Principles of Chemical Engineering

Mass Transfer

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Syllabus Contents

Distillation - Vapour-Liquid Equilibrium - Relative volatility - Distillation with reflux.

Objectives

- To give an overview of principle of distillation.
- To obtain the equilibrium relation of distillation in terms of relative volatility.

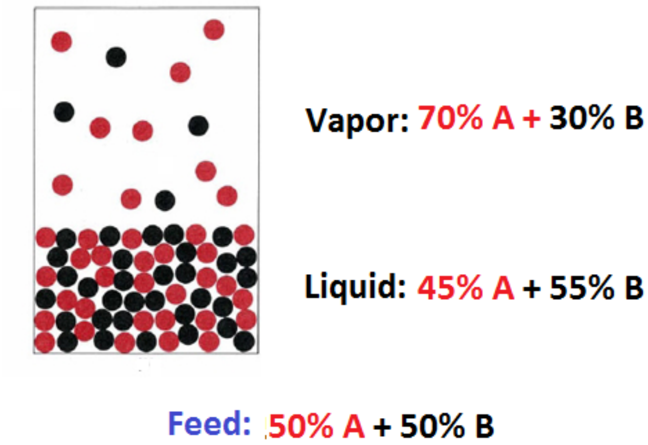
Distillation

Distillation is the separation of components of a solution based on their differences in volatility. A component having a higher vapor pressure is a more volatile one.

In the case of a solution of acetone and water, acetone is the more volatile one. At $25^\circ\mathrm{C}$,

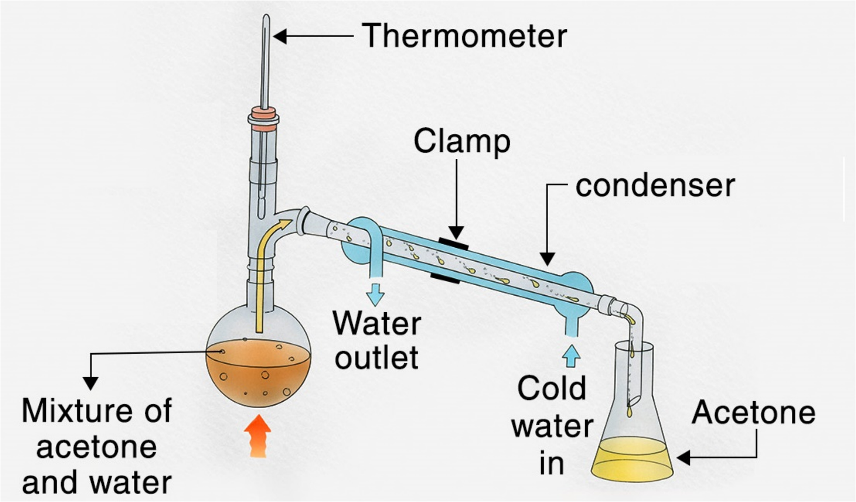
$$P^{\text{sat}}_{\text{acetone}} = 229.5 \text{ mm Hg} \qquad P^{\text{sat}}_{\text{water}} = 23.7 \text{ mm Hg}$$

Distillation



By repeated vaporization and condensation, separation of more volatile component from the less volatile is achieved.

Distillation



Relative Volatility

Relative volatility is a measure of the differences in volatility between two components, and hence their boiling points. It indicates how easy or difficult a particular separation will be. The relative volatility of component A (the more volatile component) with respect to component B in a binary mixture is defined as

$$\alpha_{AB} = \frac{y_A/x_A}{y_B/x_B} = \frac{y_A/(1-y_A)}{x_A/(1-x_A)} \tag{1}$$

where,

$y_A =$ mole fraction of component more volatile component in the vapor
$x_A =$ mole fraction of more volatile component in the liquid

For a binary system, $x_A + x_B = 1$; similarly $y_A + y_B = 1$.

Relative Volatility (contd..)

For a system obeying Raoult's law,

$$y_A P = x_A P_A^{\text{sat}}$$

Therefore, the relative volatility can be written as

$$\alpha_{AB} = \frac{P_A^{\text{sat}}}{P_B^{\text{sat}}}$$

Equilibrium Relation in terms of Relative Volatility

So Eqn.(1) can be rearranged, and expressed as

$$y_A = \frac{\alpha_{AB} x_A}{1 + (\alpha_{AB} - 1) x_A}$$

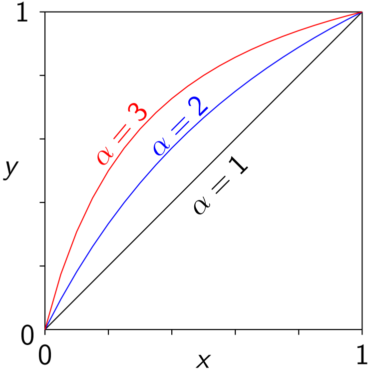
i.e.,

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

where y and x represents the mole fraction of more volatile components; and, α relative volatility of more volatile component with respect to less volatile component.

