CE407 SEPARATIONS

Lecture 11 Example Problems

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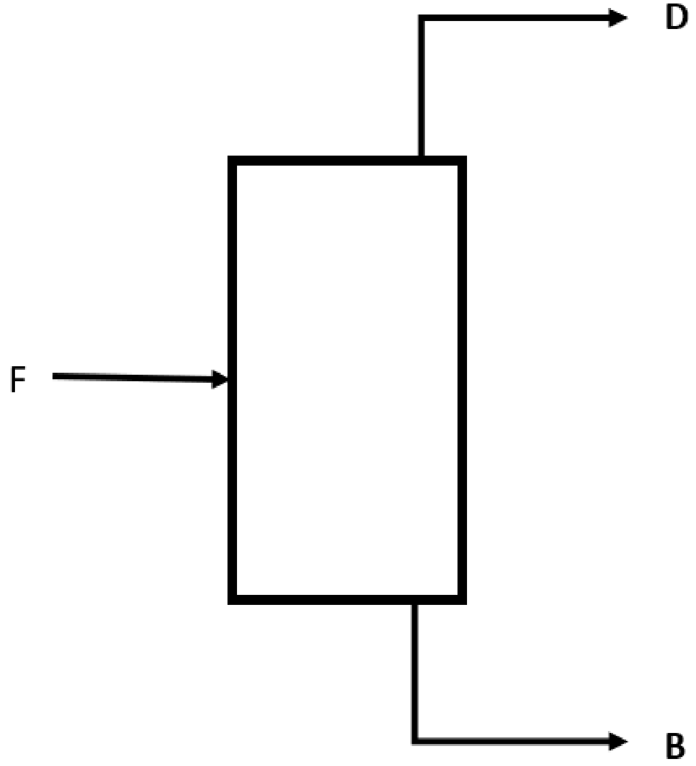
Example Problem

- We need to perform a separation on this stream:

Component, *i*	Mole Fraction in Feed, x_{fi}	Relative Volatility, $\alpha_i = \alpha_{i, HK}$
1	0.08	3.09
2 (LK)	0.40	1.95
3	0.10	1.25
4 (HK)	0.39	1.00
5	0.03	0.52

- We require a 99% recovery of the Light Key in the distillate and 99% recovery of the Heavy Key in the bottoms
  - What will be the split of Component 3 between the Distillate and the Bottoms?
  - How good is the assumption that the LLK and HHK components are not distributed?

100 mole basis



100 mole total
1: 8 moles
2: 40 moles (LK)
3: 10 moles
4: 39 moles (HK)
5: 3 moles

D:
1: 8 moles
2: 0.99 * 40 = 39.6 moles (LK)
3: δ moles
4: 39 – 38.61 = 0.39 moles (HK)
5: 0 moles

B:
1: 0 moles
2: 40 - 39.6 = 0.40 moles (LK)
3: 10 - δ moles
4: 0.99 * 39 = 38.61 moles (HK)
5: 3 moles

Use Fenske Equation to solve for N_{min} and δ

- Calculate N_{min} + 1 for LK/HK
- $i = 2$, $j = 4$

$$N_{min} + 1 = \frac{ln\left[\frac{Dx_{iD}/Bx_{iB}}{Dx_{jD}/Bx_{jB}}\right]}{ln\ \overline{\alpha_{ij}}} = \frac{ln\left[\frac{39.6/0.40}{0.39/38.61}\right]}{ln\ 1.95} = 13.76$$

- Perform Fenske for i = 3 and j = 4

$$N_{min} + 1 = \frac{ln\left[\frac{Dx_{iD}/Bx_{iB}}{Dx_{jD}/Bx_{jB}}\right]}{ln\ \overline{\alpha_{ij}}} = \frac{ln\left[\frac{\delta/(10-\delta)}{0.39/38.61}\right]}{ln\ 1.25} = 13.76$$

- Rearrange

$$13.76 * ln(1.25) = ln\left[\frac{\delta/(10-\delta)}{0.39/38.61}\right] = 3.0705$$

