Separation Process Engineering 5th edition Wankat Solutions Manual

SKU: 9780137468126-SOLUTIONS

SPE 5th Edition Solution Manual Chapter 2.

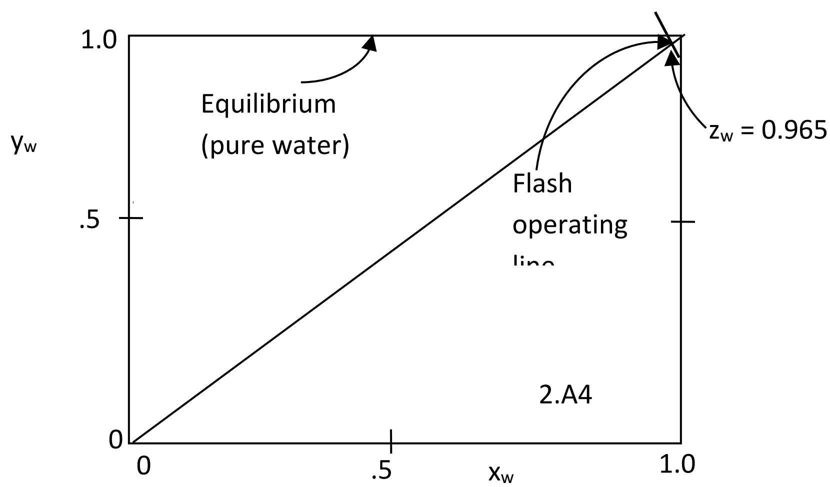
New Problems and new solutions are listed as new immediately after the solution number. These new problems in the 5th edition are: 2D4, 2.D6, 2D13, 2D14, 2D17, 2D23, 2D25, 2D26, 2G1, 2G2, 2G3, 2H5, 2H6, and 2H7. The correlation for sizing flash drums, Eq. (2-62) has been changed to a more recent correlation. As a result problems 2D1e, 2.D12, 2D21, 2D29, 2E1, 2E2 have different solutions.

2.A1. Feed to flash drum is a liquid at high pressure. At this pressure its enthalpy can be calculated as a liquid. eg. $h\left(T_{F,P_{high}}\right) = c_{p_{LIQ}}\left(T_F - T_{ref}\right)$. When pressure is dropped the mixture is above its bubble point and is a two-phase mixture (It "flashes"). Since flashing is an adiabatic process, the 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. . a. At 100ºC 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 -30ºC? 160 kPa

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

b. The answer is 36ºC

c. . 102ºC

2.A10. *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. $\alpha_{M\text{-}W} = K_M/K_W = 2.895/0.52625 = 5.501$.

2.A11. Because of the presence of air this is not a binary system. Also, it is not at equilibrium.

2.A12. 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. Although V is an extensive variable, V/F is an intensive variable and thus satisfies Gibbs phase rule.

2A14. 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.

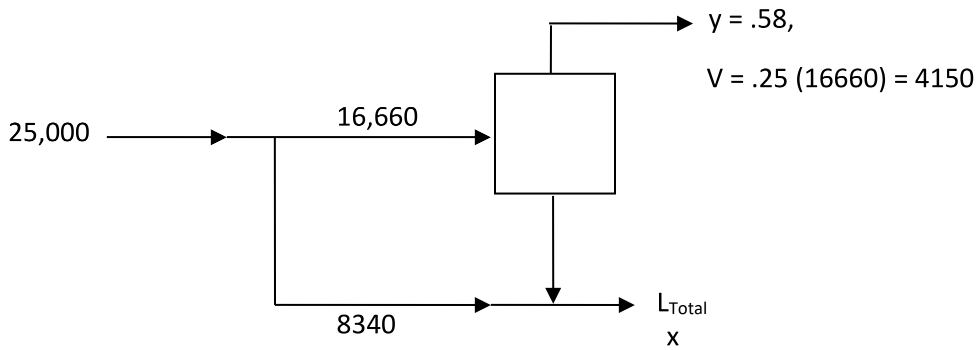
Feed rate drum can handle: F α D^2. $\frac{F_{existing}}{1000} = \left(\frac{D_{exist}}{.98}\right)^2 = \left(\frac{4}{.98}\right)^2$ gives

$F_{existing} = 16{,}660$ 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) Many other alternatives are possible.

2.C2. $$\frac{V}{F} = \left[\frac{-z_A}{(K_B - 1)} - \frac{z_B}{(K_A - 1)}\right]$$

2.C4. 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 $y\left[\frac{V+L}{V}\right] = \frac{F}{V}z$

since V + L = F, the result is y = z and therefore $x = y = z$ **(2-24)**

The intersection is at the feed composition.

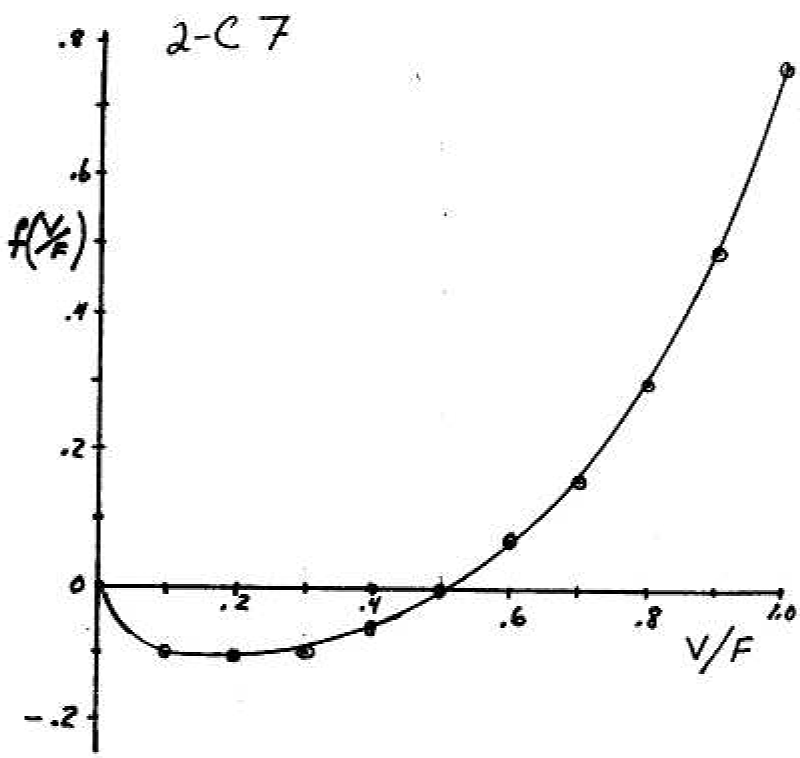
2.C5. a. Start with $x_i = \dfrac{Fz_i}{L + VK_i}$ and let $V = F - L$

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

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.C7. $\sum \dfrac{z_i}{1 + (K_i - 1)\frac{V}{F}} - 1 = f\left(\dfrac{V}{F}\right)$ 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. (2-56) and (2-57). Overall and component mass balances are,

$F = V + L_1 + L_2$ and $Fz_i = L_1 x_{i,L1} + L_2 + x_{i,L2} + Vy_i$ Substituting in Eqs. (2-54b) and 2-54c)

$$Fz_i = L_1K_{i,L1-L2}x_{i,L2} + L_2x_{i,L2} + VK_{iV-L2}x_{i,L2} \quad \text{Solving,}$$

$$x_{i,L2} = \frac{Fz_i}{L_1K_{i,L2} + L_2 + VK_{i,V-L2}} = \frac{Fz_i}{L_1K_{i,L1-L2} + F - V - L_1 + VK_{i,V-L2}}$$

Dividing numerator and denominator by F and collecting terms.

$$x_{i,liq2} = \frac{z_i}{1 + \left(K_{i,L1-L2} - 1\right)\frac{L_1}{F} + \left(K_{i,V-L2} - 1\right)\frac{V}{F}}$$

Since $y_i = K_{i,V-L2}x_{i,L2}$, $y_i = \dfrac{K_{i,V-L2}z_i}{1 + \left(K_{i,L1-L2} - 1\right)\frac{L_1}{F} + \left(K_{i,V-L2} - 1\right)\frac{V}{F}}$

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 $$\sum_{i=1}^{C} \frac{\left(K_{i,V-L2} - 1\right)z_i}{\left[1 + \left(K_{i,L1-L2} - 1\right)\frac{L_1}{F} + \left(K_{i,V-L2} - 1\right)\frac{V}{F}\right]} = 0 \qquad (2\text{-}59)$$

Since $x_{i,liq1} = K_{i,L1-L2}x_{i,liq2}$, we have $x_{i,liq1} = \dfrac{K_{i,L1-L2}z_i}{1 + \left(K_{i,L1-L2} - 1\right)\frac{L_1}{F} + \left(K_{i,V-L2} - 1\right)\frac{V}{F}}$

In addition, $$\sum x_{i,liq1} - \sum x_{i,liq2} = 0 = \sum_{i=1}^{C} \frac{\left(K_{i,L1-L2} - 1\right)z_i}{\left[1 + \left(K_{i,L1-L2} - 1\right)\frac{L_1}{F} + \left(K_{i,V-L2} - 1\right)\frac{V}{F}\right]} \qquad (2\text{-}60)$$

2.D1. *Changed solution to part e.*

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 equilibrium diagram and $y = x = z = 0.3$. $y_{intercept} = zF/V = 1.2$

$V/F = z/1.2 = 0.25$. From equil $y = 0.58$.

d. Plot $x = 0.45$ on equilibrium curve.

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

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

e. Drum dimensions. *Since Eq. (2-59) was changed, answer has changed.*
Find Liquid Density.

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

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

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

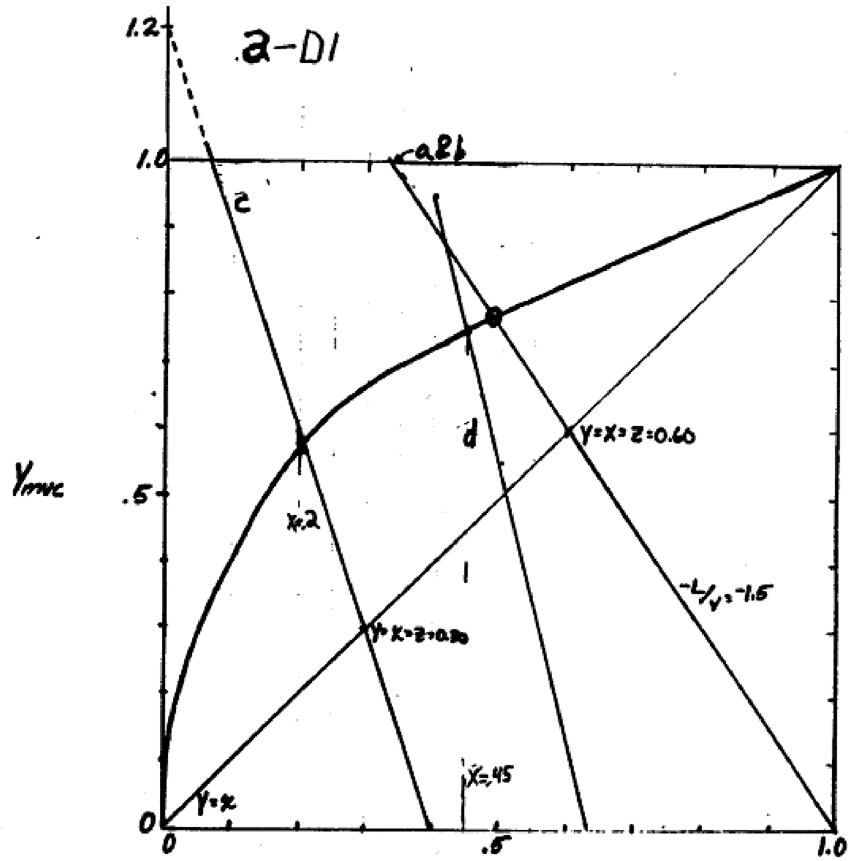
Vapor Density: $\rho_V = p(MW)_{V,avg}/RT$ (Need temperature of the drum)

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

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

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

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



Find Permissible velocity:

$u_{perm} = K_{drum}\sqrt{\frac{(\rho_L - \rho_v)}{\rho_v}}$,

$K_{drum} = exp[A + B(\ell n F_{lv}) + C(\ell n F_{lv})^2 + D(\ell n F_{lv})^3 + E(\ell n F_{lv})^4 + F(ln F_{lv})^5]$ 2-62

$V = \left(\frac{V}{F}\right)F = (0.25)1000 = 250 \text{ lbmol/h},\ W_v = V\left(\overline{MW}_v\right) = 250\left(26.15 \frac{\text{lb}}{\text{lbmol}}\right) = 6537.5 \text{ lb/h}$

$L = F - V = 1000 - 250 = 750 \text{ lbmol/h, and } W_L = (L)\left(\overline{MW}_L\right) = (750)(20.82) = 15,615 \text{ lb/h},$

$F_{lv} = \frac{W_L}{W_V}\sqrt{\frac{\rho_V}{\rho_L}} = \left(\frac{15615}{6537.5}\right)\sqrt{\frac{8.89\times10^{-4}}{.925}} = 0.0744$, and $\ell n(F_{lv}) = -1.128$

Then $K_{drum\ vertical} = .3417$, and $u_{perm} = .3417\sqrt{\frac{.925-8.98\times10^{-4}}{8.98\times10^{-4}}} = 10.96$ ft/s

