Distillation

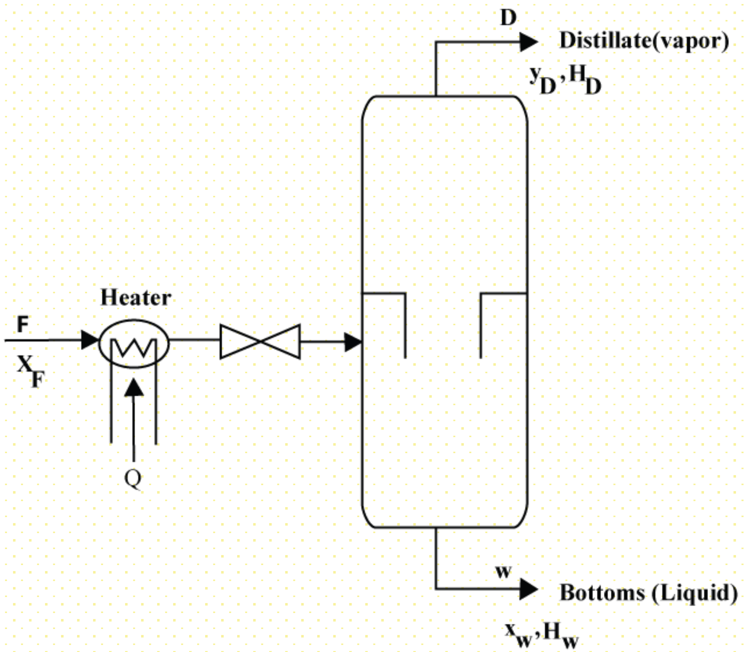
by

Selvaraju Narayanasamy
Associate Professor
Department of Biosciences and Bioengineering
Indian Institute of Technology Guwahati

Lecture 3: Flash Distillation

Definition & Purpose:

- Flash distillation (sometimes called “flash vaporization” or "equilibrium distillation") is a single stage separation technique.
- A liquid mixture feed is pumped at higher pressure through a heater to raise the temperature and enthalpy of the mixture.
- Mixture flows to the flush drum through a throttling valve under reduced pressure, causing the liquid to partially vaporize.
- Once the mixture enters the "flash drum", the liquid and vapor separate.
- The vapor and liquid are allowed to reach equilibrium.
- Vapor and liquid phases are separated and removed from the system

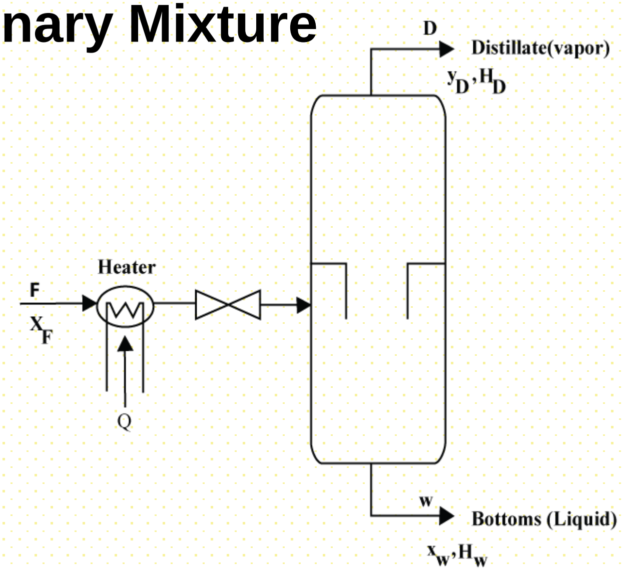


✓ Separation by flash vaporization are very common in industry, e.g., petroleum refining.

✓ Even when some other method of separation is to be used, it is not uncommon to use a "pre-flash" to reduce the load on the separation itself.

✓ When designing a flash drum it is important to provide enough space in the drum for disengagement of liquid and vapor. Drums can be designed as cyclone type.

Lecture 3: Flash Distillation of a Binary Mixture



- Consider a binary mixture of components A and B.
- Flow rates, composition and enthalpy of feed are: F, z_F, H_F
- Flow rates, composition and enthalpy of distillate (top product) are: D, z_D, H_D
- Flow rates, composition and enthalpy of bottom product are: W, z_W, H_W
- Let Q be the rate of supply of heat to the heat exchanger.