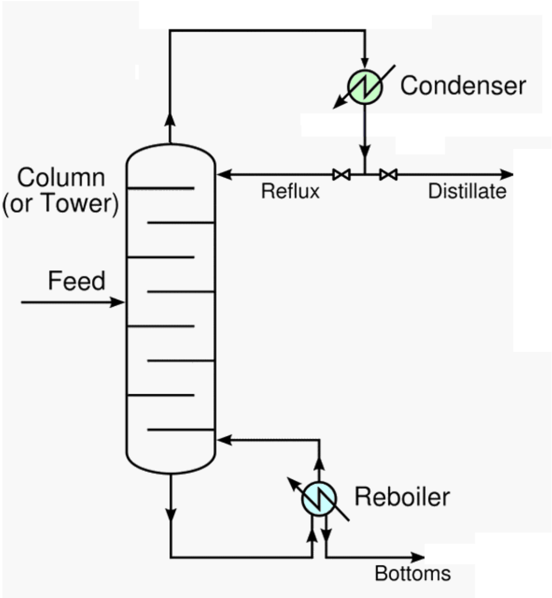
x-y diagram of Distillation (Equilibrium Curve)

Effect of Relative Volatility (α)

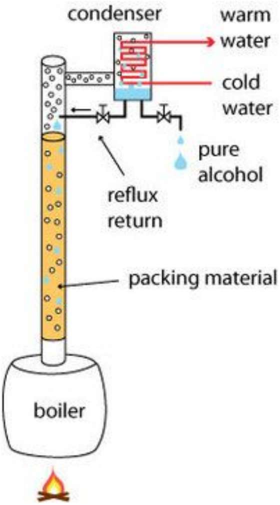


If the relative volatility between two components is equal to one, separation is not possible by distillation. The larger the value of α, above 1.0, the greater the degree of separability, i.e. the easier the separation.

Distillation Column



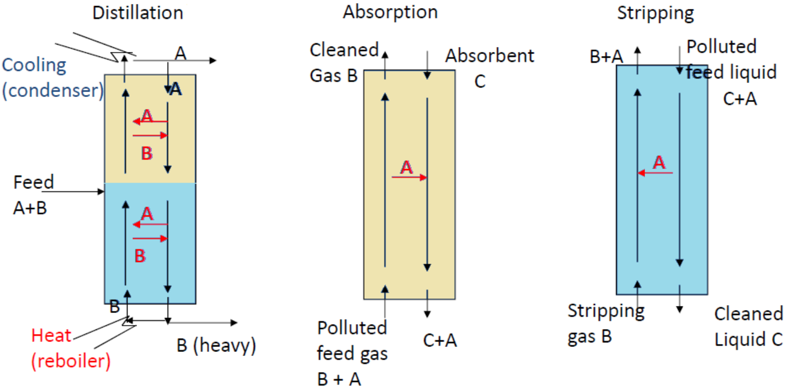
Distillation with Reflux



Without reflux, the possible separation is equal to that from a single-stage.

Because of reflux, the distillation becomes a multiple stages operation, leading to increased purity of products.

Comparison of Distillation, Absorption and Stripping



- Two key components (A+B)
- One feed (normally)
- Two pure products
- Two sections
- Heating and cooling
- Boiling mixture

- Three components
  - Inert gas B (e.g., air)
  - Inert liquid C (e.g., water)
  - Solute A (e.g., CO_2) goes from gas -> liquid
- Two feeds
- One pure product (at most)
- One section
- Non-boiling mixture
  - so p and T can be set independently

Stripping: Reverse of absorption.
Solute A goes from liquid -> gas

http://folk.ntnu.no/skoge/septek/lectures/septek-sis3-absorption.pdf

Quiz

1. For the ethanol-water solution, what is the more volatile component? At $80^\circ\mathrm{C}$, vapor pressure of water is 354.5 mm Hg, and that of ethanol is 813 mm Hg.
2. What is the need for successive vaporization and condensation in distillation operation?
3. Define 'relative volatility'.
4. Calculate the relative volatility for data given in question 1.
5. Obtain the equilibrium relation y vs. x for distillation in terms of relative volatility α.
6. What is the advantage of reflux in distillation?
7. Compare between distillation, absorption and stripping.