Mass transfer

Lecture 04: Distillation

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Learning objectives

- **Understand the general principles behind which distillation works.**
- **Become capable of designing and analyzing flash distillation with respect to (w.r.t.) operating conditions.**
- **Analyze how feed condition, and reflux ratios affect the operation of continuous distillation.**

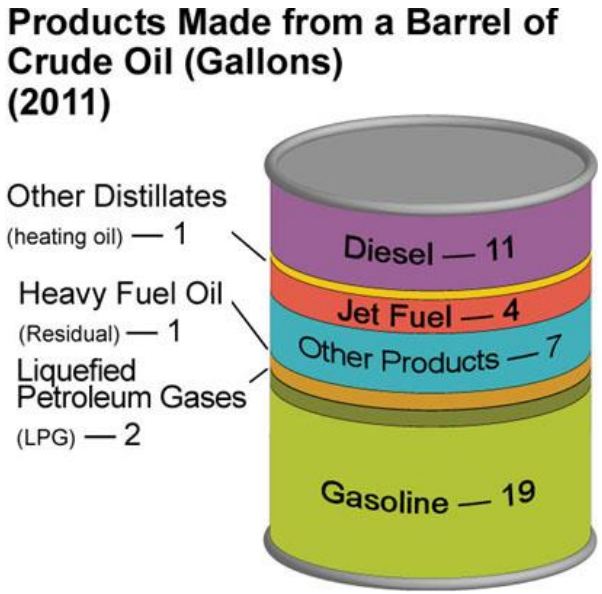
Today's outline

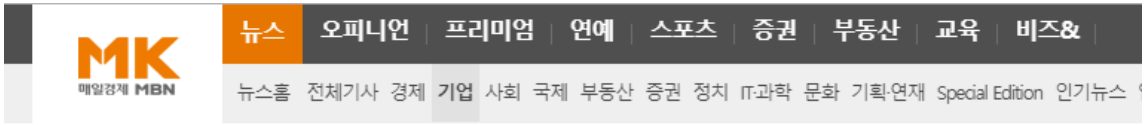
- **Introduction**
  - ✓ Definition, process, and example
  - ✓ Two types
- **Principles of stage processes**
  - ✓ Terminology
  - ✓ Material balances
  - ✓ Number of ideal stages
  - ✓ Absorption factor method for calculating # of ideal stages

21.1 Introduction

- **Definition**
  - ✓ It is a process that separates the components of a liquid mixture by selective boiling and condensation.

- **Examples**
  - ✓ Separation of water from sea water
  - ✓ Distillation of crude oil
  - ✓ Alcohol distillation
  - ✓ Production of sugar from coconut





◆ 샐러리맨 작년 연봉 분석 ◆

`검은 황금(석유)` 업종으로 불리는 정유업계 임직원들이 샐러리맨 `연봉킹` 자리를 지켰다. 지난해 국제유가 급락으로 국내 정유사들의 실적이 전년도와 비교해 나빠졌지만 직원들은 고액 연봉자 지위를 유지했다.

2일 구인·구직 매칭플랫폼 사람인이 지난해 매출액 상위 30대 기업(금융사·사업보고서 미제출 기업 제외) 임직원 연봉을 분석한 결과, SK이노베이션의 정유 부문 자회사 SK에너지 직원들이 평균 1억5200만원을 받아 지난해에 이어 2년 연속 1위에 올랐다. 지난해 매출 35조2억원, 영업이익 8285억원을 기록한 SK에너지는 2017년(매출 29조496억원, 영업이익 1조3475억원)과 비교해 수익성이 악화됐지만 직원 평균 급여는 같은 수준을 유지했다.

직원 평균 근속연수가 긴 데다 직원 다수가 4조 3교대로 근무하는 생산직이라 야근, 휴일 근무 등 각종 수당이 포함돼 급여가 높았다는 분석이다. 지난해 직원 평균 급여부터 미등기임원이 포함된 것도 상당 부분 영향을 미쳤다. 메이저 정유기업에서 일하는 직원은 평균적으로 억대 연봉을 받았다. 에쓰오일(1억3700만원), GS칼텍스(1억2500만원), 현대오일뱅크(1억1500만원) 등 국내 정유사는 모두 직원 평균 급여가 작년보다 증가해 1억원을 웃돌았다. SK이노베이션 평균 연봉도 1억2800만원으로 전년보다 1700만원 늘었다.

