Mass Transfer-II Notes

Calculation of q-value

When feed is partially vaporized: Other than saturated liquid ($q = 1$) and saturated vapor ($q = 0$), the feed condition is uncertain. In that case one must calculate the value of q. The q -value can be obtained from enthalpy balance around the feed plate. By enthalpy balance one can obtain the q-value from the following form of Equation:

$$q = \frac{H_V - H_F}{H_V - H_L}$$

Where, H_F, H_V and H_L are enthalpies of feed, vapor and liquid respectively which can be obtained from enthalpy-concentration diagram for the mixture.

When feed is cold liquid or superheated vapor:

q can be alternatively defined as the heat required to convert 1 mole of feed from its entering condition to a saturated vapor; divided by the molal latent heat of vaporization. Based on this definition, one can calculate the q-value from the following Equations for the case whereby $q > 1$ (cold liquid feed) and $q < 0$ (superheated vapor feed) as:

For cold liquid feed:

$$q = \frac{C_{p,L}(T_{bp} - T_F) + \lambda}{\lambda}$$

For superheated vapor feed:

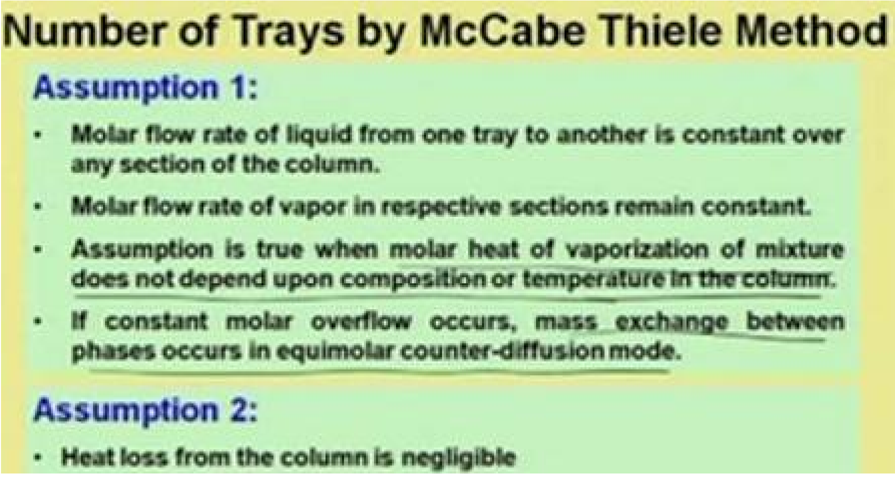
$$q = \frac{C_{p,V}(T_{dp} - T_F)}{\lambda}$$

where T_{bp} is the bubble point, λ is the latent heat of vaporization and T_{dp} is the dew point of the feed respectively.

Overall Efficiency

The overall tray efficiency, E_O is defined as:

$$E_o = \frac{\text{No. of theoratical trays}}{\text{No. of actual trays}}$$



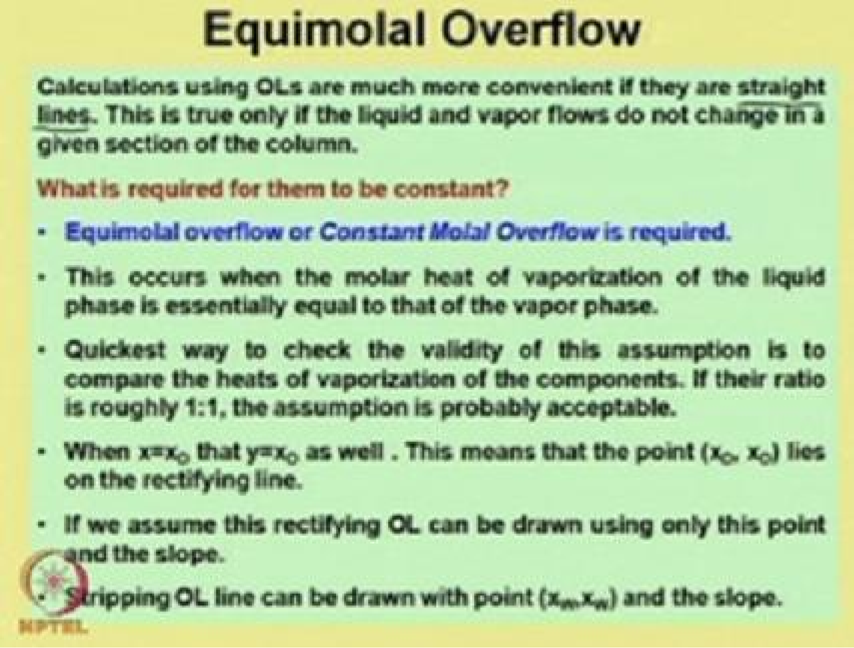
Number of Trays by McCabe Thiele Method

Assumption 1:

- Molar flow rate of liquid from one tray to another is constant over any section of the column.
- Molar flow rate of vapor in respective sections remain constant.
- Assumption is true when molar heat of vaporization of mixture does not depend upon composition or temperature in the column.
- If constant molar overflow occurs, mass exchange between phases occurs in equimolar counter-diffusion mode.

Assumption 2:

- Heat loss from the column is negligible



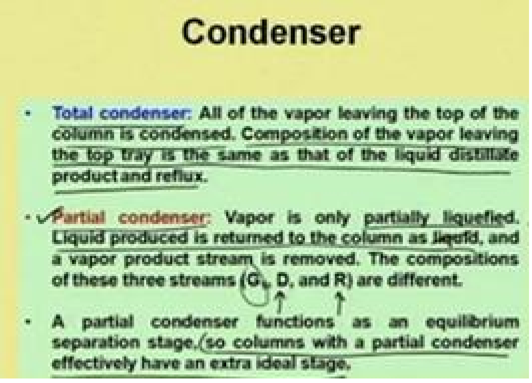
Equimolal Overflow

Calculations using OLs are much more convenient if they are straight lines. This is true only if the liquid and vapor flows do not change in a given section of the column.

What is required for them to be constant?

- Equimolal overflow or *Constant Molal Overflow* is required.
- This occurs when the molar heat of vaporization of the liquid phase is essentially equal to that of the vapor phase.
- Quickest way to check the validity of this assumption is to compare the heats of vaporization of the components. If their ratio is roughly 1:1, the assumption is probably acceptable.
- When $x=x_D$ that $y=x_D$ as well . This means that the point (x_D, x_D) lies on the rectifying line.
- If we assume this rectifying OL can be drawn using only this point and the slope.
- Stripping OL line can be drawn with point (x_W,x_W) and the slope.

NPTEL



Condenser

- **Total condenser:** All of the vapor leaving the top of the column is condensed. Composition of the vapor leaving the top tray is the same as that of the liquid distillate product and reflux.
- ✓**Partial condenser:** Vapor is only partially liquefied. Liquid produced is returned to the column as liquid, and a vapor product stream is removed. The compositions of these three streams (G_1, D, and R) are different.
- A partial condenser functions as an equilibrium separation stage, (so columns with a partial condenser effectively have an extra ideal stage.

Example problem 5.2:

A liquid mixture of benzene toluene is being distilled in a fractionating column at 101.3 k Pa pressure. The feed of 100 kmole/h is liquid and it contains 45 mole% benzene (A) and 55 mole% toluene (B) and enters at 327.6 K. A distillate containing 95 mole% benzene and 5 mole% toluene and a bottoms containing 10 mole% benzene and 90 mole% toluene are to be obtained. The amount of liquid is fed back to the column at the top is 4 times the distillate product. The average heat capacity of the feed is 159 KJ/kg mole. K and the average latent heat 32099 kJ/kg moles.

