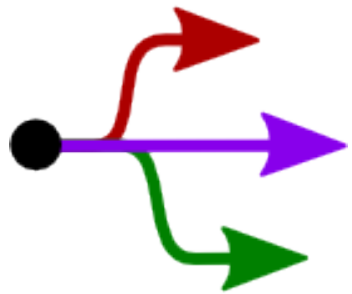
Separation Processes

ChE 4M3



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http://learnche.mcmaster.ca/4M3

Overall revision number: 110 (November 2012)

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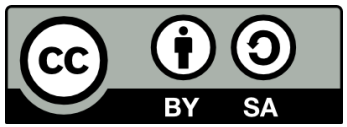


We appreciate:

- 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

If reporting errors/updates, please quote the current revision number: 110

Plan for today's class

1. Background
2. Administrative issues
3. Short brainstorming session of topics to cover
4. Course content (Friday's class)

Credits

- Dr. Santiago Faucher
  - Taught the course in 2009, 2010 and 2011
  - Course outline and topics covered are similar to his
- Dr. Raja Ghosh, taught 4M3 for a few years prior to that
- Dr. Jim Dickson, taught the course since 1984

Background

About myself

- Undergraduate degree from University of Cape Town, 1999
- Masters degree from McMaster, 2002 (not a "doctor", please)
- Worked with a number of companies since then on data analysis and consulting projects
- Worked at GSK on a 1-year contract until June 2012
- Now working full-time at McMaster since July 2012
- Drop-in hours: Tuesday and Thursday afternoons
- Office is in BSB, room B105
- Arrange a meeting: kevin.dunn@mcmaster.ca
- Cell: (905) 921 5803
- extension 27337

Teaching assistant

Daryl Sivakumaran

- sivakudn@mcmaster.ca
- JHE, room 133
- extension 27404
- Currently doing his PhD with Todd Hoare
- Office hours will be arranged

Video and audio recordings

- As long as feasible, I will try to video record all classes
- Useful if you miss a class
- Quality might not be the best
- Usually available 24 to 48 hours after the class
- Audio recordings will also be made available, when possible

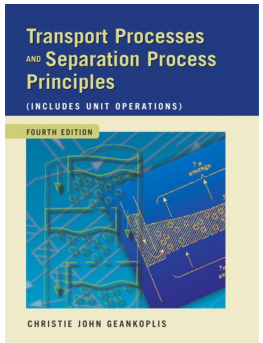
Course website

http://learnche.mcmaster.ca/4M3

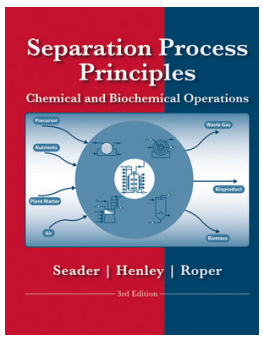
- Please check several times per week for announcements (top left)
- Slides will be added to the site before class
- Please print slides and bring to class
- Notes will be ready on the Monday before Tuesday's class
- Assignments and solutions will be posted there

References and readings

Recommended: Geankoplis, "Transport Processes and Separation Process Principles", (3rd or 4th edition)



Recommended: Seader, Henley and Roper, "Separation Process Principles" (3rd edition)



Recommended: Perry's "Chemical Engineers' Handbook", any edition. Please make full use of the library's subscription:

