Solution Manual for Separation Process Engineering Includes Mass Transfer Analysis 4th Edition Wankat 0133443655 9780133443653
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Solution Manual:

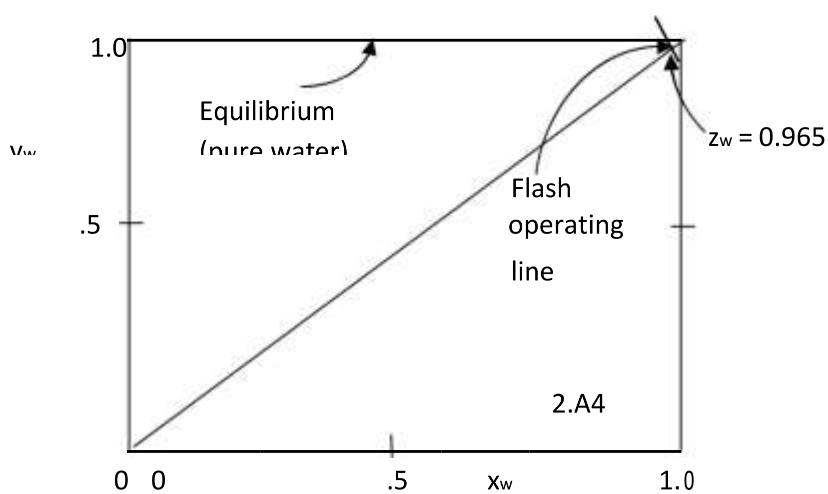
New Problems and new solutions are listed as new immediately after the solution number. These new problems are:2A8, 2A10 parts c-e, 2A11,2A12, 2A13, 2A14, 2C4, 2D1-part g, 2D3, 2D6, 2D7, 2D11, 2D13, 2D14, 2D20, 2D22, 2D23, 2D31, 2D32, 2E3, 2F4, 2G2, 2G3, 2H1, 2H3, 2H4, 2H5 and 2H6.

2.A1. Feed to flash drum is a liquid at high pressure. At this pressure its enthalpy can be calculated as a liquid. eg. $h\ T_{F,P_{high}}$ $c_{p\ LIQ}\ \ T_F\ \ \ T_{ref}$. When pressure is dropped the mixture is above its bubble point and is a two-phase mixture (It “flashes”). In the flash mixture enthalpy is unchanged but temperature changes. Feed location cannot be found from T_F and z on the graph because equilibrium data is at a lower pressure on the graph used for this calculation.

2.A2. Yes.

2.A3. The liquid is superheated when the pressure drops, and the energy comes from the amount of superheat.

2.A4.



2.A6. In a flash drum separating a multicomponent mixture, raising the pressure will:
i. Decrease the drum diameter and decrease the relative volatilities. *Answer is i.*

2.A8. *New Problem in 4th ed.*

. a. At 100°C and a pressure of 200 kPa what is the K value of n-hexane? 0.29

b. As the pressure increases, the K value

a. increases, b. decreases, c. stays constant b

c. Within a homologous series such as light hydrocarbons as the molecular weight increases, the K value (at constant pressure and temperature)

a. increases, b. decreases, c. stays constant b

d. At what pressure does pure propane boil at a temperature of -30°C? 160 kPa

2.A9. a. The answer is 3.5 to 3.6

b. The answer is 36ºC

c. *This part is new in 4th ed.* 102ºC

2.A10. *Parts c, d, and e are new in 4th ed. a.* 0.22; b. No; c. From y-x plot for Methanol x = 0.65, y_M = 0.85; thus, y_W = 0.15. d. K_M = 0.579/0.2 = 2.895, K_W = (1 – 0.579)/(1 – 0.2) = 0.52625. e. $\alpha_{M-W} = K_M/K_W$ = 2.895/0.52625 = 5.501.

2.A11. *New problem in 4th edition.* Because of the presence of air this is not a binary system. Also, it is not at equilibrium.

2.A12. *New problem in 4th edition.* The entire system design includes extensive variables and intensive variables necessary to solve mass and energy balances. Gibbs phase rule refers only to the intensive variables needed to set equilibrium conditions.

2A13. *New problem in 4th edition.* Although V is an extensive variable, V/F is an intensive variable and thus satisfies Gibbs phase rule.

2A14. *New problem in 4th edition.* 1.0 kg/cm^2 = 0.980665 bar = 0.96784 atm.

Source: http://www.unit-conversion.info/pressure.html

2.B1. Must be sure you don't violate Gibbs phase rule for intensive variables in equilibrium. Examples:

F, z, T_{drum}, P_{drum}	F, T_F, z, p	F, h_F, z, p
F, z, y, P_{drum}	F, T_F, z, y	F, h_F, z, y
F, z, x, p_{drum}	F, T_F, z, x	etc.
F, z, y, p_{drum}	$F, T_F, z, T_{drum}, p_{drum}$	
F, z, x, T_{drum}	F, T_F, y, p	
Drum dimensions, z, F_{drum}, p_{drum}	F, T_F, y, T_{drum}	
Drum dimensions, z, y, p_{drum}	F, T_F, x, p	
etc.	F, T_F, x, T_{drum}	
	F, T_F, y, x	

2.B2. This is essentially the same problem (disguised) as problem 2-D1c and e but with an existing (larger) drum and a higher flow rate.

With y = 0.58, x = 0.20, and V/F = 0.25 which corresponds to 2-D1c.

If $F = 1000 \dfrac{\text{lb mole}}{\text{hr}}$, D = .98 and L = 2.95 ft from Problem 2-D1e .

Since D α $\sqrt{V}$ and for constant V/F, V α F, we have D α $\sqrt{F}$.

With F = 25,000:

$$\sqrt{F_{new}/F_{old}} = 5,\ D_{new} = 5\ D_{old} = 4.90, \text{ and } L_{new} = 3\ D_{new} = 14.7 .$$

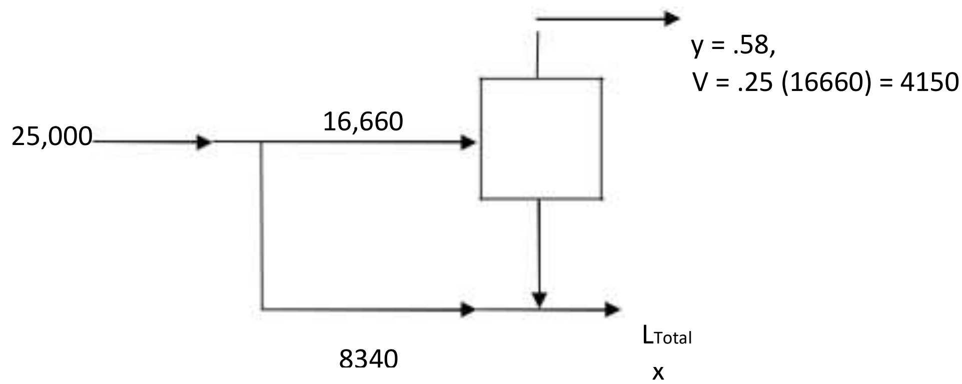
Existing drum is too small.

Feed rate drum can handle: $F \propto D^2$. $\frac{F_{existing}}{1000} = \left(\frac{D_{exist}}{.98}\right)^2 = \left(\frac{4}{.98}\right)^2$ gives

$F_{existing} = 16{,}660$ lbmol/h

Alternatives

a) Do drums in parallel. Add a second drum which can handle remaining 8340 lbmol/h.
b) Bypass with liquid mixing



Since x is not specified, use bypass. This produces less vapor.

c) Look at Eq. (2-62), which becomes

$$D = \sqrt{\frac{V\,MW_v}{3K_{drum}\,3600\sqrt{\rho_L \; \rho_v \; \rho_v}}}$$

Bypass reduces V

c1) K_{drum} is already 0.35. Perhaps small improvements can be made with a better demister → Talk to the manufacturers.
c2) ρ_v can be increased by increasing pressure. Thus operate at higher pressure. Note this will change the equilibrium data and raise temperature. Thus a complete new calculation needs to be done.
d) Try bypass with vapor mixing.
e) Other alternatives are possible.

2.C2. $$\frac{V}{F} = \frac{z_A}{K_B - 1} - \frac{z_B}{K_A - 1}$$

2.C5. a. Start with $x_i = \frac{Fz_i}{L + VK_i}$ and let $V = F - L$

$$x_i = \frac{Fz_i}{L + (F - L)K_i} \quad \text{or} \quad x_i = \frac{z_i}{\frac{L}{F} + \left(1 - \frac{L}{F}\right)K_i}$$

Then $y_i = K_i x_i = \dfrac{K_i z_i}{\frac{L}{F} + \left(1 - \frac{L}{F}\right) K_i}$

From $\sum y_i - \sum x_i = 0$ we obtain $\sum \dfrac{(K_i - 1) z_i}{\frac{L}{F} + \left(1 - \frac{L}{F}\right) K_i} = 0$

2.C4. *New Problem.* Prove that the intersection of the operating and y = x lines for binary flash distillation occurs at the mole fraction of the feed.

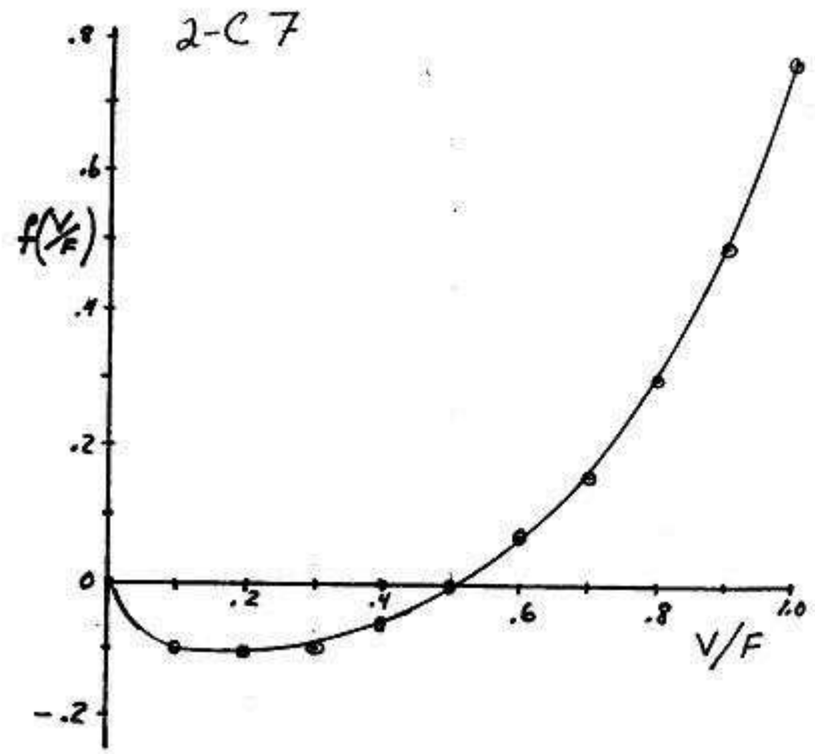
SOLUTION: $y = -\frac{L}{V} y + \frac{F}{V} z$, rearrange: $y\left(1 + \frac{L}{V}\right) = \frac{F}{V} z$, or $y \frac{V + L}{V} = \frac{F}{V} z$ since V + L = F, the result is y = z and

therefore x = y = z **(2-18)**

The intersection is at the feed composition.

2.C7. $f\left(\frac{V}{F}\right) = \sum \dfrac{z_i}{1 + (K_i - 1)\frac{V}{F}} - 1$ From data in Example 2-2 obtain:

V/F	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
f	0	-.09	-.1	-.09	-.06	-.007	.07	.16	.3	.49	.77



2.C8. Derivation of Eqs. (2-62) and (2-63). Overall and component mass balances are,

$F = V + L_1 + L_2$ and $F z_i = L_1 x_{i,L1} + L_2 x_{i,L2} + V y_i$ Substituting in Eqs. (2-60b) and 2-60c)

$$F z_i = L_1 K_{i,L1L2}\, x_{i,L2} + L_2 x_{i,L2} + V K_{i,VL2}\, x_{i,L2}$$

Solving,

$$x_{i,L2} = \frac{F z_i}{L_1 K_{i,L2} + L_2 + V K_{i,VL2}} = \frac{F z_i}{L_1 K_{i,L1L2} + (F - V - L_1) + V K_{i,VL2}}$$

Dividing numerator and denominator by F and collecting terms.

$$x_{i,liq2} = \frac{z_i}{1 + (K_{i,L1L2} - 1)\frac{L_1}{F} + (K_{i,VL2} - 1)\frac{V}{F}}$$

Since $y_i = K_{i,VL2}\, x_{i,L2}$, $y_i = \dfrac{K_{i,VL2}\, z_i}{1 + (K_{i,L1L2} - 1)\frac{L_1}{F} + (K_{i,VL2} - 1)\frac{V}{F}}$

Stoichiometric equations, $\sum_{i=1}^{C} x_{i,L2} = 1$, $\sum_{i=1}^{C} y_i = 1$, thus, $\sum_{i=1}^{C} y_i - \sum_{i=1}^{C} x_{i,L2} = 0$

which becomes

$$\sum_{i=1}^{C} \frac{(K_{i,VL2} - 1)\, z_i}{1 + (K_{i,L1L2} - 1)\frac{L_1}{F} + (K_{i,VL2} - 1)\frac{V}{F}} = 0 \qquad (2\text{-}62)$$

Since $x_{i,liq1} = K_{i,L1L2}\, x_{i,liq2}$, we have $x_{i,liq1} = \dfrac{K_{i,L1L2}\, z_i}{1 + (K_{i,L1L2} - 1)\frac{L_1}{F} + (K_{i,VL2} - 1)\frac{V}{F}}$

In addition, $\sum (x_{i,liq1} - x_{i,liq2}) = 0$

$$\sum_{i=1}^{C} \frac{(K_{i,L1L2} - 1)\, z_i}{1 + (K_{i,L1L2} - 1)\frac{L_1}{F} + (K_{i,VL2} - 1)\frac{V}{F}} = 0 \qquad (2\text{-}63)$$

2.D1. a. $V = 0.4(100) = 40$ and $L = F - V = 60$ kmol/h

Slope op. line L/V $3/2$, y x z 0.6

See graph. y 0.77 and x 0.48

b. V 0.4 1500 600 and L 900 . Rest same as part a.

c. Plot x 0.2 on equil. Diagram and y x z 0.3. $y_{int\ ercept}$ zF/V 1.2 V/F $z/1.2$ 0.25 . From equil y 0.58 .

d. Plot x 0.45 on equilibrium curve.

$$\text{Slope} \quad \frac{L}{V} \quad \frac{F \ V}{V} \quad \frac{1 \ V/F}{V/F} \quad \frac{.8}{.2} \ 4$$

Plot operating line, $y \quad x \quad z$ at $z \quad 0.51$. From mass balance $F \quad 37.5$ kmol/h.

e. *Find Liquid Density.*

$$\overline{MW}_L \quad x_m\, MW_m \quad x_w\, MW_w \quad .2 \quad 32.04 \quad .8 \;\; 18.01 \quad 20.82$$

Then, $\bar{V}_L \;\; x_m \dfrac{MW_m}{\rho_m} \;\; x_w \dfrac{MW_w}{\rho_w} \;\; .2 \dfrac{32.04}{.7914} \;\; .8 \dfrac{18.01}{1.00} \;\; 22.51$ ml/mol

$$\rho_L \quad \overline{MW}_L / \bar{V}_L \quad 20.82 / 22.51 \quad 0.925 \text{ g/ml}$$

