Mass Transfer Operations

Lec 10:Continuous Distillation

Content

Distillation Concept, Distillation Column, McCabe-Thiele Method

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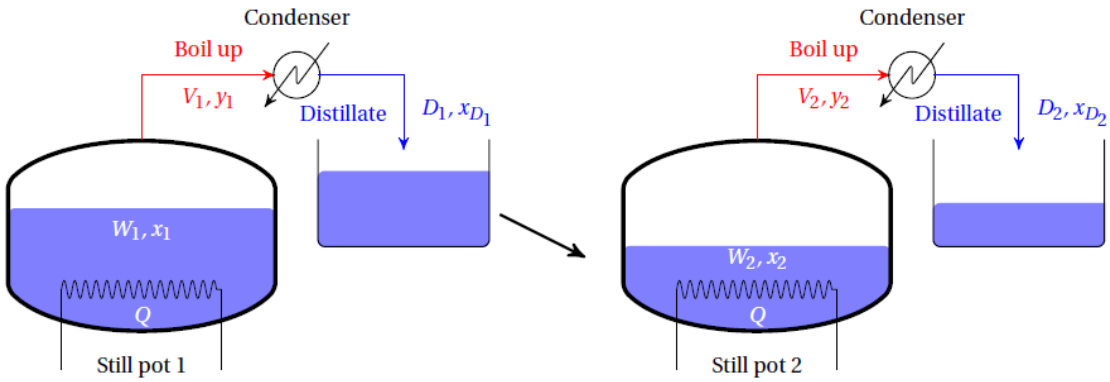
Content

- Distillation Concept
- Distillation Column
- McCabe-Thiele Method

Learning Outcomes

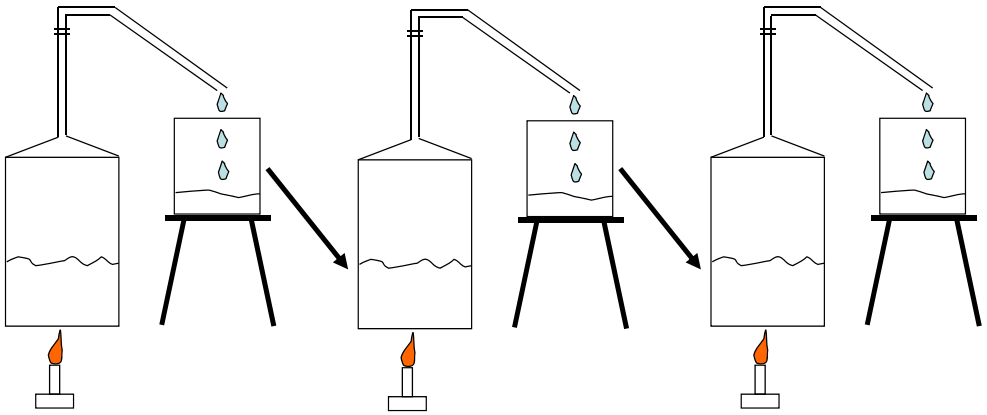
- After this lecture you should be able to…..
  - Describe how continuous distillation works
  - List the major components of a distillation column
  - Develop a mathematical model for a continuous column

How to separate a binary mixture – Pot still



- Boil the mixture, condense the vapor and collect the distillate.
- Boil the distillate and repeat the procedure until the desired purity is obtained.

How to separate a binary mixture – Pot still

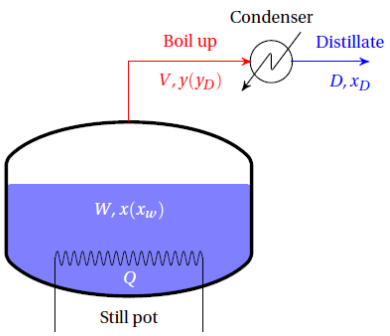


- Boil the mixture, condense the vapour and collect the distillate. Repeat the procedure until the desired purity is obtained.

Pros & Cons

Pros

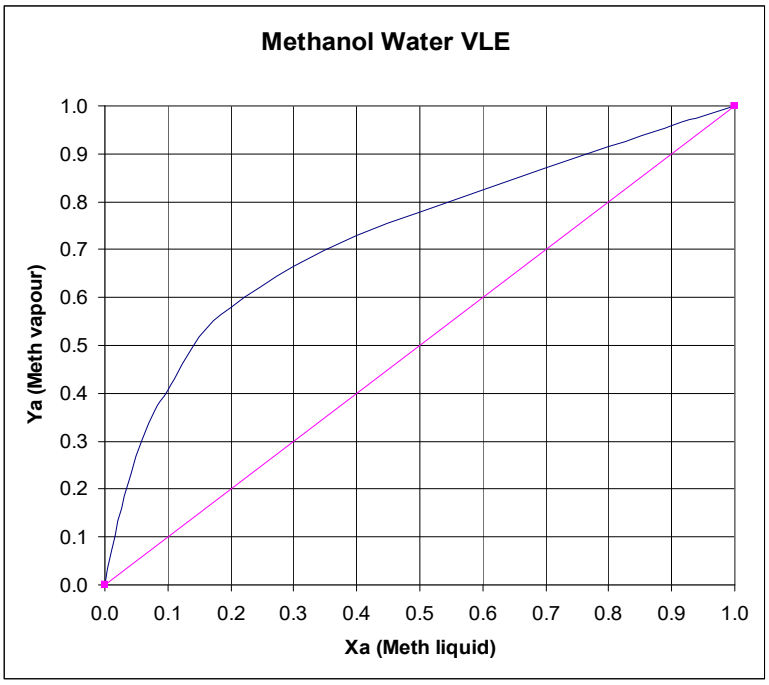
- Simple to make & operate
- Cheap component
- Flexible; can collect over time before using



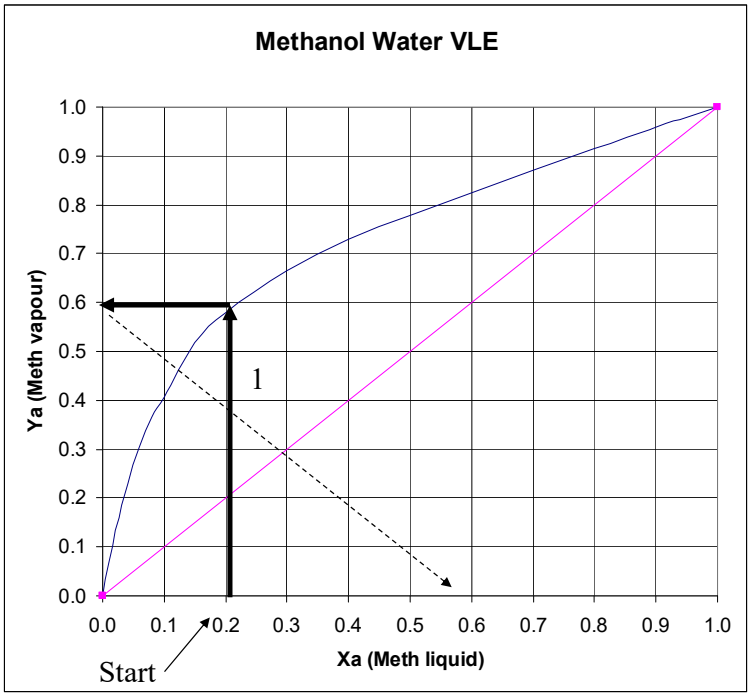
Cons

- Small amount for high purity
- Large amount for low purity
- Energy intensive
- Slow

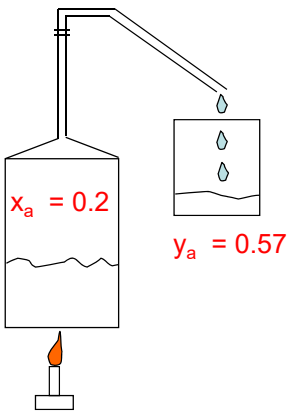
VLE for Meth H_2O



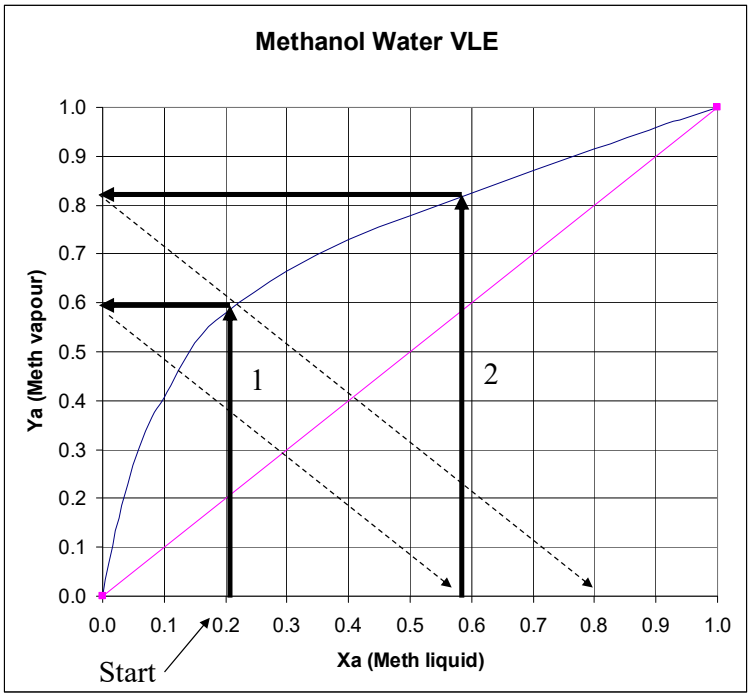
Boil and Cool 4 times



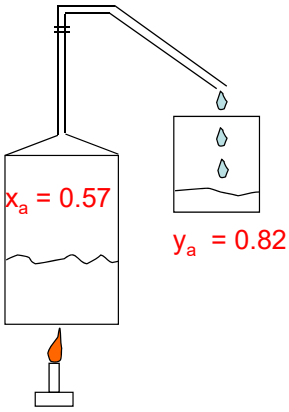
- Boiling a liquid with x_a of 0.2 produces a vapour with y_a of 0.57



