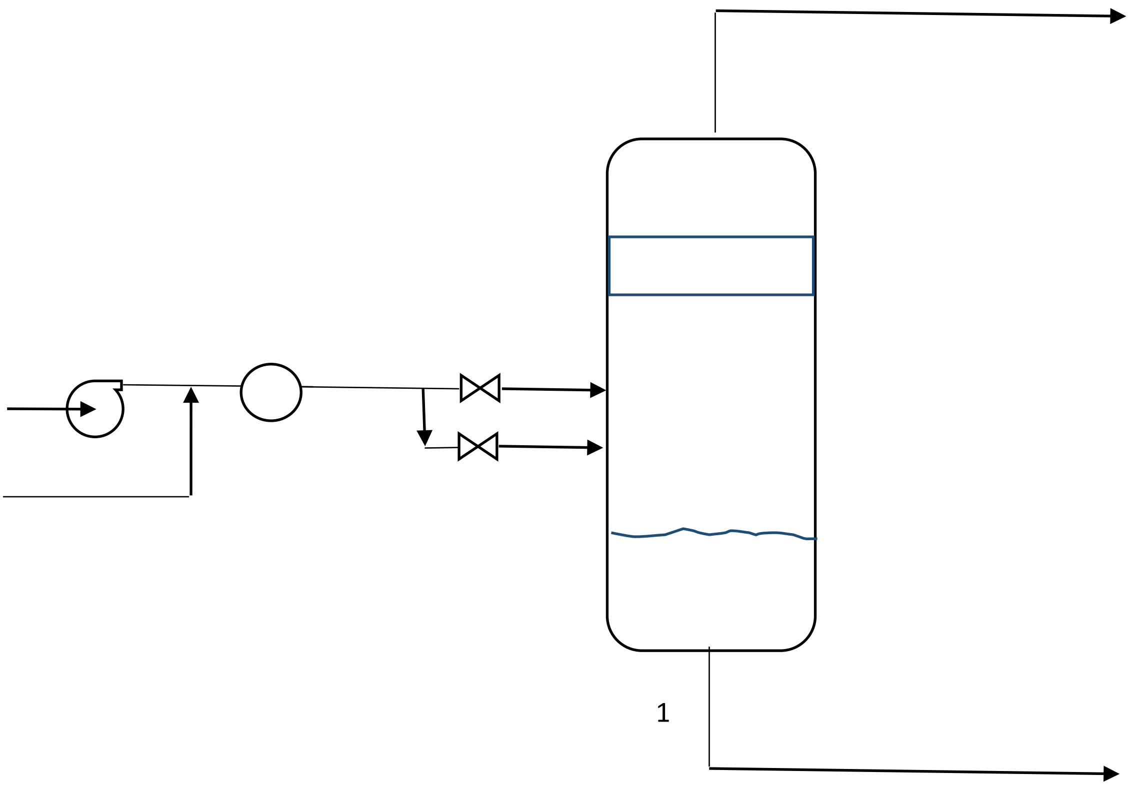
Distillation:

- ✓ Separation is based on volatility difference
- ✓ Heat is supplied to create a vapour phase in equilibrium with a liquid phase
- ✓ All components in the feed are present in both phases in different proportions (vapour phase is richer in mvc; while liquid phase is richer in lvc
- ✓ Separation is not isothermal but may be considered to be closely isobaric.
- ✓ Process may be single stage (Flash vaporization or partial condensation), differential distillation, or continuous fractionation (packed towers or multi stage counter current tray columns), each offering a varying degree of separation.

Equilibrium Flash Vaporization and Partial condensation:

- ➢ Single equilibrium stage separation processes
- ➢ Unless relative volatilities are very large, the degree of separation is poor.
- ➢ Useful for removal of light components from heavy ones (e.g. removal of NH_3, H_2S from crude oil)
- ➢ Flash vaporization: A liquid feed is partially vaporized to give a vapour richer in mvc in equilibrium with a liquid richer in lvc. The liquid may be flashed:
  - ❖ Adiabatically across a throttling valve (high pressure liquid is throttled into a flash drum).
  - ❖ Isothermally: throttling valve is not used (liquid under low pressure is vaporized in a heater then separated into two phases in a flash drum.
- ➢ Partial condensation: A vapour feed is cooled and partially condensed with phase separation taking place in a flash drum.
- ➢ Vapour and liquid leaving a flash drum are in equilibrium with each other
- ➢ Flash calculations can be used to determine the state of a stream of known composition, Temperature and Pressure.