- Take exponential

$$e^{3.0705} = \frac{\delta/(10-\delta)}{0.39/38.61} = 21.5517$$

Distributed component, solve for **δ**

$$\frac{\delta/(10 - \delta)}{0.39/38.61} = 21.5517$$

$$\delta/(10 - \delta) = 21.5517 * 0.39/38.61 = 0.2177$$

$$\delta = 0.2177 * (10 - \delta)$$

$$1.2177\delta = 2.177$$

$\delta = 1.79$ is the number of moles of component 3 in the distillate

$10 - \delta = 8.21$ is the number of moles of component 3 in the bottoms

Use Fenske Equation to Check Assumption that Component 1 Does Not Appear Appreciably in the Bottoms Stream

- Note that the calculation of N_{min} did not depend on anything except number of moles of components 2 and 4
  - Assumptions about LLK and HHK components did not affect that calculation
  - Now we will assign δ as the number of moles of component 1 in the distillate and $8-\delta$ as the number in the bottoms. The relative volatility, α_{ij}, of component 1 to the HK is 3.09
- Perform Fenske for i = 1 and j = 4

$$N_{min}+1=\frac{ln\left[\frac{Dx_{iD}/Bx_{iB}}{Dx_{jD}/Bx_{jB}}\right]}{ln\,\overline{\alpha_{ij}}}=\frac{ln\left[\frac{\delta/(8-\delta)}{0.39/38.61}\right]}{ln\,3.09}=13.76$$

- Rearrange

$$13.76*ln(3.09)=ln\left[\frac{\delta/(8-\delta)}{0.39/38.61}\right]=15.523634$$

- Take exponential

$$e^{15.5236}=\frac{\delta/(8-\delta)}{0.39/38.61}=5.518597*10^{6}$$

Use Fenske Equation to Check Assumption that Component 1 Does Not Appear Appreciably in the Bottoms Stream

$$\frac{\delta/(8-\delta)}{0.39/38.61} = 5.518597 * 10^6$$

$$\delta/(8-\delta) = 5.518597 * 10^6 * 0.39/38.61 = 55,743.40$$

$$\delta = 55,743.40 * (8-\delta)$$

$$55,744.40\,\delta = 445,947.23$$

$\delta = 8.00000000$ is the number of moles of component 1 in the distillate

$8-\delta < 10^{-8}$ is the number of moles of component 1 in the bottoms

Example Problem 2 – Required Stages

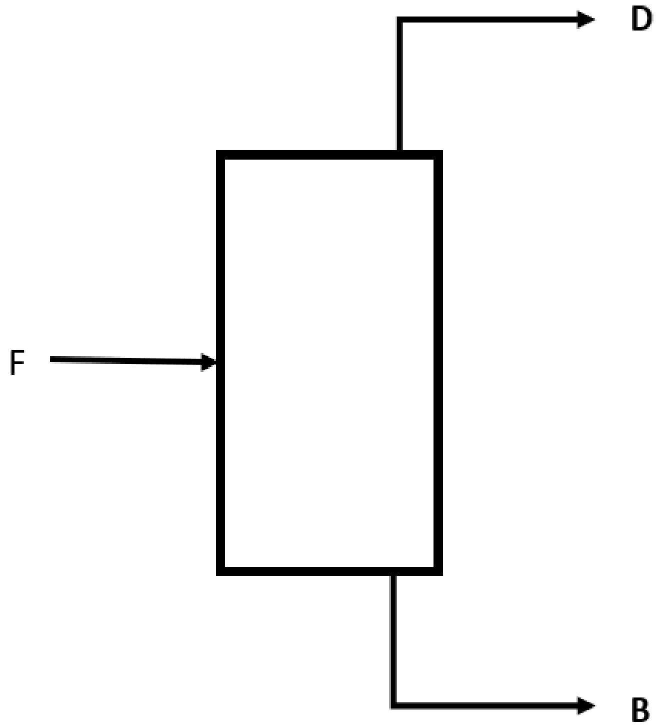
2. A four-component mixture (see table below) is to be distilled with 97.5 percent recovery of the light and heavy keys in the distillate and bottoms. Estimate the number of ideal stages required at a reflux ratio equal to 1.3 times the minimum.

component i	mole fraction in feed $(x_F)_i$	relative volatility (with respect to HK) $\alpha_i = \alpha_{i,HK}$
1	0.08	3.09
2 (LK)	0.50	1.95
3 (HK)	0.39	1.00
4	0.03	0.52

The mixture enters the distillation column as saturated liquid.