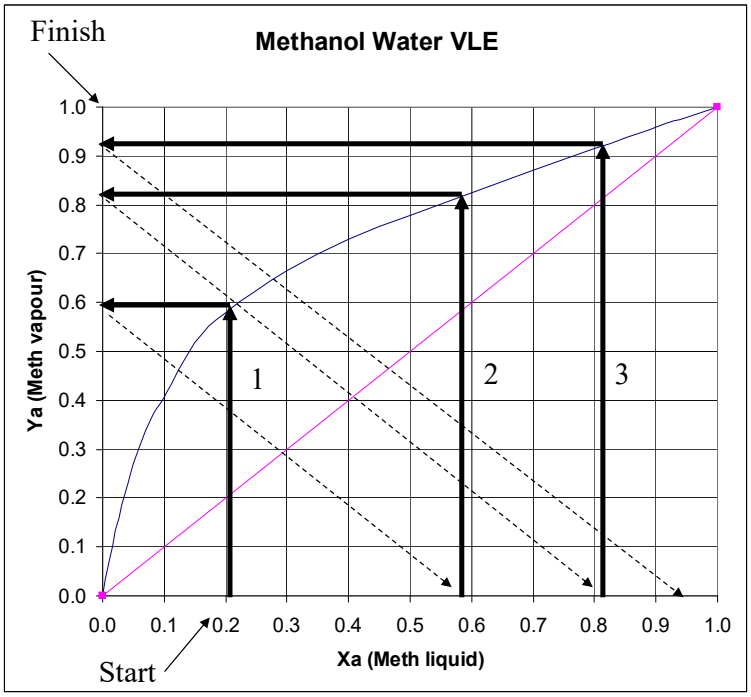
Boil and Cool 4 times



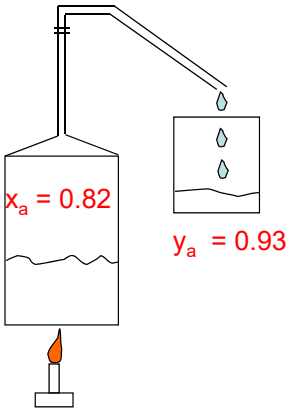
- Boiling a liquid with x_a of 0.57 produces a vapour with y_a of 0.82



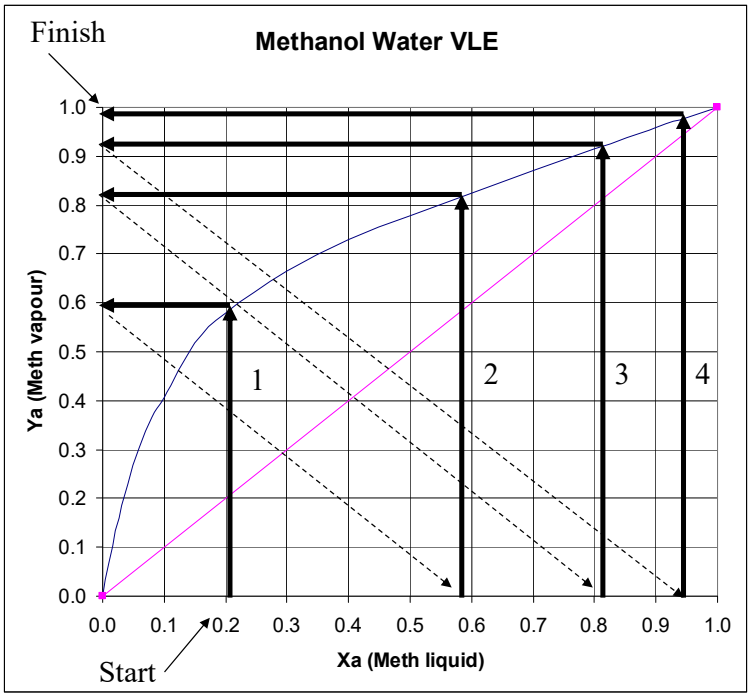
Boil and Cool 4 times



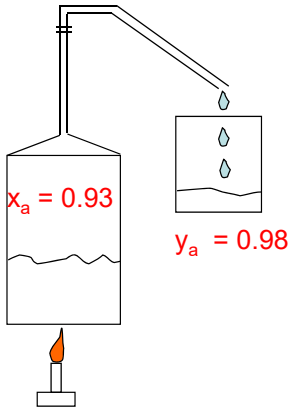
- Boiling a liquid with x_a of 0.82 produces a vapour with y_a of 0.93



Boil and Cool 4 times



- Boiling a liquid with x_a of 0.93 produces a vapour with y_a of 0.98



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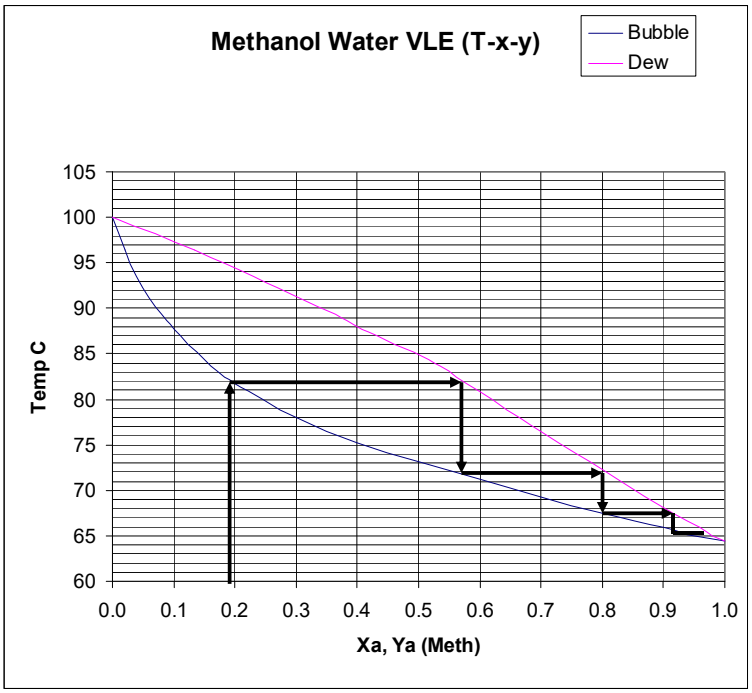
Alternatively use T-x-y Diagram



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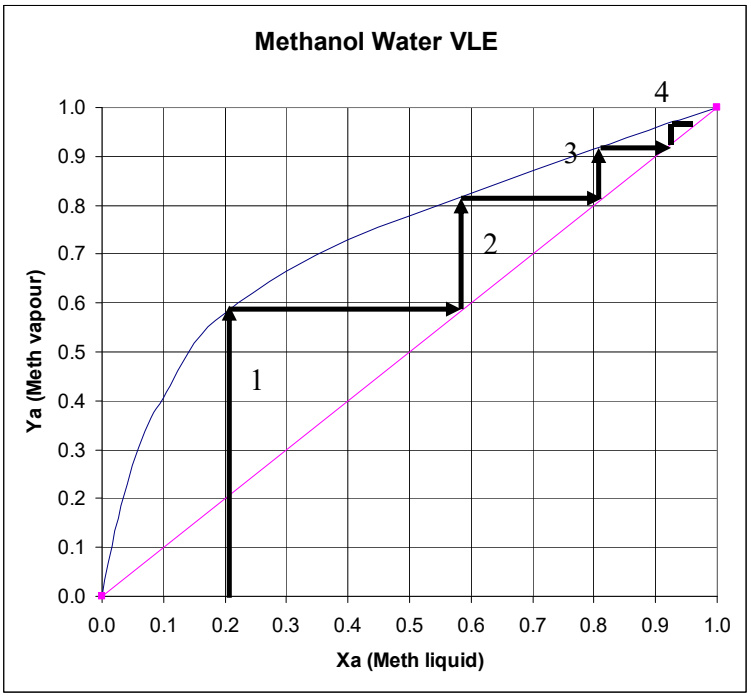
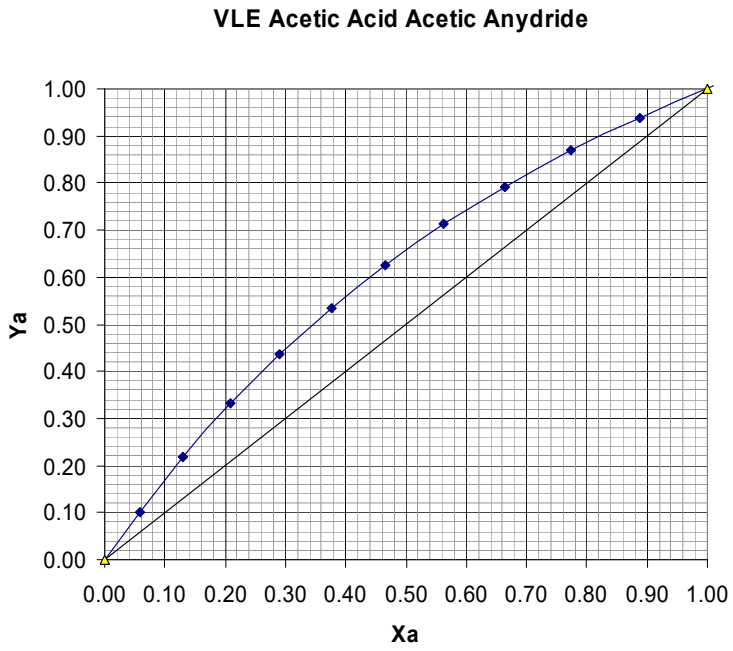
Each still is a step on the x-y curve



- Step off each stage using the x=y line gives the same result
- Each step is an ideal stage in distillation
- 4 ideal stages to go from 20% Meth to 95% Meth

Activity – Count Stages

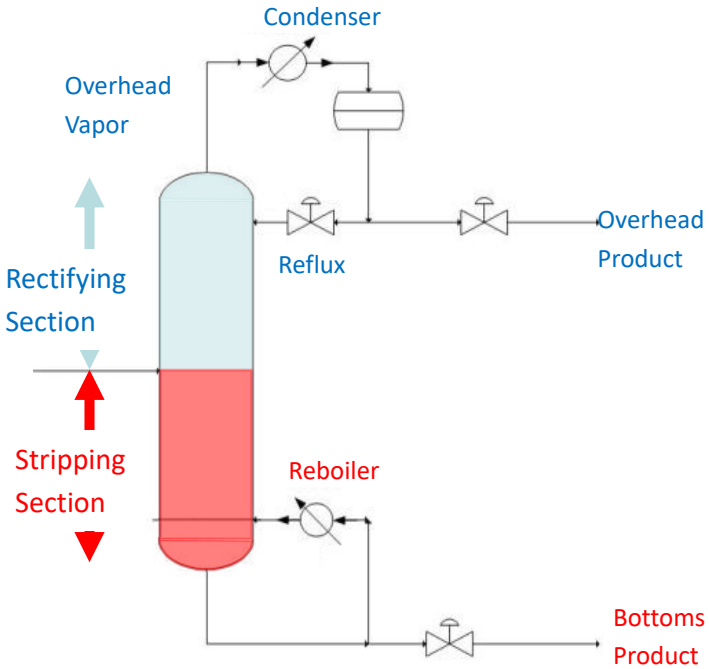


- How many ideal stages are needed to take this system from a feed composition of 0.2 to a distillate composition of 0.95?

How to improve the pot still?

- Remember that boiling results in a change of composition, and condensing also results in a change of composition
- Therefore, combine the two processes inside the column to improve the distillation process
- A distillation column is designed to encourage vapour liquid contact
- Falling liquid meets rising vapour. Boiling and condensing do not just occur in the reboiler and the condenser. They happen inside the column also

The Distillation Column



The Distillation Column

- In binary distillation, a feed mixture of two components is separated into two products, an overhead distillate and a bottom product, whose compositions differ from that of the feed.
- Rectification (fractionation) or stage distillation with reflux, from a simplified point of view, can be considered to be a process in which a series of flash-vaporization stages are arranged in a series in such a manner that the vapor and liquid products from each stage flow counter-currently to each other, i.e. it is a multistage, countercurrent separation process
- Column containing the equivalent of N theoretical stages is fed near its center at stage f with a steady flow of feed of definite composition.
- Assuming the feed is a liquid at its boiling point the feed flows down the stripping section to the bottom of the column, in which a definite level of liquid is maintained.

