



CHE482-Chemical Engineering Laboratory III

Online Education Term

2B- FRACTIONAL DISTILLATION

THEORY

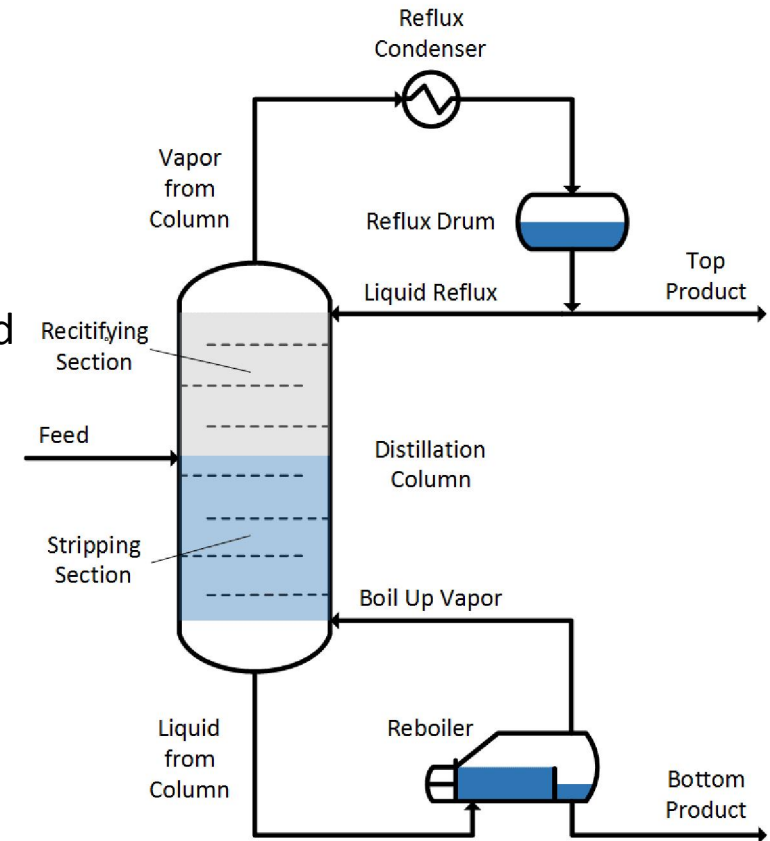
- Distillation is a method for separating the various components of a liquid solution which depends upon the distribution of these components between a vapor phase and liquid phase.
- Raoult's law, can be defined for vapor-liquid phases in equilibrium

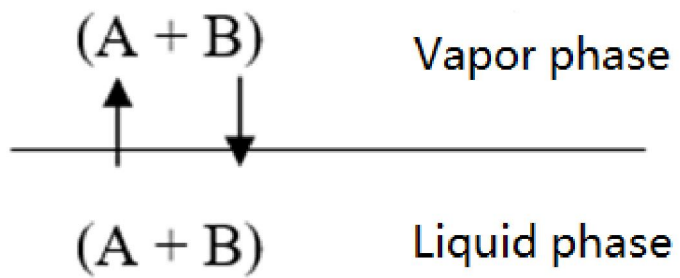
$$p_A = P_A \cdot x_A$$

p_A = Partial pressure of component A in the vapor

P_A = Vapor pressure of pure A

x_A = mol fraction of A in the liquid





- $(A + B)$: Binary mixture
 - A: More volatile component
 - B: Less volatile component
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- The more volatile component is enriched as the vapor stream rises upward.
 - The liquid phase is rich in less volatile components.

