Exam 2
Ch. 4.6 thru Ch. 6

- Take Home
- Closed Book, Closed Notes
- One 3 x 5 card with notes (both sides)
- 3 hour time limit
- 6 problems
- Wednesday (today) through Saturday
  - Due Monday morning at 10:00 am in class
- Needed:
  - Calculator
  - Ruler
  - Pencil

After the Exam

- 11 “lectures”
- 1 Exam Review
- 3rd Exam
- 5 class periods to work on Case Study
- Review for Final Exam

TA Review Session

What Do I Study?
First Look at Competencies

Level	Usage	Competency Expectation
3	M	Students will be able to solve steady-state, overall, material balances for systems which include one or more of the following: chemical reactions.
3	M	Students will understand the phase behavior of pure substances in relationship to the variables T, P, and density (including vapor pressure, critical point, freezing line, triple point, etc.).
3	M	Students will understand and be able to use the extent of reaction in material balances
2	M	Students will be able to use a degree-of-freedom approach to assist in the solution of material balances.
2	M	Students will be able to read mixture phase diagrams (solid solubility, liquid-liquid, VLE) and construct mass balances from them using the lever rule, tie lines, etc.
2	M	Students will be able to apply Raoult’s law to solve VLE problems including bubble point, dew point, and flash calculations.
2	M	Students will be introduced to equations of state and corresponding states correlations. i.e, non-ideal
2	M	Students will be introduced to process variables (e.g., P, T, flow rate, conc.) and their measurement.

Exam 2 Review Sheet
Chemical Engineering 273

1. **Material Balances with Reaction**
   a. Species balances with generation/consumption
   b. Species balances with extent of reaction (ξ)
   c. Elemental balances
   (a–c: Including DOF)
   d. Definitions
      i. Limiting reactant
      ii. Yield
      iii. Single-Pass Conversion
      iv. Overall conversion
      v. Selectivity
   e. Combustion Reactions
      i. Should be able to write and balance these reactions for complete combustion, etc.
      ii. Theoretical and excess air
      iii. Dry basis for compositions
2. **Single-Phase Systems**
   a. Liquid densities of mixtures
   b. Ideal gas
      i. Most common equation of state
      ii. Range of applicability
      iii. Mixtures (partial pressure, volume fraction, mole fraction)
   c. Standard temperature and pressure
   d. Non-ideal equations of state
      i. Van der Waals
      ii. SRK
      iii. Corresponding States ($P_r = P/P_c$, $T_r = T/T_c$) and compressibility factor (z)
      iv. Kay’s rule for mixtures ($P_c' = \sum y_i P_{c,i}$, $T_c' = \sum y_i T_{c,i}$)
3. **Multiphase Systems**
   a. Single-component phase behavior
   b. Tables for Saturated Steam (B.3, B.5, B.6)
   c. Vapor pressure estimation (P_i^*) – Antoine, DIPPR, Fig. 6.1-4
   d. Gibbs phase rule
   e. Gas liquid systems with one condensable component
      i. Raoult’s Law ($y_i P_{tot} = x_i P_i^*$, but $x_i = 1$)
      ii. Humidity and drying (relative humidity, absolute humidity, degrees superheat)
   f. Multicomponent Systems
      i. Raoult’s Law ($y_i P_{tot} = x_i P_i^*$)
         1. Assumptions
            a. Ideal systems
            b. Real systems where x_A is close to 1
         2. Dew point and bubble point
         3. 2 phase separation (Flash calculations)
         4. Non-condensable gas above liquid mixture
      ii. Henry’s Law ($y_i P_{tot} = x_i H_i$ used for small x_i) (will not be on exam)
      iii. Diagrams
         1. Vapor-liquid diagrams (T-xy and P-xy)
         2. Solid-Liquid phase diagram
         3. Liquid-Liquid ternary diagram
         4. Tie lines and lever rule
      iv. Material balances using phase equilibrium data/calculations

- Look through the review sheet with a neighbor
- Identify what you would like to review most

Definition of Pressures

- P_{tot} Total Pressure, as in PV=znRT
- P_i Partial Pressure $P_i = y_iP_{tot}$
  $P_iV = z_in_iRT$
- P_i* Vapor Pressure = f(T), used in Raoult's law
- Raoult's Law

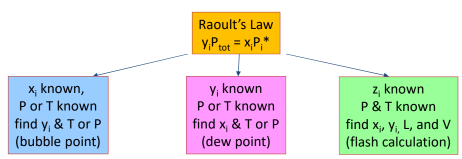
$$y_iP_{tot} = x_iP_i*$$

Standard State Conditions

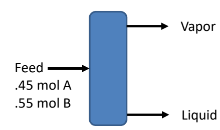
- Normally at 1 atm and 0°C
- Commonly used in measurements
- Concept: moles are the same
- $n = \left(\frac{PV}{RT}\right)_{STP} = \left(\frac{PV}{RT}\right)_{actual}$
- Example:

  Your flow meter says 30 slpm, and you measure T=30°C and P=5 psig. What is the actual volumetric flow rate?