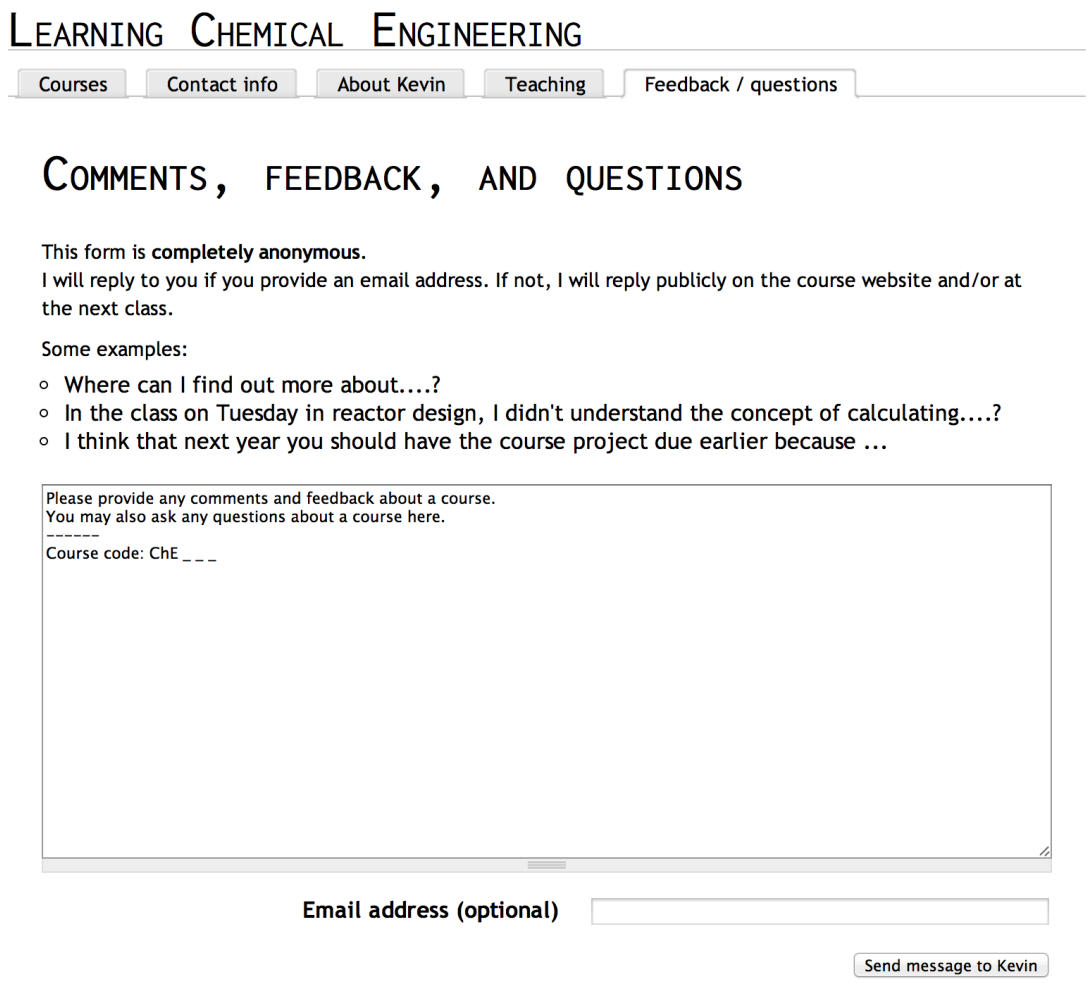
http://accessengineeringlibrary.com/browse/perrys-chemical-engineers-handbook-eighth-edition

Other references on course website (self-directed learning)

Course feedback via Learning website

- I might not have explained something clearly;
- you didn't get a chance to ask a question, *etc*

http://learnche.mcmaster.ca/feedback-questions



Expectations outside class

- You can expect TA and I to answer emails promptly
- If you have questions
  1. Please email the TA with CC to me ⟵ hopefully this solves your problem
  2. if not, set up meeting with TA or myself
- Please email from your McMaster address (filtering)

Grading

What we look for in the grading is demonstration that you/group:

1. understand the concept
2. have the ability to apply the concept to new instances
3. think creatively about problems
4. accuracy.