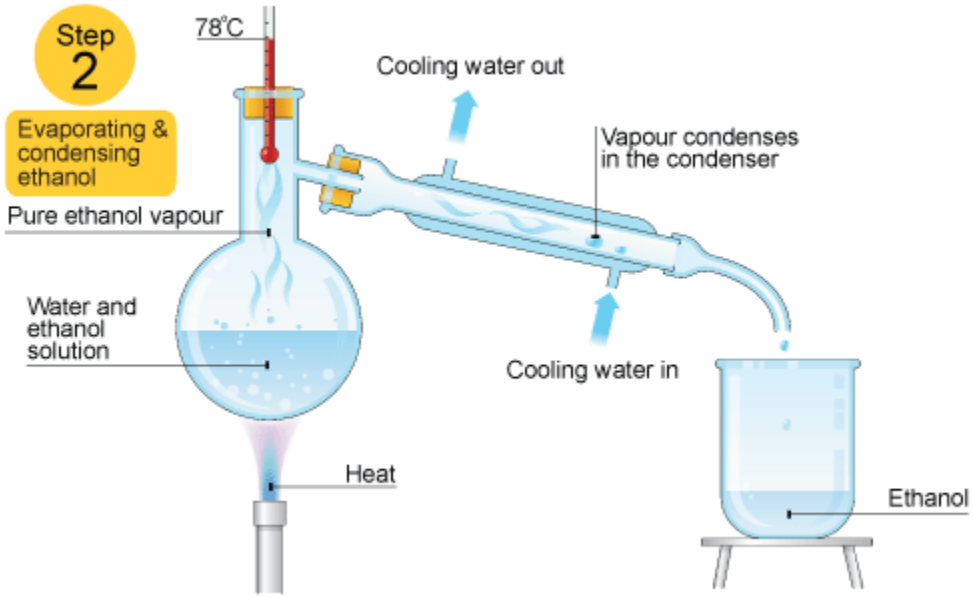
주요 기업 1인 평균 급여액 (단위=백만원)

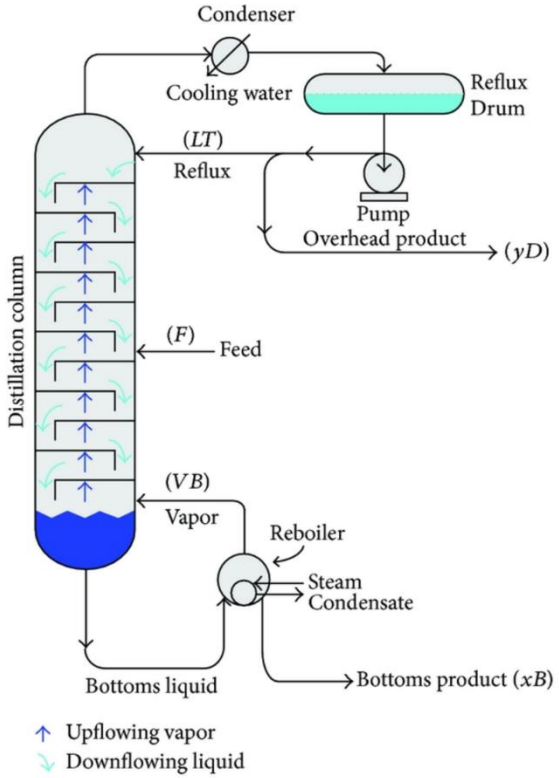
기업	합계	기업	합계
SK에너지	152	기아자동차	90
SK인천석유화학	142	현대모비스	88
SK종합화학	141	LG화학	88
S-Oil	137	현대건설	86
SK이노베이션	128	현대제철	84
GS칼텍스	125	LG전자	83
삼성전자	119	케이티	81
한화토탈	118	한국전력공사	81
SK텔레콤	116	포스코대우	81
현대오일뱅크	115	LG디스플레이	80
SK하이닉스	107	두산	79
롯데케미칼	106	한국가스공사	76
삼성물산	105	현대글로비스	67
포스코	98	한화	66
현대자동차	92	CJ제일제당	57

※ 금융감독원 전자공시시스템에 사업보고서를 제출한 주요 기업 직원 연봉. 자료=사람인

21.1 Introduction

- **It exploits the differences in volatility of the mixture's components.**
  - ✓ The composition in vapor is different from the composition in liquid.





21.1 Introduction

- **Two different types exist w.r.t. the reflux rate.**
  - ✓ Flash *vs* continuous with reflux