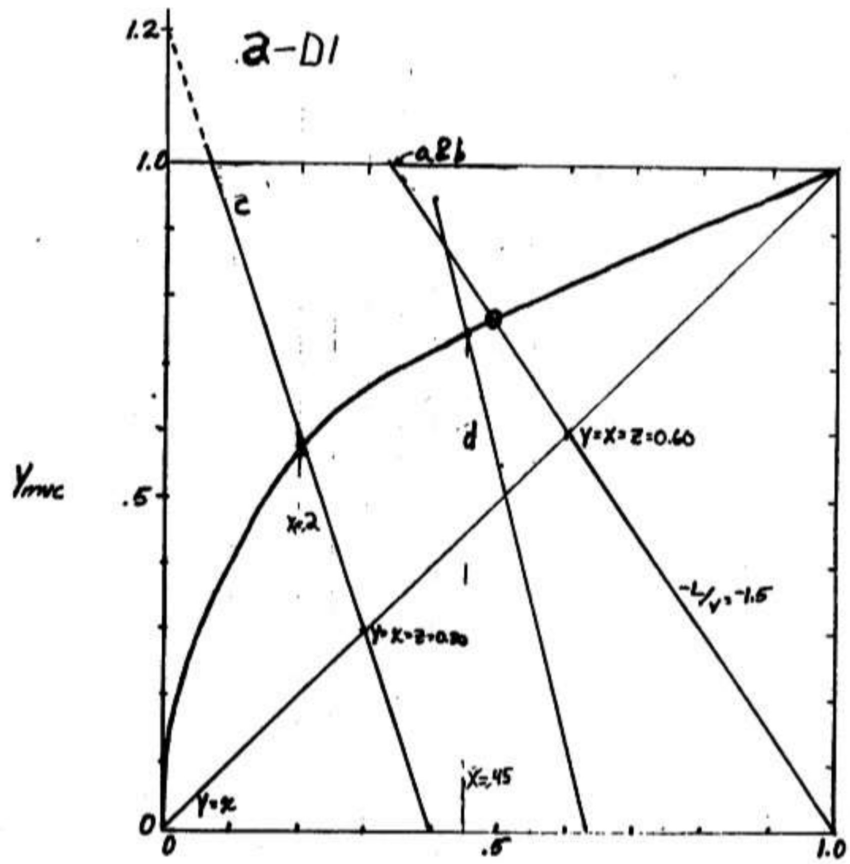
Vapor Density: $\rho_V = p(MW)_{V,avg}/RT$ (Need temperature of the drum)

$$\overline{MW}_V \; y_m \; MW_m \quad y_w \; MW_w \quad .58 \;\; 32.04 \quad .42 \;\; 18.01 \quad 26.15 \text{ g/mol}$$

Find Temperature of the Drum T: From Table 3-3 find T when

$y \;\; .58$, $x \;\; 20$, $T = 81.7$ C 354.7K

$$\rho_v \quad 1 \text{ atm} \;\; 26.15 \text{ g/mol} \Big/ 82.0575 \frac{\text{ml atm}}{\text{mol K}} \;\; 354.7 \text{ K} \;\; 8.98 \quad 10^{4} \text{ g/ml}$$



Find Permissible velocity:

$$u_{perm} \quad K_{drum} \sqrt{\;\; \rho_v \;\; / \rho_v} \;,\; K_{drum} \quad \exp\; A \;\; B \;\; \ell nF_{lv} \quad C \;\; \ell nF_{lv}^{2} \quad D \;\; \ell nF_{lv}^{3} \quad E \;\; \ell nF_{lv}^{4} \qquad \text{2-60}$$

$V \quad \dfrac{V}{F} F \quad 0.25 \;\; 1000 \quad 250$ lbmol/h, $W_v \quad V \; \overline{MW}_v \quad 250 \;\; 26.15 \dfrac{\text{lb}}{\text{lbmol}} \quad 6537.5$ lb / h

$L \quad F \quad V \quad 1000 \quad 250 \quad 750$ lbmol/h, and $W_L \quad L \quad \overline{MW}_L \quad 750 \quad 20.82 \quad 15{,}615$ lb/h,

$F_{lv} = \frac{W_L}{W_V}\sqrt{\frac{\rho_V}{\rho_L}} = \frac{15615}{6537.5}\sqrt{\frac{8.89\times 10^{-4}}{.925}} = 0.0744$, and $\ell n\, F_{lv} = -2.598$

Then $K_{drum} = .442$, and $u_{perm} = .442\sqrt{\frac{.925 - 8.98\times 10^{-4}}{8.98\times 10^{-4}}} = 14.19$ ft/s

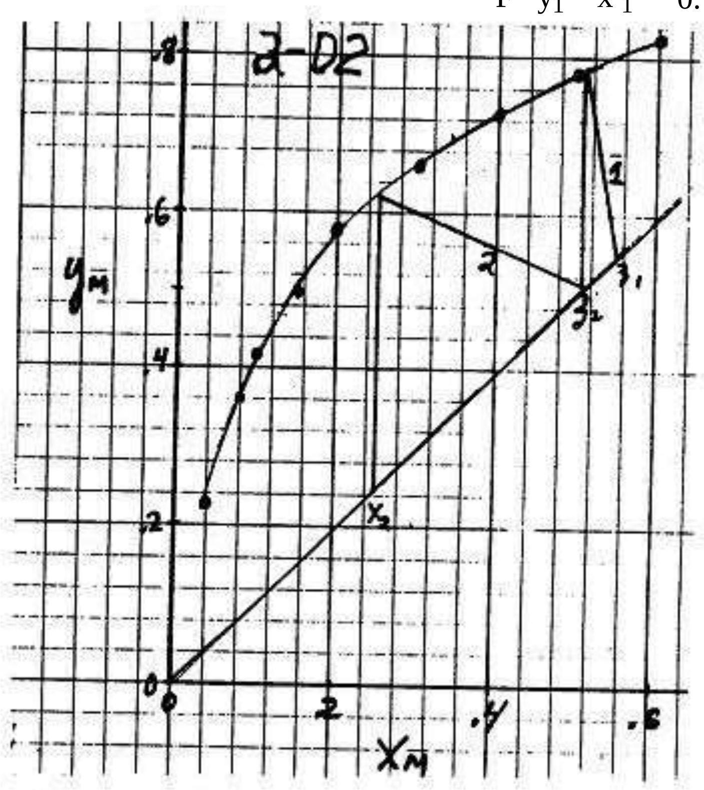
$$A_{cs} = \frac{V\, MW_v}{u_{perm}\, 3600\, \rho_v} = \frac{250\,(26.15)\,(454\text{ g/lb})}{14.19\,(3600)(8.98\times 10^{-4}\text{ g/ml})(28316.85\text{ ml/ft}^3)} = 2.28\text{ ft}^2$$

$D = \sqrt{4A_{cs}/\pi} = 1.705$ ft. Use 2 ft diameter. L ranges from 3 D = 6 ft to 5 D=10 ft Note that this design is conservative if a demister is used.

f. Plot T vs x from Table 3-3. When T = 77 C, x = 0.34, y = 0.69. This problem is now very similar to 3-D1c. Can calculate V/F from mass balance, Fz = Lx + Vy. This is $Fz = (F - V)x + Vy$ or $\frac{V}{F} = \frac{z - y}{y - x} = \frac{0.4 - 0.34}{0.69 - 0.34} = 0.17$

g. *Part g is a new problem.* V = 16.18 mol/h, L = 33.82, y= 0.892, x = 0.756.

2-D2. Work backwards. Starting with x_2, find y_2 = 0.62 from equilibrium. From equilibrium point plot op. line of slope $-(L/V)_2 = -\frac{1 - (V/F)_2}{(V/F)_2} = -3/7$. Find $z_2 = 0.51 = x_1$ (see Figure). From equilibrium, $y_1 = 0.78$. For stage 1, $\frac{V}{F} = \frac{z_1 - x_1}{y_1 - x_1} = \frac{0.55 - 0.51}{0.78 - 0.51} = 0.148$.



2.D3. *New Problem in 4th edition.*. Part a.

x ethane	T ^oC	y ethane
0	63.19	0
.025	56.18	0.1610
.05	49.57	0.2970
.10	37.57	0.5060
.15	27.17	0.6503
.20	18.26	0.7492
.25	10.64	0.8175
.30	4.11	0.8652
1.0	-37.47	1.0

b. See Figure. a. If 1 bubble of vapor product (V/F = 0) vapor product, vapor y_E = 0.7492 (highest) liquid $x_E = z_E$ = 0.20 (highest) and T = 18.26 ^oC. If 1 drop of liquid product (V/F =1) $y_E = z_E$ = 0.20 (lowest), x_E = 0.035, T (by linear interpolation) ~ 56.18 + [(49.57 – 56.18)/(.297 - .161)][.2 – 0.16] = 54.2 ^oC (highest).

c. See figure. Slope = -L/V = - (1 – V/F)/(V/F) = - .6/.4 = - 1.5. x_E = 0.12, y_E = 0.57, T = 33.4^o C. **d**. From equilibrium data y_E = 0.7492. For an F = 1, L = 1 – V, Ethane balance: .2L = 1(.3) – 0.7492 V. Solve 2 equations: V/F = 0.1821. Can also find V/F from slope of operating line.

e. If do linear interpolation on equilibrium data, x = 0.05 +(45-49.57)(0.1 -0.05)/(37.57 – 49.57) = 0.069. From equilibrium plot y = 0.375.

Mass balance for basis F = 1, L = 1 – V and 0.069 L = 0.18 – 0.375 V. Solve simultaneously, V/F = 0.363.

2.D4. *New problem in 3rd edition.* Highest temperature is dew point $V/F = 0$

Set $z_i = y_i$. $K_i = y_i / x_i$. Want $\sum x_i = \sum y_i / K_i = 1.0$

$$K_{ref}(T_{New}) = K_{ref}(T_{Old}) \sum y_i / K_i$$

If pick C4 as reference: First guess $K_{butane} = 1.0$, $T = 41\ C$: $K_{C3} = 3.1, K_{C6} = 0.125$

$$\sum \frac{y_i}{K_i} = \frac{.2}{3.1} + \frac{.35}{1.0} + \frac{.45}{.125} = 4.0145 \quad \text{T too low}$$

Guess for reference: $K_{C4} = 4.014$, $T = 118\ C$: $K_{C3} = 8.8, K_{C6} = .9$

$$\sum \frac{y_i}{K_i} = \frac{.2}{8.8} + \frac{.35}{4.0145} + \frac{.45}{.9} = 0.6099$$

$$K_{C4,NEW} = 4.0145 \times .6099 = 2.45, T = 85: K_{C2} = 6.0, K_{C6} = 0.44$$

$$\sum \frac{y_i}{K_i} = \frac{.2}{6} + \frac{.35}{2.45} + \frac{.45}{.44} = 1.20$$

$K_{C4,NEW} = 2.45(1.2) = 2.94$, T = 96 C : $K_{C3} = 6.9$, $K_{C6} = 0.56$

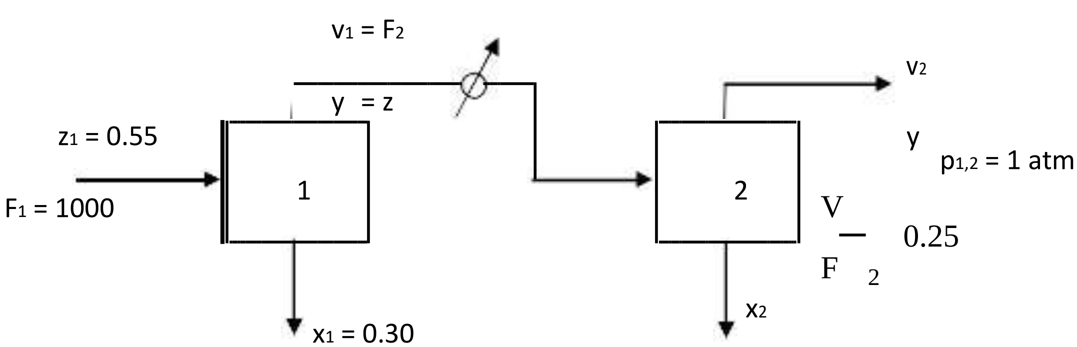
$$\sum \frac{y_i}{K_i} = \frac{.2}{6.9} + \frac{.35}{2.94} + \frac{.45}{.56} = 0.804 \text{ Gives } 84\ C$$

Use 90.5° → Avg last two T $K_{C4} = 2.7$, $K_{C3} = 6.5$, $K_{C6} = 0.49$

$$\sum y_i/K_i = \frac{.2}{6.5} + \frac{.35}{2.7} + \frac{.45}{.49} = 1.079,\ T \sim 87-88^\circ\ C$$

Note: hexane probably better choice as reference.

2.D5. a)



b) $y_1 = -\frac{L}{V} x_1 + \frac{F}{V} z$ Plot 1st Op line.

$y_1 = 0.66 = z_2$

y = x = z = 0.55 to x_1 = 0.3 on eq. curve (see graph)

Slope $-\left(\frac{L}{V}\right)_1 = \frac{0.55-0.80}{.55-0} = \frac{-.25}{.55} = -0.454545$, $L_1 + V_1 = F_1 = 1000$

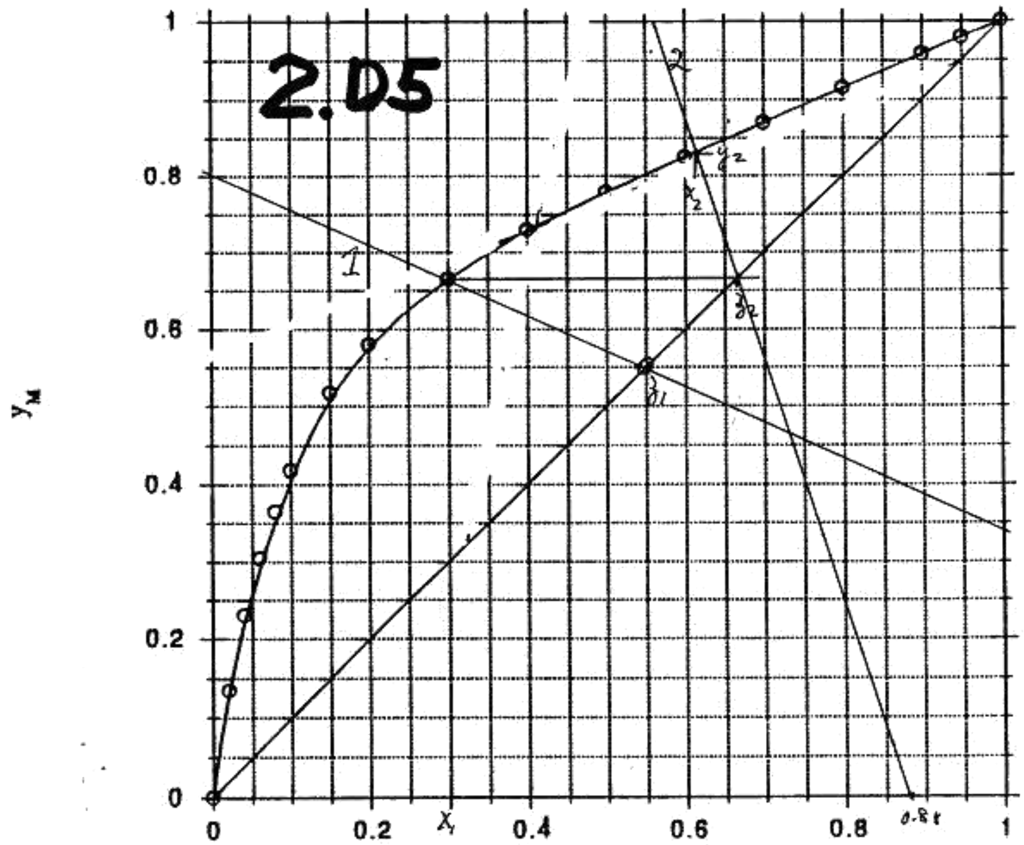
V_1 = 687.5 kmol/h = F_2

$\left(\frac{V}{F}\right)_1 = \frac{687.5}{1000} = 0.6875$

c) Stage 2 $\frac{V}{F} = 0.25$, $\frac{L}{V} = \frac{0.75F}{0.25F} = 3$, $y = x = z_2 = 0.66$. Plot op line

