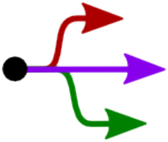
Separation Processes:
Overview of course

ChE 4M3



kevin.dunn@mcmaster.ca
http://learnche.mcmaster.ca/4M3

Overall revision number: 284 (November 2013)

Copyright, sharing, and attribution notice

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`

or anonymous messages can be sent to Kevin Dunn at

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

If reporting errors/updates, please quote the current revision number: 284

Plan for today's class

1. Background
2. Administrative issues
3. Short brainstorming session of topics to cover
4. Course content (today, and the next class also)

Credits for course material

- 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

I modified the course order and materials substantially in 2012.
You are class number 2

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 from 2002 to 2011 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
- Office is in BSB, room B105
- Arrange a meeting: `kevin.dunn@mcmaster.ca`
- Cell: (905) 921 5803

Teaching assistant

Dominik Seepersad

- chemac.4m3@gmail.com
- JHE, room 370
- extension 22008
- Currently doing his M.A.Sc with Tom Adams
- Office hours to be arranged by email with him

Video and audio recordings

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

Course website

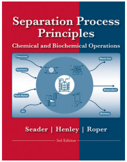
http://learnche.mcmaster.ca/4M3

- Please check several times per week for announcements (top left)
- Follow the Twitter feed: @4m3separations
  - Slides will be added to the site before class
  - Please **print slides and bring to class**
  - Assignments and solutions will be posted there
  - Other references/readings for enrichment

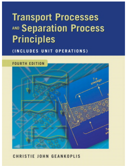
References and readings

No required textbook

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



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

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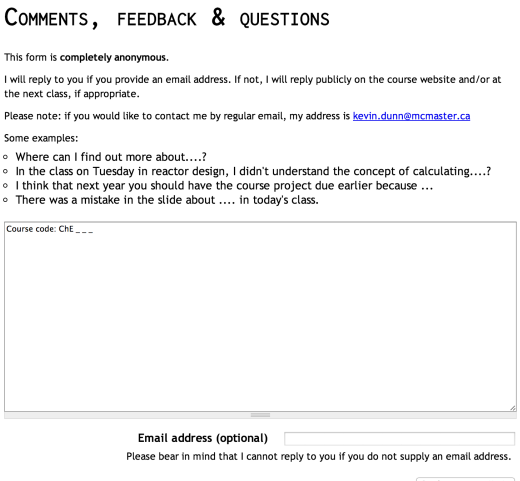
Other references on course website

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



Comments, feedback & questions

This form is **completely anonymous.**

I will reply to you if you provide an email address. If not, I will reply publicly on the course website and/or at the next class, if appropriate.

Please note: if you would like to contact me by regular email, my address is kevin.dunn@mcmaster.ca

Some examples:

- Where can I find out more about....?
- In the class on Tuesday in reactor design, I didn't understand the concept of calculating....?
- I think that next year you should have the course project due earlier because ...
- There was a mistake in the slide about .... in today's class.

Course code: ChE _ _ _

Email address (optional)

Please bear in mind that I cannot reply to you if you do not supply an email address.

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. apply a systematic problem-solving strategy
   - `Define, Explore, Plan`, **Do**, `Check, Generalize`
3. have the ability to apply the concept to new instances
4. think creatively about problems
5. accuracy.

Grading

Assignments (about 5)	20%
Written midterm	15%
Quest tests	8%
Project	12%
Final exam	45%

- *Grading allocation is subject to change*
- Course letters will be assigned using standard system
- Two important **minimum prerequisites** to pass `4M3`:
  - 50% or more in the final exam
  - Must submit a course project

Midterms and exam

- Written midterm: 22 October, 18:30
  - Optional, no make-up
- Quest tests
  - Short duration, computer-based tests
  - Quick answers, to help you stay on top of the material
- Final exam
  - Cumulative of all material

All tests and exams:

- open notes – any form of paper
- any calculator

Project

AIM: a short report on a selected separation process
(choice of 3 or 4 units)

- Details to come later on the report's scope
- Only electronic hand-in will be accepted
- Important dates:

Topic selection	04 October, or earlier
Outline due	15 October
Project due	12 November

Group-based assignments

- "Appropriate" group work is highly encouraged
  - 32% of course
- Learn with each other: **groups of 2**, no larger, no exceptions

Group-based assignments

- **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 from both group members' notes
    - 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
  - Neither learns the other material

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Over to you ...

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

- Identify separation processes that begin with each letter

A:	**I:**	**R:**
B:	**J:**	**S:**
C:	**K:**	**T:**
C:	**L:**	**U:**
D:	**M:**	**V:**
E:	**N:**	**W:**
F:	**O:**	**X:**
G:	**P:**	**Y:**
H:	**Q:**	**Z:**

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

Usually there are multiple ways to achieve a required separation.