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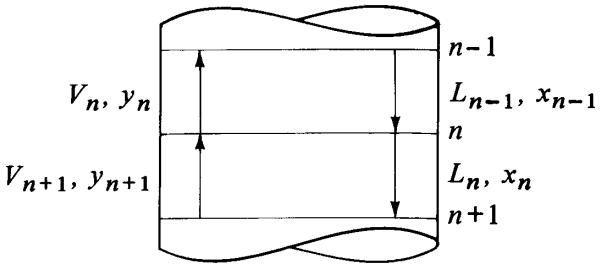
The Distillation Column

- The liquid in a stage is conducted or flows to the stage below and the vapor from a stage flows upward to the stage above.
- Hence, in each stage a vapor stream V and a liquid stream L enter, are mixed and equilibrated, and a vapor and a liquid stream leave in equilibrium.
- The vapor continues up to the next tray or stage, where it is contacted with a down flowing liquid.
- In this case the concentration of the more volatile component (the lower-boiling component *A)* is being increased in the vapor from each stage going upward and decreased in the liquid from each stage going downward.



Vapor and liquid flows entering and leaving a tray

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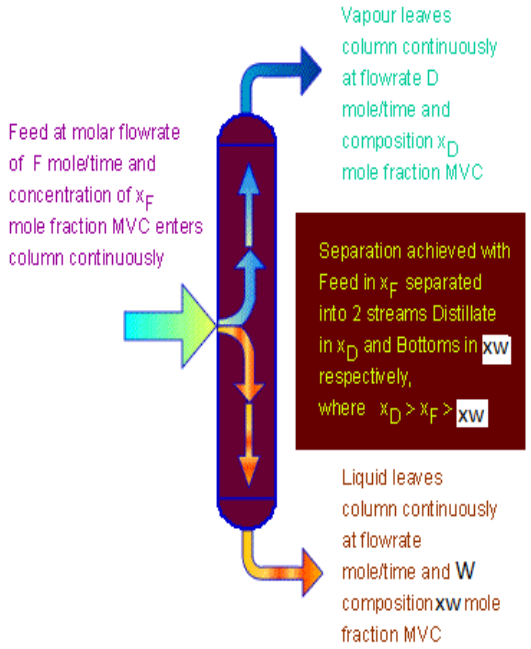
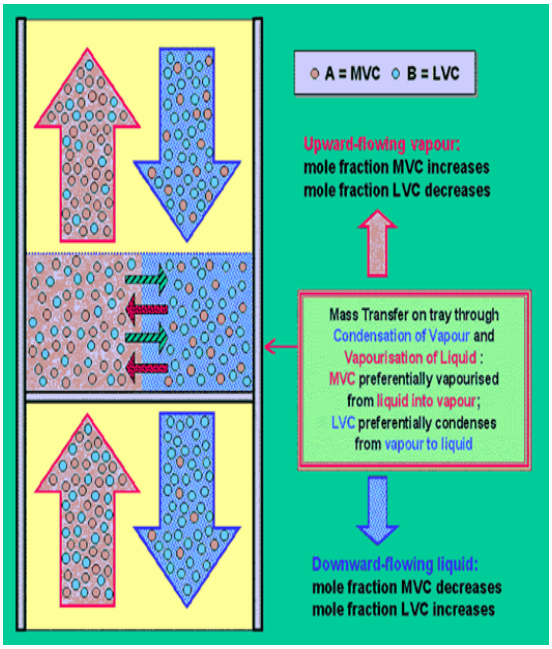
The Distillation Column

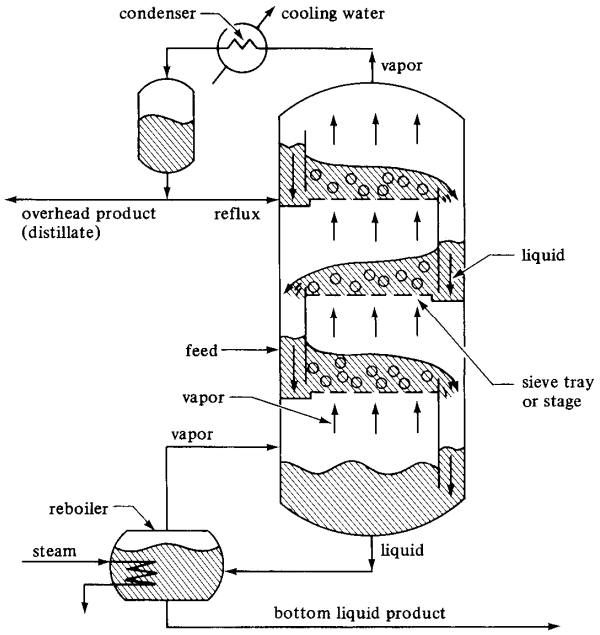




The Distillation Column

- Liquid from the bottom (stage 1) flows by gravity to partial reboiler, which generates vapor and returns it to the bottom stage or tray of the column.
- The **liquid bottom product richer in the less volatile component** is withdrawn from the reboiler.
- A total condenser in which **the overhead vapor richer in the more volatile component** leaving the top stage *N* is completely condensed to a bubble-point liquid distillate and a liquid reflux that is re-turned to the top stage.
- Inside the column, the liquids and vapors are always at their bubble and dew points respecti-vely, so that the highest temperature is at the bottom, the lowest at the top.
- For a binary mixture it is ordinarily possible by this method to separate the solution into its components, recovering each in any desired purity.
- **Note**: In a distillation column the stages (referred to as sieve plates or trays) in a distillation tower are arranged vertically,

The Distillation Column

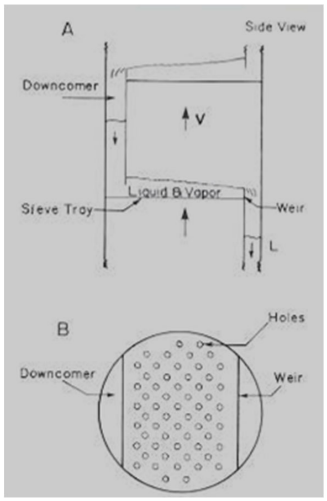


Process flow of a fractionating tower containing sieve trays

Distillation Column Components

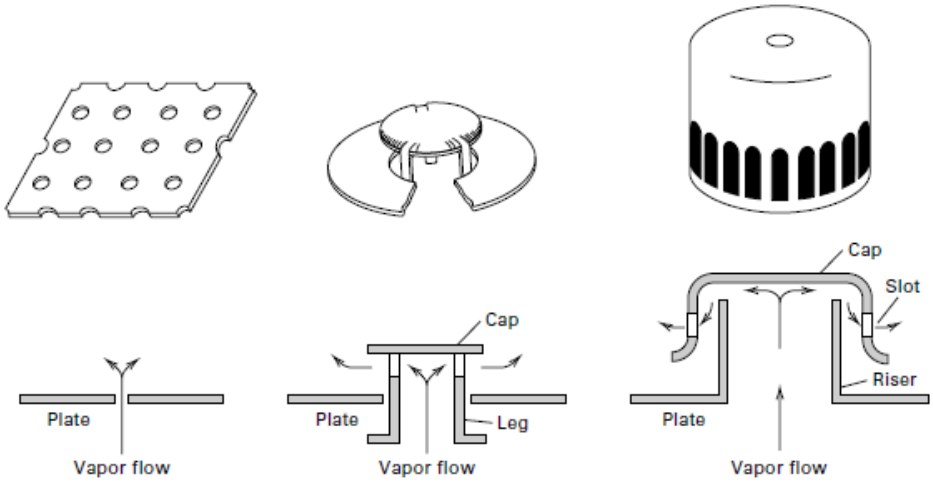
- Reboiler – this heats the liquid
- Stripping Section – MVC is vapourised
- Rectifying Section – LVC is condensed
- Trays/Plates – encourage vapour liquid contact (Stages numbering usually starts from the bottom (with reboiler=1))
- Packing – alternative to trays
- Condenser – Vapour from column is cooled to liquid
- Reflux – condensed vapour can be returned to column
- Top product – from condenser
- Bottom product – from reboiler

Plates or Trays



Plates or Trays

Plates or Trays



Perforation valve cap bubble cap

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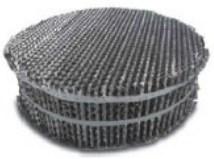
Packing Materials

Structured packing materials.

Mellapak

Flexipak

Montez Corrugated metal sheet



Wire mesh packing

(a) Intalox Metal Tower Packing (IMTP)

(b) Nutter ring

(c) Cascade Mini-Ring (CMR)

(d) Jaeger Tripac

Dumped or Random Packing

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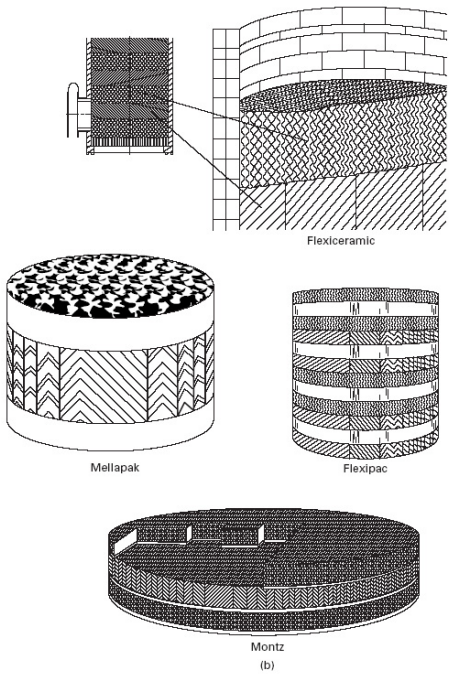
Packing Materials



Structured packing

Total and Partial Condenser

1-Total condenser:-

In total condenser all saturated vapors at the top of the distillation column condensed to saturated liquid

