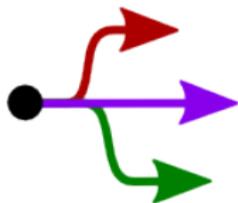


# Separation Processes

ChE 4M3



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

Overall revision number: 156 (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: 156

## Final exam details

- ▶ On Monday, 10 December 2012
- ▶ 12:30 to 15:30
- ▶ Building T-28
- ▶ It will likely be around 100 marks
- ▶ As we discussed previously, the number of questions you see is immaterial
- ▶ The question style will be mostly conceptual
- ▶ You can be sure there will be 100% coverage of the topics

**Please note:** *I've not set the final exam yet*, so please do not interpret anything from this lecture as being more/less important.

## What's in the exam?

Everything that was covered in class time

- ▶ Guest lecture
- ▶ Course presentations
- ▶ My lectures
- ▶ “Interactive tutorial-type” classes (i.e. Friday classes)

## To bring to the exam

- ▶ **Psychrometric chart:** available on course website. *It will not be provided*, and it will be required.
- ▶ Any notes, assignments, midterms, *etc* that you will feel are helpful
- ▶ Any textbooks and printed materials

Only limitation: no iPads, tablets, electronic devices

# How to do well in the final exam

- ▶ Review the midterm without solutions: *it should be easy now*
- ▶ 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 and from Seader *et al.*

# What can I do to prepare?

## Some tips from the educational research area:

- ▶ Don't look at a question/topic and say: "Yeah, I can do that". Prove that you can.
- ▶ While you are learning check/ask yourself whether you actually understand that topic.
- ▶ 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\*:

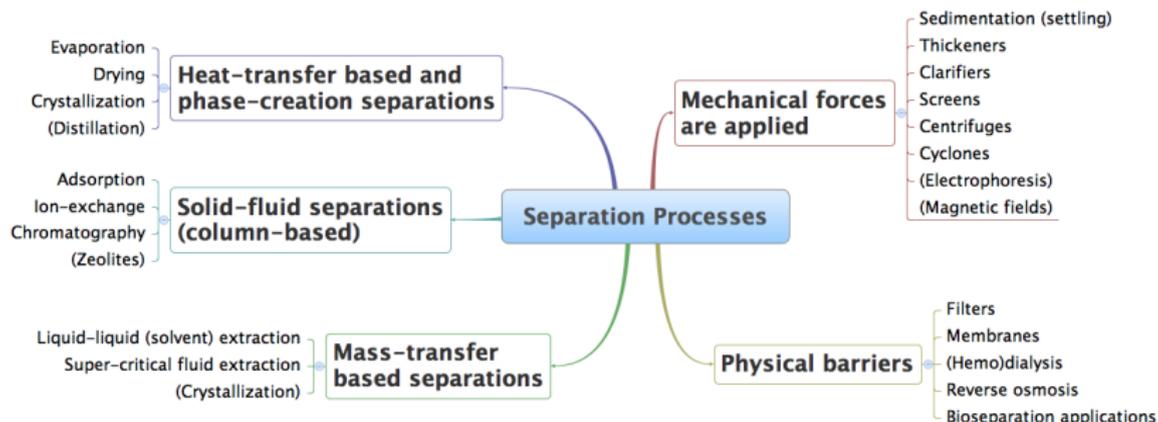
- ▶ Distractions: study with music, cellphones and email/website checking, TV on in background
- ▶ Skip over parts you don't understand
- ▶ After finishing, try to repeat text literally

\* 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)
  - ▶ centrifugation and drying (washing and tumble drying clothes)
  - ▶ absorption (your lungs)
  - ▶ membranes (your skin, kidneys)
  - ▶ adsorption (water filter)

# Some more context around the 4M3 course



# Can't remember what was covered when?

[http://learnche.mcmaster.ca/4M3/Course\\_videos\\_from\\_2012](http://learnche.mcmaster.ca/4M3/Course_videos_from_2012)



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## Course videos from 2012

All videos for the course "Separation Processes" are available for download from this page.

