Homework #8
Multicomponent
Distillation

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1) **Vaporization of Multicomponent Alcohol Mixtures**

The vapor-pressure at 101.325 kPa (760 mm Hg) is available for several alcohols:

	Vapor Pressure (mm Hg)			
T (°C)	Methanol (MeOH)	Ethanol (EtOH)	n-Propanol (nPOH)	n-Butanol (nBOH)
50	415	220.0	88.9	33.7
60	629	351.5	148.9	59.2
65	767	438	190.1	77.7
70	929	542	240.6	99.6
75	1119	665	301.9	131.3
80	1339	812	376	165.0
85	1593	984	465	206.1
90	1884	1185	571	225.9
100	2598	1706	843	387.6

An alcohol feed mixture at 101.325kPa (760 mmHg) consisting of 30 % methanol, 20% ethanol, 15% n-propyl alcohol and 35% n-butyl alcohol is to be fed to a distillation column. Calculate the following assuming the mixture follows Raoult's Law:

a) The boiling point and composition of the vapor in equilibrium.
b) The dew point and composition of the liquid in equilibrium.
c) The temperature and composition of both phases when 40% of the feed is vaporized in a flash distillation (single 'stage' vapor-liquid separation)

Equilibrium And Flash Distillation Calculation Validation

NOTES:

MeOH → A
EtOH → B
nPOH → C
nBOH → D

(a). Calc. b. pt. and compos'n of vapor in equil.

Trial 1 - assume 85°C

	x_i (feed)	$\boxed{P_i}$ mm	$P_i/760 = K_i$	$\alpha_i = P_i/P_c$	$\boxed{\alpha_i x_i}$
A	0.30	1593		3.426	1.028
B	0.20	984		2.116	0.423
C(H)	0.15	465	0.612	1.000	0.150
D	0.35	206.1		0.443	0.155
	1.00			$\Sigma \alpha_i x_i =$	1.756

$K_c = 1/\Sigma \alpha_i x_i = 0.569 = P_c/760$

$\therefore P_c = 432$ mm (83°C)

Trial 2 - assume 83°C

						y_i (Vapor in Equil)
A	0.30	1490		3.489	1.0467	0.589
B	0.20	915		2.143	0.4286	0.241
C	0.15	427	0.562	1.000	0.1500	0.084
D	0.35	187		0.438	0.1533	0.086
					1.7786	1.000

$t = 83°C$

$K = 1/1.7786 = 0.5622 = P_c/760$ $P_c = 427$ mm (83°C)

* Convergence criteria

(b) Calc. dew pt and compos'n of liquid in equilibrium

Trial 1 - assume 90°C

	y_i	P_i	$P_i/760 = K_i$	$\alpha_i = P_i/P_c$	$\boxed{y_i/\alpha_i}$
A	0.30	1884		3.299	0.0909
B	0.20	1185		2.075	0.0964
C(H)	0.15	571	0.751	1.000	0.1500
D	0.35	255.9		0.448	0.7813

$K_c = \Sigma y_i/\alpha_i = 1.1186$

$K_c = 1.1186 = P_c/760$

$\therefore P_c = 850$ (100°C)

Final Trial - assume 100°C

	y_i	$\boxed{P_i}$	$\boxed{K_i}$	$\alpha_i = P_i/P_c$	$\boxed{y_i/\alpha_i}$
A	0.30	2598		3.082	0.0973
B	0.20	1706		2.024	0.0988
C	0.15	843	1.109	1.000	0.1500
D	0.35	387.6		0.4598	0.7612

$K_c = \Sigma y_i \alpha_i = 1.1073$

$K_c = 1.1073 = P_c/760$

$P_c = 841.5$

$t = 100°C$

$$x_i = \frac{y_i/\alpha_i}{\Sigma y_i \alpha_i}$$

	x_i (Liq. in Equil)
A	0.088
B	0.089
C	0.136
D	0.687
	1.000

$t = 100°C$

* Convergence criteria

2) **Multicomponent Alcohol Distillation**

An alcohol feed mixture at 101.325kPa (760 mmHg) consisting of 30 % methanol, 20% ethanol, 15% n-propyl alcohol and 35% n-butyl alcohol is distilled so that 95% of the methanol along with a residue of 5% methanol and other trace components is recovered in the distillate. The feed is below the boiling point, so that q=1.10. The operating reflux ratio is 3.0. Assume Raoult's Law applies.