Calculate

- **i.** The kg moles per hour distillate, kg mole per hour bottoms
- **ii.** No. of theoretical stages at the operating reflux.
- **iii.** The minimum no. of theoretical stages required at total reflux
- **iv.** If the actual no. of stage is 10, what is the overall efficiency increased at operating condition compared to the condition of total reflux?

The equilibrium data:

Temp.(K)	353.3	358.2	363.2	366.7	373.2	378.2	383.8
$x_{A\ (\text{mole fraction})}$	1.000	0.780	0.580	0.450	0.258	0.13	0
$y_{A(\text{mole fraction})}$	1.000	0.900	0.777	0.657	0.456	0.261	0

Solution 5.2:

F = D + B

100 = D + B

F x_F = D x_D + B x_B

Therefore, D = 41.2 kg mole/h, B = 58.8 kg mole/h

y = [R/(R+1)] x + x_D/(R+1) = 0.8 x +0.190

q = 1+ cpL (T_B-T_F)/Latent heat of vaporization

T_B = 366.7 K from boiling point of feed, T_F = 327.6 K (inlet feed temp)

Therefore q = 1.195

Slope of q line = 6.12

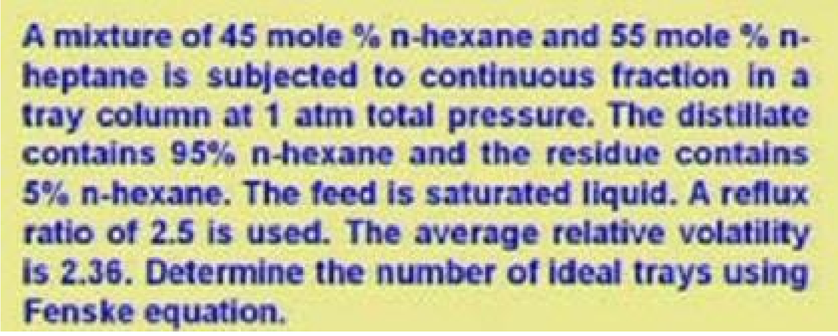
From the graph (Figure E1), Total no of theoretical stages is 8 at operating reflux (Red color)

From the graph (Figure E1), Total no of theoretical stages is 6 at total reflux (Black color)

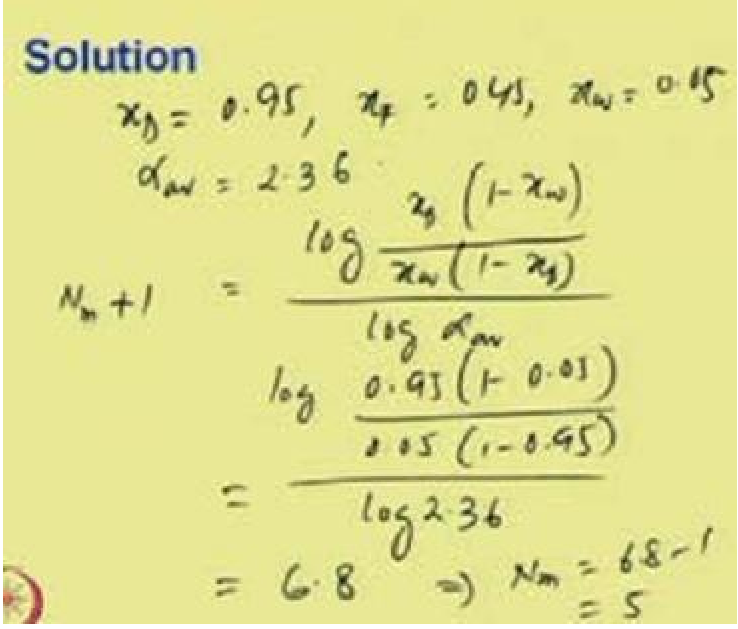
Overall efficiency at operating conditions: Eo (Operating) = No of ideal stage/ No of actual trays = 7.9/10 = 0.79

Overall efficiency at total reflux conditions: Eo (total relux) = No of ideal stage/ No of actual trays = 5.9/10=0.59

Overall efficiency increased: 0.79-0.59 = 0.20



A mixture of 45 mole % n-hexane and 55 mole % n-heptane is subjected to continuous fraction in a tray column at 1 atm total pressure. The distillate contains 95% n-hexane and the residue contains 5% n-hexane. The feed is saturated liquid. A reflux ratio of 2.5 is used. The average relative volatility is 2.36. Determine the number of ideal trays using Fenske equation.