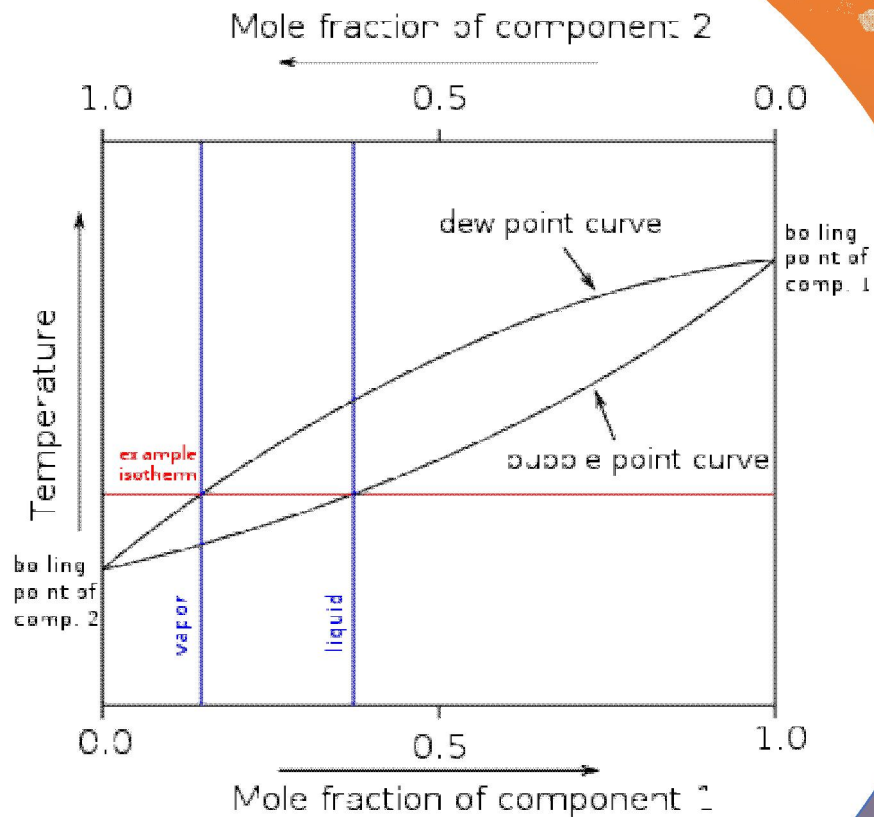
Distillation terms

- **Volatility:** Volatility is a material quality which describes how readily a substance vaporizes. At a given temperature and pressure, a substance with high volatility is more likely to exist as a vapor.
- **Relative Volatility:** Ratio of the concentration of A in the vapor to the concentration of A in the liquid divided by the ratio of the concentration of B in the vapor to the concentration of B in the liquid.

$$a_{AB} = \frac{\left(\frac{y_A}{x_A}\right)}{\left(\frac{y_B}{x_B}\right)} = \frac{\left(\frac{y_A}{x_A}\right)}{(1-y_A)/(1-x_A)} = \frac{P_A}{P_B}$$

$$a_{AB} = 1 \quad ?$$

$$a_{AB} > 1 \quad ?$$



The **bubble point** is the temperature where the first bubble of vapor is formed when heating a liquid consisting of two or more components.

Dew point is the temperature to which air must be cooled to become saturated with water vapor.

Phase Rule

$$F = C + 2 - P$$

The equilibrium between two phase in a given situation is restricted by the phase rule;

