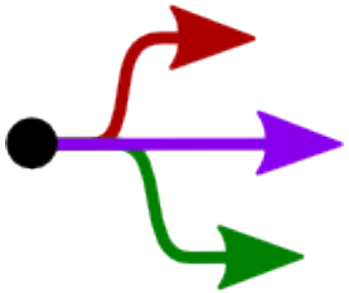
Separation Processes:
Course review

ChE 4M3



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

Overall revision number: 326 (December 2014)

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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`

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: 326

Course evaluation

Please fill in a course evaluation.

Comments and feedback about the following

- the assignments
- course project
- guest lectures
- course website, video and audio files
- extra resources posted on the course website

Every year get better and better from your comments and ideas.
Thank you!

Final exam details

- On Tuesday, 09 December 2014
- 16:00 to 19:00
- IWC-2
- There will be 90 marks
- The number of questions does not matter: **time management does**
- Covers all topics learned
- Expect combination questions: use multiple parts of the course to solve a problem

More final exam details

Note:

- You may bring in any materials to the exam; any textbooks, any papers, *etc*.
- You may use **any calculator** during the exam.
- You may answer the questions in any order on all pages of the answer booklet.
- *Time saving tip*: **never repeat the question** back in your answer.
- Please use a problem solving strategy on longer questions that is proven to work; *define, explore, plan, do, and importantly, always check*.
- **If anything seems unclear, or information appears to be incomplete, please make a reasonable assumption and continue with the question.**
- Total marks: 90 marks.
- Total time: 3 hours.

What's in the exam?

Everything that was covered in class time

- Guest lectures
- My lectures
- Videos shown in class time
- All "interactive tutorial" (question and answer) classes
- Short quizzes used in class

What you may bring to the exam

- Any notes, assignments, midterms, *etc* that you will feel are helpful
- Any textbooks and printed materials are allowed
- Any calculator is allowed

Only limitation: no iPads, laptops, tablets, electronic devices, *etc*

How to do well in the final exam

- Repeat the midterm without solutions
- Redo assignment questions you got wrong
- More importantly: understand **why** you initially got the question wrong
  - what concept did you misunderstand?
  - take time to review that concept(s) again
- Review questions from
  - Geankoplis [3M] textbook: Centrifuges, filtration, membranes
  - Seader *et al.*: membranes, LLE, adsorption, drying

- I have posted practice questions to the course website, including all my prior final exams

What can I do to study well?

Some tips from the educational research area:

- Don't just look at a question/topic and say: "Yeah, I could do that". Prove that you can.
- While you are studying:
  - can you explain the concept to a study partner without looking at the notes?
  - can you explain **the approach** you would take to solve a problem?

Poor students do this*:

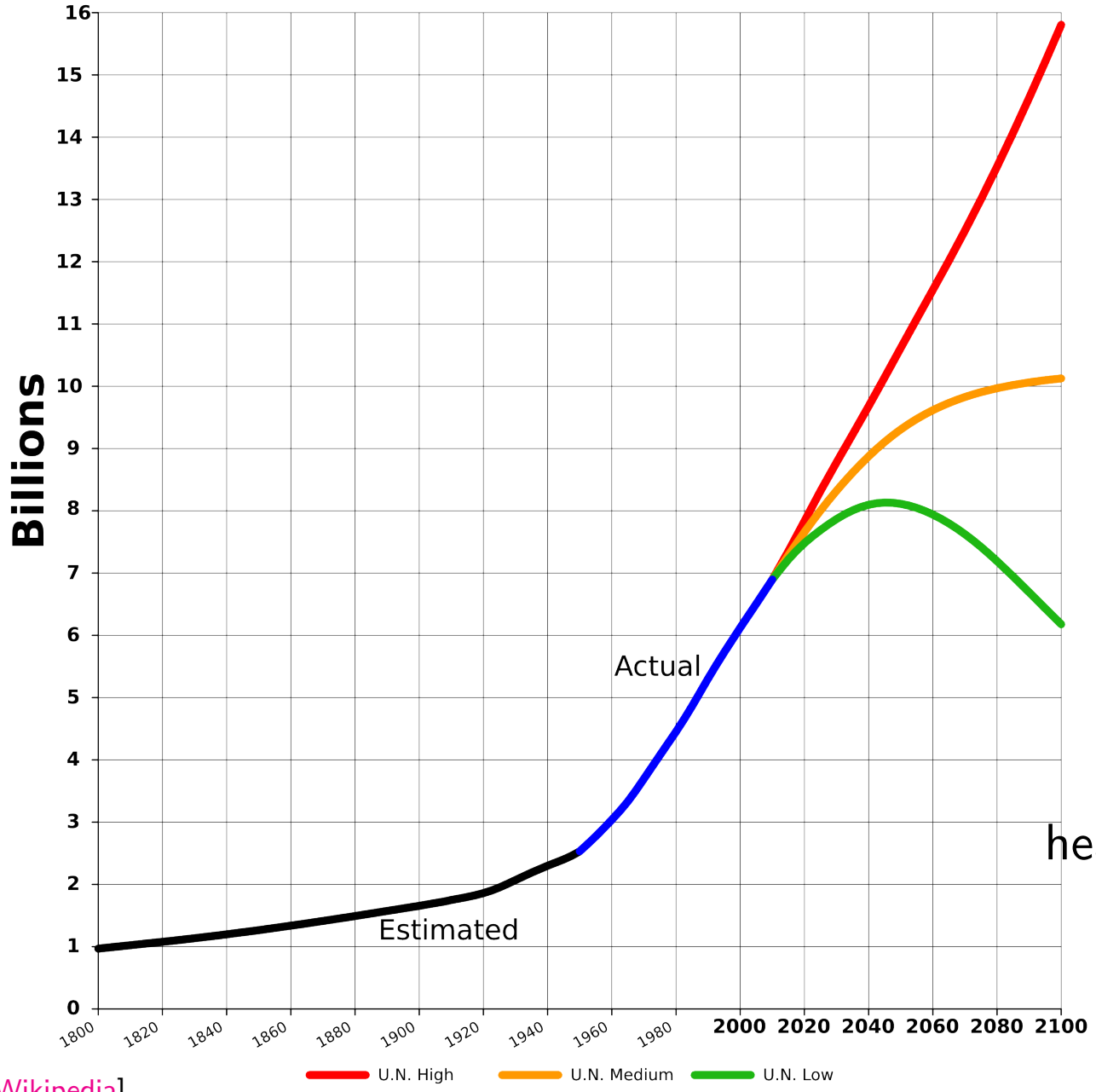
- Distractions while studying: music, cellphones and email/website checking, TV on in background
- Skip over parts you don't understand
- After reading a text, try to repeat it back exactly

*Meneghetti et al. "Strategic knowledge and consistency in students with good and poor study skills", *European Journal of Cognitive Psychology*, **19**, 2007.