At x = 0, $y = z/(V/F) = \frac{0.66}{0.25} = 2.64$. At y = 0, $x_2 = \frac{F}{L} z = \frac{z}{L/F} = \frac{0.66}{0.75} = 0.88$

From graph $y_2 = 0.82$, $x_2 = 0.63$. $V_2 = \left(\frac{V}{F}\right)_2 F_2 = 0.25(687.5) =$ 171.875 kmol/h



2.D6. *New problem in 4th ed.* a.) The answer is VP = 19.30 mm Hg

$$\log_{10} VP \quad 6.8379 \quad \frac{1310.62}{100 \quad 136.05} \quad 1.2856$$

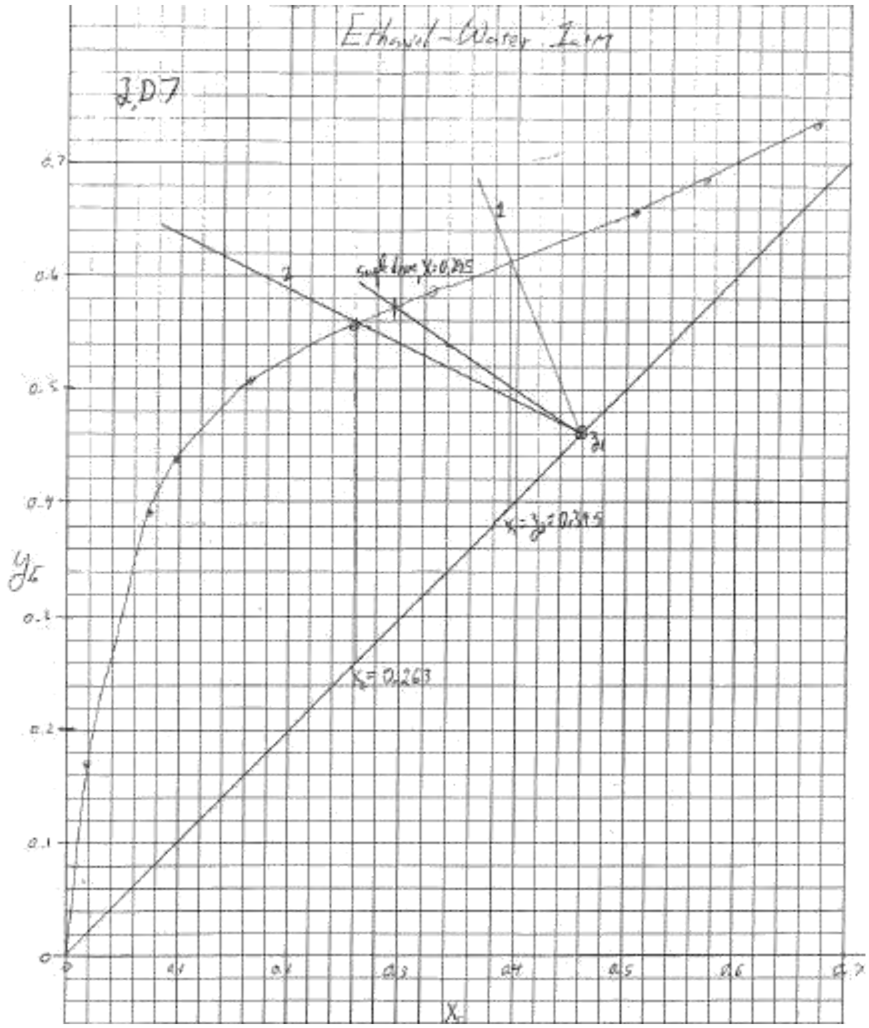
b.) The answer is K = 0.01693.

$$K \quad \frac{VP}{P_{tot}} \quad \frac{19.30}{1.5\ 760}$$

2.D7. *New problem 4th ed.*

Part a. Drum 1: V_1/F_1 = 0.3, Slope op line = -L/V = -.7/.3 = -7/3, y=x=z_1 =0.46. L_1 = F_2 = 70. From graph x_1 = z_2 = 0.395
Drum 2: V_1/F_1 = 30/70, Slope op line = -L/V = -7/3, y=x=z_2 =0.395. L_1 = F_2 – V_2 = 40. From graph x_2 = 0.263

Part b. Single drum: V/F = 0.6, Slope op line = -L/V = -40/60 = -2/3, From graph x = 0.295. More separation with 2 drums.



2.D8. Use Rachford-Rice eqn: $f\left(\frac{V}{F}\right) = \sum \frac{(K_i - 1) z_i}{1 + (K_i - 1) V/F} = 0$. Note that 2 atm = 203 kPa.

Find K_i from DePriester Chart: $K_1 = 73$, $K_2 = 4.1$, $K_3 = .115$

Converge on $V/F = .076$, $V = F(V/F) = 152$ kmol/h, $L = F - V = 1848$ kmol/h.

From $x_i = \frac{z_i}{1 + \frac{V}{F}(K_i - 1)}$ we obtain $x_1 = .0077$, $x_2 = .0809$, $x_3 = .9113$

From $y_i = K_i x_i$, we obtain $y_1 = .5621$, $y_2 = .3649$, $y_3 = .1048$

2.D9. Need h_F to plot on diagram. Since pressure is high, feed remains a liquid

$$h_F = \bar{C}_{P_L}(T_F - T_{ref}), \; T_{ref} = 0 \quad \text{from chart}$$

$$\bar{C}_{P_L} = C_{P_{EtOH}} x_{EtOH} + C_{P_w} x_w$$

Where x_{EtOH} and x_w are *mole* fractions. Convert weight to mole fractions.

Basis: 100 kg mixture: 30 kg EtOH $\frac{30}{46.07} = 0.651$ kmol

70 kg water	70/18.016	3.885	Total = 4.536 kmol

Avg. MW $\frac{100}{4.536}$ 22.046   Mole fracs: x_E $\frac{0.6512}{4.536}$ 0.1435, x_w 0.8565 .

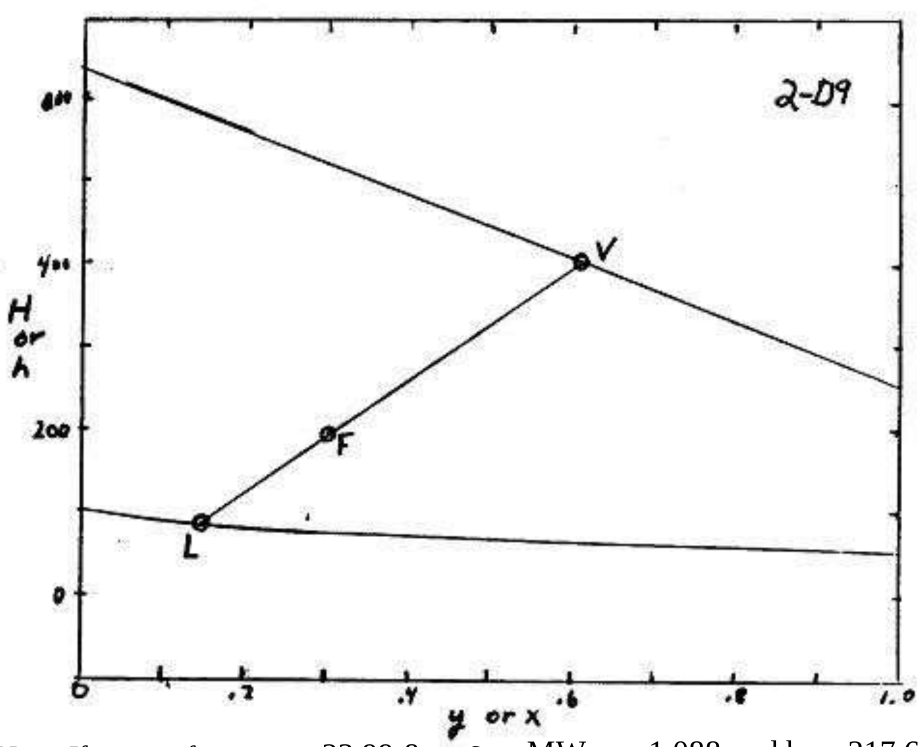
Use $C_{P_{L_{EtOH}}}$ at 100 C as an average C_P value.

$\bar{C}_{P_L}$ 37.96 .1435 18.0 .8565 20.86 $\frac{\text{kcal}}{\text{kmol C}}$

Per kg this is $\frac{C_{P_L}}{MW_{avg}}$ $\frac{20.86}{22.046}$ 0.946 $\frac{\text{kcal}}{\text{kg C}}$

h_F 0.946 2000 189.2 kcal/kg

which can now be plotted on the enthalpy composition diagram.
Obtain T_{drum} 88.2 C, x_E 0.146, and y_E 0.617 .
For F 1000 find L and V from F = L + V and Fz Lx Vy which
gives V = 326.9, and L = 673.1



Note: If use wt. fracs. C_{P_L} 23.99 & C_{P_L} MW_{avg} 1.088 and h_F 217.6 . All *wrong.*

2.D.10 *Solution* 400 kPa, 70ºC z_{C4} 35 Mole % n-butane x_{C6} 0.7

From DePriester chart K_{C3} 5, K_{C4} 1.9, K_{C6} 0.3

Know y_i K_i x_i , x_i $\frac{z_i}{\ \ }$ $\frac{\ \ }{V}$, $x_i y_i$ 1z_i

–

1 K_i 1 F

R.R. $\sum \frac{(K_i - 1) z_i}{1 + (K_i - 1)\frac{V}{F}} = 0$ $\quad z_{C3} = 1 - z_{C6} - z_{C4} = .65 - z_{C6}$

C6: $0.7 = \frac{z_{C6}}{1 + (K_{C6} - 1)\frac{V}{F}} = \frac{z_{C6}}{1 + (0.7 - 1)\frac{V}{F}}$, $z_{C6} = 0.7 - 0.21\frac{V}{F}$ ... $z_{C6} = 0.7 - 0.49\frac{V}{F}$

RR Eq: $\frac{4(.65 - z_{C6})}{1 + 4\frac{V}{F}} + \frac{0.9(.35)}{1 + 0.9\frac{V}{F}} - \frac{0.7 z_{C6}}{1 - 0.7\frac{V}{F}} = 0$

2 equations & 2 unknowns. Substitute in for z_{C6}. Do in Spreadsheet. Use Goal – Seek to find V/F. V/F = 0.594 when R.R. equation 0.000881.

$z_{C6} = 0.7 - 0.49\frac{V}{F} = 0.7 - (0.49)(0.594) = 0.40894$

2.D11. *New Problem 4th ed.* Obtain K ethylene = 2.2, K propylene = 0.56 from De Priester chart.

$K_E = y_E/x_E$ and $K_P = y_P/x_P$ Since $y_p = 1 - y_E$ and $x_p = 1 - x_E$, $K_p = (1 - y_E)/(1 - x_E)$.
Thus, 2 eqs and 2 unknowns. Solve for y_E and x_E.
$x_E = (1 - K_p) / (K_E - K_p)$ and $y_E = K_E x_E = K_E (1 - K_p) / (K_E - K_p)$
$x_E = (1 - 0.56) / (2.2 - 0.56) = 0.268$ and $y_E = K_E x_E = (2.2)(0.268) = 0.590$
Check: $x_p = 1 - x_E = 1 - 0.268 = 0.732$ and $y_p = 1 - y_E = 1 - 0.590 = 0.410$
$K_p = y_p/x_p = 0.410/ 0.732 = 0.56$ OK

2.D12. For problem 2.D1c, plot x = 0.2 on equilibrium diagram with feed composition of 0.3. The resulting operating line has a y intercept $z/(V/F) = 1.2$. Thus $V/F = 0.25$ (see figure in Solution to 2.D1) Vapor mole fraction is y = 0.58.

Find Liquid Density.

$\overline{MW}_L = x_m MW_m + x_w MW_w = .2(32.04) + .8(18.01) = 20.82$

Then, $\overline{V}_L = x_m \frac{MW_m}{\rho_m} + x_w \frac{MW_w}{\rho_w} = .2\frac{32.04}{.7914} + .8\frac{18.01}{1.00} = 22.51$ ml/mol

$\rho_L = \overline{MW}_L / \overline{V}_L = 20.82/22.51 = 0.925$ g/ml

Find Vapor Density. $\rho_v = \frac{p\,\overline{MW}_v}{RT}$ (Need temperature of the drum)

$\overline{MW}_v = y_m MW_m + y_w MW_w = .58(32.04) + .42(18.01) = 26.15$ g/mol

Find Temperature of the Drum T:

From Table 2-7 find T corresponding to $y = .58$, $x = .20$, T=81.7 C = 354.7K

$\rho_v = \frac{(1\text{ atm})(26.15\text{ g/mol})}{\left(82.0575\frac{\text{ml atm}}{\text{mol K}}\right)(354.7\text{ K})} = 8.98 \times 10^{-4}$ g/ml

$\sqrt{\quad /\quad}$

Find Permissible velocity: u_{perm} K_{drum} L v v

30

$K_{drum,horizontal} = 1.25\, K_{drum,vertical}$ $\exp[A + B(\ln F_{lv}) + C(\ln F_{lv})^2 + D(\ln F_{lv})^3 + E(\ln F_{lv})^4]$ 1.25

Since $V = (V/F)F = 0.25(1000) = 250$ lbmol/h,

$W_v = V(MW_v) = 250(26.15\ \text{lb/lbmol}) = 6537.5$ lb / h

$L = F - V = 1000 - 250 = 750$ lbmol/h, and $W_L = L(MW_L) = 750(20.82) = 15{,}615$ lb/h,

$$F_{lv} = \frac{W_L}{W_V}\sqrt{\frac{\rho_V}{\rho_L}} = \frac{15615}{6537.5}\sqrt{\frac{8.98\times 10^{-4}}{.925}} = 0.0744, \text{ and } \ln F_{lv} = -2.598$$

$K_{drum,vertical} = 0.442$, and $K_{drum,horiz} = 0.5525$

$$u_{perm} = 0.5525\sqrt{\frac{0.925 - 8.98\times 10^{-4}}{8.98\times 10^{-4}}} = 17.74 \text{ ft/s}$$

$$A_{cs} = \frac{V(MW_v)}{u_{perm}(3600)\rho_v} = \frac{250(26.15)(454 \text{ g/lbm})}{17.74(3600)(8.98\times 10^{-4} \text{ g/ml})(28316.85 \text{ ml/ft}^3)}$$

$A_{Cs} = 1.824\ \text{ft}^2$, $A_T = A_{Cs}/0.2 = 9.12\ \text{ft}^2$

With L/D = 4, $D = \sqrt{4A_T/\pi} = 3.41$ ft and $L = 13.6$ ft

2.D13. *New Problem 4th ed.* $x_{butane} = 1 - x_E = 0.912$, $y_{butane} = 1 - y_E = 0.454$. $K_E = y_E/x_E = 0.546/0.088 = 6.20$, $K_{butane} = y_B/x_B = 0.454/0.912 = 0.498$.
Plot K_E and K_{butane} on DePriester chart. Draw straight line between them. Intersections with T and P axis give $T_{drum} = 15\ ^oC$, and $p_{drum} = 385$ kPa from Figure 2-12.
Use mass balances to find V/F: F = L + V and $Fz_E = Lx_E + Vy_E$. Substitute L = F – V into ethane balance and divide both sides by F. Obtain: z = (1 – V/F)x + y(V/F).
Solve for V/F = (z-x)/(y-x) = (0.36 – 0.088)/(0.546 – 0.088) = 0.594.
Spreadsheet used as a check (using T=15 and p = 385) gave V/F = 0.593.

