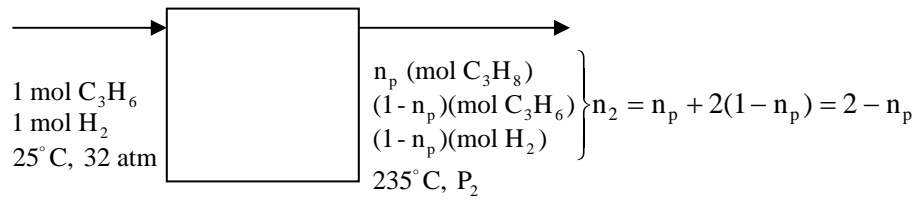
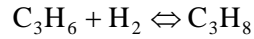
$$\text{d. } y_A = 50 \times 10^{-6} \quad \dot{m}_A = 9.0 \text{ g/h}$$

$$\left(\dot{V}_{\text{air}} \right)_{\text{min}} = \frac{\dot{m}_A}{k y_A} \frac{RT}{M_A P} = \frac{9.0 \text{ g/h}}{0.5(50 \times 10^{-6})} \left| \frac{8.314 \frac{\text{m}^3 \cdot \text{Pa}}{\text{mol} \cdot \text{K}}}{101.3 \times 10^3 \text{ Pa}} \right| \left| \frac{293 \text{ K}}{104.14 \text{ g/mol}} \right| = \underline{\underline{83 \text{ m}^3/\text{h}}}$$

Concentration of styrene could be higher in some areas due to incomplete mixing (high concentrations of A near source); 9.0 g/h may be an underestimate; some individuals might be sensitive to concentrations < PEL.

- e. Increase in the room temperature could increase the volatility of A and hence the rate of evaporation from the tank. T in the numerator of expression for \dot{V}_{air} : At higher T, need a greater air volume throughput for y to be < PEL.

5.38 Basis: 2 mol feed gas



- a. At completion, $n_p = 1 \text{ mol}$, $n_2 = 2 - 1 = 1 \text{ mol}$

$$\frac{P_2 V}{P_1 V} = \frac{n_2 R T_2}{n_1 R T_1} \Rightarrow P_2 = \frac{n_2}{n_1} \frac{T_2}{T_1} P_1 = \frac{1 \text{ mol}}{2 \text{ mol}} \left| \frac{508 \text{ K}}{298 \text{ K}} \right| 32.0 \text{ atm} = 27.3 \text{ atm}$$

- b. $P_2 = 35.1 \text{ atm}$

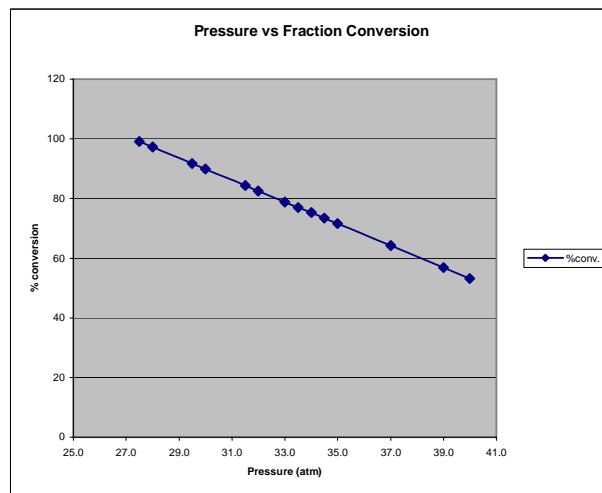
$$n_2 = \frac{P_2}{P_1} \frac{T_1}{T_2} n_1 = \frac{35.1 \text{ atm}}{32.0 \text{ atm}} \left| \frac{298 \text{ K}}{508 \text{ K}} \right| 2 \text{ mol} = 1.29 \text{ mol}$$

$$1.29 = 2 - n_p \Rightarrow n_p = 0.71 \text{ mol C}_3\text{H}_8 \text{ produced}$$

$$\Rightarrow (1 - 0.71) = 0.29 \text{ mol C}_3\text{H}_6 \text{ unreacted} \Rightarrow 71\% \text{ conversion of propylene}$$

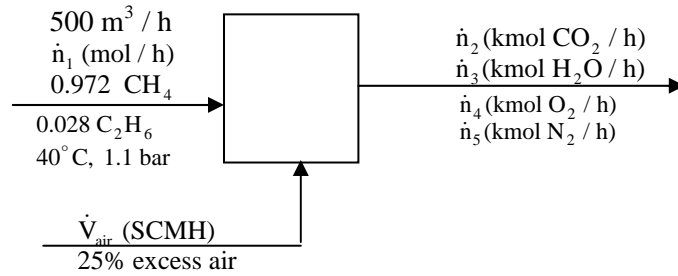
- c.

$P_2 \text{ (atm)}$	n_2	$\text{C}_3\text{H}_8 \text{ prod.}$	$\% \text{ conv.}$
27.5	1.009	0.99075	99.075
28.0	1.028	0.9724	97.24
29.5	1.083	0.91735	91.735
30.0	1.101	0.899	89.9
31.5	1.156	0.84395	84.395
32.0	1.174	0.8256	82.56
33.0	1.211	0.7889	78.89
33.5	1.229	0.77055	77.055
34.0	1.248	0.7522	75.22
34.5	1.266	0.73385	73.385
35.0	1.285	0.7155	71.55
37.0	1.358	0.6421	64.21
39.0	1.431	0.5687	56.87
40.0	1.468	0.532	53.2



5.39 Convert fuel composition to molar basis

$$\text{Basis: } 100 \text{ g} \Rightarrow \left. \begin{array}{l} 95 \text{ g CH}_4 (1 \text{ mol}/16.04 \text{ g}) = 5.92 \text{ mol CH}_4 \\ 5 \text{ g C}_2\text{H}_6 (1 \text{ mol}/30.07 \text{ g}) = 0.17 \text{ mol C}_2\text{H}_6 \end{array} \right\} \Rightarrow \begin{array}{l} 97.2 \text{ mol \% CH}_4 \\ 2.8 \text{ mol \% C}_2\text{H}_6 \end{array}$$



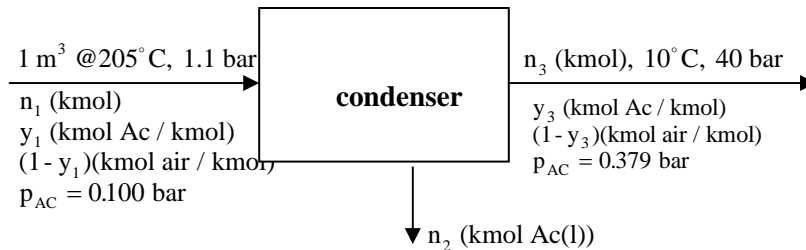
$$\dot{n}_1 = \frac{P_1 \dot{V}_1}{RT_1} = \frac{1.1 \text{ bar}}{313 \text{ K}} \left| \frac{500 \text{ m}^3}{\text{h}} \right| \left| \frac{\text{kmol} \cdot \text{K}}{0.08314 \text{ m}^3 \cdot \text{bar}} \right| = 21.1 \text{ kmol/h}$$



$$\begin{aligned} \text{Theoretical O}_2 &= \frac{21.1 \text{ kmol}}{\text{h}} \left[\frac{0.972 \text{ kmol CH}_4}{\text{kmol}} \left| \frac{2 \text{ kmol O}_2}{1 \text{ kmol CH}_4} \right| + \frac{0.028 \text{ kmol C}_2\text{H}_6}{\text{kmol}} \left| \frac{3.5 \text{ kmol O}_2}{1 \text{ kmol C}_2\text{H}_6} \right| \right] = 43.1 \frac{\text{kmol O}_2}{\text{h}} \end{aligned}$$

$$\text{Air Feed: } \frac{1.25(43.1 \text{ kmol O}_2)}{\text{h}} \left| \frac{1 \text{ kmol Air}}{0.21 \text{ kmol O}_2} \right| \left| \frac{22.4 \text{ m}^3(\text{STP})}{1 \text{ kmol}} \right| = \underline{\underline{5700 \text{ SCMh}}}$$

5.40 Basis: 1 m³ gas fed @ 205°C, 1.1 bars Ac = acetone



$$\text{a. } n_1 = \frac{1.00 \text{ m}^3}{478 \text{ K}} \left| \frac{273 \text{ K}}{1.10 \text{ bars}} \right| \left| \frac{1 \text{ kmol}}{22.4 \text{ m}^3(\text{STP})} \right| = 0.0277 \text{ kmol}$$

$$y_1 = \frac{0.100 \text{ bar}}{1.1 \text{ bars}} = 0.0909 \text{ kmol Ac/kmol}, \quad y_3 = \frac{0.379 \text{ bar}}{40.0 \text{ bars}} = 9.47 \times 10^{-3} \text{ kmol Ac/kmol}$$

$$\text{Air balance: } (0.0277)(0.910) = (1 - 9.47 \times 10^{-3})n_3 \Rightarrow n_3 = 0.0254 \text{ kmol}$$

$$\text{Mole balance: } 0.0277 = 0.0254 + n_2 \Rightarrow n_2 = 0.0023 \text{ kmol Ac condensed}$$

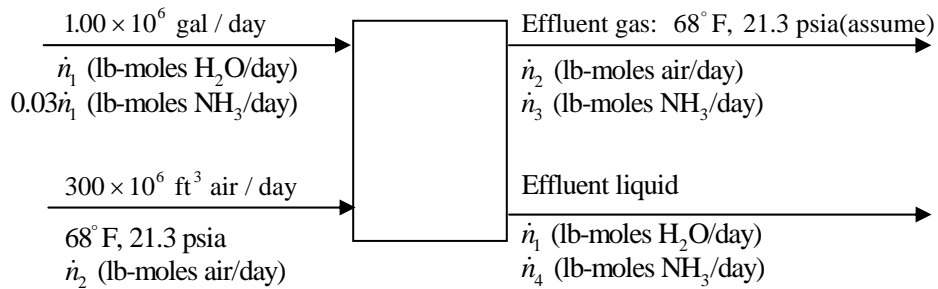
$$\text{Acetone condensed} = \frac{0.0023 \text{ kmol Ac}}{1 \text{ kmol Ac}} \left| \frac{58.08 \text{ kg Ac}}{1 \text{ kmol Ac}} \right| = \underline{\underline{0.133 \text{ kg acetone condensed}}}$$

5.40 (cont'd)

$$\text{Product gas volume} = \frac{0.0254 \text{ kmol}}{273\text{K}} \times \frac{22.4 \text{ m}^3(\text{STP})}{283\text{K}} \times \frac{1.0132 \text{ bars}}{40.0 \text{ bars}} = \underline{\underline{0.0149 \text{ m}^3}}$$

b.
$$\frac{20.0 \text{ m}^3 \text{ effluent}}{\text{h}} \times \frac{0.0277 \text{ kmol feed}}{0.0149 \text{ m}^3 \text{ effluent}} \times \frac{0.0909 \text{ kmol Ac}}{\text{kmol feed}} \times \frac{58.08 \text{ kg Ac}}{\text{kmol Ac}} = \underline{\underline{196 \text{ kg Ac/h}}}$$

5.41 Basis: 1.00×10^6 gal. wastewater/day. Neglect evaporation of water.



a. Density of wastewater: Assume $\rho = 62.4 \text{ lb}_m/\text{ft}^3$

$$\left[\frac{n_1 \text{ lb-moles H}_2\text{O}}{\text{day}} \times \frac{18.02 \text{ lb}_m}{1 \text{ lb-mole}} + \frac{0.03n_1 \text{ lb}_m \text{ NH}_3}{\text{day}} \times \frac{17.03 \text{ lb}_m}{1 \text{ lb-mole}} \right] \times \frac{1 \text{ ft}^3}{62.4 \text{ lb}_m} = \frac{7.4805 \text{ gal}}{1 \text{ ft}^3}$$

$$= 1.00 \times 10^6 \frac{\text{gal}}{\text{day}}$$

$$\Rightarrow n_1 = 4.50 \times 10^5 \text{ lb-moles H}_2\text{O fed/day}, 0.03n_1 = 1.35 \times 10^4 \text{ lb-moles NH}_3 \text{ fed/day}$$

$$n_2 = \frac{300 \times 10^6 \text{ ft}^3}{\text{day}} \times \frac{492^\circ\text{R}}{527.7^\circ\text{R}} \times \frac{21.3 \text{ psi}}{14.7 \text{ psi}} \times \frac{1 \text{ lb-mole}}{359 \text{ ft}^3(\text{STP})} = \underline{\underline{1.13 \times 10^6 \text{ lb-moles air/day}}}$$

$$\underline{\text{93\% stripping: } n_3 = 0.93 \times 13500 \text{ lb-moles NH}_3 \text{ fed/day} = 12555 \text{ lb-moles NH}_3/\text{day}}$$

Volumetric flow rate of effluent gas

$$\frac{P\dot{V}_{\text{out}}}{P\dot{V}_{\text{in}}} = \frac{\dot{n}_{\text{out}}RT}{\dot{n}_{\text{in}}RT} \Rightarrow \dot{V}_{\text{out}} = \dot{V}_{\text{in}} \frac{\dot{n}_{\text{out}}}{\dot{n}_{\text{in}}} = \frac{300 \times 10^6 \text{ ft}^3}{\text{day}} \times \frac{(1.13 \times 10^6 + 12555) \text{ lb-moles/day}}{1.13 \times 10^6 \text{ lb-moles/day}}$$

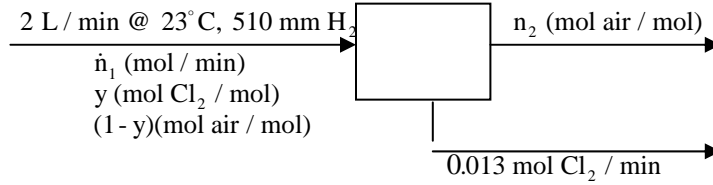
$$= \underline{\underline{303 \times 10^6 \text{ ft}^3/\text{day}}}$$

$$\underline{\text{Partial pressure of NH}_3} = y_{\text{NH}_3} P = \frac{12555 \text{ lb - moles NH}_3/\text{day}}{(1.129 \times 10^6 + 12555) \text{ lb - moles/day}} \times 21.3 \text{ psi}$$

$$= \underline{\underline{0.234 \text{ psi}}}$$

5.42 Basis: 2 liters fed / min

$$\text{Cl ads.} = \frac{2.0 \text{ L soln}}{60 \text{ min}} \left| \frac{1130 \text{ g}}{\text{L}} \right| \frac{0.12 \text{ g NaOH}}{\text{g soln}} \left| \frac{1 \text{ mol}}{40.0 \text{ g}} \right| \frac{0.23 \text{ NaOH ads.}}{\text{mol NaOH}} \left| \frac{1 \text{ mol Cl}_2}{2 \text{ mol NaOH}} \right| = 0.013 \frac{\text{mol}}{\text{min}}$$

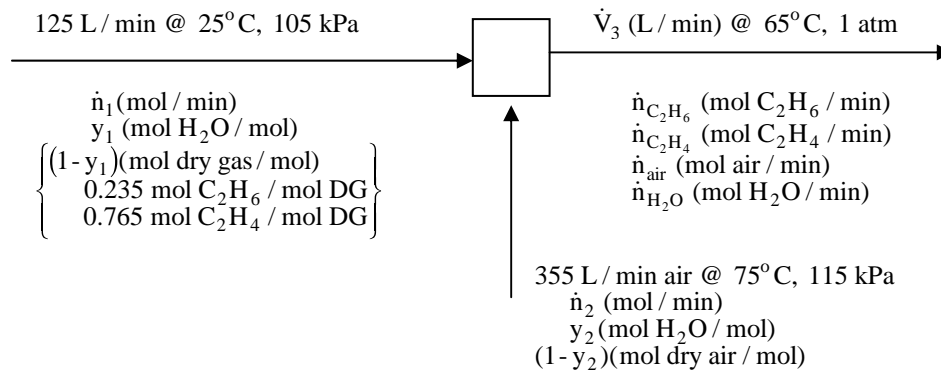


Assume $P_{\text{atm}} = 10.33 \text{ m H}_2\text{O} \Rightarrow (P_{\text{abs}})_{\text{in}} = (10.33 + 0.510) \text{ m H}_2\text{O} = 10.84 \text{ m H}_2\text{O}$

$$\dot{n}_1 = \frac{2 \text{ L}}{\text{min}} \left| \frac{273\text{K}}{296\text{K}} \right| \left| \frac{10.84 \text{ m H}_2\text{O}}{10.33 \text{ m H}_2\text{O}} \right| \left| \frac{1 \text{ mol}}{22.4 \text{ L(STP)}} \right| = 0.0864 \text{ mol/min}$$

Cl balance: $0.0864y = 0.013 \Rightarrow y = 0.150 \frac{\text{mol Cl}_2}{\text{mol}}$, \therefore specification is wrong

5.43



a. Hygrometer Calibration $\ln y = bR + \ln a$ ($y = ae^{bR}$)

$$b = \frac{\ln(y_1/y_2)}{R_2 - R_1} = \frac{\ln(0.2/10^{-4})}{90 - 5} = 0.08942$$

$$\ln a = \ln y_1 - bR_1 = \ln 10^{-4} - 0.08942(5) \Rightarrow a = 6.395 \times 10^{-5} \Rightarrow y = 6.395 \times 10^{-5} e^{0.08942R}$$

b. $\dot{n}_1 = \frac{125 \text{ L}}{\text{min}} \left| \frac{273\text{K}}{298\text{K}} \right| \left| \frac{105 \text{ kPa}}{101 \text{ kPa}} \right| \left| \frac{1 \text{ mol}}{22.4 \text{ L (STP)}} \right| = 5.315 \text{ mol/min wet gas}$

$$\dot{n}_2 = \frac{355 \text{ L}}{\text{min}} \left| \frac{273\text{K}}{348\text{K}} \right| \left| \frac{115 \text{ kPa}}{101 \text{ kPa}} \right| \left| \frac{1 \text{ mol}}{22.4 \text{ L (STP)}} \right| = 14.156 \text{ mol/min wet air}$$

$$R_1 = 86.0 \rightarrow y_1 = 0.140, R_2 = 12.8 \rightarrow y_2 = 2.00 \times 10^{-4} \text{ mol H}_2\text{O/mol}$$