Grading

Assignments (about 5)	20%
Written midterm	15%
Mid/end term take-home exam	10%
Project, including a short class presentation	10%
Final exam	45%

- *Grading allocation is subject to change*
- Course letters will be assigned using standard system

Midterms and exam

- Written midterm: 18 October, 18:30
  - Optional, no make-up
- Take-home exam: due 30 November, 08:30
  - 5-day group-based exam
  - mostly open-ended questions
- Final exam
  - Cumulative of all material

All tests and exams:

- open notes – any form of paper
- any calculator
- no e-books (ideas on how to handle this? Please reply via feedback form)

Project

AIM: a short report and presentation to the class on a separation process that interests you

- More details to come on the report's scope
- List of areas to choose from: first-come first-served basis
- Only electronic hand-in via Google Docs will be accepted
- Short group presentation to the class
- Presentation content will be examinable
- Important dates:

Topic selection	27 September (minor iterations after that)
Outline due	12 October
Project due	09 November
Presentations	week of 19 to 23 November

Group-based assignments

- "Appropriate" group work is highly encouraged (about 40% of course)
- Learn with each other: groups of 2, no larger

- Optimal group work: *an example of one approach*
  - Sarah and Brad work on an assignment
  - Both Sarah and Brad do **all questions** in draft: quick notes at home, on the bus, *etc*, ± 4 days before assignment due
  - Meet in the library next day and go over each other's notes
  - Explain to the other why you disagree
  - e.g. Sarah sees a mistaken interpretation in Brad's work
    - She explains why it is a mistake to Brad: Sarah learns
    - Brad also learns: he's heard this in class, and from Sarah now
    - If neither can resolve it? speak with TA or Kevin
  - Write up a joint solution; e.g. Sarah does Q1 and 2, Brad does Q3
  - Both review it before submitting

- Other approaches are possible: your group decides
- What doesn't work: Sarah does Q1 and Q2, Brad does Q3; staple and submit

Over to you ...

Work on the hand-out in groups of 3 or 4

Last class (06 September 2012)

- We covered the admin issues
- Grading
- And in particular what is appropriate group work
- Midterm: leaning towards Friday, 12 October (before CSChE)

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
  - and even the kitchen sink