Date in 2012	Link to 2012 files	Download video/audio file	Video
06 September 2012	Course overview: administrative issues	38 minutes Download video # (91 M) Download audio # (35 M)	
07 September 2012	Overview of separation processes	46 minutes Download video # (103 M) Download audio # (42 M)	
11 September 2012	Mechanical separation: sedimentation	Download video # (118 M) [47 minutes]	

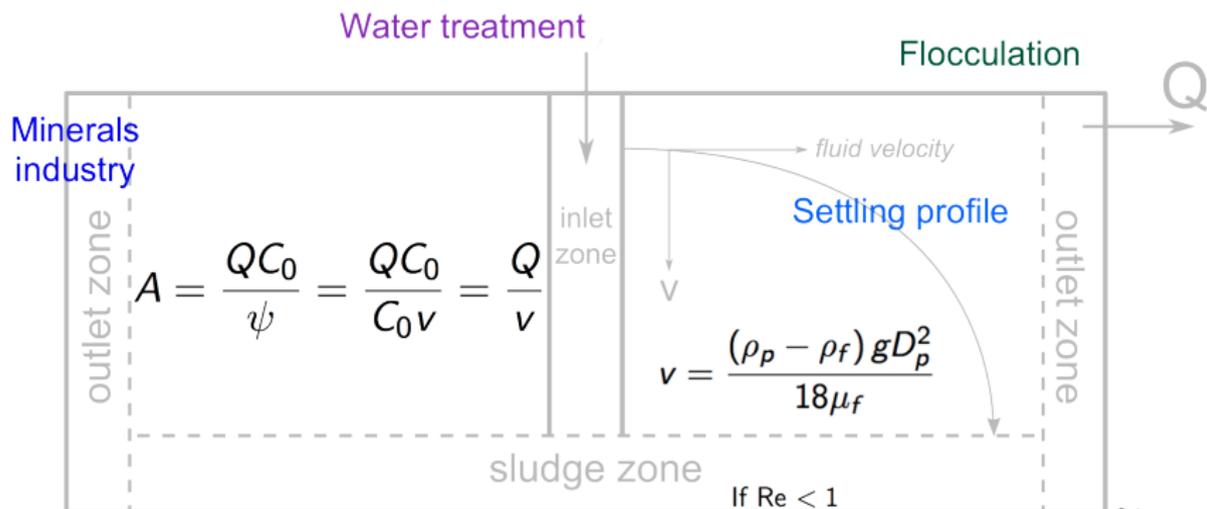
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# Mechanical separations

<b>Part</b>	<b>Topic</b>	<b>Week number</b>
1	Sedimentation	02A, 02B, 02C
2	Screens	03A
3	Centrifuges	03B, 03C, 04A
4	Cyclones	04B

# Sedimentation: 02A, 02B, 02C



Terminal velocity of an unhindered particle

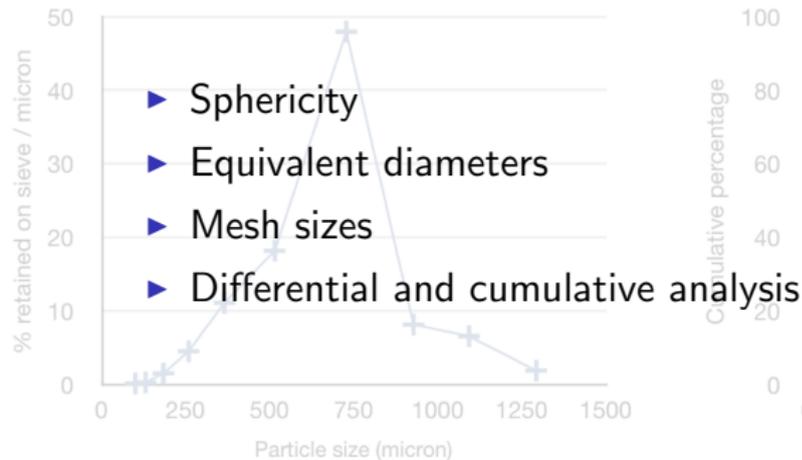
$$v = \sqrt{\frac{4(\rho_p - \rho_f)gD_p}{3C_D\rho_f}}$$