5.43 (cont'd)

$$\begin{aligned}\text{C}_2\text{H}_6 \text{ balance: } \dot{n}_{\text{C}_2\text{H}_6} &= (5.315 \text{ mol/min}) \left((1 - 0.140) \frac{\text{mol DG}}{\text{mol}} \right) \left(0.235 \frac{\text{mol C}_2\text{H}_6}{\text{mol DG}} \right) \\ &= 1.07 \text{ mol C}_2\text{H}_6/\text{min}\end{aligned}$$

$$\text{C}_2\text{H}_4 \text{ balance: } \dot{n}_{\text{C}_2\text{H}_4} = (5.315)(0.860)(0.765) = 3.50 \text{ mol C}_2\text{H}_4/\text{min}$$

$$\text{Dry air balance: } \dot{n}_{\text{air}} = (14.156)(1 - 2.00 \times 10^{-4}) = 14.15 \text{ mol DA/min}$$

$$\text{Water balance: } \dot{n}_{\text{H}_2\text{O}} = (5.315)(0.140) + (14.156)(1.00 \times 10^{-4}) = 0.746 \text{ mol H}_2\text{O/min}$$

$$\dot{n}_{\text{dry product gas}} = (1.07 + 3.50 + 14.15) \text{ mol/min} = 18.72 \text{ mol/min},$$

$$\dot{n}_{\text{total}} = (18.72 + 0.746) = 19.47 \text{ mol/min}$$

$$\dot{V}_3 = \frac{19.47 \text{ mol/min}}{\text{mol}} \left| \frac{22.4 \text{ L (STP)}}{\text{mol}} \right| \frac{338\text{K}}{273\text{K}} = \underline{\underline{540 \text{ liters/min}}}$$

$$\text{Dry basis composition: } \left(\frac{1.07}{18.72} \right) \times 100\% = \underline{\underline{5.7\% \text{ C}_2\text{H}_6, 18.7\% \text{ C}_2\text{H}_4, 75\% \text{ dry air}}}$$

$$\text{c. } p_{\text{H}_2\text{O}} = y_{\text{H}_2\text{O}} \cdot P = \frac{0.746 \text{ mol H}_2\text{O}}{19.47 \text{ mol}} \times 1 \text{ atm} = \underline{\underline{0.03832 \text{ atm}}}$$

$$y_{\text{H}_2\text{O}} = 0.03832 \Rightarrow R = \frac{1}{0.08942} \ln \left(\frac{0.03832}{6.395 \times 10^{-5}} \right) = \underline{\underline{71.5}}$$

5.44 $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$

$$\dot{n}_{\text{CO}_2} = \frac{1350 \text{ m}^3}{\text{h}} \left| \frac{273\text{K}}{1273\text{K}} \right| \frac{1 \text{ kmol}}{22.4 \text{ m}^3(\text{STP})} = 12.92 \text{ kmol CO}_2/\text{h}$$

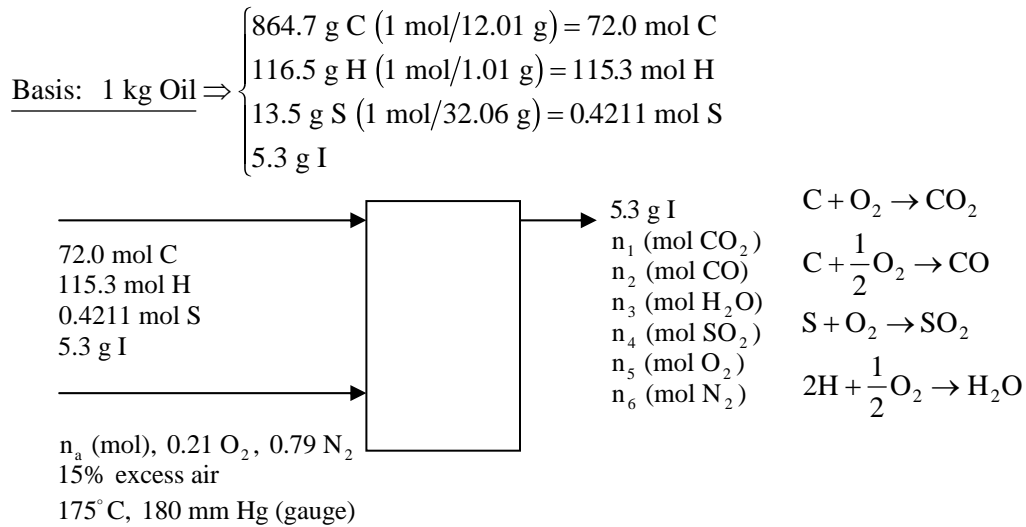
$$\frac{12.92 \text{ kmol CO}_2}{\text{h}} \left| \frac{1 \text{ kmol CaCO}_3}{1 \text{ kmol CO}_2} \right| \frac{100.09 \text{ kg CaCO}_3}{1 \text{ kmol CaCO}_3} \left| \frac{1 \text{ kg limestone}}{0.95 \text{ kg CaCO}_3} \right| = \underline{\underline{1362 \text{ kg limestone/h}}}$$

$$\frac{1362 \text{ kg limestone}}{\text{h}} \left| \frac{0.17 \text{ kg clay}}{0.83 \text{ kg limestone}} \right| = \underline{\underline{279 \text{ kg clay/h}}}$$

Weight % Fe_2O_3

$$\frac{\frac{\text{kg Fe}_2\text{O}_3/\text{kg clay}}{279} (0.07)}{\frac{1362}{\text{kg limestone}} + \frac{279}{\text{kg clay}} - \underbrace{12.92(44.1)}_{\text{kg CO}_2 \text{ evolved}}} \times 100\% = \underline{\underline{1.8\% \text{ Fe}_2\text{O}_3}}$$

5.45



a. Theoretical O_2 :

$$\begin{array}{c|c|c|c} 72.0 \text{ mol C} & 1 \text{ mol O}_2 & 115.3 \text{ mol H} & 0.25 \text{ mol O}_2 \\ \hline & 1 \text{ mol C} & & 1 \text{ mol H} \\ \hline \end{array} + \begin{array}{c|c} 0.4211 \text{ mol S} & 1 \text{ mol O}_2 \\ \hline & 1 \text{ mol S} \\ \hline \end{array} = 101.2 \text{ mol O}_2$$

$$\text{Air Fed: } \frac{1.15(101.2 \text{ mol O}_2)}{0.21 \text{ mol O}_2} \left| \frac{1 \text{ mol Air}}{0.21 \text{ mol O}_2} \right. = 554 \text{ mol Air} = n_a$$

$$\frac{554 \text{ mol Air}}{1 \text{ kg oil}} \left| \frac{22.4 \text{ liter (STP)}}{\text{mol}} \right| \left| \frac{1 \text{ m}^3}{10^3 \text{ liter}} \right| \left| \frac{448\text{K}}{273\text{K}} \right| \left| \frac{760 \text{ mm Hg}}{940 \text{ mm Hg}} \right. = \underline{\underline{16.5 \text{ m}^3 \text{ air/kg oil}}}$$

b. S balance: $n_4 = 0.4211 \text{ mol SO}_2$

H balance: $115.3 = 2n_3 \Rightarrow n_3 = 57.6 \text{ mol H}_2\text{O}$

C balance: $0.95(72.0) = n_1 \Rightarrow n_1 = 68.4 \text{ mol CO}_2 \Rightarrow 0.05(72.0) = n_2 = 3.6 \text{ mol CO}$

N_2 balance: $0.79(554) = n_6 \Rightarrow n_6 = 437.7 \text{ mol N}_2$

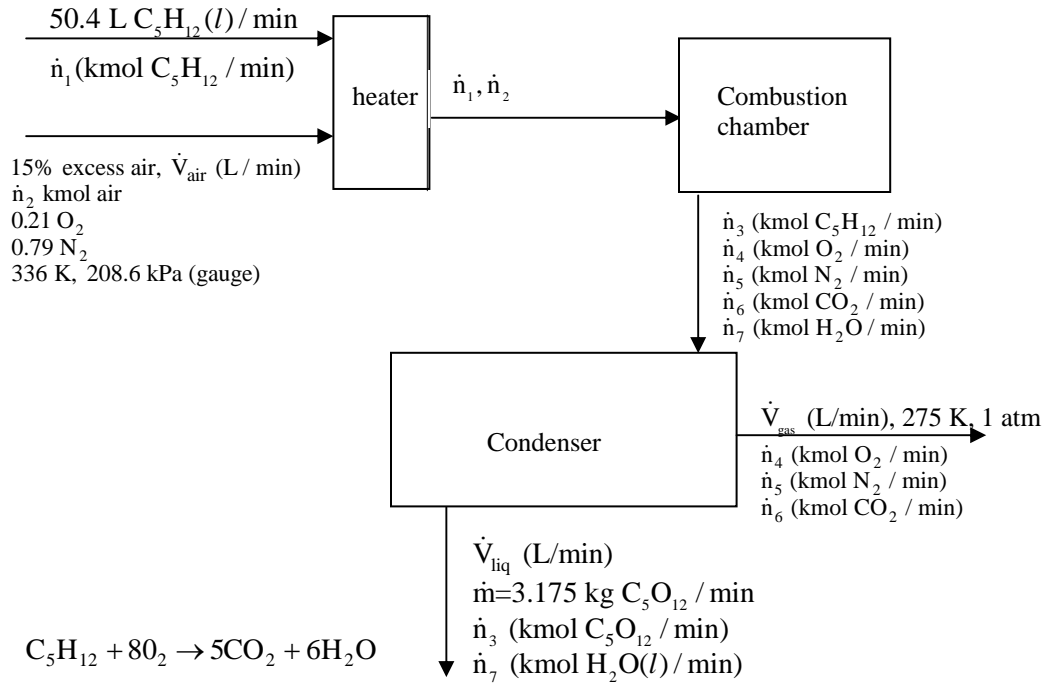
O balance: $0.21(554) \cdot 2 = 57.6 + 3.6 + 2(68.4) + 2(0.4211) + 2n_5 \Rightarrow n_5 = 16.9 \text{ mol O}_2$

Total moles (excluding inerts) wet: 585 mols dry: 527 mols

$$\text{dry basis: } \frac{3.6 \text{ mol CO}}{527 \text{ mol}} = 6.8 \times 10^{-3} \frac{\text{mol CO}}{\text{mol}}, \frac{0.4211 \text{ mol SO}_2}{527 \text{ mol}} = 7.2 \times 10^{-4} \frac{\text{mol SO}_2}{\text{mol}}$$

$$\text{wet basis: } \frac{3.6 \text{ mol CO}}{585 \text{ mol}} \times 10^6 = \underline{\underline{6150 \text{ ppm CO}}}, \frac{0.4211 \text{ mol SO}_2}{585 \text{ mol}} \times 10^6 = \underline{\underline{720 \text{ ppm SO}_2}}$$

5.46 Basis: 50.4 liters $C_5H_{12}(l)$ / min



a. $\dot{n}_1 = \frac{50.4 \text{ L}}{\text{min}} \left| \frac{0.630 \text{ kg}}{\text{L}} \right| \left| \frac{1 \text{ kmol}}{72.15 \text{ kg}} \right| = 0.440 \text{ kmol/min}$

$\dot{n}_3 = \frac{3.175 \text{ kg}}{\text{min}} \left| \frac{1 \text{ kmol}}{72.15 \text{ kg}} \right| = 0.044 \text{ kmol / min}$

frac. convert = $\frac{0.440 - 0.044 \text{ kmol}}{0.440} \times 100 = \underline{\underline{90\% \text{ } C_5H_{12} \text{ converted}}}$

$\dot{n}_2 = \frac{0.440 \text{ kmol } C_5H_{12}}{\text{min}} \left| \frac{1.15(8 \text{ kmol } O_2)}{\text{kmol } C_5H_{12}} \right| \left| \frac{1 \text{ mol air}}{0.21 \text{ mol } O_2} \right| = 19.28 \text{ kmol air/min}$

$\dot{V}_{air} = \frac{19.28 \text{ kmol}}{\text{min}} \left| \frac{22.4 \text{ L(STP)}}{\text{mol}} \right| \left| \frac{336 \text{ K}}{273 \text{ K}} \right| \left| \frac{101 \text{ kPa}}{309.6 \text{ kPa}} \right| \left| \frac{1000 \text{ mol}}{\text{kmol}} \right| = \underline{\underline{173000 \text{ L/min}}}$

$\dot{n}_4 = [(0.21)(19.28) - (0.90)(0.440)(8)] \frac{\text{kmol } O_2}{\text{min}} = \underline{\underline{0.882 \text{ kmol } O_2 / \text{min}}}$

$\dot{n}_5 = \frac{19.28 \text{ kmol air}}{\text{min}} \left| \frac{0.79 \text{ kmol } N_2}{\text{kmol air}} \right| = 15.23 \text{ kmol } N_2 / \text{min}$

$\dot{n}_6 = \frac{0.90(0.440 \text{ kmol } C_5H_{12})}{\text{min}} \left| \frac{5 \text{ kmol } CO_2}{\text{kmol } C_5H_{12}} \right| = 1.98 \text{ kmol } CO_2 / \text{min}$

$\dot{V}_{gas} = \frac{0.882 + 15.23 + 1.98 \text{ kmol}}{\text{min}} \left| \frac{22.4 \text{ L(STP)}}{\text{mol}} \right| \left| \frac{275 \text{ K}}{273 \text{ K}} \right| \left| \frac{1000 \text{ mol}}{\text{kmol}} \right| = \underline{\underline{4.08 \times 10^5 \text{ L/min}}}$

5.46 (cont'd)

$$\dot{n}_7 = \frac{0.9(0.440 \text{ kmol C}_5\text{H}_{12})}{\text{min}} \left| \frac{6 \text{ kmol H}_2\text{O}}{\text{kmol C}_5\text{H}_{12}} \right| = 2.38 \text{ kmol H}_2\text{O}(l) / \text{min}$$

Condensate:

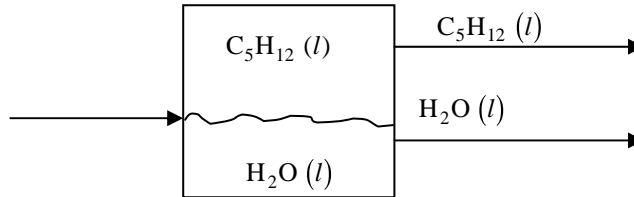
$$\dot{V}_{\text{C}_5\text{H}_{12}} = \frac{0.044 \text{ kmol}}{\text{min}} \left| \frac{72.15 \text{ kg}}{\text{kmol}} \right| \left| \frac{\text{L}}{0.630 \text{ kg}} \right| = 5.04 \text{ L/min}$$

$$\dot{V}_{\text{H}_2\text{O}} = \frac{2.38 \text{ kmol}}{\text{min}} \left| \frac{18.02 \text{ kg}}{\text{kmol}} \right| \left| \frac{\text{L}}{1 \text{ kg}} \right| = 42.89 \text{ L/min}$$

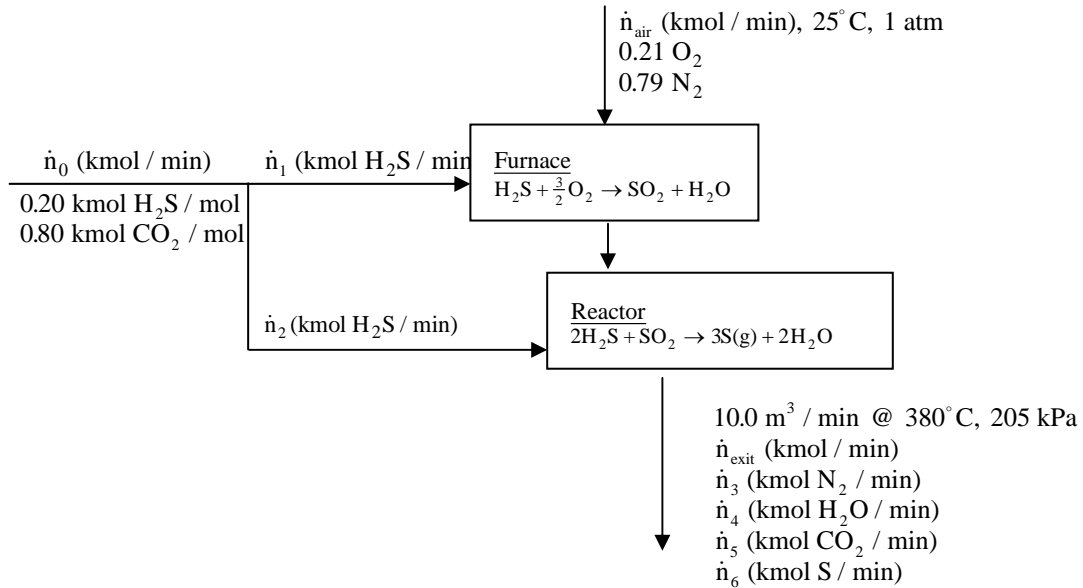
Assume volume additivity (liquids are immiscible)

$$\dot{V}_{\text{liq}} = 5.04 + 42.89 = \underline{\underline{47.9 \text{ L/min}}}$$

b.



5.47



$$\dot{n}_{\text{exit}} = \frac{P\dot{V}}{RT} = \frac{205 \text{ kPa}}{8.314 \frac{\text{m}^3 \cdot \text{kPa}}{\text{kmol} \cdot \text{K}}} \left| \frac{10.0 \text{ m}^3 / \text{min}}{653 \text{ K}} \right| = 0.377 \text{ kmol / min}$$

$$\dot{n}_1 = (0.20)\dot{n}_0 / 3 = 0.0667\dot{n}_0; \quad \dot{n}_2 = 2\dot{n}_1 = 0.133\dot{n}_0$$

5.47 (cont'd)

$$\begin{aligned} \text{Air feed to furnace: } \dot{n}_{\text{air}} &= \frac{0.0667\dot{n}_0 \text{ (kmol H}_2\text{S fed)}}{(\text{min})} \left| \frac{1.5 \text{ kmol O}_2}{1 \text{ kmol H}_2\text{S}} \right| \frac{1 \text{ kmol air}}{0.21 \text{ kmol O}_2} \\ &= 0.4764\dot{n}_0 \text{ kmol air / min} \end{aligned}$$

$$\text{Overall N}_2 \text{ balance: } \dot{n}_3 = \frac{0.4764\dot{n}_0 \text{ (kmol air)}}{(\text{min})} \left| \frac{0.79 \text{ kmol N}_2}{\text{min}} \right| = 0.3764\dot{n}_0 \text{ (kmol N}_2 \text{ / min)}$$

$$\text{Overall S balance: } \dot{n}_6 = \frac{0.200\dot{n}_0 \text{ (kmol H}_2\text{S)}}{(\text{min})} \left| \frac{1 \text{ kmol S}}{1 \text{ kmol H}_2\text{S}} \right| = 0.200\dot{n}_0 \text{ (kmol S / min)}$$

$$\text{Overall CO}_2 \text{ balance: } \dot{n}_5 = 0.800\dot{n}_0 \text{ (kmol CO}_2 \text{ / min)}$$

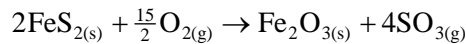
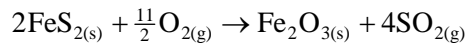
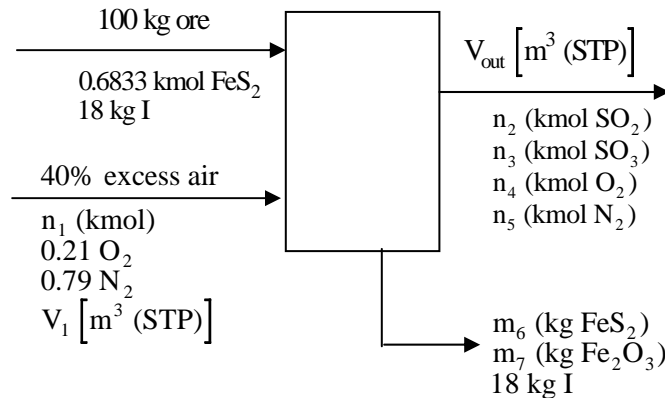
$$\begin{aligned} \text{Overall H balance: } \frac{0.200\dot{n}_0 \text{ (kmol H}_2\text{S)}}{(\text{min})} \left| \frac{2 \text{ kmol H}}{1 \text{ kmol H}_2\text{S}} \right| &= \frac{\dot{n}_4 \text{ kmol H}_2\text{O}}{\text{min}} \left| \frac{2 \text{ kmol H}}{1 \text{ kmol H}_2\text{O}} \right| \\ \Rightarrow \dot{n}_4 &= 0.200\dot{n}_0 \text{ (kmol H}_2\text{O / min)} \end{aligned}$$

$$\dot{n}_{\text{exit}} = \dot{n}_0(0.376 + 0.200 + 0.200 + 0.800) = 0.377 \text{ kmol / min} \Rightarrow \dot{n}_0 = \underline{\underline{0.24 \text{ kmol / min}}}$$

$$\dot{n}_{\text{air}} = 0.4764(0.24 \text{ kmol air / min}) = \underline{\underline{0.114 \text{ kmol air / min}}}$$

