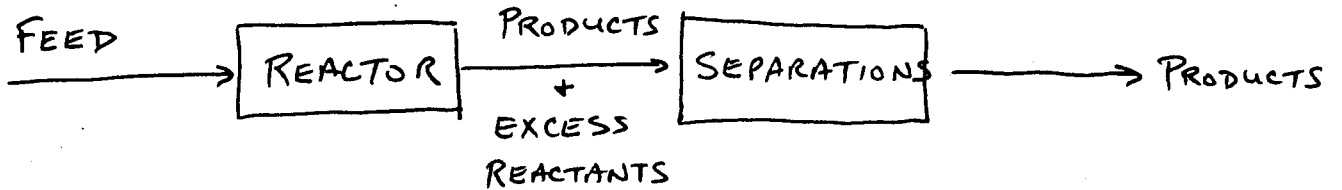


SEPARATION PROCESSES :

CHAPTER ONE :

TYPICAL CHEMICAL PROCESS

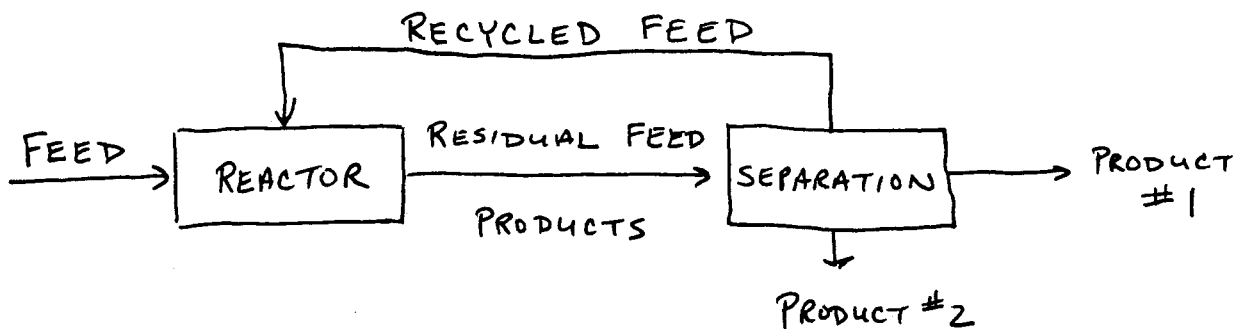


- LARGE SCALE
- ECONOMICAL

EXAMPLES :

- 1) DISTILLATION
- 2) ABSORPTION
- 3) LIQ-LIQ EXTRACTION
- 4) ADSORPTION
- 5) MEMBRANES
- 6) CRYSTALLIZATION

OPERATION : CONTINUOUS, SEMI-CONTINUOUS, BATCH



PROCESSES WITH ONLY REACTION

- complete reaction
- stoichiometric feed
- no side reactions
- no catalyst

PROCESSES WITH ONLY SEPARATION

- clean stream
- low purity products ok (enriched air)
- phase separation

NOT VERY COMMON \rightarrow USUALLY HAVE BOTH.

MIXTURES :

\rightarrow In general very stable

Why?

more disorder \Rightarrow entropy increases

WHY ARE SEPARATIONS DIFFICULT (AND EXPENSIVE)?

③

SEPARATION \Rightarrow ENTROPY \downarrow

(THERMODYNAMICALLY UNFAVORABLE)

\Rightarrow ADD ENERGY \Rightarrow \$\$\$

MECHANISMS FOR SEPARATION OF MIXTURES:

① PHASES

\rightarrow CREATE MORE THAN ONE PHASE

\rightarrow COMPOSITION IN EACH PHASE DIFFERENT

i.e., $x_i \neq y_i$

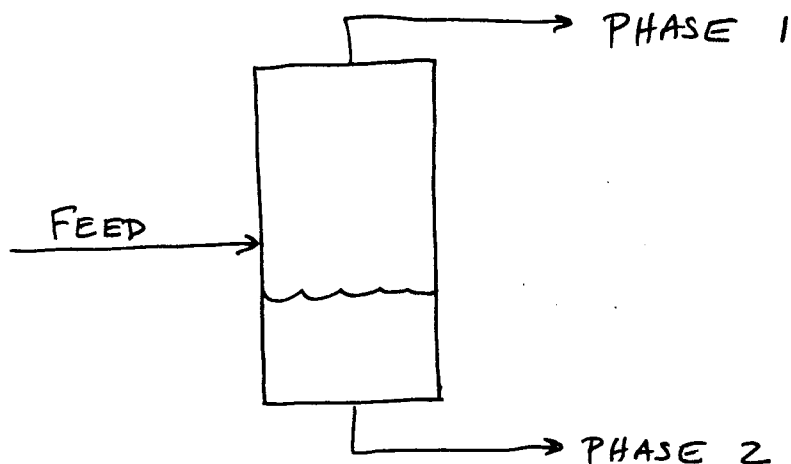
(GOVERNED BY THERMODYNAMIC EQUILIBRIUM)

\rightarrow SEPARATE PHASES

\rightarrow GENERATE 2 STREAMS, EACH WITH COMPOSITION DIFFERENT FROM FEED.