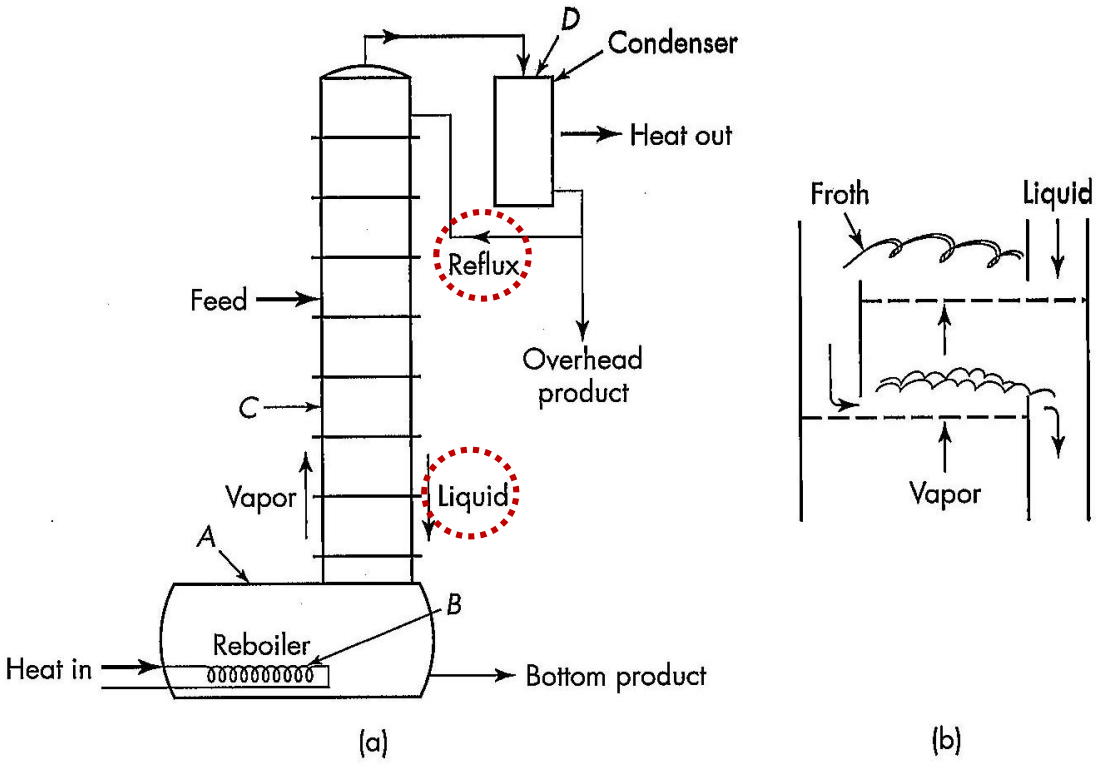
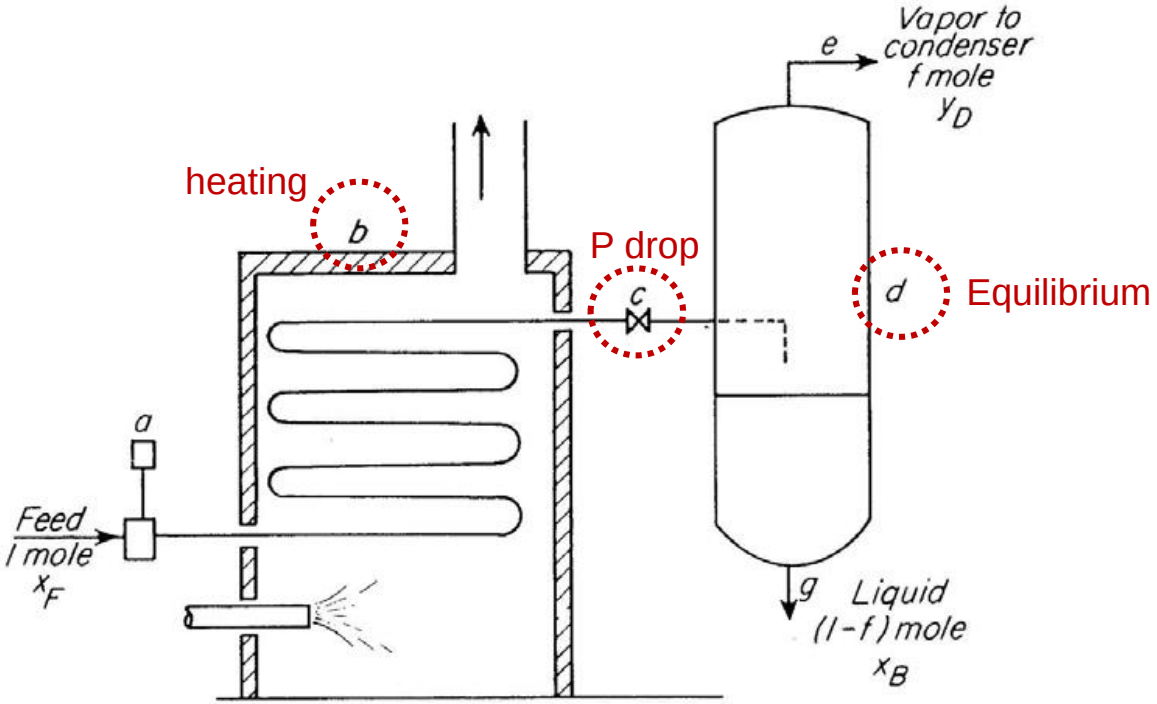


FIGURE 20.1
(*a*) Reboiler with fractionating column: *A*, reboiler; *B*, heating element; *C*, column; *D*, condenser. (*b*) Detail of sieve plate.

21.2 Flash distillation

- **Hypothetical equipment schematic**
  - ✓ material balance eqn.?



  - ✓ flash: partial vaporization that occurs when a saturated liquid stream undergoes a reduction in pressure (why?)

21.2 Material balance

- **For 1 mol of 2-component mixture**

$$x_F = f\ y_D + (1 - f)x_B$$

✓ relative volatility, $\alpha_{AB} = \frac{y_{A_e}/x_{A_e}}{y_{B_e}/x_{B_e}} = \frac{p'_A}{p'_B}$ (eqn. 21.2)

where e represents equilibrium conditions for A or B;

✓ What would α_{AB} equal to for ideal mixtures?