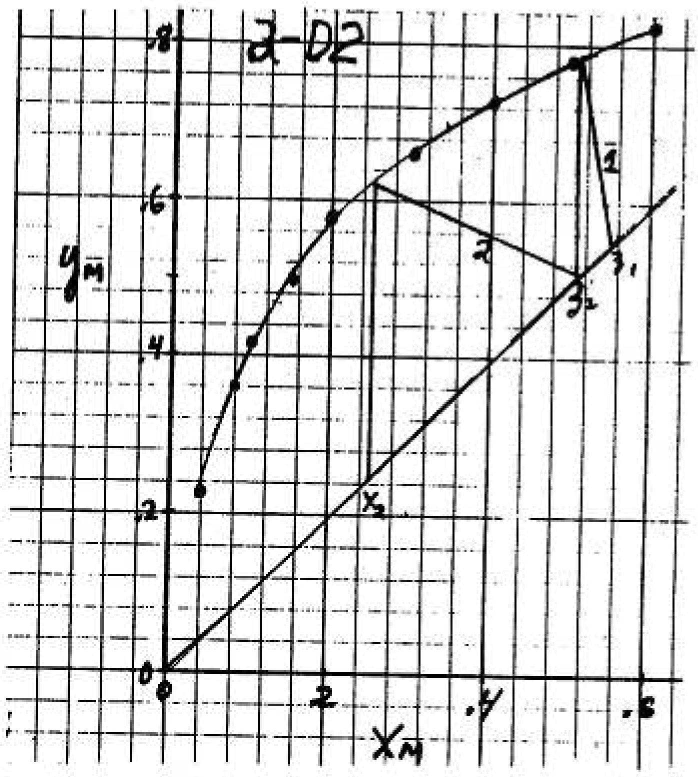
$$A_{cs} = \frac{V(\overline{MW}_v)}{u_{perm}3600\rho_v} = \frac{250(26.15)(454\text{ g/lb})}{(10.96)(3600)(8.98\times10^{-4}\text{ g/ml})(28316.85\text{ ml/ft}^3)} = 2.95\text{ ft}^2.$$

$D = \sqrt{\frac{4A_{cs}}{\pi}} = 1.94$ ft. Use 2 ft diameter. L ranges from $3\times D = 6$ ft to $5\times$ D=10 ft

f. Plot T vs x from Table 3-3. When $T = 77^\circ C$, $x = 0.34$, $y = 0.69$. 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. V = 16.18 mol/h, L = 33.82, y= 0.892, x = 0.756.

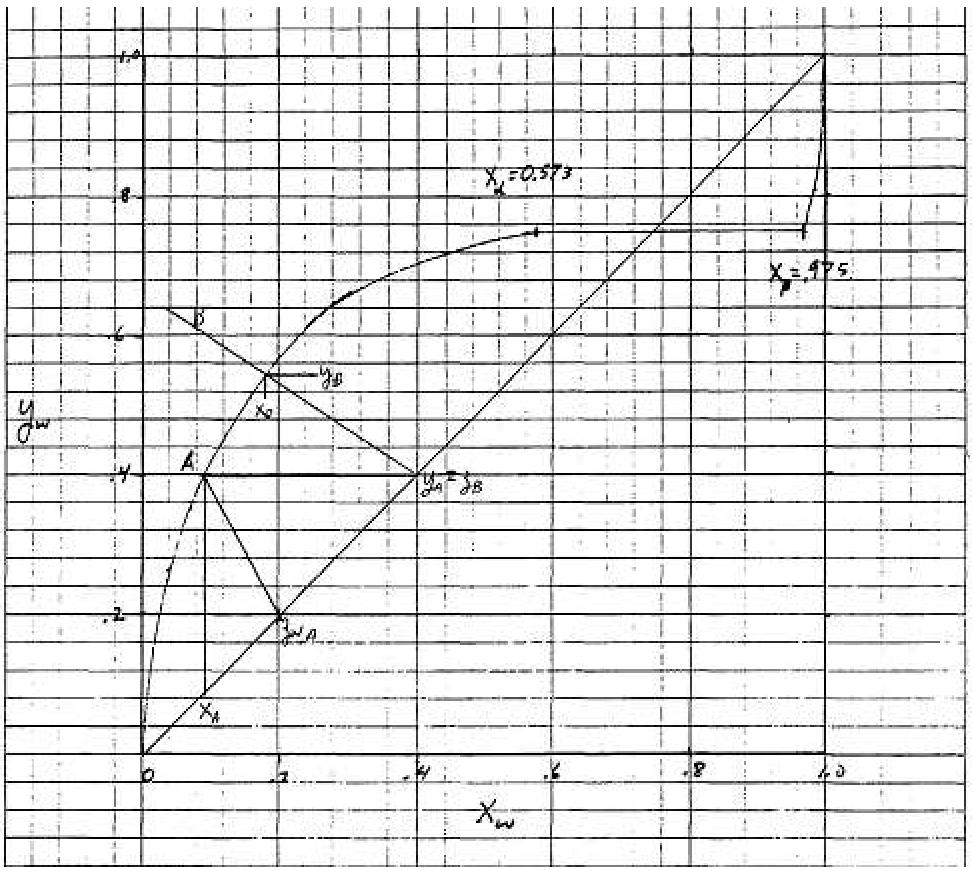
2-D2. Work backwards. Starting with x_2, find $y_2 = 0.62$ from equilibrium. From equilibrium point plot op. line of slope $= -(L/V)_2 = -\left(1-\frac{V}{F}\right)_2 \Big/ (V/F)_2 = -3/7$. Find $z_2 = 0.51 = x_1$ (see Figure). From equilibrium, $y_1 = 0.78$ .For stage 1, $\frac{V}{F} = \frac{z_1 - x_1}{y_1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



2.D3.*Was 2D30 in 4th edition.* 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. $L_A + V_A = F_A = 100$ & $L_A(.09) + V_A(.40) = (100)(.20)$. Results: $V_A = 35.48$ 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. See 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.D3.

2.D4. *New problem in 5th edition*

a. Slope operating line is -2/3, intersects equilibrium curve at x = 0.18 & y = 0.55. By linear interpolation T = 82.3C.

b. At 78C, x = 0.3 and y = 0.665. Slope = (.665 – 0.4)/(0.3 – 0.4) = -2.65. V/F = 0.274, V = 2.74 & L = 7.26.

c. y = .8, x (equilibrium) = 0.55; V/F = 0.3 & F = 10; thus, V = 3 and L = F – V = 7. Solve overall mass balance for z, z = (yV + Lx)/F = 0.625

2.D5.

a) $y_1 = -\frac{L}{V_1}x_1 + \frac{F}{V_1}z$ Plot 1st Op line.

$\boxed{y_1 = 0.66 = z_2}$

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

$$\text{Slope} = -\frac{L}{V_1} = \frac{0.55-0.80}{.55-0} = -\frac{.25}{.55} = -0.454545 \quad L_1 + V_1 = F_1 = 1000$$

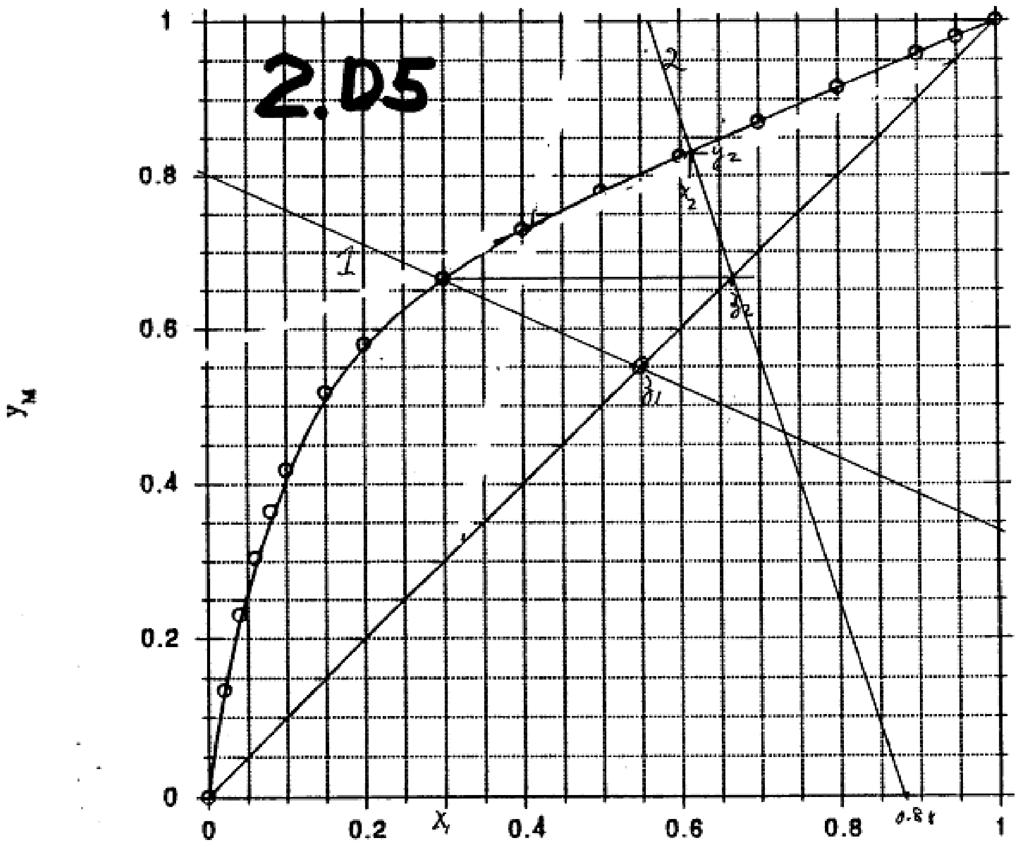
$\boxed{V_1 = 687.5 \text{ kmol/h} = F_2}$

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

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



2.D6. *New Antoine Constants and part d is new.*

a.) T = 273.15 + 100.0 = 373.15, p = (1.5 atm)(1.013 bar/1.0 atm) = 1.5195 bar

Table 2-3: A = 4.80915, B = 1753.525, C = − 99.0

VP = 0.025877 bar (1.0 atm/1.013 bar)(760 mm Hg/ 1.0 atm) =19.41 mm Hg.

b.) Raoult's law, K = Vp/P = 0.025877 bar/1.5195 bar = 0.01703

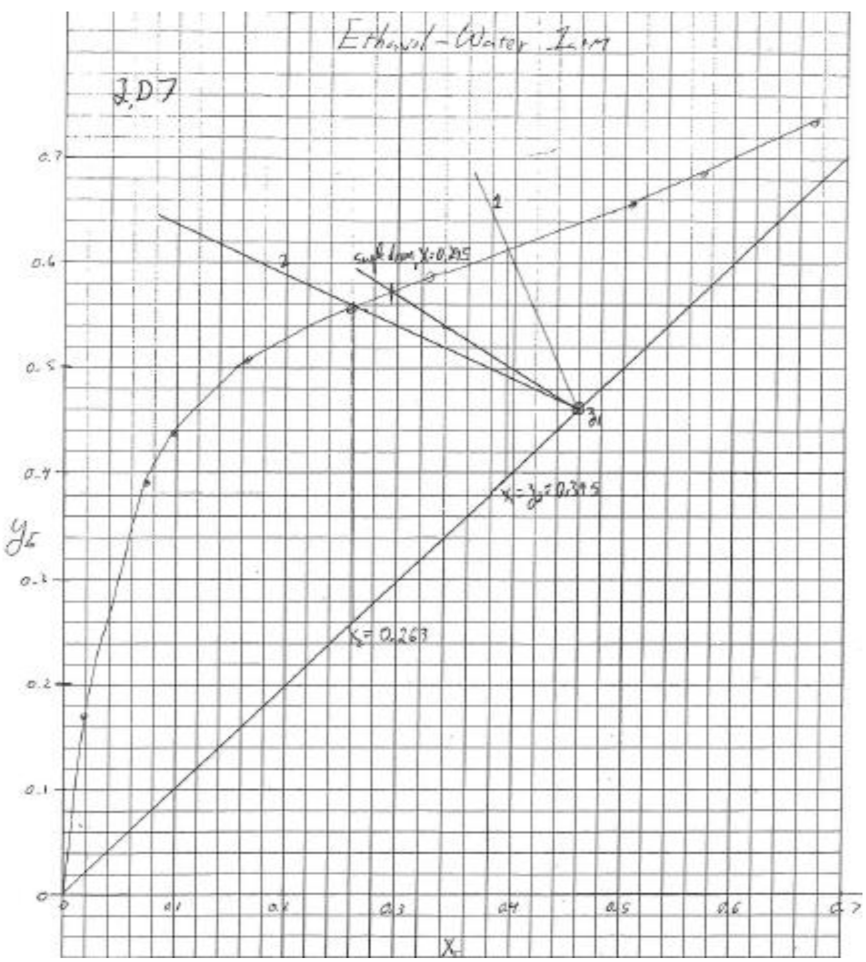
c) Alternate formula answers) VP = 19.30 mm Hg $\log_{10}(\mathrm{VP}) = 6.8379 - \frac{1310.62}{100+136.05} = 1.2856$

The answer is K = 0.01693. $K = \frac{\mathrm{VP}}{P_{tot}} = \frac{19.30}{1.5(760)}$

d) At 25.3°C, Table 2-3 values: T = 25.3 + 273.5 = 298.8 K. VP (bar) = power (10,5.31384 -1690.84/(298.8-51.904)) =0.02855 = 21.4255 mm Hg.
Table in problem 6.D4 lists 20 mm Hg.
At 75°C Antoine's equation gives VP = 303.03 mm Hg.
Linear interpolation on Table in 6.D4 VP = 200+(75-66.8)*(400-200)/(82-66.8) = 307.9 mm Hg. Since linear interpolation is not totally accurate, the Antoine result is probably more accurate.