Solution

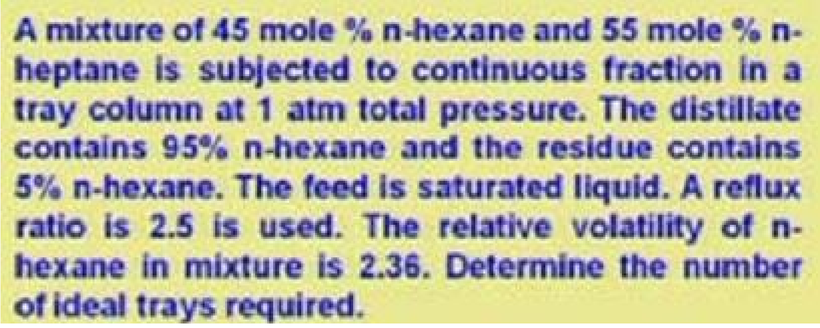
$x_D = 0.95, \quad x_F = 0.45, \quad x_W = 0.05$

$\alpha_{av} = 2.36$

$$N_m + 1 = \frac{\log \dfrac{x_D(1-x_W)}{x_W(1-x_D)}}{\log \alpha_{av}}$$

$$= \frac{\log \dfrac{0.95(1-0.05)}{0.05(1-0.95)}}{\log 2.36}$$

$$= 6.8 \Rightarrow N_m = 6.8 - 1 = 5$$



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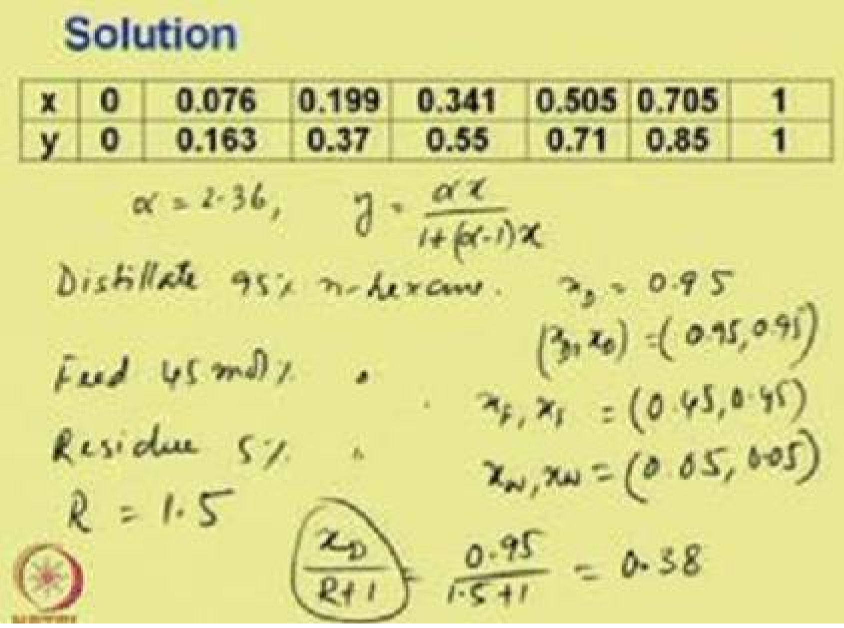