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 salts

Reference: King, p 16

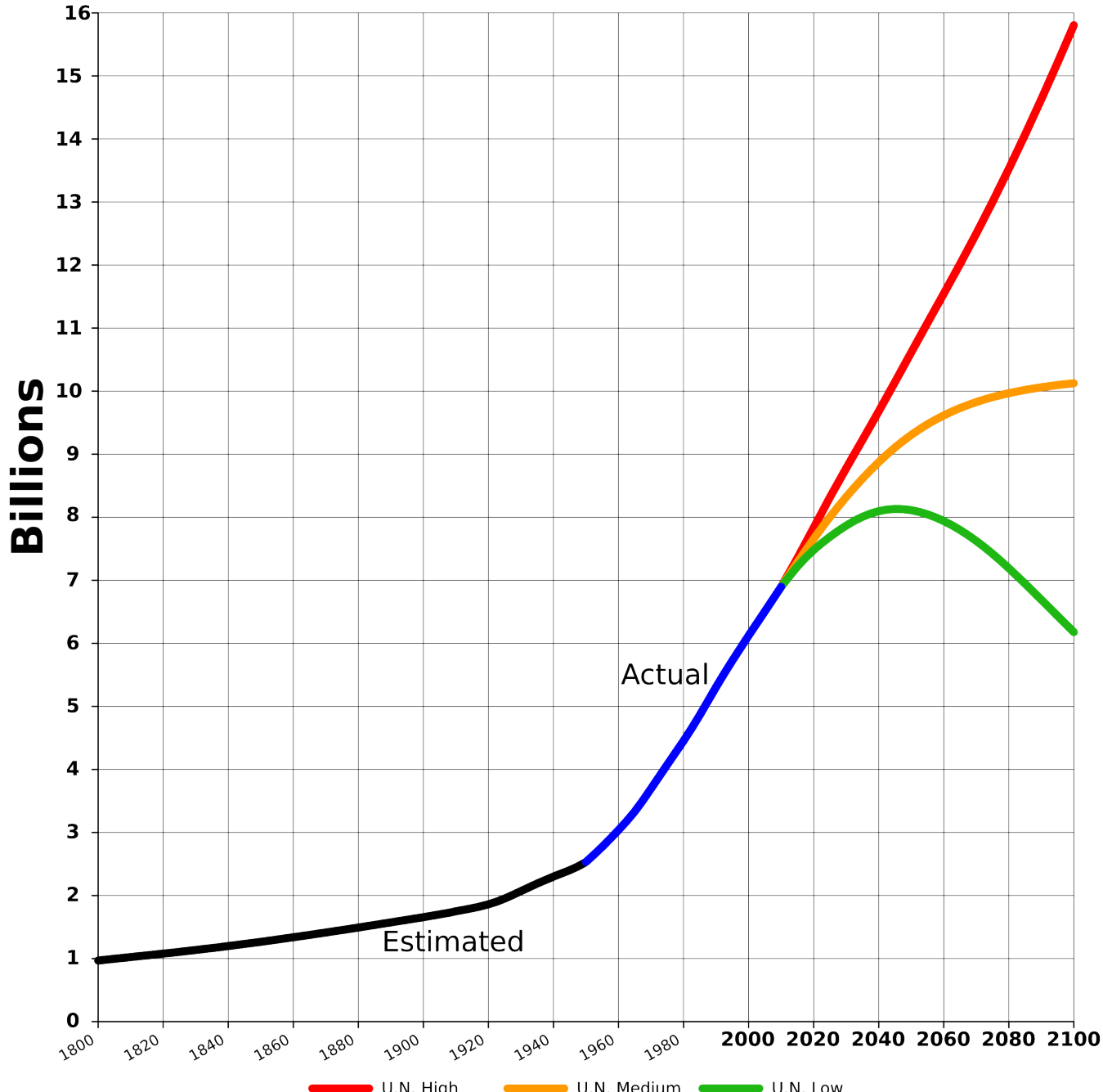
Usually there are multiple ways to achieve a required separation.

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

Everyday examples

Separation processes in your body:

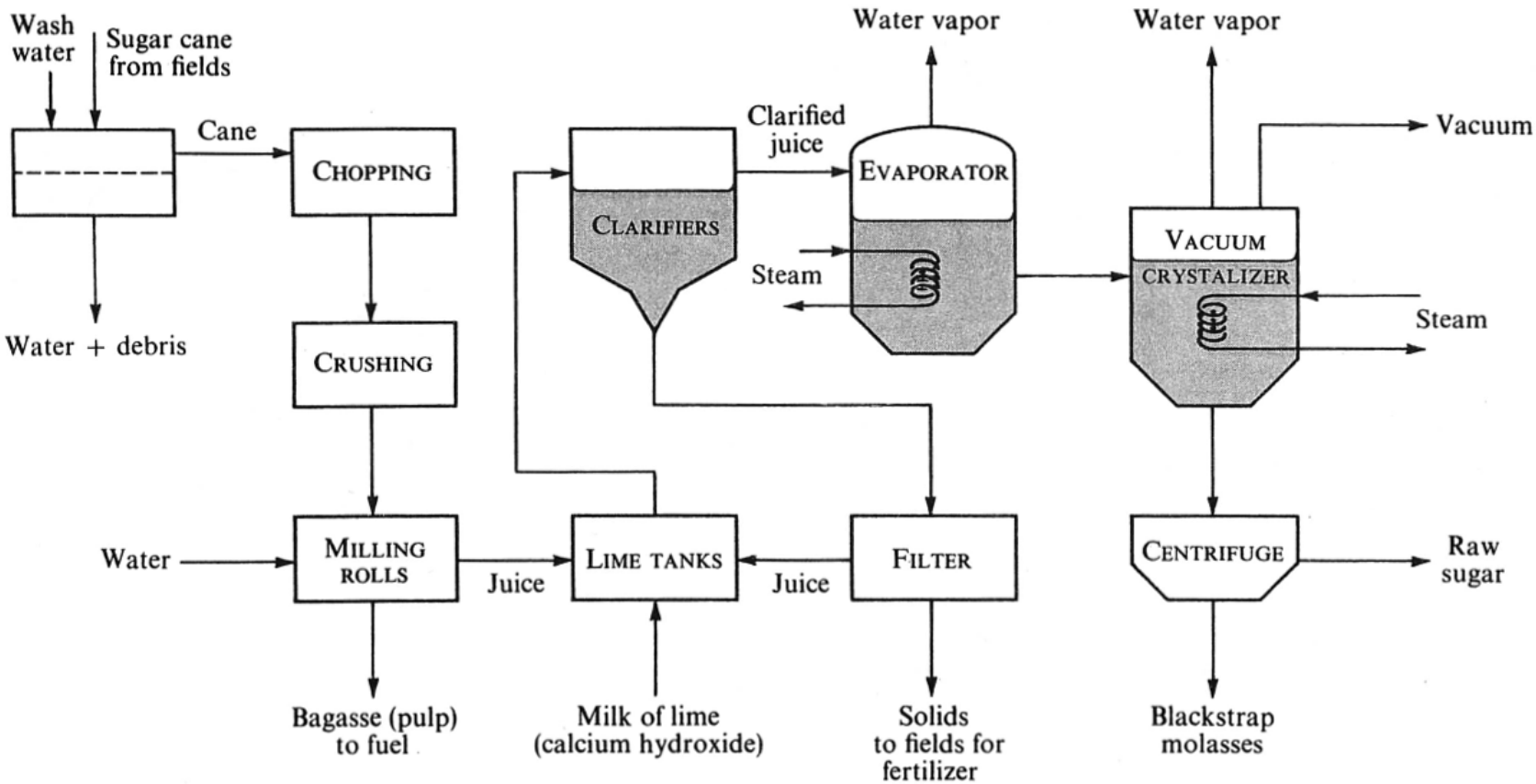
- kidneys: separates waste from blood; reabsorbs water and salts back into blood
- lungs: release of CO_2 from blood
- liver: breaks down toxins, excreted into bile
- gallbladder: concentrates bile
- intestines: absorb nutrients
- spleen: removes old red blood cells
- lymph nodes: filter foreign particles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