2.D7. 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. *Was 2D3 in 4[th] edition.* Part a.

x ethane	T °C	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. Easiest to follow if you draw a 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 °C. 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 °C (highest).

c. Draw a figure. Slope = – L/V = – (1 – V/F)/(V/F) = – .6/.4 = – 1.5. x_E = 0.12, y_E = 0.57, T = 33.4°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.D9. Need h_F to plot on diagram. Since pressure is high, feed remains a liquid

$$h_F = \bar{C}_{P_L}\left(T_F - T_{ref}\right),\quad T_{ref} = 0^\circ \text{ from chart.}\quad \bar{C}_{P_L} = C_{P_{EtOH}} x_{EtOH} + C_{P_w} x_w$$

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

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

$$70 \text{ kg water } = 70/18.016 = 3.885 \quad \text{Total} = 4.536 \text{ kmol}$$

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

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

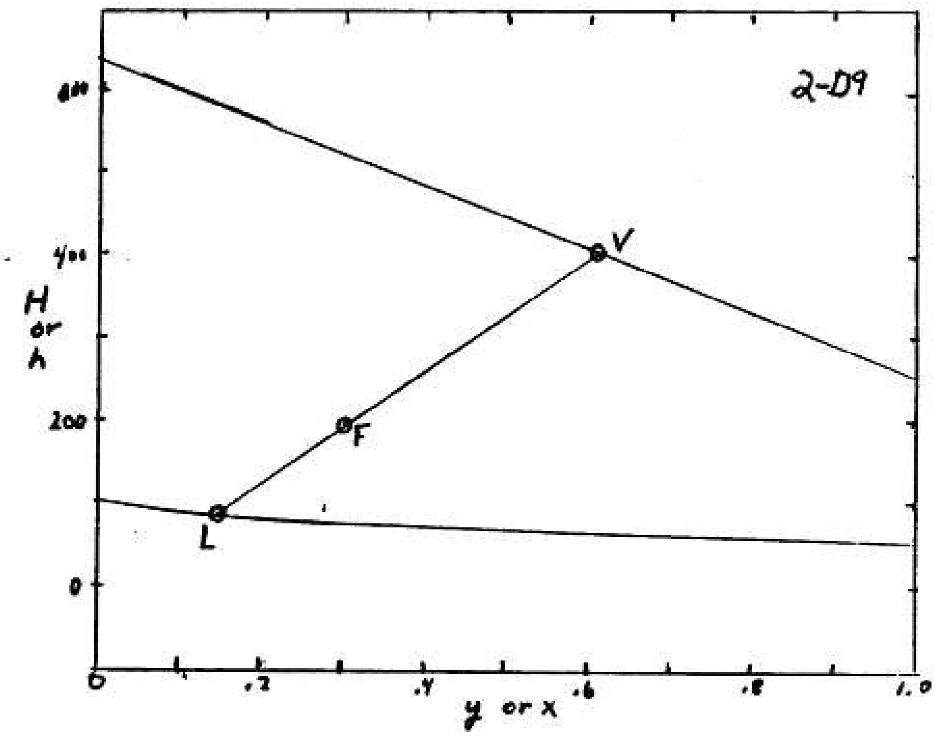
$$\bar{C}_{P_L} = 37.96(.1435) + 18.0(.8565) = 20.86 \frac{\text{kcal}}{\text{kmol }^\circ\text{C}}$$

$$\text{Per kg this is } \frac{\bar{C}_{P_L}}{MW_{avg}} = \frac{20.86}{22.046} = 0.946 \frac{\text{kcal}}{\text{kg }^\circ\text{C}}.\quad h_F = 0.946(2000) = 189.2 \text{ kcal/kg}$$

which can now be plotted on the enthalpy composition diagram.

Obtain $T_{drum} \approx 88.2\ ^\circ C$, $x_E = 0.146$, 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. $\bar{C}_{P_L} = 23.99$ & $\bar{C}_{P_L}/MW_{avg} = 1.088$ and $h_F = 217.6$. All *wrong*.



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

From DePriester chart $\quad K_{C3} = 5, \quad K_{C4} = 1.9, \quad K_{C6} = 0.3$

Know $y_i = K_i x_i$, $\quad x_i = \dfrac{z_i}{1+(K_i - 1)\dfrac{V}{F}}$, $\quad \sum x_i = \sum y_i = 1 = \sum z_i$

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

$$\text{C6: } 0.7 = \frac{z_{C6}}{1+(K_{C6}-1)\frac{V}{F}} = \frac{z_{C6}}{1-0.7\frac{V}{F}} \Rightarrow z_{C6} = 0.7\left(1-0.7\frac{V}{F}\right),\ z_{C6} = 0.7 - 0.49\frac{V}{F}$$

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

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. 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. *Since Eq. (2-59) was changed and instructions for horizontal drums has changed, answer has changed.*

Drum dimensions.

Find Liquid Density.

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

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

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

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

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

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

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

$$\rho_v=(1 \text{ atm})(26.15 \text{ g/mol})\Big/\left[\left(82.0575\frac{\text{ml atm}}{\text{mol }^\circ K}\right)(354.7 \text{ K})\right]=8.98\times10^{-4} \text{ g/ml}$$

Find Permissible velocity:

$$u_{perm}=K_{drum}\sqrt{\frac{(\rho_L-\rho_v)}{\rho_v}},$$

$$K_{vertical}=exp[A+B(\ell nF_{lv})+C(\ell nF_{lv})^2+D(\ell nF_{lv})^3+E(\ell nF_{lv})^4+F(lnF_{lv})^5] \quad \text{(2-62a)}$$

$$V=\left(\frac{V}{F}\right)F=(0.25)1000=250 \text{ lbmol/h},\ W_v=V\left(\overline{MW}_v\right)=250\left(26.15\frac{\text{lb}}{\text{lbmol}}\right)=6537.5 \text{ lb/h}$$

$$L=F-V=1000-250=750 \text{ lbmol/h, and } W_L=(L)\left(\overline{MW}_L\right)=(750)(20.82)=15{,}615 \text{ lb/h},$$

$$F_{lv}=\frac{W_L}{W_V}\sqrt{\frac{\rho_V}{\rho_L}}=\left(\frac{15615}{6537.5}\right)\sqrt{\frac{8.89\times10^{-4}}{.925}}=0.0744, \text{ and } \ell n(F_{lv})=-1.128$$

Then $K_{drum\ vertical}$ = .3417, and $K_{drum\ horizontal} = 1.25\ K_{drum\ vertical} = .4271$

$$u_{perm} = .4271\sqrt{\frac{.925 - 8.98 \times 10^{-4}}{8.98 \times 10^{-4}}} = 13.70 \text{ ft/s}$$

$$A_{cs} = \frac{V(\overline{MW}_v)}{u_{perm}3600\rho_v} = \frac{250(26.15)(454 \text{ g/lb})}{(13.7)(3600)(8.98\times10^{-4} \text{ g/ml})(28316.85 \text{ ml/ft}^3)} = 2.36 \text{ ft}^2.$$

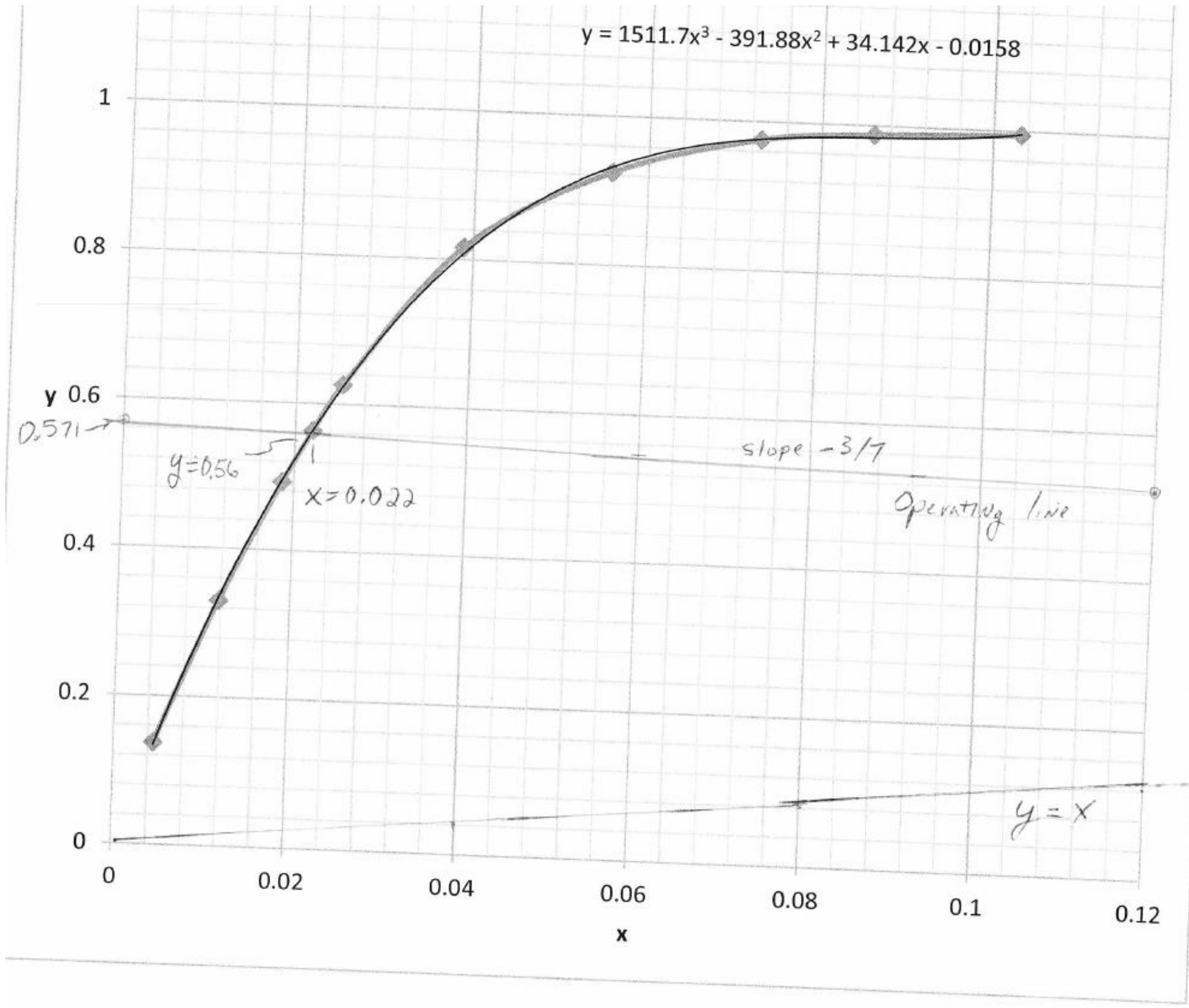
From Eq. (2-64b) $A_{total} = A_{cs}/0.2 = 11.8 \text{ ft}^2$