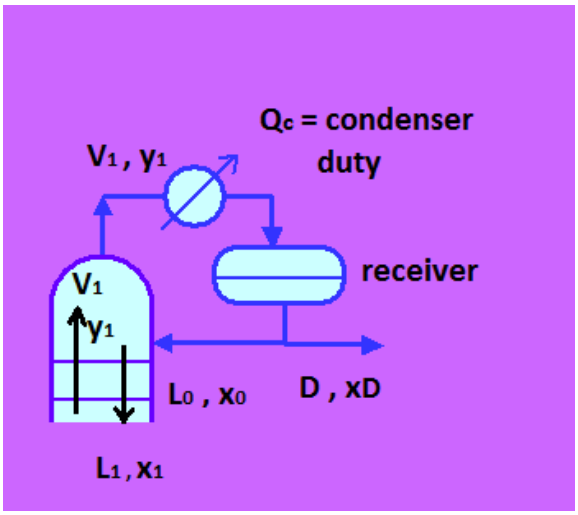
$$\therefore\ y_1 = x_0 = x_D$$

$$Q_C = V_1\ \lambda_{mix}$$

$$Q_C = (L_0 + D)\ \lambda_{mix}$$

$$\frac{Q_C}{D} = \left(\frac{L_0}{D} + 1\right) \lambda_{mix}$$

$$= (R + 1)\ \lambda_{mix}$$



Where:-

Q_C = condenser duty

V_1 = vapor flow rate at the top plate in the distillation column

y_1 = vapor composition at the top plate in the distillation column

D = distillate flow rate

x_D = distillate composition leaving condenser

L_0 = liquid flow rate returning back to the top plate

x_0 = liquid composition returning back to the top plate

$$R = \frac{L_0}{D}$$

= reflux ratio

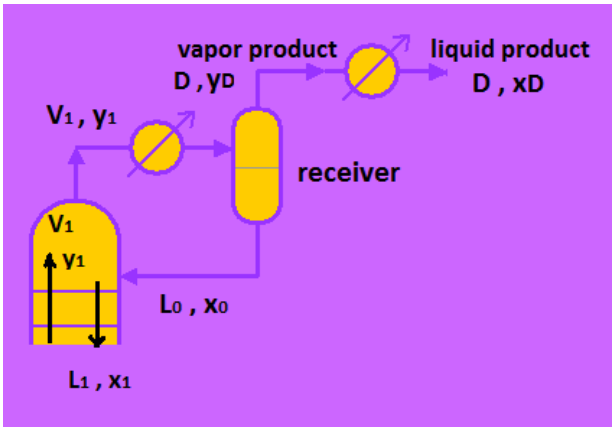
2- Partial Condenser:-

Partial condenser acts as one plate with y_D in equilibrium with top plate condensate x_0

$\Rightarrow$

$y_D P = P^{sat} x_0$

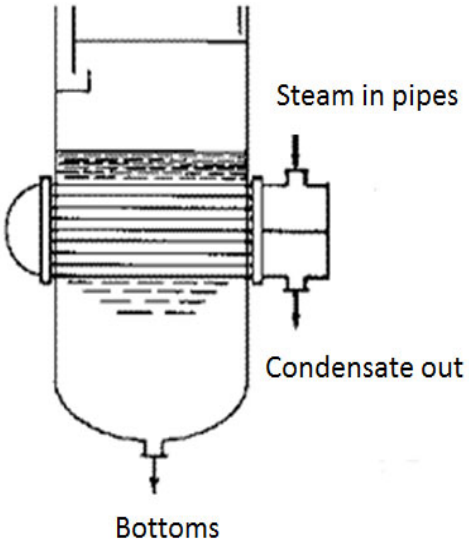
and $y_D = x_D$



Reboilers

1- Internal Reboiler:-

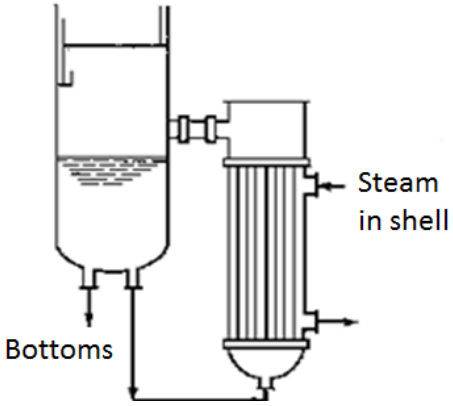
- The tubular heat exchanger built into the bottom of the tower provides large surface area (no shell),
- Cleaning requires a shut-down of the distillation operation.
- Liquid level is controlling for small Capacity towers and for materials which aren't corrosive and scaling.



2-External Reboilers:-

A-Thermosiphon Reboiler:-

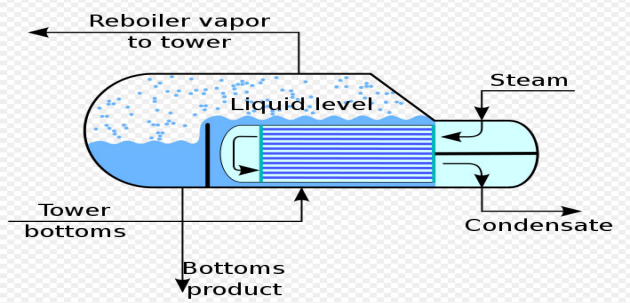
The vertical thermosiphon reboiler as shown) with the heating medium outside the tubes, can be operated so as to vaporize all the liquid entering it to produce a vapor of the same composition as the residue product, in which no enrichment is provided.

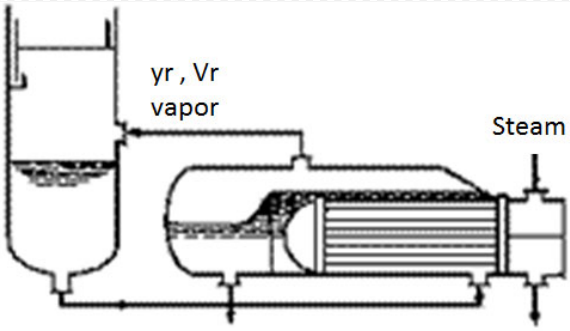


B- Kettle Reboiler:-

The kettle reboiler shown with heating medium inside the tubes, provides a vapor to the tower essentially in equilibrium with the residue product and Thus it behaves like a theoretical stage.

It's large in size , better to control, long residence time , not used for thermally sensitive materials





Bottoms
W,xw

Pipe still heater:-

Sometimes we use a Furnace or a pipe still heater instead of the reboiler.

Advantages:-

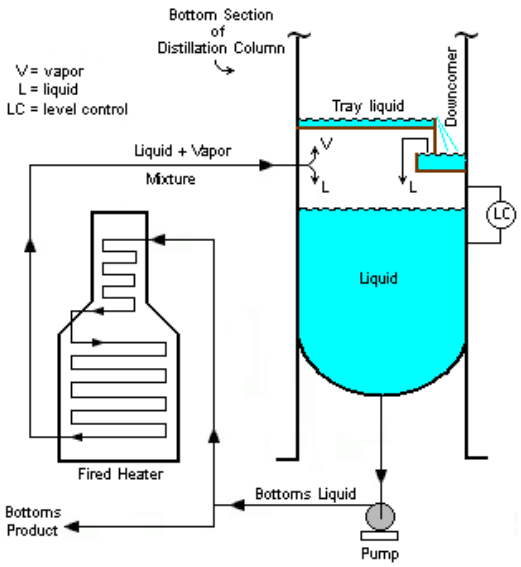
1-Used when no steam is available(heating media is hot oil or hot gases).

2- high temperatures is needed.

Disadvantages:-

1-Expensive.

2- Not suitable for sensitive materials.



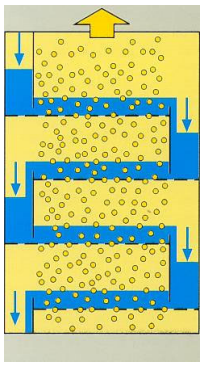
Applications and Distillation Equipment

Applications:

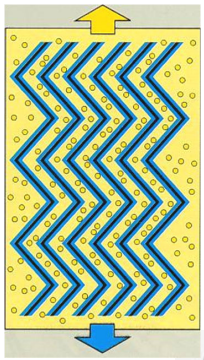
- The most widely used large-scale method for separating homogeneous fluid mixtures in the chemical and petrochemical industry
- If no azeotropes are encountered, overhead and bottom products may be obtained in any desired purity
- Suitable for the separation of liquid mixtures of components having similar boiling points into their individual components (at low relative volatility, but α>1,05)

Equipment:

- Tray Columns (stagewise contact between the phases on individual trays)

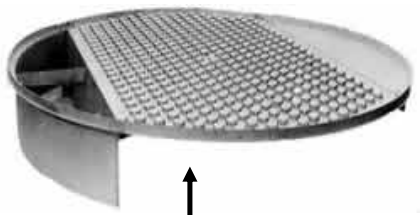


- Packed Columns (continuous contact between the phases on the surface of a packing material)

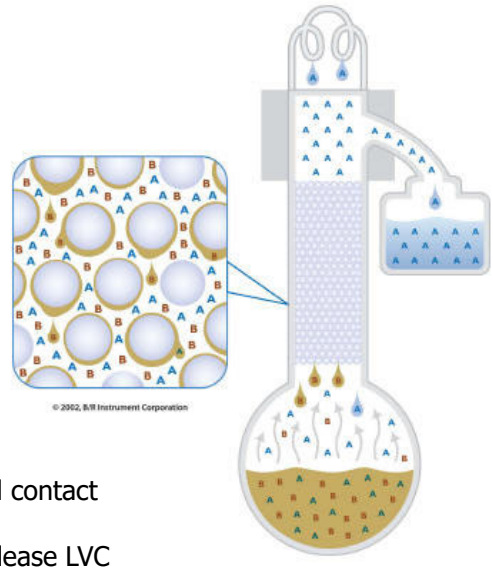


Trays and Packing

Liquid

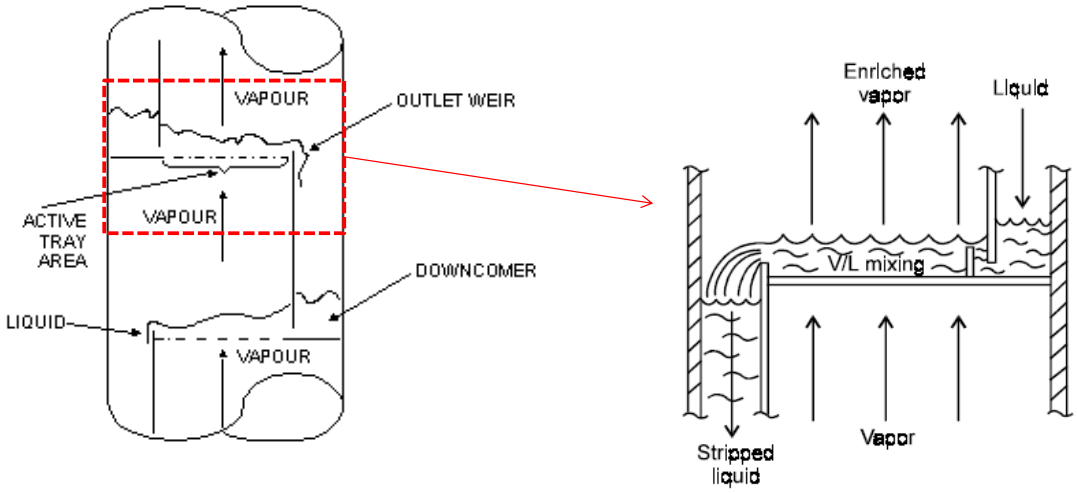


Vapour



- Encourage vapour liquid contact
- Vapour condenses to release LVC
- Liquid uses this energy to boil and release MVC

Trays and Packing



Calculation Methods

Types of Binary Distillation Calculation

- ➔ Energy requirements and heat exchanger design for a given adiabatic separation process (calculate the heat duties of the condenser and reboiler, specify the heating steam consumption and coolant requirements, thermal-hydraulic design of the condenser and reboiler)
- ➔ Determination of main dimensions of the distillation column: estimating the number of equilibrium stages required for a given separation, the column height and the column diameter for a desired pressure drop (H = f(N), D)

Historical Review of Calculation Methods

until 1970s:	simplified, partially graphical design procedures for tray columns separating binary mixtures: *Ponchon-Savarit* (1921/22), *McCabe-Thiele* (1925)
	approximate calculation methods for the solution of multicomponent, multistage separation problems (Shortcut methods): *Fenske* (1932), *Gilliland* (1940), *Underwood* (1946)
	design of packed columns based on NTU/HTU concepts: *Chilton, Colburn* (1935)
in the present:	complex mathematical matrix methods allow to find exact solutions of nonlinear equation systems: *Wang-Henke* (1966), *Naphtali-Sandholm* (1971)
	commercial process simulation software allowing design and rating calculations of tray and packed columns operating at steady or unsteady state conditions (ASPEN®, CHEMCAD®)

McCabe-Thiele Method

- A mathematical-graphical method for determining the number of theoretical trays or stages needed for a given separation of a binary mixture of *A* and *B* has been developed by McCabe and Thiele.
- The method uses material balances around certain parts of the tower, which give operating lines, and the *xy* equilibrium curve for the system.

