Separation Processes

ChE 4M3

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- if you let us know about **any errors** in the slides
- **any suggestions to improve the notes**

All of the above can be done by writing to

`kevin.dunn@mcmaster.ca`

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If reporting errors/updates, please quote the current revision number: 174

From the previous class

- We covered the admin issues
- Grading
- And in particular what is appropriate group work

Overview of Separation Processes

- Why study separation processes?
- Economics of separation processes
- Some everyday examples
- Example flowsheet: Sugar production
- Separating agents
- Classification of separation processes

Why separate?

- Can't beat Nature: "Second Law of Thermodynamics"
  - salt left in water
  - CO_2 pumped into the atmosphere
  - pollutants dumped into water
  - your house / condo / apartment
- Things seldom separate out for us in the desired way, unless we put in some form of work or add another material
- "No free lunch"

How to separate salts from water

- electrodialysis
- electrodeionization
- evaporation through heating with condensation
- evaporation under vacuum
- freezing to form ice crystals
- reverse osmosis
- ion exchange
- apply pressure and force it through a membrane that delays (filters out) salts

Reference: King, p 16

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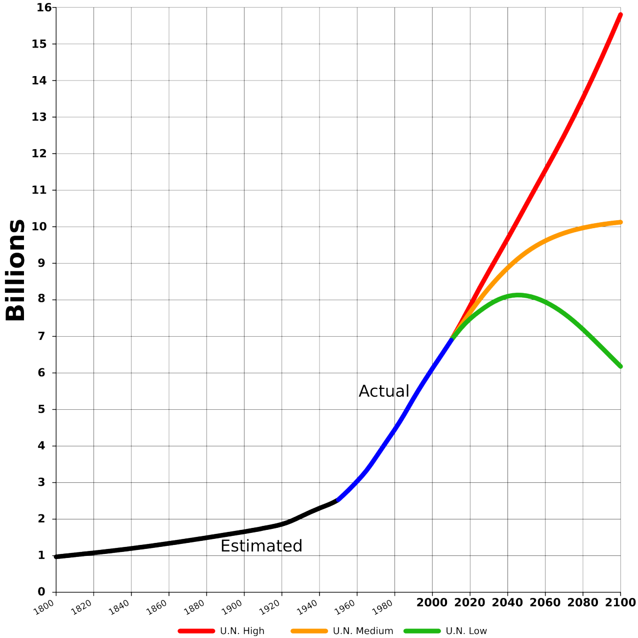
Why study separation processes?

- 50% to 90% of capital investment on petroleum and other chemical-reaction based flowsheets [King, p 15]
  - Expense often in proportion to the level of purity (called the separation factor) [Treybal, p 2]
- 60 to 100% of the ongoing operating costs in chemical plants
- Some important problems facing (the global) "us" are **separation problems**:
  - carbon capture and sequestration/storage (CCS) ... don't forget about methane
  - other air pollutants (e.g. cleaning small dust particles $\sim 5\mu$m)
  - access to clean water/sanitation

These problems will be an important part of your career, and impact your life, as the world's population approaches 8, 9 and then 10 billion in our lifetime (expected around 2050 to 2080).

World population: UN projections



Everyday examples

Separation processes at home:

- screening: sieve to strain water from pasta
- absorption: washing dishes/hands (fat dissolves into non-polar branch)
- liquid/liquid extraction: soak spices in oil to extract flavour
- cyclone: vacuum cleaner
- filtering: vacuum cleaner; furnace filter
- leaching: coffee/espresso maker
- leaching: making tea
- adsorption: water filter
- centrifugation: clothes washing machine
- phase change by heat addition: clothes drier
- phase change by heat removal: dehumidifier

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Everyday examples

Separation processes in your body:

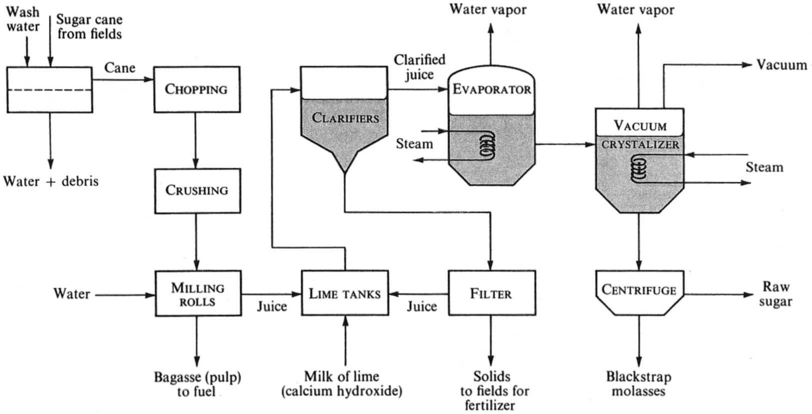
- kidneys: separates waste from blood; reabsorbs water and salts back into blood
- lungs: release of CO_2 from blood
- liver: breaks down toxins, excreted into bile
- gallbladder: concentrates bile
- intestines: absorb nutrients
- spleen: removes old red blood cells
- lymph nodes: filter foreign particles (e.g. cancers)

Engineering example

A common, everyday substance: sugar [King, p 2 to 9]