If  $1 < Re < 1000$

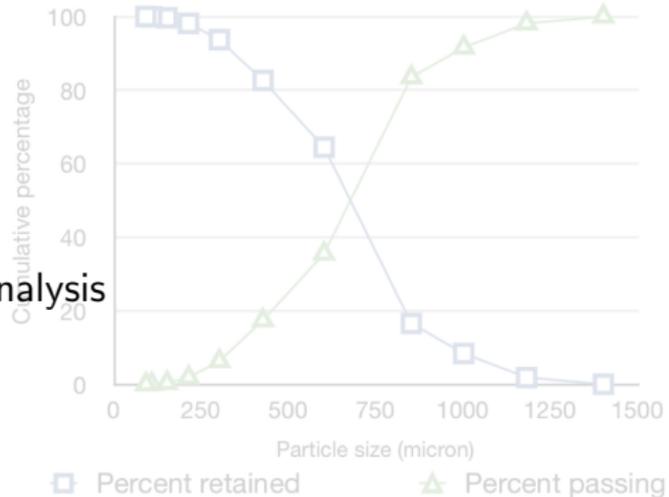
$$C_D = \frac{24}{Re} (1 + 0.15Re^{0.687})$$

# Screens: 03A

### Differential analysis



### Cumulative analysis



# Centrifuges: 03B, 03C, 04A

liquid discharge

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

liquid surface

bowl wall

particle trajectory

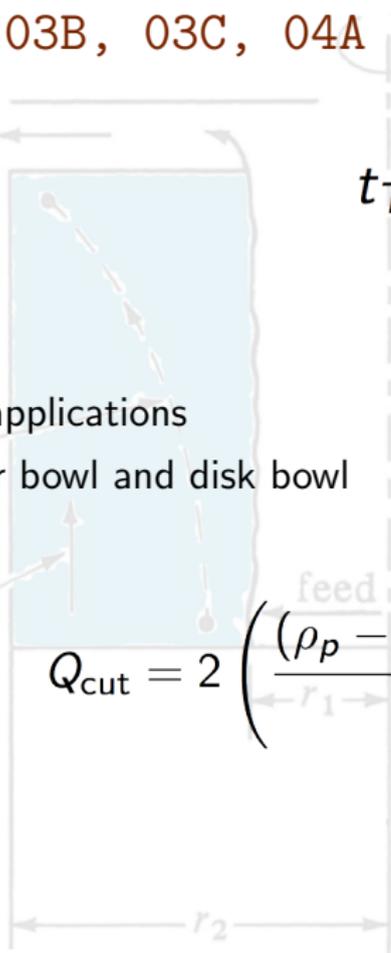
- ▶ Many applications
- ▶ Tubular bowl and disk bowl

feed flow

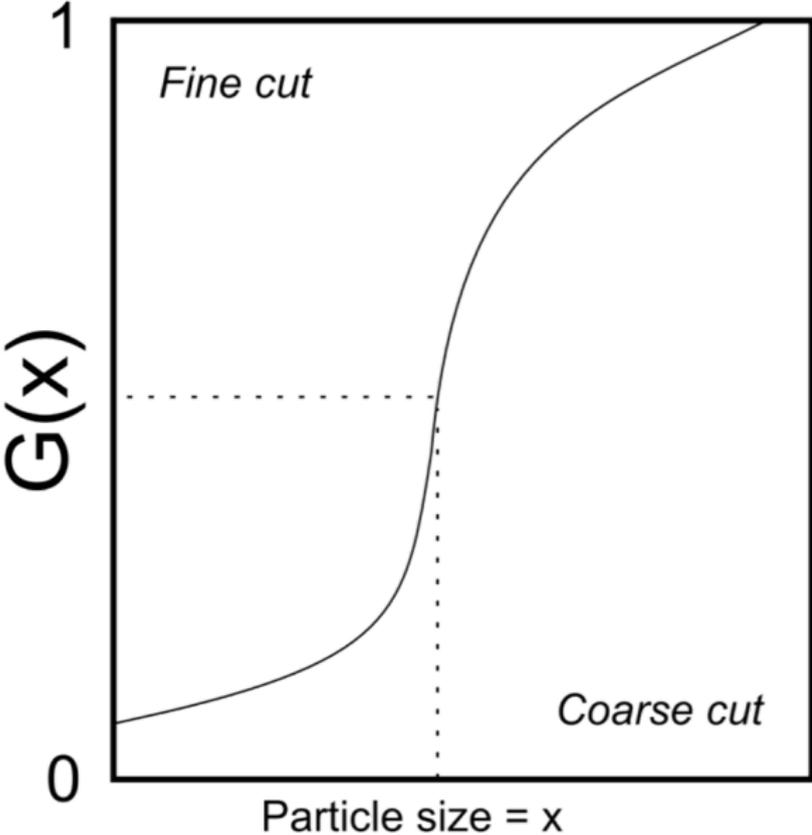
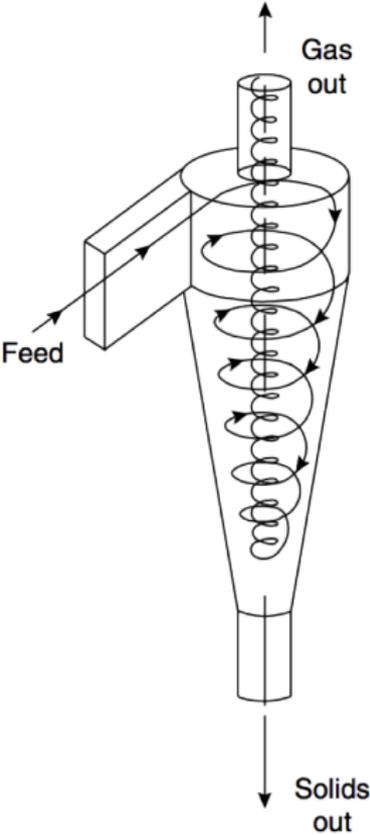
feed