Why study this course: Separation Processes?

- Can't beat Nature: "Second Law of Thermodynamics"
- There are multiple ways to achieve a required separation
- 50% to 90% of capital investment on petroleum and other chemical-reaction based flowsheets
- Expense often in proportion to the level of purity (called the separation factor)
- 60 to 100% of the ongoing operating costs in chemical plants
- These systems are all around us
  - leaching (coffee; tea)
  - centrifugation and drying (washing and tumble drying clothes)
  - absorption (your lungs)
  - membranes (your skin, kidneys)
  - adsorption (water filter)
  - drying (clothes dryer)

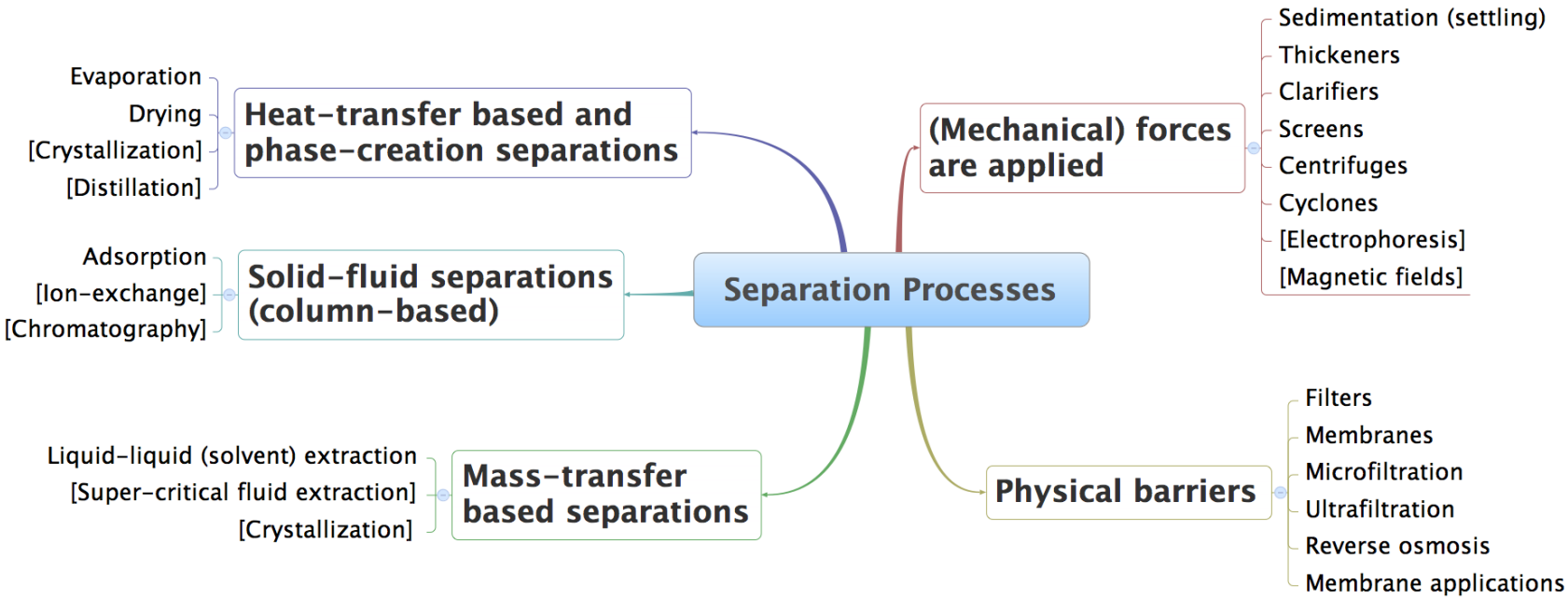
The course is driven by real needs in society



Food, energy, water, healthcare

[Loren Cobb, Wikipedia]

Some more context around the 4M3 course



Can't remember what was covered when?

Review the subsections on the website

Main page

Toolbox
- What links here
- Upload file
- Page information

Read | Edit | View history | Search

Adsorption separations - 2014

References [edit]

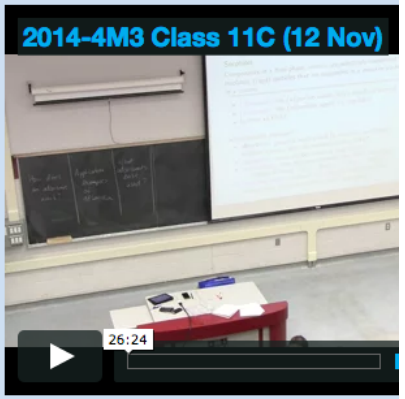
Please use these references to read ahead, or for extra background reading. In alphabetical order:

- Ghosh, R. "Principles of Bioseparations Engineering", Chapter 8, McMaster (reserve)
- Geankoplis, C.J. "Transport Processes and Separation Process Principles", Chapter 12 in 3rd and 4th edition, McMaster Libraries (reserve)
- Perry's Chemical Engineers' Handbook, Chapter 22, Direct link (McMaster subscription)
- Richardson and Harker, "Chemical Engineering, Volume 2", 5th edition, Chapter 17 ebook
- Schweitzer, "Handbook of Separation Techniques for Chemical Engineers", Chapter 3.1, McMaster library
- Seader, Henley and Roper, "Separation Process Principles", Chapter 16 in 2nd and 3rd edition McMaster Libraries (reserve)
- Uhlmanns Encyclopedia article on Adsorption
- Wankat, "Separation Process Engineering", Chapter 16, McMaster library