✓ α is nearly constant over the T-range typical to distillation

✓ eqn. 21.2 can be rearranged into y=f(x) for component A:

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

21.2 Energy balance

- **For 1 mol of 2-component mixture**

$$H_F = f\ H_y + (1 - f)H_x$$

Ex. 21.1 A mixture of 50 mol% benzene and toluene is subjected to flash distillation at a separator pressure of 1 atm. The incoming liquid is heated to a temperature that will cause 40% to flash. (**In-class**)

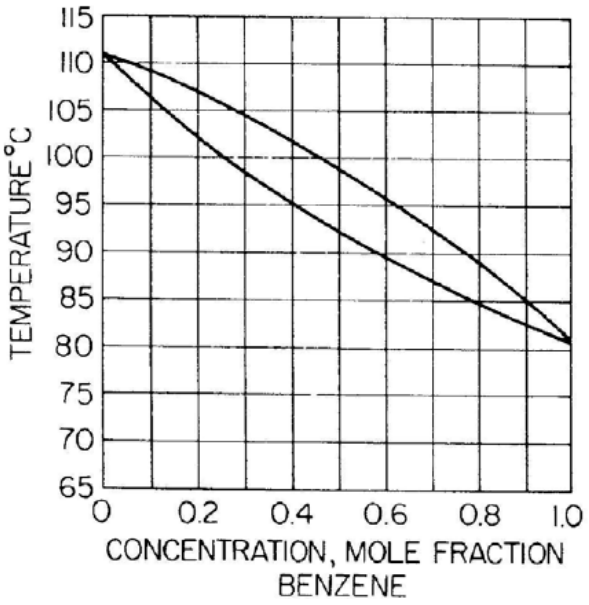
(a) Calculate x_i, y_i in the flows leaving the column.

(b) What is the required feed temperature?

$\alpha_{AB} = 2.45,$

$C_{p,benzene} = 33\ \frac{cal}{mol\ ^{o}C}, C_{p,toluene} = 40\ \frac{cal}{mol\ ^{o}C}$

$\Delta H_{vap,B} = 7{,}360\ \frac{cal}{g\ mol}, \Delta H_{vap,T} = 7{,}960\ \frac{cal}{g\ mol}$



Doosan wins $422m Saudi desalination plant contract

01-04-2017

Leading South Korean group Doosan Heavy Industries & Construction Company said it has secured a 470 billion won ($422.05 million) construction contract for a seawater reverse osmosis desalination (SWRO) plant in Saudi Arabia.

The contract for building the nation's largest SWRO plant in Shuaibah, 110 km south of Jeddah, on the coast of Red Sea, was awarded by Saudi Arabia's Saline Water Conversion Corporation (SWCC), reported *Business Korea*.

As per the deal, Doosan Heavy will complete the construction of the plant as the engineering, procurement, and construction (EPC) contractor.