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

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



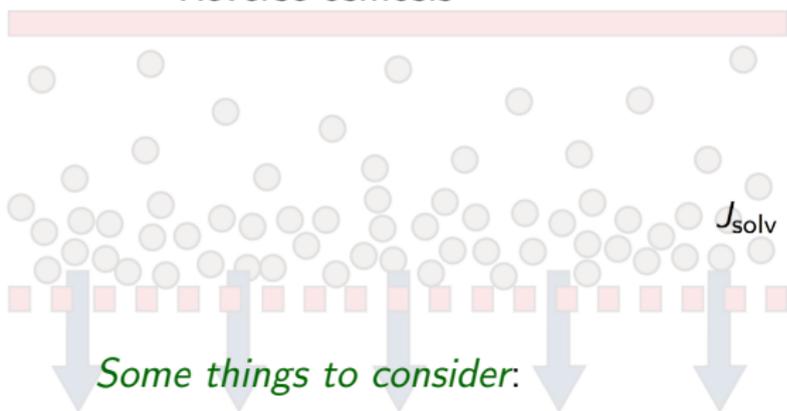
# Cyclones: 04B



## Membranes: 04C to 07C

### We studied:

- ▶ Microfiltration
- ▶ Ultrafiltration
- ▶ Reverse osmosis



*Some things to consider:*

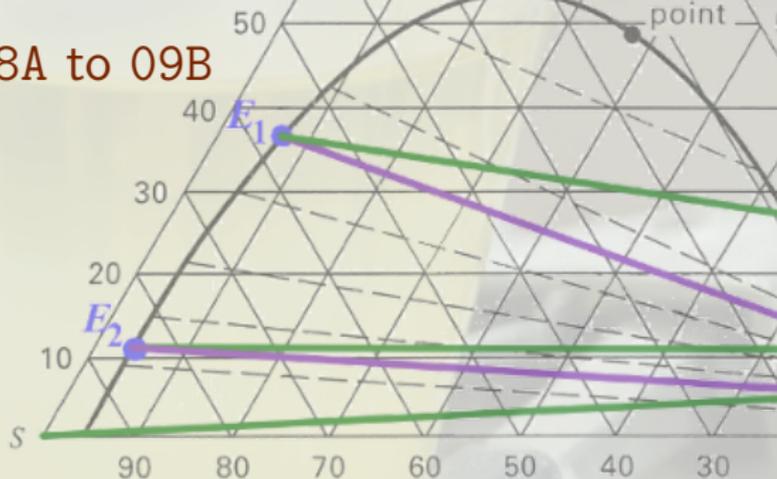
- ▶ What are typical LMHs,  $\Delta P$  and particle sizes retained?
- ▶ When can we set  $C_p \approx 0$
- ▶ When can we disregard membrane or cake resistance?
- ▶ How are permeances calculated?

$$\text{Flux} = J = \frac{\Delta P}{\mu (R_m \ell_M + R_c L_c)}$$
$$\frac{J L_c}{D_{AB}} = \frac{J}{h_w} = \ln \left( \frac{C_w}{C_f} \right)$$
$$J_{\text{solv}} = \frac{(\Delta P - \Delta \pi)}{R_{m,v} + R_{cp,v}} = \frac{P_{\text{solv}}}{\ell_M} (\Delta P - \Delta \pi)$$