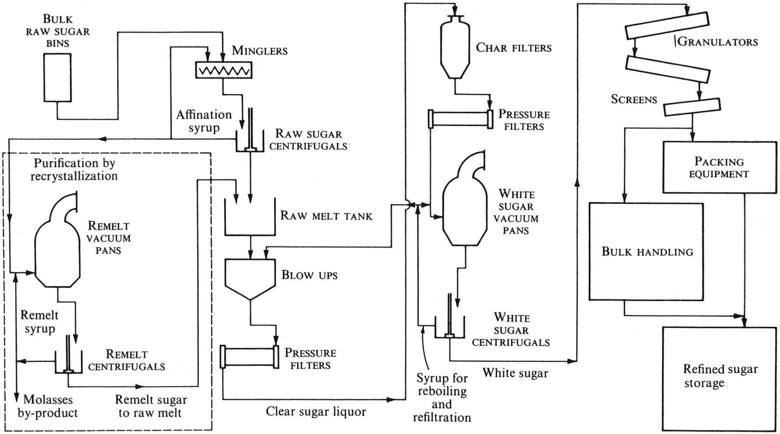
Video http://www.youtube.com/watch?v=ZBOou6cahtw

Sugar flowsheet (part 1)



Source: C.J. King, Separation Processes

Sugar flowsheet (part 2)



Source: C.J. King, Separation Processes

Topics that you want to cover

Based on the class activity yesterday, from highest to lowest:

5 Distillation, including rectification, flash, divided-wall columns

4 Membranes, including reverse osmosis

3 Filtration (various types: regular, ultra-, nano-)

3 Various types of water treatment

2 Centrifuges

2 Carbon capture and sequestration

1 Crystallization

1 Chromatography

1 Scrubbers (gas/solid/liquid)

1 Flotation

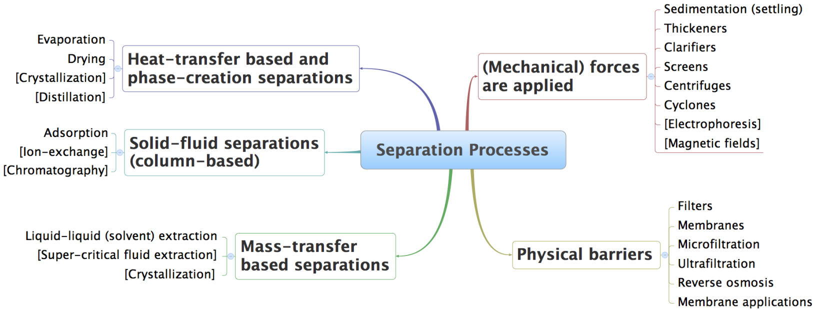
1 Liquid-liquid extraction

1 Electrostatic precipitation

How this course is structured

- We aim to consider a variety of separation systems
- Solids and (liquids and gases) = fluids
- Cover unit operations that rely on:
  - mechanical techniques to separate
  - mass transfer
  - phase creation or addition
  - heat transfer

Current plan for 4M3 in 2013



Bioseparations

- Many of the topics we will cover are part of a pure bioseparations course
- Often called "downstream" processing in the bio literature
- Only difference: they are operated under "bio-compatible" conditions: T, P, pH, aqueous media
  - i.e. all unit operations downstream of the bioreactors
- Unit operations include:
  - cell disruption: increase entropy!
  - centrifugation $*$
  - precipitation
  - adsorption and chromatography $*$
  - filtration $*$
  - membrane separation $*$
  - electrophoresis

$*$ = a topic we will cover in `4M3`

In this regard, you can see bioprocess separations are naturally designed and operated by chemical engineers.

How this course is structured

For each unit operation we consider

- the physical principle that causes separation
- basic concepts to size the unit and specify it; scale-up issues
- issues that affect the unit's cost
- troubleshoot problems with the unit
- how to optimize it (e.g. use less energy, increase separation efficiency, modify an existing unit's purpose)

Tutorial question: another way of looking at separations

Fill in various separation processes in these 9 rectangles:

		Minor component		
		Solid	Liquid	Gas/Vapour
Major component	Solid			
	Liquid			
	Gas/Vapour			

Separating agents: MSA and ESA

A material, force, or energy source applied to the feed for separation

i.e. what you add to get a separation. MSA = mass separating agent and ESA = energy separating agent

- heat (ESA)
- liquid solvent (MSA)
- pressure (ESA)
- vacuum
- membrane
- filter media
- electric field
- temperature gradient
- gravitational field (natural, or artificially created)
- adsorbent
- absorbent

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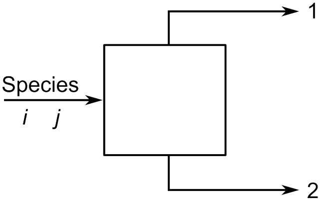
Separation factor

As mentioned, we will introduce a number of important principles we will re-use later.

Separation factor

$$S_{ij} = \frac{x_{i,1}/x_{j,1}}{x_{i,2}/x_{j,2}}$$



- select i and j so that $S_{ij} \geq 1$
- units of x terms in the above equation can be mass or mole fractions (or flows)
- any units can be used, as long as you are consistent

Based on this definition: we can see why solid-fluid separations often have high separation factors