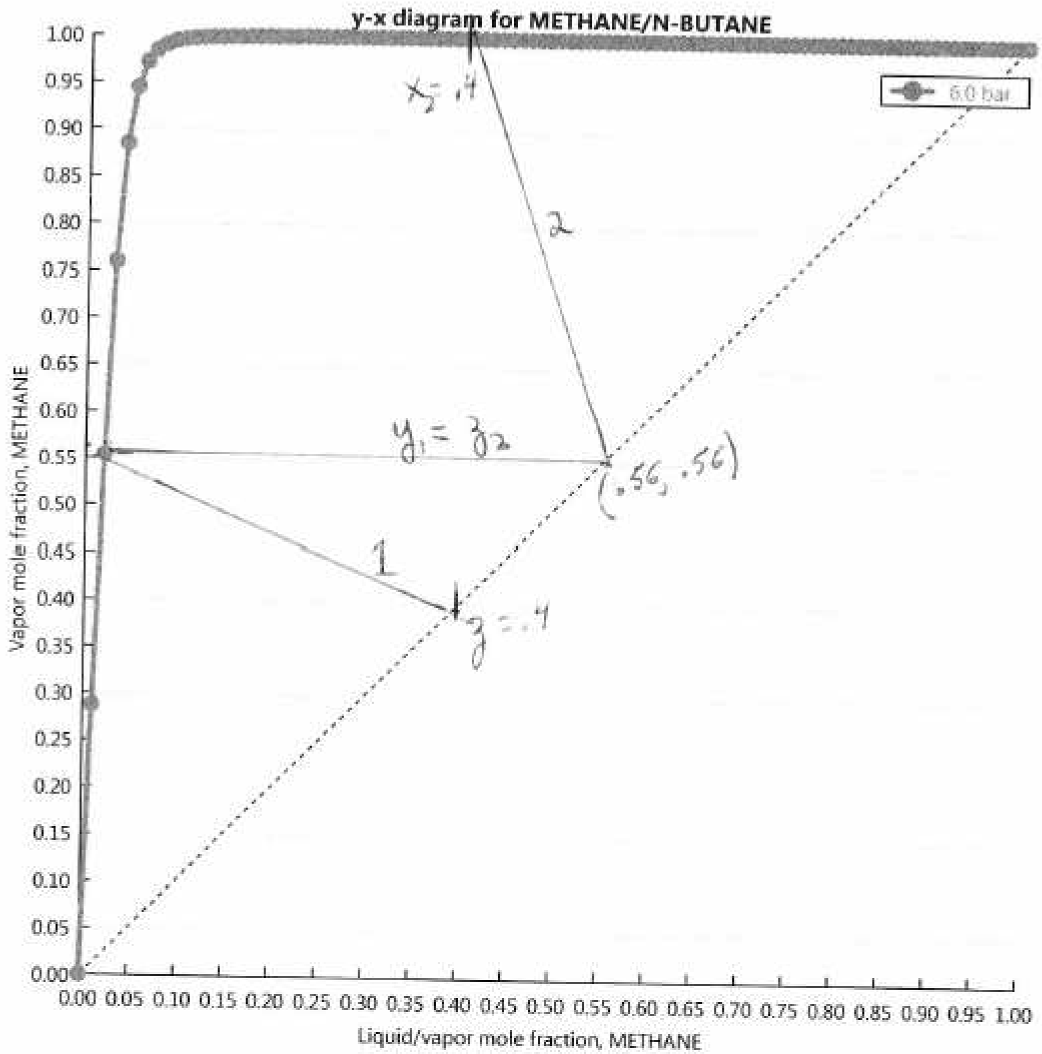
$D = (4A_{total}/\pi)^{0.5} = 3.88$ ft, use 4 ft diameter and determine h from Eq. (2-69) T = 1h = 60 min.
$T = (60 \text{ min/h})(0.8\ A_{total} \text{ ft}^2)(\rho_L \text{ lb/ft}^3)(h \text{ ft})/(W_L \text{ lb/h})$
Solving for h, $h = (T\ W_L)/[(60)(0.8\ A_{total})(\rho_L)]$
$= (60 \text{ min})(15615 \text{ lb/h})/\{(60 \text{ min/h})(0.8)(11.8 \text{ ft}^2)(0.925 \text{ g/ml})[(62.428 (\text{lb/ft}^3)/((\text{g/ml})]\} = 28.64$ ft. If we build h = 30 ft, we have an h/d ratio = 30/4 = 7.5.

2.D13. *New Problem in 5th edition*

a. Procedure: Pick a T that gives $K_{methane} > 1$ and $K_{butane} < 1$. Then $y_m = K_m x_m$ and $y_B = K_B x_B$. Also, $y_B + y_m = 1$ becomes $K_m x_m + K_B x_B = 1$. Since $x_m + x_B = 1$, $x_B = 1 - x_m$. Substitute x_B into previous equation and solve for $x_m = (1 - K_B)/(K_m - K_B)$. Then $y_m = K_m x_m$. See graph in part b.
b. Operating equation $y = -L_F/V_F\ x + Fz/V_F$. $L_F = .3$ F and $V_F = .7$ F = 175. Thus slope $= -L_F/V_F = -3/7$. Intersects y = x line at y = x = z = 0.4. The y intercept (x = 0) is at $y = z/(V_F/F) = .4/.7 = 0.571$.

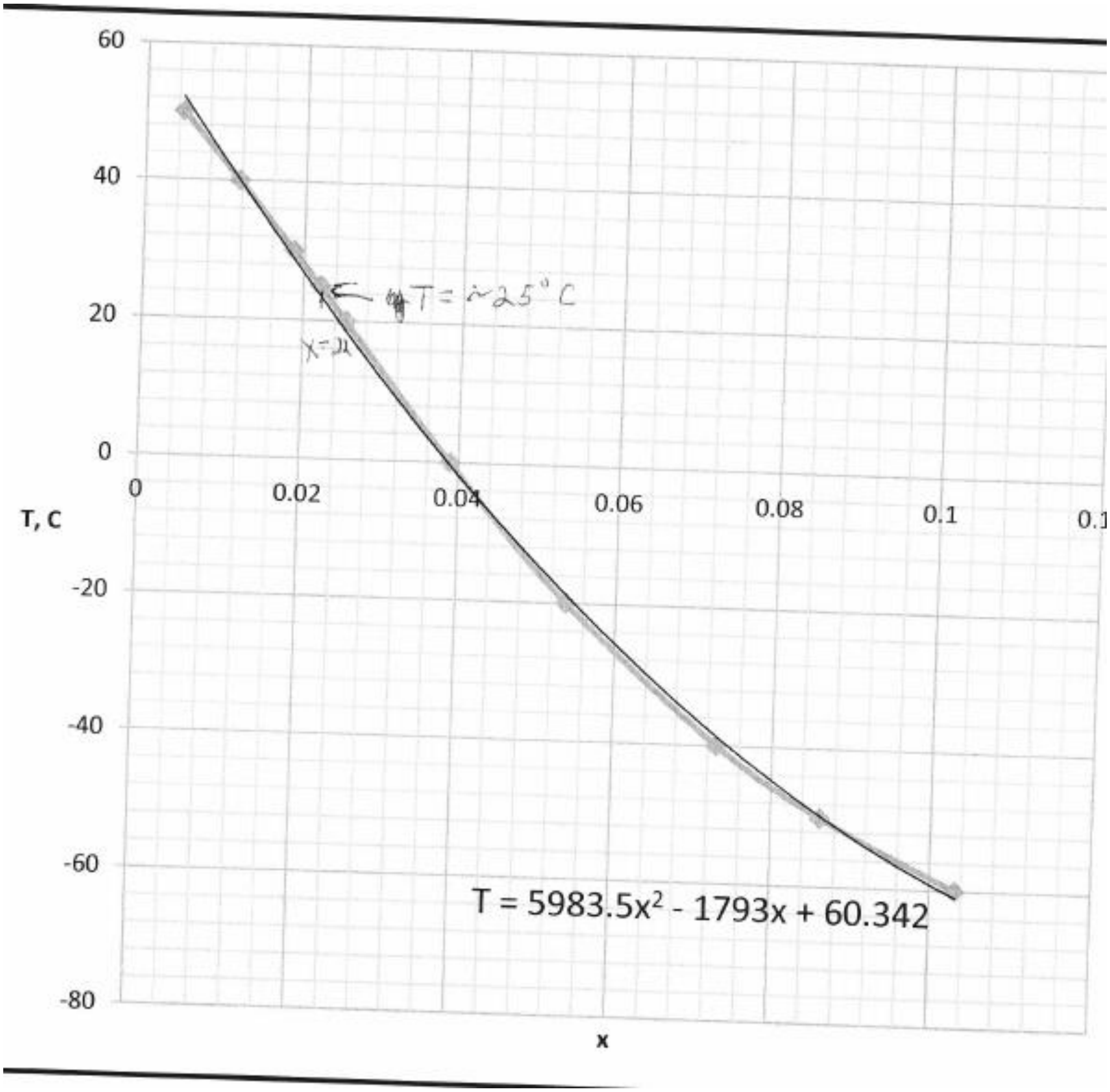
Two y-x graphs are shown, the expanded graph from Eq. (2-28) is more accurate, but the intersection of the operating line and the y = x line is not on the graph. The larger graph (printed from Aspen Plus to solve part c) is easier to see, but not as accurate. Answer part b: x = 0.022, y = 0.56, and T = 25°C. Temperature graph is after the two y vs x graphs.


y = 1511.7x³ - 391.88x² + 34.142x - 0.0158
1
0.8
y 0.6
0.4
0.2
0
0
0.02
0.04
0.06
0.08
0.1
0.12
x
0.571
y=0.56
x=0.022
slope -3/7
Operating line
y = x



c. For the second flash drum $z_2 = y_1 = 0.56$, $F_2 = V_1 = 175$ and $x_2 = 0.4$. From the graph $y_2 = 1.0$. Slope operating line $= (y - z)/(x - z) = (1 - .56)/(0.4 - 0.56) = -2.75 = -L_F/V_F = -(1 - V_2/F_2)/(V_2/F_2) \rightarrow$

$V_2/F_2 = 1/3.75 = 0.2667$. Then $V_2 = 0.2667\ (175) = 46.67$ and $L_2 = F_2 - V_2 = 175 - 46.47 = 128.33$.



2.D14. *New problem in 5[th] edition.*

SOLUTION part a. From Raoult's law, $K_p = (VP)_p/p$. $K_m = \alpha_{m-p}K_p$, $K_B = \alpha_{BP}K_p$. The Rachford-Rice eq is

$\sum \frac{(K_i - 1)z_i}{1+(K_i-1)(V/F)} = 0$ The lowest temperature occurs when V/F = 0 or the numerator = 0.

Expanding the numerator, $(\alpha_{m-p}K_p - 1)z_m + (\alpha_{p-p}K_p - 1)z_p + (\alpha_{B-p}K_p - 1)z_B = 0$, and with numbers,

$$K_p = \frac{\sum z_i}{\sum \alpha_{i-p} z_i} = \frac{1}{(3.58(0.36) + 1.0(0.42) + 0.412(0.22))} = \frac{1}{1.7994} = 0.5557 = \frac{(VP)_p}{p}$$

Then $(VP)_p$ = 0.5557(0.74) = 0.411 atm = 312.5 mm Hg. From Table in problem 6.D4 by linear interpolation, $312.5 = 200 + \frac{400-200}{82-66.8}(T_{low} - 66.8)$. Solving for T_{low} = 75.35 °C.

Part b. At 82°C, VP = 400 mm Hg, K_p = 400/(0.74(760)) = 0.7112, K_m = 3.58 (0.7112) = 2.546, K_B = 0.293.

RR eq is, $0 = \frac{(2.546-1).36}{1+1.546(V/F)} + \frac{(0.7112-1).42}{1-0.2888(V/F)} + \frac{(0.293-1)0.22}{1-0.707(V/F)}$

Solution is V/F = 0.3828, x_M = 0.2262, x_P = 0.4722, x_B = 0.3016; y_M = 0.5758, y_P = 0.3358, y_B = 0.0884

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 equations: $z_{iC4}/z_{nC4} =$ 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,

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

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

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

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

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

Combine Eqs. (2-42b) & (2-42c)
$$\left.\frac{V}{F}\right)_2 = \left(\frac{V}{F}\right)_1 + \frac{f\left(V/F\right)_1}{\sum \frac{z_i\left(K_i-1\right)^2}{\left[1-\left(K_i-1\right)\frac{V}{F}\right]^2}}$$

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

calculate $\left(V/F\right)_2 = .53 + 0.157/2.92 = 0.584$

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

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

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

Similar for other components.

See Figure 2-B2 in Chapter 2 Appendix B2 for answer from spreadsheet.

2-D17. *New Problem in 5th edition. Note problems 2D17 and 2D25 are similar.*

Since the vapor in a flash drum is well mixed, mix the two feeds before separating.

$F = F_1 + F_2 = 150 + 100 = 250$, $z = (F_1z_1 + F_2z_2)/F = [150(0.10) + 100(0.30)]/250 = 45/250 = 0.18$.

$V = V_1 + V_2 = 150(0.4) + 100(0.6) = 60 + 60 = 120$. $V/F = 120/250 = 0.48$

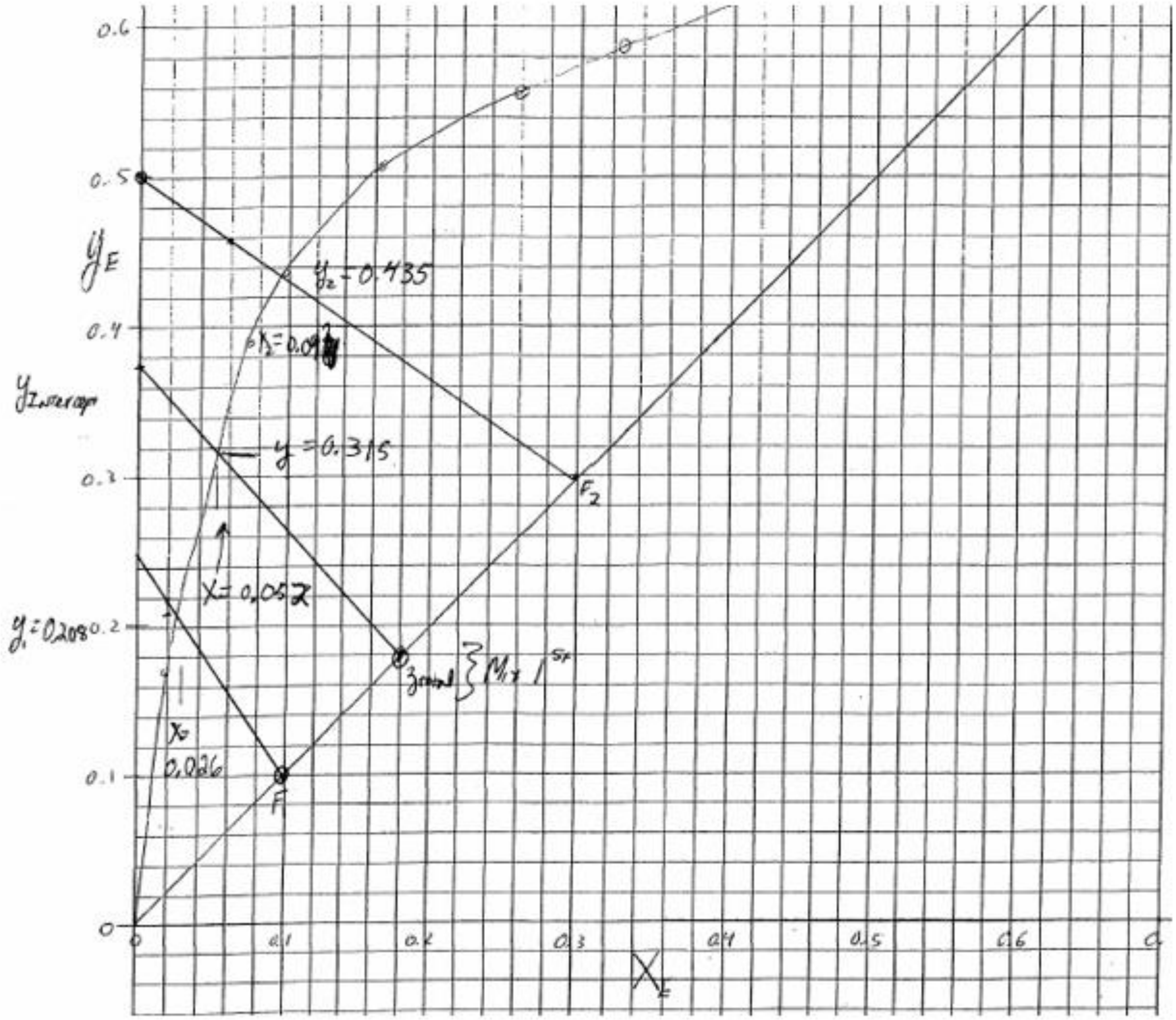
Operating equation: $y = - (L/V)x + (F/V)z$