F ; the number of variants ofdegrees of freedom of the system

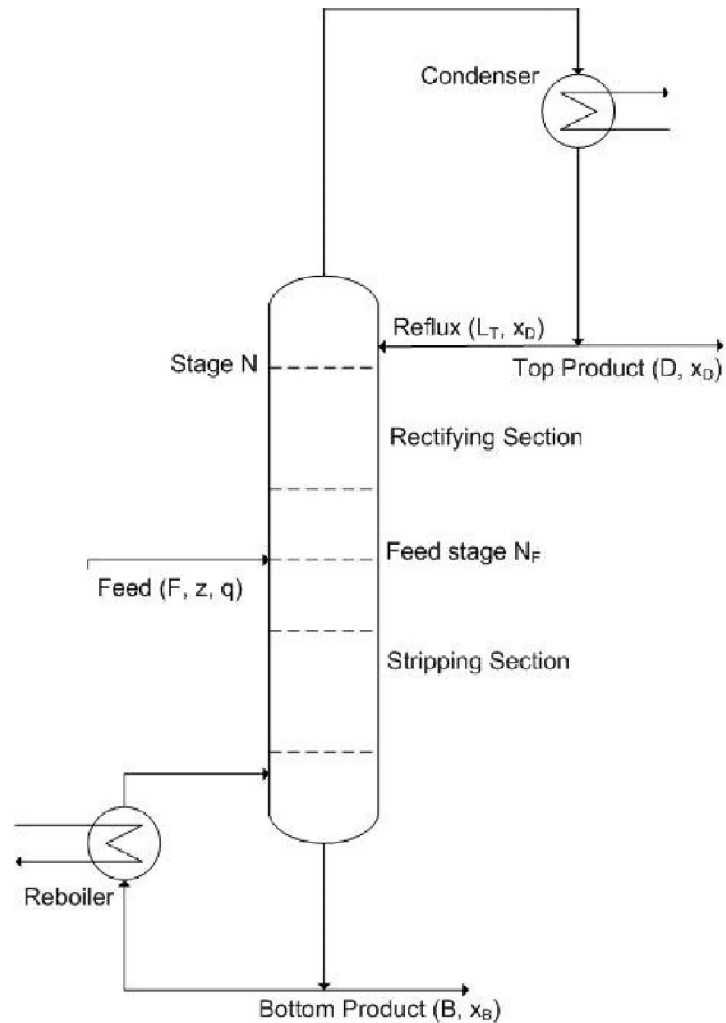
C ; the number of total components

P ; the number of phases at equilibrium

Phase rule applies to the ethanol-water system

?

Components of the Distillation System



Which section is used in the experiment ?

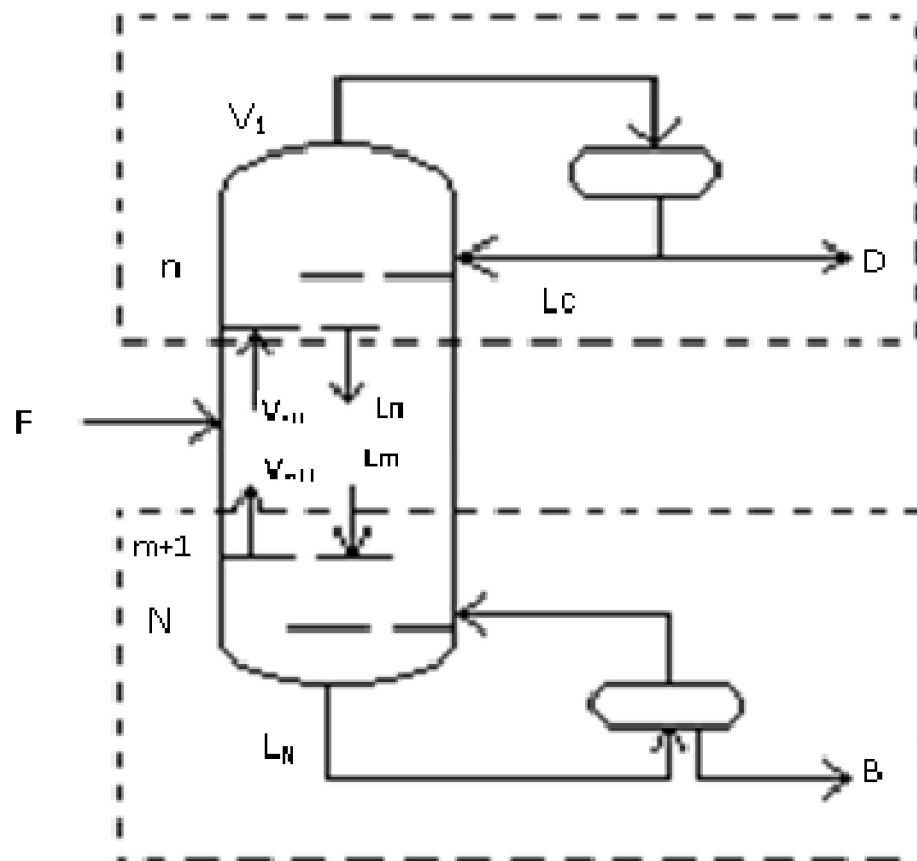
Enriching Section

Stripping Section

Where are the hottest and coldest parts of the system?

Why tray distillation is used ?

Distillation Column Overall Material Balance



The entering feed of F in mol/h must equal the distillate D in mol/h plus the bottoms W in mol/h.