Equipment needed:



Operation: (Ex: adiabatic flash)

- Feed is pressurised and heated (if necessary)
- Feed is the passed through a throttling valve or nozzle into a flash drum at a lower pressure
- Due to large drop in pressure, a fraction of the liquid vaporises
- Vapour is taken off overhead, while the liquid drains to the bottom of the drum
- Demister prevents liquid droplet from being entrained in the vapour

Design Considerations

The design of an equipment involves → Stream variables calculations

The design of an equipment involves → Size of equipment (last calculation)

Stream and process variables for flash or partial condensation, N_V:

$$\mathbf{F, V, L, \vec{Z}, \vec{y}, \vec{x}, T_F, T_V, T_L, P_F, P_V, P_L, \text{and } Q}$$

$\therefore$ $N_V = 3\,(C+3) + 1$ OR $N_V = 3\,(C+2) + 1$

Number of Equations, N_E:

Mechanical Equilibrium	$P_V = P_L$	1	1
Thermal Equilibrium	$T_V = T_L$	1	1
Phase Equilibrium	$y_i = k_i\, x_i$	C	C
Component Balance	$Fz_i = V\, y_i + L\, x_i$	C-1	C-1
Overall Balance	$F = V + L$	1	1
Enthalpy Balance	$H_F F + Q = H_V V + H_L L$	1	1
Feed mole fraction	$\sum z_i = 1$	1	Not Counted
Vapour mole fractions	$\sum y_i = 1$	1	
Liquid mole fraction	$\sum x_i = 1$	1	
	Number of Equations, N_E	2C+6	2C+3

Degrees of Freedom, N_D:

$N_D = N_V - N_E$	[3(C+3) +1] – [2C+6]	[3(C+2) +1] – [2C+3]
N_D	C + 4	C + 4

Usually the designer has information about:

- Feed flow rate F 1
- Feed Temperature T_F 1
- Feed Pressure P_F 1
- Feed Composition $\vec{\mathbf{Z}}$ C-1 since $\sum z_i = 1$ is not needed

C + 2

∴ $N_D = 2$

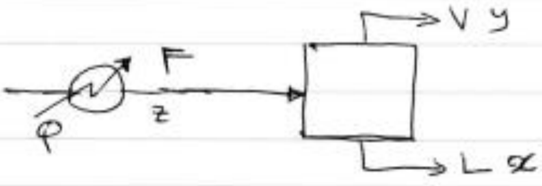
This means that two additional variables can be specified and the rest are calculated.

The choice of the specified variables controls the choice of the computational procedure. The designer may be required to solve material balance equations and equilibrium equation then solve for energy balance (sequential solution procedure) or solve material , equilibrium and energy equation (simultaneous solution).

Examples:

Case	Specified variables	Type of Computational Procedure	Output Variables					
1	$\mathbf{T_V, P_V}$	Isothermal	**Q**		**V**	$\vec{\mathbf{y}}$	**L**	$\vec{\mathbf{x}}$
2	$\mathbf{P_V}$ **and** $\mathbf{Q = 0}$	Adiabatic		$\mathbf{T_V}$	**V**	$\vec{\mathbf{y}}$	**L**	$\vec{\mathbf{x}}$
3	$\mathbf{L, P_V}$	Percent Liquid	**Q**	$\mathbf{T_V}$	**V**	$\vec{\mathbf{y}}$		$\vec{\mathbf{x}}$
4	$\mathbf{V, P_V}$ **(or** $\mathbf{T_V}$**)**	Percent Vapour	**Q**	$\mathbf{T_V(P_V)}$		$\vec{\mathbf{y}}$	**L**	$\vec{\mathbf{x}}$
5	$\mathbf{P_V, Q \neq 0}$	Non Adiabatic		$\mathbf{T_V}$	**V**	$\vec{\mathbf{y}}$	**L**	$\vec{\mathbf{x}}$
6	$\mathbf{P_V, x_j}$	Liquid Purity	**Q**	$\mathbf{T_V}$	**V**	$\vec{\mathbf{y}}$	**L**	$\vec{\mathbf{x}}_{\mathbf{i \neq j}}$
7	$\mathbf{P_V, y_j}$	Vapour purity	**Q**	$\mathbf{T_V}$	**V**	$\vec{\mathbf{y}}_{\mathbf{i \neq j}}$	**L**	$\vec{\mathbf{x}}$
8	$\boldsymbol{y_j, x_k}$	Separation	$\mathbf{P_V, Q}$	$\mathbf{T_V}$	**V**	$\vec{\mathbf{y}}_{\mathbf{i \neq j}}$	**L**	$\vec{\mathbf{x}}_{\mathbf{i \neq k}}$

Binary Mixtures: Graphical Methods.



x-y diagram:

Material Balances for mvc

Component: $y = -\frac{L}{V}x + \frac{F}{V}.z$ $\qquad \frac{y-z}{x-z} = -\frac{L}{V}$

Total : $L = F - V$

$\Psi = \frac{V}{F}$ (fraction vaporized).

$$y = -\frac{(F-V)}{V}x + \frac{F}{V}z$$

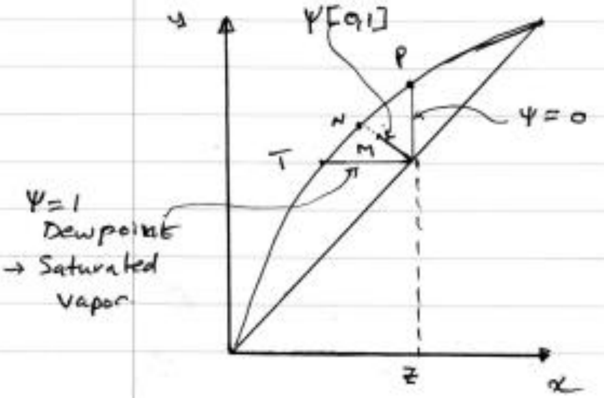
$$= -\frac{1 - V/F}{\frac{V}{F}}x + \frac{F}{\frac{V}{F}}z.$$

$$\boxed{y = -\frac{(1-\Psi)}{\Psi}x + \frac{z}{\Psi}}$$

st. line (operating line).

slope (of $\frac{(1-\Psi)}{\Psi}$), intercept (of $\frac{z}{\Psi}$).

The line also passes through the point $z = x = y$
$[x = y \rightarrow z = x.]$



(Bubble point → Saturated liquid.

- M : non eqm Stage product
- N : eqm Stage product
- P : richest point of feed $\Psi = 0$
- T : leanest point of feed $\Psi = 1$

Hyx diagram: (Solving material and Energy Balances)

EB: $H_F \cdot F + Q = H_V \cdot V + H_L \cdot L$

$$F\left(H_F + \frac{Q}{F}\right) = H_V \cdot V + H_L \cdot L$$

$$(V+L)\left(H_F + \frac{Q}{F}\right) = H_V \cdot V + H_L \cdot L$$

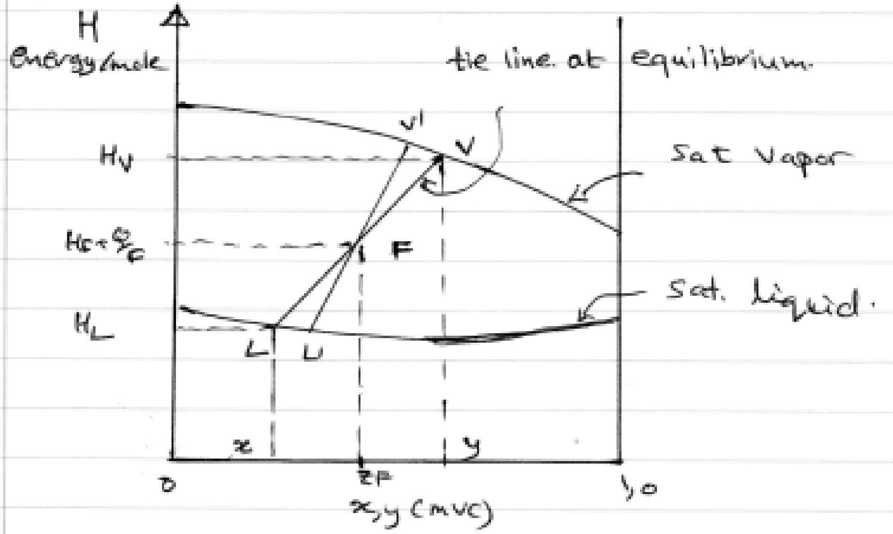
$$\Rightarrow \left[H_V - \left(H_F + \frac{Q}{F}\right)\right]V = -\left[H_L - \left(H_F + \frac{Q}{F}\right)\right] \cdot L$$

$$\Rightarrow \boxed{-\frac{L}{V} = \frac{H_V - (H_F + Q_F/F)}{H_L - (H_F + Q_F/F)} = \frac{y - z}{x - z}}$$

Enthalpy of feed after Heat exchanger.

This is a straight line on the Hyx diagram with the following coordinates:

point V $\longrightarrow (H_V, y)$
Point L $\longrightarrow (H_L, x)$
Point F $\longrightarrow \left[\left(H_F + \frac{Q}{F}\right), z\right]$



LV is also a tie line for an equilibrium process
L' V' corresponds to a non equilibrium stage.