EXAMPLES: 1) DISTILLATION } (VLE)
2) ABSORPTION }
3) CRYSTALLIZATION (SLE)

④



② MASS SEPARATING AGENT

→ ADD 3RD COMPONENT (USUALLY NEW PHASE)

→ MASS TRANSFER TO NEW PHASE

EG.: LIQ PHASE → LIQ PHASE (EXTRACTION)

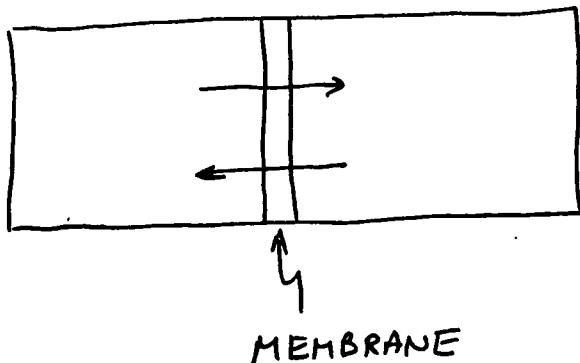
LIQ/GAS PHASE → SOLID PHASE (ADSORPTION)

→ IN ALL CASES WANT GOOD CONTACT BETWEEN PHASES

⇒ MIXING IN LLE

⇒ LARGE SURFACE AREA FOR SOLIDS

③ BARRIER (MEMBRANES)



SELECTIVE TRANSPORT
ACROSS MEMBRANE

④ SOLID AGENT (~ PACKED BEDS)

→ ACTIVATED CARBON (ORGANICS IN H_2O)

→ ION EXCHANGE (IONS)

⑤ FORCE FIELD OR GRADIENT

→ IMPOSED ELECTRIC FIELD (LIQ)

→ VELOCITY GRADIENT (LIQ)

→ PRESSURE (CENTRIFUGE) (VAPOR)

→ ELECTROPHORESIS (LIQ)

EVALUATING THE SEPARATION (HOW WELL ARE YOU DOING?)

- ① RATE OF SEPARATION (MASS TRANSFER)
 - GOOD CONTACT
 - T, P, COMPOSITION
 - PHASE (GAS, LIQ, SOLID)
- ② EXTENT OF SEPARATION (THERMODYNAMICS)
 - DIFFERENCES BETWEEN MOLECULES
 - INTERACTIONS

TO GET A SEPARATION, LOOK FOR ASPECTS THAT YOU CAN EXPLOIT (PROPERTY DIFFERENCES)

① MOLECULAR PROPERTIES

MOLECULAR WEIGHT, POLARIZABILITY, DIELECTRIC CONSTANT, ELECTRIC CHARGE, MOLECULAR SHAPE, RADIUS OF GYRATION, DIPOLE MOMENT

② THERMODYNAMIC PROPERTIES

VAPOR PRESSURE, ADSORPTIVITY, SOLUBILITY, DIFFUSIVITY

MORE ON MECHANISMS OF SEPARATION

⑦

① PHASE ADDITION / CREATION

Ⓐ ENERGY SEPARATION AGENT (ESA)

→ HEAT TRANSFER (VAPORIZATION)

→ SHAFT WORK (COMPRESSION)

→ LOWER PRESSURE (CONDENSATION)

Ⓑ MASS SEPARATION AGENT (MSA)

→ LIQUID (CLEAN SOLVENT)

→ VAPOR (CLEAN AIR)

→ SOLID (ION EXCHANGE RESIN,
MOLECULAR SIEVES)

EXERCISE:

SEPARATIONS THAT UTILIZE THIS MECHANISM
(ESA OR MSA, HOW IS PHASE ADDED / CREATED?)