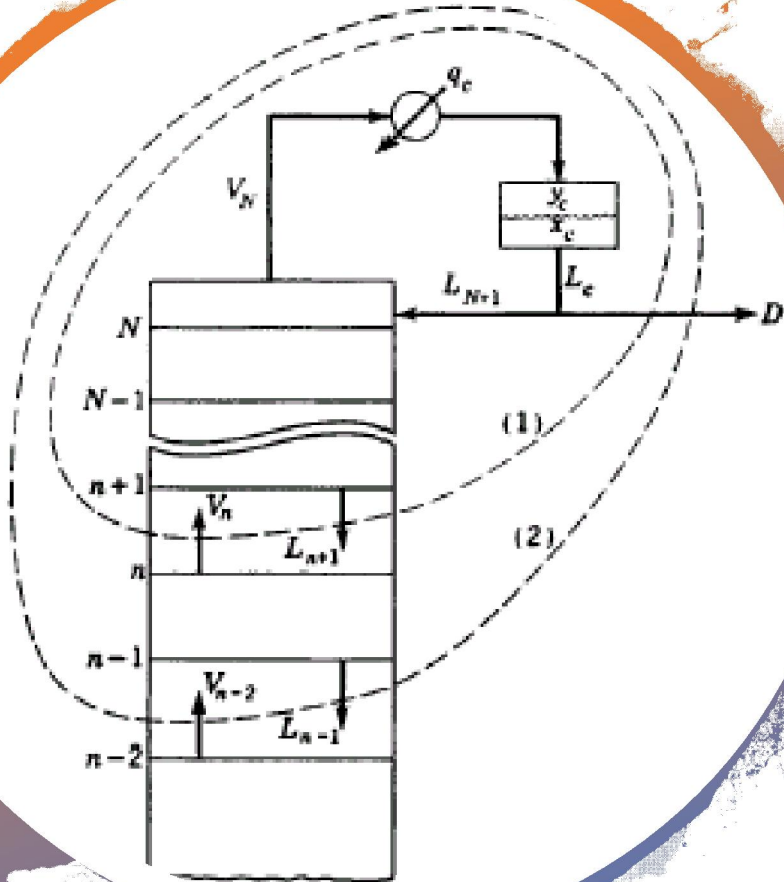
Overall Material Balance;

$$F = D + B$$

Total Material Balance on Component A;

$$F \cdot X_F = D \cdot X_D + B \cdot X_B$$

Equation for Enriching Section



- $V_N = L_{N+1} + D$
- $D = V_N - L_{N+1}$
- $V_N \cdot Y_N = L_{N+1} \cdot X_{N+1} + D \cdot X_D$
- $D \cdot X_D = L_{N+1} \cdot X_{N+1} - V_N \cdot Y_N$

Operating Line

$$Y_N = \frac{L_{N+1}}{V_N} X_{N+1} + \frac{DX_D}{V_N}$$

$$Y_N = \frac{L_{N+1}}{(L_{N+1} + D)} X_{N+1} + \frac{DX_D}{(L_{N+1} + D)}$$

Reflux Ratio

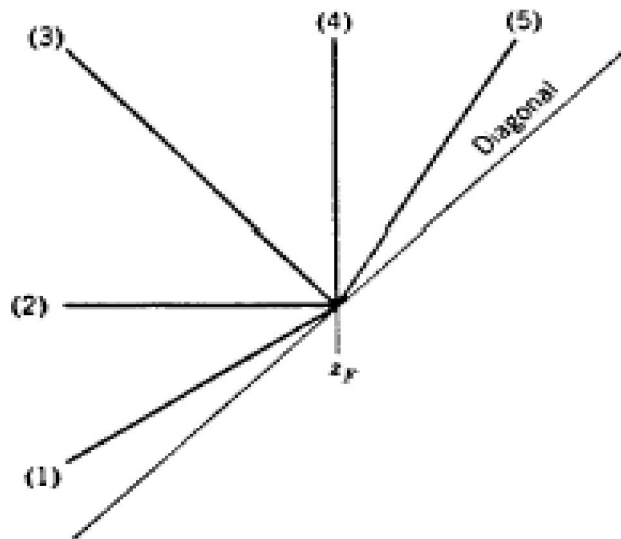
$$R_D = L_0 / D$$

If R_D increases?