5.48 Basis: 100 kg ore fed \Rightarrow 82.0 kg FeS₂(s), 18.0 kg I.

$$n_{\text{FeS}_2} \text{ fed} = (82.0 \text{ kg FeS}_2) \left(\frac{1 \text{ kmol}}{120.0 \text{ kg}} \right) = 0.6833 \text{ kmol FeS}_2$$



$$\text{a. } n_1 = \frac{0.6833 \text{ kmol FeS}_2}{2 \text{ kmol FeS}_2} \left| \frac{7.5 \text{ kmol O}_2}{1 \text{ kmol air req'd}} \right| \frac{1.40 \text{ kmol air fed}}{0.21 \text{ kmol O}_2} \left| \frac{1 \text{ kmol air req'd}}{\text{kmol air req'd}} \right| = 17.08 \text{ kmol air}$$

$$V_1 = (17.08 \text{ kmol}) \left(\frac{22.4 \text{ SCM}}{\text{kmol}} \right) = \underline{\underline{382 \text{ SCM / 100 kg ore}}}$$

$$n_2 = \frac{(0.85)(0.40)0.6833 \text{ kmol FeS}_2}{2 \text{ kmol FeS}_2} \left| \frac{4 \text{ kmol SO}_2}{1 \text{ kmol FeS}_2} \right| = 0.4646 \text{ kmol SO}_2$$

5.48 (cont'd)

$$n_3 = \frac{(0.85)(0.60)0.6833 \text{ kmol FeS}_2}{2 \text{ kmol FeS}_2} \left| \frac{4 \text{ kmol SO}_2}{2 \text{ kmol FeS}_2} \right| = 0.6970 \text{ kmol SO}_3$$

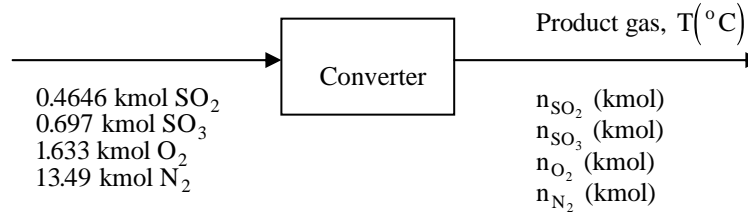
$$n_4 = (0.21 \times 17.08) \text{ kmol O}_2 \text{ fed} - \frac{.4646 \text{ kmol SO}_2}{4 \text{ kmol SO}_2} \left| \frac{5.5 \text{ kmol O}_2}{4 \text{ kmol SO}_2} \right| - \frac{.697 \text{ kmol SO}_3}{4 \text{ kmol SO}_3} \left| \frac{7.5 \text{ kmol O}_2}{4 \text{ kmol SO}_3} \right| = 1.641 \text{ kmol O}_2$$

$$n_5 = (0.79 \times 17.08) \text{ kmol N}_2 = 13.49 \text{ kmol N}_2$$

$$V_{\text{out}} = [(0.4646 + 0.6970 + 1.641 + 13.49) \text{ kmol}] [22.4 \text{ SCM (STP)/kmol}] = \underline{\underline{365 \text{ SCM/100 kg ore fed}}}$$

$$y_{\text{SO}_2} = \frac{0.4646 \text{ kmol SO}_2}{16.285 \text{ kmol}} \times 100\% = \underline{\underline{2.9\%}}; \quad y_{\text{SO}_3} = \underline{\underline{4.3\%}}; \quad y_{\text{O}_2} = \underline{\underline{10.1\%}}; \quad y_{\text{N}_2} = \underline{\underline{82.8\%}}$$

b.



Let ξ (kmol) = extent of reaction

$$\left. \begin{array}{l} n_{\text{SO}_2} = 0.4646 - \xi \\ n_{\text{SO}_3} = 0.697 + \xi \\ n_{\text{O}_2} = 1.641 - \frac{1}{2}\xi \\ n_{\text{N}_2} = 13.49 \\ n = 16.29 - \frac{1}{2}\xi \end{array} \right\} \Rightarrow \begin{array}{l} y_{\text{SO}_2} = \frac{0.4646 - \xi}{16.29 - \frac{1}{2}\xi}, \quad y_{\text{SO}_3} = \frac{0.697 + \xi}{16.29 - \frac{1}{2}\xi} \\ y_{\text{O}_2} = \frac{1.641 - \frac{1}{2}\xi}{16.29 - \frac{1}{2}\xi}, \quad y_{\text{N}_2} = \frac{13.49}{16.29 - \frac{1}{2}\xi} \end{array}$$

$$K_p(T) = \frac{P \cdot y_{\text{SO}_3}}{P \cdot y_{\text{SO}_2} (P \cdot y_{\text{O}_2})^{\frac{1}{2}}} \Rightarrow \frac{(0.697 + \xi)(16.29 - \frac{1}{2}\xi)^{\frac{1}{2}}}{(0.4646 - \xi)(1.641 - \frac{1}{2}\xi)^{\frac{1}{2}}} \cdot P^{-\frac{1}{2}} = K_p(T)$$

$$P = 1 \text{ atm}, T = 600^\circ\text{C}, K_p = 9.53 \text{ atm}^{-\frac{1}{2}} \Rightarrow \xi = 0.1707 \text{ kmol}$$

$$\Rightarrow n_{\text{SO}_2} = 0.2939 \text{ kmol} \Rightarrow f_{\text{SO}_2} = \frac{(0.4646 - 0.2939) \text{ kmol SO}_2 \text{ reacted}}{0.4646 \text{ kmol SO}_2 \text{ fed}} = \underline{\underline{0.367}}$$

$$P = 1 \text{ atm}, T = 400^\circ\text{C}, K_p = 397 \text{ atm}^{-\frac{1}{2}} \Rightarrow \xi = 0.4548 \text{ kmol}$$

$$\Rightarrow n_{\text{SO}_2} = 0.0098 \text{ kmol} \Rightarrow f_{\text{SO}_2} = \underline{\underline{0.979}}$$

The gases are initially heated in order to get the reaction going at a reasonable rate. Once the reaction approaches equilibrium the gases are cooled to produce a higher equilibrium conversion of SO_2 .

5.48 (cont'd)

c. SO_3 leaving converter: $(0.6970 + 0.4687) \text{ kmol} = 1.156 \text{ kmol}$

$$\Rightarrow \frac{1.156 \text{ kmol SO}_3}{\text{min}} \left| \frac{1 \text{ kmol H}_2\text{SO}_4}{1 \text{ kmol SO}_3} \right| \frac{98 \text{ kg H}_2\text{SO}_4}{\text{kmol}} = 113.3 \text{ kg H}_2\text{SO}_4$$

$$\text{Sulfur in ore: } \frac{0.683 \text{ kmol FeS}_2}{\text{kmol FeS}_2} \left| \frac{2 \text{ kmol S}}{\text{kmol FeS}_2} \right| \frac{32.1 \text{ kg S}}{\text{kmol}} = 43.8 \text{ kg S}$$

$$\frac{113.3 \text{ kg H}_2\text{SO}_4}{43.8 \text{ kg S}} = 2.59 \frac{\text{kg H}_2\text{SO}_4}{\text{kg S}}$$

$$100\% \text{ conv. of S: } \frac{0.683 \text{ kmol FeS}_2}{\text{kmol FeS}_2} \left| \frac{2 \text{ kmol S}}{\text{kmol FeS}_2} \right| \left| \frac{1 \text{ kmol H}_2\text{SO}_4}{1 \text{ kmol S}} \right| \frac{98 \text{ kg}}{\text{kmol}} = 133.9 \text{ kg H}_2\text{SO}_4$$

$$\Rightarrow \frac{133.9 \text{ kg H}_2\text{SO}_4}{43.8 \text{ kg S}} = 3.06 \frac{\text{kg H}_2\text{SO}_4}{\text{kg S}}$$

The sulfur is not completely converted to H_2SO_4 because of (i) incomplete oxidation of FeS_2 in the roasting furnace, (ii) incomplete conversion of SO_2 to SO_3 in the converter.

5.49 $\text{N}_2\text{O}_4 \rightleftharpoons 2\text{NO}_2$

$$\text{a. } n_0 = \frac{(P_{\text{gauge}} + 1.00)V}{RT_0} = \frac{(2.00 \text{ atm})(2.00 \text{ L})}{(473 \text{ K})(0.08206 \text{ L} \cdot \text{atm/mol} \cdot \text{K})} = 0.103 \text{ mol NO}_2$$

$$\text{b. } n_1 = \text{mol NO}_2, n_2 = \text{mol N}_2\text{O}_4$$

$$P_{\text{NO}_2} = y_{\text{NO}_2} P = \left(\frac{n_1}{n_1 + n_2} \right) P, P_{\text{N}_2\text{O}_4} = \left(\frac{n_2}{n_1 + n_2} \right) P \Rightarrow K_p = \frac{n_1^2}{n_2(n_1 + n_2)} P$$

$$\text{Ideal gas equation of state } \Rightarrow PV = (n_1 + n_2)RT \Rightarrow n_1 + n_2 = PV / RT \quad (1)$$

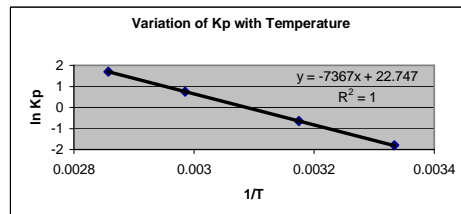
Stoichiometric equation \Rightarrow each mole of N_2O_4 present at equilibrium represents a loss of two moles of NO_2 from that initially present $\Rightarrow n_1 + 2n_2 = 0.103 \quad (2)$

$$\text{Solve (1) and (2) } \Rightarrow n_1 = 2(PV / RT) - 0.103 \quad (3), \quad n_2 = 0.103 - (PV / RT) \quad (4)$$

Substitute (3) and (4) in the expression for K_p , and replace P with $P_{\text{gauge}} + 1$

$$K_p = \frac{(2n_t - 0.103)^2}{n_t(0.103 - n_t)} (P_{\text{gauge}} + 1) \quad \text{where } n_t = \frac{(P_{\text{gauge}} + 1)V}{RT} \Rightarrow n_t = \frac{24.37(P_g + 1)}{T}$$

T(K)	P _{gauge} (atm)	n _t	K _p (atm)	(1/T)	ln(K _p)
350	0.272	0.088568	5.46915	0.002857	1.699123
335	0.111	0.080821	2.131425	0.002985	0.756791
315	-0.097	0.069861	0.525954	0.003175	-0.64254
300	-0.224	0.063037	0.164006	0.003333	-1.80785

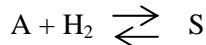
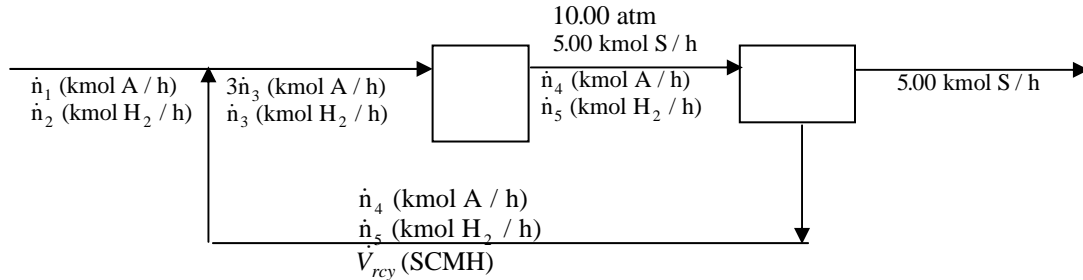


5.49 (cont'd)

- c. A semilog plot of K_p vs. $\frac{1}{T}$ is a straight line. Fitting the line to the exponential law yields

$$\ln K_p = -\frac{7367}{T} + 22.747 \Rightarrow K_p = 7.567 \times 10^9 \exp\left(\frac{-7367}{T}\right) \Rightarrow \begin{matrix} a = 7.567 \times 10^9 \text{ atm} \\ b = 7367\text{K} \end{matrix}$$

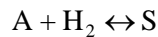
5.50



Overall A balance: $n_1 = \frac{5.00 \text{ kmol S}}{h} \left| \frac{1 \text{ kmol A react}}{1 \text{ kmol S form}} \right| = 5.00 \text{ kmol A / h}$

Overall H₂ balance: $n_2 = \frac{5.00 \text{ kmol S}}{h} \left| \frac{1 \text{ kmol H}_2 \text{ react}}{1 \text{ kmol S form}} \right| = 5.00 \text{ kmol H}_2 / h$

Extent of reaction equations: $\dot{n}_i = \dot{n}_{i0} + \nu_i \dot{\xi}$



A: $\dot{n}_4 = 3\dot{n}_3 - \dot{\xi}$

H₂: $\dot{n}_5 = \dot{n}_3 - \dot{\xi}$

S: $5.00 = \dot{\xi} \Rightarrow \left. \begin{matrix} \dot{n}_4 = 3\dot{n}_3 - 5.00 \\ \dot{n}_5 = \dot{n}_3 - 5.00 \\ \dot{n}_S = 5.00 \\ \dot{n}_{\text{tot}} = 4\dot{n}_3 - 5.00 \end{matrix} \right\} \Rightarrow p_A = y_A P = \frac{\dot{n}_4}{\dot{n}_{\text{tot}}} P = \frac{3\dot{n}_3 - 5.00}{4\dot{n}_3 - 5.00} 10.0$

$$p_{H_2} = y_{H_2} P = \frac{\dot{n}_5}{\dot{n}_{\text{tot}}} P = \frac{\dot{n}_3 - 5.00}{4\dot{n}_3 - 5.00} 10.0$$

$$p_S = y_S P = \frac{5.00}{4\dot{n}_3 - 5.00} 10.0$$

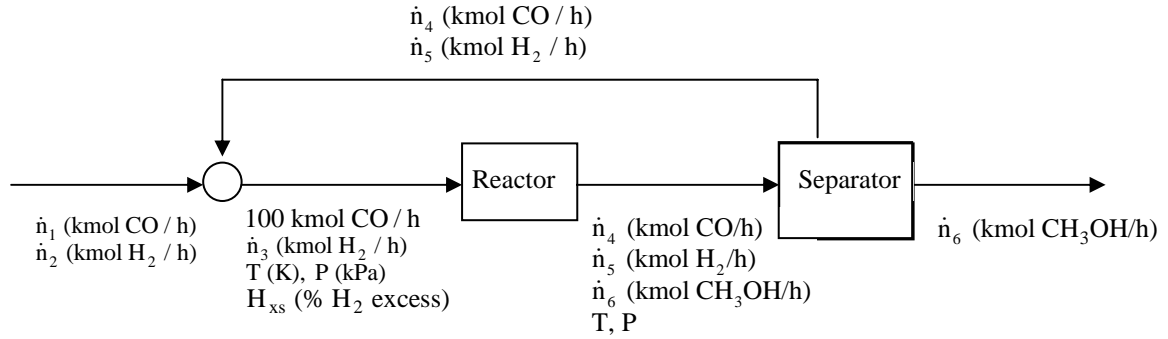
$$K_p = \frac{p_S}{p_A p_{H_2}} = \frac{5.00(4\dot{n}_3 - 5.00)}{10.0(3\dot{n}_3 - 5.00)(\dot{n}_3 - 5.00)} = 0.100 \Rightarrow \dot{n}_3 = 11.94 \text{ kmol H}_2 / h$$

$$\dot{n}_4 = 3(11.94) - 5.00 = 30.82 \text{ kmol A / h}$$

$$\dot{n}_5 = 11.94 - 5.00 = 6.94 \text{ kmol H}_2 / h$$

$$\dot{V}_{\text{rcy}} = [(30.82 + 6.94) \text{ kmol / h}] (22.4 \text{ m}^3 (\text{STP}) / \text{kmol}) = \underline{\underline{846 \text{ SCMh}}}$$

5.51



- a. Balances on reactor \Rightarrow 4 equations in \dot{n}_2 , \dot{n}_4 , \dot{n}_5 , and \dot{n}_6 .

$$\text{5.0\% XS H}_2: \dot{n}_3 = \frac{100 \text{ kmol CO fed}}{\text{h}} \left| \frac{2 \text{ kmol H}_2 \text{ reqd}}{1 \text{ kmol CO fed}} \right| \frac{1.05 \text{ kmol H}_2 \text{ fed}}{1 \text{ kmol H}_2 \text{ reqd}} = 210 \frac{\text{kmol H}_2}{\text{h}}$$

$$\text{C balance: } \frac{100 \text{ kmol CO}}{\text{h}} \left| \frac{1 \text{ kmol C}}{1 \text{ kmol CO}} \right| = \dot{n}_4(1) + \dot{n}_6(1) \Rightarrow 100 = \dot{n}_4 + \dot{n}_6 \quad (1)$$

$$\text{H balance: } 210(2) = \dot{n}_5(2) + \dot{n}_6(4) \Rightarrow 210 = \dot{n}_5 + 2\dot{n}_6 \quad (2)$$

$$\text{(O balance: } 100 = \dot{n}_4 + \dot{n}_6 \Rightarrow \text{identical to C balance} \Rightarrow \text{not independent})$$

$$(1) \Rightarrow \dot{n}_4 = 100 - \dot{n}_6, \quad (2) \Rightarrow \dot{n}_5 = 210 - 2\dot{n}_6$$

$$\dot{n}_{\text{tot}} = \dot{n}_4 + \dot{n}_5 + \dot{n}_6 = (100 - \dot{n}_6) + (210 - 2\dot{n}_6) + \dot{n}_6 = 310 - 2\dot{n}_6$$

$$K_p(T=500\text{K}) = 1.390 \times 10^{-4} \exp \left(\frac{21.225 + \frac{9143.6}{500 \text{ K}} - 7.492 \ln(500\text{K})}{+4.076 \times 10^{-3} (500\text{K}) - 1.161 \times 10^{-8} (500\text{K})^2} \right) = 9.11 \times 10^{-7} \text{ kPa}^{-2}$$

$$K_p = \frac{y_M P}{y_{\text{CO}} P (y_{\text{H}_2} P)^2} \Rightarrow K_p P^2 = \frac{y_M}{y_{\text{CO}} (y_{\text{H}_2})^2} \xrightarrow{(1)-(3)} \frac{\dot{n}_6}{(310 - 2\dot{n}_6)} \frac{(100 - \dot{n}_6)}{(310 - 2\dot{n}_6)} \frac{(210 - 2\dot{n}_6)^2}{(310 - 2\dot{n}_6)^2}$$

$$K_p P^2 = 9.11 \times 10^{-7} \text{ kPa}^{-2} (5000 \text{ kPa})^2 = 22.775 = \frac{\dot{n}_6 (310 - 2\dot{n}_6)^2}{(100 - \dot{n}_6) (210 - 2\dot{n}_6)^2}$$

$$\text{Solving for } \dot{n}_6 \Rightarrow \dot{n}_6 = \underline{\underline{75.7 \text{ kmol CH}_3\text{OH/h}}}, \quad \dot{n}_4 = 100 - \dot{n}_6 = \underline{\underline{24.3 \text{ kmol CO/h}}}$$

$$\dot{n}_5 = 210 - 2\dot{n}_6 = \underline{\underline{58.6 \text{ kmol H}_2/\text{h}}}$$

$$\text{Overall C balance: } \dot{n}_1(1) = \dot{n}_6(1) \Rightarrow \dot{n}_1 = \underline{\underline{75.7 \text{ kmol CO/h}}}$$

$$\text{Overall H balance: } \dot{n}_2(2) = \dot{n}_6(4) \Rightarrow \dot{n}_2 = \underline{\underline{151 \text{ kmol H}_2/\text{h}}}$$

$$\dot{V}_{\text{rec}} = (\dot{n}_4 + \dot{n}_5) \frac{22.4 \text{ m}^3(\text{STP})}{\text{kmol}} = \underline{\underline{1860 \text{ SCM/h}}}$$

5.51 (cont'd)

b.