Slope = - (L/V) = - (1 – 0.48)/0,48 = - 1.082; y = x intercept with operating line at y = x = z = 0.48

y intercept (x = 0) = (F/V)z = (250/120)0.18 = 0.375.

Plot operating line. Find values of y and x at intersection of operating line and equilibrium curve. Find y = 0.315 and x = 0.052. See middle operating line on graph.

A plausible, but incorrect solution is to do the two flashes separately and then mix the products. The flash of the first feed has a slope of – 1.5 and intersects y = x = 0.1 (see bottom operating line on graph). The result is y = 0.208 and x = 0.026. The flash of the second feed: slope = -2/3, y = x = 0.3, x = 0 intercept = 0.5 and result y = 0.435, x = 0.092 (see top operating line on graph). Total ethanol in vapor after mixing = 60 (0.208) + 60 (0.435) = 38.58 and y_{mix} = 38.58/120 = 0.3215. Total ethanol in mixed liquids = 90(0.026) + 40 (0.092) = 6.02 and x_{mix} = 6.02/130 = 0.046. Results are close but not identical to the correct solution.



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

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

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

Initial guess: T_{drum} must be less than temperature to boil pure hexane $\left(K_h = 1.0,\ T = 94^\circ C\right)$. 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 .

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

Try $T=73^{\circ}C$ where $K_h=0.6$. Then $K_b=3.8,\ K_p=9.9$.

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

Check:

$$\sum\frac{(K_i-1)z_i}{1+(K_i-1)V/F}=\frac{(8.9)(.1)}{1+(8.9).735}+\frac{(2.8)(.3)}{1+(2.8).735}+\frac{(-.4)(.6)}{1-(.4)(735)}=0.05276$$

Converge on $T\sim 65.6^{\circ}C$ and $V/F\sim 0.57$.

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

$$z_{C6}=.93C_6+\frac{(.9)z_{C6}KV/F}{1-V/F}$$

Solve for V/F. $\frac{V}{F}=\frac{.1}{(.9K_{C6})+.1}$. Trial and error scheme.

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

If not $K_{ref_{new}}=\frac{K_{ref}(T_{old})}{1+d\,f(T)}$

Try $T=70^{\circ}C.\ K_{C4}=3.1,\ K_{C5}=.93,\ K_{C6}=.37=K_{ref}$

$$\frac{V}{F}=\frac{.1}{(.9)(.37)+.1}=0.231.$$

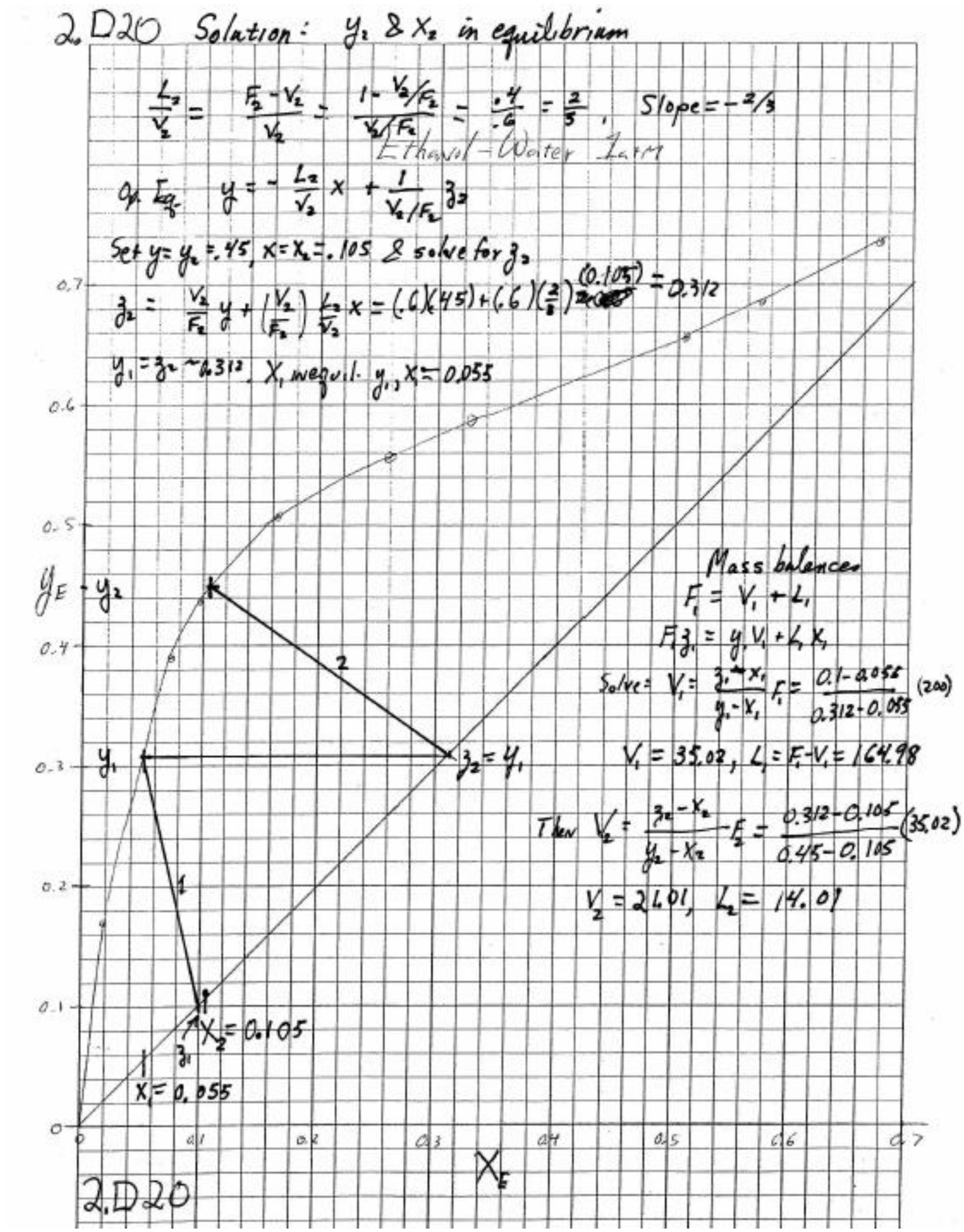
Rachford Rice equation

$$f=\frac{(2.1).4}{1+(2.1).231}+\frac{(-.08).25}{1-(.08).231}-\frac{(.63).35}{1-(.63)(.231)}=.28719$$

$$K_{ref}(T_{new})=\frac{.37}{1+0.28719}=0.28745 \text{ (use .28)}$$

Converge on $T_{New}\sim 57^{\circ}C$. Then $K_{C4}=2.50,\ K_{C8}=.67$, and $V/F=0.293$.

2.D20.



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

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

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

b.) *Changed correlation for Eq. (2-59) changes this solution*

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

$$F = 100{,}000\frac{\text{kg}}{\text{hr}}\left|\frac{\text{kmol}}{49.17\text{ kg}}\right| = 2033.7\text{ kmol/h} = 4483.6\text{ lbmol/h}$$

$$V = (V/F)F = 1079.7, \quad L = F - V = 954.0\text{ kmol/h}$$

V = (1079.7 kmol/h)(1.0 lbmol/.45359 kmol) = 2380.3 lbmol/h

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

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:

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

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

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

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

K_{drum}: Use Eq. (2-62a) with $F_{lV} = \dfrac{W_L}{W_V}\sqrt{\dfrac{\rho_v}{\rho_L}}$

$W_L = 954\frac{kmol}{h}\left|\frac{64.48\text{ kg}}{kmol}\right| = 61{,}513{,}9$ kg/h, $W_V = 1079.7\left|\underline{35.33}\right| = 38145.8$kg/h

$$F_{lV} = \frac{61513.9}{38{,}145.8}\sqrt{\frac{0.009814}{0.621}} = 0.20277$$

Note that the kg/h cancels so the ratio is the same as if used lb/h for W_L and W_V and F_{LV} is OK.

From Eqs. (2-59a) and (2-59c) we obtain $K_{vertical}$ =0.24097, and

$$u_{Perm} = (0.24097)\sqrt{\frac{0.621 - 0.009814}{0.009814}}\frac{ft}{s} = 1.902\text{ ft/s}$$

$A_C = [V(MW_V)]/[u_{perm}(3600)(0.00314)(28316.85)]$

$= [(2380.3 \text{ lbmol/h})(35.33\text{lb/lbmol})]/[(1.902 \text{ ft/s})(3600\text{s/h})(0.009814\text{g/ml})(1000\text{kg/m}^3)/(1.0 \text{ g/ml})]$

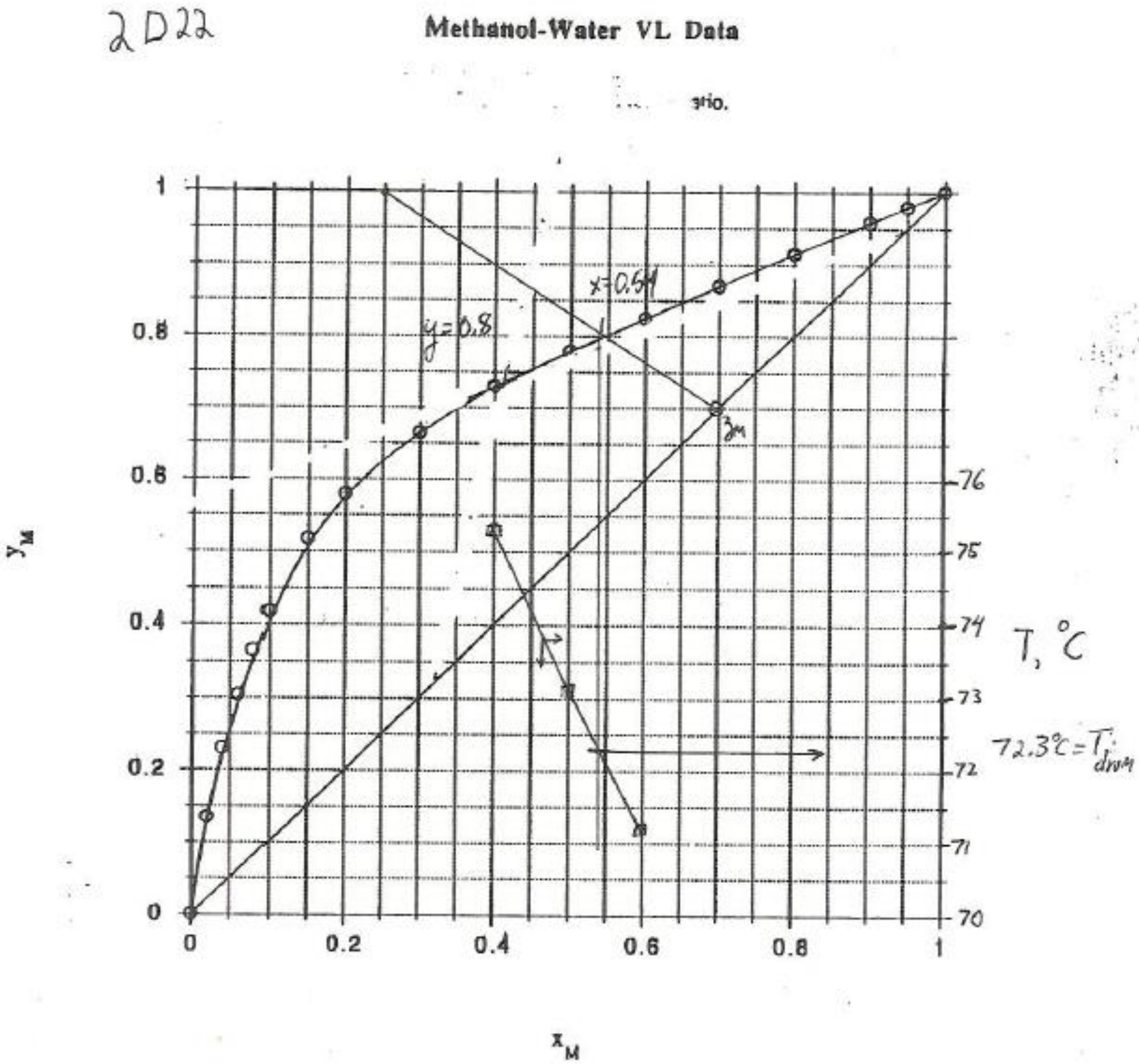
$A_C = 20.068 \text{ ft}^2$, $D = \sqrt{\frac{4A_C}{\pi}} = 5.056$ ft Arbitrarily $\frac{L}{D} = 4$, $L = 19.2$ ft

In US specify 5.5 ft diameter drum, 22 ft long.