Engineering example

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

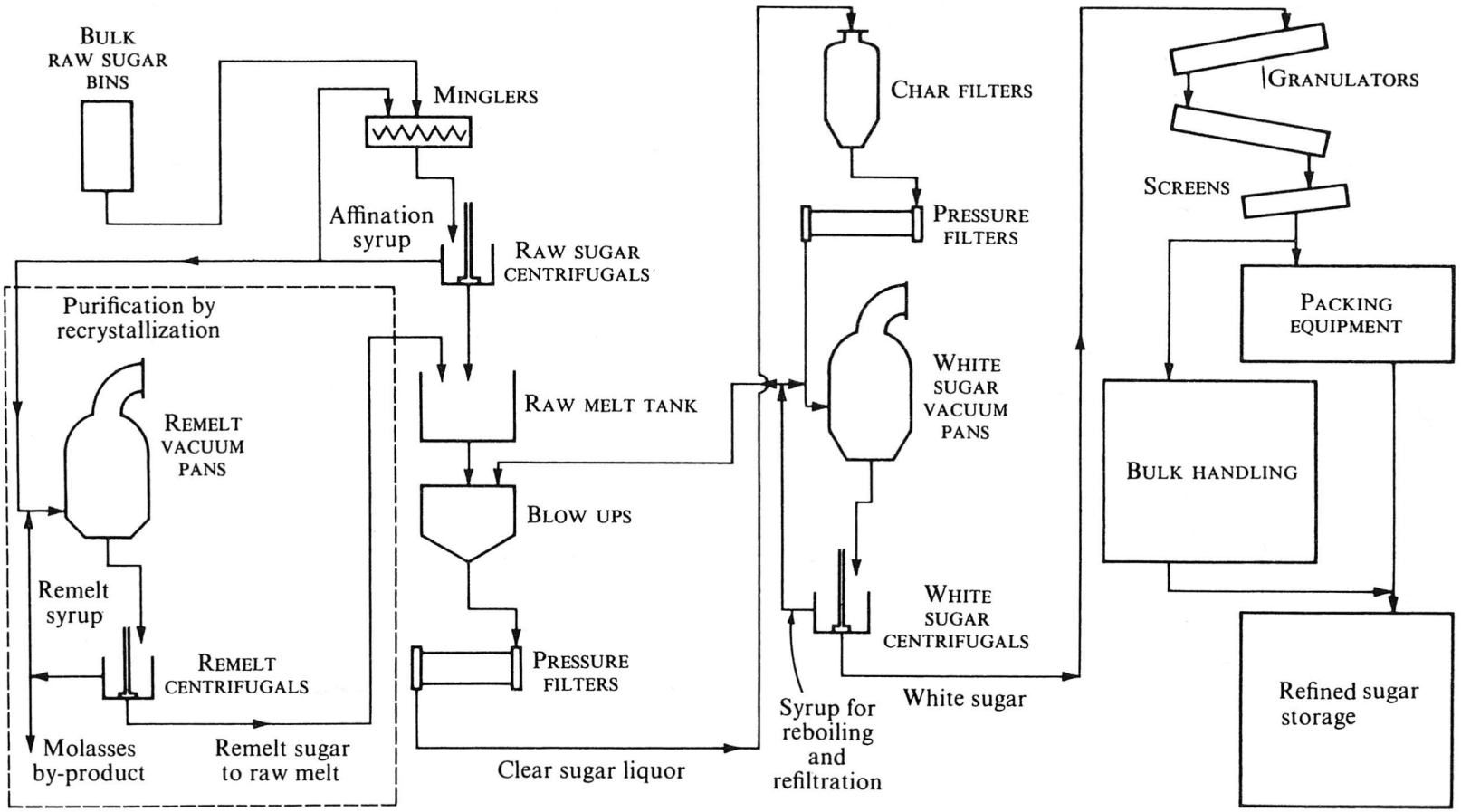
Video http://www.youtube.com/watch?v=ZBOou6cahtw

Sugar flowsheet (part 1)



Source: C.J. King, Separation Processes

Sugar flowsheet (part 2)