Assumptions and Simplifications

Assumptions and Simplifications:

1) The two components have equal and constant molar enthalpies of vaporization (latent heats).
2) The component heat capacity changes and the heat of mixing are negligible compared to the heat of vaporization (considering ideal behaviour of binary mixtures).
3) The distillation column, the condenser and the reboiler are well insulated so that heat losses to environment are negligible.
4) The pressure is constant throughout the column, no pressure drop occurs.

- The above assumptions lead to the concept of constant molar overflow.
- This approach assumes that the amount of molecules which evaporate and which condensate in each stage are the same or nearly the same.

Assumptions and Simplifications

- That means, that all liquid and vapor molar flow rates in the rectifying section are constant and that all liquid and vapor molar flow rates in the stripping section are constant but not the same as those in the rectifying section.

Further requirements are:

5) Kinetic and potential energies are negligible.

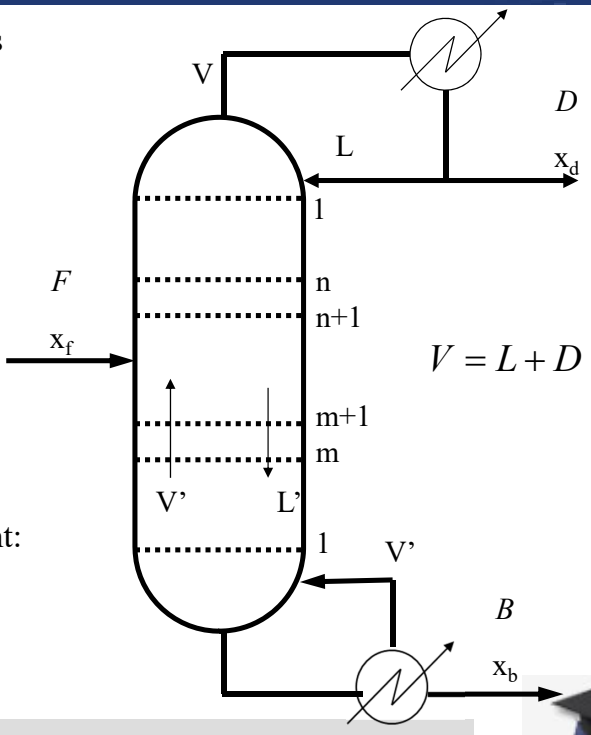
6) The distillation column is operated at continuous steady state conditions.

7) The streams leaving each stage are assumed to be in vapor-liquid equilibrium. The liquids and vapors are always at their bubble points and dew points, respectively.

Column Mass Balance

- *F, B, D*, etc are flow rates in mol/s
- x_f etc are mol fractions
- n trays in the rectifying section
- m trays in the stripping section
- V, L different
- Total balance $F = D + B$
- Can also write for each component:

$$Fx_{f,a} = Dx_{d,a} + Bx_{b,a}$$



Activity – Mass balance on Acetic Acid/Acetic Anhydride problem

- A mixture of Acetic Acid and Acetic Anydride containing 40 mol % Acetic Acid is to be separated by distillation. The top product is to be 90 mol % Acetic Acid and the bottom product 10 mol % Acetic Acid.
- The feed is heated to its boiling point. The vapour is condensed but not cooled and some is returned at a reflux ratio of 3 kmol/kmol product.
- Carry out a mass balance on this column

Constant Molal Overflow

- The assumption of constant molal overflow is used to simplify the above equations.
- It means that for every mole of vapour condensed, 1 mole of liquid is vaporised.
- This does not happen in reality but it is an acceptable approximation.
- It is based on negligible heat of mixing and heat loss and on constant molar enthalpies
- It means that while the liquid and vapour compositions may change the overall flow rate of each is constant through the column, i.e.

$$L_o = L_n = L_{n+1} \quad \text{and} \quad V_o = V_n = V_{n+1}$$

Also $L_m = L' = L_{m+1}$ and $V_{biler} = V' = V_m = V_{m+1}$

The Rectifying Section

- Condenser at the top of the column cools the vapour, collected in the reflux drum
- A portion is returned to the column as reflux
- Remainder is removed as Distillate or Top Product

Reflux Ratio = Reflux/Distillate

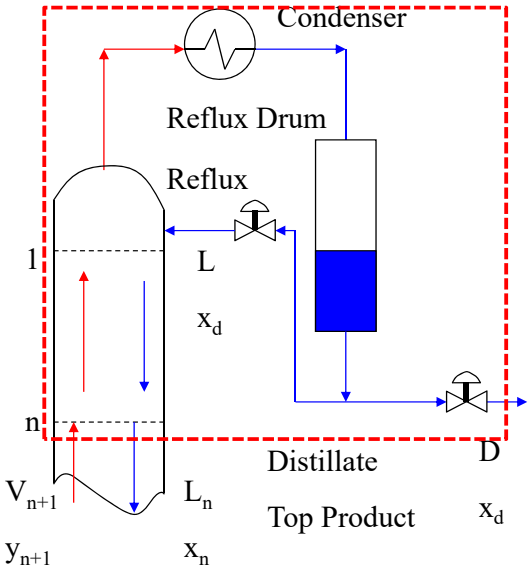
- Mass balance on flow rates gives

Vapour = Liquid + Distillate

$$V_{n+1} = L_n + D$$

$$V_{n+1}y_{n+1} = L_n x_n + Dx_d$$

$$\Rightarrow y_{n+1} = \frac{L_n}{V_{n+1}}x_n + \frac{D}{V_{n+1}}x_d$$



The rectifying (enriching) section operating line from material balance

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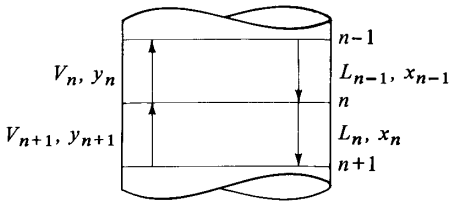
Applying Constant Molal Overflow

Rectifying Section

$$y_{n+1} = \frac{L_n}{V_{n+1}}x_n + \frac{D}{V_{n+1}}x_d$$



Applying constant molal overflow gives

$$y_{n+1} = \frac{L}{V}x_n + \frac{D}{V}x_d$$

The rectifying (enriching) section operating line

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Reflux

- Some condensed liquid is removed from the column as distillate. Some is returned. The reflux ratio is the ratio of liquid returned to the column over the amount removed

$$R = \frac{L}{D} \qquad \text{or} \qquad L = DR \qquad \text{and} \qquad V_{n+1} = L_n + D$$

$$\text{or} \qquad V = L + D$$

- Activity – rewrite the operating line for the rectification section using the reflux ratio.

Rectifying Operating Line

- The rectifying operating line is:

$$y_{n+1} = \frac{L}{V} x_n + \frac{D}{V} x_d$$

- Since $L = DR$ and $V = RD + D$, we get:

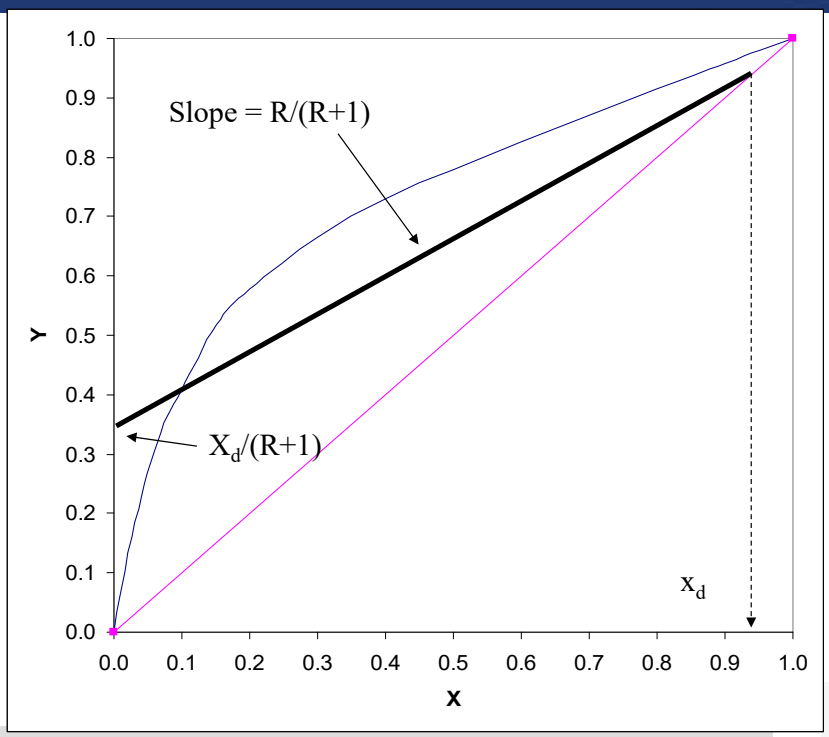
$$y_{n+1} = \frac{RD}{RD + D} x_n + \frac{D}{RD + D} x_d$$

$$y_{n+1} = \frac{R}{R+1} x_n + \frac{1}{R+1} x_d$$

The rectifying (enriching) section operating line

- Compare this to y = mx + c – it is a straight line
- It intersects the y = x line (45° diagonal line) at $x = x_d$