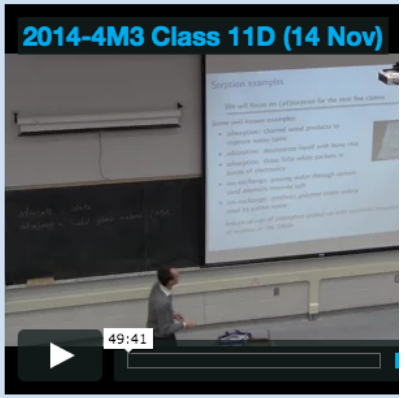
Date	Class number	Topic	Slides for class	Video and audio files		References and Notes
12 November	11C	Overview of various adsorbents and their application	Slides	Video	Audio	
14 November	11D	Some adsorbents and equilibrium theory	Slides	Video	Audio	
19 November	12A	More adsorption case studies, focussing on equilibrium	Slides	Video	Audio	Apart from the case studies on adsorption, we consider learning skills, based on the two axes presented in this diagram. My challenge to you is to honestly locate your capabilities on this graph, and aim to push yourself to the peak.
21 November	12B	More details on continuous adsorption with some problems posted in the notes to work through.	Slides	Video	Audio	Here are the data from the batch adsorber (slide 32). See if you can calculate the Langmuir isotherm values.

C_A	$C_{S,A}$
0.004	0.026
0.009	0.053
0.019	0.075
0.027	0.082
0.094	0.123

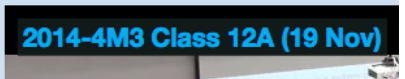
Class date(s): 12 November 2014



Download video: Link [426 M]



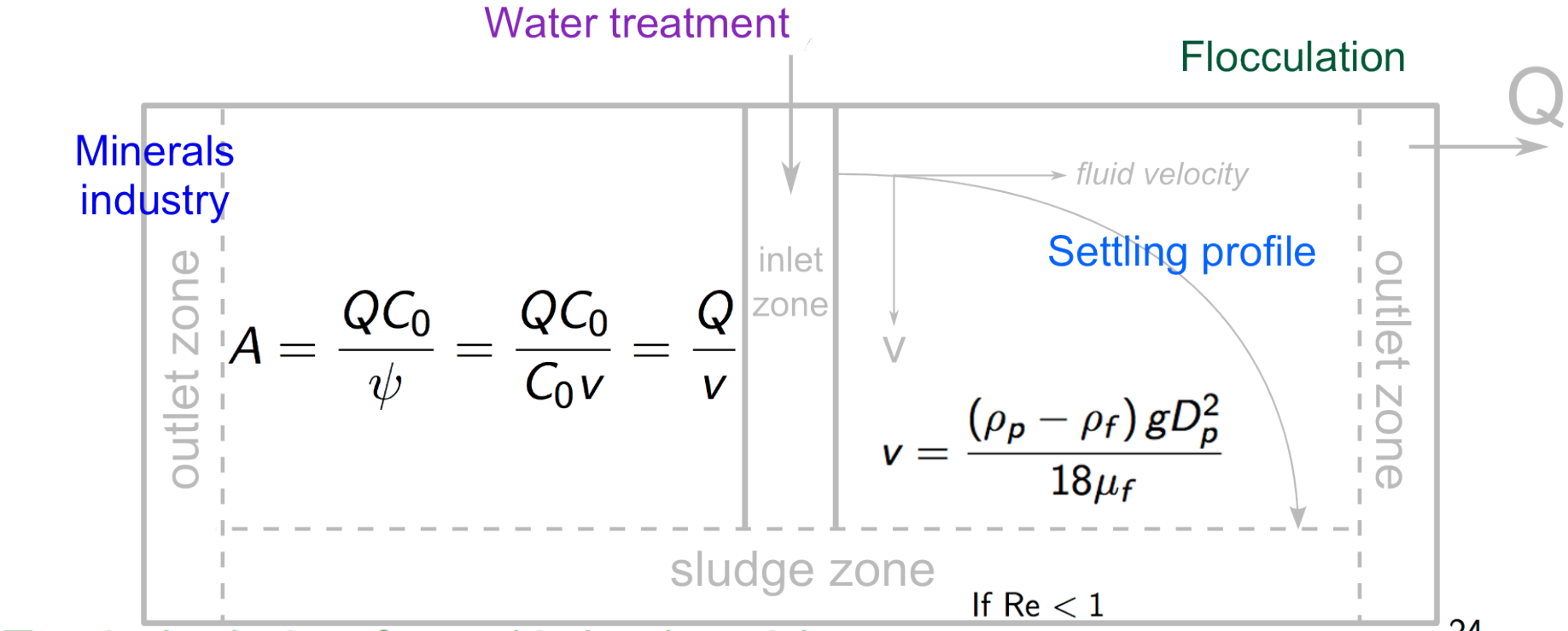
Download video: Link [801 M]



Mechanical separations

Part	Topic	Week number
1	Sedimentation	2B, 2C, 3A, 3B
2	Particle size	3C, 3D
3	Centrifuges	3E, 4A, 4B
4	Filtration	4C, 5A, 5B
5	Cyclones	5C, 6A, 6B