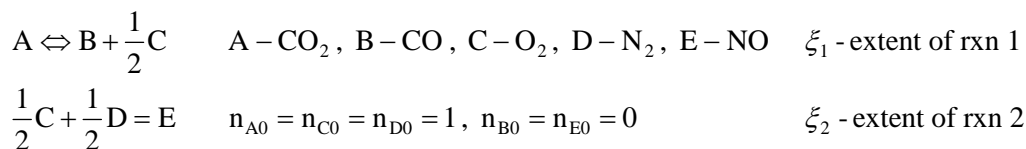
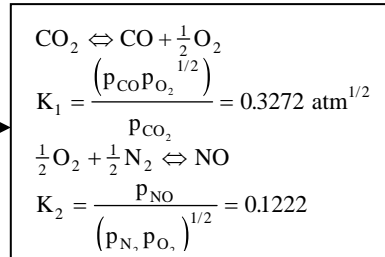
P(kPa)	T(K)	Hs(%)	K _T EB	K _P P2	r3(kmol H2h)	r4(kmol COh)	r5(kmol H2h)
1000	500	5	9.1E+01	0.91	210	74.45	158.90
5000	500	5	9.1E+01	22.78	210	91.00	192.00
10000	500	5	9.1E+01	91.11	210	13.28	36.56
5000	400	5	3.1E+04	789.77	210	1.07	12.15
5000	500	5	9.1E+01	22.78	210	24.32	58.64
5000	600	5	1.6E+00	0.41	210	85.42	180.84
5000	500	0	9.1E+01	22.78	200	26.65	53.30
5000	500	5	9.1E+01	22.78	210	24.32	58.64
5000	500	10	9.1E+01	22.78	220	22.23	64.45

r6(kmol Mh)	r4d (kmol/h)	K _T EB	K _P P2	r1(kmol COh)	r2(kmol H2h)	V _{ec} (SMH)
25.55	258.90	9.1E+01	1.3E+05	25.55	51.10	52.7
9.00	292.00	2.3E+01	2.3E+01	9.00	18.00	63.9
86.72	136.56	9.1E+01	4.9E+03	86.72	173.44	111.6
98.93	112.15	7.8E+03	3.2E+03	98.93	197.85	296
75.68	158.64	2.3E+01	3.4E+03	75.68	151.36	188.8
14.58	280.84	4.1E+01	-2.9E+04	14.58	29.16	56.4
73.35	153.30	2.3E+01	9.8E+03	73.35	146.70	179.1
75.68	158.64	2.3E+01	3.4E+03	75.68	151.36	188.8
77.77	164.45	2.3E+01	-3.1E+03	77.77	155.55	194.2

- c. Increase yield by raising pressure, lowering temperature, increasing H_{ss} . Increasing the pressure raises costs because more compression is needed.
- d. If the temperature is too low, a low reaction rate may keep the reaction from reaching equilibrium in a reasonable time period.
- e. Assumed that reaction reached equilibrium, ideal gas behavior, complete condensation of methanol, not steady-state measurement errors.

5.52

1.0 mol CO₂
 1.0 mol O₂
 1.0 mol N₂
 T = 3000 K, P = 5.0 atm



5.52 (cont'd)

$$\left. \begin{array}{l} n_A = 1 - \xi_1 \\ n_B = \xi_1 \\ n_C = 1 + \frac{1}{2}\xi_1 - \frac{1}{2}\xi_2 \\ n_D = 1 - \frac{1}{2}\xi_2 \\ n_E = \xi_2 \\ n_{\text{tot}} = 3 + \frac{1}{2}\xi_1 = \frac{6 + \xi_1}{2} \end{array} \right\} \begin{array}{l} y_A = n_A / n_{\text{tot}} = 2(1 - \xi_1) / (6 + \xi_1) \\ y_B = 2\xi_1 / (6 + \xi_1) \\ y_C = (2 + \xi_1 - \xi_2) / (6 + \xi_1) \\ y_D = (2 - \xi_2) / (6 + \xi_1) \\ y_E = 2\xi_2 / (6 + \xi_1) \end{array} \quad p_i = y_i P$$

$$K_1 = \frac{p_{\text{CO}} p_{\text{O}_2}^{1/2}}{p_{\text{CO}_2}} = \frac{y_B y_C^{1/2}}{y_A} p^{(1+1/2-1)} = \frac{2\xi_1 (2 + \xi_1 - \xi_2)^{1/2}}{2(1 - \xi_1)(6 + \xi_1)^{1/2}} (5)^{1/2} = 0.3272$$

$$\Rightarrow 0.3272(1 - \xi_1)(6 + \xi_1)^{1/2} = 2.236\xi_1(2 + \xi_1 - \xi_2)^{1/2} \quad (1)$$

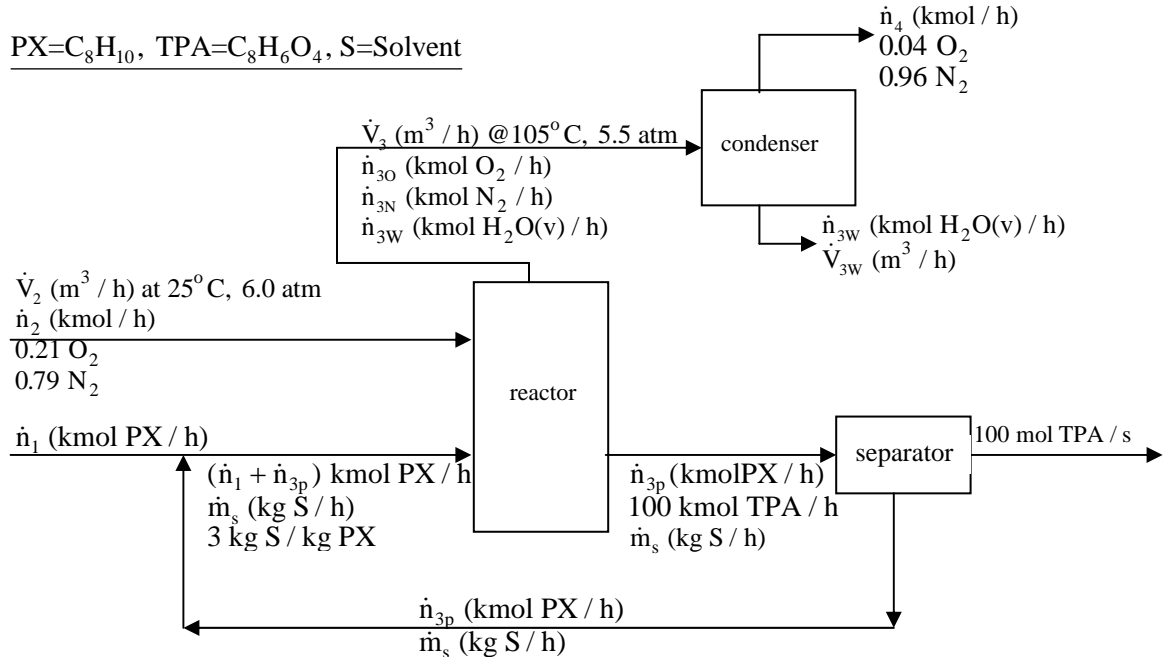
$$K_2 = \frac{p_{\text{NO}}}{(p_{\text{O}_2} p_{\text{N}_2})^{1/2}} = \frac{y_E}{y_C^{1/2} y_D^{1/2}} p^{1-1/2-1/2} = \frac{2\xi_2}{(2 + \xi_1 - \xi_2)^{1/2} (2 - \xi_2)^{1/2}} = 0.1222$$

$$\Rightarrow 0.1222(2 + \xi_1 - \xi_2)^{1/2} (2 - \xi_2)^{1/2} = 2\xi_2 \quad (2)$$

Solve (1) and (2) simultaneously with E-Z Solve $\Rightarrow \xi_1 = 0.20167$, $\xi_2 = 0.12081$,

$$\begin{array}{ll} y_A = 2(1 - \xi_1) / (6 + \xi_1) = 0.2574 \text{ mol CO}_2 / \text{mol} & y_D = 0.3030 \text{ mol N}_2 / \text{mol} \\ y_B = 0.0650 \text{ mol CO} / \text{mol} & y_E = 0.0390 \text{ mol NO} / \text{mol} \\ y_C = 0.3355 \text{ mol O}_2 / \text{mol} & \end{array}$$

5.53 a. PX=C₈H₁₀, TPA=C₈H₆O₄, S=Solvent



5.53 (cont'd)

- b. Overall C balance:

$$\dot{n}_1 \left(\frac{\text{kmol PX}}{\text{h}} \right) \frac{8 \text{ kmol C}}{\text{kmol PX}} = \frac{100 \text{ kmol TPA}}{\text{h}} \frac{8 \text{ kmol C}}{\text{kmol TPA}} \Rightarrow \dot{n}_1 = \underline{\underline{100 \text{ kmol PX / h}}}$$

c. $\underline{\text{O}_2 \text{ consumed}} = \frac{100 \text{ kmol TPA}}{\text{h}} \frac{3 \text{ kmol O}_2}{1 \text{ kmol TPA}} = 300 \text{ kmol O}_2/\text{h}$

$$\left. \begin{array}{l} \text{Overall O}_2 \text{ balance: } 0.21\dot{n}_2 = 300 \frac{\text{kmol O}_2}{\text{h}} + 0.04\dot{n}_4 \\ \text{Overall N}_2 \text{ balance: } 0.79\dot{n}_2 = 0.96\dot{n}_4 \end{array} \right\} \Rightarrow \begin{array}{l} \dot{n}_2 = 1694 \text{ kmol air/h} \\ \dot{n}_4 = 1394 \text{ kmol/h} \end{array}$$

Overall H₂O balance: $\dot{n}_{3w} = \frac{100 \text{ kmol TPA}}{\text{h}} \frac{2 \text{ kmol H}_2\text{O}}{1 \text{ kmol TPA}} = 200 \text{ kmol H}_2\text{O / h}$

$$\dot{V}_2 = \frac{\dot{n}_2 RT}{P} = \frac{1694 \text{ kmol}}{\text{h}} \frac{0.08206 \text{ m}^3 \cdot \text{atm}}{\text{kmol} \cdot \text{K}} \frac{298 \text{ K}}{6.0 \text{ atm}} = \underline{\underline{6.90 \times 10^3 \text{ m}^3 \text{ air/h}}}$$

$$\dot{V}_3 = \frac{(\dot{n}_{3w} + \dot{n}_4) RT}{P} = \frac{(200 + 1394) \text{ kmol}}{\text{h}} \frac{0.08206 \text{ m}^3 \cdot \text{atm}}{\text{kmol} \cdot \text{K}} \frac{378 \text{ K}}{5.5 \text{ atm}} = \underline{\underline{8990 \text{ m}^3/\text{h}}}$$

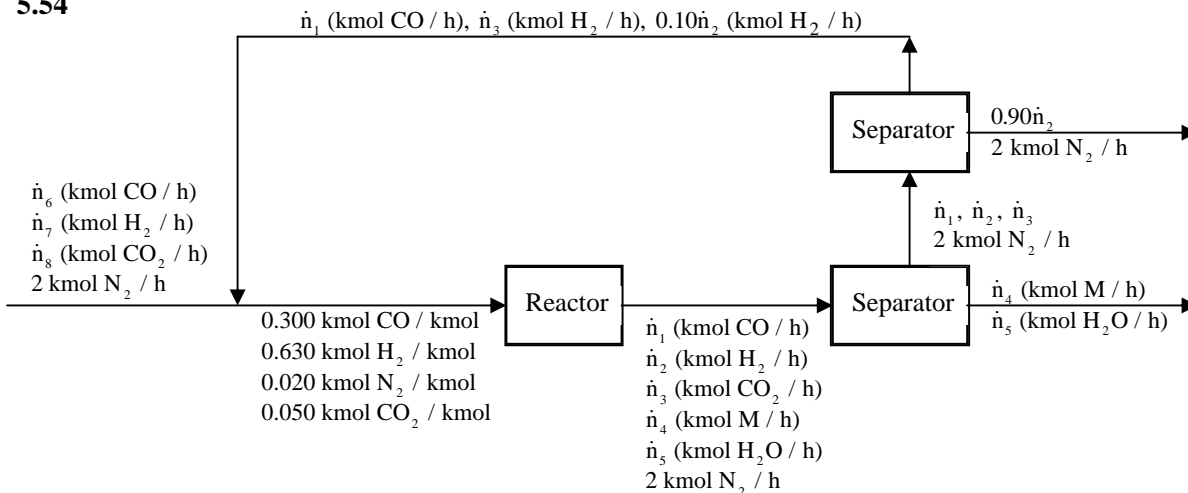
$$\dot{V}_{3w} = \frac{200 \text{ kmol H}_2\text{O (l)}}{\text{h}} \frac{18.0 \text{ kg}}{\text{kmol}} \frac{1 \text{ m}^3}{1000 \text{ kg}} = \underline{\underline{3.60 \text{ m}^3 \text{ H}_2\text{O(l) / h leave condenser}}}$$

d. 90% single pass conversion $\Rightarrow \dot{n}_{3p} = 0.10(\dot{n}_1 + \dot{n}_{3p}) \xRightarrow{\dot{n}_1=100} \dot{n}_{3p} = 11.1 \text{ kmol PX / h}$

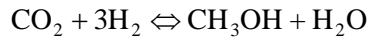
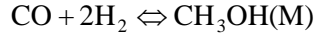
$$\begin{aligned} \dot{m}_{\text{recycle}} = \dot{m}_S + \dot{m}_{3P} &= \frac{(100 + 11.1) \text{ kg PX}}{\text{h}} \frac{106 \text{ kg PX}}{1 \text{ kmol PX}} \frac{3 \text{ kg S}}{\text{kg PX}} + \frac{11.1 \text{ kmol PX}}{\text{h}} \frac{106 \text{ kg PX}}{1 \text{ kmol PX}} \\ &= \underline{\underline{3.65 \times 10^4 \text{ kg/h}}} \end{aligned}$$

- e. O₂ is used to react with the PX. N₂ does not react with anything but enters with O₂ in the air. The catalyst is used to accelerate the reaction and the solvent is used to disperse the PX.
- f. The stream can be allowed to settle and separate into water and PX layers, which may then be separated.

5.54



5.54 (cont'd)



a. Let ξ_1 (kmol / h) = extent of rxn 1, ξ_2 (kmol / h) = extent of rxn 2

$$\left. \begin{array}{l} \text{CO: } \dot{n}_1 = 30 - \xi_1 \\ \text{H}_2: \dot{n}_2 = 63 - 2\xi_1 - 3\xi_2 \\ \text{CO}_2: \dot{n}_3 = 5 - \xi_2 \\ \text{M: } \dot{n}_4 = \xi_1 + \xi_2 \\ \text{H}_2\text{O: } \dot{n}_5 = \xi_2 \\ \text{N}_2: \dot{n}_{\text{N}_2} = 2 \\ \hline \dot{n}_{\text{tot}} = 100 - 2\xi_1 - 2\xi_2 \end{array} \right\} \Rightarrow (K_p)_1 = \frac{P \cdot y_{\text{M}}}{P \cdot y_{\text{CO}} (P \cdot y_{\text{H}_2})^2}, \quad (K_p)_2 = \frac{(P \cdot y_{\text{M}})(P \cdot y_{\text{H}_2\text{O}})}{(P \cdot y_{\text{CO}_2})(P \cdot y_{\text{H}_2})^3}$$

$$(K_p)_1 \cdot P^2 = \frac{\frac{\dot{n}_4}{\dot{n}_{\text{tot}}}}{\frac{\dot{n}_1}{\dot{n}_{\text{tot}}} \left(\frac{\dot{n}_2}{\dot{n}_{\text{tot}}} \right)^2} = \frac{(\xi_1 + \xi_2)(100 - 2\xi_1 - 2\xi_2)^2}{(30 - \xi_1)(63 - 2\xi_1 - 3\xi_2)^2} = 84.65 \quad (1)$$

$$(K_p)_2 \cdot P^2 = \frac{\left(\frac{\dot{n}_4}{\dot{n}_{\text{tot}}} \right) \left(\frac{\dot{n}_5}{\dot{n}_{\text{tot}}} \right)}{\left(\frac{\dot{n}_3}{\dot{n}_{\text{tot}}} \right) \left(\frac{\dot{n}_2}{\dot{n}_{\text{tot}}} \right)^3} = \frac{\xi_2(\xi_1 + \xi_2)(100 - 2\xi_1 - 2\xi_2)^2}{(5 - \xi_2)(63 - 2\xi_1 - 3\xi_2)^2} = 1.259 \quad (2)$$

Solve (1) and (2) for $\xi_1, \xi_2 \Rightarrow \xi_1 = 25.27 \text{ kmol / h}$ $\xi_2 = 0.0157 \text{ kmol / h}$

$$\begin{aligned} \dot{n}_1 &= 30.0 - 25.27 = \underline{4.73 \text{ kmol CO / h}} && \underline{9.98\% \text{ CO}} \\ \dot{n}_2 &= 63.0 - 2(25.27) - 3(0.0157) = \underline{12.4 \text{ kmol H}_2 \text{ / h}} && \underline{26.2\% \text{ H}_2} \\ \dot{n}_3 &= 5.0 - 0.0157 = \underline{4.98 \text{ kmol CO}_2 \text{ / h}} && \underline{10.5\% \text{ CO}_2} \\ \Rightarrow \dot{n}_4 &= 25.27 + 0.0157 = \underline{25.3 \text{ kmol M / h}} && \Rightarrow \underline{53.4\% \text{ M}} \\ \dot{n}_5 &= 0.0157 = \underline{0.0157 \text{ kmol H}_2\text{O / h}} && \underline{0.03\% \text{ H}_2\text{O}} \\ n_{\text{total}} &= 49.4 \text{ kmol / h} \end{aligned}$$

$$\left. \begin{array}{l} \text{C balance: } \dot{n}_4 = 25.3 \text{ kmol / h} \\ \text{O balance: } \dot{n}_6 + 2\dot{n}_8 = \dot{n}_4 + \dot{n}_5 = 25.44 \text{ mol / s} \end{array} \right\} \Rightarrow \dot{n}_6 = \underline{25.4 \text{ kmol CO / h}} \\ \dot{n}_8 = \underline{0.02 \text{ kmol CO}_2 \text{ / h}}$$

$$\text{H balance: } 2\dot{n}_7 = 2(0.9\dot{n}_2) + 4\dot{n}_4 + 2\dot{n}_5 = 123.7 \Rightarrow \dot{n}_7 = \underline{61.8 \text{ mol H}_2 \text{ / s}}$$

b. $(\dot{n}_4)_{\text{process}} = 237 \text{ kmol M / h}$

$$\Rightarrow \text{Scale Factor} = \frac{237 \text{ kmol M / h}}{25.3 \text{ kmol / h}}$$