Solution

x	0	0.076	0.199	0.341	0.505	0.705	1
y	0	0.163	0.37	0.55	0.71	0.85	1

$\alpha = 2.36$, $y = \frac{\alpha x}{1+(\alpha-1)x}$

Distillate 95% n-hexane. $x_D = 0.95$

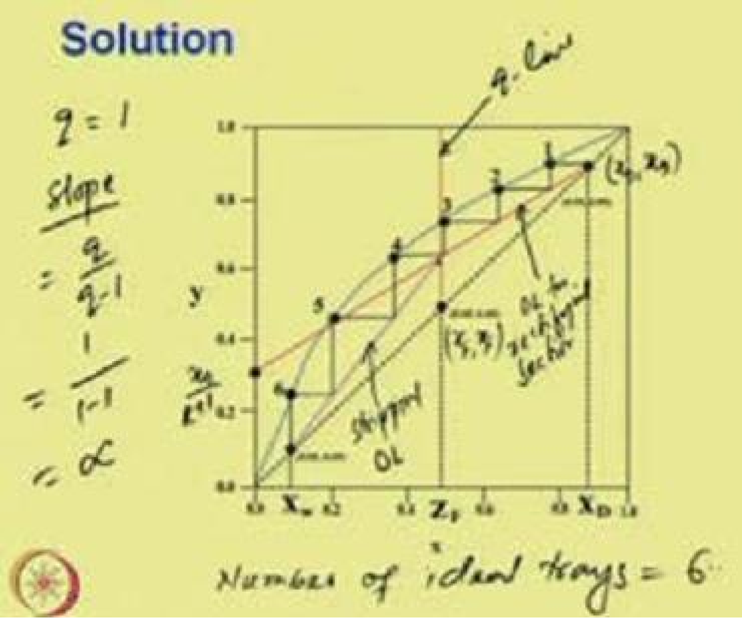
$(y_D, x_D) = (0.95, 0.95)$

Feed 45 mol% . $x_F, x_F = (0.45, 0.45)$

Residue 5% . $x_W, x_W = (0.05, 0.05)$

$R = 1.5$

$\boxed{\frac{x_D}{R+1}} = \frac{0.95}{1.5+1} = 0.38$



Solution

$q = 1$

slope $= \frac{q}{q-1} = \frac{1}{1-1} = \infty$

Number of ideal trays = 6

3. A continuous fractionating column is to be designed for separating 10,000 kg per hour of a liquid mixture containing 40 mole percent methanol and 60 mole percent water into an overhead product containing 97 mole percent methanol and a bottom product having 98 mole percent water. A mole reflux ratio of 3 is used. Calculate (i) moles of overhead product obtained per hour and (ii) number of ideal plates and location of the feed plate if the feed is at its bubble point.

Equilibrium data:

x	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
y	0.417	0.579	0.669	0.729	0.78	0.825	0.871	0.915	0.959

Where x = mole fraction of methanol in liquid

And y = mole fraction of methanol in vapor

Data:

Feed rate = 10,000 kg/hr

$z_F = 0.4$

$x_D = 0.97$

$x_W = 0.02$

R = 3

Calculations:

(i) Moles of overhead product:

Average molecular weight of feed = 0.4 x 32 + 0.6 x 18 = 23.6

Molal flow rate of feed = 10000/23.6 = 423.73 kmol/hr

Material balance equations:

$F = D + W$

$F z_F = D x_D + W x_W$

Where F = feed; D = distillate; W = residue

Substituting for the known quantities,

$423.73 = D + W$

$423.73 \times 0.4 = 0.97 D + 0.02 W$

$0.97 D - 0.02 D = 169.492 - 8.4746$

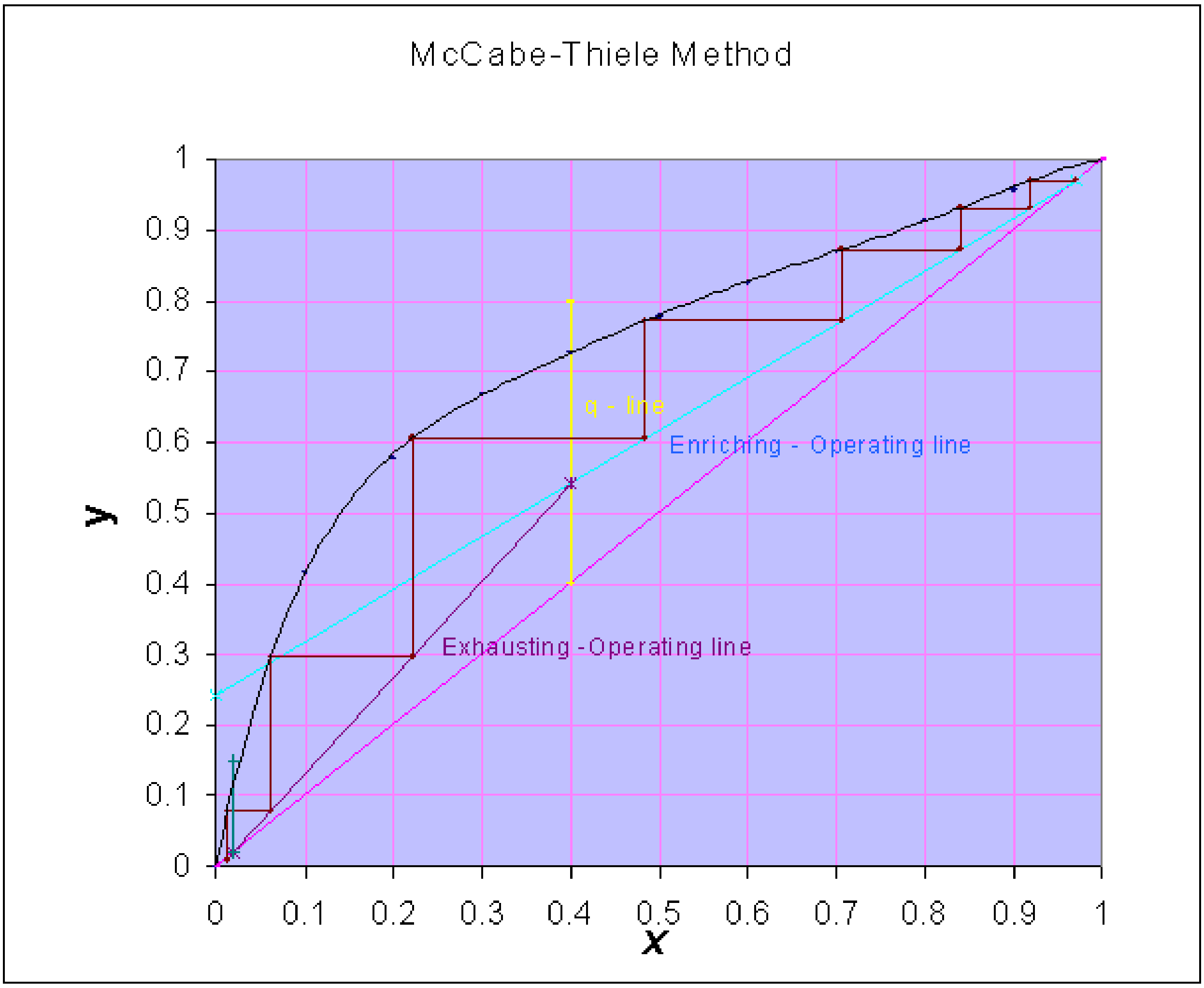
$D = 169.492$ kmol/hr

Overhead product obtained = 169.492 kmol/hr

(ii) Number of ideal plates:

Slope of 'q - line' = $\propto$ (feed is at its bubble point)

$R = L/D = 3$



Number of theoretical plates are estimated from the McCabe-Thiele graphical construction method and found to be equal to 7. And the location of feed plate is 5th plate (counting from the top)