Sedimentation: 2B, 2C, 3A, 3B



$$A = \frac{QC_0}{\psi} = \frac{QC_0}{C_0 v} = \frac{Q}{v}$$

$$v = \frac{(\rho_p - \rho_f)\, g D_p^2}{18\mu_f}$$

Terminal velocity of an unhindered particle

$$v = \sqrt{\frac{4\,(\rho_p - \rho_f)\, g D_p}{3 C_D \rho_f}}$$

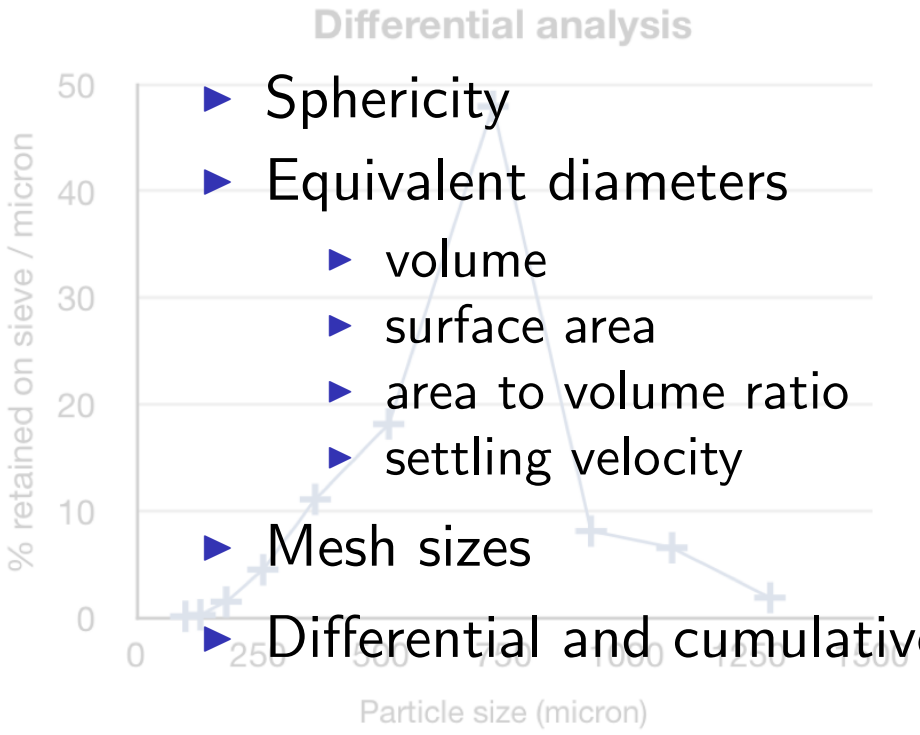
If $\mathrm{Re} < 1$

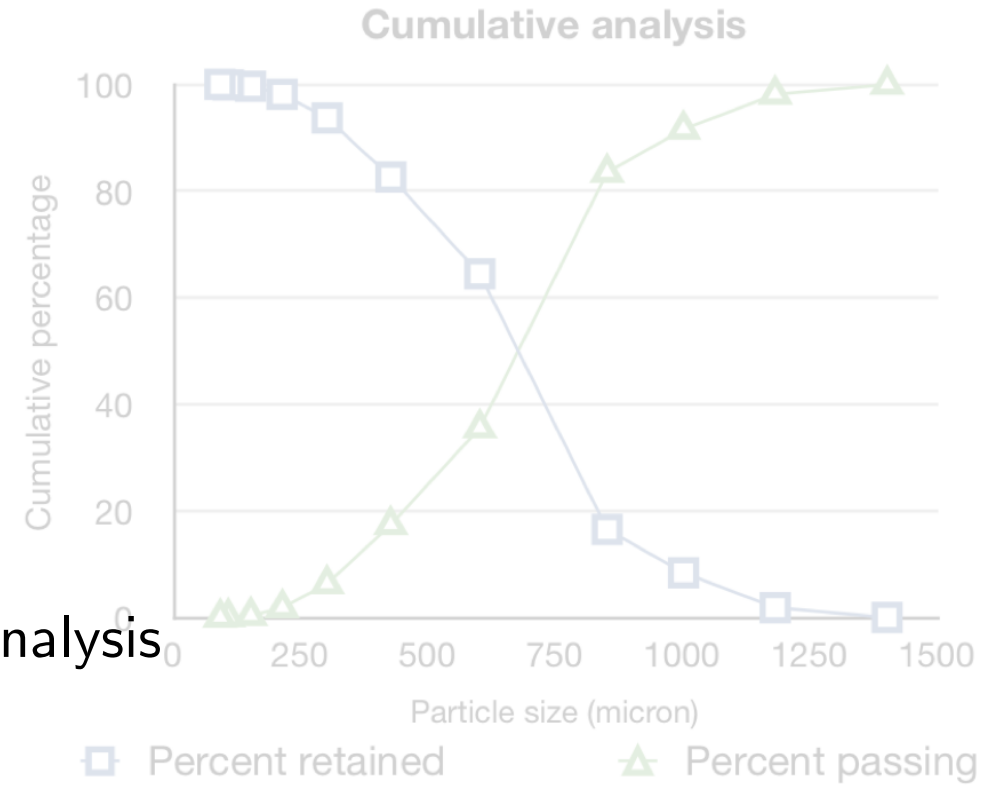
$$C_D = \frac{24}{\mathrm{Re}}$$

If $1 < \mathrm{Re} < 1000$

$$C_D = \frac{24}{\mathrm{Re}}\left(1 + 0.15\mathrm{Re}^{0.687}\right)$$

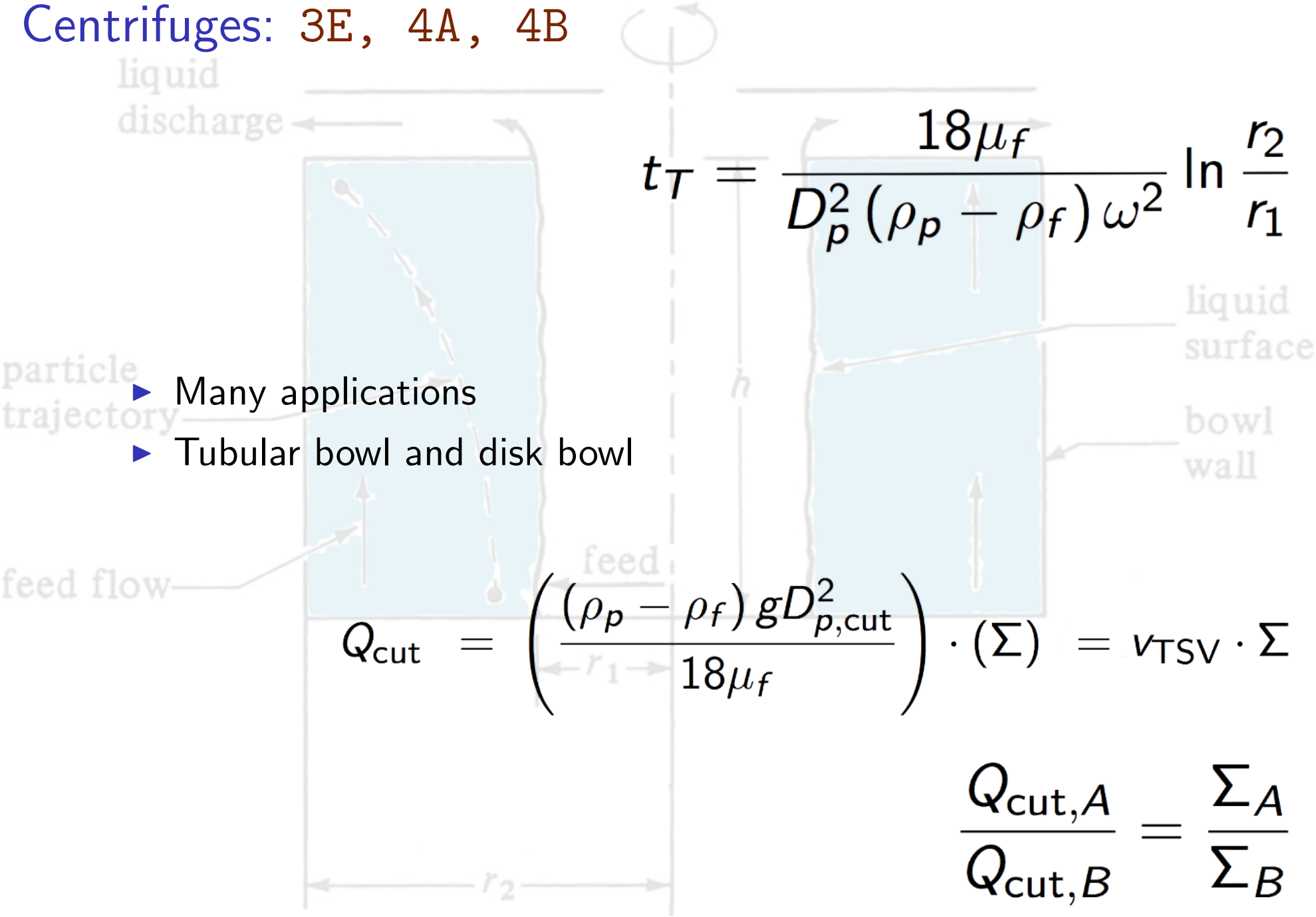
Screens: 3C, 3D





- Sphericity
- Equivalent diameters
  - volume
  - surface area
  - area to volume ratio
  - settling velocity
- Mesh sizes