Multicomponent Logic Chart



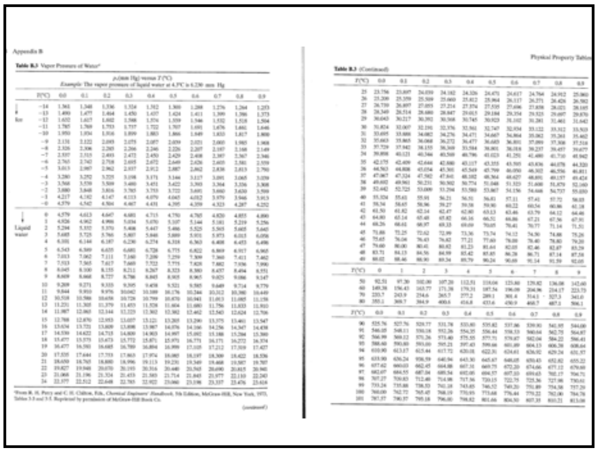
Flash Calculation Example



T = 50°C
P_{tot} = 700 mm Hg

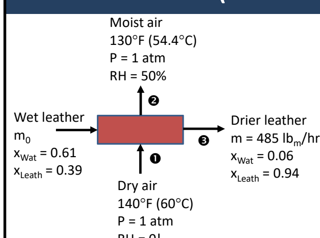
Using T = 50°C
P_A* = 600 mm Hg
P_B* = 800 mm Hg

- Start with Raoult's Law
  $y_AP = x_AP_A*$
  $y_BP = x_BP_B*$
- Add the two equations
  $y_AP + y_BP = x_AP_A* + x_BP_B*$
- So
  $P = x_AP_A* + (1-x_A)P_B*$ to get x_A
- From x_A get x_B, y_A, y_B
- Mole Balances
  $n_F = n_L + n_V$
  $.45\ n_F = y_A\ n_V + x_A\ n_L$
  Solve for n_V/n_F



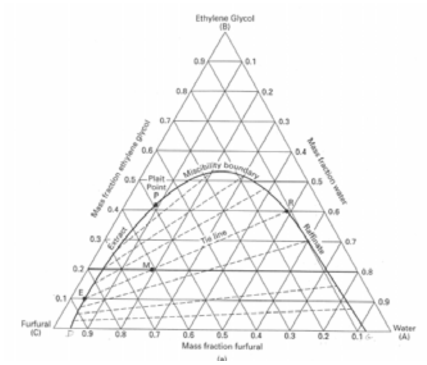
Humidity Problem Example

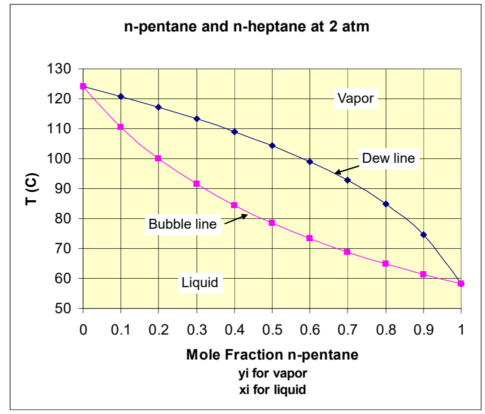
(Problem 6.34)



Find:
(a) m_0 (inlet mass flow rate of wet leather)
(b) V_1 (volumetric flow of dry air)

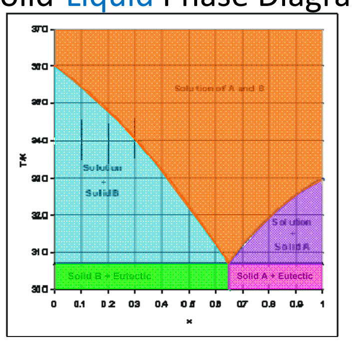
- Dry leather balance
  $0.39\ m_0 = 0.94 \times 485\ lb_m/hr$
- Find $y_{H2O,2}$
  $y_{H2O,2}\ P = RH \times P*_{H2O}$
- Water balance
  $0.61\ m_0 = y_{H2O,2}\ n_2$ (18 lb/lbmol) + 0.06 (485 lb_m/hr) (solve for n_2)
- Dry air balance
  $n_1 = (1 - y_{H2O,2})\ n_2$
  Then use $PV_1 = n_1RT$





Generated from Raoult's law using the DIPPR vapor pressure correlations

Solid-Liquid Phase Diagrams



Mole fraction of A

Non-Ideal Eqns. of State

(that are in the text)