Ⓐ SIMPLE (ONE STAGE)

PARTIAL VAPORIZATION OR FLASH DISTILLATION

Ⓑ BETTER PURITY (MULTIPLE STAGES)

DISTILLATION ← MOST POPULAR IN INDUSTRY

⑧

① NOT EASY TO CONDENSE (DILUTE COMP. IN AIR)
ABSORPTION

② DILUTE COMPONENT IN LIQUID (+ VOLATILE)
STRIPPING

③ AZEOTROPE OR TEMPERATURE SENSITIVE
AZEOTROPIC DISTILLATION AND EXTRACTION

④ VERY PURE SOLID PRODUCT
CRYSTALLIZATION

⑤ BARRIERS - MEMBRANE

- REVERSE OSMOSIS (IONS), PERVAPOARATION
(ORGANICS, DEHYDRATION), ULTRAFILTRATION, GAS

⑥ SOLID AGENTS - GENERALLY BATCH OR SEMI-
CONTINUOUS

(FINITE CAPACITY)

- ADSORPTION

→ LOW CONCENTRATION OF COMPONENT TO BE
REMOVED

9

- CHROMATOGRAPHY

→ PACKED COLUMN

→ COLLECT AS FRACTIONS

→ RATE THROUGH COLUMN DIFFERS

- ION EXCHANGE

→ CHARGED SPECIES

④ EXTERNAL FIELD OR GRADIENT

- CENTRIFUGE

→ MOLECULAR WEIGHT DIFFERENCE

- ELECTRODIALYSIS

→ APPLIED ELECTRIC FIELD + MEMBRANE

- ELECTROPHORESIS

→ APPLIED ELECTRIC FIELD

- FIELD FLOW FRACTIONATION

→ PARTICLE SEPARATION

ACCOUNTING IN SEPARATIONS

⇒ CONSERVATION OF MASS

HOWEVER, SINCE NO REACTION, MOLES CONSERVED,

NOTE: WE WILL USE MATERIAL BALANCES EXTENSIVELY
IN THIS COURSE (CHE 254).

⇒ MOLE FRACTIONS USED COMMONLY

⇒ BEST TO WORK WITH THESE UNLESS OTHERWISE
STATED.

SELECTING YOUR SEPARATION PROCESS:

→ IN GENERAL GOVERNED BY ECONOMICS

ALSO: A) FEED CONDITIONS

COMPOSITION, FLOW RATE, T, P, PHASE

B) PRODUCT CONDITIONS

PURITY, T, P, PHASE

C) PROPERTY DIFFERENCES THAT CAN BE
EXPLOITED: MOLECULAR, THERMO, TRANSPORT

D) CHARACTERISTICS OF SEPARATION OPERATION

E.G.: SCALE-UP, STAGING, T, P, PHASE,
SIZE LIMITATIONS, ENERGY REQUIREMENTS.

MOST COMMON:

T, P, PHASE

WHY? CAN BE ALTERED EASILY

A) FEED CONDITIONS

1) COMPOSITION

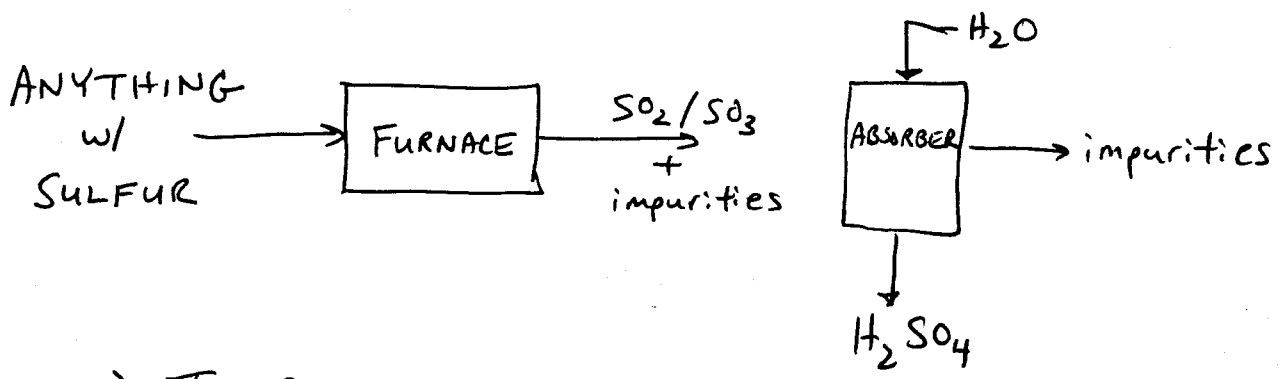
a) LOW CONCENTRATION SPECIES OF INTEREST