Rectifying line on X-Y Diagram



Rectifying Operating Line

between stages: Operating line from material balance

$$y_1 = \frac{L}{V}x_o + \frac{D}{V}x_d$$

$$y_2 = \frac{L}{V}x_1 + \frac{D}{V}x_d$$

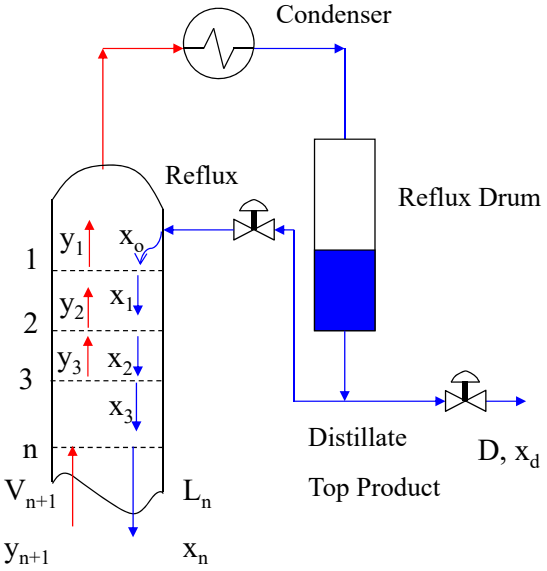
$$y_3 = \frac{L}{V}x_2 + \frac{D}{V}x_d$$

On stages: Equilibrium

$$y_1, x_1 : Equi.$$

$$y_2, x_2 : Equi.$$

$$y_3, x_3 : Equi.$$



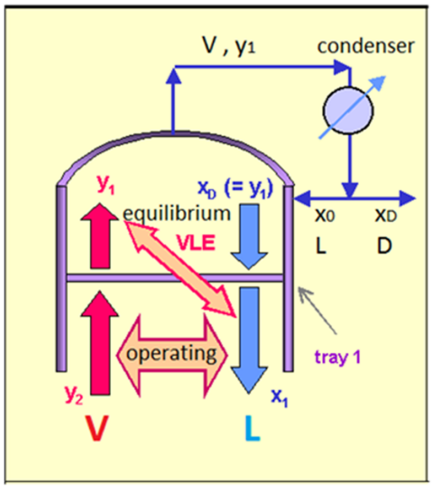
Rectifying Operating Line

- At the top of the column and
  For total condenser: $x_o = x_d$

  But $y_1 = \frac{L}{V}x_o + \frac{D}{V}x_d$

  $\Rightarrow y_1 = x_d$

- At stage 1: $y_1, x_1 : VLE$



Rectifying Operating Line

- Between stage 1 and stage 2:
  material balance leads to

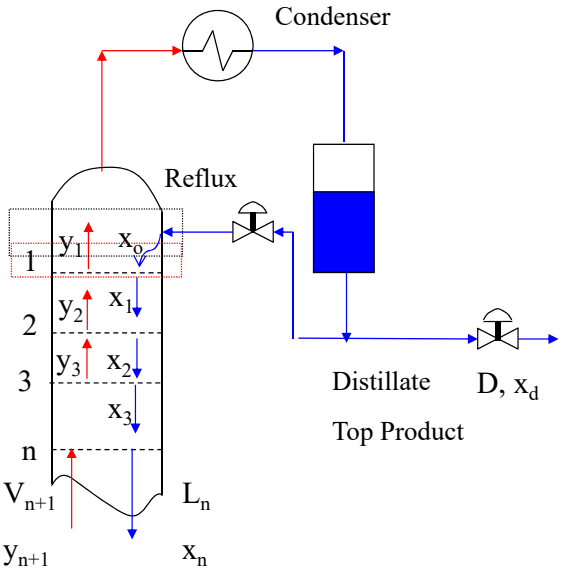
  $$y_2 = \frac{L}{V}x_1 + \frac{D}{V}x_d$$

  $y_2, x_1 : M.B\ Operating\ Line$

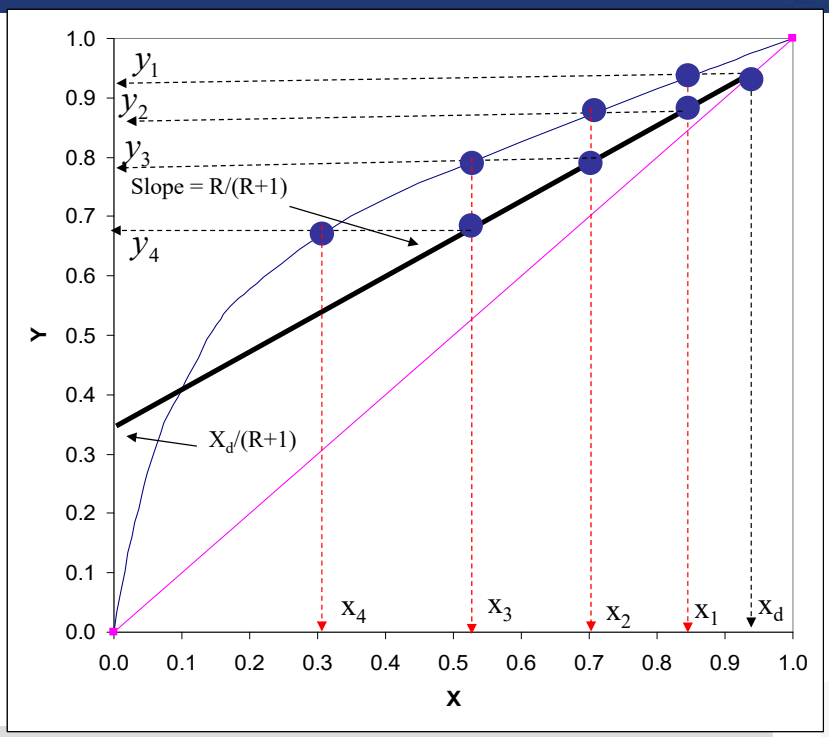
- Between stage 2 and stage 3:
  material balance leads to

  $$y_3 = \frac{L}{V}x_2 + \frac{D}{V}x_d$$

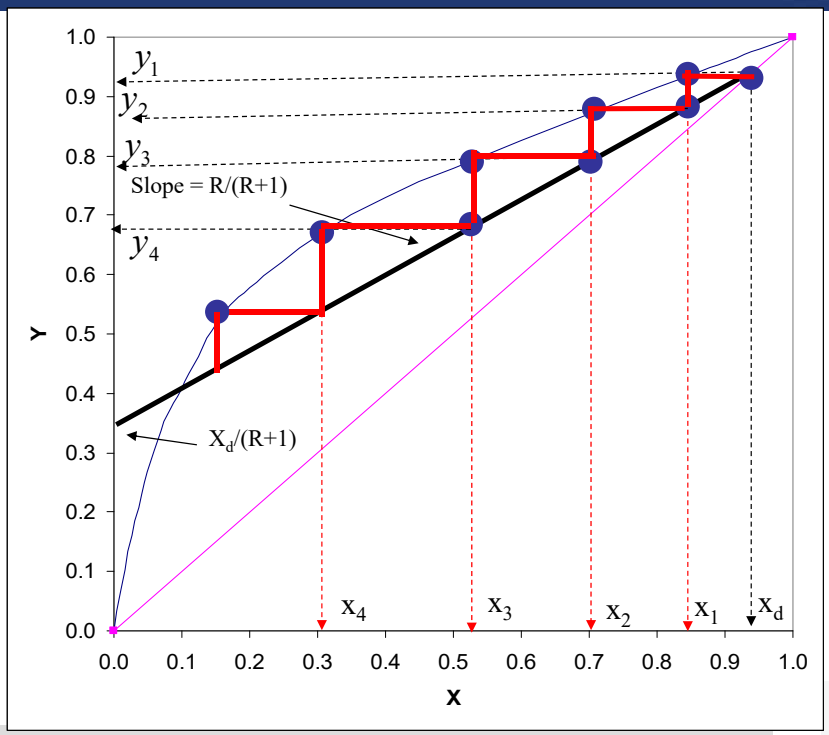
  $y_3, x_2 : M.B\ Operating\ Line$



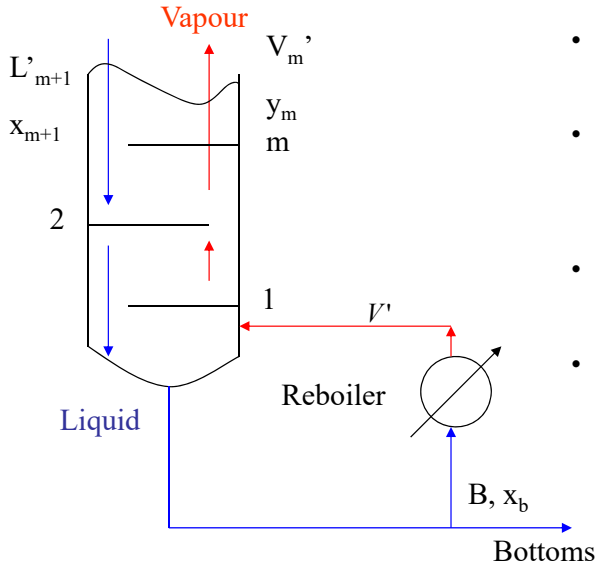
Rectifying line on X-Y Diagram



Rectifying line on X-Y Diagram



The Stripping Section



- Feed flows down column to reboiler
- Reboiler heats liquid to BP and vapour rises
- Liquid that does not vaporise is removed as bottoms product
- Vapor leaving the partial reboiler is assumed to be in equilibrium with the liquid bottoms product, B, making the partial reboiler an equilibrium stage
- Vapour rises and is forced into contact with falling liquid
- On the trays, some liquid reboils and some vapour condenses due to heat transfer between the phases - more stages are created

$$L'_{m+1} = V'_m + B$$

$$L'_{m+1}\, x_{m+1} = V'_m\, y_m + B x_b$$

$$\Rightarrow y_m = \frac{L'_{m+1}}{V'_m} x_{m+1} - \frac{B}{V'_m} x_b$$

Applying constant molal overflow

Stripping Section

$$y_m = \frac{L'_{m+1}}{V'_m} x_{m+1} - \frac{B}{V'_m} x_b$$

Applying constant molal overflow gives

$$y_m = \frac{L'}{V'} x_{m+1} - \frac{B}{V'} x_B$$

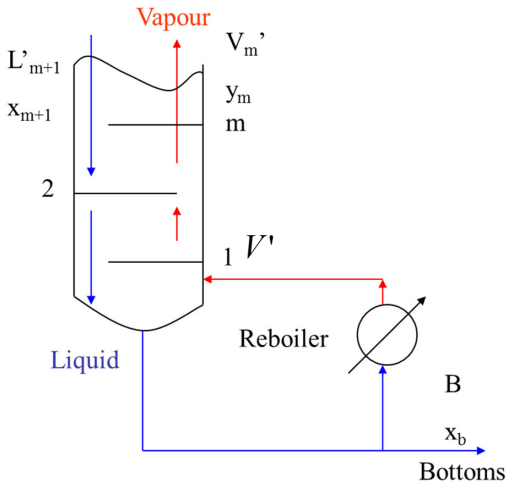
Stripping operating line

Stripping Operating Line

- The boilup ratio is defined as the ratio of vapour returning to the column to the bottoms product flow:

$$V_B = \frac{V'}{B}$$

But $L' = V' + B$ Or $L' = (V_B + 1)B$

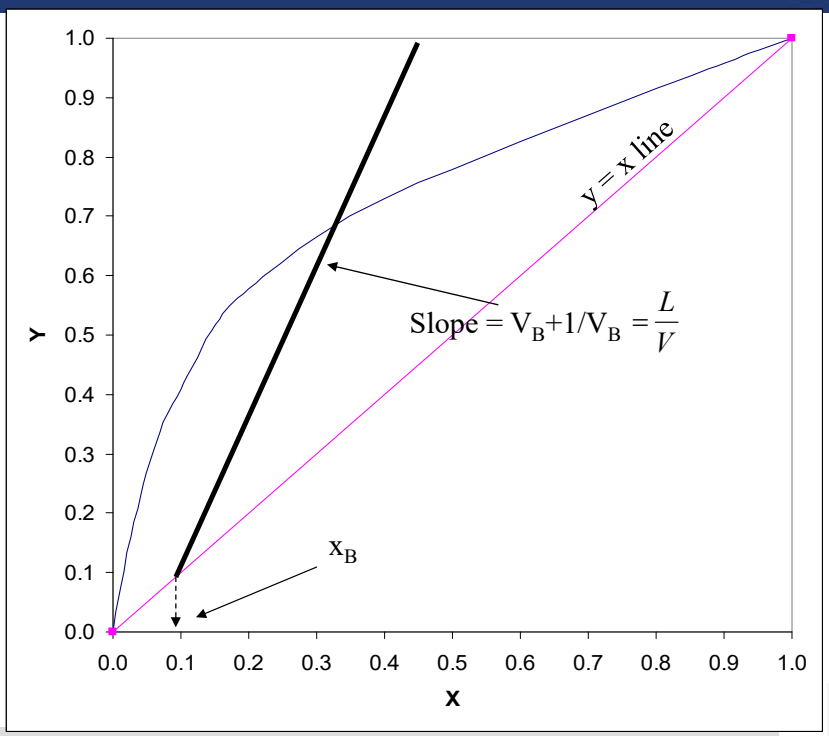


- Therefore, the stripping operating line can be written as

$$y_m = \frac{V_B + 1}{V_B} x_{m+1} - \frac{1}{V_B} x_B$$

- Again of the form y = mx + c, another straight line
- It intersects the y = x line (45° diagonal line) at $x = x_b$

Stripping line on X-Y Diagram



Summary – Operating lines

- The rectifying section (upper column)

$$y_{n+1} = \frac{R}{R+1} x_n + \frac{1}{R+1} x_d$$

- The stripping section (lower column)

$$y_m = \frac{V_B + 1}{V_B} x_{m+1} - \frac{1}{V_B} x_B$$

Or

$$y_m = \frac{L'}{V'} x_{m+1} - \frac{B}{V'} x_B$$

- Note minus sign in stripping line

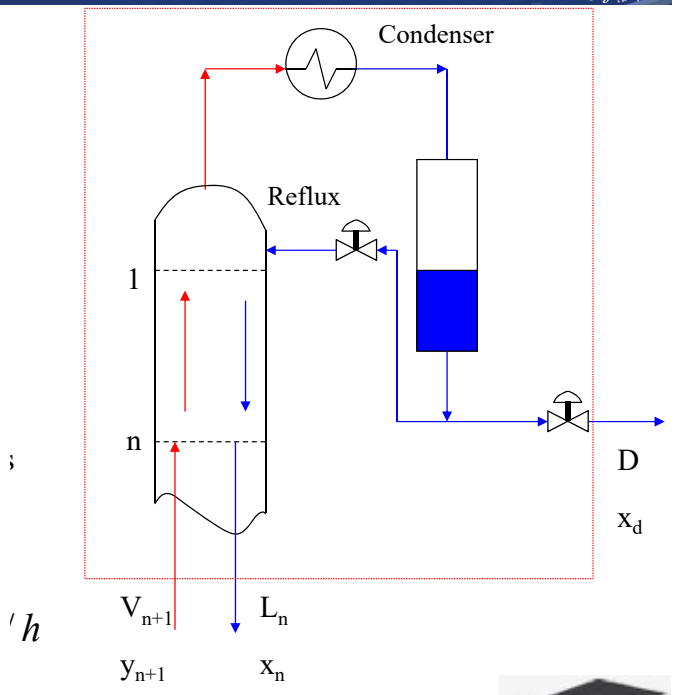
Activity – Operating lines

- A mixture of Acetic Acid and Acetic Anydride containing 40 mol % Acetic Acid is to be separated by distillation. The top product is to be 90 mol % Acetic Acid and the bottom product 10 mol % Acetic Acid.
- The feed is heated to its boiling point. The vapour is condensed but not cooled and some is returned at a reflux ratio of 3 kmol/kmol product.
- Determine the operating lines for the rectifying and stripping sections and draw them on an equilibrium curve.
- To help you:
  - Start with the rectifying line – it is easy – just use the reflux ratio.
  - Stipping line is harder – we don't know the boilup rate needed. So…
  - Determine B and D from an overall mass balance

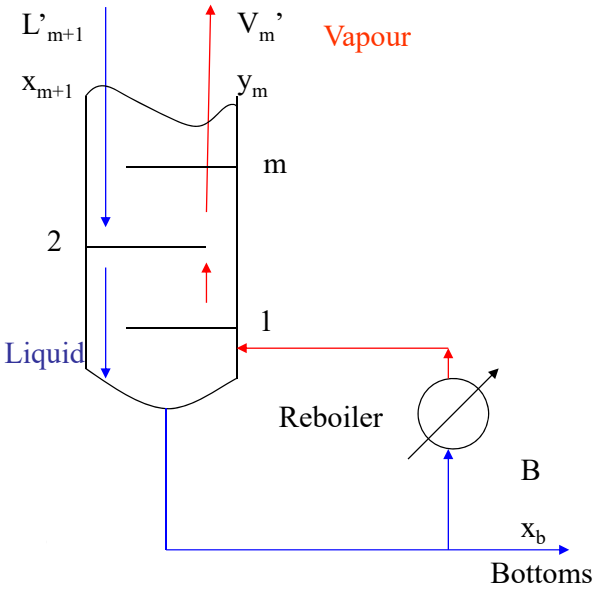
Activity – Contd

- Use D and R to give L for rectifying section (L_n)
- Use L and D to give V for rectifying section
- L for stripping section (L'_m) comes from F and L_n
- V is the same for both sections as feed enters as liquid
- Use L'_m and B and V to give stripping operating line

Activity – Solution



Activity – Solution Contd.



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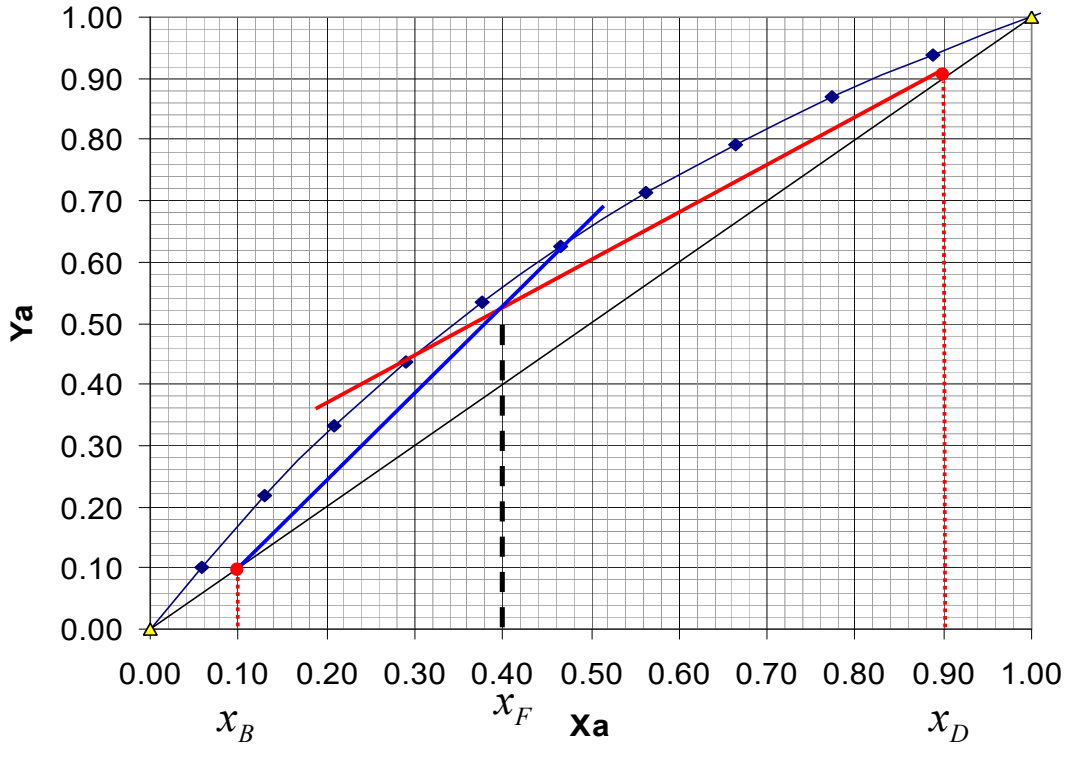


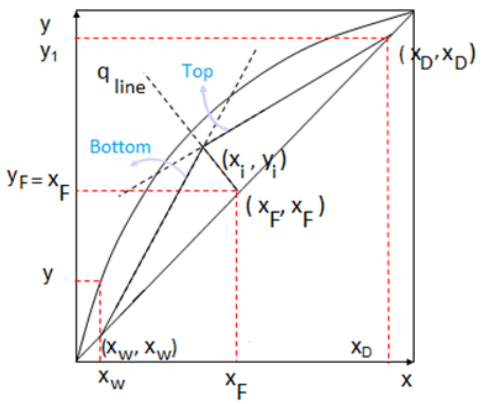
Feed Stage Consideration

- The point of intersection of the enriching and the stripping operating-line equations on an xy plot can be derived as follows

$$V'_m\, y = L'_m\, x - Bx_b$$

$$V_n y = L_n x + Dx_d$$

where the *y* and x values are the point of intersection of the two operating lines.