5.54 (cont'd)

$$\text{Process feed: } (25.4 + 61.8 + 0.02 + 2.0) \left(\frac{237 \text{ kmol/h}}{25.3 \text{ kmol/h}} \right) \left(\frac{22.4 \text{ m}^3 \text{ (STP)}}{\text{kmol}} \right) = \underline{\underline{18,700 \text{ SCMh}}}$$

$$\text{Reactor effluent flow rate: } (49.4 \text{ kmol/h}) \left(\frac{237 \text{ kmol/h}}{25.3 \text{ kmol/s}} \right) = 444 \text{ kmol/h}$$

$$\Rightarrow \dot{V}_{\text{std}} \left(444 \frac{\text{kmol}}{\text{h}} \right) \left(\frac{22.4 \text{ m}^3 \text{ (STP)}}{\text{kmol}} \right) = \underline{\underline{9946 \text{ SCMh}}}$$

$$\Rightarrow \dot{V}_{\text{actual}} = \frac{9950 \text{ m}^3 \text{ (STP)}}{\text{h}} \left| \frac{473.2 \text{ K}}{273.2 \text{ K}} \right| \left| \frac{101.3 \text{ kPa}}{4925 \text{ kPa}} \right| = \underline{\underline{354 \text{ m}^3/\text{h}}}$$

$$\text{c. } \hat{V} = \frac{\dot{V}}{\dot{n}} = \frac{354 \text{ m}^3/\text{h}}{444 \text{ kmol/h}} \left| \frac{1000 \text{ L}}{\text{m}^3} \right| \left| \frac{1 \text{ kmol}}{1000 \text{ mol}} \right| = \underline{\underline{0.8 \text{ L/mol}}}$$

$$\hat{V} < 20 \text{ L/mol} \xrightarrow{(5.2-36)} \text{ideal gas approximation is poor}$$

Most obviously, the calculation of \hat{V} from \dot{n} using the ideal gas equation of state is likely to lead to error. In addition, the reaction equilibrium expressions are probably strictly valid only for ideal gases, so that every calculated quantity is likely to be in error.

$$\text{5.55 a. } \frac{P\hat{V}}{RT} = 1 + \frac{B}{\hat{V}} \Rightarrow B = \frac{RT_c}{P_c} (B_o + \omega B_1)$$

From Table B.1 for ethane: $T_c = 305.4 \text{ K}$, $P_c = 48.2 \text{ atm}$

From Table 5.3-1 $\omega = 0.098$

$$B_o = 0.083 - \frac{0.422}{T_r^{1.6}} = 0.083 - \frac{0.422}{(308.2\text{K}/305.4\text{K})^{1.6}} = -0.333$$

$$B_1 = 0.139 - \frac{0.172}{T_r^{4.2}} = 0.139 - \frac{0.172}{(308.2\text{K}/305.4\text{K})^{4.2}} = -0.0270$$

$$B(T) = \frac{RT_c}{P_c} (B_o + \omega B_1) = \frac{0.08206 \text{ L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \left| \frac{305.4 \text{ K}}{48.2 \text{ atm}} \right| [-0.333 - (0.098)(0.0270)] \\ = -0.1745 \text{ L/mol}$$

$$\frac{P\hat{V}^2}{RT} - \hat{V} - B = \left(\frac{10.0 \text{ atm}}{308.2 \text{ K}} \left| \frac{\text{mol} \cdot \text{K}}{0.08206 \text{ L} \cdot \text{atm}} \right| \right) \hat{V}^2 - \hat{V} + 0.1745 = 0$$

$$\Rightarrow \hat{V} = \frac{1 \pm \sqrt{1 - 4(0.395 \text{ mol/L})(0.1745 \text{ L/mol})}}{2(0.395 \text{ mol/L})} = \underline{\underline{2.343 \text{ L/mol}, 0.188 \text{ L/mol}}}$$

$\hat{V}_{\text{ideal}} = RT/P = 0.08206 \times 308.2 / 10.0 = 2.53$, so the second solution is likely to be a mathematical artifact.

$$\text{b. } z = \frac{P\hat{V}}{RT} = \frac{10.0 \text{ atm}}{0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}}} \left| \frac{2.343 \text{ L/mol}}{308.2 \text{ K}} \right| = \underline{\underline{0.926}}$$

$$\text{c. } \dot{m} = \frac{\dot{V}}{\hat{V}} \text{ MW} = \frac{1000 \text{ L}}{\text{h}} \left| \frac{\text{mol}}{2.343 \text{ L}} \right| \left| \frac{30.0 \text{ g}}{\text{mol}} \right| \left| \frac{1 \text{ kg}}{1000 \text{ g}} \right| = \underline{\underline{12.8 \text{ kg/h}}}$$

$$5.56 \quad \frac{P\hat{V}}{RT} = 1 + \frac{B}{\hat{V}} \Rightarrow B = \frac{RT_c}{P_c}(B_o + \omega B_1)$$

$$\text{From Table B.1 } T_c(\text{CH}_3\text{OH}) = 513.2 \text{ K}, P_c = 78.50 \text{ atm}$$

$$T_c(\text{C}_3\text{H}_8) = 369.9 \text{ K}, P_c = 42.0 \text{ atm}$$

$$\text{From Table 5.3-1 } \omega(\text{CH}_3\text{OH}) = 0.559, \omega(\text{C}_3\text{H}_8) = 0.152$$

$$B_o(\text{CH}_3\text{OH}) = 0.083 - \frac{0.422}{T_r^{1.6}} = 0.083 - \frac{0.422}{\left(\frac{373.2\text{K}}{513.2\text{K}}\right)^{1.6}} = -0.619$$

$$B_o(\text{C}_3\text{H}_8) = 0.083 - \frac{0.422}{T_r^{1.6}} = 0.083 - \frac{0.422}{\left(\frac{373.2\text{K}}{369.9\text{K}}\right)^{1.6}} = -0.333$$

$$B_1(\text{CH}_3\text{OH}) = 0.139 - \frac{0.172}{T_r^{4.2}} = 0.139 - \frac{0.172}{\left(\frac{373.2\text{K}}{513.2\text{K}}\right)^{4.2}} = -0.516$$

$$B_1(\text{C}_3\text{H}_8) = 0.139 - \frac{0.172}{T_r^{4.2}} = 0.139 - \frac{0.172}{\left(\frac{373.2\text{K}}{369.9\text{K}}\right)^{4.2}} = -0.0270$$

$$\begin{aligned} B(\text{CH}_3\text{OH}) &= \frac{RT_c}{P_c}(B_o + \omega B_1) \\ &= \frac{0.08206 \text{ L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \left| \frac{513.2 \text{ K}}{78.5 \text{ atm}} \right| (-0.619 - (0.559)(-0.516)) = -0.4868 \frac{\text{L}}{\text{mol}} \end{aligned}$$

$$\begin{aligned} B(\text{C}_3\text{H}_8) &= \frac{RT_c}{P_c}(B_o + \omega B_1) \\ &= \frac{0.08206 \text{ L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \left| \frac{369.9 \text{ K}}{42.0 \text{ atm}} \right| (-0.333 - (0.152)(-0.0270)) = -0.2436 \frac{\text{L}}{\text{mol}} \end{aligned}$$

$$B_{\text{mix}} = \sum_i \sum_j y_i y_j B_{ij} \Rightarrow B_{ij} = 0.5(B_{ii} + B_{jj})$$

$$B_{ij} = 0.5(-0.4868 - 0.2436) \text{ L} / \text{mol} = -0.3652 \text{ L} / \text{mol}$$

$$\begin{aligned} B_{\text{mix}} &= (0.30)(0.30)(-0.4868) + 2(0.30)(0.70)(-0.3652) + (0.70)(0.70)(-0.2436) \\ &= -0.3166 \text{ L} / \text{mol} \end{aligned}$$

$$\frac{P\hat{V}^2}{RT} - \hat{V} - B_{\text{mix}} = \left(\frac{10.0 \text{ atm}}{373.2 \text{ K}} \left| \frac{\text{mol} \cdot \text{K}}{0.08206 \text{ L} \cdot \text{atm}} \right| \right) \hat{V}^2 - \hat{V} + 0.3166 = 0$$

$$\text{Solve for } \hat{V}: \hat{V} = \frac{1 \pm \sqrt{1 - 4(0.326 \text{ mol} / \text{L})(0.3166 \text{ L} / \text{mol})}}{2(0.326 \text{ mol} / \text{L})} = 2.70 \text{ L} / \text{mol}, 0.359 \text{ L} / \text{mol}$$

$$\hat{V}_{\text{ideal}} = \frac{RT}{P} = \frac{0.08206 \text{ L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \left| \frac{373.2 \text{ K}}{10.0 \text{ atm}} \right| = 3.06 \text{ L} / \text{mol} \Rightarrow \underline{\underline{\hat{V}_{\text{virial}} = 2.70 \text{ L} / \text{mol}}}$$

$$\dot{V} = \hat{V} \dot{n} = \frac{2.70 \text{ L} / \text{mol}}{\left| \frac{15.0 \text{ kmol CH}_3\text{OH} / \text{h}}{0.30 \text{ kmol CH}_3\text{OH} / \text{kmol}} \right|} \left| \frac{1000 \text{ mol}}{1 \text{ kmol}} \right| \left| \frac{1 \text{ m}^3}{1000 \text{ L}} \right| = \underline{\underline{135 \text{ m}^3 / \text{h}}}$$

5.57 a. van der Waals equation: $P = \frac{RT}{(\hat{V} - b)} - \frac{a}{\hat{V}^2}$

Multiply both sides by $\hat{V}^2(\hat{V} - b) \Rightarrow P\hat{V}^3 - P\hat{V}^2b = RT\hat{V}^2 - a\hat{V} + ab$

$P\hat{V}^3 + (-Pb - RT)\hat{V}^2 + a\hat{V} - ab = 0$

$c_3 = P = \underline{50.0 \text{ atm}}$

$c_2 = (-Pb - RT) = (-50.0 \text{ atm})(0.0366 \text{ L/mol}) - (0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(223 \text{ K}) = \underline{-20.1 \text{ L}\cdot\text{atm/mol}}$

$c_1 = -a = \underline{1.33 \text{ atm}\cdot\text{L}^2/\text{mol}^2}$

$c_0 = -ab = -(1.33 \text{ atm}\cdot\text{L}^2/\text{mol}^2)(0.0366 \text{ L/mol})$

$= \underline{-0.0487 \frac{\text{atm}\cdot\text{L}^3}{\text{mol}^3}}$

b. $\hat{V}_{\text{ideal}} = \frac{RT}{P} = \frac{0.08206 \text{ L}\cdot\text{atm}}{\text{mol}\cdot\text{K}} \frac{223 \text{ K}}{50.0 \text{ atm}} = 0.366 \text{ L/mol}$

c.

T(K)	P(atm)	c3	c2	c1	c0	V(ideal) (L/mol)	V (L/mol)	f(V)	%error
223	1.0	1.0	-18.336	1.33	-0.0487	18.2994	18.2633	0.0000	0.2
223	10.0	10.0	-18.6654	1.33	-0.0487	1.8299	1.7939	0.0000	2.0
223	50.0	50.0	-20.1294	1.33	-0.0487	0.3660	0.3313	0.0008	10.5
223	100.0	100.0	-21.9594	1.33	-0.0487	0.1830	0.1532	-0.0007	19.4
223	200.0	200.0	-25.6194	1.33	-0.0487	0.0915	0.0835	0.0002	9.6

← b

d. 1 eq. in 1 unknown - use Newton-Raphson.

$(1) \Rightarrow g(\hat{V}) = 50.0\hat{V}^3 + (-20.1294)\hat{V}^2 + (1.33)\hat{V} - 0.0487 = 0$

Eq. (A.2-13) $\Rightarrow a = \frac{\partial g}{\partial \hat{V}} = 150\hat{V}^2 - 40.259\hat{V} + 1.33$

Eq. (A.2-14) $\Rightarrow \text{solve } -g \Rightarrow d = \frac{-g}{a}$

Then $\hat{V}^{(k+1)} = \hat{V}^{(k)} + d$ Guess $\hat{V}^{(1)} = \hat{V}_{\text{ideal}} = 0.3660 \text{ L/mol}$.

	$\hat{V}^{(k)}$	$\hat{V}^{(k+1)}$	
1	0.3660	0.33714	
2	0.33714	0.33137	
3	0.33137	0.33114	
4	0.33114	0.33114	converged

5.58 C_3H_8 : $T_C = 369.9 \text{ K}$ $P_C = 42.0 \text{ atm}$ ($4.26 \times 10^6 \text{ Pa}$) $\omega = 0.152$

Specific Volume $\frac{5.0 \text{ m}^3}{75 \text{ kg}} \left| \frac{44.09 \text{ kg}}{1 \text{ kmol}} \right| \frac{1 \text{ kmol}}{10^3 \text{ mol}} = 2.93 \times 10^{-3} \text{ m}^3/\text{mol}$

Calculate constants

$$a = \frac{0.42747}{4.26 \times 10^6 \text{ Pa}} \left| \frac{(8.314 \text{ m}^3 \cdot \text{Pa}/\text{mol} \cdot \text{K})^2}{(369.9 \text{ K})^2} \right| = 0.949 \text{ m}^6 \cdot \text{Pa}/\text{mol}^2$$

$$b = \frac{0.08664}{4.26 \times 10^6 \text{ Pa}} \left| \frac{(8.314 \text{ m}^3 \cdot \text{Pa}/\text{mol} \cdot \text{K})}{(369.9 \text{ K})} \right| = 6.25 \times 10^{-5} \text{ m}^3/\text{mol}$$

$$m = 0.48508 + 1.55171(0.152) - 0.15613(0.152)^2 = 0.717$$

$$\alpha = \left[1 + 0.717 \left(1 - \sqrt{298.2/369.9} \right) \right]^2 = 1.15$$

SRK Equation:

$$P = \frac{(8.314 \text{ m}^3 \cdot \text{Pa}/\text{mol} \cdot \text{K})(298.2 \text{ K})}{(2.93 \times 10^{-3} - 6.25 \times 10^{-5}) \text{ m}^3/\text{mol}} - \frac{1.15(0.949 \text{ m}^6 \cdot \text{Pa}/\text{mol}^2)}{2.93 \times 10^{-3} \text{ m}^3/\text{mol} (2.93 \times 10^{-3} + 6.25 \times 10^{-5}) \text{ m}^3/\text{mol}}$$

$$\Rightarrow P = 7.40 \times 10^6 \text{ Pa} \Rightarrow \underline{\underline{7.30 \text{ atm}}}$$

Ideal: $P = \frac{RT}{\hat{V}} = \frac{(8.314 \text{ m}^3 \cdot \text{Pa}/\text{mol} \cdot \text{K})(298.2 \text{ K})}{2.93 \times 10^{-3} \text{ m}^3/\text{mol}} = 8.46 \times 10^6 \text{ Pa} \Rightarrow 8.35 \text{ atm}$

Percent Error: $\frac{(8.35 - 7.30) \text{ atm}}{7.30 \text{ atm}} \times 100\% = \underline{\underline{14.4\%}}$

5.59 CO_2 : $T_C = 304.2 \text{ K}$ $P_C = 72.9 \text{ atm}$ $\omega = 0.225$

Ar: $T_C = 151.2 \text{ K}$ $P_C = 48.0 \text{ atm}$ $\omega = -0.004$

$P = 51.0 \text{ atm}$, $\hat{V} = 35.0 \text{ L} / 50.0 \text{ mol} = 0.70 \text{ L}/\text{mol}$

Calculate constants (use $R = 0.08206 \text{ L} \cdot \text{atm}/\text{mol} \cdot \text{K}$)

CO_2 : $a = 3.65 \frac{\text{L}^2 \cdot \text{atm}}{\text{mol}^2}$, $m = 0.826$, $b = 0.0297 \frac{\text{L}}{\text{mol}}$, $\alpha = \left[1 + 0.826 \left(1 - \sqrt{T/304.2} \right) \right]^2$

Ar: $a = 1.37 \frac{\text{L}^2 \cdot \text{atm}}{\text{mol}^2}$, $m = 0.479$, $b = 0.0224 \frac{\text{L}}{\text{mol}}$, $\alpha = \left[1 + 0.479 \left(1 - \sqrt{T/151.2} \right) \right]^2$

$$f(T) = \frac{RT}{\hat{V} - b} - \frac{a}{\hat{V}(\hat{V} + b)} \left[1 + m \left(1 - \sqrt{T/T_C} \right) \right]^2 - P = 0$$

Use E-Z Solve. Initial value (ideal gas):

$$T_{\text{ideal}} = (51.0 \text{ atm}) \left(0.70 \frac{\text{L}}{\text{mol}} \right) / \left(0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \right) = \underline{\underline{435.0 \text{ K}}}$$

E - Z Solve $\Rightarrow (T_{\text{max}})_{\text{CO}_2} = 455.4 \text{ K}$, $(T_{\text{max}})_{\text{Ar}} = 431.2 \text{ K}$

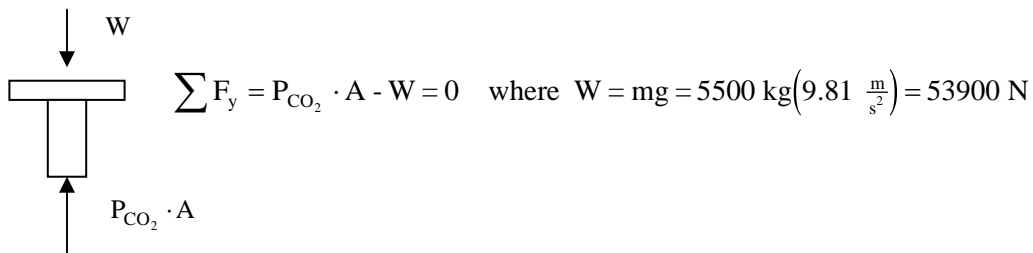
5.60 $\underline{\text{O}_2}$: $T_c = 154.4 \text{ K}$; $P_c = 49.7 \text{ atm}$; $\omega = 0.021$; $T = 208.2 \text{ K}(65^\circ \text{ C})$; $P = 8.3 \text{ atm}$;
 $\dot{m} = 250 \text{ kg/h}$; $R = 0.08206 \text{ L} \cdot \text{atm/mol} \cdot \text{K}$

SRK constants: $a = 1.38 \text{ L}^2 \cdot \text{atm/mol}^2$; $b = 0.0221 \text{ L/mol}$; $m = 0.517$; $\alpha = 0.840$