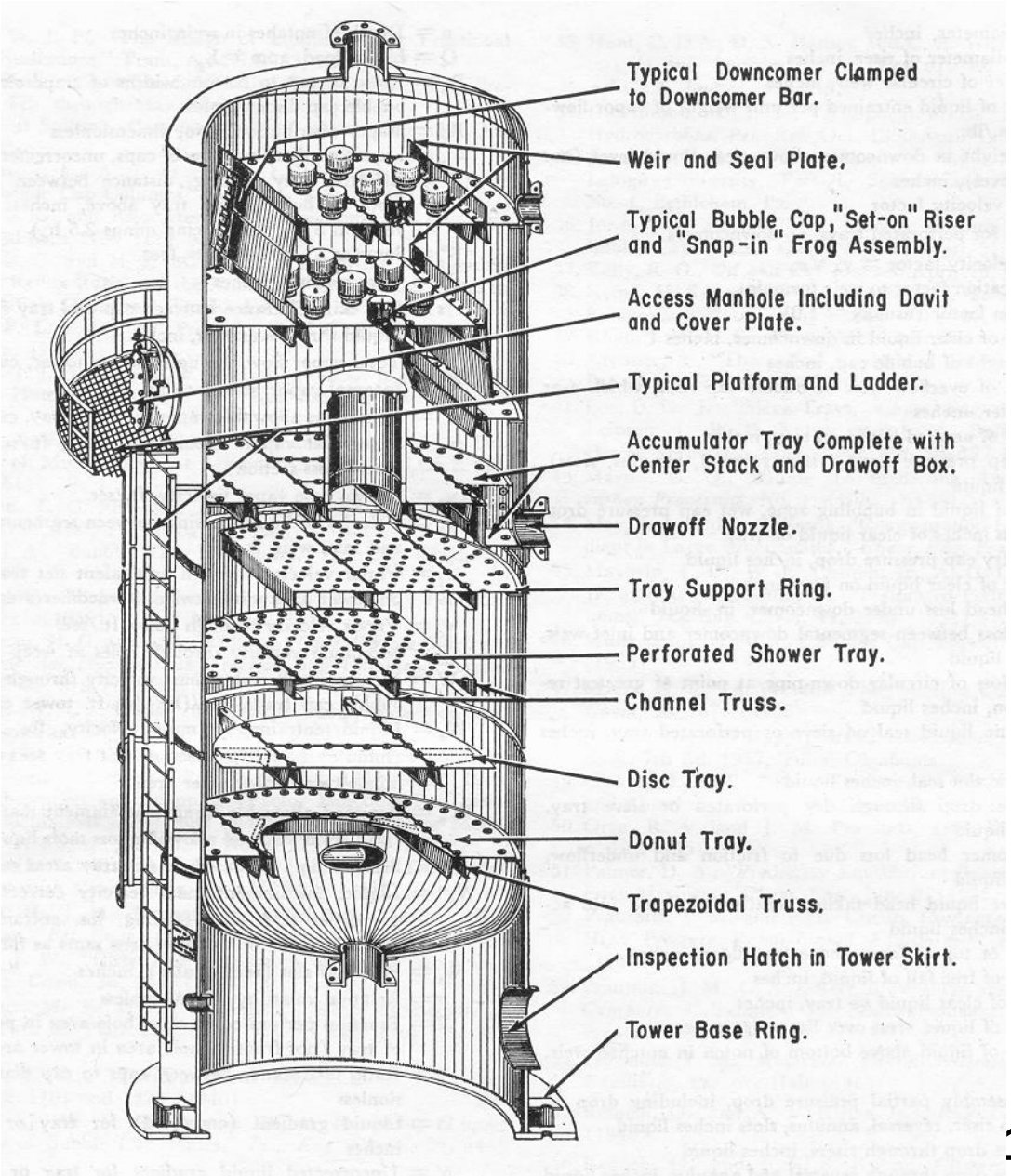
Once the facility is completed, it will process 400,000 tonnes of sea water into fresh water a day, to meet the requirements of 1.3 million people, and supply it to western Saudi Arabia.

With the latest deal, the Korean group has re-entered the Saudi Arabian seawater desalination market after five long years, stated the report.

The company had last worked on the desalination plant project at Ras Al Khair in 2010 and Yanbu seawater desalination plant Phase Three deal in 2012, it added.