It is the ratio between the amount of reflux that goes back down the distillation column and the amount of reflux that is collected in the receiver (distillate).

q Line

- $\text{Slope} = -\frac{(1-f)}{f} = -\frac{q}{(1-q)}$



1= Superheated steam $f > 1$ $q < 0$

2= Saturated steam $f = 1$ $q = 0$

3= Vapor-liquid mixture $0 < f < 1$ $0 < q < 1$

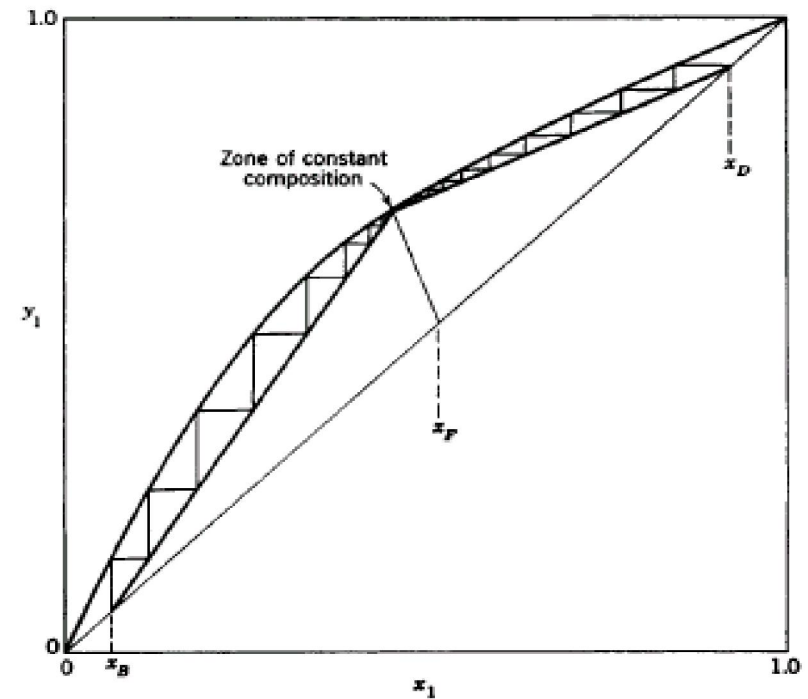
4= Saturated liquid $f = 0$ $q = 1$

5= Cold liquid $f < 0$ $q > 1$

Calculation for Number of Theoretical Stages- McCabe Thiele Method

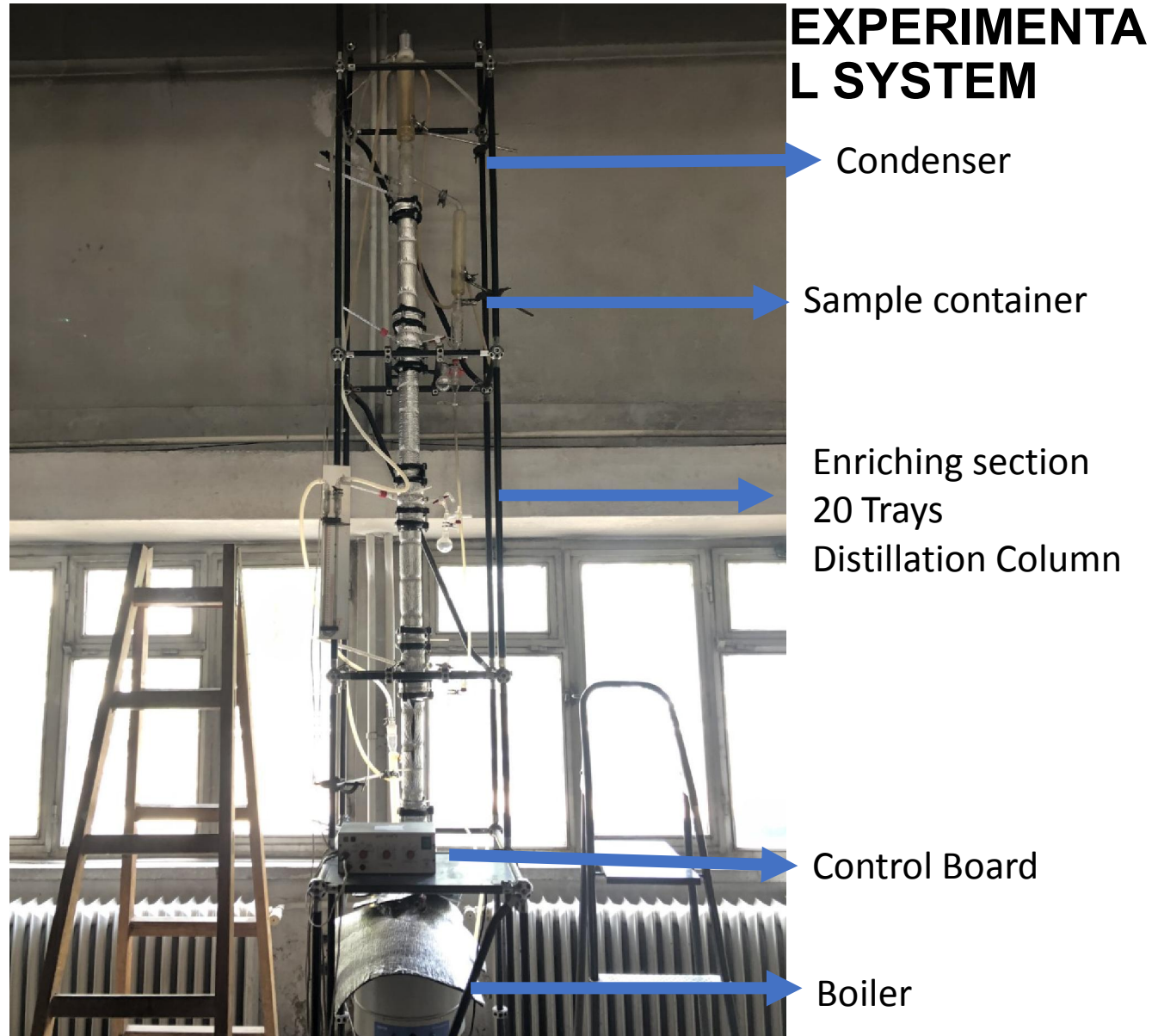
- A mathematical-graphical method for determining the number of theoretical trays or stages needed for a given separation of binary mixture of A and B.

- It intersects the $y=x$ line (45° diagonal line) at $x=x_D$
- The intercept of the operating line at $x=0$ is $y=x_D/(R+1)$