SRK equation: $f(\hat{V}) = \frac{RT}{(\hat{V} - b)} - \frac{a\alpha}{\hat{V}(\hat{V} + b)} - P = 0 \xrightarrow{\text{E-Z Solve}} \hat{V} = 2.01 \text{ L/mol}$

$$\Rightarrow \dot{V} = \frac{250 \text{ kg}}{\text{h}} \left| \frac{\text{kmol}}{32.00 \text{ kg}} \right| \left| \frac{10^3 \text{ mol}}{1 \text{ kmol}} \right| \left| \frac{2.01 \text{ L}}{\text{mol}} \right| = \underline{\underline{15,700 \text{ L/h}}}$$

5.61



a. $P_{\text{CO}_2} = \frac{W}{A_{\text{piston}}} = \frac{53900 \text{ N}}{\frac{\pi}{4}(0.15 \text{ m})^2} \left| \frac{1 \text{ atm}}{1.013 \times 10^5 \text{ N/m}^2} \right| = \underline{\underline{30.1 \text{ atm}}}$

b. SRK equation of state: $P = \frac{RT}{(\hat{V} - b)} - \frac{\alpha a}{\hat{V}(\hat{V} + b)}$

For CO_2 : $T_c = 304.2$, $P_c = 72.9 \text{ atm}$, $\omega = 0.225$

$a = 3.654 \text{ m}^6 \cdot \text{atm/kmol}^2$, $b = 0.02967 \text{ m}^3/\text{kmol}$, $m = 0.8263$, $\alpha(25^\circ \text{ C}) = 1.016$

$$30.1 \text{ atm} = \frac{\left(0.08206 \frac{\text{m}^3 \cdot \text{atm}}{\text{kmol} \cdot \text{K}}\right)(298.2 \text{ K})}{\left(\hat{V} - 0.02967 \frac{\text{m}^3}{\text{kmol}}\right)} - \frac{(1.016)\left(3.654 \frac{\text{m}^6 \cdot \text{atm}}{\text{kmol}^2}\right)}{\hat{V}(\hat{V} + 0.02967) \frac{\text{m}^6}{\text{kmol}^2}}$$

$\xrightarrow{\text{E-Z Solve}} \hat{V} = \underline{\underline{0.675 \text{ m}^3/\text{kmol}}}$

$$V(\text{before expansion}) = 0.030 \text{ m}^3$$

$$V(\text{after expansion}) = 0.030 \text{ m}^3 + \frac{\pi}{4}(0.15 \text{ m})^2(1.5 \text{ m}) = 0.0565 \text{ m}^3$$

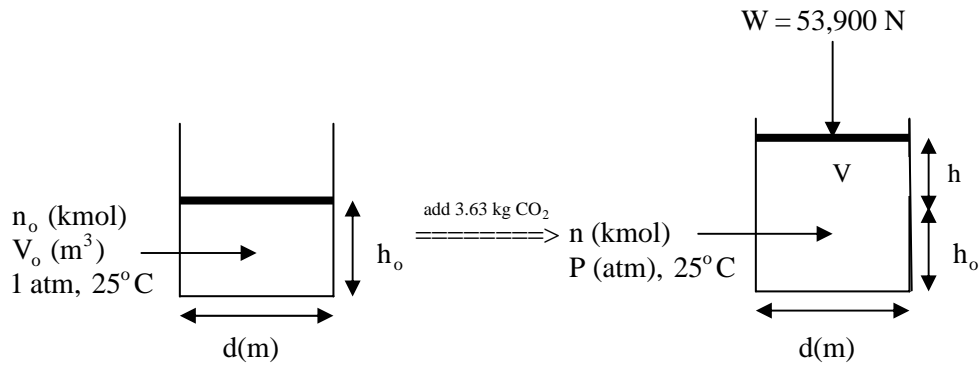
$$m_{\text{CO}_2} = \frac{V}{\hat{V}} \text{MW} = \frac{0.0565 \text{ m}^3}{0.675 \text{ m}^3/\text{kmol}} \left| \frac{44.01 \text{ kg}}{\text{kmol}} \right| = 3.68 \text{ kg}$$

$$m_{\text{CO}_2}(\text{initially}) = \frac{PV}{RT} \text{MW} = \frac{1 \text{ atm}}{0.08206 \frac{\text{m}^3 \cdot \text{atm}}{\text{kmol} \cdot \text{K}}} \left| \frac{0.030 \text{ m}^3}{298.2 \text{ K}} \right| \left| \frac{44.01 \text{ kg}}{\text{kmol}} \right| = 0.0540 \text{ kg}$$

$$m_{\text{CO}_2}(\text{added}) = 3.68 - 0.0540 \text{ kg} = \underline{\underline{3.63 \text{ kg}}}$$

5.61 (cont'd)

c.



Given T , V_o , h , find d

Initial: $n_o = \frac{V_o}{RT} \quad (P_o = 1)$

Final: $V = V_o + \frac{\pi d^2 h}{4}$, $n = n_o + \frac{3.63 \text{ (kg)}}{44 \text{ (kg / kmol)}} = \frac{V_o}{RT} + 0.0825$

$$\hat{V} = \frac{V}{n} = \frac{V_o + \frac{\pi d^2 h}{4}}{\frac{V_o}{RT} + 0.0825}$$

$$P = \frac{W}{A_{\text{piston}}} = \frac{RT}{\hat{V} - b} - \frac{\alpha a}{\hat{V}(\hat{V} + b)} \Rightarrow \frac{53,900}{\pi d^2 / 4} = \frac{RT}{\hat{V} - b} - \frac{\alpha a}{\hat{V}(\hat{V} + b)} \quad (1)$$

Substitute expression for \hat{V} in (1) \Rightarrow one equation in one unknown. Solve for d .

5.62 a. Using ideal gas assumption:

$$P_g = \frac{nRT}{V} - P_{\text{atm}} = \frac{35.3 \text{ lb}_m \text{ O}_2}{32.0 \text{ lb}_m} \left| \frac{1 \text{ lb-mole}}{32.0 \text{ lb}_m} \right| \frac{10.73 \text{ ft}^3 \cdot \text{psia}}{\text{lb-mole} \cdot ^\circ\text{R}} \left| \frac{509.7^\circ\text{R}}{2.5 \text{ ft}^3} \right| - 14.7 \text{ psia} = \underline{\underline{2400 \text{ psig}}}$$

b. SRK Equation of state: $P = \frac{RT}{(\hat{V} - b)} - \frac{\alpha a}{\hat{V}(\hat{V} + b)}$

$$\hat{V}_{\text{ideal}} = \frac{2.5 \text{ ft}^3}{35.3 \text{ lb}_m} \left| \frac{32.0 \text{ lb}_m / \text{lb-mole}}{35.3 \text{ lb}_m} \right| = 2.27 \frac{\text{ft}^3}{\text{lb-mole}}$$

(Use as a first estimate when solving the SRK equation)

For O_2 : $T_c = 277.9^\circ\text{R}$, $P_c = 730.4 \text{ psi}$, $\omega = 0.021$

$$a = 5203.8 \frac{\text{ft}^6 \cdot \text{psi}}{\text{lb-mole}^2}, \quad b = 0.3537 \frac{\text{ft}^3}{\text{lb-mole}}, \quad m = 0.518, \quad \alpha(50^\circ\text{F}) = 0.667$$

$$(2400 + 14.7) \text{ psi} = \frac{\left(10.73 \frac{\text{ft}^3 \cdot \text{psi}}{\text{lb-mole} \cdot ^\circ\text{R}}\right)(509.7^\circ\text{R})}{\left(\hat{V} - 0.3537\right) \frac{\text{ft}^3}{\text{lb-mole}}} - \frac{(0.667)(5203.8 \frac{\text{ft}^6 \cdot \text{psi}}{\text{lb-mole}^2})}{\hat{V}(\hat{V} + 0.3537) \frac{\text{ft}^6}{\text{lb-mole}^2}}$$

$$\text{E-Z Solve} \Rightarrow \hat{V} = 2.139 \text{ ft}^3 / \text{lb-mole}$$

5.62 (cont'd)

$$m_{O_2} = \frac{V}{\hat{V}} MW = \frac{2.5 \text{ ft}^3}{2.139 \text{ ft}^3 / \text{lb} - \text{mole}} \left| \frac{32.0 \text{ lb}_m}{\text{lb} - \text{mole}} \right| = \underline{\underline{37.4 \text{ lb}_m}}$$

Ideal gas gives a conservative estimate. It calls for charging less O_2 than the tank can safely hold.

- c.
1. Pressure gauge is faulty
 2. The room temperature is higher than 50°F
 3. Crack or weakness in the tank
 4. Tank was not completely evacuated before charging and O_2 reacted with something in the tank
 5. Faulty scale used to measure O_2
 6. The tank was mislabeled and did not contain pure oxygen.

5.63 a. SRK Equation of State:
$$P = \frac{RT}{(\hat{V} - b)} - \frac{\alpha a}{\hat{V}(\hat{V} + b)}$$

\Rightarrow multiply both sides of the equation by $\hat{V}(\hat{V} - b)(\hat{V} + b)$:

$$f(\hat{V}) = P\hat{V}(\hat{V} - b)(\hat{V} + b) - RT\hat{V}(\hat{V} + b) + \alpha a(\hat{V} - b) = 0$$

$$f(\hat{V}) = P\hat{V}^3 - RT\hat{V}^2 + (\alpha a - b^2P - bRT)\hat{V} - \alpha ab = 0$$

b.

Problem 5.63-SRK Equation Spreadsheet

Species	CO2	
Tc(K)	304.2	R=0.08206 m ³ atm/kmol K
Pc(atm)	72.9	
ω	0.225	
a	3.653924 m ⁶ atm/kmol ²	
b	0.029668 m ³ /kmol	
m	0.826312	

$$f(V) = B14 * E14^3 - 0.08206 * A14 * E14^2 + (\$B\$7 * C14 - \$B\$8^2 * B14 - \$B\$8 * 0.08206 * A14) * E14 - C14 * \$B\$7 * \$B\$8$$

T(K)	P(atm)	alpha	V(ideal)	V(SRK)	f(V)
200	6.8	1.3370	2.4135	2.1125	0.0003
250	12.3	1.1604	1.6679	1.4727	0.0001
300	6.8	1.0115	3.6203	3.4972	0.0001
300	21.5	1.0115	1.1450	1.0149	0.0000
300	50.0	1.0115	0.4924	0.3392	0.0001

c. E-Z Solve solves the equation $f(V)=0$ in one step. Answers identical to V_{SRK} values in part b.

d. REAL T, P, TC, PC, W, R, A, B, M, ALP, Y, VP, F, FP
 INTEGER I
 CHARACTER A20 GAS
 DATA R 10.08206/
 READ (5, *) GAS
 WRITE (6, *) GAS
 10 READ (5, *) TC, PC, W

5.63 (cont'd)

```

READ (5, *) T, P
IF (T.LT.Q.) STOP
R = 0.42747 * R * R / PC * TC * TC
B = 0.08664 * R * TC / PC
M = 0.48508 + W = (1.55171 - W * 0.15613)

ALP = (1. + M * (1 - (T / TC) ** 0.5)) ** 2.
VP = R * T / P
DO 20 I = 7, 15
V = VP
F = R * T / (V - B) - ALP * A / V / (V + B) - P
FP = ALP * A * (2. * V + B) / V / (V + B) ** 2 - R * T / (V - B) ** 2.
VP = V - F / FP
IF (ABS(VP - V) / VP .LT. 0.0001) GOTO 30
20 CONTINUE
WRITE (6, 2)
2  FORMAT ('DID NOT CONVERGE')
STOP
30 WRITE (6, 3) T, P, VP
3  FORMAT (F6.1, 'K', 3X, F5.1, 'ATM', 3X, F5.2, 'LITER/MOL')
GOTO 10
END

```

```

$ DATA
CARBON          DIOXIDE
304.2           72.9           0.225
200.0           6.8
250.0           12.3
300.0           21.5
-1              0.

```

RESULTS

```

CARBON DIOXIDE
200.0 K          6.8 ATM          2.11 LITER/MOL
250.0 K          12.3 ATM         1.47 LITER/MOL
300.0 K          6.8 ATM          3.50 LITER/MOL
300.0 K          21.5 ATM         1.01 LITER/MOL
300.0 K          50.0 ATM         0.34 LITER/MOL

```

- 5.64 a.** $\underline{\text{N}_2}$: $T_C = 126.2 \text{ K}$ $T_r = (40 + 273.2) / 126.2 = 2.48$ $P_C = 33.5 \text{ atm}$ $\Rightarrow P_r = \frac{40 \text{ MPa}}{33.5 \text{ atm}} \left| \frac{10 \text{ atm}}{1.013 \text{ MPa}} \right| = 11.78$ $\Rightarrow \underline{\underline{z = 1.2}}$ Fig. 5.4-4
- b.** $\underline{\text{He}}$: $T_C = 5.26 \text{ K}$ $T_r = (-200 + 273.2) / (5.26 + 8) = 5.52$ $P_C = 2.26 \text{ atm}$ $\Rightarrow P_r = 350 / (2.26 + 8) = 34.11$ $\Rightarrow \underline{\underline{z = 1.6}}$ Fig. 5.4-4
- ↑
Newton's correction

$$\begin{aligned}
 \text{5.65 a. } \rho \left(\text{kg} / \text{m}^3 \right) &= \frac{m \left(\text{kg} \right)}{V \left(\text{m}^3 \right)} = \frac{(\text{MW})P}{RT} \\
 &= \frac{30 \text{ kg/kmol}}{465 \text{ K}} \left| \frac{9.0 \text{ MPa}}{0.08206 \frac{\text{m}^3 \cdot \text{atm}}{\text{kmol} \cdot \text{K}}} \right| \left| \frac{10 \text{ atm}}{1.013 \text{ MPa}} \right| = \underline{\underline{69.8 \text{ kg/m}^3}}
 \end{aligned}$$

$$\text{b. } \left. \begin{array}{l} T_r = 465/310 = 1.5 \\ P_r = 9.0/4.5 = 2.0 \end{array} \right\} \xRightarrow{\text{Fig. 5.4-3}} z = 0.84$$

$$\rho = \frac{(\text{MW})P}{zRT} = \frac{69.8 \text{ kg/m}^3}{0.84} = \underline{\underline{83.1 \text{ kg/m}^3}}$$

$$\text{5.66 Moles of CO}_2: \frac{100 \text{ lb}_m \text{ CO}_2}{44.01 \text{ lb}_m \text{ CO}_2} = 2.27 \text{ lb - moles}$$

$$\left. \begin{array}{l} T_C = 304.2 \text{ K} \\ P_C = 72.9 \text{ atm} \end{array} \right\} \Rightarrow P_r = P/P_C = \frac{(1600 + 14.7) \text{ psi}}{72.9 \text{ atm}} \left| \frac{1 \text{ atm}}{14.7 \text{ psi}} \right| = 1.507$$

$$\hat{V}_r = \frac{\hat{V}P_C}{RT_C} = \frac{10.0 \text{ ft}^3}{2.27 \text{ lb-moles}} \left| \frac{72.9 \text{ atm}}{304.2 \text{ K}} \right| \left| \frac{\text{lb-mole} \cdot ^\circ\text{R}}{0.7302 \text{ ft}^3 \cdot \text{atm}} \right| \left| \frac{1 \text{ K}}{1.8 ^\circ\text{R}} \right| = 0.80$$

Fig. 5.4-3: $P_r = 1.507$, $V_r = 0.80 \Rightarrow z = 0.85$

$$T = \frac{PV}{znR} = \frac{1614.7 \text{ psi}}{0.85} \left| \frac{10.0 \text{ ft}^3}{2.27 \text{ lb - moles}} \right| \left| \frac{\text{lb - mole} \cdot ^\circ\text{R}}{0.7302 \text{ ft}^3 \cdot \text{atm}} \right| \left| \frac{1 \text{ atm}}{14.7 \text{ psi}} \right| = 779^\circ\text{R} = \underline{\underline{320 ^\circ\text{F}}}$$

$$\text{5.67 } \underline{\text{O}_2}: \left. \begin{array}{ll} T_C = 154.4 \text{ K} & T_{r1} = 298/154.4 = 1.93 \\ P_C = 49.7 \text{ atm} & P_{r1} = 1/49.7 = 0.02 \end{array} \right\} z_1 = 1.00 \text{ (Fig. 5.4 - 2)}$$

$$\left. \begin{array}{ll} T_{r2} = 358/154.4 = 2.23 \\ P_{r2} = 1000/49.7 = 20.12 \end{array} \right\} z_2 = 1.61 \text{ (Fig. 5.4 - 4)}$$

$$V_2 = V_1 \frac{z_2}{z_1} \frac{T_2}{T_1} \frac{P_1}{P_2}$$

$$V_2 = \frac{127 \text{ m}^3}{\text{h}} \left| \frac{1.61}{1.00} \right| \left| \frac{358 \text{ K}}{298 \text{ K}} \right| \left| \frac{1 \text{ atm}}{1000 \text{ atm}} \right| = \underline{\underline{0.246 \text{ m}^3/\text{h}}}$$

$$\begin{aligned}
 \text{5.68 } \underline{\text{O}_2}: \quad T_C &= 154.4 \text{ K} & T_r &= (27 + 273.2)/154.4 = 1.94 \\
 P_C &= 49.7 \text{ atm} & P_{r1} &= 175/49.7 = 3.52 \Rightarrow z_1 = 0.95 & (\text{Fig. 5.3-2}) \\
 & & P_{r2} &= 1.1/49.7 = 0.02 \Rightarrow z_2 = 1.00
 \end{aligned}$$

$$n_1 - n_2 = \frac{V}{RT} \left(\frac{P_1}{z_1} - \frac{P_2}{z_2} \right) = \frac{10.0 \text{ L}}{300.2 \text{ K}} \left| \frac{\text{mol} \cdot \text{K}}{0.08206 \text{ L} \cdot \text{atm}} \right| \left(\frac{175 \text{ atm}}{0.95} - \frac{1.1 \text{ atm}}{1.00} \right) = \underline{\underline{74.3 \text{ mol O}_2}}$$

$$\text{5.69 a. } \hat{V} = \frac{V}{n} = \frac{50.0 \text{ mL}}{5.00 \text{ g}} \left| \frac{44.01 \text{ g}}{\text{mol}} \right| = 440.1 \text{ mL} / \text{mol}$$

$$P = \frac{RT}{\hat{V}} = \frac{82.06 \text{ mL} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \left| \frac{1000 \text{ K}}{440.1 \text{ mL} / \text{mol}} \right| = \underline{\underline{186 \text{ atm}}}$$

b. For CO_2 : $T_c = 304.2 \text{ K}$, $P_c = 72.9 \text{ atm}$

$$T_r = \frac{T}{T_c} = \frac{1000 \text{ K}}{304.2 \text{ K}} = 3.2873$$

$$V_r^{\text{ideal}} = \frac{\hat{V}P_c}{RT_c} = \frac{440.1 \text{ mL}}{\text{mol}} \left| \frac{72.9 \text{ atm}}{304.2 \text{ K}} \right| \frac{\text{mol} \cdot \text{K}}{82.06 \text{ mL} \cdot \text{atm}} = 1.28$$

Figure 5.4-3: $V_r^{\text{ideal}} = 1.28$ and $T_r = 3.29 \Rightarrow z = 1.02$

$$P = \frac{zRT}{\hat{V}} = \frac{1.02}{\hat{V}} \left| \frac{82.06 \text{ mL} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \right| \frac{\text{mol}}{440.1 \text{ mL}} \left| \frac{1000 \text{ K}}{1} \right| = \underline{\underline{190 \text{ atm}}}$$

c. $a = 3.654 \times 10^6 \text{ mL}^2 \cdot \text{atm} / \text{mol}^2$, $b = 29.67 \text{ mL} / \text{mol}$, $m = 0.8263$, $\alpha(1000 \text{ K}) = 0.1077$

$$P = \frac{(82.06 \frac{\text{mL} \cdot \text{atm}}{\text{mol} \cdot \text{K}})(1000 \text{ K})}{(440.1 - 29.67) \frac{\text{mL}}{\text{mol}}} - \frac{(0.1077)(3.654 \times 10^6 \frac{\text{mL}^2 \cdot \text{atm}}{\text{mol}^2})}{440.1(440.1 + 29.67) \frac{\text{mL}^2}{\text{mol}^2}} = \underline{\underline{198 \text{ atm}}}$$

5.70 a. The tank is being purged in case it is later filled with a gas that could ignite in the presence of O_2 .

b. Enough N_2 needs to be added to make $x_{\text{O}_2} = 10 \times 10^{-6}$. Since the O_2 is so dilute at this condition, the properties of the gas will be that of N_2 .