Example Problem 2 – Required Stages

100 mole basis



100 mole total
1: 8 moles
2: 50 moles (LK)

3: 39 moles (HK)
4: 3 moles

1: 8 moles
2: 0.975 * 50 = 48.750 moles (LK)
3: 39 – 38.025 = 0.975 moles (HK)
4: 0 moles

D = 57.725 moles

1: 0 moles
2: 50 – 48.750 = 1.250 moles (LK)
3: 0.975 * 39 = 38.025 moles (HK)
4: 3 moles

B = 42.275 moles

Use Fenske to Calculate N_{min}

- Calculate N_{min} + 1 for LK/HK
- i = 2, j = 3

$$N_{min} + 1 = \frac{ln\left[\frac{Dx_{iD}\ /Bx_{iB}}{Dx_{jD}\ /Bx_{jB}}\right]}{ln\ \overline{\alpha_{ij}}} = \frac{ln\left[\frac{48.750/1.250}{0.975/38.025}\right]}{ln\ 1.95} = 11.0$$

$$N_{min} = 10.0$$

Minimum Reflux Ratio – Underwood's Method

- Eq 22.29 $$\mathbf{1} - \boldsymbol{q} = \sum_i \frac{\alpha_i x_{i,F}}{\alpha_i - \varphi}$$ sum *i* is over ALL components
- Because feed is a saturated liquid, $\boldsymbol{q} = 1$

$$\mathbf{1} - \boldsymbol{q} = \mathbf{1} - \mathbf{1} = \mathbf{0} = \sum_i \frac{\alpha_i x_{i,F}}{\alpha_i - \varphi}$$

- Solve using GoalSeek in Excel
  - (or however you prefer…)

D2 =C2*B2/(C2-M$3)

	A	B	C	D	E	F	K	L	M
1	i	x_{Fi}	α_i	Contribution to Sum				q =	1
2	1	0.08	3.09	0.134832				1 - q =	0
3	2	0.50	1.95	1.406142				φ =	1.256613
4	3	0.39	1.00	-1.5198					
5	4	0.03	0.52	-0.02118					
6			Sum =	0.00000					

Minimum Reflux Ratio – Underwood's Method

- Eq 22.30 $$R_{min} + 1 = \sum_i \frac{\alpha_i x_{i,D}}{\alpha_i - \varphi}$$ sum *i* is over only components in distillate
- Solving for R_{min} is straightforward, no iteration required

I2 =C2*H2/(C2-M$3)

	F	G	H	I	J	K	L	M	N
1		# moles in D	x_{Di}	R_{min} Sum contribution			q =	1	
2		8	0.1386	0.233577			1 - q =	0	
3		48.75	0.8445	2.375034			φ =	1.256613	
4		0.975	0.0169	-0.06582					
5		0	0.0000						
6		57.72500	1.0000	2.543	Sum for R_{min}				
7									
8			R_{min} =	1.543					
9									

Required Number of stages for a Given Value of R

- ## Gilliland Correlation

- From problem Statement: $R = 1.3 * R_{min} = 1.3 * 1.543 = 2.006$

$$\frac{R - R_{min}}{R+1} = \frac{2.006 - 1.543}{2.006+1} = 0.15$$

- Read $\frac{N' - N'_{min}}{N'+1}$ off of the graph

$$\frac{N' - N'_{min}}{N' + 1} = 0.48$$

- Solve for N'

$N_{min} = 10.0$ (From Fenske, see slide 10)

$$N'_{min} = N_{min} + 1 = 11.0$$

$$\frac{N' - 11.0}{N' + 1} = 0.48$$

$$N' = 22.1$$

- **N = N' - 1** Report as 21.1 stages + Reboiler – would round up to **22 stages + Reboiler**