- Virial
  - 1 constant
  - $B = f(T_c, P_c, \omega)$
  - Table 5.3.1 for ω

$$\frac{P\hat{V}}{RT} = 1 + \frac{B}{\hat{V}} \quad (5.3.2)$$

$$B_0 = 0.083 - \frac{0.42}{T_r^{1.6}}$$

$$B_1 = 0.139 - \frac{0.172}{T_r^{4.2}}$$

$$B = \frac{RT_c}{P_c}(B_0 + \omega B_1)$$

- Van der Waals
  - 2 constants
  - a & $b = f(T_c, P_c)$

$$P = \frac{RT}{\hat{V} - b} - \frac{a}{\hat{V}^2} \quad (5.3.6)$$

$$a = \frac{27R^2T_c^2}{64P_c}$$

$$b = \frac{RT_c}{8P_c}$$

- Soave-Redlich-Kwong (SRK)
  - 3 constants
  - a & $b = f(T_c, P_c)$
  - $\alpha = f(T_c, P_c, \omega)$

$$P = \frac{RT}{\hat{V} - b} - \frac{a\alpha}{\hat{V}(\hat{V} + b)} \quad (5.3.7)$$

$a = 0.42747\,(RT_c)^2/P_c$
$b = 0.08664\,(RT_c)/P_c$
$m = 0.48508 + 1.55171\,\omega - 0.1561\,\omega^2$
$\alpha = [1 + m(1 - T_r^{0.5})]^2$

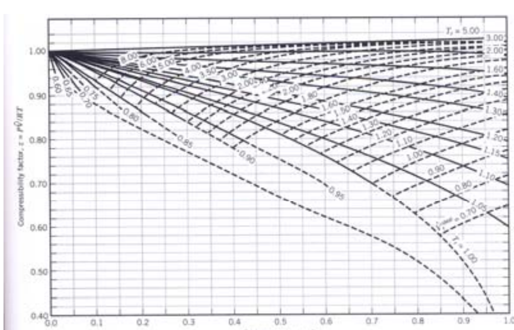


Figure 5.4-2 Generalized compressibility chart, low pressures. (From D. M. Himmelblau, *Basic Principles and Calculations in Chemical Engineering*, 3rd Edition, copyright © 1974, p. 175. Reprinted by permission of Prentice Hall, Inc., Englewood Cliffs, NJ.)

Corresponding States: Mixtures

(Kay's Rule)

Note that these are weighted by mole fraction

$$T_c' = y_A T_{cA} + y_B T_{cB} + y_C T_{cC} + \ldots.$$

$$P_c' = y_A P_{cA} + y_B P_{cB} + y_C P_{cC} + \ldots.$$

$$T_r' = T / T_c'$$

$$P_r' = P / P_c'$$

$z_{tot} \neq \sum y_i z_i$

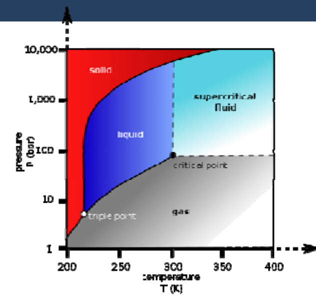
Hint: We will be using this a lot for mixtures!

Compressibility Experiment in UO Lab (ChE 475)

- 25% CO_2, 75% Ar
- T = 20°C
- Find z at different pressures

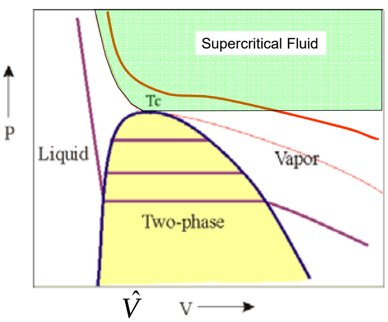
- Compressibility Chart
  (Law of Corresponding States)
- Kay's Rule for mixture
  - Seniors get mixing rules for non-ideal equations of state from the Thermo class

Phase Diagram



Pressure-temperature phase diagram for CO_2

Phase Diagram for H_2O (Quiz Answers)



1. Please draw
2. Label the following:
   a. 2-phase envelope
   b. Critical point
   c. P_c
3. Draw 3 isotherms
   a. Through 2-phase
   b. Through P_c
   c. Supercritical
4. Label T_c

1. Molecular Species Balances (reacting systems – used least)

- Use generation and consumption terms
- Use ratios of species based on stoichiometry
  - Moles species j generated/moles species i consumed
- Add # of independent chemical rxns to DOF analysis

+ # of unknowns
+ # of independent chemical reactions
- # of independent molecular species balances
- # of other equations
= DOF

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2. Atomic Element Balances (reacting systems – useful)

- No generation and consumption terms
  In = Out
- Count moles of atoms
  - Split up species into atoms
- Add # of independent atomic element balances to DOF analysis

+ # of unknowns
- # of independent atomic element balances
- # of independent non-reacting molecular species balances
- # of other equations
= DOF

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3. Balances Using Extent of Reaction (useful)

- Use definition of ξ
  $n_i = n_{i,o} + \nu_i \xi$, or using flow rates
- One ξ_j for each reaction
  - Use problem info to get ξ_i's, then calculate unknown variables
- Add extent of reaction variables to DOF analysis

+ # of unknowns
+ # of independent ξ_i's
- # of independent reacting molecular species balances
- # of independent non-reacting species
- # of other equations
= DOF

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