Mass transfer

Lecture 8: *Batch distillation*

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2019. 10. 7

Learning objectives

- Derive and apply material balance equation for the simple batch distillation.

- Analyze the batch distillation with reflux using the McCabe-Thiele method.

Today's outline

- **Introduction**
  - ✓ simplest equipment setup

- **Mass balance in the batch distillation**
  - ✓ Composition variation and Rayleigh equation
  - ✓ Alternative to Rayleigh equation
  - ✓ Ex. 21.10

- **Batch distillation with refulx**

21.5 Introduction

- **Some small plants use batch distillation to recover volatile products from liquid solution.**
  - ✓ The simplest form of this process is shown in below.

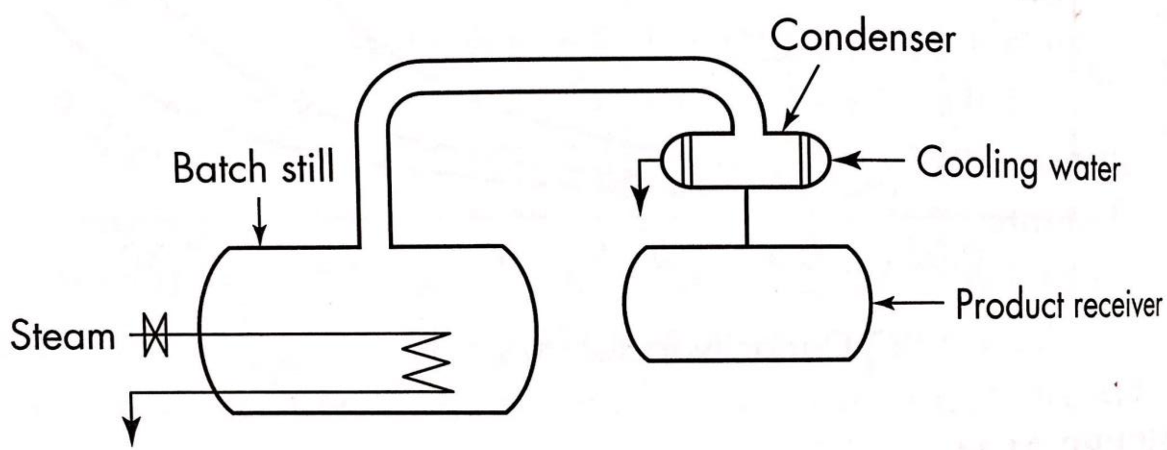

FIGURE 21.35
Simple distillation in a batch still.

21.5 Composition variation

- **The vapor phase becomes richer in the volatile component(s) throughout the time.**
  - ✓ Compositions of each change with time. How about in fractionating column (do they change over time?)
  - ✓ For *n* moles of liquid left in the batch at a given time, the total moles of component A left in the still are $n_A = x_A\, n$ (let $x_A = x$).
  - ✓ If d*n* is vaporized, the differential mass balance for A becomes

$$\mathrm{d}n_A = \mathrm{d}(x\, n) = n\, \mathrm{d}x + x\, \mathrm{d}n = y\, \mathrm{d}n$$

$$\frac{\mathrm{d}n}{n} = \frac{\mathrm{d}x}{y-x}$$

  - ✓ Integrating the above between x_o and x_1 gives the Rayleigh eqn.:

$$\int_{n_0}^{n_1} \frac{\mathrm{d}n}{n} = \int_{x_0}^{x_1} \frac{\mathrm{d}x}{y-x}$$

how do you integrate the right side?

21.5 Alternative to Rayleigh eqn

- **For ideal mixture, one can use instead relative volatility, the value of which often doesn't change over time.**
  - ✓ Rearrange α_{AB} expression into $\frac{y_A}{y_B} = \alpha_{AB}\frac{x_A}{x_B}$
  - ✓ If d*n* is vaporized, the differential mass balance becomes

$$\frac{\mathrm{d}n_A}{\mathrm{d}n_B} = \frac{\mathrm{d}n_A/\mathrm{d}n}{\mathrm{d}n_B/\mathrm{d}n} = \alpha_{AB}\frac{x_A}{x_B} = \alpha_{AB}\frac{n_A}{n_B} \rightarrow \frac{\mathrm{d}n_A}{n_A} = \alpha_{AB}\frac{\mathrm{d}n_B}{n_B}$$

  - ✓ Integrating the above between t_0 (n_{A0}, n_{B0}) and t (n_A, n_B) gives

$$\ln\frac{n_A}{n_{A0}} = \alpha_{AB}\ln\frac{n_B}{n_{B0}} \rightarrow \frac{n_B}{n_{B0}} = \left(\frac{n_A}{n_{A0}}\right)^{1/\alpha_{AB}}$$

21.5 Simple batch distillation

Ex. 21.10. A batch of crude pentane contains 15 mol% n-butane and 85 mol% n-pentane. If a simple batch distillation at atmospheric pressure is used to remove 90 mol% of the butane, how much pentane will be removed? What will be the composition of the remaining liquid? (**In-class**)

미정제된 pentane은 15 mol%의 n-butane과 85 mol%의 n-pentane으로 구성되어 있다. 이로부터 단순한 회분식 증류공정(대기압 아래 운행)을 통해 90 mol%의 butane을 제거하고자 한다면, pentane은 얼마나 함께 제거되겠는가? 또한 남은 액체의 조성은 어떻게 되는가? (두 화합물을 이상적인 혼합물로 간주하라)

21.5 Batch distillation with reflux

- **Relative volatility needs to be high/low enough for the simple batch distillation to be effective.**
  - ✓ Often, rectifying column with reflux is added to improve performance
  - ✓ Such operation can be analyzed using the McCabe-Thiele method

$$y_{n+1} = \frac{R_D}{R_D+1} x_n + \frac{x_D}{R_D+1}$$

  - ✓ The reflux ratio can be varied to maintain the same number of plates needed in achieving the given separation.
  - ✓ Which is the later time point? Upper or lower?