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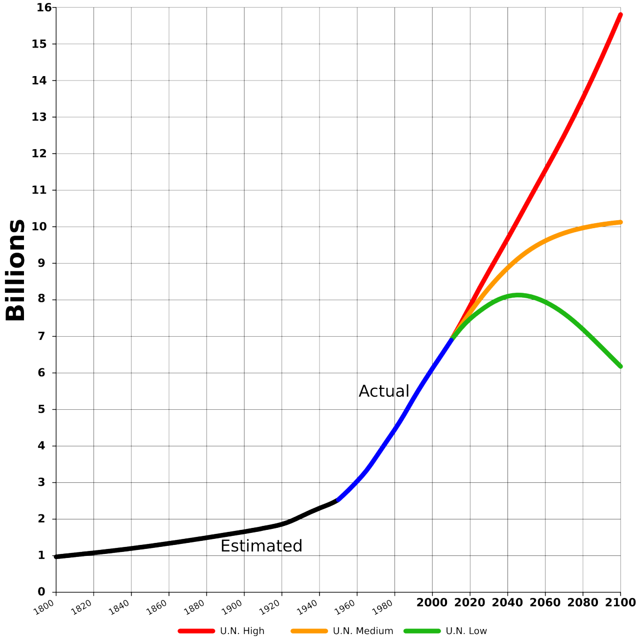
Why study separation processes?

- 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:

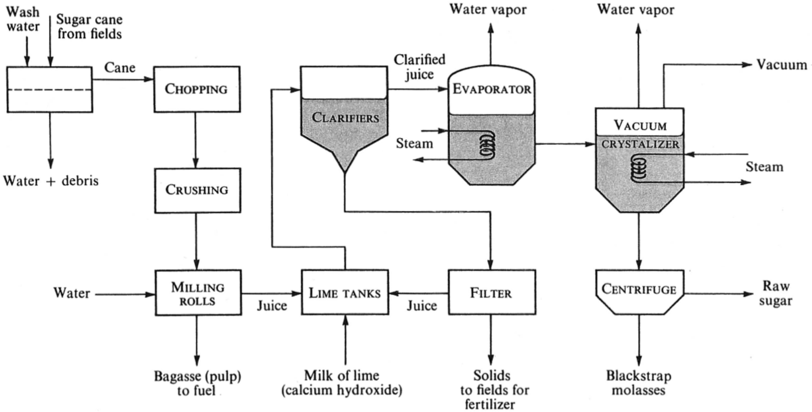
- kidneys: separates waste from blood; reabsorbs water and salts back into blood
- lungs: release of CO_2 from blood
- liver: breaks down toxins, excreted into bile
- gallbladder: concentrates bile
- intestines: absorb nutrients
- spleen: removes old red blood cells
- lymph nodes: filter foreign particles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

Engineering example

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

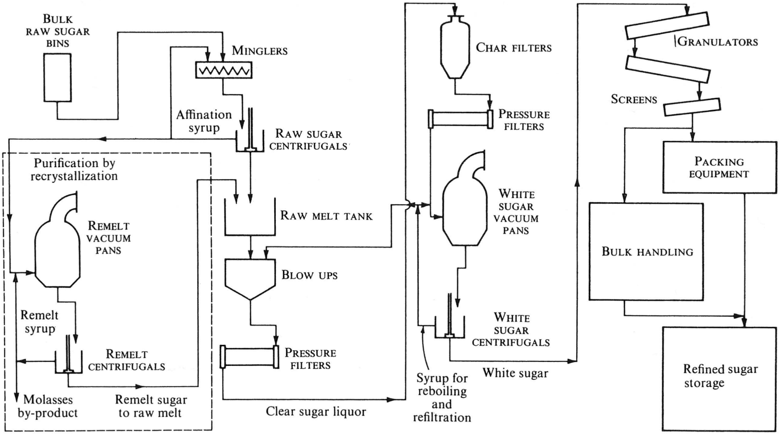
Video http://www.youtube.com/watch?v=ZBOou6cahtw

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

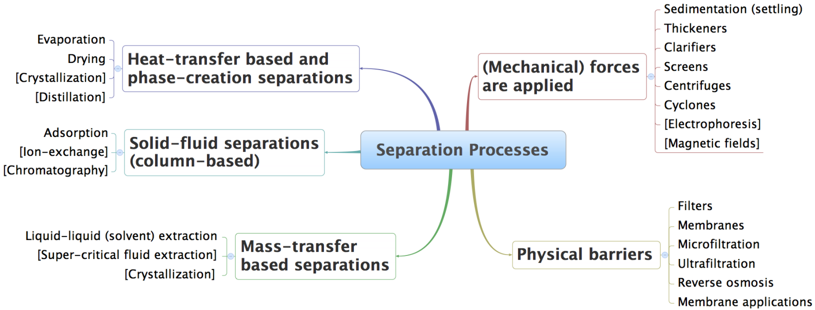
1 Liquid-liquid extraction

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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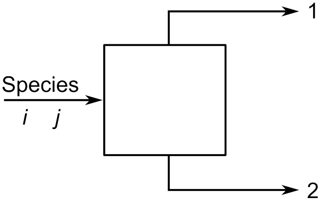
Separation factor

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 the 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