- Operating lines are plotted and two lines intersect on the q line.
- A convenient way to locate the stripping operating line is to first plot the enriching operating line and the q line. Then draw the stripping line between the intersection of the q line and enriching operating line and the point $y=x=x_W$



OBJECTIVE

- Determination of ideal tray number in distillation column
- Calculation of column efficiency
- Calculation of thermal loads



Ethanol Boiling Point?

EXPERIMENTAL PROCEDURE

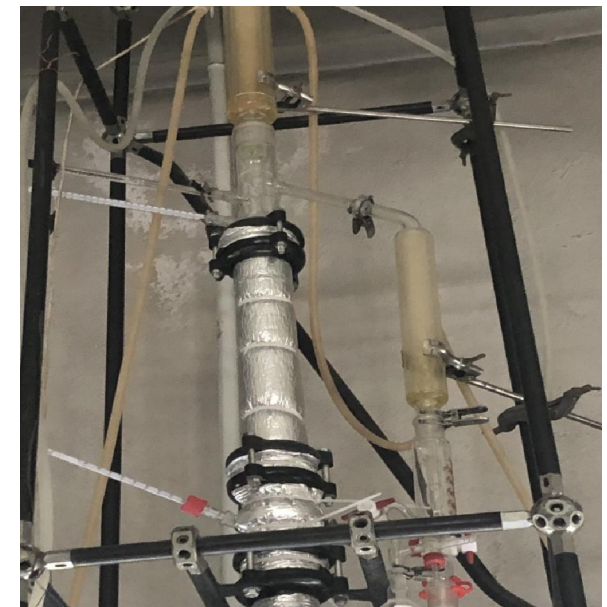


- Start feeding the condenser water.
 - Start heating the mixture in the boiler until it reaches the boiling point.
 - Be sure the ethanol-water mixture with known composition exists in the reboiler.(vol%34)
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- Check the positions of the hose pipes and valves.
 - Check thermometer values to be steady state.

