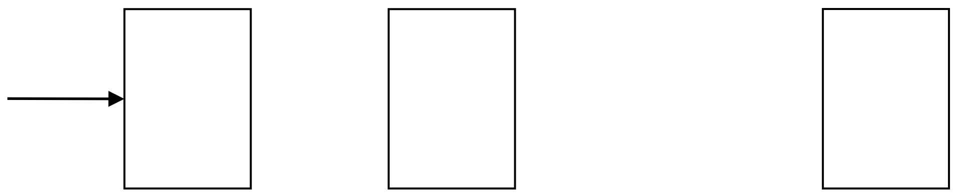
Batch Distillation:

Used when:

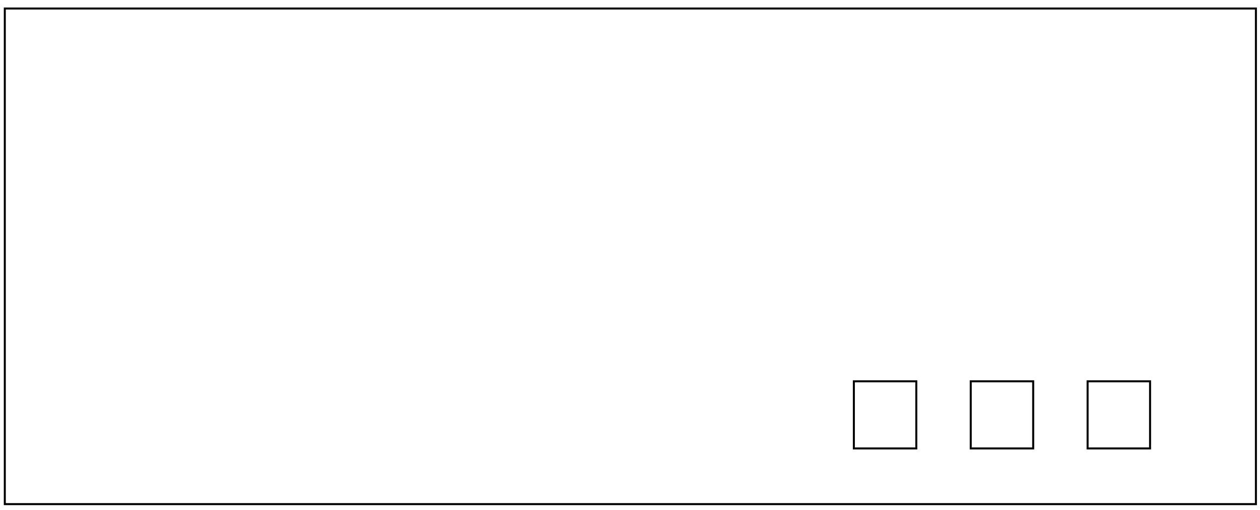
- The required operating capacity is very small
- Batch equipment offer more operating flexibility [feed fluctuations]

Differential distillation [Simple distillation]

Definition: It is the limit of a multistage flash process in which n→∞ and ψ→0 [differential distillation].



In practice this is impossible to achieve and can only be approximated:



Mode of operation:

- Still pot is initially charged with feed [Charge]
- Heat is supplied at a constant rate, and the charge is boiled
- Vapors are withdrawn immediately and collected in cuts as required

Features:

- The first cut will be richest in mvc
- Operation is unsteady → product composition changes with time
- At any instant, the vapor leaving the still pot is assumed to be in equilibrium with the liquid in the pot (residue) → y_D *in equilibrium with* x_W .

Material Balances:

Binary Mixtures:

General: Rate of material = Rate of Material - Rate of Material
Accumulation IN OUT

Total: $\frac{dW}{dt} = 0 - D$ D: distillate flow rate mole/hr

$$dW = -Ddt$$

Component (mvc): $\frac{dx_W.W}{dt} = 0 - x_D D \rightarrow dx_W.W = -x_D.Ddt$

$$x_D = y_D$$

Substitute: $dx_W.W = y_D.dW$

Differentiate: $x_W dW + W dx_W = y_D.dW$

Rearrange: $W dx_W = y_D.dW - x_W dW$

$$\int_{W_o=F}^{W} \frac{dW}{W} = \int_{x_{W_o}=Z_F}^{x_W} \frac{dx_W}{(y_D - x_W)}$$

Differential Mass Balance Equation

Rayleigh Equation

W_o: moles of charge of composition $x_{W_o} = Z_F$

W: moles of residue of composition x_W

Reverse limits and integrate:

$$\ln\frac{F}{W} = \int_{x_W}^{x_{W_o}=Z_F} \frac{dx_W}{(y_D - x_W)}$$

In order to integrate the right hand side, the equilibrium relation between y_D $and x_W$ must be known.