- Differential and cumulative analysis

Centrifuges: 3E, 4A, 4B



$$t_T = \frac{18\mu_f}{D_p^2\left(\rho_p - \rho_f\right)\omega^2} \ln \frac{r_2}{r_1}$$

- Many applications
- Tubular bowl and disk bowl

$$Q_{\text{cut}} = \left(\frac{\left(\rho_p - \rho_f\right) g D_{p,\text{cut}}^2}{18\mu_f}\right) \cdot (\Sigma) = v_{\text{TSV}} \cdot \Sigma$$

$$\frac{Q_{\text{cut},A}}{Q_{\text{cut},B}} = \frac{\Sigma_A}{\Sigma_B}$$

Filtration: 4C, 5A, 5B

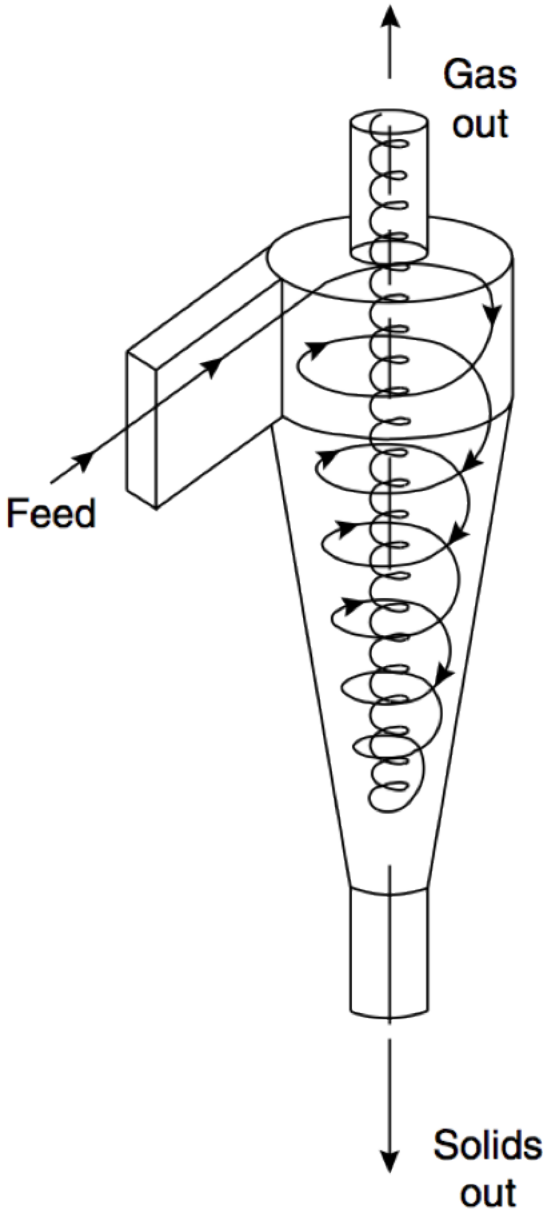
- transitioning lab data to full scale is common practice
- there are two resistances
- the medium resistance is often negligible
- performance metric: time required and pressure used
- capital cost: mostly due to press area, A