Determine the following:

a) Composition and amounts of the distillate and bottoms streams for a feed of 100 mole/hr.
b) Top and bottom temperatures and the number of stages at total reflux.
c) The distribution of components at the conditions determined in part (b).
d) The minimum reflux ratio, and number of stages when R=3.0.
e) The feed tray location.

Multicomponent Fractional Distillation Calculation Validation

(a).

	Dist. $x_D = y_D$
A (L)	0.95
B (H)	0.05
C	~0
D	~0
	1.00

F = Feed = 100 mol

	x_F	$x_F F$	
A	0.30	30.00	← MeOH (A)
B	0.20	20.00	← EtoH (B)
C	0.15	15.00	← nPOH (C)
D	0.35	35.00	← nBOH (D)

assume no C + D in ohd (traces) as first trial

Material Bal Overall. Bal on A

$F = 100 = D + W$ $\quad 0.3(100) = 0.95D + 0.05W$

$30.0 = 0.95D + 0.05(100 - D)$. solving $\boxed{D = 27.778 \\ W = 72.222}$ ← Bottoms flow rate is denoted as "W"

$x_{AD}D = 0.95(27778) = 26.389$

$x_{AW}W = 0.05(72.222) = \underline{3.611}$

30.000

$\boxed{x_{AD} = 0.95, x_{BD} = 0.05 \\ x_{CD} = 0, x_{DD} = 0}$

	Btms W $x_W W$	x_W
A (L)	3.611	$0.0500 = x_{AW}$
B (H)	18.611	$0.2577 = x_{BW}$
C	15.000	$0.2077 = x_{CW}$
D	35.000	$0.4846 = x_{DW}$
	W = 72.222	1.0000

$x_{WB}W = 72.222 - 3.611 - 15.000 - 35.000 = 18.611$

(b) Top. Temp. Dew Pt

Trial and error. Final trial assume 65.5°C

Comp.	y_{iD}	P_i'	$K_i = P_i'/760$	α_i'	y_i/α_i'
A (L)	0.95	781		1.736	0.5472
B (H)	0.05	450	0.592	1.000	0.0500
C	0	193		0.429	
D	0	80		0.1778	

$K_B = \Sigma y_i/\alpha_i' = 0.5972$

$0.5972 = P_B/760$

$P_B = 453.8$

$\therefore \boxed{t = 65.5\,°C}$

$\alpha_A = 1.736 = \alpha_{LD}$

Btm. Temp. B.Pt assume $t = 94°C$

Comp.	x_{iW}	P_i'	$P_i'/760 = K_i'$	$\alpha_i = P_i/P_B$	$\alpha_i x_i'$
A (L)	0.0500	2150	2.829	1.558	0.0779
B (H)	0.2577	1380	1.816	1.000	0.2577
C	0.2077	675		0.4891	0.1016
D	0.4846	305		0.2210	0.1071

$\Sigma \alpha_i x_i = 0.5443$

$K_{B(H)} = 1/\Sigma \alpha_i x_i$

$= 1/0.5443 = 0.1837$

$0.1837 = P_i/760$

$P_B = 1396$ $\boxed{t = 94.3\,°C}$

$\alpha_A = 1.558 = \alpha_{LW}$

No. of Stages at Total Reflux. N_m

$\alpha_{av} = \sqrt{\alpha_{LD} \times \alpha_{LW}} = \sqrt{1.736(1.558)} = 1.645$

$$N_m = \frac{\log\left[\frac{x_{LD}D}{x_{HD}D} \cdot \frac{x_{HW}W}{x_{LW}W}\right]}{\log \alpha_{av}}$$

Multicomponent Fractional Distillation Calculation Validation Continued

$$N_m = \frac{\log\left[\frac{0.95(27.778)}{0.05(27.778)} \cdot \frac{0.2577 \times 72.222}{0.0500 \times 72.222}\right]}{\log 1.645}$$

$\boxed{N_m = 9.21 \text{ theoret. stages}}$

<u>Distribution of trace components C + D in Dist, Btms</u>

$$\frac{x_{iD} D}{x_{iW} W} = (\alpha_{i,av})^{N_m} \frac{x_{HD} D}{x_{HW} W}$$

<u>Component C</u> $\alpha_{C,av} = \sqrt{0.429 \times 0.4891} = 0.4581$

$$\frac{x_{CD} D}{x_{CW} W} = (0.4581)^{9.21}\left(\frac{0.05 \times 27.778}{0.2577 \times 72.222}\right) = 5.628 \times 10^{-5}$$