2.D14. *New Problem 4th ed.* DePriester chart, Fig. 2-12: $K_{C1} = 50$, $K_{C4} = 1.1$, and $K_{C5} = 0.37$; $z_1 = 0.12$, $z_4 = 0.48$, $z_5 = 0.40$

Rachford-Rice equation:
$$\frac{(K_{C2}-1)z_{C1}}{1+(K_{C1}-1)\frac{V}{F}} + \frac{(K_{iC4}-1)z_{nC4}}{1+(K_{nC4}-1)\frac{V}{F}} + \frac{(K_{nC4}-1)z_{nC5}}{1+(K_{nC5}-1)\frac{V}{F}} = 0$$

5.88   0.048   0.252

Equation becomes: $\frac{5.88}{1+49(V/F)} + \frac{0.048}{1+0.1(V/F)} - \frac{0.252}{1-0.63(V/F)} = 0$

Trials: V/F = 0.4, Eq. = -.005345; V/F = 0.39, Eq. = 0.004506; V/F = 0.394, Eq. = 0.000546, which is close enough with DePriester chart.

Liquid mole fractions:

$$x_{C1} = \frac{z_{C1}}{1+(K_{C1}-1)(V/F)} = \frac{.12}{1+49(.394)} = 0.00591;$$

$x_{C4} = 0.4618$, $x_{C5} = 0.5321$, and $\sum x_i = 0.9998$

Vapor mole fractions: $y_i = K_i x_i$: $y_{C1} = 50(0.00591) = 0.2955$, $y_{C4} = 0.5080$, $y_{C5} = 0.1969$, $\sum y_i = 1.0004$.

2.D15. This is an unusual way of stating problem. However, if we count specified variables we see that problem is not over or under specified. Usually V/F would be the variable, but here it isn't. We can still write R-R eqn. Will have three variables: z_{C2}, z_{iC4}, z_{nC4}. Need two other eqns: $z_{iC4}/z_{nC4} = \text{constant}$, and $z_{C2} + z_{iC4} + z_{nC4} = 1.0$

Thus, solve three equations and three unknowns simultaneously.

Do It. Rachford-Rice equation is,

$$\frac{(K_{C2}-1)z_{C2}}{1+(K_{C2}-1)\frac{V}{F}} + \frac{(K_{iC4}-1)z_{iC4}}{1+(K_{iC4}-1)\frac{V}{F}} + \frac{(K_{nC4}-1)z_{nC2}}{1+(K_{nC4}-1)\frac{V}{F}} = 0$$

Can solve for $z_{C2} = 1 - z_{iC4}$ and $z_{iC4} = (.8)\, z_{nC4}$. Thus $z_{C2} = 1 - 1.8\, z_{nC4}$

Substitute for z_{iC4} and z_{C2} into R-R eqn.

$$\frac{K_{C2}-1}{1+(K_{C2}-1)\frac{V}{F}}(1-1.8\, z_{nC4}) + \frac{.8(K_{iC4}-1)}{1+(K_{iC4}-1)\frac{V}{F}} z_{nC4} + z_{nC4}\frac{K_{nC4}-1}{1+(K_{nC4}-1)\frac{V}{F}} = 0$$

Thus,

$$z_{nC4} = \frac{-\dfrac{K_{C2}-1}{1+(K_{C2}-1)\frac{V}{F}}}{-1.8\dfrac{K_{C2}-1}{1+(K_{C2}-1)\frac{V}{F}} + \dfrac{.8(K_{iC4}-1)}{1+(K_{iC4}-1)\frac{V}{F}} + \dfrac{K_{nC4}-1}{1+(K_{nC4}-1)\frac{V}{F}}}$$

Can now find K values and plug away. $K_{C2} = 2.92$, $K_{iC4} = .375$, $K_{nC4} = .26$.

Solution is $z_{nC4} = 0.2957$, $z_{iC4} = .8\,(.2957) = 0.2366$, and $z_{C2} = 0.4677$

2.D16. $z_{C1} = 0.5$, $z_{C4} = 0.1$, $z_{C5} = 0.15$, $z_{C6} = 0.25$, $K_{C1} = 50$, $K_{C4} = .6$, $K_{C5} = .17$, $K_{C6} = 0.05$

1st guess. Can assume all C_1 in vapor, ~ 1/3 C_4 in vapor, C_5 & C_6 in bottom

$$(V/F)_1 = .5 + .1/3 = .53 \quad \text{This first guess is not critical.}$$

$$\text{R.R. eq.} \quad f\left(\frac{V}{F}\right) = \sum \frac{(K_i-1)z_i}{1+(K_i-1)V/F} = 0$$

$$\frac{(49)(.5)}{1+(49)(.53)} + \frac{(-.4)(.1)}{1+(-.4)(.53)} + \frac{(-.83)(.15)}{1+(-.83)(.53)} + \frac{(-.95)(.25)}{1+(-.95)(.53)} = 0.157$$

Eq. 3.33

$$\left(\frac{V}{F}\right)_2 = \left(\frac{V}{F}\right)_1 - \frac{f(V/F)_1}{\sum \dfrac{z_i(K_i-1)^2}{\left[1+(K_i-1)\frac{V}{F}\right]^2}}$$

where $(V/F)_1 = 0.53$ and $f(V/F)_1 = 0.157$. $V/$

calculate $F_2 = .53 - 0.157/2.92 = 0.584$

$$V = (.584)(150) = 87.6 \text{ kmol/h and } L = 150 - 87.6 = 62.4$$

$$x_{C1} = \frac{z_{C1}}{1 + (K_{C1} - 1)(V/F)} = \frac{.5}{1 + 49(.584)} = 0.016883$$

$$y_{C1} = K_{C1}\, x_{C1} = 50(0.016883) = 0.844$$

Similar for other components.

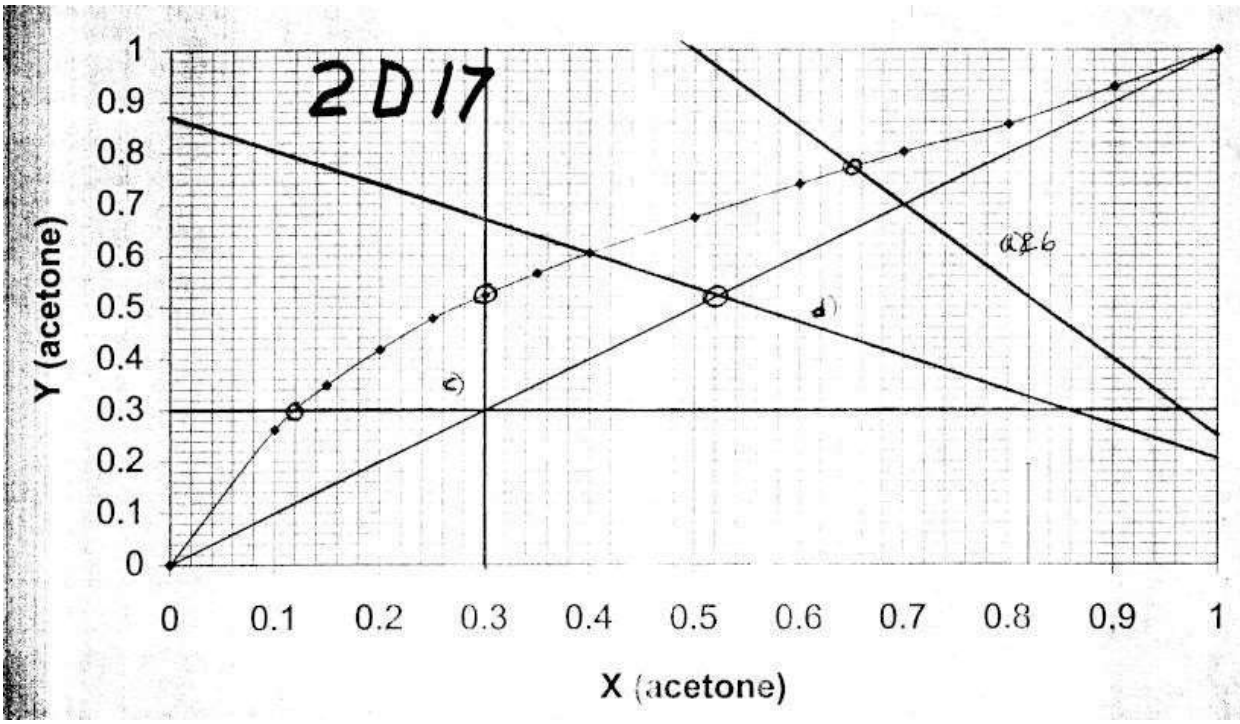
2-D17. a. $V = 0.4F = 400$, $L = 600$ Slope $= -L/F = -1.5$

Intercepts y = x = z = 0.70. Plot line and find $x_A = 0.65$, $y_A = 0.77$ (see graph)

b. V = 2000, L = 3000. Rest identical to part a.

c. Lowest x_A is horizontal op line (L = 0). $x_A = 0.12$

Highest y_A is vertical op line (V = 0). $y_A = 0.52$. See graph



d. V = 600, L = 400, -L/V = -0.667.

Find $x_A = 0.40$ on equilibrium curve. Plot op line & find intersection point with y = x line. $z_A = 0.52$

2.D18. From $x_i = \dfrac{z_i}{1 + (K_i - 1)\frac{V}{F}}$, we obtain $\dfrac{V}{F} = \dfrac{\frac{z_h}{x_h} - 1}{K_h - 1}$

Guess T_{drum}, calculate K_h, K_b and K_p, and then determine V/F.

Check: $\sum \dfrac{(K_1 - 1)\, z_i}{1 + (K_1 - 1)\, V/F} = 0$?

Initial guess: T_{drum} must be less than temperature to boil pure hexane

K_h 1.0, T 94 C . Try 85°C as first guess (this is not very critical and the calculation will tell us if there is a mistake). K_h =0.8, K_b 4.8, K_p =11.7 .

$$\frac{V}{F} \quad \frac{\frac{0.6}{0.85} - 1}{0.8 - 1} \quad 1.471$$. Not possible. Must have K_h $\frac{0.6}{0.85}$ 0.706

Try T 73 C where K_h 0.6 . Then K_b 3.8, K_p 9.9 .

$$\frac{V}{F} \quad \frac{\frac{0.6}{.85} - 1}{.6 - 1} \quad 0.735$$

Check:

$$\frac{K_i - 1\; z_i}{1 \quad K_i - 1\; V/F} \quad \frac{8.9 \;\; .1}{1 \quad 8.9\; .735} \quad \frac{2.8 \;\; .3}{1 \quad 2.8\; .735} \quad \frac{.4 \;\; .6}{1 \quad .4 \;\; 735} \; 0.05276$$

Converge on T ~ 65.6 C and V/F ~ 0.57 .

2.D19. 90% recovery n-hexane means 0.9 Fz_{C6} L x_{C6} Substitute in L F V to obtain z_{C6} .9 1 V/F x_{C6}

C_8 balance: z_{C6} F Lx_{C6} Vy_{C6} F V x_{C6} K_{C6} Vx_{C6}

or z_{C6} 1 V/F x_{C6} x_{C6} K_{C6} V/F Two equations and two unknowns. Remove x_{C6} and solve

$$z_{C6} \quad \frac{.93C_6}{} \quad \frac{.9\; z_{C6}\; KV\; F}{1 \quad V/F}$$

Solve for V/F. $$\frac{V}{F} \quad \frac{.1}{.9K_{C6} \quad .1}$$. Trial and error scheme.

Pick T, Calc K_{C6}, Calc V/F, and Check f V/F 0 ?

If not $$K_{ref_{new}} \quad \frac{K_{ref}\; T_{old}}{1 \;\; d\,f \;\; T}$$

Try T 70 C. K_{C4} 3.1, K_{C5} .93, K_{C6} .37 K_{ref}

$$\frac{V}{F} \quad \frac{.1}{.9 \;\; .37 \quad .1} \quad 0.231.$$

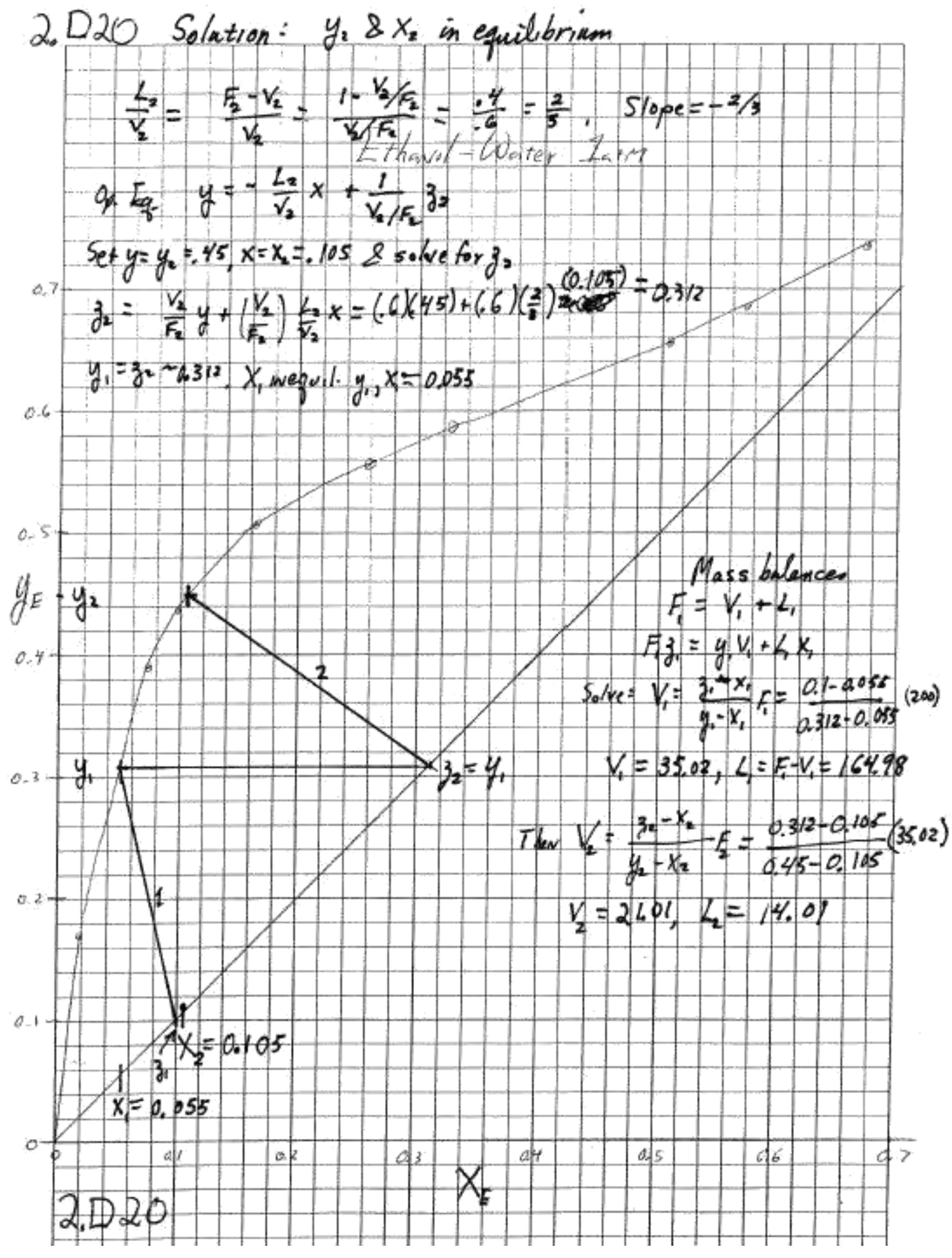
Rachford Rice equation

$$f \quad \frac{2.1\; .4}{1 \quad 2.1\; .231} \quad \frac{.08\; .25}{1 \quad .08\; .231} \quad \frac{.63\; .35}{1 \quad .63 \quad .231} \; .28719$$

$$K_{ref}\; T_{new} \quad \frac{.37}{1 \quad 0.28719} \; 0.28745 \;\; \text{use } .28$$

Converge on T_{New} ~ 57 C. Then K_{C4} 2.50, K_{C8} .67, and V/F 0.293 .