The following cases are considered:

1] Constant equilibrium constant (close boiling mixtures)

- y = k x ; k > 1

$$\ln\frac{F}{W} = \frac{1}{k-1}\ln\frac{Z_F}{x_W}$$

If k varies slightly with composition, an average value can be used in the concentration range.

- Local equilibrium constant: $y = k'x + c$

$$\ln\frac{F}{W} = \frac{1}{k'-1}\ln\left(\frac{Z_F(k'-1) + c}{x_W(k'-1) + c}\right)$$

2] Use of average relative volatility:

$$y_D = \frac{\alpha\, x_W}{1 + x_W(\alpha-1)} \qquad \alpha > 1$$

$$\ln\frac{F}{W} = \int_{x_W}^{Z_F} \frac{dx_W}{x_W\left(\frac{\alpha}{1+x_W(\alpha-1)} - 1\right)}$$

$$\ln\frac{F}{W} = \frac{1}{\alpha-1}\ln\left[\frac{Z_F(1-x_W)}{x_W(1-Z_F)}\right] + \ln\left[\frac{(1-x_W)}{(1-Z_F)}\right]$$

This equation can be rearranged to give:

$$\ln\frac{F}{W} = \frac{1}{\alpha-1}\left[\ln\left(\frac{Z_F}{x_W}\right) + \ln\left(\frac{(1-x_W)}{(1-Z_F)}\right) + (\alpha-1)\ln\frac{(1-x_W)}{(1-Z_F)}\right]$$

$$\ln\frac{F}{W} = \frac{1}{\alpha-1}\left[\ln\left(\frac{Z_F}{x_W}\right) + \alpha\ln\frac{(1-x_W)}{(1-Z_F)}\right]$$

$$(\alpha-1)\ln\frac{F}{W} = \left[\ln\left(\frac{Z_F}{x_W}\right) + \alpha\ln\frac{(1-x_W)}{(1-Z_F)}\right]$$

$$\ln\left(\frac{F\,Z_F}{W\,x_W}\right) = \alpha\ln\frac{F\,(1-Z_F)}{W(1-x_W)}$$

$$\ln\left(\frac{F\,Z_F}{W\,x_W}\right)_{mvc} = \alpha\ln\left(\frac{F\,Z_F}{W\,x_W}\right)_{lvc}$$

3] Graphical Integration:

Plot $\frac{1}{(y_D - x_W)}$ $vs\ x_W$

$\ln\left(\frac{F}{W}\right) = \text{area under the curve between } Z_F \text{ and } x_W$

Multicomponent Mixtures (ideal solutions):

The equations used for binary mixtures can be used for each component in the mixture:

For any component i with reference component j:

$$\ln\left(\frac{F\ Z_{i,F}}{W\ x_{i,W}}\right) = \alpha_{i,j}\ln\left(\frac{F\ Z_{j,F}}{W\ x_{j,W}}\right)$$

$$\sum_{i=1}^{c} x_{i,W} = 1$$

Average composition:

- The total amount of vapor (distillate) is not in equilibrium with the residue
- Overall vapor composition (composited distillate composition, average composition) is obtained from material balance as follows:

$$F\ Z_{i,F} = D\ \left(y_{i,D}\right)_{Average} + W\ x_{i,W}$$

D = F – W

$$F\ Z_{i,F} = (F-W)\left(y_{i,D}\right)_{Average} + W\ x_{i,W}$$

$$\boxed{\left(y_{i,D}\right)_{Average} = \frac{F\ Z_{i,F} - W\ x_{i,W}}{(F-W)}}$$

ABET: Ex. Comparison of Flash distillation and Differential distillation:

A liquid containing 50 mole% Benzene (A), 25 mole % Toluene (B) and 25 mole % O-Xylene.

a) The liquid is flash vaporized at 1 atm and 100°C. What is the fraction vaporized (ψ) ? And what is the vapor composition?
b) Under the same pressure and with the same (ψ), the liquid is to be differentially distilled. Calculate the distillate and residue compositions.

Component	$Z_{i,F}$	P_{mmHg} at 100°C	Flash ψ=0.325		Differential distillation		
			y_{iD}	x_{iW}	α (100°C)	$(y_{i,D})_{Ave}$	$x_{i,W}$
A	0.50	1370	0.715	0.397	2.49		
B	0.25	550	0.198	0.274	1.00		
C	0.25	220	0.087	0.329	0.364		
		∑	1.000	1.000	∑	1.000	1.000

Basis: F =100 moles → D = 32.5 moles and W = 67.5 moles

For A:

$$\ln\left(\frac{100*0.5}{67.5*x_{A,W}}\right) = 2.49\ \ln\left(\frac{100*0.25}{67.5*x_{B,W}}\right)$$

For C:

$$\ln\left(\frac{100*0.25}{67.5*x_{C,W}}\right) = 0.364\ln\left(\frac{100*0.25}{67.5*x_{B,W}}\right)$$

$$x_{A,W} + x_{B,W} + x_{C,W} = 1.000$$

Solve Simultaneously.