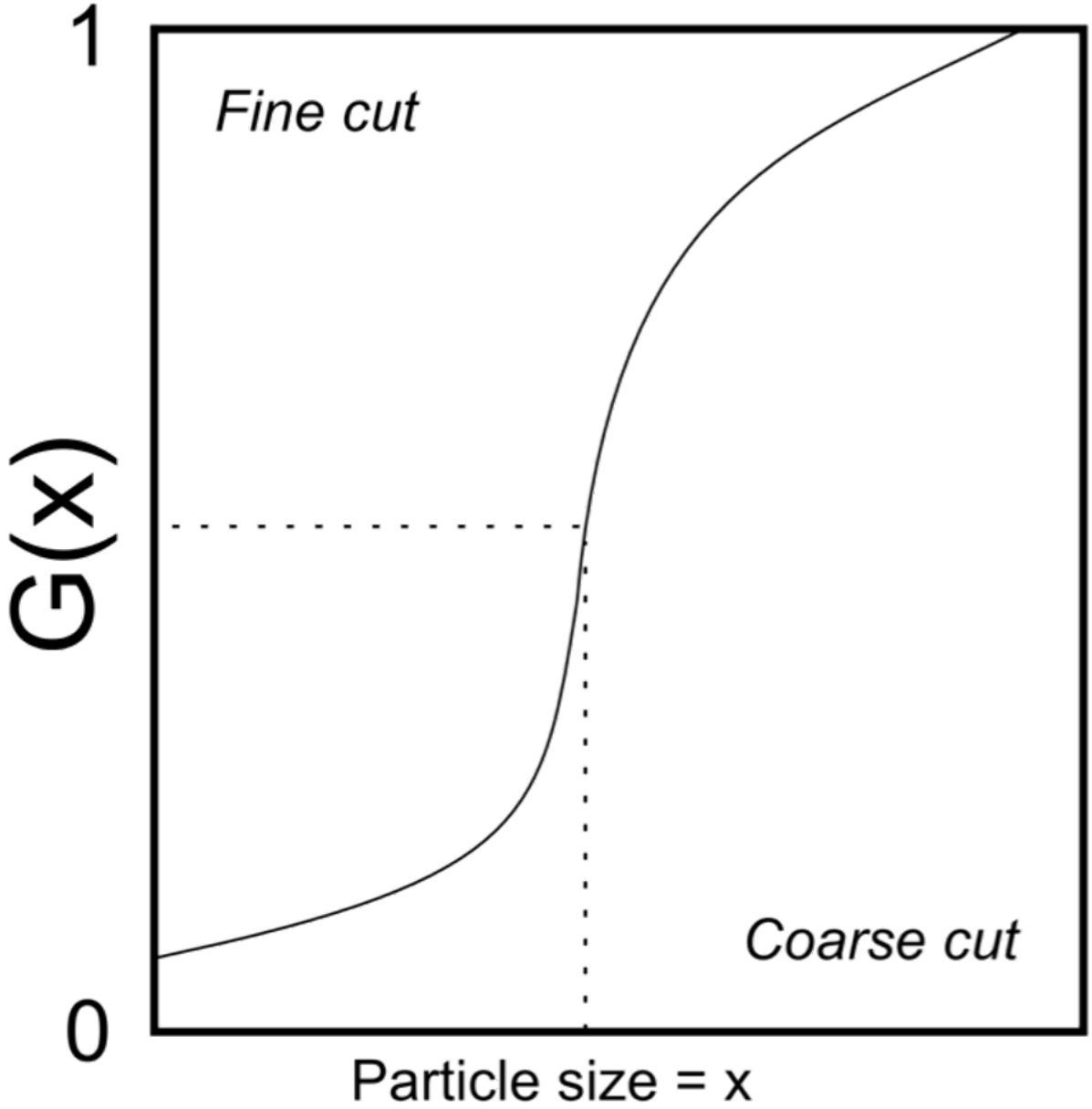
$$t = BV + \frac{K_p V^2}{2}$$

$$B = \frac{\mu}{A(-\Delta P_{\text{tot}})} R_m$$

$$K_p = \frac{\mu C_S \alpha}{A^2 (-\Delta P_{\text{tot}})}$$

Cyclones: 5C, 6A, 6B

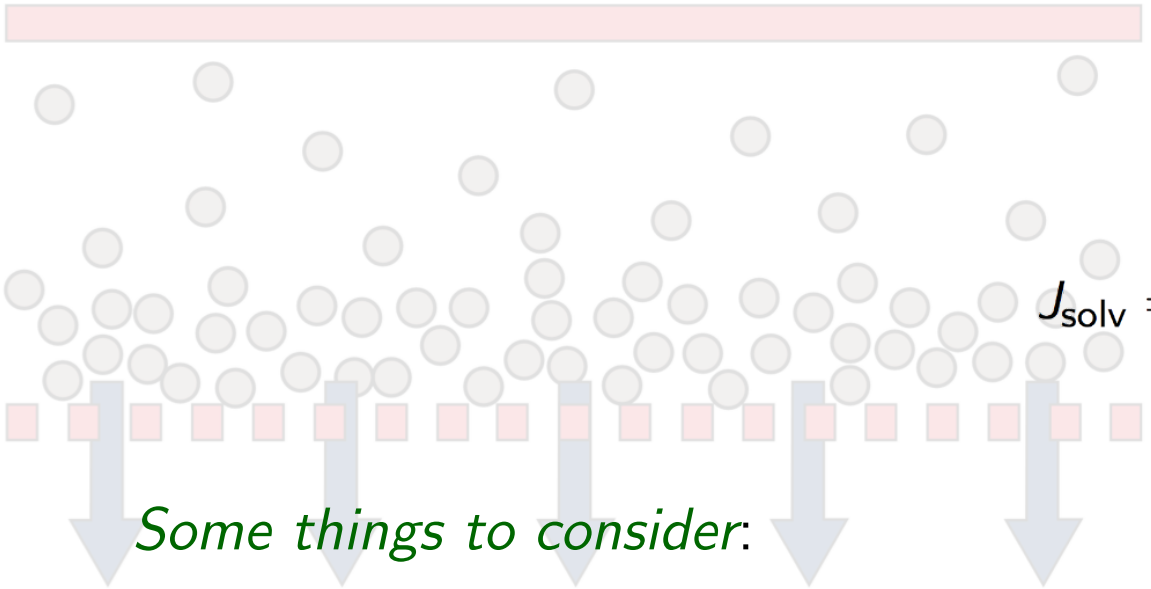




Membranes: 06C to 09A

We studied:

- Microfiltration
- Ultrafiltration
- Reverse osmosis



$$\text{Flux} = J = \frac{\Delta P}{\mu\left(R_m \ell_M + R_c L_c\right)}$$

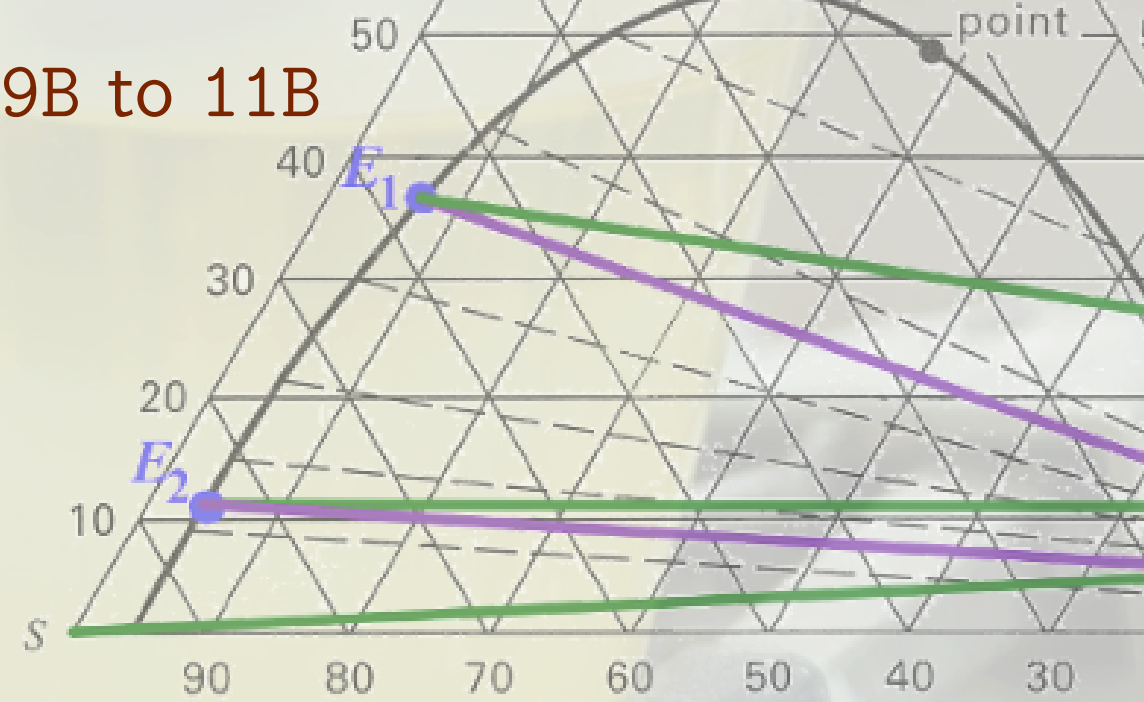
$$\frac{J L_c}{D_{AB}} = \frac{J}{h_w} = \ln\left(\frac{C_w}{C_f}\right)$$

$$J_{\text{solv}} = \frac{(\Delta P - \Delta\pi)}{R_{m,v} + \cancelto{0}{R_{cp,v}}} = \frac{P_{\text{solv}}}{\ell_M}(\Delta P - \Delta\pi)$$

Some things to consider:

- What are typical LMHs, ΔP and particle sizes retained?
- When can we set $C_p \approx 0$?
- When can we disregard membrane resistance?
- How are permeances calculated?

Liquid-liquid extraction 09B to 11B



Plenty of new concepts

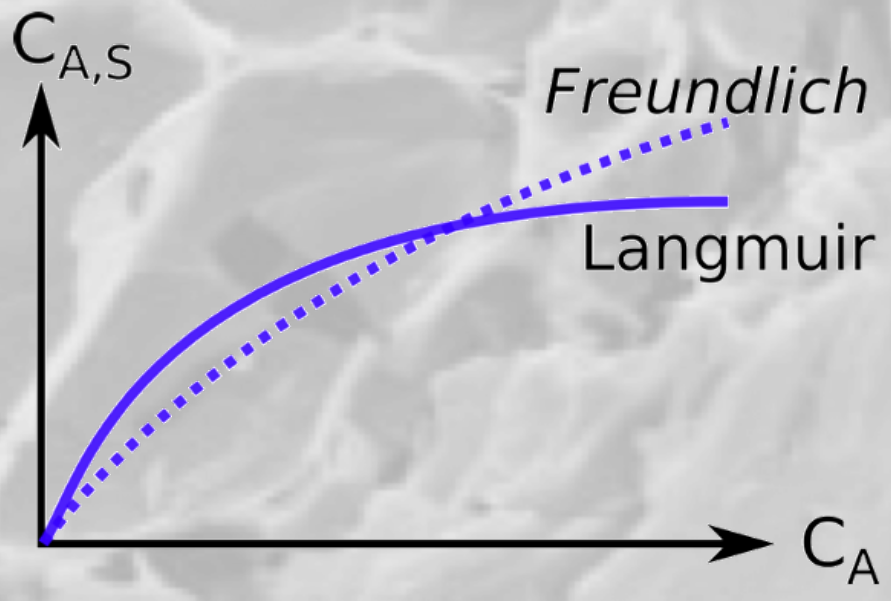
- ternary diagrams
- lever rule
- tie lines
- equilibrium
- solute, solvent, carrier
- mixer-settler, and other equipment alternatives
- extract, raffinate, distribution coefficient $D_A = \frac{y_{E,A}}{x_{R,A}}$
- recovery and concentration
- units in sequence
- cross-current *vs* countercurrent units
- operating point P