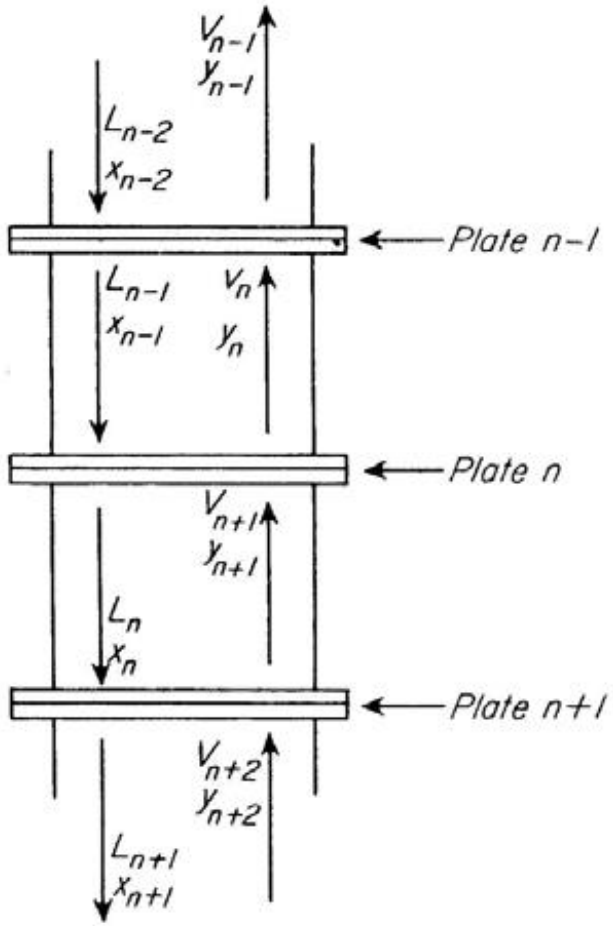
21.3 Continuous w/ reflux

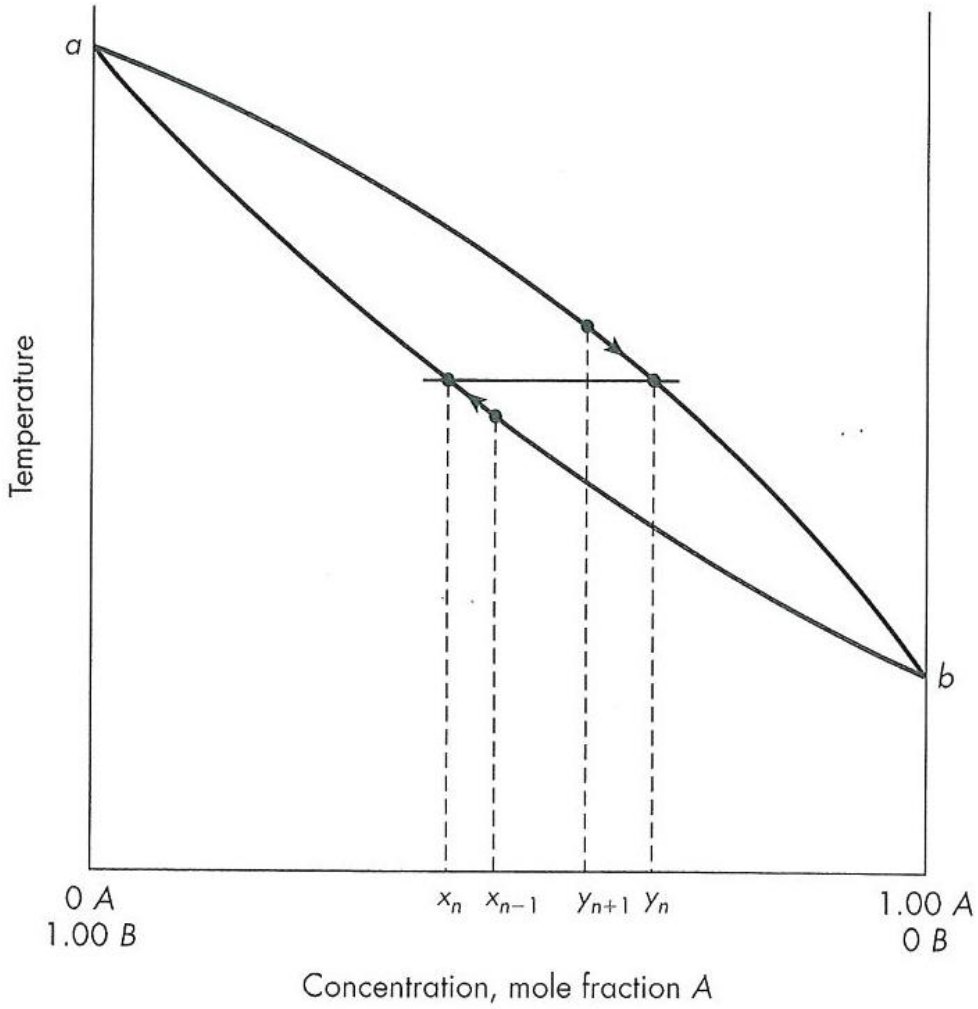
- **It can be used to separate molecules with comparable volatility.**
- **Continuous is far more common than the batch mode. (why?)**



21.3 Boiling point diagram

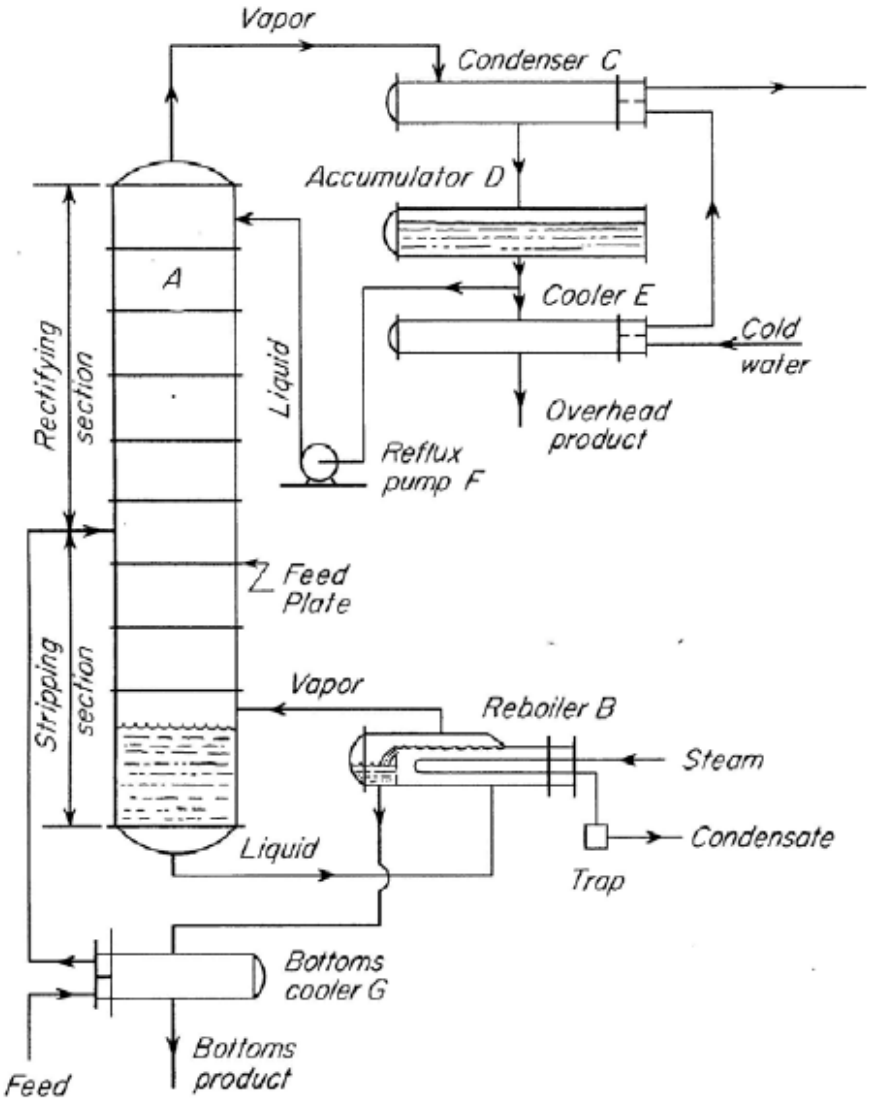
- **[A] increases as you reach the top of the column.**