2.D20. *New Problem 4th ed.*



2.D21. a.) $K_{C2} = 4.8 \quad K_{C5} = 0.153$

Soln to Binary R.R. eq. $\frac{V}{F} = -\frac{z_A}{K_B - 1} - \frac{z_B}{K_A - 1}, \quad \frac{V}{F} = -\frac{0.55}{.153 - 1} - \frac{0.45}{4.8 - 1} = 0.5309$

$x_{C2} = \frac{z_{C2}}{1 + (K_{C2} - 1)\frac{V}{F}} = \frac{0.55}{1 + 3.8(.5309)} = 0.1823, \quad y_{C2} = 0.8749, \; x_{C5} = 0.8177, \; y_{C5} = 0.1251$

$1 \quad K_{C2} \quad 1 \quad F$

Need to convert F to kmol. Avg MW $= 0.55(30.07) + 0.45(72.15) = 49.17$

$$F = 100{,}000 \frac{kg}{hr}\left|\frac{kmol}{49.17\ kg}\right| = 2033.7\ kmol/h, \quad V = (V/F)F = 1079.7, \quad L = F - V = 954.0\ kmol/h$$

b.) $$u_{Perm} = K_{drum}\sqrt{\frac{\rho_L - \rho_v}{\rho_v}}$$

To find $\overline{MW}_L = 0.1823(30.07) + 0.8177(72.15) = 64.48$

$\overline{MW}_V = 0.8749(30.07) + 0.1251(72.15) = 35.33$

For liquid assume ideal mixture:

$$\bar{V} = x_{C2}\bar{V}_{C2,liq} + x_{C5}\bar{V}_{C5,liq} = x_{C2}\frac{\overline{MW}_{C2}}{\rho_{C2,liq}} + x_{C5}\frac{\overline{MW}_{C5}}{\rho_{C5,liq}}$$

$$\bar{V}_L = 0.1823\left(\frac{30.07}{0.54}\right) + 0.8177\left(\frac{72.15}{0.63}\right) = 103.797\ ml/mol$$

$$\rho_L = \frac{\overline{MW}_L}{\bar{V}_L} = \frac{64.48}{103.797} = 0.621\ g/ml$$

For vapor: ideal gas:
$$\rho_v = \frac{p\,\overline{MW}_v}{RT} = \frac{(700\ kPa)\left|\frac{atm}{101.3\ kPa}\right|35.33\frac{g}{mol}}{\left(82.0575\frac{ml\ atm}{mol\ K}\right)(303.16K)} = 0.009814\ g/ml$$

K_{drum} : Use Eq. (2-60) with $F_{lV} = \frac{W_L}{W_V}\sqrt{\frac{\rho_v}{\rho_L}}$

$$W_L = 997.7\frac{kmol}{h}\left|\frac{64.48\ kg}{kmol}\right| = 6,4331.7\ kg/h, \quad W_v = 881.5(35.33) = 31{,}143.4\ kg/h$$

$$F_{lV} = \frac{64331.7}{31{,}143.3}\sqrt{\frac{0.009814}{0.621}} = 0.2597$$

$$K_{drum} = \exp[-1.877478 - 0.81458\ln(.2597) - 0.18707(\ln 0.2597)^2$$
$$+ 0.0145229(\ln 0.2597)^3 + 0.0010149(\ln 0.2597)^4] = 0.3372$$

$$u_{Perm} = 0.3372\sqrt{\frac{0.621 - 0.009814}{0.009814}}\ \frac{ft}{s}\left|\frac{1.0\ m}{3.2808\ ft}\right| = 0.8111\ m/s$$

$$A_C = \frac{V\,\overline{MW}_V}{u_{Perm}\,3600\,\rho_v} = \frac{\left(1079.7\frac{kmol}{h}\right)\left(35.33\frac{kg}{kmol}\right)}{\left(0.8111\frac{m}{s}\right)\left(3600\frac{s}{h}\right)\left(0.009814\frac{g}{cm^3}\right)\left(\frac{kg}{1000g}\right)\left(10^6\frac{cm^3}{m}\right)} = 1.392\ m^2$$

$D = \sqrt{4A_C/\pi} = 1.33$ m. Arbitrarily $L/D = 4$, $L = 5.32$ m

2.D22. *New problem in 4th edition.*

a. V = F – L = 50 – 20 = 20 kmol/h. V/F = 3/5, Slope operating line = -L/V = -20/30 = - 2/3, z_M = 0.7

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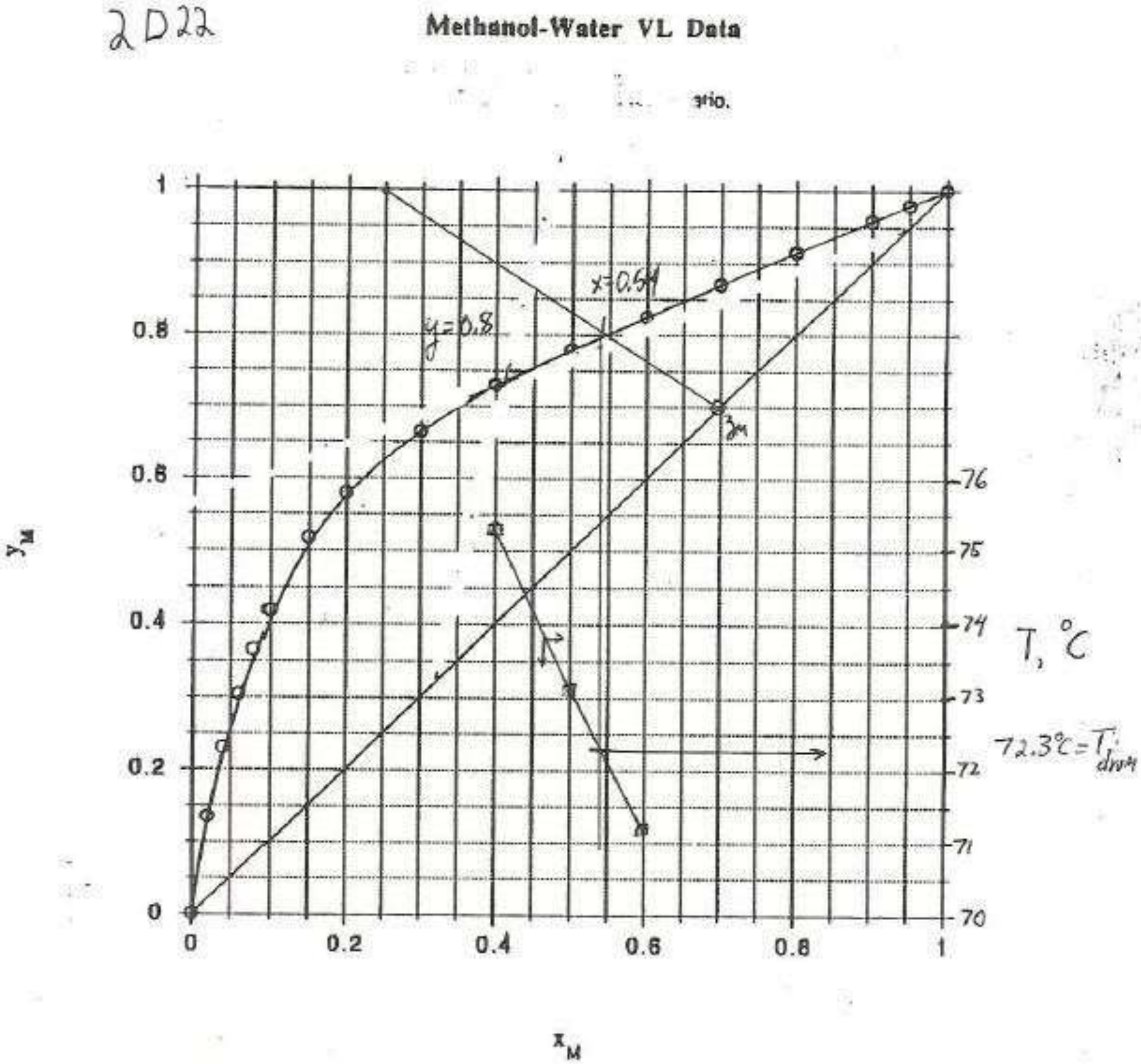
From graph, y = 0.8, x = 0.54.

b. From graph of T vs. x_M, T_{drum} = 72.3°C. (see graph).



2.D23. *New Problem 4th ed.*

Part a. F_{new} = (1500 kmol/h)(1.0 lbmol/(0.45359 kmol)) = 3307 lb mol/h. V, W_V, L, and W_L are the values in Example 2-4 divided by 0.45359. The conversion factor divides out in F_{lv} term. Thus, F_{lv}, K_{drum}, and u_{perm} are the same as in Example 2-4. The Area increases because V increases: Area = $Area_{Example\ 2\text{-}4}$/0.45359 = 16.047/0.45359 = 35.38 ft^2.

$$Diameter \quad \sqrt{4\ Area\ /} \quad 6.71\ feet$$

Probably round this off to 7.0 feet and use a drum height of 28 feet.

b. $F_{parallel}$ = 3307 – 1500 = 1807 lbmol/h.

F_{lv}, K_{drum}, and u_{perm} are the same as in Example 2-4. $V_{parallel}$ = (V/F) $F_{parallel}$ = 0.51 (1807) = 921.6 kmol/h.

$A_c = 16.047 \dfrac{V_{parallel}}{V_{Example\_2\ 4}} = 16.047\ (921.6 / 765) = 19.33\ ft^2$

Then, $Diameter = \sqrt{4\ Area / \pi} = 4.96\ feet$, Use a 5.0 feet diameter and a length of 20 feet.

2.D24. p = 300 kPa At any T. $K_{C3} = y_{C3} / x_{C3}$, K's are known. $K_{C6} = y_{C6} / x_{C6} = (1 - y_{C3}) / (1 - x_{C3})$

Substitute 1st equation into 2nd $K_{C6} = (1 - K_{C3}\, x_{C3}) / (1 - x_{C3})$

Solve for x_{C3}, $(1 - x_{C3})\, K_{C6} = 1 - K_{C3}\, x_{C3}$, $x_{C3}\,(K_{C3} - K_{C6}) = 1 - K_{C6}$

$$x_{C3} = \frac{1 - K_{C6}}{K_{C3} - K_{C6}} \quad \& \quad y_{C3} = \frac{K_{C3}\,(1 - K_{C6})}{K_{C3} - K_{C6}}$$

At 300 kPa pure propane $K_{C3} = 1.0$ boils at -14°C (Fig. 2-10)

At 300 kPa pure n-hexane $K_{C6} = 1.0$ boils at 110°C

Check: at -14°C $x_{C3} = \dfrac{1 - K_{C6}}{1 - K_{C6}} = 1$, $y_{C3} = \dfrac{1\,(1 - K_{C6})}{1 - K_{C6}} = 1.0$

at 110°C $x_{C3} = \dfrac{0}{K_{C3} - 1} = 0$, $y_{C3} = \dfrac{K_{C3}\,(0)}{K_{C3} - 1} = 0$

Pick intermediate temperatures, find K_{C3} & K_{C6} , calculate x_{C3} & y_{C3} .

T	K_{C3}	K_{C6}	x_{C3}	$y_{C3} = K_{C3}\, x_{C3}$	
0°C	1	0.(	$\frac{1 - 0.02}{1.45 - 0.(}$ 0.684	0	See Graph
10°C	[illegible]	0.(	0.4	0	
20°C	[illegible]	0.(	0.3	0	
30°C	3	0.	0.2	0	
40°C	3	(	0.2	(	
50°C	4	(	0.1	(	
60°C	5	(	0.1	(	
70°C	6.4	0.38	0.103	0.659	

b. $x_{C3} = 0.3$, $V/F = 0.4$, $L/V = 0.6/0.4 = 1.5$

Operating line intersects $y = x = 0.3$, Slope $= -1.5$

$y = -\dfrac{L}{V} x + \dfrac{F}{V} z$ at $x = 0$, $y = \dfrac{F}{V} z = \dfrac{0.3}{0.4} = 0.75$

Find $y_{C3} = 0.63$ and $x_{C3} = 0.062$

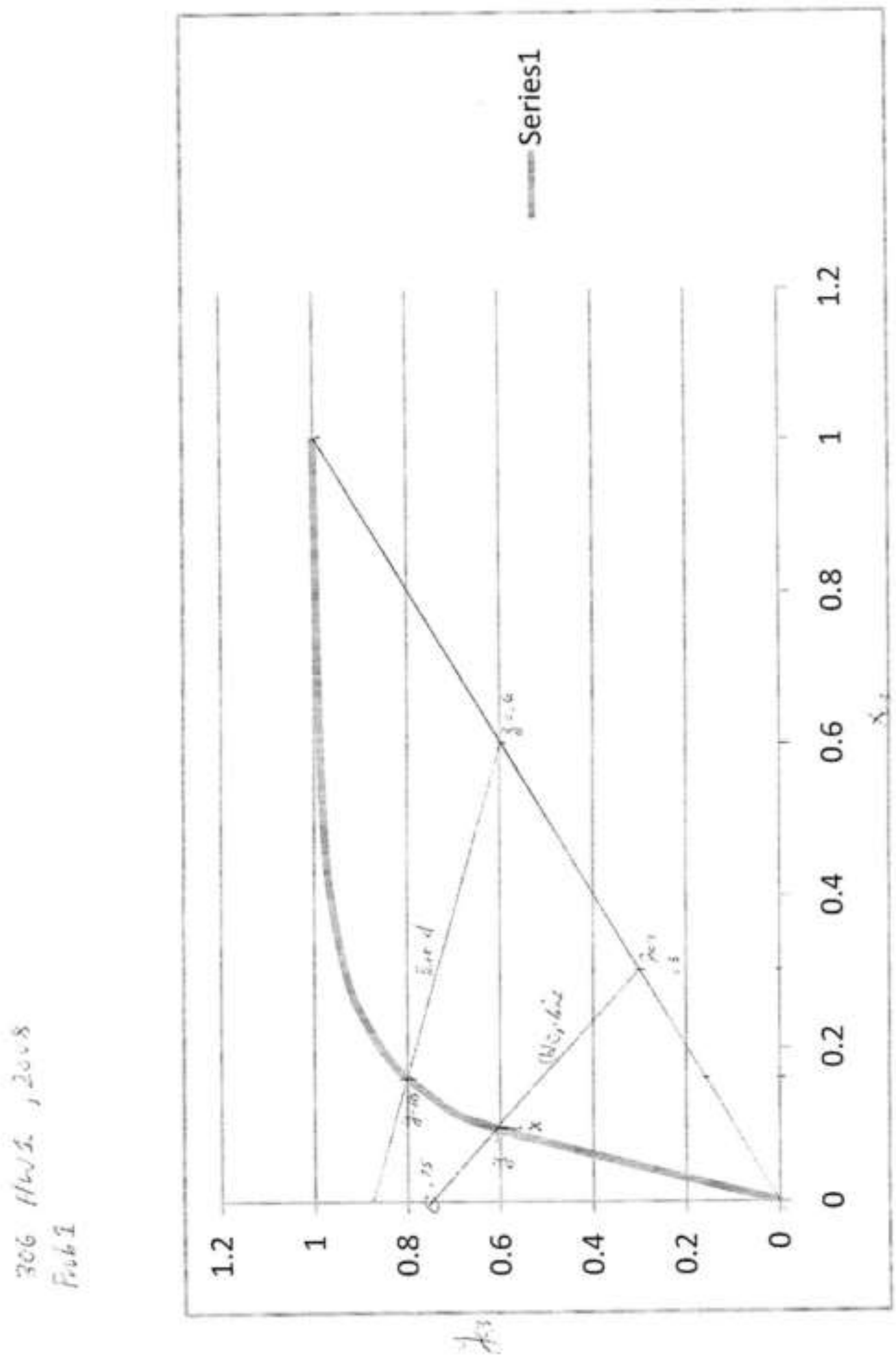
Check with operating line: 0.63 = −1.5 (.062) + 0.75 = 0.657 OK within accuracy of the graph.