Adsorption 11C to 12B

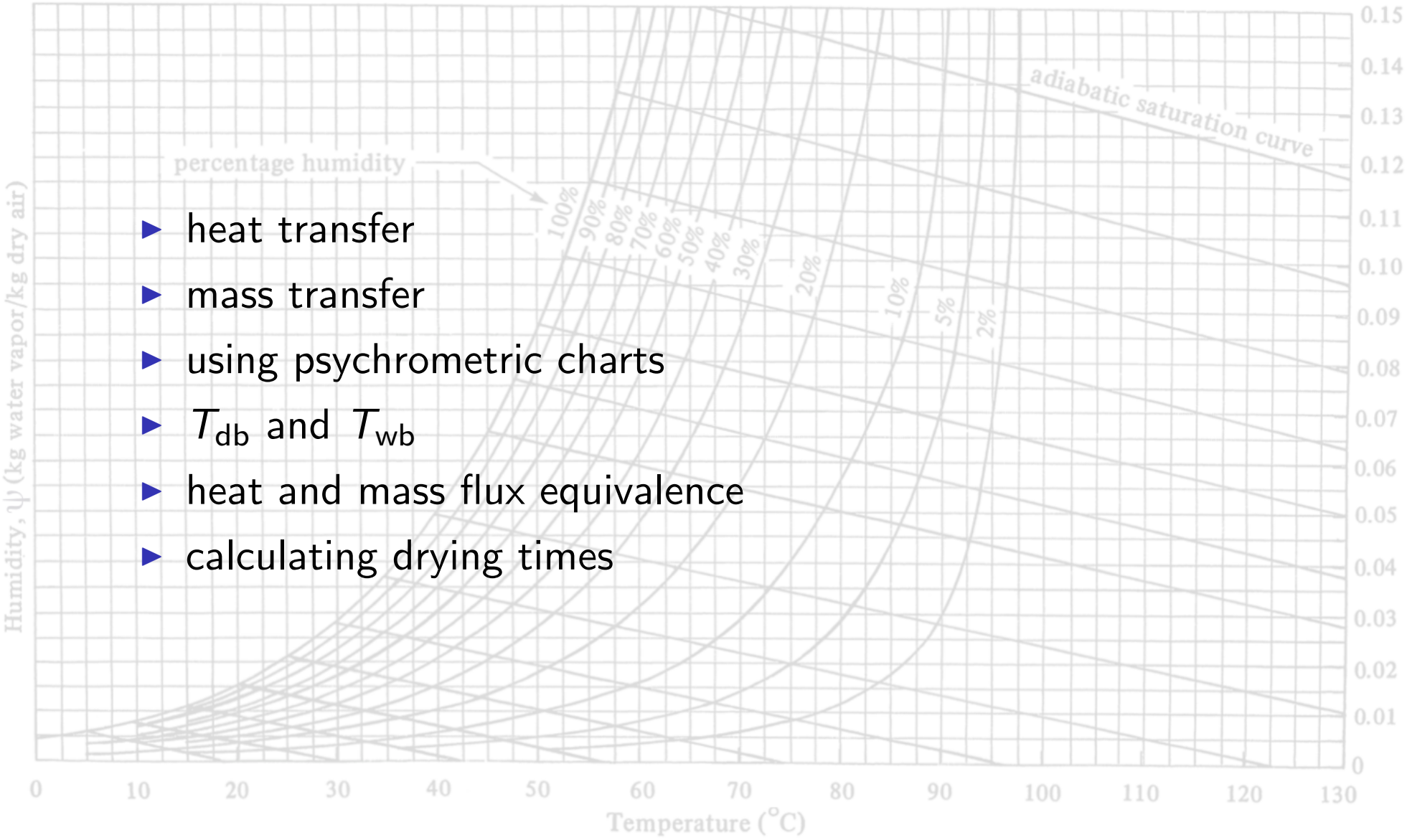
$$C_{A,S} = K\,(C_A)^{1/m}$$

$$C_{A,S} = \frac{K_3 C_A}{1 + K_4 C_A}$$

- Langmuir and Freundlich isotherms
- Breakthrough
- MTZ
- L_{LUB}
- Bed mass balance



Drying 13A, 13B, 13C, 14A



- heat transfer
- mass transfer
- using psychrometric charts
- T_{db} and T_{wb}
- heat and mass flux equivalence
- calculating drying times

Common themes in all sections

- Separation factor $= S_{ij} = \dfrac{x_{i,1}/x_{j,1}}{x_{i,2}/x_{j,2}}$
- Concentration of recovered compound in stream i
- Recovery $= \dfrac{\text{mass of desired compound recovered in stream } i}{\text{mass of desired compound in the feed}}$
- Separating agents: mass (MSA) and energy (ESA)
- Type of capital costs (equipment) involved

Take the following into account

For each separator we looked at, please aim to:

- understand the **physical principle** used in the separation
- know which **phases** are present and being separated?
- determine what affects the **unit's cost**?
- **identify variables** that can be used to fix a problem with the unit
- optimize an existing unit: increase throughput, boost recovery, aka "intensification"
- **repurpose** an existing unit for a similar, but different use.

Other tips

- Understand the concepts being learned. My courses are not about applying the correct equation and solving.
- Read the questions carefully: they are worded precisely. Answer all parts of the questions.
- None of the final exam questions are going to be from the assignments (even with different values).
- Check that your answers are reasonable (can you really have a flow rate of 1050 $m^3.s^{-1}$ through a pipe?)
- Computer questions in assignments: make sure you can repeat them by hand, where reasonable.

Most important advice

- Treat the exam as a closed-book test: have a formula sheet for the equations, and understand all the concepts without referring to a textbook or notes
- Textbooks and other papers should be used to refer to as a backup only.

Thank you

- It's been a long semester, **really busy**
- You've been the third round with 4M3 overhaul.
- Next year the class will be refocused a little more to water and energy topics
- But you have helped me tremendously with feedback about the notes and good questions in class and by email.
- Further comments? https://evals.mcmaster.ca or ...
- anonymously at http://learnche.mcmaster.ca/feedback-questions

Thank you.