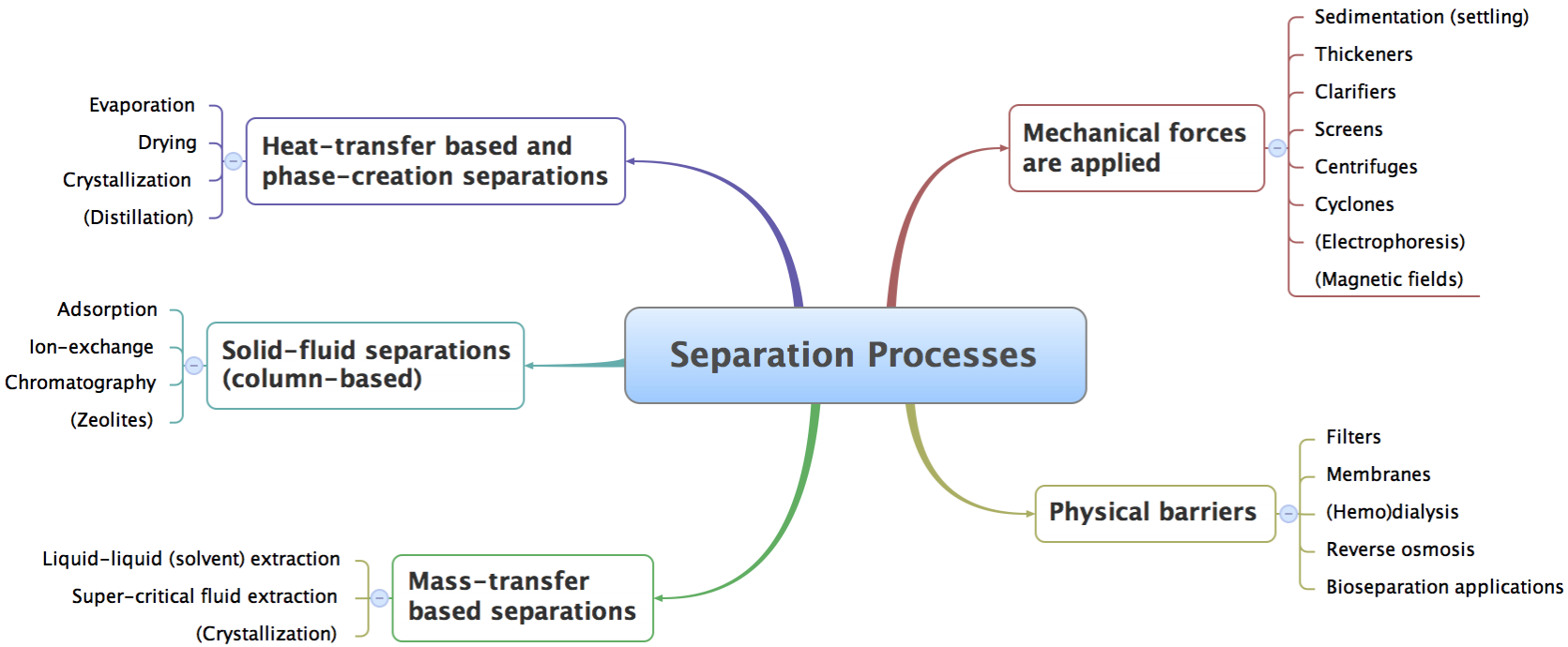
Source: C.J. King, Separation Processes

Topics that you want to cover

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

- Reverse osmosis
- Membranes, including (hemo)dialysis and pervaporation
- Distillation
- Centrifuges
- Cyclones
- Filtration (various types: regular, ultra-, nano-)
- Juicing (has relationship to bioseparation steps)
- Ion-exchange
- Crystallization
- Chromatography
- Electrophoresis
- Zeolites
- Column-based operations: stripping, absorption, packed beds
- Interesting: petro fracking, hydro-fracking, winnowing, demisters

Current plan for 4M3 in 2012



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

- 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
- For each unit operation we consider
  - the physical principle that causes separation
  - how 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			

Admin issues

- Group size: 2 (preferred), but groups of 3 will be allowed if you email me with a convincing explanation
- Midterm: 12 October 2012, 18:30 to 21:30; split venue
- Assignment 1 is posted on website

Mechanical separations

We will start with this topic

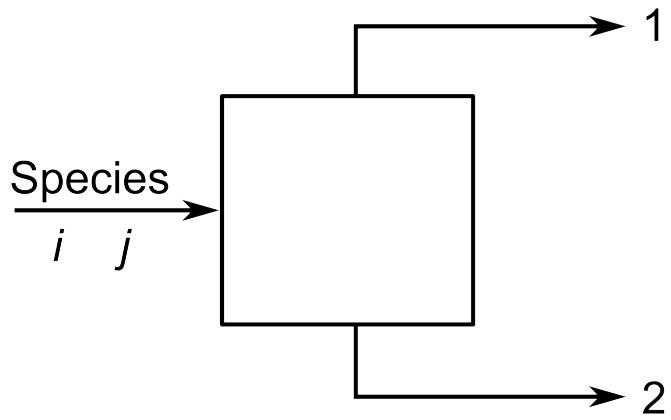
- It's easy to understand!
- Requires only a knowledge of basic physics (e.g. 1st year physics)
- It introduces a number of important principles we will re-use later
- Mechanical separations remain some of the most widely used steps in many flowsheets. Why?
  - reliable units
  - relatively inexpensive to maintain and operate
  - we can often achieve a very high *separation factor* (that's desirable!)