c. Drum T: $K_{C3} = y_{C3} / x_{C3} = 0.63 / 0.062 = 10.2$, DePriester Chart T = 109ºC

d. $y = .8$, $x \sim .16$ Slope $= -\dfrac{L}{V} = \dfrac{\Delta y}{\Delta x} = \dfrac{.8 - .6}{.16 - .6}$

V/F = f =1/1.45 = 0.69

$$0.45 \qquad \frac{1\ \ f}{f}.45$$


Series1
0
0.2
0.4
0.6
0.8
1
1.2

2.D25. 20% Methane and 80% n-butane. T_{drum} .50 ºC , $\frac{V}{F}$ 0.40 , Find p_{drum}

$$0 \; f\frac{V}{F} \quad \frac{K_A \;\; 1 \; z_A}{1 \;\; K_A \;\; 1 \; \frac{V}{F}} \quad \frac{K_B \;\; 1 \; z_B}{1 \;\; K_B \;\; 1 \; \frac{V}{F}}$$

Pick p_{drum} 1500 kPa: K_{C4} 13 K_{nC4} 0.4

(Any pressure with K_{C1} 1 and K_{C4} 1.0 is OK)

Trial 1 $f_1 \quad \frac{12 \;.2}{1 \;\; 12 \;.4} \quad \frac{.6 \;\; .8}{1 \;\; .6 \;.4} \; 0.2178$ Need lower p_{drum}

$$K_{C4} \; P_{new} \quad \frac{K_{C4} \;\; P_{old}}{1 \;\; d\,f \;\; P_{old}} \quad \frac{0.4}{1 \;\; .2138} \; 0.511 \text{ with } d = 1.0$$

P_{new} 1160 $\quad K_{C1}$ 16.5 , $f_2 \quad \frac{15.5 \;\; .2}{1 \;\; 15.5 \;.4} \quad \frac{.489 \;.8}{1 \;\; .489 \;\; .4} \; 0.4305 \;\; .4863 \quad 0.055769$

$$K_{C4} \; P_{new} \quad \frac{0.511}{1 \;\; 0.055769} \; 0.541 , \;\; P_{new} \;\; 1100, \; K_{C1} \;\; 17.4$$

$$f_3 \quad \frac{16.4 \;.2}{1\,16.4 \;\; .4} \quad \frac{.459 \;\; .8}{1 \;\; .459 \;\; .4} \; 0.0159$$, OK. Drum pressure = 1100 kPa

b.) $x_i \quad \frac{z_i}{1 \;\; K_i \;\; 1 \;\; \frac{V}{F}} , \quad x_{C1} \quad \frac{0.2}{1 \;\; 16.4 \;\; .4} \; 0.02645$

$$y_{C1} \quad K_{C1} \; x_{C1} \quad 17.4 \;\; 0.02645 \;\; 0.4603$$

2.D26. a) Can solve for L and V from M.B. 100 = F = V + L

45 Fz 0.8V 0.2162L

L = 59.95 and V = 40.05

Find: y

b) Stage is equil. $K_{C3} \quad \frac{y_{C3}}{x_{C3}} \quad \frac{0.8}{0.2162}$ 3.700 , $K_{C5} \quad \frac{0.2}{0.7838}$ .2552

These K values are at same T, P. Find these 2 K values on DePriester chart.

Draw straight line between them. Extend to T_{drum} , p_{drum} . Find 10ºC, 160 kPa.

2.D27. a.) VP_{C5} : $\log_{10}$ VP 6.853 $\frac{1064.8}{0 \;\; 233.01}$ 2.2832 , VP 191.97 mmHg

b.) VP 3 760 2280 mmHg , $\log_{10}$ VP 6.853 1064.8 / T 233.01

Solve for T = 71.65ºC

c.) $P_{tot}\ \ 191.97$ mm Hg [at boiling for pure component $P_{tot}\ \ VP$]

d.) C5: $\log_{10} VP\ \ 6.853\ \ -\frac{1064.8}{30\ \ 233.01}\ \ 2.8045$, $VP\ \ 637.51$ mm Hg

$$K_{C5}\ \ VP_{C5}/P_{tot}\ \ 637.51/500\ \ 1.2750$$

$$C6:\ \log_{10} VP_{C6} \quad 6.876 \quad \frac{1171.17}{30 \quad 224.41} \quad 2.2725 \quad , \quad VP_{C6} \quad 187.29 \text{ mm Hg}$$

$$K_{C6} \quad 187.29/500 \quad 0.3746$$

e.) $K_A \quad y_A / x_A \qquad K_B \quad y_B / x_B \quad (1 \quad y_A)/(1 \quad x_A)$

If K_A & K_B are known, two eqns. with 2 unknowns K_A & y_A Solve.

$$x_{C5} \quad \frac{1 \quad K_{C6}}{K_{C5} \quad K_{C6}} \quad \frac{1 \quad 0.3746}{1.2750 \quad 0.3746} \quad 0.6946$$

$$y_{C5} \quad K_{C5}\, x_{C5} \quad 1.2750 \quad 0.6946 \quad 0.8856$$

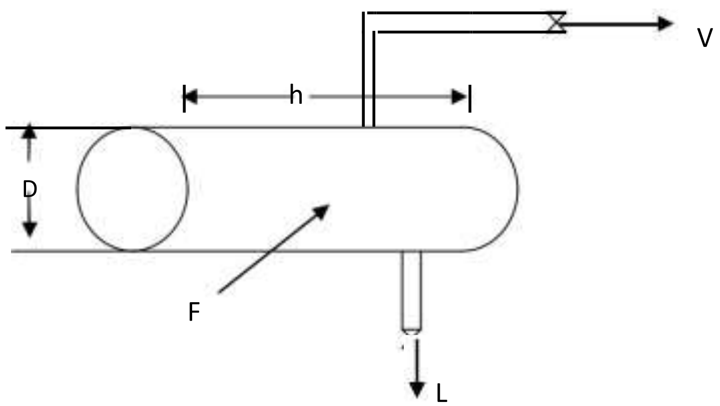
f.) Overall, M.B., F = L + V or 1 = L + V

$C5: Fx_F \quad Lx \quad Vy \qquad .75 \quad 0.6946 L + 0.8856 V$

Solve for L & V: L = 0.7099 & V = 0.2901 mol

g.) Same as part f, except units are mol/min.

2.D28.



From example 2-4, $x_H \quad 0.19$, $T_{drum} \quad 378K$, $V/F \quad 0.51$, $y_H \quad 0.6$, $z_H \quad 0.40$

MW_v = 97.39 lbm/lbmole (Example 2-4)

$$\rho_v \quad 3.14 \quad 10^{3} \text{ g/mol} \left| \frac{1}{454 g/lbm} \right| \frac{28316.85 cm^3}{ft^3} \quad 0.198 \quad \frac{lbm}{ft^3}$$

Example 2.4

$$u_{perm} \quad K_{drum} \sqrt{\frac{\rho_L \quad \rho_v}{\rho_v}} , \qquad K_{horiz} \quad 1.25\, K_{vertical}$$

From Example 2-4, $K_{vertical} \quad 0.4433$, $K_{horiz} \quad 1.25 \quad 0.4433 \quad 0.5541$

$$u_{perm} \quad 0.5541 \left(\frac{0.6960 \quad 0.00314}{0.00314}\right)^{1/2} \quad 8.231 \text{ ft/s}$$ [densities from Example 2-4]

$$V = \frac{V}{F} F = 0.51 \left(3000 \frac{lbmol}{h}\right) = 1530\ lbmol/h$$

$$A_{vap} = \frac{1530 \frac{lbmol}{h} \left(97.39 \frac{lbm}{lbmole}\right)}{8.231 \frac{ft}{s}\left(3600 \frac{s}{h}\right)\left(0.1958 \frac{lbm}{ft^3}\right)} = 25.68\ ft^2$$

$$A_{total} = A_{vap}/0.2 = 128.4 ft^3,\ D_{min} = \sqrt{4A_{total}/\pi} = 12.8 ft$$

$$V_{liq} = \frac{160,068}{43.41} \frac{5}{60\ min/h} = 8603.8 ft^3,\ h = \frac{5V_{liq}}{\pi D^2} = 83.51 ft \text{ and } h/D = 6.5.$$

2.D29. The stream tables in Aspen Plus include a line stating the fraction vapor in a given stream. Change the feed pressure until the feed stream is all liquid (fraction vapor = 0). For the Peng-Robinson correlation the appropriate pressure is 74 atm.

The feed *mole* fractions are: methane = 0.4569, propane = 0.3087, n-butane = 0.1441, i-butane = 0.0661, and n-pentane = 0.0242.

b. At 74 atm, the Aspen Plus results are; L = 10169.84 kg/h = 201.636 kmol/h, V = 4830.16 kg/h = 228.098 kmol/h, and T_{drum} = -40.22 ^oC.

The vapor mole fractions are: methane = 0.8296, propane = 0.1458, n-butane = 0.0143, i-butane = 0.0097, and n-pentane = 0.0006.

The liquid mole fractions are: methane = 0.0353, propane = 0.4930, n-butane = 0.2910, i-butane = 0.1298, and n-pentane = 0.0509.

c. Aspen Plus gives the liquid density = 0.60786 g/cc, liquid avg MW = 50.4367, vapor density = 0.004578 g/cc = 4.578 kg/m^3, and vapor avg MW = 21.17579 g/mol = kg/kmol.

The value of u_{perm} (in ft/s) can be determined by combining Eqs. (2-64), (2-65) and (2-69)

$F_{lv} = (W_L/W_V)[\rho_V/\rho_L]^{0.5} = (10169.84/4830.16)[0.004578/0.60786]^{0.5} = 0.18272$

Resulting $K_{vertical}$ = 0.378887 , $K_{horizontal}$ = 0.473608, and u_{perm} = 5.436779 ft/s = 1.657m/s

$$A_{vap} = \frac{4830.16 \frac{kg}{h}}{1.657 \frac{m}{s}\left(3600 \frac{s}{h}\right)\left(4.578 \frac{kg}{m^3}\right)} = 0.177\ m^2$$

$$A_{total} = A_{vap}/0.2 = 0.884 m^3,\ D_{min} = \sqrt{4A_{total}/\pi} = 1.06 m$$

$$h/D = 6 = \frac{5V_{liq}}{\pi D^2},\ \text{thus } V_{liq} = 6\pi D^3/5 = 4.23 m^3$$

$$V_{liq} = (Volrate)(holdtime + surgetime) = \left(\frac{10169.84 kg/h}{607.86 kg/m^3}\right)(9/60\ st)$$

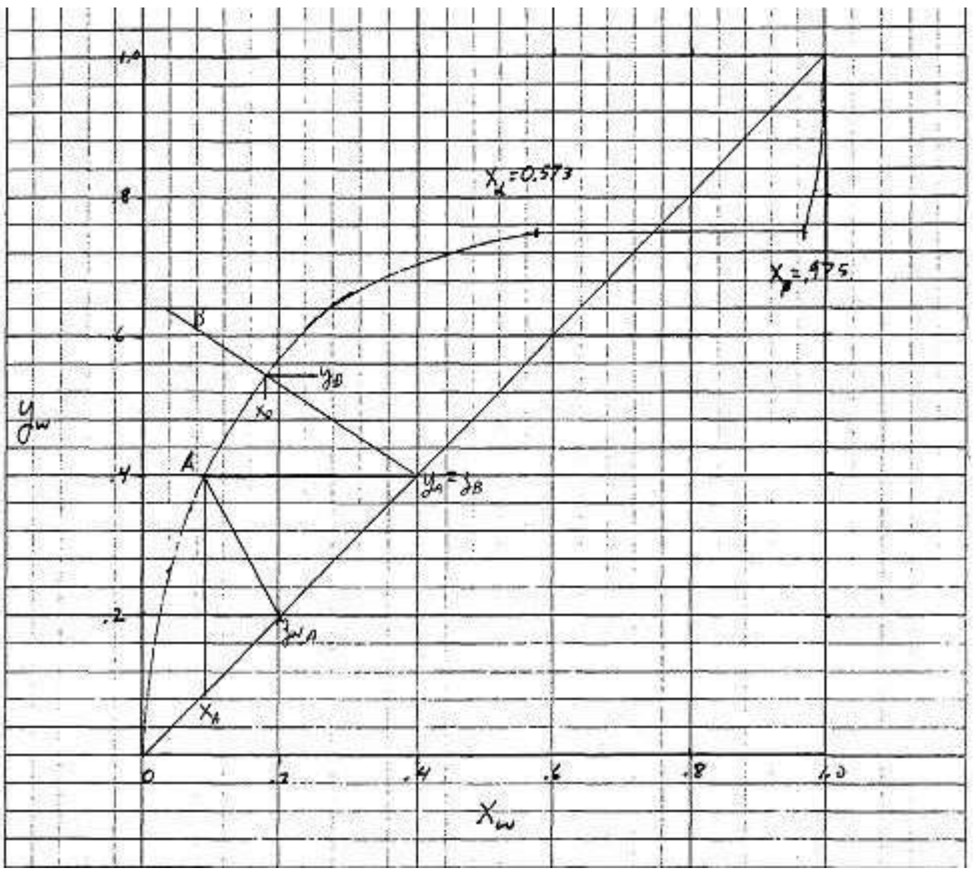
$$st = 607.86 V_{liq}/10169.84\ 9/60 = 0.103 hours = 6.18\ min$$

2.D30.. a. From the equilibrium data if y_A = .40 mole fraction water, then x_A = 0.09 mole fraction water. Can find L_A and V_A by solving the two mass balances for stage A simultaneously.
$L_A + V_A = F_A = 100$ and $L_A (.09) + V_A (.40) = (100) (.20)$. The results are $V_A = 35.48$ and $L_A = 64.52$.

b. In chamber B, since 40 % of the vapor is condensed, $(V/F)_B = 0.6$. The operating line for this flash chamber is,

$y = -(L/V)x + F_B/V)\, z_B$ where $z_B = y_A = 0.4$ and $L/V + .4F_B/.6F_B = 2/3$. This operating line goes through the point $y = x = z_B = 0.4$ with a slope of -2/3. This is shown on the graph. Obtain $x_B = 0.18$ & $y_B = 0.54$. L_B = (fraction condensed)(feed to B) = 0.4(35.48) = 14.19 kmol/h and $V_B = F_B - L_B = 21.29$.

c. From the equilibrium if $x_B = 0.20$, $y_B = 0.57$. Then solving the mass balances in the same way as for part a with $F_B = 35.48$ and $z_B = 0.4$, $L_B = 16.30$ and $V_B = 19.18$. Because $x_B = z_A$, recycling L_B does not change $y_B = 0.57$ or $x_A = 0.09$, but it changes the flow rates $V_{B,new}$ and $L_{A,new}$. With recycle these can be found from the overall mass balances: $F = V_{B,new} + L_{A,new}$ and $Fz_A = V_{B,new}y_B + L_{A,new}\, x_A$. Then $V_{B,new} = 22.92$ and $L_{A,new} = 77.08$.