2.D22.

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

The area of the 5.5 ft diameter drum that was actually built, $A_c = \pi D^2/4 = 23.74$ ft^2, which is a bit larger than the minimum area needed for the original problem statement. Since we have the same flow factor and decide to use the value of $K_{drum} = 0.3458$, then $u_{perm} = 5.1362$ ft/s. The required area was 20.57 ft^2 to process 1500 lbmol/h of feed and 765 lbmol/h of vapor.

$V_{5.5\ drum} = V_{reqd}\ (A_{c,5.5}/A_{c,reqd}) = 765\ (23.74/20.619) = 880.8$ lbmol/h.

The feed rate that the 5.5 ft diameter drum can handle = 1500 lbmol (880.8/765) =1727 lbmol/h.

The new required feed rate = 1500 kmol/h (1.0 lbmol/0.45359kmol) = 3307 lbmol feed/h; thus, the 5.5 ft diameter drum cannot meet the corrected specification.

Amountt to be processed by new drum in parallel = 3307 – 1727 = 1580 lbmol/h, and vapor flow rate $V_{new\ drum} = (V/F)\ F_{new\ drum} = (0.51)\ 1580 = 805.8$ lbmol/h.

Since all flow rates scale the same, the ratio W_L/W_V is unchanged; thus, F_{lv}, K_{drum}, and u_{perm} are all unchanged. Then $A_{c,new} = (V_{new}/V_{old\ design})\ A_{c,old\ design} = (805.8/880.8)(23.74\ \text{ft}^2) = 21.72\ \text{ft}^2$

Diameter required for new drum in parallel, $D_{new} = (4A_{c,new}/\pi)^{0.5} = 5.25$ ft. Use another 5.5 ft diameter drum 22 ft long in parallel with existing 5.5 ft diameter drum.

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 $\quad K_{C6} = (1-K_{C3}x_{C3})/(1-x_{C3})$

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

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

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 $\quad x_{C3} = \frac{1-K_{C6}}{1-K_{C6}} = 1, \quad y_{C3} = \frac{1(1-K_{C6})}{1-K_{C6}} = 1.0$

at 110°C $\quad x_{C3} = \frac{0}{K_{C3}} = 0, \quad y_{C3} = \frac{K_{C3}(0)}{K_{C3}} = 0$

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

T	K_{C3}	K_{C6}	x_{C3}	$y_{C3} = K_{C3}x_{C3}$	
0ºC	1.45	0.027	$\frac{1-0.027}{1.45-0.027} = 0.684$	0.9915	
10ºC	2.1	0.044	0.465	0.976	See
20ºC	2.6	0.069	0.368	0.956	Graph
30ºC	3.3	0.105	0.280	0.924	
40ºC	3.9	0.15	0.227	0.884	
50ºC	4.7	0.21	0.176	0.827	
60ºC	5.5	0.29	0.136	0.75	
70ºC	6.4	0.38	0.103	0.659	

b. $x_{C3} = 0.3$, $V/F = 0.4$, $L/V = 0.6/0.4 = 1.5$, Op. line intersects $y = x = 0.3$, Slope -1.5

$$y = -\frac{L}{V}x + \frac{F}{V}z \qquad \text{at} \qquad x = 0, \quad y = \frac{F}{V}z = \frac{0.3}{0.4} = 0.75$$

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: $K_{C3} = y_{C3}/x_{C3} = 0.63/0.062 \approx 10.2$, DePriester Chart T = 109ºC

d. $y = .8$, $x \sim .16$ Slope $= -\frac{L}{V} = \frac{\Delta y}{\Delta x} = \frac{.8-.6}{.16-.6} = -0.45 = -\frac{1-f}{f} = -.45$, V/F = f =1/1.45 = 0.69

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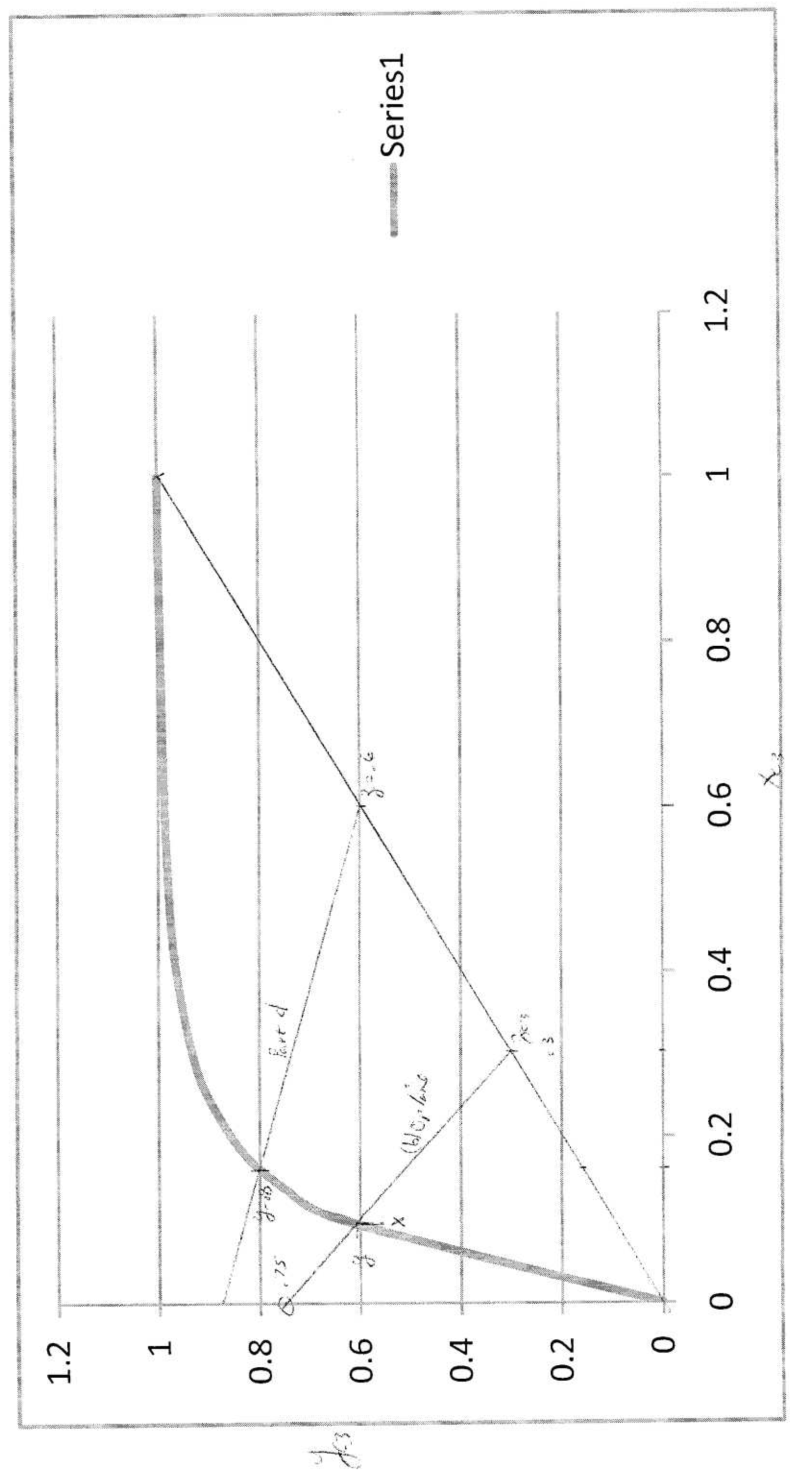
Prob 1



2.D25. *New problem in 5th edition.*

Since the vapor in a flash drum is well mixed, mix the two feeds before separating.

$F = F_1 + F_2 = 150 + 75 = 225$, $z = (F_1z_1 + F_2z_2)/F = [150(0.20) + 75(0.30)]/225 = 52.5/225 = 0.2333$.

$V = V_1 + V_2 = 150(0.4) + 75(0.6) = 60 + 45 = 105$. $V/F = 105/225 = 0.46667$

Operating equation: $y = - (L/V)x + (F/V)z$

Slope $= - (L/V) = - (1 – 0.46667)/0.46667 = - 1.1429$

$y = x$ intercept with operating line at $y = x = z = 0.2333$

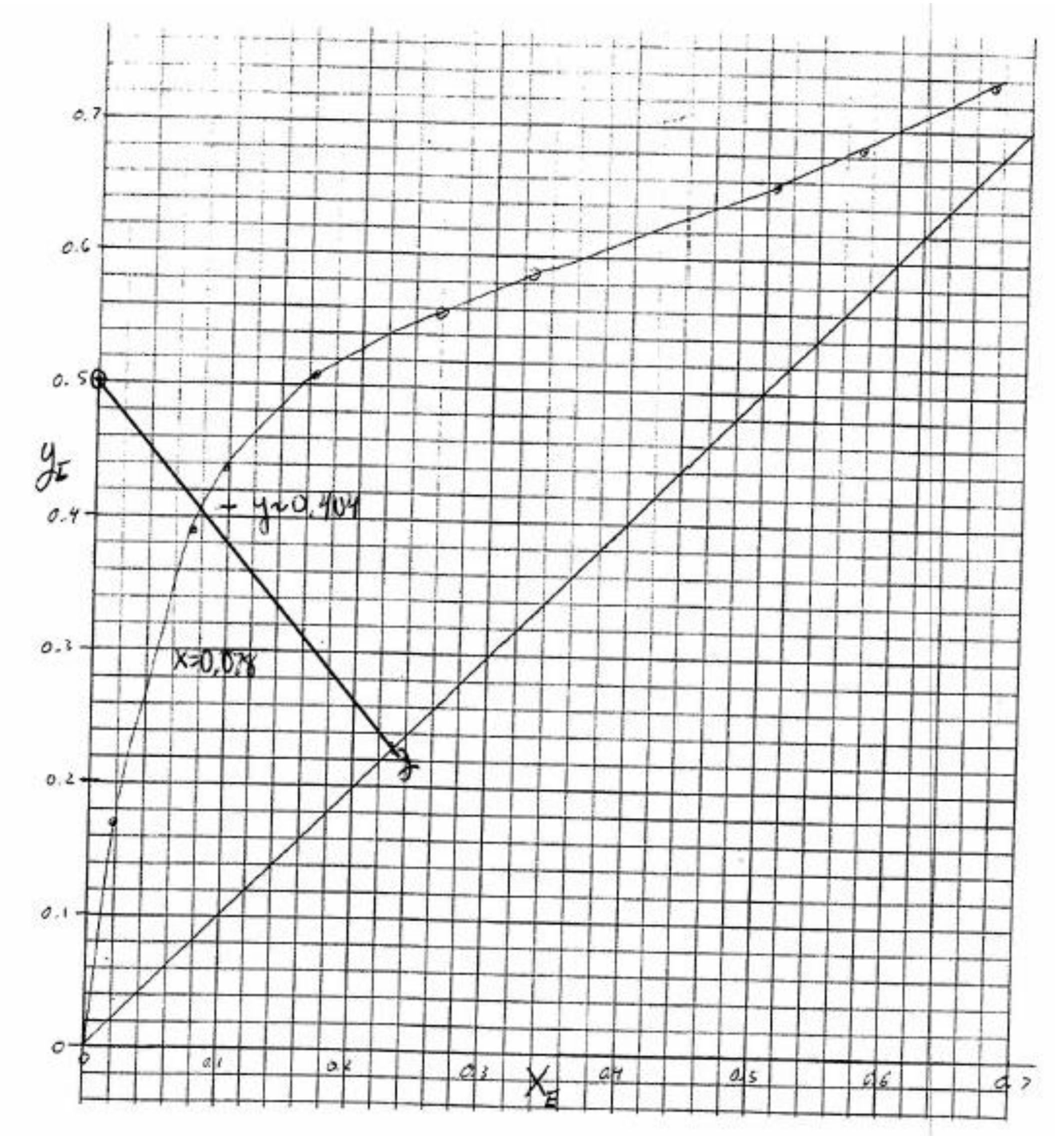
y intercept $(x = 0) = (F/V)z = (225/105)0.2333 = 0.5000$.

Plot operating line. Find values of y and x at intersection of operating line and equilibrium curve.

Find $y = 0.404$ and $x = 0.078$ See operating line on graph.