Subtracting

$$(V'_m - V_n)y = (L'_m - L_n)x - (Dx_d + Bx_b)$$

Note that $(Fx_{f,a} = Dx_{d,a} + Bx_{b,a})$

$$\rightarrow \quad y\,\frac{(V'_m - V_n)}{F} = \frac{(L'_m - L_n)}{F}x - x_F \qquad *$$

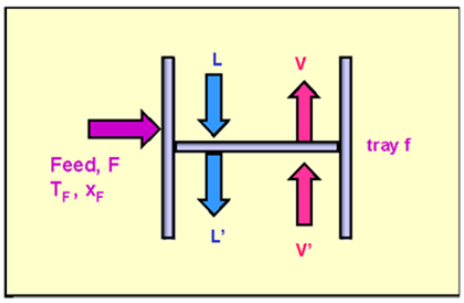
q- Line Definition

Material balance on feed entrance

$$F + L_n + V'_m = V_n + L'_m$$

$$F + (V'_m - V_n) = (L'_m - L_n)$$

$$1 + \frac{(V'_m - V_n)}{F} = \frac{(L'_m - L_n)}{F} = q$$



Figure(53) Feed section

$$\rightarrow \quad q = \frac{L'_m - L_n}{F} \quad \text{and} \quad q - 1 = \frac{V'_m - V_n}{F}$$

By Substitution these values in the previously marked equation

$$y_q = \underbrace{\frac{q}{q-1}}_{\text{slope}} x_q - \frac{x_f}{q-1}$$

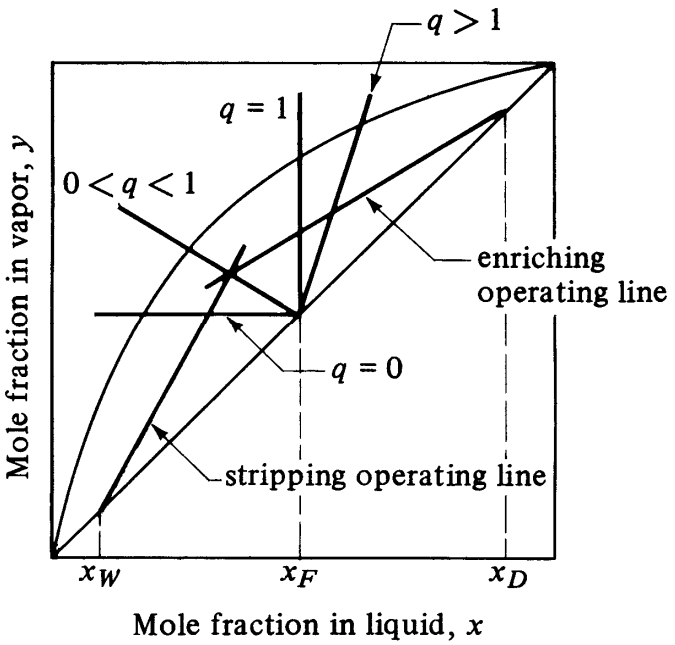
The q line equation

The intersection of the operating lines

- The slope of the q line depends on the feed condition
- Setting y= x in the q line equation, the intersection of the q-line equation with the 45° line is

$$y = x = x_f$$

- In the figure, the enriching and operating lines are plotted for the case of **a feed of part liquid and part vapor** and the two lines intersect on the **q line**



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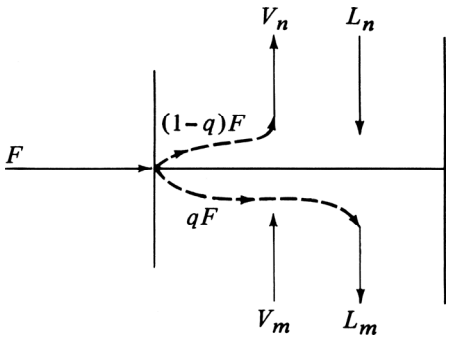
Feed Condition

- The condition of the feed stream F entering the tower determines the relation between the vapor V_m in the stripping section and V_n in the enriching section and also between L_m and L_n .
- The feed to the column can vary in form. It can be:
  - Subcooled liquid
  - Bubble point liquid
  - Partially vaporised feed
  - Dew point vapour
  - Superheated vapour



- Think, Pair, Share briefly (5 min) what this means for the liquid and vapour flow rates in the stripping and rectifying sections of the column.

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Calculation of q-value

- q = the enthalpy change needed to bring the feed to a dew point vapour divided by the enthalpy of vaporisation of the feed
- Defined as:

$$q = \frac{\text{Heat to vaporise 1 mol of Feed}}{\text{Molar latent heat of vaporisation of the Feed}}$$

$$\rightarrow \quad q = \frac{H_v - H_F}{H_v - H_L}$$

where

H_v is the enthalpy of the feed at the dew point,

H_L the enthalpy of the feed at the boiling point (bubble point), and

H_F the enthalpy of the feed at its entrance conditions

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1 – Saturated liquid feed:-

$\therefore\ h_F = h_L$

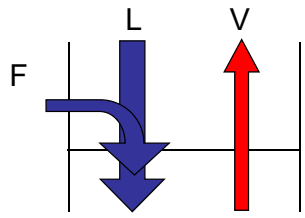
$\because\ q = \dfrac{H_V - h_F}{H_V - h_L} \rightarrow$

$\therefore\ q = \dfrac{H_V - h_L}{H_V - h_L} = \dfrac{\lambda}{\lambda} = 1$

q – line:-

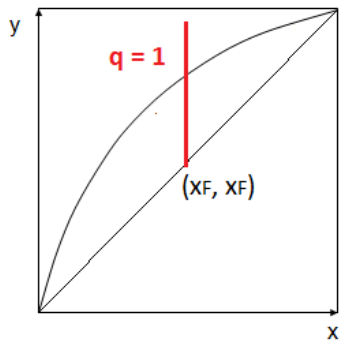
$\dfrac{q}{q-1} = \dfrac{1}{1-1} = \infty$

$\Rightarrow$ q-line is a vertical line



bubble point

liquid feed



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2–Saturated vapor feed:-

$\therefore\ h_F = h_V$

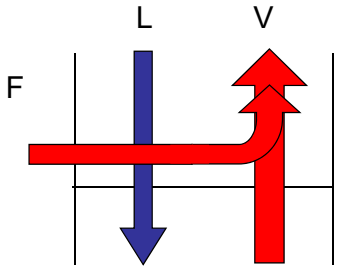
$\because\ q = \dfrac{H_V - h_V}{H_V - h_L} \rightarrow$

$\therefore\ q = \dfrac{H_V - h_V}{H_V - h_L} = 0$

q – line:-

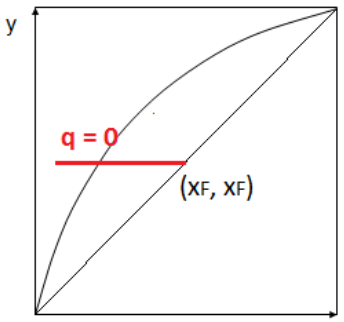
$\dfrac{q}{q-1} = \dfrac{0}{0-1} = 0$

$\Rightarrow$ q-line is a horizontal line



dew point

vapour feed



3 – Partial vaporized feed:-

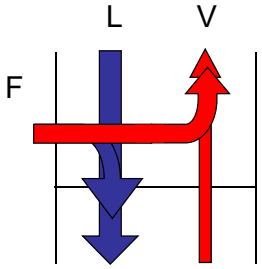
$\therefore\quad 0 < q < 1$

e.g $\quad q = 0.7$

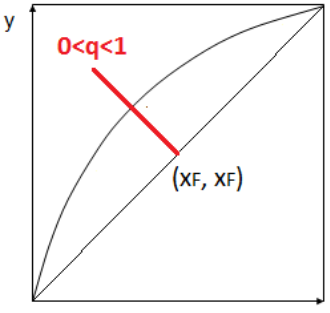
q – line:-

$\dfrac{q}{q-1} = \dfrac{0.7}{0.7-1} = \dfrac{0.7}{-0.3} = -\ ve$

$\Rightarrow$ q-line has a -ve slope



partially vaporized feed



4–Subcooled feed:-

$\therefore\ h_F < h_V$

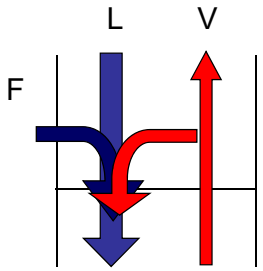
$\because\ q = \dfrac{H_V - h_V}{H_V - h_L}$

$= \dfrac{m\ cp\ \Delta T + \lambda}{\lambda} > 1$

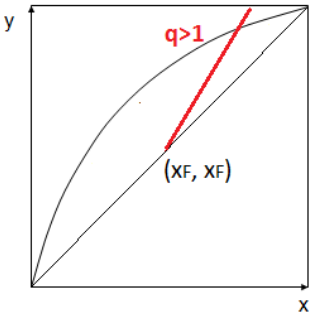
q – line:- (assume $q = 1.5$)

$\dfrac{q}{q-1} = \dfrac{1.5}{1.5-1} = \dfrac{+ve}{+ve}$

→ line in the first quarter



Subcooled liquid feed



$\rightarrow\ q = 1 + \dfrac{c_{pL}(T_b - T_F)}{\lambda}$

C_{pL} heat capacity of liquid

T_b bubble point

T_F Feed temp

λ Latent heat of vapor'n

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5 – Superheated feed:-

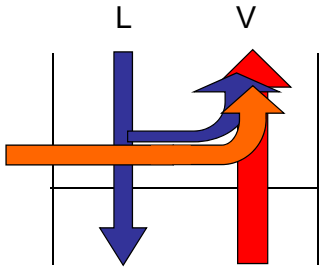
$\therefore\ h_F > H_V$

$q = \dfrac{H_V - h_F}{H_V - h_L} = \dfrac{-ve}{+ve} = -ve$

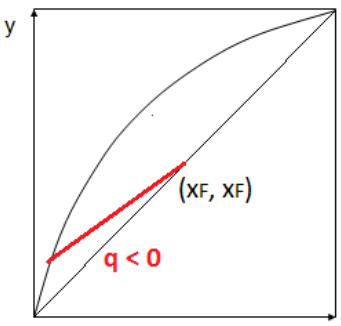
q – line:-

$\dfrac{q}{q-1} = \dfrac{-ve}{-ve-1} = \dfrac{-ve}{-ve}$

⇒ q-line in the third quarter



superheatedvapour feed



$\rightarrow\ q = -\dfrac{c_{pV}(T_F - T_d)}{\lambda}$

C_{pV} heat capacity of vapour

T_d dew point

T_F Feed temp

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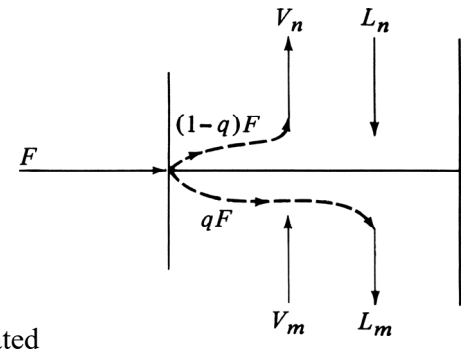
In Summary

- The feed condition can now be described by the q line:
- Subcooled liquid $q > 1$
- Bubble point liquid $q = 1$
- Partially vaporised feed $0 < q < 1$
- Dew point vapour $q = 0$
- Superheated vapour $q < 0$



- We can look at q also as the number of moles of saturated liquid produced on the feed plate by each mole of feed added to the tower. Hence,

$$L'_m = L_n + qF \quad *$$

$$V_n = V'_m + (1-q)F \quad *$$

The relationship between flows above and below the feed extrance

$$q = \frac{L'_m - L_n}{F}$$

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