Graph for problem 2.D30.

2.D31. *New problem in 4th US edition. Was 2.D13 in 3rd International Edition.*

a) Since K's are for mole fractions, need to convert feed to mole fractions.

Basis: 100 kg feed

50 kg n C_4	$\frac{1\ \text{kmol}}{58.12\ \text{kg}}$	0.8603 kmol	z_4 0.555
50 kg n C_5	$\frac{1\ \text{kmol}}{72.5\ \text{kg}}$	0.6897 kmol n C_5	z_5 0.445
	Total	1.5499 kmol	

DePriester Chart $K_{C4} = 2.05$, $K_{C5} = 0.58$, Result similar if use Raoult's law .

$$\frac{V}{F} = \frac{0.555}{0.58-1} + \frac{0.445}{1.05} = 1.3214 - 0.424 = 0.8976$$

Check $f = \frac{1.05(.555)}{1+.05(.8976)} + \frac{-.42(.445)}{1-.42(.8976)} = 0.3000 - .29999 \approx 0$ OK

Eq. 3.23 $x_{C4} = \frac{z_{C4}}{1+(K_{C4}-1)V/F} = \frac{.555}{1+1.05(.8976)} = 0.2857$,

$x_{C5} = .7143$, $y_{C4} = K_{C4}x_{C4} = 0.5857$, $y_{C5} = 0.4143$

b) From problem 2.D.g., $K_{C4} = 1.019$ and $K_{C5} = 0.253$.
Solving RR equation,

$$\frac{V}{F} = \frac{z_A}{K_B - 1} + \frac{z_B}{K_A - 1} = \frac{.555}{0.253-1} + \frac{0.445}{0.019} = 23.28$$

NOT possible. Won't flash at 0ºC.

2.D32. *New problem in 4th US edition. Was 2.D28 in 3rd International Edition.*

$V/F_A = 2/3$, $L/V = \frac{1/3}{2/3} = 1/2$ Slope $= -1/2$ Through $y = x = z_A = 0.6$ See figure

a. $L_A = \frac{1}{3}F = 33.33$, $x_{M,A} = 0.375$ (from Figure) $V_A = \frac{2}{3}F = 66.67$, $y_{M,A} = 0.72$ (from Figure)

$$\left.\frac{V}{F}\right|_B = 0.4 \qquad \left.\frac{L}{V}\right|_B = \frac{1-f}{f} = \frac{0.6}{0.4} = 1.5$$

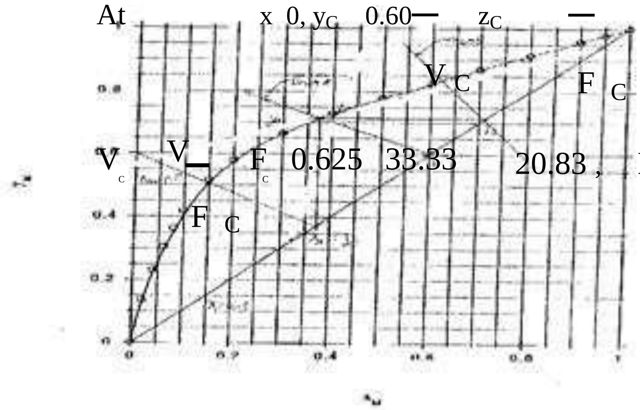
Through $y = x = z_B = y_A = 0.72$

$V_B = 0.4F_B = 0.4V_A = 0.4(66.67) = 26.67$, $L_B = 0.6F_B = 0.6(66.67) = 40.00$

b. $z_C = x_A = 0.375$, $x_C = 0.15$, $F_C = L_A = 33.33$, From equilibrium $y_C = 0.51$

At $x = 0$, $y_C = 0.60 = \frac{F}{V}z_C$, $\frac{V}{F_C} = \frac{z_C}{y_C} = \frac{0.375}{0.6} = 0.625$

$V_C = \frac{V}{F_C}F_C = 0.625(33.33) = 20.83$, $L_C = F_C - V_C = 33.33 - 20.83 = 12.5$



2.E1. From Aspen Plus run with 1000 kmol/h at 1 bar, L = V = 500 kmol/h, W_L = 9212.78 kg/h, W_V = 13010.57 kg/h, liquid density = 916.14 kg/m^3 , liquid avg MW = 18.43, vapor density = 0.85 kg/m^3 , and vapor avg MW = 26.02, T_{drum} = 94.1 ^oC, and Q = 6240.85 kW.

The diameter of the vertical drum in meters (with u_{perm} in ft/s) is

$D = \{[4(MW_V) V]/[3600\ \pi\ \rho_V\ u_{perm}\ (1\ m/3.281\ ft)]\}^{0.5} = \{[4(26.02)(500)]/[3600(3.14159)(0.85)(1/3.281)u_{perm}]\}^{0.5}$

$F_{lv} = (W_L/W_V)[\rho_V/\rho_L]^{0.5} = (9212.78/13010.57)[0.85/916.14]^{0.5} = 0.02157$

Resulting $K_{vertical}$ = 0.404299, and u_{perm} = 13.2699 ft/s, and D = 1.16 m. Appropriate standard size would be used. Mole fractions isopropanol: liquid = 0.00975, vapor = 0.1903

b. Ran with feed at 9 bar and p_{drum} at 8.9 bar with V/F = 0.5. Obtain W_L = 9155.07 kg/h, W_V = 13068.27, density liquid = 836.89, density vapor = 6.37 kg/m^3

$D = \{[4(MW_V) V]/[3600\ \pi\ \rho_V\ u_{perm}\ (1\ m/3.281\ ft)]\}^{0.5} = \{[4(26.14)(500)]/[3600(3.14159)(6.37)(1/3.281)u_{perm}]\}^{0.5}$

$F_{lv} = (W_L/W_V)[\rho_V/\rho_L]^{0.5} = (9155.07/13068.27)[6.37/836.89]^{0.5} = 0.06112$

Resulting $K_{vertical}$ = .446199, u_{perm} = 5.094885 ft/s, and D = 0.684 m. Thus, the method is feasible.

c. Finding a pressure to match the diameter of the existing drum is trial and error. If we do a linear interpolation between the two simulations to find a pressure that will give us D = 1.0 m (if linear), we find p = 3.66. Running this simulation we obtain, W_L = 9173.91 kg/h, W_V = 13049.43, density liquid = 874.58, density vapor = 2.83 kg/m^3, MW_v = 26.10

$D = \{[4(MW_V) V]/[3600\ \pi\ \rho_V\ u_{perm}\ (1\ m/3.281\ ft)]\}^{0.5} = \{[4(26.10)(500)]/[3600(3.14159)(2.83)(1/3.281)u_{perm}]\}^{0.5}$

$F_{lv} = (W_L/W_V)[\rho_V/\rho_L]^{0.5} = (9173.91/13049.43)[2.83/874.58]^{0.5} = 0.0400$

Resulting $K_{vertical}$ = .441162, u_{perm} = 7.742851 ft/s, and D = 0.831 m.

Plotting the curve of D versus p_{drum} and setting D = 1.0, we interpolate p_{drum} = 2.1 bar At p_{drum} = 2.1 bar simulation gives, W_L = 9188.82 kg/h, W_V = 13034.53, density liquid = 893.99 , density vapor = 1.69 kg/m^3, MW_v = 26.07.

$D = \{[4(MW_V) V]/[3600\ \pi\ \rho_V\ u_{perm}\ (1\ m/3.281\ ft)]\}^{0.5} = \{[4(26.07)(500)]/[3600(3.14159)(1.69)(1/3.281)u_{perm}]\}^{0.5}$

$F_{lv} = (W_L/W_V)[\rho_V/\rho_L]^{0.5} = (9188.82/13034.53)[1.69/893.99]^{0.5} = 0.0307$

Resulting $K_{vertical}$ = .42933, u_{perm} = 9.865175ft/s, and D = 0.953 m.

This is reasonably close and will work OK. T_{drum} = 115.42 ^oC, Q = 6630.39 kW,
Mole fractions isopropanol: liquid = 0.00861, vapor = 0.1914

In this case there is an advantage operating at a somewhat elevated pressure.

2.E2. This problem was 2.D13 in the 2nd edition of *SPE*.

a. Will show graphical solution as a binary flash distillation. Can also use R-R equation. To generate equil. data can use

$x_{C6} + x_{C8} = 1.0$, and $y_{C6} + y_{C8} = K_{C6}\, x_{C6} + K_{C8}\, x_{C8} = 1.0$

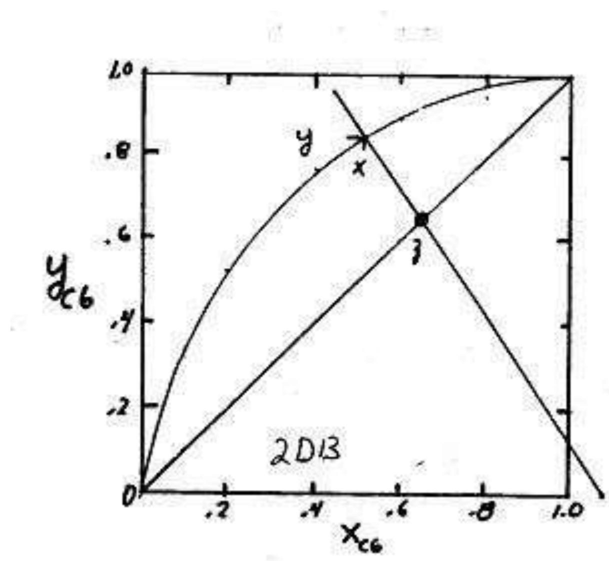
Substitute for x_{C6} $\quad x_{C6} = \dfrac{1 - K_{C8}}{K_{C6} - K_{C8}}$

Pick T, find K_{C6} and K_{C8} (e.g. from DePriester charts), solve for x_{C6}. Then $y_{C6} = K_{C6} x_{C6}$

T°C	K_{C6}	K_{C8}	x_{C6}	$y_{C6} = K_{C6}\, x_{C6}$
125	4	1.0	0	0
120	3.7	.	.0357	.321
110	3.0	.	.1379	.141
100	2.37	.	.2595	.615
90	1.8	.	.4406	.793
80	1.4	.	.650	.909
66.5	1.0	.17	1.0	1.0

Op Line Slope $-\dfrac{L}{V} = -\dfrac{1 - V/F}{V/F} = -\dfrac{.6}{.4} = -1.5$, Intersection y = x = z = 0.65.

See Figure. y_{C6} = 0.85 and x_{C6} = 0.52. Thus K_{C6} = .85/.52 = 1.63.
This corresponds to T = 86°C = 359K



b. Follows Example 2-4.

$\overline{MW}_L = x_{C6}\, MW_{C6} + x_{C8}\, MW_{C8} = .52(86.17) + .48(114.22) = 99.63$

$\overline{V}_L = x_{C6} \dfrac{MW_{C6}}{\rho_{C6}} + x_{C8} \dfrac{MW_{C8}}{\rho_{C8}} = .52 \left(\dfrac{86.17}{.659}\right) + .48 \left(\dfrac{114.22}{.703}\right) = 145.98 \text{ ml/mol}$

$\rho_L = \dfrac{\overline{MW}_L}{\overline{V}_L} = \dfrac{99.63}{145.98} = .682 \text{ g/ml} \dfrac{28316 \text{ ml/ft}^3}{} = 42.57 \dfrac{\text{lbm}}{\text{ft}^3}$

V_L	145.98	454 g/lbm	ft

$\overline{MW}_v = y_{C6}\, MW_{C6} + y_{C8}\, MW_{C8} = (.85)(86.17) + (.15)(114.22) = 90.38$

$$\rho_v = \frac{p\overline{MW}_v}{RT} = \frac{(1.0)(90.38\ \text{g/mol})}{\left(82.0575\ \frac{\text{ml atm}}{\text{mol K}}\right)(359\text{K})} = 0.00307\ \text{g/ml} = 0.19135\ \text{lbm/ft}^3$$

Now we can determine flow rates

$$V = \frac{V}{F}\,F = (.4)(10{,}000) = 4000\ \text{lbmol/h}$$

$$W_v = V\,\overline{MW}_v = (4000)(90.38) = 361{,}520\ \text{lb/h}$$

$L = F - V = 6000$ lbmol/h, $W_L = L\,\overline{MW}_L = (6000)(99.63) = 597{,}780$ lb/h

$$F_{lv} = \frac{W_L}{W_v}\sqrt{\frac{\rho_v}{\rho_L}} = \frac{597{,}780}{361{,}520}\sqrt{\frac{0.19135}{42.57}} = 0.111, \quad \ln F_{lv} = -2.1995$$

$$K_{drum} = \exp[-1.87748 - .81458(-2.1995) - .18707(-2.1995)^2 - 0.01452(-2.1995)^3 + 0.00101(-2.1995)^4] = 0.423$$

$$u_{Perm} = K_{drum}\sqrt{(\rho_L - \rho_v)/\rho_v} = 0.423\sqrt{(42.57 - .19135)/.19135} = 6.30\ \text{ft/s}$$

$$A_{Cs} = \frac{V\,\overline{MW}_v}{u_{Perm}\,(3600)\,\rho_v} = \frac{(4000)(90.38)}{(6.3)(3600)(0.19135)} = 83.33\ \text{ft}^2$$

$$D = \sqrt{4A_{Cs}/\pi} = \sqrt{4(83.33)/\pi} = 10.3\ \text{ft. Use 10.5 ft.}$$

L ranges from 3 × 10.5 = 31.5 ft to 5 × 10.5 = 52.5 ft.

Note: This u_{Perm} is at 85% of flood. If we want to operate at lower % flood (say 75%)

$u_{Perm\ 75\%} = (0.75/0.85)\, u_{Perm85\%} = (0.75/0.85)(6.3) = 5.56$ Then at

75% of flood, A_{Cs} = 94.44 which is D = 10.96 or 11.0 ft.

2.E3. *New problem 4th edition.* The difficulty of this problem is it is stated in weight units, but the VLE data is in molar units. The easiest solution path is to work in weight units, which requires converting some of the equilibrium data to weight units and replotting – good practice. The difficulty with trying to work in molar units is the ratio L/V = 0.35/0.65 = 0.5385 in weight units becomes in molar units,

$$\frac{L_{molar}}{V_{molar}} = \frac{L_{wt}}{V_{wt}}\frac{(MW)_{vapor}}{(MW)_{liquid}}$$, but x and y are not known the molecular weights are unknown.

In weight units, V = F(V/F) =2000 kg/h (0.35) = 700 kg/h. L = F – V = 1300 kg/h.