A plausible, but incorrect solution is to do the two flashes separately and then mix the products. Results are close but not identical to the correct solution.

Note: Mixing two different feeds before a separator is normally a bad idea. It works here because flash units are well mixed single equilibrium stages.



2.D26. *New problem in 5th edition.*

From $y = \frac{ax}{1+(a-1)x} + bx(1-x)$, a = 7.15, b = -0.33, generate following table

x_m	y_m Eq. (2-11)	y_m Table 2-7	
0.02	0.121	0.134	
.04	.217	.230	
.06	.295	.304	
.08	.359	.365	
.1	.413	.418	
.15	.516	.517	
.2	.588	.579	
.3	.685	.665	
.4	.747	.729	
.5	.795	.779	
.6	.836	.825	
.7	.874	.870	
.8	.913	.915	
.9	.955	.958	
.95	.977	.979	
1	1	1	

Fit is a bit low for x $\le$ 0.15 and for x $\ge$ ~0.8, and fit is a bit high for 0.20 $\le$ x $\le$ ~ 0.8. Maximum deviation is + 0.02 at x = 0.3 and – 0.013 at x = 0.02 and 0.04. Largest % errors are −9.7% at x = 0.02 and + 3.5% at x = 0.30. Unless one is trying for quite low values of methanol in the bottoms, the errors are acceptable, and the error in a low bottoms would be conservative (require more stages).

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

b.) $VP = 3\times 760 = 2280$ 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: $\log_{10} VP_{C6} = 6.876 - \frac{1171.17}{30+224.41} = 2.2725$, $VP_{C6} = 187.29$ mm Hg

$$K_{C6} = 187.29/500 = 0.3746$$

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

If K_A & K_B are known, two eqns. with 2 unknowns $(K_A \,\&\, y_A)$ Solve.

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

$$y_{C5} = K_{C5}x_{C5} = (1.2750)(0.6946) = 0.8856$$

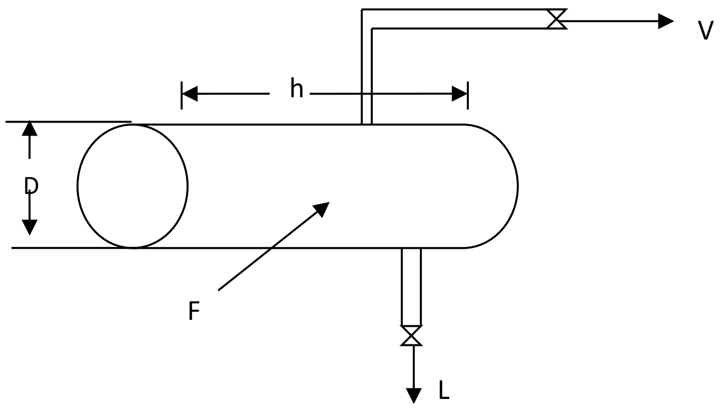
f.) Overall, M.B., F = L + V or 1 = L + V

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

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, $x_H = 0.19,\ T_{drum} = 378K,\ V/F = 0.51,\ y_H = 0.6,\ z_H = 0.40$

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

$$\rho_v = 3.14\times10^{-3}\ g/mol \left|\frac{1}{454 g/lbm}\right| \frac{28316.85 cm^3}{ft^3} = 0.198 \frac{lbm}{ft^3}$$

Example 2.4

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

From Example 2-4, $K_{vertical} = 0.4433$, $K_{horiz} = 1.25(0.4433) = 0.5541$

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

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

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

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

$$V_{liq} = \frac{160,068}{43.41}\frac{55+85}{60\min/h} = 8603.8 ft^3, h = \frac{5V_{liq}}{\pi D^2} = 83.51 ft \text{ and h/D = 6.5.}$$

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 = 444.53 lbmol/h, V = 4830.16 kg/h = 228.098 kmol/h =502.87 lbmol/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 = lb/lbmol.
The value of u_{perm} (in ft/s) can be determined by combining Eqs. (2-58) and (2-59)
$W_L = L(MW_L) = 444.5\ (50.437) = 22420.8$, $W_V = V(MW_V) = (502.87)(21.176) = 10648.8$

$F_{lv} = (W_L/W_V)[\rho_V/\rho_L]^{0.5} = (22420.8/10648.8)[0.004578/0.60786]^{0.5} = 0.18272$

Resulting $K_{vertical} = 0.2493$, $K_{horizontal} = 0.3115$, $u_{perm,vert} = 2.861$ ft/s, $u_{perm,horiz} = 3.5767$

$A_{C,vert} = 3.621$ ft^2, $A_{c,horiz} = 2.896$, $A_{total,\ horiz}, = A_{c,horiz}/0.2 = 14.482$ ft^2 $D_{horiz} = 4.295$ ft.

h/D = 6, h = 25.771 ft, $T = (60\ \text{min/hour})(0.8\ A_{total}\ \text{ft}^2)(\rho_L\ \text{lb/ft}^3)(h\ \text{ft})/(W_L\ \text{lb/h})$

$T = [60(0.8)(14.482)(0.60786)(62.428)(25.771)]/22420.8 = 30.32$ min

2.D30. *Was 2D31 in 4th edition.*
a) Since K's are for mole fractions, need to convert feed to mole fractions.

Basis: 100 kg feed

$$50\ \text{kg}\ \underline{n\ C_4}\ \frac{1\ \text{kmol}}{58.12\ \text{kg}} = 0.8603\ \text{kmol} \qquad z_4 = 0.555$$

$$50\ \text{kg}\ \underline{n\ C_5}\ \frac{1\ \text{kmol}}{72.5\ \text{kg}} = \underline{\ 0.6897\ \text{kmol n}\ C_5\ } \qquad z_5 = 0.445$$

Total 1.5499 kmol

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

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

Check $$f\left(\frac{V}{F}\right) = \frac{(1.05)(.555)}{1+(.05)(.8976)} + \frac{(-.42).445}{1-.42(.8976)} = 0.3000 - .29999 = 0 \quad \text{OK}$$

Eq. 3.23 $$x_{C4} = \frac{z_{C4}}{1+(K_{C4}-1)V/F} = \frac{.555}{1+1.056(.8976)} = 0.2857\ ,$$

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

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

$$\frac{V}{F} = \left[-\frac{z_A}{(K_B - 1)} - \frac{z_B}{(K_A - 1)} \right] = \frac{-.555}{(0.253-1)} - \frac{0.445}{0.019} = -23.28$$

NOT possible. Won't flash at 0ºC.

2.D31. *Was 2D32 in 4th edition.*

Drum A: $(V/F)_A = 2/3,\quad L/V = \frac{1/3}{2/3} = 1/2\quad$ Slope $= -1/2$ Through $y = x = z_A = 0.6$

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

Drum B: $\left.\frac{V}{F}\right|_B = 0.4 \quad -\left(\frac{L}{V}\right)_B = -\frac{1-f}{f} = -\frac{0.6}{0.4} = -1.5$

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

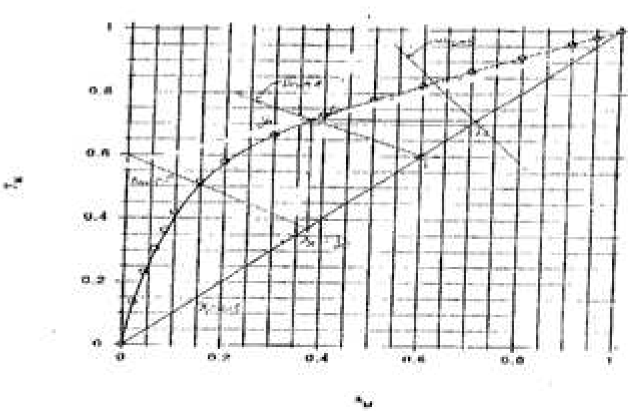
$V_B = 0.4F_B = 0.4V_A = 0.4(66.67) = 26.67,\quad L_B = 0.6F_B = 0.6(66.67) = 40.00$

From figure $x_B = 0.62$ and $y_B = 0.84$

Drum C: $z_C = x_A = 0.375,\quad x_C = 0.15,\quad F_C = L_A = 33.33$, From equilibrium $y_C = 0.51$

At $x = 0,\ y_C = 0.60 = \left(\frac{F}{V}\right)_C z_C \Rightarrow \left(\frac{V}{F}\right)_C = \frac{z_C}{y_C} = \frac{0.375}{0.6} = 0.625$

$V_C = \left(\frac{V}{F}\right)_C F_C = 0.625(33.33) = 20.83,\quad L_C = F_C - V_C = 33.33 - 20.83 = 12.5$



2.E1. *The solution has changed because of different correlation for K_{drum}.*
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 $K_{vertical} = 0.6$, which is too high, so use max $K_{drum} = 0.4$ and $u_{perm} = 13.1259$ ft/s, and D = 3.819 ft = 1.164 m. Appropriate standard size would be used (4 ft = 1.2192 m). 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 $K_{vertical} = .3675$, $u_{perm} = 4.196$ ft/s, and D = 2.467 ft =0.7520 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= 4.1447 bar. From past experience, know this is too high. Try 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 kg/m^3,

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

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

Resulting $K_{vertical}$ = ..44217, use max K = 0.4 $u_{perm} = 7.0204$ ft/s, and D = 0.873 m.

Next guess $p_{drum} = 2.1$ 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 $K_{vertical} = 0.5005$ use K = 0.4, $u_{perm} = 9.1912$ft/s, and D = 0.987 m.

This is reasonably close and will work OK. $T_{drum} = 115.42$ °C, 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. *The solution has changed because of different correlation for K_{drum}. Was 2.D13 in the 2nd ed.*

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

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

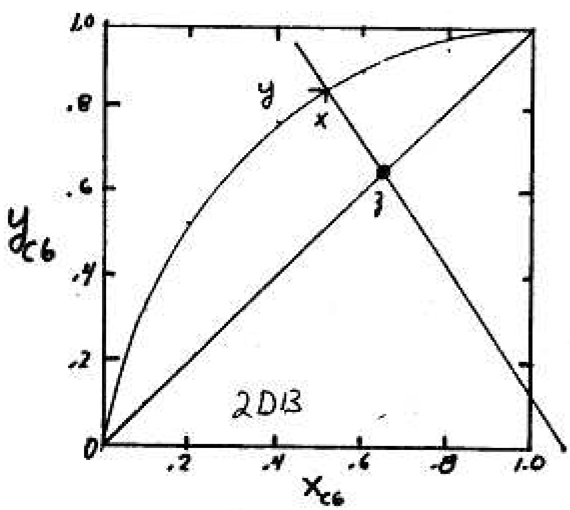
Substitute for x_{C6} $\quad x_{C6} = \dfrac{1 - K_{C8}}{K_{C6} - K_{C8}}$

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	.90	.0357	.321
110	3.0	.68	.1379	.141
100	2.37	.52	.2595	.615
90	1.8	.37	.4406	.793
80	1.4	.26	.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.

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

$$\bar{V}_L = x_{C6}\frac{(MW)_{C6}}{\rho_{C6}} + x_{C8}\frac{(MW)_{C8}}{\rho_{C8}} = (.52)\frac{86.17}{.659} + (.48)\frac{114.22}{.703} = 145.98 \text{ ml/mol}$$

$$\rho_L = \frac{\overline{MW}_L}{\bar{V}_L} = \frac{99.63}{145.98} = .682 \text{ g/ml}\left[\frac{28316 \text{ ml/ft}^3}{454 \text{ g/lbm}}\right] = 42.57\frac{\text{lbm}}{\text{ft}^3}$$

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

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

Now we can determine flow rates

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

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

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

$$F_{lv} = \frac{W_L}{W_v}\sqrt{\frac{\rho_v}{\rho_L}} = \frac{597{,}780}{361{,}520}\sqrt{\frac{0.19135}{42.57}} = 0.111, \ell\text{nF}_{\text{lv}} = -0.9552$$

$K_{drum} = 0.2951$

$$u_{Perm} = K_{drum}\sqrt{\frac{\rho_L-\rho_v}{\rho_v}} = (0.2952)\sqrt{\frac{(42.57-19135)}{.19135}} = 4.393\ \text{ft/s}$$

$$A_{Cs} = \frac{V(MW_v)}{u_{Perm}(3600)\rho_v} = \frac{(4000)(90.38)}{(4.393)(3600)(0.19135)} = 119.5\ \text{ft}^2$$

$$D = \sqrt{\frac{4A_{Cs}}{\pi}} = \sqrt{4\frac{(119.5)}{\pi}} = 12.3\ ft.\ \text{Use } 12.5\ ft.$$

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 with 1% liquid entrainment if a demister is used.