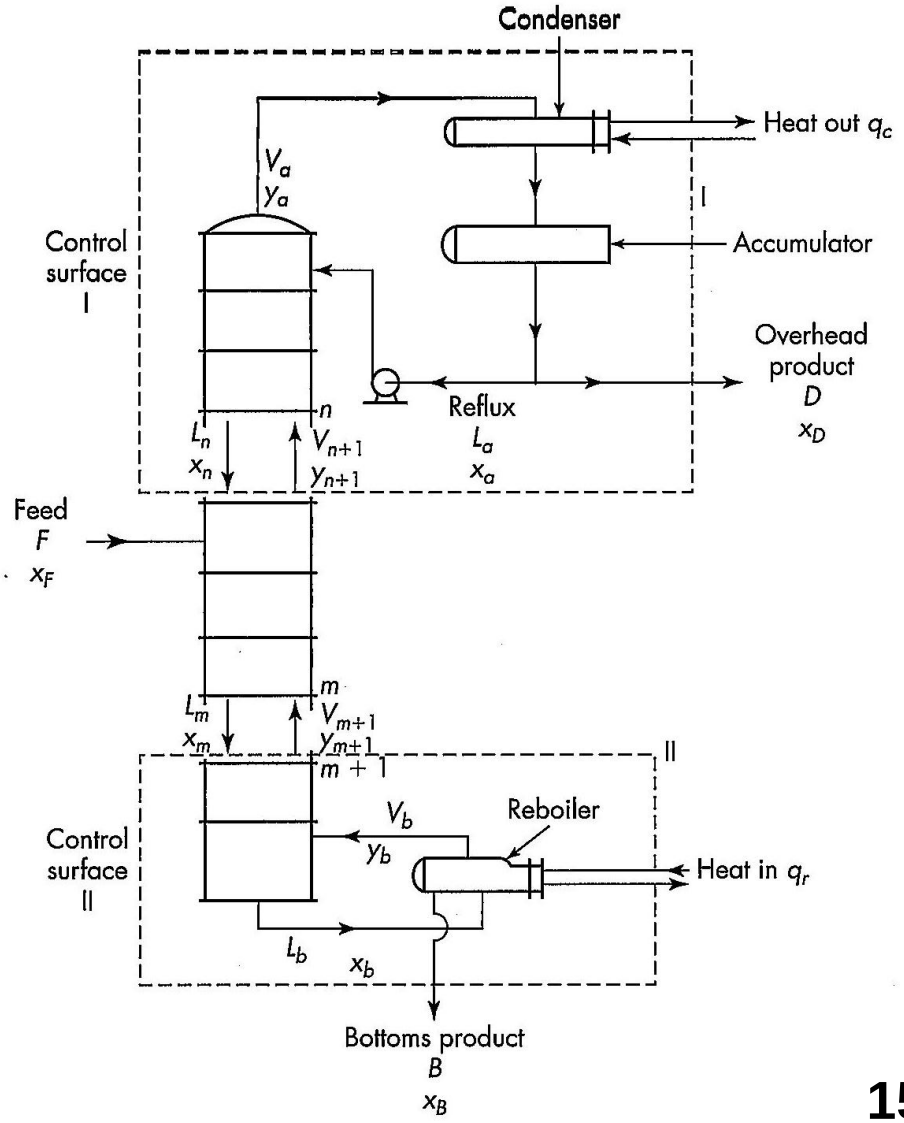
21.3 Typical configuration

- **Terminology**
  - ✓ feed plate
  - ✓ rectifying section
  - ✓ stripping section (includes the feed plate)
  - ✓ reboiler
  - ✓ weir
  - ✓ condenser
  - ✓ accumulator
  - ✓ reflux
  - ✓ product cooler