In weight units the equilibrium data (Table 2-7) can be converted as follows:

Basis: 1 mol, x = 0.4 and y = 0.729, T = 75.3 C

Liquid: 0.4 mol methanol ×32.04 g/mol = 12.816 g

0.6 mol water × 18.016 g/mol = 10.806 g

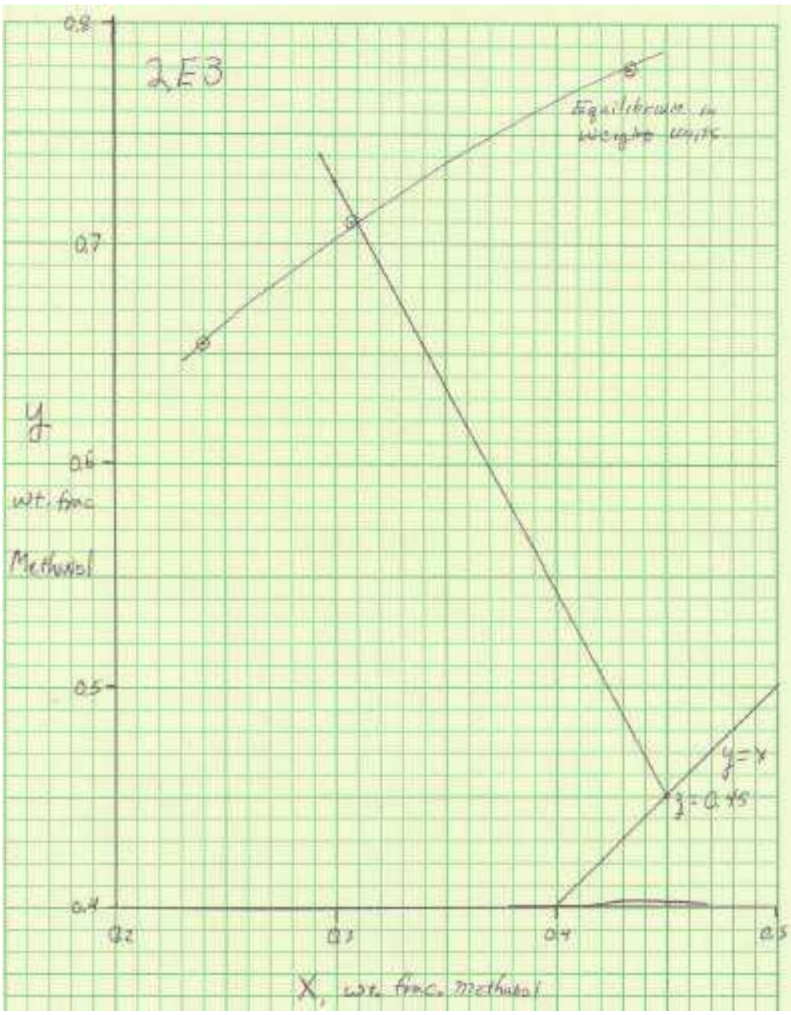
Total = 23.622 g → x = 0.5425 wt frac methanol

Vapor: 0.729 mol methanol = 23.357 g
0.271 mol water = 4.881 g
28.238 g → y = 0.8271 wt frac methanol.

Similar calculations for: 0.3 mole frac liquid give x_{wt} = 0.433 and y_{wt} = 0.7793, T = 78.0 C 0.2
mole frac liquid give x_{wt} = 0.3078 and y_{wt} = 0.7099, T = 81.7 C
0.15 mole frac liquid give x_{wt} = 0.2389 and y_{wt} = 0.6557, T = 84.4 C.

Plot this data on y_{wt} vs x_{wt} diagram. Operating line is y = - (L/V)x +(F/V)z in weight units.
Slope = - 1.857, y =x = z = 0.45, and y intercept = z/(V/F) = 1.286 all in weight units.

Result is $x_{M,wt}$ = 0.309, $y_{M,wt}$ = 0.709 (see graph). Note that plotting only the part of the graph needed to solve the problem, the scale could be increased resulting in better accuracy. By linear interpolation T_{drum} = 81.66 C.



2.F1

x_B	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1
y_B	0	.22	.38	.52	.62	.71	.79	.85	.91	.96	1

Benzene-toluene equilibrium is plotted in Figure 13-8 of *Perry's Chemical Engineers Handbook*, 6^{th} ed.

2.F2. See Graph. Data is from *Perry's Chemical Engineers Handbook*, 6^{th} ed., p. 13-12.

Stage 1) z_{F_1} .4 f 1 3 Slope $\frac{2/3}{1/3}$ 2,

Intercept $\frac{.4}{1/3}$ 1.2 y_1 .872 x_1 .164 z_2

Stage 2) z_{F_2} .164 f 2/3 Slope $\frac{1/3}{2/3}$. 1/2

Intercept $\frac{.164}{2/3}$ .246 x_2 .01 y_2 .240 z_3

Stage 3) z_{F_3} .240 f 1/2 Slope 1

Intercept $\frac{.240}{1/2}$ .480 x_3 .022 y_3 .461

2.F3. *Bubble Pt.* At P = 250 kPa. Want $K_1 z_1$ 1 .Solution uses DePriester chart for K values.

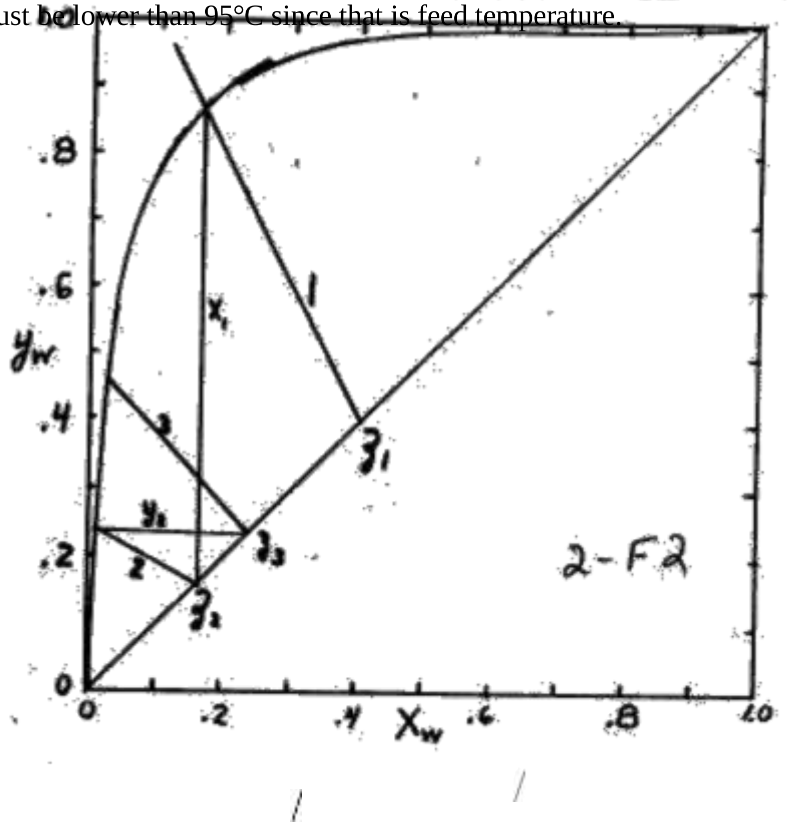
Guess T 18 C, K_1 1, K_2 .043, K_3 .00095, .52

Converge to T 0 C

Dew Pt. Calc. Want $\frac{z_1}{K_1}$ 1.0

Try T 0 C, K_1 1.93, K_2 0.11, K_3 0.0033, 120.26

Converge to $T \approx 124$ C . This is a wide boiling feed.
T_{drum} must be lower than 95°C since that is feed temperature.



First Trial: Guess $T_{d,1}$ 70 C : K_1 7.8, K_2 1.07, K_3 .083

Guess V/F 0.5 . Rachford Rice Eq.

$$f\,V/F \quad \frac{7.8\ 1\ .517}{1\ \ 6.8\ \ .5} \quad \frac{.07\ \ .091}{1\ \ .07\ \ .5} \quad \frac{.083\ \ 1\ \ .392}{1\ \ .083\ \ 1\ \ .5} \ .14$$

V/F .6 gives f .6 .101

By linear interpolation: V/F .56. f 0.56 .0016 which is close enough for first trial.

V V F/F 56, L 44

$$x_i \quad \frac{z_i}{1\ \ K_i\ \ \ 1\ V\,F} \quad \text{and } y_i \quad K_i\, x_i$$

x_1 .1075 x_2 .088 x_3 .806 x 1.001

y_1 .839 y_2 .094 y_3 .067 y .9999

Data: Pick T_{ref} 25 C . (Perry's 6[th] ed; p. 3-127), and (Perry's 6[th] ed; p. 3-138)

$_1$ 81.76 cal/g 44 3597.44 kcal/kmol

$_2$ 87.54 cal/g 72 6302.88 kcal/kmol $_3$

86.80 cal/g 114 9895.2 kcal/kmol

at T 0 C, C_{pL1} 0.576 cal / (g C) 44 25.34 kcal/(kmol C) .

For T 20 to 123 C, C_{pL3} 65.89 kcal/(kmol C)

at T 75 C, C_{pL2} 39.66 kcal/(kmol C) . (Himmelblau/Appendix E-7)

C_{pv} a bT cT^2

propane a = 16.26 b = 5.398×10^{-2} c = -3.134×10^{-5}

n-pentane a = 27.45 b = 8.148×10^{-2} c = -4.538×10^{-5}

**n-octane a = 8.163 b = 140.217×10^{-3} c = -44.127×10^{-6}

** Smith & Van Ness p. 106

Energy Balance: $E(T_d) = VH_v + Lh_L - Fh_F = 0$

Fh_F 100 .577 25.34 .091 39.66 .392 65.89 95.25 297,773 kcal/h

Lh_L 44 .1075 25.34 .088 39.66 .806 65.89 70.25 117, 450

VH_v 56 .839 3597.4 16.26 5.398 10^2 45

0.94 6302.88 27.45 8.148 10^2 45

0.67 9895.3 8.163 140.217 10^3 45240,423

E T_{drum} 60,101 Thus, T_{drum} is too high.

Converge on T_{drum} 57.2 C : K_1 6.4, K_2 .8, K_3 .054

For V/F 0.513, f 0.513 0.0027. V 51.3, L 48.7

x_1 .137, x_2 .101, x_3 .762, x_1 1.0000

y_1 .878, y_2 .081, y_3 .041, y_1 1.0000

Fh_F 297,773; Lh_L 90,459; VH_v 209,999; E T_{drum} 2685

Thus T_{drum} must be very close to 57.3°C.

x_1 .136, x_2 .101, x_3 .762 , y_1 .328, y_2 .081, y_3 .041 V 51.3 kmol/h, L 48.7 kmol/h

Note: With different data T_{drum} may vary significantly.

2.F4. *New Problem 4th edition.* This is a mass and energy balance problem disguised as a flash distillation problem. Data is readily available in steam tables.. At 5000 kPa and 500K the feed is a liquid, h_F = 17.604 kJ/mol. For an adiabatic flash, $h_F = [VH_V + Lh_L]/F$

Vapor and liquid are in equilibrium. Saturated steam at 100 kPa is at T = 372.76K, h_L = 7.5214 kJ/mol, H_V = 48.19 kJ/mol

Mass balance: F = V + L where F in kmol/min = (1500 kg/min)(1 kmol/18.016 kg) = 83.259 kmol/min

EB: $Fh_F = VH_V + Lh_L \rightarrow$

(83.259 kmol/min)(17.604 kJ/mol)(1000 mol/kmol) = (48.19)(1000)V + (7.5214)(1000)L.

Solve equations simultaneously. L = 62.617 kmol/min = 1128.12 kg/min and V = 20.642 kmol/min = 371.88 kg/min

2.G1. Used Peng-Robinson for hydrocarbons.

Find T_{drum} 33.13 C, L 34.82 and V 65.18 kmol/h

In order ethylene, ethane, propane, propylene, n-butane, x_i (y_i) are:

0.0122 0.0748 , 0.0866 0.3005 , 0.3318 0.3781 , 0.0306 0.0404 , 0.5388 0.2062.

2.G2. *New problem in 4th edition.* Part a. p = 31.26 kPa with $V/F)_{feed}$ = 0.0009903.

Part b. Use p_{feed} = 31.76 kPa, $V/F)_{feed}$ = 0.0

Part c. Drum p = 3.9 bar, T_{drmu} = 19.339, V/F = 0.18605,

Liquid mole fractions: C1 = 0.14663, C2 = 0.027869 (∑ = 0.05253 is in spec), C5 = 0.6171, C6 = 0.3404.

Vapor mole fractions: C1 = 0.68836, C2 = 0.20057, C5 = 0.9523, and C6 = 0.01584.

2.G3. *New problem 4th edition.* K values in Aspen Plus are higher by 17.6% (methane), 7.04% (n-butane) and 0.07% n-pentane. Since the K values are higher V/F is higher by 10.2%.

Results:

	x	y	K
Methane	0.004599	0.27039	58.79
n-butane	0.44567	0.52474	1.1774
n-pentane	0.54973	0.20488	0.37269

$V/F)_{drum}$ = 0.43419; $V/F)_{feed}$ = 0.3654; Q = -3183.4 cal/s

2.G4.

COMP	x(I)	y(I)
METHANE	0.12053E-01	0.84824
BUTANE	0.12978	0.78744E-01
PENTANE	0.29304	0.47918E-01
HEXANE	0.56513	0.25101E-01
V/F = 0.58354		

2.G5. *N.* Used NRTL. T = 368.07, Q = 14889 kW, 1st liquid/total liquid = 0.4221,

Comp	Liquid 1, x_1	Liquid 2, x_2	Vapor, y

Furfural	0.630	0.0226	0.0815
Water	0.346	0.965	0.820
Ethanol	0.0241	0.0125	0.0989

2.G6. Used Peng Robinson. Feed pressure = 10.6216 atm, Feed temperature = 81.14^{o}C, V/F = 0.40001, Q_{drum} =0. There are very small differences in feed temperature with different versions of AspenPlus.

COMP	x(I)	y(I)
METHANE	0.000273	0.04959
BUTANE	0.18015	0.47976
PENTANE	0.51681	0.39979
HEXANE	0.30276	0.07086
V/F = 0.40001		

2.H1. *New Problem 4th ed* A. 563.4 R, b.V/F = .4066. c. 18.264 psia

2.H3. *New Problem. 4th ed.* Answer V/F = 0.564; xE = 0.00853, xhex = 0.421, x hept = .570; yE = .421,

y Hex = 0.378, y Hept = .201.

2H4. *New Problem, 4th ed.* Answer: p_{drum} = 120.01, kPa = 17.40 psia

xB = 0.1561, xpen = 0.4255, x hept = 0.4184, yB = 0.5130, yPen = 0.4326 , yhept = 0.0544

2H5. *New problem 4th ed.*

a. SOLUTION. P = 198.52 kPa.
b. V/F = 0.24836, ethane x = 0.00337, y = 0.0824; Propane x =0.05069, y = 0.3539;
   Butane x= 0.1945, y = 0.3536; Pentane x = 0.3295, y = 0.1584; Hexane x = 0.3198, y = 0.0469
   Heptane x = 0.1022, y = 0.00464
c. T = 34.48^{o}C
d. T = -1.586^{o}C and V/F = 0.0567

2H6. New problem in 4th ed.

C2.H6

	A	B	C	D	E	F	G	H	I	J
1										
2	Example 2-2 on spreadsheet									
3	K1	7	K2	2.4	K3	0.8	K4	0.3		
4	z1	0.3	z2	0.1	z3	0.15	z4	0.45		
5	Guess V/F	0.500823								
6	x1	0.074908	x2	0.058784	x3	0.166697	x4	0.692922		
7	y1	0.524353	y2	0.141081	y3	0.12	y4	0.207877	sum ↓	
8	yk-xi	0.449445		0.082297		-0.0467		-0.48505	-2.1E-07	
9								chk	-0.00021	
10		Goal seek 9I to zero by changing B5								