2.E3. 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 since 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

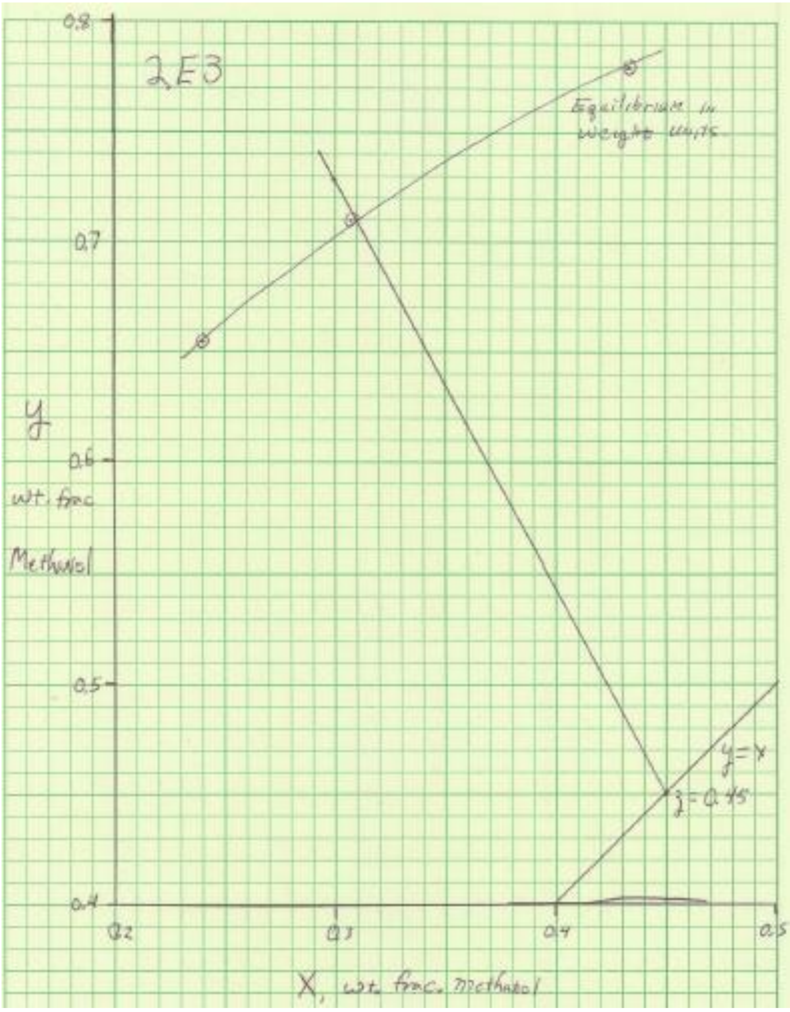
0.2 mole frac liquid give $x_{wt} = 0.3078$ and $y_{wt} = 0.7099$, T = 81.7 C

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, allowed the scale to 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*, 6th ed.

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

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

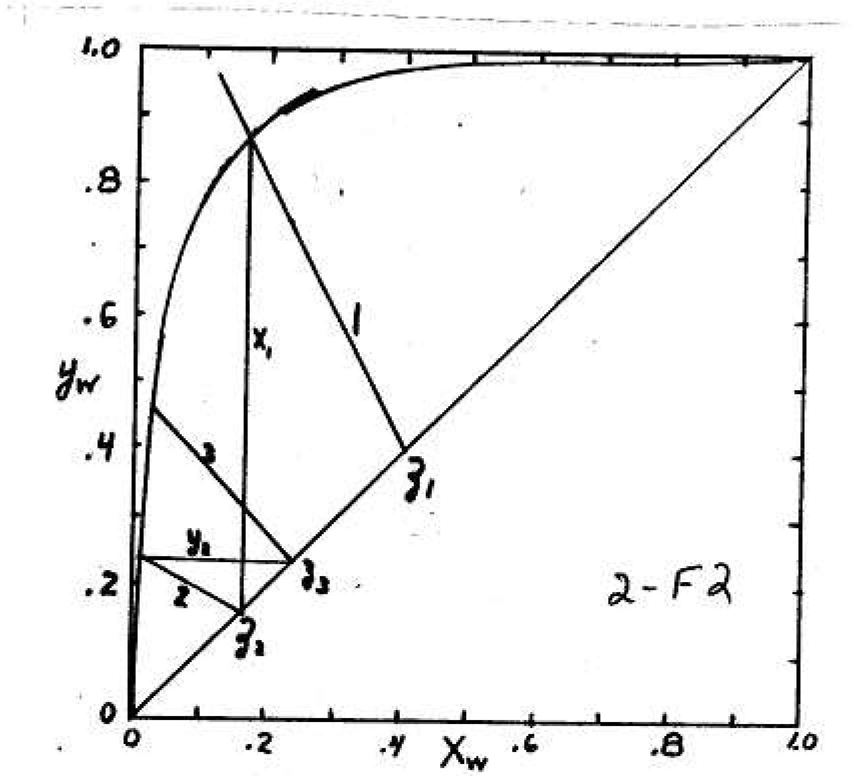
$\text{Intercept} = \frac{.4}{1/3} = 1.2 \quad y_1 = .872 \quad x_1 = .164 = z_2$

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

$\text{Intercept} = \frac{.164}{2/3} = .246 \quad x_2 \simeq .01 \quad y_2 = .240 = -z_3$

Stage 3) $z_{F_3} = .240 \quad f = 1/2 \quad \text{Slope} = -1$

$\text{Intercept} = \frac{.240}{\frac{1}{2}} = .480 \quad x_3 \simeq .022 \quad y_3 = .461$



2.F3. 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. *New problem in 5th ed.* Aspen Plus: x_m = 0.02037, y_m = 0.05627, T = 25.455ºC, Q = 5.1543 GJ/h.

2.G2. *New problem in 5th edition.* **Aspen Plus.** Same result when I did hand calculation and mixed the two feeds before inputting into flash2 and when I put the 2 feeds in separately.

T = 88.28°C, x_M = 0.0898, y_M = 0.397, V/F = 0.4667 so V = 0.4667(225) =105 kmol/h and L = 120.

2G3. *New problem in 5th edition (May not look new, but Problem 2D14 was changed).*

V/F = 0.45713, x = 0.20586 (M), 0.47606(P), 0.31808(B); y = 0.54306(M), 0,35342(P), 0.10352(B), used NRTL correlation. K values: KM = 2.638, KP = .74239, KB = 0.325545,

Since K values are all higher, V/F is higher. Note, When I use the K values from NRTL in the spread sheet V/F = 0.457197, which is close to Aspen value.

With Wilson (ideal gas model) KM = 2.6445, KP = .74251, and KB = 0.32619 and V/F = 0.4592.

With Wilson HOC , KM = 2.5450, KP = 0.74812, KB = 0.33372, V/F = 0.44893

Ideal (Raoult's law, but not constant relative volatility): V/F = 0.43751

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 = 81.14ºC, 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. A. 563.4 R, b.V/F = .4066. c. 18.264 psia

2.H3.. Answer V/F = 0.564; xE = 0.00853, xhex = 0.421, x hept = .570; yE = .421, y Hex = 0.378, y Hept = .201.

2H4. 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 in 5th edition*

a. P = 230.1 kPa.

b. V/F = .1274, ethane x = 0.008178, y = 0.1480
   Propane x =0.0739, y = 0.3560
   Butane x= 0.1936, y = 0.3301
   Pentane x = 0.2855, y = 0.1406
   Hexane x = 0.2888, y = 0.0471
   Heptane x = 0.1501, y = 0.0082.

c. T = 52.71ºC

	A	B	C	D	E	F	G	H	I
1	SPE 5th, 2H5	MC flash, based on App 2B.			Eq 2-30				
2	K const.	aT1	aT2	aT6	ap1	ap2	ap3		
3	Methane	-292860	0	8.2445	-0.8951	59.8465	0		
4	nB	-1280557	0	7.94986	-0.96455	0	0		
5	nPentane	-1524891	0	7.33129	-0.89143	0	0		
6	nHex	-1778901	0	6.96783	-0.84634	0	0		
7	T deg R	536.7	p psia	21.75222113	F	150			
8	zM	0	z nB	0.211	z npent	0.267	znhex	zprop	
9	V/F guess	0.127418938	z et	0.026	z nhept	0.132	0.258	0.106	
10	KM	99.2477922		Pick P in kPa	p, kPa	150	sum z	1	
11	KnB	1.705170986			deg F	77			
12	KnPen	0.49264836		Pick T in C	deg C	25			
13	KnHex	0.162937135							
14		Goal seek cell B25 = 0 change B9 if V/F unknown, change F12 if T unknown,							
15	xM	0	y methan	0	change F10 if p unknown.				
16	xnb	0.193604245	y but	0.330128341					
17	xnPen	0.285453485	y Pen	0.140628191					
18	xnHex	0.288803059	y Hex	0.047056743					
19	Sum x	0.999999909	sum y	1.000000626	xpen spec	0.3			
20	RR M	0	sumx-1	-9.14499E-08					
21	RR nB	0.136524096	1000 D20	-9.14499E-05	Part a. Min P all liquid, set V/F=0, goal				
22	RRnP	-0.144825294			seek B25=0, changing F12. 230.1 kPa				
23	RRnHex	-0.241746316			Part b. V/F = 0.1274		Part c. T = 52.71C		
24	sum RR	7.1771E-07							
25	1000*sum RR	0.00071771							
26	propane	-970688.5625	0	7.15059	-0.76984	0	6.9022		
27	ethane	-687248.25	0	7.90694	-0.886	49.02654	0		
28	n-heptane	-2013803	0	6.52914	-0.79543	0	0		
29	KE	18.10226151							
30	K hept	0.054378215							
31	xE	0.008178282	yE	0.148045391					
32	xhept	0.15008359	y Hept	0.008161278					
33	RR E	0.139867109							
34	RR Hept	-0.141922313							
35	Kpropane	4.412463805	z prop	0.106					
36	x propane	0.073877248	y prop	0.325980683					
37	RR prop	0.252103435							
38									

2H6. *New Problem in 5th edition.*
Develop a spread sheet to solve problem 2D13, part b.
Find y = 0.0562, x = 0.0220, which agrees well with the graphical solution.

2H7. *New Problem in 5th ed.* The spreadsheet modified from Figure 2B2 is shown below for case B, constant V/F & T=57.871 C. It is labeled Figure 2.B3.

Case A: Constant T = 10°C gave V/F = 0.43994; however, since the total feed rate has increased by 37.5 kmol/h, the value of V/F overstates the change. At T = 10°C, V= 88.4409 kmol/h when there is no nonvolatile component and V = 82.48898 kmol/h when there is a nonvolatile.

Case C: A better idea of the effect of the non-volatile on the temperature can be obtained with 37.5 kmol/h of nonvolatile added from constant V =88.4409, which makes V/F = 0.471685. Then converge on T = 23.659°C, which is a significant temperature increase from the original 10°C.

	A	B	C	D	E	F	G	H
1	Figure 2.B3 modified to include non-volatile				Case B, constant V/F			
2	K const.	aT1	aT6	ap1	ap2			
3	M	-292860	8.2445	-0.8951	59.847			
4	nB	-1280557	7.94986	-0.96455	0			
5	nPentane	-1524891	7.33129	-0.89143	0			
6	nHex	-1778901	6.96738	-0.84634	0			
7	input T C	57.8791	calc T deg F	136.18238	z original feed order M, nB,nC5, nC6			
8	input p Kpa	250	Orig Feed ra	150	0.5	0.1	0.15	0.25
9	calc T deg R	595.8824	calc p psia	36.253702	mol frac non volatile			0.2
10	zM + NV	0.4	z nB +NV	0.08	added moles NV		37.5	
11	znpentane +I	0.12	znhex +NV	0.2	sum + NV	1		
12	V/F guess	0.589606	Formulas in Cells are listed below:					
13	KM	70.20074	Cell B13: = EXP(B3/(B9*B9)+C3+D3*LN(D9)+E3/(D9*D9))					
14	KnB	2.411311	Cell B14: = EXP(B4/(B9*B9)+C4+D4*LN(D9)+E4/(D9*D9))					
15	KnPen	0.848762	Cell B15: = EXP(B5/(B9*B9)+C5+D5*LN(D9)+E5/(D9*D9))					
16	KnHex	0.339135	CellB16: = EXP(B6/(B9*B9)+C6+D6*LN(D9)+E6/(D9*D9))					
17	KNV	0						
18	RRM	0.662189	Cell B18: = (B10*(B13-1))/(1+(B13-1)*B12)					
19	RRnB	0.061625	Cell B19: = (D10*(B14-1))/(1+(B14-1)*B12)					
20	RRnPen	-0.01993	Cell B20: = (B11*(B15-1))/(1+(B15-1)*B12)					
21	RRnHex	-0.21655	Cell B21: = (D11*(B16-1))/(1+(B16-1)*B12)					
22	RR NV	-0.48734	Cell B22 = (D11*(B17-1))/(1+(B17-1)*B12)					
23	Sum RR	-1.7E-08	Cell B23: = SUM(B18:B22)					
24	less error	-1.7E-05	Cell B23: = 1000*B23					
25	Goal seek cell B24 = 0 change B12 If Tdrum constant, change B7 if V/F = constant							
26	xM	0.009569	Cell B25: = B10/(1+(B13-1)*B12)					
27	xnb	0.043665	Cell B26: = D10/(1+(B14-1)*B12)					
28	xnPen	0.131748	Cell B27: = B11/(1+(B15-1)*B12)					
29	xnHex	0.327681	Cell B28: = D11/(1+(B16-1)*B12)					
30	x NV	0.487337	Cell B29 = H9/(1+(B17-1)*B12					
31	Sum	1	Cell B31: = SUM(B25:B30)					
32	V	110.5511	Cell B32: = B12*D8					
33	L	76.94888	Cell B33: = D8-B32					
34	yM	0.671759						
35	ynB	0.105291						
36	ynPen	0.111823						
37	ynHex	0.111128						
38	y NV	0						
39	sum y	1						
40								