$T_c = 126.2 \text{ K}$, $P_c = 33.5 \text{ atm}$, $T_r = 2.36$

$$n_{\text{initial}} = n_1 = \frac{PV}{RT} = \frac{1 \text{ atm}}{0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}}} \left| \frac{5000 \text{ L}}{298.2 \text{ K}} \right| = 204.3 \text{ mol}$$

$$n_{\text{O}_2} = 204.3 \text{ mol air} \left(\frac{0.21 \text{ mol O}_2}{\text{mol air}} \right) = 42.9 \text{ mol O}_2$$

$$\frac{n_{\text{O}_2}}{n_2} = 10 \times 10^{-6} \Rightarrow n_2 = 4.29 \times 10^6 \text{ mol}$$

$$\hat{V} = \frac{5000 \text{ L}}{4.29 \times 10^6 \text{ mol}} = 1.16 \times 10^{-3} \text{ L} / \text{mol}$$

$$\hat{V}_r^{\text{ideal}} = \frac{\hat{V}P_c}{RT_c} = \frac{1.16 \times 10^{-3} \text{ L}}{\text{mol}} \left| \frac{\text{mol} \cdot \text{K}}{0.08206 \text{ L} \cdot \text{atm}} \right| \frac{33.5 \text{ atm}}{126.2 \text{ K}} = 3.8 \times 10^{-3}$$

\Rightarrow not found on compressibility charts

$$\text{Ideal gas: } P = \frac{RT}{\hat{V}} = \frac{0.08206 \text{ L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \left| \frac{298.2 \text{ K}}{1.16 \times 10^{-3} \text{ L} / \text{mol}} \right| = \underline{\underline{2.1 \times 10^4 \text{ atm}}}$$

The pressure required will be higher than $2.1 \times 10^4 \text{ atm}$ if $z \geq 1$, which from Fig. 5.3 - 3 is very likely.

$$n_{\text{added}} = 4.29 \times 10^6 - 204.3 \cong (4.29 \times 10^6 \text{ mol N}_2)(0.028 \text{ kg N}_2 / \text{mol}) = \underline{\underline{1.20 \times 10^5 \text{ kg N}_2}}$$

5.70 (cont'd)

c.

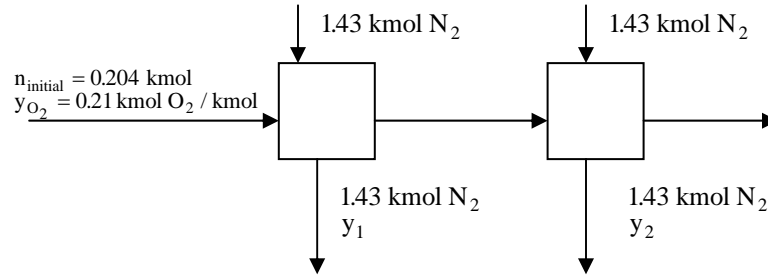


Fig 5.4-2

N_2 at 700 kPa gauge = 7.91 atm abs. $\Rightarrow P_r = 0.236$, $T_r = 2.36 \Rightarrow z = 0.99$

$$n_2 = \frac{P_2 V}{zRT} = \frac{7.91 \text{ atm}}{0.99} \left| \frac{5000 \text{ L}}{0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}}} \right| \frac{1}{298.2 \text{ K}} = 1.633 \text{ kmol}$$

$$y_1 = \frac{y_{\text{init}} n_{\text{init}}}{1.634} = \frac{(0.21)(0.204)}{1.634} = 0.026$$

$$y_2 = \frac{y_1 n_{\text{init}}}{1.634} = y_{\text{init}} \left(\frac{n_{\text{init}}}{1.634} \right)^2 = 0.0033$$

$$y_n = y_{\text{init}} \left(\frac{n_{\text{init}}}{1.634} \right)^n \Rightarrow n = \frac{\ln \left(\frac{y_n}{y_{\text{init}}} \right)}{\ln \left(\frac{n_{\text{init}}}{1.634} \right)} = 4.8 \Rightarrow \underline{\underline{\text{Need at least 5 stages}}}$$

$$\text{Total } N_2 = 5(1.43 \text{ kmol } N_2)(28.0 \text{ kg / kmol}) = \underline{\underline{200 \text{ kg } N_2}}$$

d. Multiple cycles use less N_2 and require lower operating pressures. The disadvantage is that it takes longer.

$$5.71 \quad \text{a.} \quad \dot{m} = MW \frac{P\dot{V}}{RT} \Rightarrow \text{Cost (\$/h)} = \dot{m}S = MW \frac{SP\dot{V}}{RT} = \left(\frac{44.09 \text{ lb}_m / \text{lb-mol}}{0.7302 \frac{\text{ft}^3 \cdot \text{atm}}{\text{lb-mol} \cdot ^\circ\text{R}}} \right) \frac{SP\dot{V}}{T} = \underline{\underline{60.4 \frac{SP\dot{V}}{T}}}$$

$$\text{b.} \quad \left. \begin{array}{l} T_c = 369.9 \text{ K} = 665.8^\circ\text{R} \Rightarrow T_r = 0.85 \\ P_c = 42.0 \text{ atm} \Rightarrow P_r = 0.16 \end{array} \right\} \xrightarrow{\text{Fig. 5.4-2}} z = 0.91$$

$$\dot{m} = 60.4 \frac{P\dot{V}}{zT} = \frac{\dot{m}_{\text{ideal}}}{z} = 1.10 \dot{m}_{\text{ideal}}$$

$\Rightarrow \underline{\underline{\text{Delivering 10\% more than they are charging for (undercharging their customer)}}$

5.72 a. For N_2 : $T_c = 126.20 \text{ K} = 227.16^\circ \text{R}$, $P_c = 33.5 \text{ atm}$

$$\left. \begin{array}{l} \text{After heater: } T_r = \frac{609.7^\circ \text{R}}{227.16^\circ \text{R}} = 2.68 \\ P_r = \frac{600 \text{ psia}}{33.5 \text{ atm}} \left| \frac{1 \text{ atm}}{14.7 \text{ psia}} \right| = 1.2 \end{array} \right\} \Rightarrow z = 1.02$$

$$\dot{n} = \frac{150 \text{ SCFM}}{359 \text{ SCF/lb-mole}} = 0.418 \text{ lb-mole/min}$$

$$\dot{V} = \frac{zRT\dot{n}}{P} = \frac{1.02}{1} \left| \frac{0.418 \text{ lb-mole}}{\text{min}} \right| \left| \frac{10.73 \text{ ft}^3 \cdot \text{psia}}{\text{lb-mole} \cdot ^\circ \text{R}} \right| \frac{609.7^\circ \text{R}}{600 \text{ psia}} = \underline{\underline{4.65 \text{ ft}^3/\text{min}}}$$

$$\begin{aligned} \text{b. tank} &= \frac{0.418 \text{ lb-mole}}{\text{min}} \left| \frac{28 \text{ lb}_m/\text{lb-mole}}{(0.81)62.4 \text{ lb}_m/\text{ft}^3} \right| \left| \frac{60 \text{ min}}{\text{h}} \right| \left| \frac{24 \text{ h}}{\text{day}} \right| \left| \frac{7 \text{ days}}{\text{week}} \right| \left| \frac{2 \text{ weeks}}{\text{week}} \right| \\ &= \underline{\underline{4668 \text{ ft}^3 = 34,900 \text{ gal}}} \end{aligned}$$

5.73 a. For CO : $T_c = 133.0 \text{ K}$, $P_c = 34.5 \text{ atm}$

$$\left. \begin{array}{l} \text{Initially: } T_{r1} = \frac{300 \text{ K}}{133.0 \text{ K}} = 2.26 \\ P_{r1} = \frac{2514.7 \text{ psia}}{34.5 \text{ atm}} \left| \frac{1 \text{ atm}}{14.7 \text{ psia}} \right| = 5.0 \end{array} \right\} \begin{array}{l} \text{Fig. 5.4-3} \\ \Rightarrow z = 1.02 \end{array}$$

$$n_1 = \frac{2514.7 \text{ psia}}{1.02} \left| \frac{150 \text{ L}}{300 \text{ K}} \right| \left| \frac{1 \text{ atm}}{14.7 \text{ psia}} \right| \left| \frac{\text{mol} \cdot \text{K}}{0.08206 \text{ L} \cdot \text{atm}} \right| = 1022 \text{ mol}$$

$$\left. \begin{array}{l} \text{After 60h: } T_{r1} = \frac{300 \text{ K}}{133.0 \text{ K}} = 2.26 \\ P_{r1} = \frac{2258.7 \text{ psia}}{34.5 \text{ atm}} \left| \frac{1 \text{ atm}}{14.7 \text{ psia}} \right| = 4.5 \end{array} \right\} \begin{array}{l} \text{Fig. 5.4-3} \\ \Rightarrow z = 1.02 \end{array}$$

$$n_2 = \frac{2258.7 \text{ psia}}{1.02} \left| \frac{150 \text{ L}}{300 \text{ K}} \right| \left| \frac{1 \text{ atm}}{14.7 \text{ psia}} \right| \left| \frac{\text{mol} \cdot \text{K}}{0.08206 \text{ L} \cdot \text{atm}} \right| = 918 \text{ mol}$$

$$\dot{n}_{\text{leak}} = \frac{n_1 - n_2}{60 \text{ h}} = \underline{\underline{1.73 \text{ mol/h}}}$$

$$\text{b. } n_2 = y_2 n_{\text{air}} = y_2 \frac{PV}{RT} = \frac{200 \times 10^{-6} \text{ mol CO}}{\text{mol air}} \left| \frac{1 \text{ atm}}{0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}}} \right| \left| \frac{30.7 \text{ m}^3}{300 \text{ K}} \right| \left| \frac{1000 \text{ L}}{\text{m}^3} \right| = 0.25 \text{ mol}$$

$$t_{\text{min}} = \frac{n_2}{\dot{n}_{\text{leak}}} = \frac{0.25 \text{ mol}}{1.73 \text{ mol/h}} = \underline{\underline{0.14 \text{ h}}}$$

$\Rightarrow t_{\text{min}}$ would be greater because the room is not perfectly sealed

- c. (i) CO may not be evenly dispersed in the room air; (ii) you could walk into a high concentration area; (iii) there may be residual CO left from another tank; (iv) the tank temperature could be higher than the room temperature, and the estimate of gas escaping could be low.

5.74 CH_4 : $T_c = 190.7 \text{ K}$, $P_c = 45.8 \text{ atm}$

C_2H_6 : $T_c = 305.4 \text{ K}$, $P_c = 48.2 \text{ atm}$

C_2H_4 : $T_c = 283.1 \text{ K}$, $P_c = 50.5 \text{ atm}$

Pseudocritical temperature: $T'_c = (0.20)(190.7) + (0.30)(305.4) + (0.50)(283.1) = 271.3 \text{ K}$

Pseudocritical pressure: $P'_c = (0.20)(45.8) + (0.30)(48.2) + (0.50)(50.5) = 48.9 \text{ atm}$

<u>Reduced temperature:</u>	$T_r = \frac{(90 + 273.2) \text{ K}}{271.3 \text{ K}} = 1.34$	$\left. \begin{array}{l} \text{Figure 5.4-3} \\ \Rightarrow z = 0.71 \end{array} \right\}$
<u>Reduced pressure:</u>	$P_r = \frac{200 \text{ bars}}{48.9 \text{ atm}} \left \frac{1 \text{ atm}}{1.01325 \text{ bars}} \right = 4.04$	

Mean molecular weight of mixture:

$$\begin{aligned} \bar{M} &= (0.20)M_{\text{CH}_4} + (0.30)M_{\text{C}_2\text{H}_6} + (0.50)M_{\text{C}_2\text{H}_4} \\ &= (0.20)(16.04) + (0.30)(30.07) + (0.50)(28.05) \\ &= 26.25 \text{ kg/kmol} \end{aligned}$$

$$V = \frac{znRT}{P} = \frac{0.71}{1} \left| \frac{10 \text{ kg}}{26.25 \text{ kg}} \right| \left| \frac{1 \text{ kmol}}{26.25 \text{ kg}} \right| \left| \frac{0.08314 \text{ m}^3 \cdot \text{bar}}{\text{kmol} \cdot \text{K}} \right| \left| \frac{(90 + 273) \text{ K}}{200 \text{ bars}} \right| = \underline{\underline{0.041 \text{ m}^3 (41 \text{ L})}}$$

5.75 N_2 : $T_c = 126.2 \text{ K}$, $P_c = 33.5 \text{ atm}$ } $T'_c = 0.10(309.5) + 0.90(126.2) = 144.5 \text{ K}$
 N_2O : $T_c = 309.5 \text{ K}$, $P_c = 71.7 \text{ atm}$ } $P'_c = 0.10(71.7) + 0.90(33.5) = 37.3 \text{ atm}$

$$\bar{M} = 0.10(44.02) + 0.90(28.02) = 29.62$$

$$n = 5.0 \text{ kg} / (1 \text{ kmol} / 29.62 \text{ kg}) = 0.169 \text{ kmol} = 169 \text{ mol}$$

a. $T_r = (24 + 273.2) / 144.5 = 2.06$

$\hat{V}_r = \frac{30 \text{ L}}{169 \text{ mol}} \left \frac{37.3 \text{ atm}}{144.5 \text{ K}} \right \left \frac{\text{mol} \cdot \text{K}}{0.08206 \text{ L} \cdot \text{atm}} \right = 0.56$	$\left. \begin{array}{l} \Rightarrow z = 0.97 \text{ (Fig. 5.4 - 3)} \end{array} \right\}$

$$P = \frac{0.97}{1} \left| \frac{169 \text{ mol}}{30 \text{ L}} \right| \left| \frac{297.2 \text{ K}}{\text{mol} \cdot \text{K}} \right| \left| \frac{0.08206 \text{ L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \right| = 133 \text{ atm} \Rightarrow \underline{\underline{132 \text{ atm gauge}}}$$

b. $P_r = 273 / 37.3 = 7.32$

$\hat{V}_r = 0.56 \text{ (from a.)}$	$\left. \begin{array}{l} \Rightarrow z = 1.14 \text{ (Fig. 5.4 - 3)} \end{array} \right\}$

$$T = \frac{273 \text{ atm}}{1.14} \left| \frac{30 \text{ L}}{169 \text{ mol}} \right| \left| \frac{\text{mol} \cdot \text{K}}{0.08206 \text{ L} \cdot \text{atm}} \right| = 518 \text{ K} \Rightarrow \underline{\underline{245^\circ \text{C}}}$$

$$\begin{array}{l}
 \text{5.76 CO: } T_c = 133.0 \text{ K, } P_c = 34.5 \text{ atm} \\
 \text{H}_2: T_c = 33 \text{ K, } P_c = 12.8 \text{ atm}
 \end{array}
 \left\{
 \begin{array}{l}
 T'_c = 0.60(133.0) + 0.40(33 + 8) = 96.2 \text{ K} \\
 P'_c = 0.60(34.5) + 0.40(12.8 + 8) = 29.0 \text{ atm}
 \end{array}
 \right.$$

$$\begin{array}{l}
 \text{Turbine inlet: } T_r = (150 + 273.2)/96.2 = 4.4 \\
 P_r = \frac{2000 \text{ psi}}{29.0 \text{ atm}} \left| \frac{1 \text{ atm}}{14.7 \text{ psi}} \right| = 4.69
 \end{array}
 \left. \vphantom{\begin{array}{l} T_r \\ P_r \end{array}} \right\} \xrightarrow{\text{Fig. 5.4-1}} z \approx 1.01$$

$$\begin{array}{l}
 \text{Turbine exit: } T_r = 373.2/96.2 = 3.88 \\
 P_r = 1/29.0 = 0.03
 \end{array}
 \left. \vphantom{\begin{array}{l} T_r \\ P_r \end{array}} \right\} \Rightarrow z = 1.0$$

$$\frac{P_{\text{in}} \dot{V}_{\text{in}}}{P_{\text{out}} \dot{V}_{\text{out}}} = \frac{z_{\text{in}} n R T_{\text{in}}}{z_{\text{out}} n R T_{\text{out}}} \Rightarrow V_{\text{in}} = V_{\text{out}} \times \frac{P_{\text{out}}}{P_{\text{in}}} \frac{z_{\text{in}}}{z_{\text{out}}} \frac{T_{\text{in}}}{T_{\text{out}}} = 15,000 \frac{\text{ft}^3}{\text{min}} \left| \frac{14.7 \text{ psia}}{2000 \text{ psia}} \right| \left| \frac{1.01}{1.00} \right| \left| \frac{423.2 \text{ K}}{373.2} \right|$$

$$= \underline{\underline{126 \text{ ft}^3 / \text{min}}}$$

If the ideal gas equation of state were used, the factor 1.01 would instead be 1.00

$$\Rightarrow \underline{\underline{-1\% \text{ error}}}$$

$$\begin{array}{l}
 \text{5.77 CO: } T_c = 133.0 \text{ K, } P_c = 34.5 \text{ atm} \\
 \text{CO}_2: T_c = 304.2 \text{ K, } P_c = 72.9 \text{ atm}
 \end{array}
 \left\{
 \begin{array}{l}
 T'_c = 0.97(133.0) + 0.03(304.2) = 138.1 \text{ K} \\
 P'_c = 0.97(34.5) + 0.03(72.9) = 35.7 \text{ atm} = 524.8 \text{ psi}
 \end{array}
 \right.$$

$$\begin{array}{l}
 \text{Initial: } T_r = 303.2/138.1 = 2.2 \\
 P_r = 2014.7/524.8 = 3.8
 \end{array}
 \left. \vphantom{\begin{array}{l} T_r \\ P_r \end{array}} \right\} \xrightarrow{\text{Fig. 5.4-3}} z_1 = 0.97$$

$$\text{Final: } P_r = 1889.7/524.8 = 3.6 \Rightarrow z_1 = 0.97$$

Total moles leaked:

$$n_1 - n_2 = \left(\frac{P_1}{z_1} - \frac{P_2}{z_2} \right) \frac{V}{RT} = \frac{(2000 - 1875) \text{ psi}}{0.97} \left| \frac{30.0 \text{ L}}{303 \text{ K}} \right| \left| \frac{1 \text{ atm}}{14.7 \text{ psi}} \right| \left| \frac{\text{mol} \cdot \text{K}}{0.08206 \text{ L} \cdot \text{atm}} \right|$$