- Set the reflux ratios (R). Allow the column to reach steady-state conditions by waiting 10 minutes after the first liquid drop from the product condenser arrives.
- Determine the distillate flow rate using sample container. (20 mL)



How the flow rate changes for different reflux values?



- Record all temperature and pressure data.
- Repeat the above procedure for different R values.
- Stop heating the boiler.
- Continue to pass the cooling water from the condenser for at least half an hour.

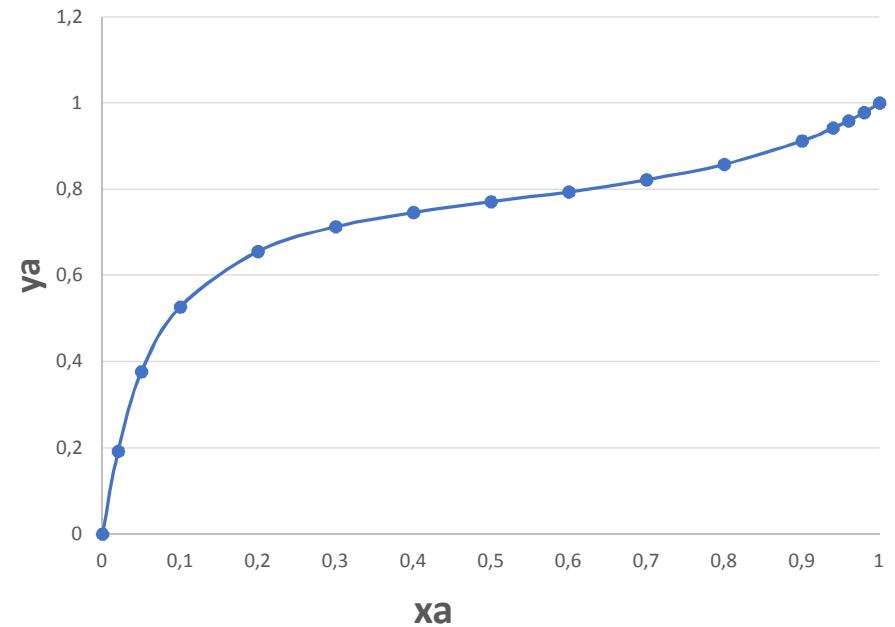
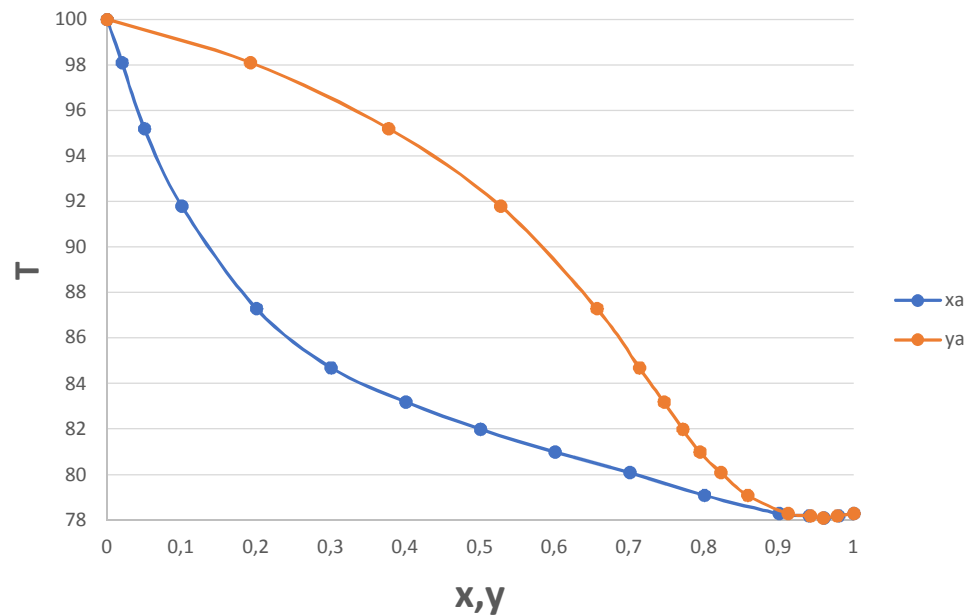