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)

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

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
- flow
- temperature gradient
- concentration gradient
- gravitational field (natural, or artificially created)
- adsorbent
- absorbent

Units we will consider in depth

Under the title of "Mechanical Separations" we will consider:

- free settling (sedimentation)
- screening of particles
- centrifuges
- cyclones

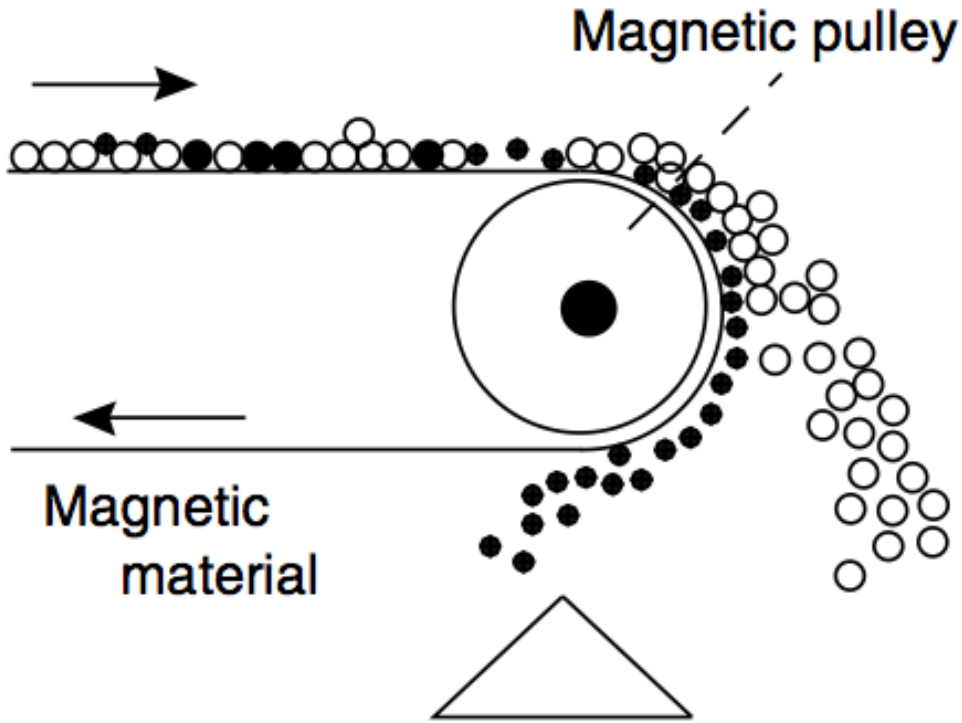
There are also others that go in this category. Deserving a quick mention are:

- magnetic separation
- electrostatic precipitation

Quick mention: Magnetic separation

- used mainly in the mineral processing industries
- high throughputs: up to 3000 kg/hour per meter of rotating drum
- e.g. remove iron from feed
- Also used in food and drug industries at multiple stages to ensure product integrity

[Sinnott, 4ed, v6, Ch10]



Quick mention: Electrostatic separators

- depends on differences in conductivity of the material
- materials passes through a high-voltage field while on a rotating drum
- the drum is earthed
- some of the particles acquire a charge and adhere stronger to the drum surface
- they are carried further than the other particles, creating a split

[Sinnott, 4ed, v6, Ch10]