→ ADSORPTION

→ MEMBRANES

b) QUALITY OF FEED

→ EXAMPLE: H_2SO_4 PRODUCTION



c) TEMPERATURE SENSITIVE

→ SOLVENT EXTRACTION

→ E.G.: AROMATICS + SULFUR FROM KEROSENE

OIL FROM SEEDS (+ FLAVORINGS)

↑ SOLID-LIQ EXTRACTION

2) FLOW RATE

a) LARGE FLOW RATES

⇒ DISTILLATION

⇒ ABSORPTION

(PACKED BED WOULD BE BAD. WHY? LARGE ΔP)

b) SMALL FLOW RATES

⇒ MEMBRANES

⇒ ADSORPTION

⇒ BATCH SEPARATIONS

3) TEMPERATURE

a) HEAT OF VAPORIZATION (\$\$)

⇒ DISTILLATION

⇒ MEMBRANES (SOME)

b) COOLING (\$\$)

⇒ CRYSTALLIZATION

4) PRESSURE

→ DISTILLATION (~ ATMOSPHERIC PRESSURE)

→ MEMBRANE (SEA WATER DESALINATION)

→ EXTRACTION

5) PHASE STATE

a) GAS

→ ADSORPTION

→ ABSORPTION

b) LIQUID

→ EXTRACTION

→ DISTILLATION

c) SOLID

→ EXTRACTION

B) PRODUCT CONDITIONS

→ HOW GOOD DO YOU HAVE TO DO?

→ WHAT CONDITIONS?

1) PURITY

a) HIGH

→ EXTRACTION

→ ADSORPTION

b) LOW

→ MEMBRANES

2) TEMPERATURE

AVOID HEATING / COOLING UNNECESSARILY

3) PRESSURE

→ AVOID PACKED BEDS

→ MEMBRANES → KEEP SPECIES OF INTEREST
ON FEED (HIGH PRESSURE) SIDE

E.G.: FUEL CELL + H_2/CO_2

SELECTIVELY TRANSPORT CO_2 ACROSS MEMBRANE
TO AVOID NEED FOR REPRESSURIZATION OF H_2

4) PHASE

→ PRODUCT IN CORRECT PHASE

C) PROPERTY DIFFERENCES TO BE EXPLOITED

1) RELATIVE VOLATILITY

⇒ DISTILLATION

2) SOLUBILITY

⇒ CRYSTALLIZATION, ABSORPTION, EXTRACTION

3) SPECIFIC INTERACTIONS

⇒ ADSORPTION, CHROMATOGRAPHY

4) SIZE / MASS

⇒ MEMBRANES, CENTRIFUGATION

5) DENSITY

⇒ FLOTATION

D) CHARACTERISTICS OF SEPARATION OPERATION

(15)

1) EASE OF SCALE-UP

- a) EASIEST: DISTILLATION, ABSORPTION
- b) NEXT EASIEST: EXTRACTION, MEMBRANES
- c) HARDEST: ADSORPTION, CRYSTALLIZATION

ECONOMY OF SCALE \Rightarrow SIZE \uparrow
\$\$/VOLUME \downarrow

(TRUE FOR DISTILLATION, ABSORPTION)

NOT TRUE FOR MEMBRANES \Rightarrow SIZE \uparrow
\$\$/VOLUME CONSTANT

WHY? PARALLEL UNITS VS. ONE LARGER UNIT
(MEMBRANES) (DISTILLATION)

2) EASE OF STAGING

COLUMN VS. MODULE

NEED FOR REPRESSURIZATION

3) T, P, COMPOSITION (LIKE BEFORE)

4) SIZE

E.G.: NAVY SHIP \Rightarrow LIMITED SPACE

EXISTING PLANT \Rightarrow LIMITED SPACE

5) ENERGY

⇒ PHASE CHANGE

⇒ UTILITIES (LOCATION)

(16)

OTHER FACTORS:

1) DILUTE PRODUCT ⇒ HIGHER SELLING PRICE
TO BE SEPARATED

⇒ CAN USE EXOTIC SEPARATION (PHARMACEUTICALS)

2) HIGH PURITY ⇒ LARGE # OF STAGES

3) SCALABILITY

SMALL OR BATCH ⇒ MORE EXOTIC

LARGE ⇒ TRADITIONAL

4) MATURITY (+ COMFORT LEVEL)

MOST MATURE

DISTILLATION

ABSORPTION

EXTRACTION

ADSORPTION

ION EXCHANGE

CRYSTALLIZATION

MEMBRANES

CHROMATOGRAPHY

MOST USED

LEAST MATURE

AFFINITY SEPARATIONS

LEAST USED