Universiti Malaysia PAHANG
Engineering • Technology • Creativity

Process Chem and Pharmaceutical Engineering 1

Vapour-liquid Separation Part 1

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Chapter Description

- Aims
  - Solve problems related to extraction process by applying the formula relevant to specific operations

- Expected Outcomes
  - Describe the vapour-liquid separation in single condensable component and multicomponent systems
  - Apply Raoult's law and Henry's Law in problem solving
  - Comprehend the distillation process

- References
  - Principles of Mass Transfer and Separation Processes, Binay K. Dutta, PHI Learning Private Limited, 2009

The Nature of Equilibrium

Equilibrium: a static condition, whereby no changes occur in the macroscopic properties of a system with time

Measure of Composition

Measure of composition

- Mass or mole fraction

$$x_i = \frac{m_i}{m} = \frac{\dot{m}_i}{\dot{m}}$$

- Molar concentration

$$C_i = \frac{x_i}{V}$$

- Molar mass for a mixture or solution

$$M = \sum_i x_i M_i$$

Bubble Point and Dew Point

- The **bubble point** is the temperature (at a given pressure) where the first bubble of vapour is formed when heating a liquid consisting of two or more components.

- **Dew point** is the atmospheric temperature (varying according to pressure and humidity) below which water droplets begin to condense and dew can form.

Source: Principles of Mass Transfer and Separation Processes

VLE Model

Model for VLE: Find T,P composition

- Raoult's Law
- Henry's Law

Raoult's Law

Assumptions

- V phase is an ideal gas – applicable for low to moderate pressure
- L phase is an ideal solution – valid only if the species are chemically similar (size, same chemical nature, e.g. isomers such as ortho-, meta- & para-xylene)

$$y_i P = x_i P_i^{sat} (i = 1,2, \ldots N)$$

Where:

x_i = L-phase mole fraction

y_i = V-phase mole fraction

P_i^{sat} = vapour pressure of pure species

P = total pressure

Dew Point & Bubble Point Calculations with Raoult's Law

	FIND GIVEN
Bubble P	Calculate $\{y_i\}$ and P, given $\{x_i\}$ and T
Dew P	Calculate $\{x_i\}$ and P, given $\{y_i\}$ and T
Bubble T	Calculate $\{y_i\}$ and T, given $\{x_i\}$ and P
Dew T	Calculate $\{x_i\}$ and T, given $\{y_i\}$ and P

For binary systems to solve for bubble point calculation (T is given);

$$\sum_i y_i = 1$$

$$\mathrm{P} = \sum_i x_i P_i^{sat}$$

$$\mathrm{P} = P_2^{sat} + (P_1^{sat} - P_2^{sat})x_1$$

$$y_i = \frac{x_i P_i^{sat}}{P}$$

Raoult's law equation can be solved for xi to solve for dew point calculation (T is given)

$$\sum_i x_i = 1$$

$$P = \frac{1}{\sum_i y_i / P_i^{sat}}$$

$$P = \frac{1}{\frac{y_i}{P_1^{sat}} + y_2 / P_2^{sat}}$$

$$y_i = \frac{y_i P}{P_i^{sat}}$$

Example 1

Binary system acetonitrile(1)/nitromethane(2) conforms closely to Raoult's law. Vapour pressure for the pure species are given by the following Antoine equations:

$$\ln\frac{P_1^{sat}}{kPa} = 14.2724 - \frac{2945.47}{t/^oC + 244} \qquad \ln\frac{P_2^{sat}}{kPa} = 14.2043 - \frac{2972.64}{t/^oC + 209}$$

a. Prepare a table showing P vs x_1 and P vs y_1 at temperature 75 °C (x1=0.6)

a. Bubble P calculations are required. Since this is a binary system

$$P = P_2^{sat} + (P_1^{sat} - P_2^{sat})x_1$$

At 75 oC, the saturated pressure is given by Antoine equation:

$P_1^{sat} = 154.31$ $P_2^{sat} = 41.98$

Substitute both values in (A) to find P:

P = 41.98 + (154.31-41.98)(0.6)

P = 109.38 kPa

The corresponding value of y1 is found from:

$$y_i P = x_i P_i^{sat}$$

$$y_i = \frac{x_i P_i^{sat}}{P} = \frac{(0.6)(154.31)}{109.38} = 0.8464$$

x_i	y_i	P/kPa
0.0	0.0000	41.98
0.2		
0.4		
0.6	0.8464	109.38
0.8	0.9363	131.84
1.0	1.0000	154.32

Conclusion of The Chapter

- This chapter discussed about bubble and dew point

  - Raoult's law and Henry's law

  - Azeotrope

  - Flash calculation

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<u>Reference</u>

Principles of Mass Transfer and Separation Processes, Binay K. Dutta, PHI Learning Private Limited, 2009