Calculations

- Antoine Equation $\ln P_i^o = A(i) - \frac{B(i)}{C(i)+T}$
- Raoult's Law



Ethanol-Water Equilibrium Data



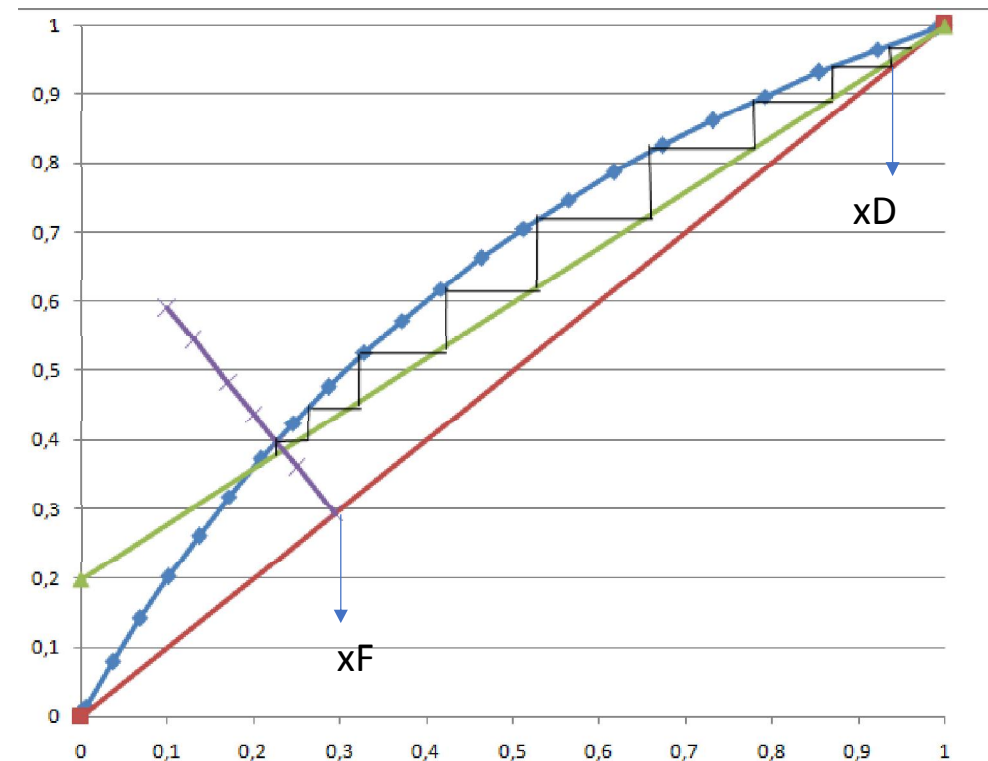
Uysal, B. Z. (2003). *Kütle transferi: esasları ve uygulamaları*. Gazi Üniversitesi.
Geankoplis, C. J. (2011). *Taşınma Süreçleri ve Ayırma Süreci İlkeleri*.

- L_0 and V_{N+1} values are calculated for different R_D values.
- x_D is determined from the equilibrium data for constant temperature.
- x_F is determined using the value of %vol composition.
- Material balance for enriching section is written.

- Enriching operation line is plotted.

$$y_{N+1} = \frac{R_D \cdot (x_N)}{R_D + 1} + \frac{x_D}{R_D + 1}$$

- Q line is plotted.
- Calculate ideal tray number.



- Tray efficiencies = $\frac{N_{ideal}}{N_{actual}}$
- Condenser thermal load = $Q = V_{N+1} * \lambda$
- Calculate the ideal tray number for each of the reflux ratio conditions studied by using McCabe-Thiele method.