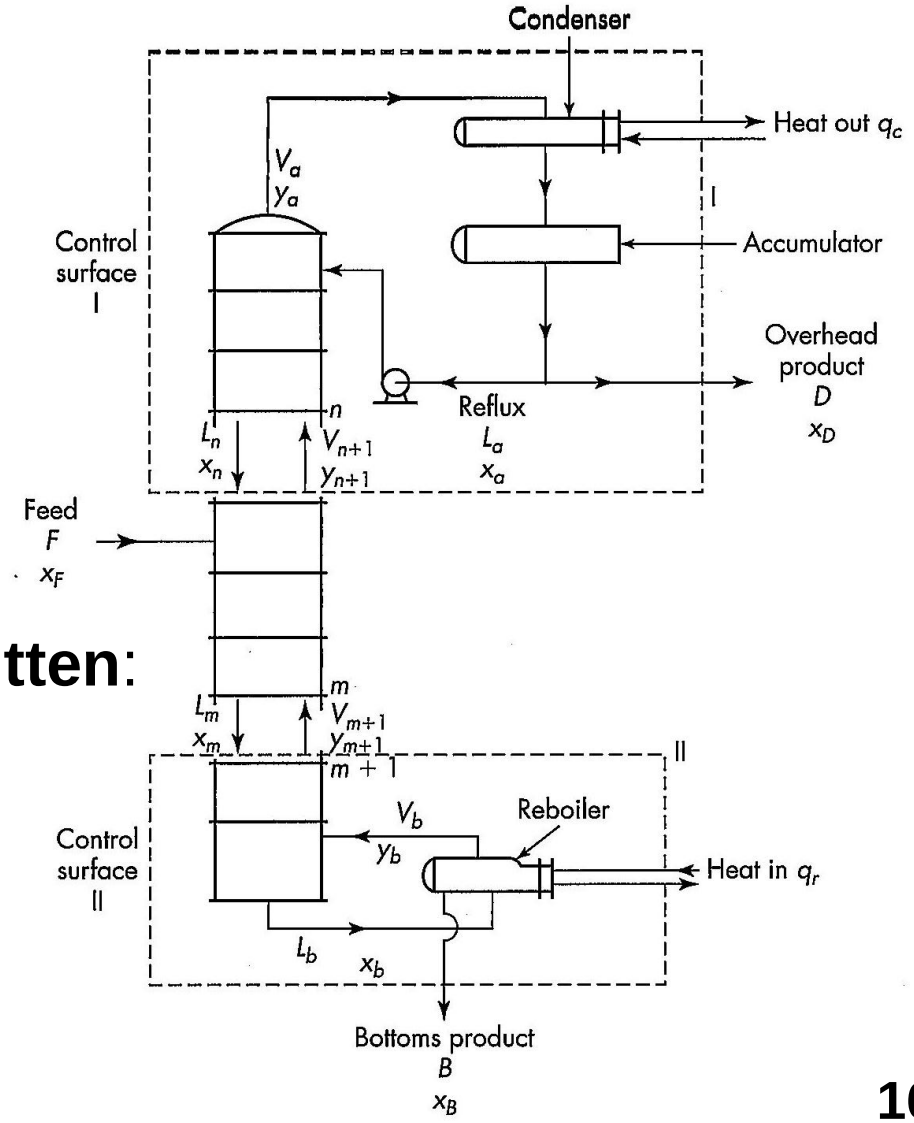
21.3 Material balance

- **Overall material balance for a 2-component system**
  - ✓ $\mathrm{F} = D + B$
  - ✓ For component A,
    $F\ x_F = D\ x_D + B\ x_B$
  - ✓ Eliminating D or B gives,
    $\frac{D}{F} = \frac{x_F - x_B}{x_D - x_B}$ or $\frac{B}{F} = \frac{x_D - x_F}{x_D - x_B}$



21.3 Operating lines

- **Net flow rates can be calculated as follows:**
  - ✓ MB around the condenser:
    $V_a = L_a + D$
  - ✓ In the upper control volume,
    $V_{n+1} = L_n + D$
  - ✓ In the lower control volume,
    $L_m = V_{m+1} + B$



- **Operating lines can be rewritten**:
  - ✓ In the upper or lower section,

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

$$y_{m+1} = \frac{L_m}{L_m-B} x_m - B \frac{x_B}{L_m-B}$$

21.3 Reflux ratio

- **It facilitates the analysis of the columns:**
  - ✓ two ratios are used:

    $R_D = \frac{L}{D} = \frac{V-D}{D}$ and $R_V = \frac{L}{V} = \frac{L}{L+D}$

  - ✓ For constant molar overflow (L and V), the op line for the upper is

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

  - ✓ What if n = D?

21.3 Effect of feed condition

- **Feed condition affects the molar flows:**

$$q = \frac{\text{heat needed to evaporate 1 mol of feed at entering conditions}}{\text{molar latent heat of vaporization of feed}}$$

$$= \frac{H_V - H_F}{H_V - H_L} = \frac{(H_V - H_L) + (H_L - H_F)}{H_V - H_L} = 1 + \frac{H_L - H_F}{H_V - H_L}$$

Hv: enthalpy at the dew point
H_F: enthalpy of feed at the entrance
H_L: enthalpy at the boiling point

✓ physical meaning of q?

✓ which will be which? q=?

partial vapor
cold liquid
saturated vapor at dew pt
saturated liquid at bubble pt
superheated vapor