Following are the assumptions:

1. No heat losses to surroundings, 2. Ideal gas behavior for vapor, 3. Perfect mixing

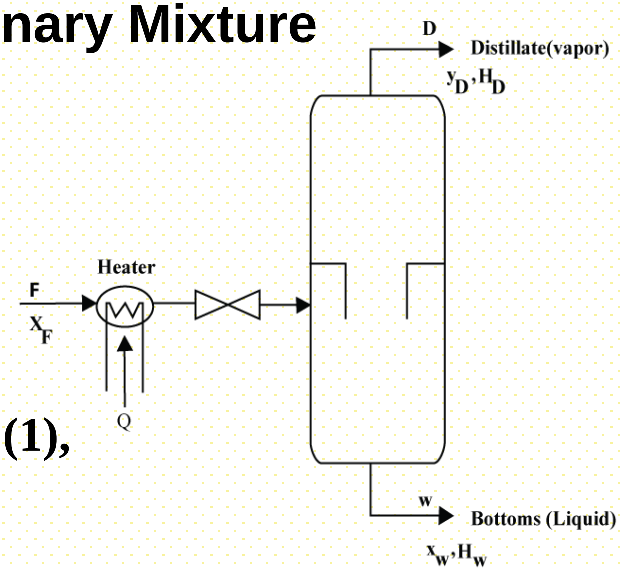
Materials and energy balance equations for a steady-state flash vaporization unit:

Total material balance: F = D + W (1)

Component balance: $Fz_F = Dy_D + Wx_W$ (2)

Energy balance: $FH_F + Q = DH_D + WH_W$ (3)

Lecture 3: Flash Distillation of a Binary Mixture



Total material balance: F = D + W (1)

Component balance: $Fz_F = Dy_D + Wx_W$ (2)

Energy balance: $FH_F + Q = DH_D + WH_W$ (3)

Using equations (2) and (1), we have

$$(D+W)z_F = Dy_D + Wx_W$$

$$\Rightarrow D(z_F - y_D) = W(x_W - z_F)$$

$$\Rightarrow -\frac{W}{D} = \frac{y_D - z_F}{x_W - z_F} \qquad (4)$$

Using equations (3) and (1), we have

$$FH_F + Q = (F-W)H_D + WH_W$$

$$\Rightarrow \frac{W}{F}(H_D - H_W) = H_D - \left(H_F + \frac{Q}{F}\right) \qquad (5)$$

Similarly, using equations (3) and (1) again, we have

$$FH_F + Q = DH_D + (F-D)H_W$$

$$\Rightarrow \frac{D}{F}(H_W - H_D) = H_W - \left(H_F + \frac{Q}{F}\right) \qquad (6)$$

Dividing eq (5) by eq (6) we have,

$$-\frac{W}{D} = \frac{H_D - (H_F + Q/F)}{H_W - (H_F + Q/F)} \qquad (7)$$

Lecture 3: Flash Distillation of a Binary Mixture

We'll consider a different rearrangement of the steady state model. These will be useful in some of the solution methods.

Let the *fraction vaporized* of the feed as f=D/F.

Material balance can be rewritten as: $1 = \frac{D}{F} + \frac{W}{F} = f + \frac{W}{F} \quad \Rightarrow \frac{W}{F} = 1 - f \qquad (8)$

Component balance can then be written as: $z_F = \frac{D}{F} y_D + \frac{W}{F} x_W = f y_D + (1 - f) x_W \qquad (9)$

There are two unknown in eq (9). A second equation between the unknown must be available. This is provided by equilibrium curve or equation based on relative volatility, α. For binary system:

$$\alpha_{AB} = \frac{y_A / x_A}{y_B / x_B}$$

where x_A = 1-x_A and y_B = 1-y_A

The above equation can be rearranged to get:

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

Lecture 3: Flash Distillation of a Binary Mixture

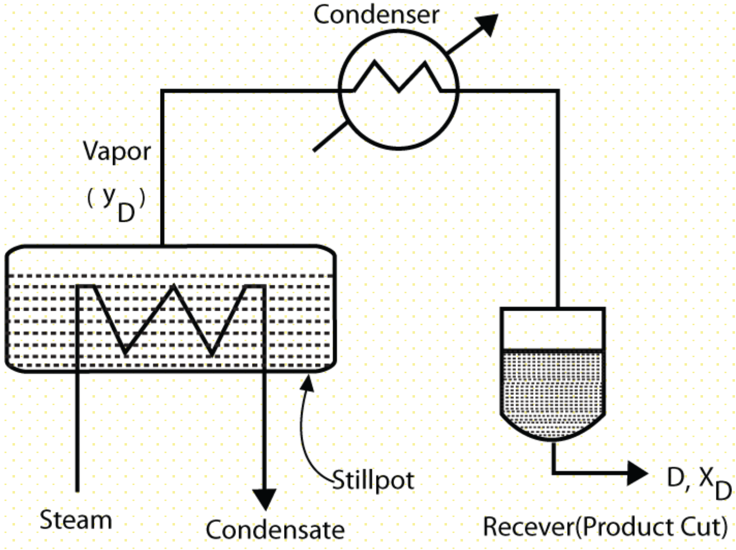
Calculation Techniques

- **To solve a flash distillation problem, one simultaneously solves the operating and equilibrium equations.**
- **Flash calculations can be solved directly, but usually require an iterative solution.**
- **Graphical techniques are also common.**
- **Often, the choice of technique depends on the available form of the equilibrium relationship.**

EXAMPLE: A mixture of liquid containing 50 mole % n-hexane and 50% n-heptane is subjected to flash distillation at 1 atm total pressure and 40^{o}C to vaporize 50 mol% of feed. The relative volatility of n-hexane in the mixture is 2.36. Calculate the composition of vapor and liquid leaving the flash chamber considering an equilibrium stage.

Lecture 4: Batch Distillation

- In batch distillation, a tank is charged with feed and then heated using steam jacket or steam coil.
- Vapor flows overhead, is condensed and collected in a receiver.
- The liquid remaining in the tank is generally called the *residue*. T
- he composition of the material collected in the receiver varies with time, so the composition of the product is an average of all the material collected.
- Often, the receiver will be emptied or switched several times during a distillation to collect separate *cuts* of product.



A batch process is inherently dynamic -- it cannot be modeled steady state.

Batch distillation can be conducted with or without reflux. When reflux is used, any of several different operating *policies* may be used -- you might use a constant reflux rate, you might vary it, etc.

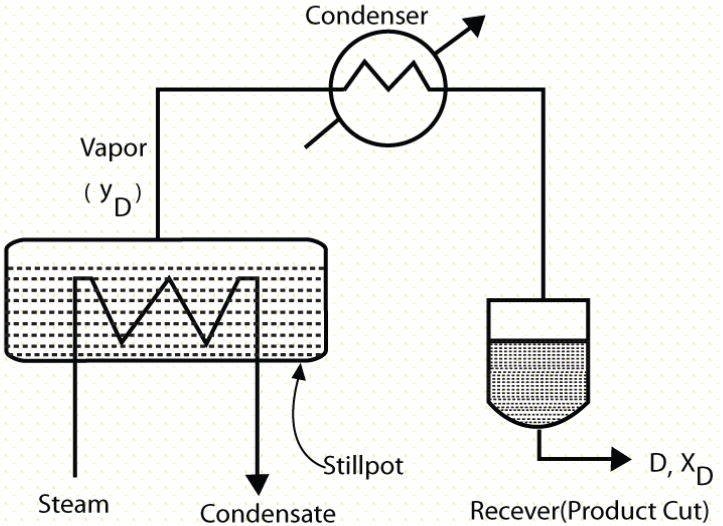
Lecture 4: " Differential" Distillation of a Binary Mixture

Batch distillation is most common:

- **in small capacity plants**
- **when feed or products vary widely and frequently (as in specialty chemical production)**
- **for test runs on new products**
- **when the feed is the result of batch processing**
- **when the process requires frequent cleaning which would interrupt continuous processing**

We want to consider one main variant -- without reflux. Other variant –with reflux will be considered later.

Batch distillation without reflux is often called *differential distillation*. Because there is no reflux, the vapor product is assumed in equilibrium with the liquid residue in the tank at any given time.



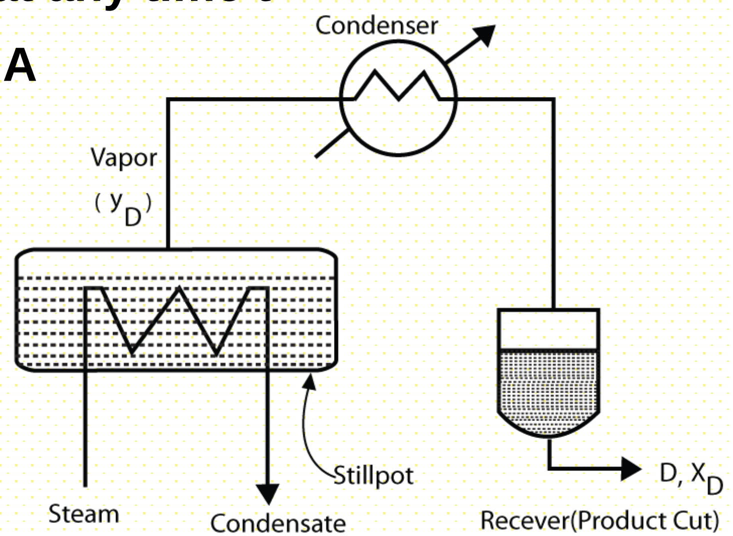
Lecture 4: " Differential" Distillation of a Binary Mixture