Mat'l bal of C $x_{CF} F = x_{CD} D + x_{CW} W$, $15.00 = 5.628 \times 10^{-4} x_{CW} W + 1.0\, x_{CW} W$

Solving, $x_{CW} W = 14.999155$, $x_{CD} D = 0.000845 = 8.45 \times 10^{-4}$

<u>Component D</u> $\alpha_{D,av} = \sqrt{0.1778 \times 0.2210} = 0.1982$

$$\frac{x_{DD} D}{x_{DW} W} = (0.1982)^{9.21}\left(\frac{0.05 \times 27.778}{0.2577 \times 72.222}\right) = 2.51 \times 10^{-8}$$

Mat'l. bal of D $x_{DF} F = x_{DD} D + x_{DW} W$, $35.0 = x_{DD} D + \frac{x_{DD} D}{2.51 \times 10^{-8}}$

Solving, $x_{DD} D = 8.79 \times 10^{-7}$, $x_{DW} W = 35.00$

<u>New compositions of D and W including traces</u>

	D, Dist. x_{iD}	$x_{iD} D$	W, Btms x_{iW}	$x_{iW} W$
A (L)	0.9500	26.389	0.0500	3.611
B (H)	0.0500	1.389	0.2577	18.611
C	3.04×10^{-5}	8.45×10^{-4}	0.2077	14.999155
D	3.16×10^{-8}	8.79×10^{-7}	0.4846	~35.00
	1.000	D = 27.78	1.000	W = 72.222

$\boxed{x_{CD} = 3.04 \times 10^{-5}}$ Trace Compositions
$\boxed{x_{DD} = 8.79 \times 10^{-7}}$

(c) <u>Minimum Reflux R_m</u>

$t_{av} = (65.5 + 94.3)/2 = 79.9°C$ (80°C)

	P_i	α_i
P_A	1339 mm	1.649
P_B	812	1.000
P_C	376	0.463
P_D	165	0.2032

Eq.(11.7-19) $1 - q = \sum \frac{\alpha_i x_{iF}}{\alpha_i - \theta}$ Trial and error.

$$1 - 1.1 = -0.100 = \frac{1.649 \times 0.30}{1.649 - \theta} + \frac{1.000 \times 0.20}{1.000 - \theta} + \frac{0.463 \times 0.15}{0.463 - \theta} + \frac{0.2032 \times 0.35}{0.2032 - \theta}$$

Assumed θ	$\frac{0.4947}{1.649 - \theta}$	$+ \frac{0.2000}{1.000 - \theta}$	$+ \frac{0.06945}{0.463 - \theta}$	$+ \frac{0.07112}{0.2032 - \theta}$	Σ
1.200	1.1018	−1.000	−0.0942	−0.0713	−0.0637
1.195	1.0896	−1.0256	−0.0949	−0.0717	−0.1026
1.196	1.0921	−1.0204	−0.0947	−0.0714	−0.0944

Hence, use $\theta = 1.1955$

$$R_m + 1 = \sum \frac{\alpha_i x_{iD}}{\alpha_i - \theta}$$

$$R_m + 1 = \frac{1.649 \times 0.95}{1.649 - 1.1955} + \frac{1.000 \times 0.050}{1.000 - 1.1955} + \frac{0.463(3.04 \times 10^{-5})}{0.463 - 1.1955} + \frac{0.2032(3.16 \times 10^{-8})}{0.2032 - 1.1955}$$

$R_m = 2.199$ $\boxed{R_m = 2.20}$

<u>Use operating R = 3.00</u>

$\frac{R}{R+1} = \frac{3}{3+1} = 0.75$ $\frac{R_m}{R_m + 1} = \frac{2.20}{2.20 + 1} = 0.6875$

$N_m / N = 0.57$ $9.21/N = 0.57$

$\boxed{N = 16.2 \text{ theoretical stages}}$

<u>Kirkbride Feed Tray Location</u>

$$\log \frac{N_e}{N_s} = 0.206 \log\left[\left(\frac{x_{HF}}{x_{LF}}\right) \frac{W}{D} \left(\frac{x_{LW}}{x_{HD}}\right)^2\right]$$

$$= 0.206 \log\left[\left(\frac{0.20}{0.30}\right) \frac{72.222}{27.778} \left(\frac{0.0500}{0.0500}\right)^2\right]$$

$$\log \frac{N_e}{N_s} = 0.04921$$

$N_e / N_s = 1.1199$ $N_e + N_s = 16.2$ Solving,

$\boxed{N_e = 8.6 \text{ (Feed on stage 8.6 from top)}}$