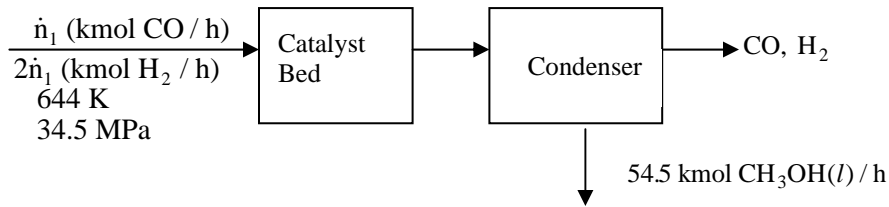
$$= 10.6 \text{ mol leaked}$$

$$\text{Moles CO leaked: } 0.97(10.6) = 10.3 \text{ mol CO}$$

$$\text{Total moles in room: } \frac{24.2 \text{ m}^3}{1 \text{ m}^3} \left| \frac{10^3 \text{ L}}{303 \text{ K}} \right| \left| \frac{1 \text{ mol}}{22.4 \text{ L(STP)}} \right| = 973.4 \text{ mol}$$

$$\text{Mole\% CO in room} = \frac{10.3 \text{ mol CO}}{973.4 \text{ mol}} \times 100\% = \underline{\underline{1.0\% \text{ CO}}}$$

5.78 Basis: 54.5 kmol CH₃OH/h CO + 2H₂ → CH₃OH



a. $\dot{n}_1 = \frac{54.5 \text{ kmol CH}_3\text{OH}}{\text{h}} \left| \frac{1 \text{ kmol CO react}}{1 \text{ kmol CH}_3\text{OH}} \right| \left| \frac{1 \text{ kmol CO fed}}{0.25 \text{ kmol CO react}} \right| = 218 \text{ kmol/h CO}$

$2\dot{n}_1 = 2(218) = 436 \text{ kmol H}_2/\text{h} \Rightarrow (218 + 436) = 654 \text{ kmol/h (total feed)}$

CO: $T_c = 133.0 \text{ K}$ $P_c = 34.5 \text{ atm}$

H₂: $T_c = 33 \text{ K}$ $P_c = 12.8 \text{ atm}$

⇓ Newton's corrections

$T'_c = \frac{1}{3}(133.0) + \frac{2}{3}(33 + 8) = 71.7 \text{ K}$

$P'_c = \frac{1}{3}(34.5) + \frac{2}{3}(12.8 + 8) = 25.4 \text{ atm}$

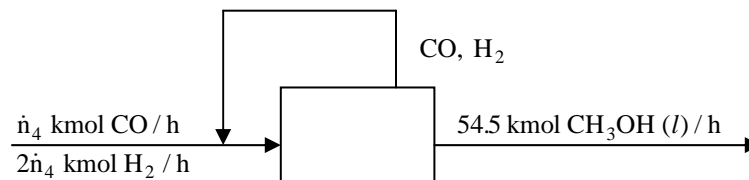
$T_r = 644/71.7 = 8.98$

$P_r = \frac{34.5 \text{ MPa}}{24.5 \text{ atm}} \left| \frac{10 \text{ atm}}{1.013 \text{ MPa}} \right| = 13.45 \left\{ \begin{array}{l} \text{Fig. 5.4-4} \\ \rightarrow z_1 = 1.18 \end{array} \right.$

$\dot{V}_{\text{feed}} = \frac{1.18}{\text{h}} \left| \frac{654 \text{ kmol}}{\text{h}} \right| \left| \frac{644 \text{ K}}{34.5 \text{ MPa}} \right| \left| \frac{0.08206 \text{ m}^3 \cdot \text{atm}}{\text{kmol} \cdot \text{K}} \right| \left| \frac{1.013 \text{ MPa}}{10 \text{ atm}} \right| = \underline{\underline{120 \text{ m}^3/\text{h}}}$

$V_{\text{cat}} = \frac{120 \text{ m}^3/\text{h}}{25,000 \text{ m}^3/\text{h}} \left| \frac{1 \text{ m}^3 \text{ cat}}{\text{m}^3} \right| = \underline{\underline{0.0048 \text{ m}^3 \text{ catalyst (4.8 L)}}}$

b.



Overall C balance $\Rightarrow \dot{n}_4 = 54.5 \text{ mol CO/h}$

Fresh feed: $\frac{54.5 \text{ kmol CO/h} + 109.0 \text{ kmol H}_2/\text{h}}{163.5 \text{ kmol feed gas/h}}$

$\dot{V}_{\text{feed}} = \frac{1.18}{\text{h}} \left| \frac{163.5 \text{ kmol}}{\text{h}} \right| \left| \frac{644 \text{ K}}{34.5 \text{ MPa}} \right| \left| \frac{0.08206 \text{ m}^3 \cdot \text{atm}}{\text{kmol} \cdot \text{K}} \right| \left| \frac{1.013 \text{ MPa}}{10 \text{ atm}} \right| = \underline{\underline{29.9 \text{ m}^3/\text{h}}}$

$$\begin{array}{ll} \text{5.79} & \underline{\text{H}_2}: T_c = (33.3 + 8) \text{ K} = 41.3 \text{ K} \quad \underline{\text{1-butene}}: T_c = 419.6 \text{ K} \\ & P_c = (12.8 + 8) \text{ atm} = 20.8 \text{ atm} \quad P_c = 39.7 \text{ atm} \end{array}$$

$$\left. \begin{array}{ll} T_c' = 0.15(41.3 \text{ K}) + 0.85(419.6 \text{ K}) = 362.8 \text{ K} & T_r' = 0.89 \\ P_c' = 0.15(20.8 \text{ atm}) + 0.85(39.7 \text{ atm}) = 36.9 \text{ atm} & P_r' = 0.27 \end{array} \right\} \xRightarrow{\text{Fig. 5.4-2}} z = 0.86$$

$$\dot{V} = \frac{z \dot{n} R T}{P} = \frac{0.86 \left| 35 \text{ kmol} \right| \left| 0.08206 \text{ m}^3 \cdot \text{atm} \right| \left| 323 \text{ K} \right| \left| 1 \text{ h} \right|}{\left| \text{h} \right| \left| \text{kmol} \cdot \text{K} \right| \left| 10 \text{ atm} \right| \left| 60 \text{ min} \right|} = 1.33 \text{ m}^3 / \text{min}$$

$$\dot{V} \left(\frac{\text{m}^3}{\text{min}} \right) = u \left(\frac{\text{m}}{\text{min}} \right) A (\text{m}^2) = u \times \frac{\pi d^2}{4} \Rightarrow d = \sqrt{\frac{4 \dot{V}}{\pi u}} = \sqrt{\frac{4 (1.33 \text{ m}^3 / \text{min})}{\pi (150 \text{ m} / \text{min})}} \left(\frac{100 \text{ cm}}{\text{m}} \right) = \underline{\underline{10.6 \text{ cm}}}$$

$$\begin{array}{ll} \text{5.80} & \underline{\text{CH}_4}: T_c = 190.7 \text{ K} \quad P_c = 45.8 \text{ atm} \\ & \underline{\text{C}_2\text{H}_4}: T_c = 283.1 \text{ K} \quad P_c = 50.5 \text{ atm} \\ & \underline{\text{C}_2\text{H}_6}: T_c = 305.4 \text{ K} \quad P_c = 48.2 \text{ atm} \end{array}$$

$$\left. \begin{array}{ll} T_c' = 0.15(190.7 \text{ K}) + 0.60(283.1 \text{ K}) + 0.25(305.4 \text{ K}) = 274.8 \text{ K} & \xrightarrow{T=90^\circ \text{C}} T_r' = 1.32 \\ P_c' = 0.15(45.8 \text{ atm}) + 0.60(50.5 \text{ atm}) + 0.25(48.2 \text{ atm}) = 49.2 \text{ atm} & \xrightarrow{P=175 \text{ bar}} P_r' = 3.5 \end{array} \right\} \xrightarrow{\text{Fig. 5.4-3}} z = 0.67$$

$$\dot{V} \left(\frac{\text{m}^3}{\text{s}} \right) = u \left(\frac{\text{m}}{\text{s}} \right) A (\text{m}^2) = \left(10 \frac{\text{m}}{\text{s}} \right) \left(60 \frac{\text{s}}{\text{min}} \right) \frac{\pi}{4} (0.02 \text{ m})^2 = 0.188 \frac{\text{m}^3}{\text{min}}$$

$$\dot{n} = \frac{P \dot{V}}{z R T} = \frac{175 \text{ bar} \left| 1 \text{ atm} \right| \left| \text{kmol} \cdot \text{K} \right| \left| 0.188 \text{ m}^3 / \text{min} \right|}{0.67 \left| 1.013 \text{ bar} \right| \left| 0.08206 \text{ m}^3 \cdot \text{atm} \right| \left| 363 \text{ K} \right|} = \underline{\underline{1.63 \text{ kmol} / \text{min}}}$$

$$\begin{array}{ll} \text{5.81} & \underline{\text{N}_2}: T_c = 126.2 \text{ K} = 227.16^\circ \text{R} \quad P_c = 33.5 \text{ atm} \\ & \underline{\text{acetonitrile}}: T_c = 548 \text{ K} = 986.4^\circ \text{R} \quad P_c = 47.7 \text{ atm} \end{array}$$

$$\underline{\text{Tank 1 (acetonitrile)}}: T_1 = 550^\circ \text{F}, P_1 = 4500 \text{ psia} \Rightarrow T_{r1} = 1.02 \quad P_{r1} = 6.4 \xRightarrow{\text{Fig. 5.4-3}} z_1 = 0.80$$

$$\Rightarrow \dot{n}_1 = \frac{P_1 V_1}{z_1 R T_1} = \frac{306 \text{ atm} \left| 0.200 \text{ ft}^3 \right| \left| \text{lb} \cdot \text{mole} \cdot ^\circ \text{R} \right|}{0.80 \left| 1009.7^\circ \text{R} \right| \left| 0.7302 \text{ ft}^3 \cdot \text{atm} \right|} = 0.104 \text{ lb} \cdot \text{mole}$$

$$\underline{\text{Tank 2 (N}_2\text{)}}: T_2 = 550^\circ \text{F}, P_2 = 10 \text{ atm} \Rightarrow T_{r2} = 4.4, P_{r2} = 6.4 \xRightarrow{\text{Fig. 5.4-3}} z_2 = 1.00$$

$$\Rightarrow \dot{n}_2 = \frac{P_2 V_2}{z_2 R T_2} = \frac{10.0 \text{ atm} \left| 2.00 \text{ ft}^3 \right| \left| \text{lb} \cdot \text{mole} \cdot ^\circ \text{R} \right|}{1.00 \left| 1009.7^\circ \text{R} \right| \left| 0.7302 \text{ ft}^3 \cdot \text{atm} \right|} = 0.027 \text{ lb} \cdot \text{mole}$$

5.81 (cont'd)

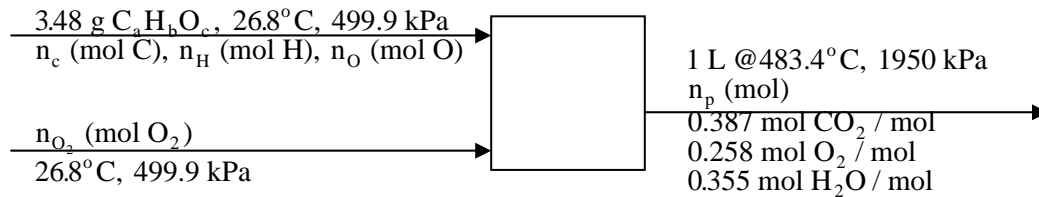
$$\text{Final: } T_c' = \left(\frac{0.104}{0.131} \right) 986.4^\circ \text{R} + \left(\frac{0.027}{0.131} \right) 227.16^\circ \text{R} = 830^\circ \text{R} \xrightarrow{T=550^\circ \text{F}} T_r' = 1.22$$

$$P_c' = \left(\frac{0.104}{0.131} \right) 47.7 \text{ atm} + \left(\frac{0.027}{0.131} \right) 33.5 \text{ atm} = 44.8 \text{ atm}$$

$$\left(\hat{V}_r \right)_{\text{ideal}} = \frac{\hat{V} P_c'}{R T_c'} = \frac{2.2 \text{ ft}^3}{0.131 \text{ lb-mole}} \left| \frac{44.8 \text{ atm}}{830^\circ \text{R}} \right| \frac{\text{lb-mole} \cdot ^\circ \text{R}}{0.7302 \text{ ft}^3 \cdot \text{atm}} = 1.24 \xrightarrow{\text{Fig. 5.4-2}} z = 0.85$$

$$P = \frac{z n R T}{V} = \frac{0.85}{2.2 \text{ ft}^3} \left| \frac{0.131 \text{ lb-mole}}{\text{lb-mole} \cdot ^\circ \text{R}} \right| \frac{.7302 \text{ ft}^3 \cdot \text{atm}}{1009.7^\circ \text{R}} = \underline{\underline{37.3 \text{ atm}}}$$

5.82



a. Volume of sample: $3.42 \text{ g} (1 \text{ cm}^3 / 1.59 \text{ g}) = 2.15 \text{ cm}^3$

O₂ in Charge:

$$n_{\text{O}_2} = \frac{\left[1.000 \text{ L} - 2.15 \text{ cm}^3 (10^{-3} \text{ L/cm}^3) \right]}{0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}}} \left| \frac{499.9 \text{ kPa}}{300 \text{ K}} \right| \frac{1 \text{ atm}}{101.3 \text{ kPa}} = 0.200 \text{ mol O}_2$$

Product

$$n_p = \frac{1.000 \text{ L}}{0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}}} \left| \frac{1950 \text{ kPa}}{756.6 \text{ K}} \right| \frac{1 \text{ atm}}{101.3 \text{ kPa}} = 0.310 \text{ mol product}$$

Balances:

O: $2(0.200) + n_{\text{O}} = 0.310 [2(0.387) + 2(0.258) + 0.355] \Rightarrow n_{\text{O}} = 0.110 \text{ mol O in sample}$

C: $n_{\text{C}} = 0.387(0.310) = 0.120 \text{ mol C in sample}$

H: $n_{\text{H}} = 2(0.355)(0.310) = 0.220 \text{ mol H in sample}$

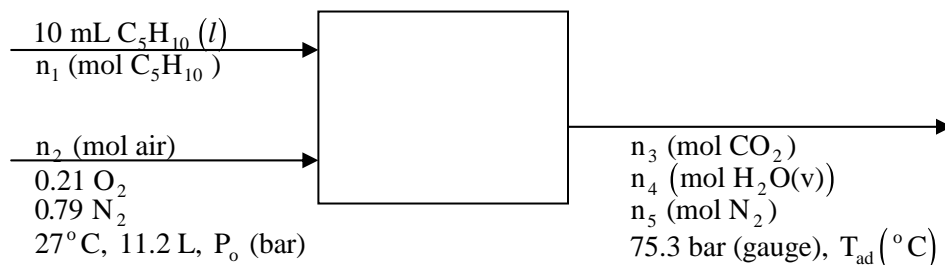
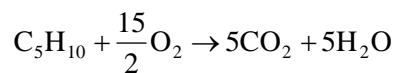
Assume $c = 1 \Rightarrow a = 0.120/0.110 = 1.1 \quad b = 0.220/0.110 = 2$

Since a, b, and c must be integers, possible solutions are (a,b,c) = (11,20,10), (22,40,20), etc.

b. $\text{MW} = 12.01a + 1.01b + 16.0c = 12.01(1.1c) + 1.01(2c) + 16.0c = 31.23c$

$300 < \text{MW} < 350 \Rightarrow c = 10 \Rightarrow \underline{\underline{\text{C}_{11}\text{H}_{20}\text{O}_{10}}}$

5.83 Basis: 10 mL C₅H₁₀(l) charged to reactor



a. $n_1 = \frac{10.0 \text{ mL C}_5\text{H}_{10}(\text{l})}{1 \text{ mL}} \left| \frac{0.745 \text{ g}}{70.13 \text{ g}} \right| \frac{1 \text{ mol}}{1} = 0.1062 \text{ mol C}_5\text{H}_{10}$

Stoichiometric air: $n_2 = \frac{0.1062 \text{ mol C}_5\text{H}_{10}}{1 \text{ mol C}_5\text{H}_{10}} \left| \frac{7.5 \text{ mol O}_2}{0.21 \text{ mol O}_2} \right| \frac{1 \text{ mol air}}{1} = 3.79 \text{ mol air}$

$P_o = \frac{nRT}{V} = \frac{3.79 \text{ mol}}{11.2 \text{ L}} \left| \frac{0.08314 \text{ L} \cdot \text{bar}}{\text{mol} \cdot \text{K}} \right| \frac{300 \text{ K}}{1} = 8.44 \text{ bars}$

(We neglect the C₅H₁₀ that may be present in the gas phase due to evaporation)

Initial gauge pressure = 8.44 bar – 1 bar = 7.44 bar

b.
$$\left. \begin{aligned} n_3 &= \frac{0.1062 \text{ mol C}_5\text{H}_{10}}{1 \text{ mol C}_5\text{H}_{10}} \left| \frac{5 \text{ mol CO}_2}{1} \right| = 0.531 \text{ mol CO}_2 \\ n_4 &= \frac{0.531 \text{ mol CO}_2}{1 \text{ mol CO}_2} \left| \frac{1 \text{ mol H}_2\text{O}}{1} \right| = 0.531 \text{ mol H}_2\text{O} \\ n_5 &= 0.79(3.79) = 2.99 \text{ mol N}_2 \end{aligned} \right\} \Rightarrow 4.052 \text{ mol product gas}$$

CO₂: $y_3 = 0.531 / 4.052 = 0.131 \text{ mol CO}_2 / \text{mol}$, $T_c = 304.2 \text{ K}$ $P_c = 72.9 \text{ atm}$

H₂O: $y_4 = 0.531 / 4.052 = 0.131 \text{ mol H}_2\text{O} / \text{mol}$, $T_c = 647.4 \text{ K}$ $P_c = 218.3 \text{ atm}$

N₂: $y_5 = 2.99 / 4.052 = 0.738 \text{ mol N}_2 / \text{mol}$, $T_c = 126.2 \text{ K}$ $P_c = 33.5 \text{ atm}$

$T_c' = 0.131(304.2 \text{ K}) + 0.131(647.4 \text{ K}) + 0.738(126.2 \text{ K}) = 217.8 \text{ K}$

$P_c' = 0.131(72.9 \text{ atm}) + 0.131(218.3 \text{ atm}) + 0.738(33.5 \text{ atm}) = 62.9 \text{ atm} \Rightarrow P_r' = 1.21$

$\hat{V}_r^{\text{ideal}} = \frac{\hat{V}P_c'}{RT_c'} = \frac{11.2 \text{ L}}{4.052 \text{ mol}} \left| \frac{62.9 \text{ atm}}{217.8 \text{ K}} \right| \frac{\text{mol} \cdot \text{K}}{0.08206 \text{ L} \cdot \text{atm}} = 9.7 \Rightarrow z \approx 1.04 \text{ (Fig. 5.4 - 3)}$

$T = \frac{PV}{z n R} = \frac{(75.3 + 1) \text{ bars}}{1.04} \left| \frac{11.2 \text{ L}}{4.052 \text{ mol}} \right| \frac{\text{mol} \cdot \text{K}}{0.08314 \text{ L} \cdot \text{bar}} = 2439 \text{ K} - 273 = \underline{\underline{2166^\circ \text{C}}}$