Let L= number of moles of liquid in still pot at any time t

x = mol fraction of more volatile component A

D = moles of condensate accumulated

y* = concentration of equilibrium vapor



Differential mass balance is as follows:

Total material balance: -dL = dD (1)

Component A balance: -d(Lx) = y* dD

$\Rightarrow$ **-Ldx – x dL = y* dD**

Using eq.1:

-Ldx + x dD = y* dD

$\Rightarrow$ **-Ldx = (y*-x) dD**

Now again using eq.1

-Ldx = (y*-x) dL

$$\Rightarrow \frac{dL}{L} = \frac{dx}{(y^*-x)}$$

If F = amount of feed, moles

z_F = concentration of feed

W = moles of residue

x_W = concentration of more volatiles in the residue

Then,

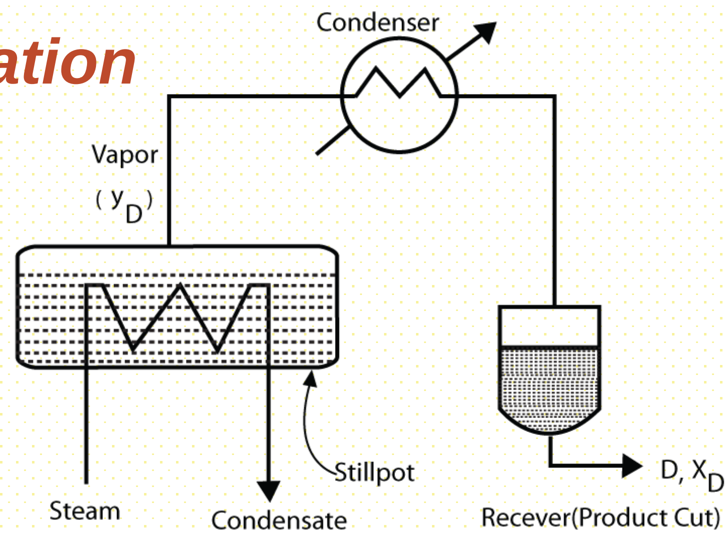
$$\int_F^W \frac{dL}{L} = \int_{z_F}^{x_W} \frac{dx}{(y^*-x)} \quad \Rightarrow \ln\frac{F}{W} = \int_{x_W}^{z_F} \frac{dx}{(y^*-x)}$$

This is the *Rayleigh Equation* which relates the amount of residue to the composition.

Lecture 4: " Differential" Distillation of a Binary Mixture

$$\ln\frac{F}{W}=\int_{x_W}^{z_F}\frac{dx}{(y^*-x)}$$

Rayleigh Equation



- If equilibrium data (x-y*) are available in tabular form, graphical integration of the RHS is possible
- If algebraic relation between x and y is available then analytical integration is possible.

Example $$y^*=\frac{\alpha x}{1+(\alpha-1)x}$$

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

More convenient form

$$\ln\frac{Fz_F}{Wx_W}=\alpha\ln\frac{F}{W}\left(\frac{1-z_F}{1-x_W}\right)$$

Average conc. ($y_{D,avg}$) of the accumulated distillate can be obtained by material balance:

$F\,z_F = D\,y_{D,avg} + W\,x_W$ and $F = D + W$

Lecture 4: " Differential" Distillation of a Binary Mixture

EXAMPLE: **A liquid mixture of 150 mol containing 40 mole% n-hexane and 60 mole% n-heptane is to be batch-distilled at 1 atm total pressure.**

(a) If 50 mol is distilled, what is the average composition of the distillate and the composition of the liquid left in the still?

(b) If the accumulated vapor is 90% n-hexane, calculate the amount of distillate. The relative volatility of the n-hexane in the mixture is 2.36.

SOLUTION: **(a) Given, F = 150 mol, Z_F = 0.4, Distillate, D = 50, W = 100 mol, $y_{D,\,avg}$=?**

$$FZ_F = Dy_{D,avg} + Wx_W$$

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

$\Rightarrow$

$\Rightarrow$

$\Rightarrow$

$\Rightarrow$

After solving

$\rightarrow$ **Composition of the Distillate**