## Liquid-liquid extraction 08A to 09B

### Plenty of new concepts

- ▶ ternary diagrams
- ▶ lever rule
- ▶ mixer-settlers
- ▶ tie lines
- ▶ equilibrium
- ▶ solute, solvent, carrier
- ▶ extract, raffinate, distribution coefficient  $D_A = \frac{y_{E,A}}{x_{R,A}}$
- ▶ recovery and concentration
- ▶ units in sequence
- ▶ countercurrent units

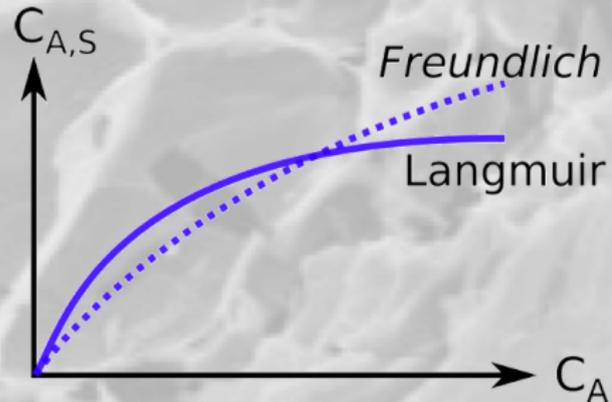


## Adsorption 10B to 11A

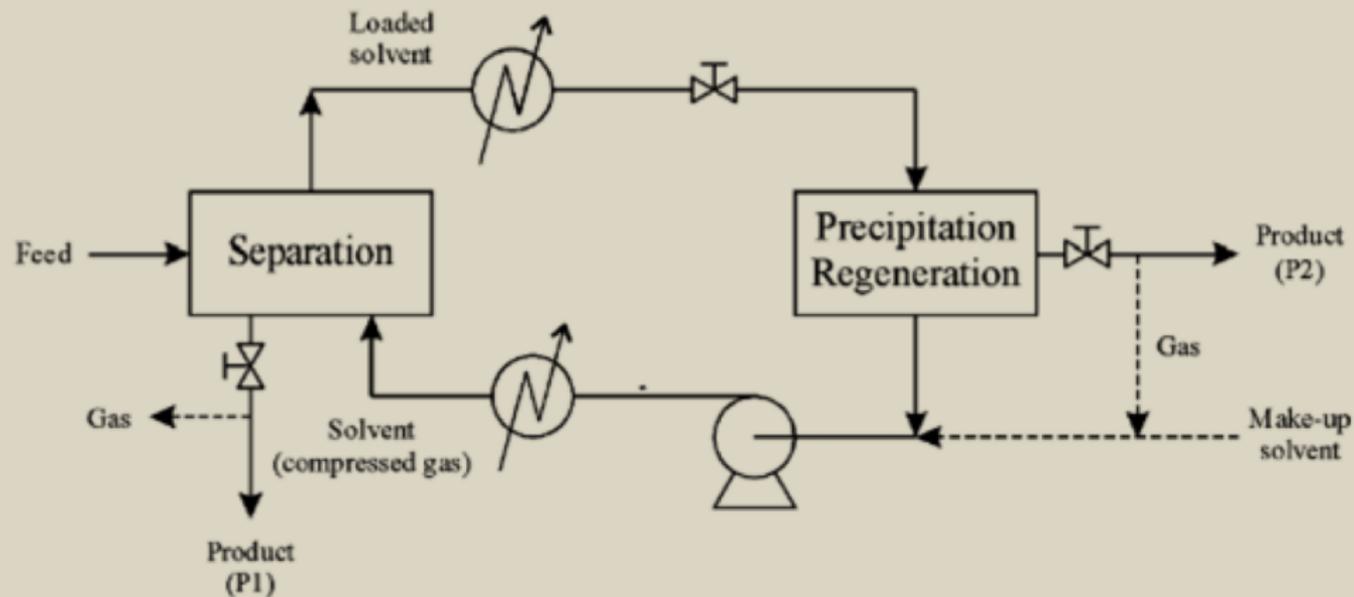
- ▶ Langmuir and Freundlich isotherms
- ▶ Breakthrough
- ▶ MTZ
- ▶  $L_{UNB}$
- ▶ Bed mass balance

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

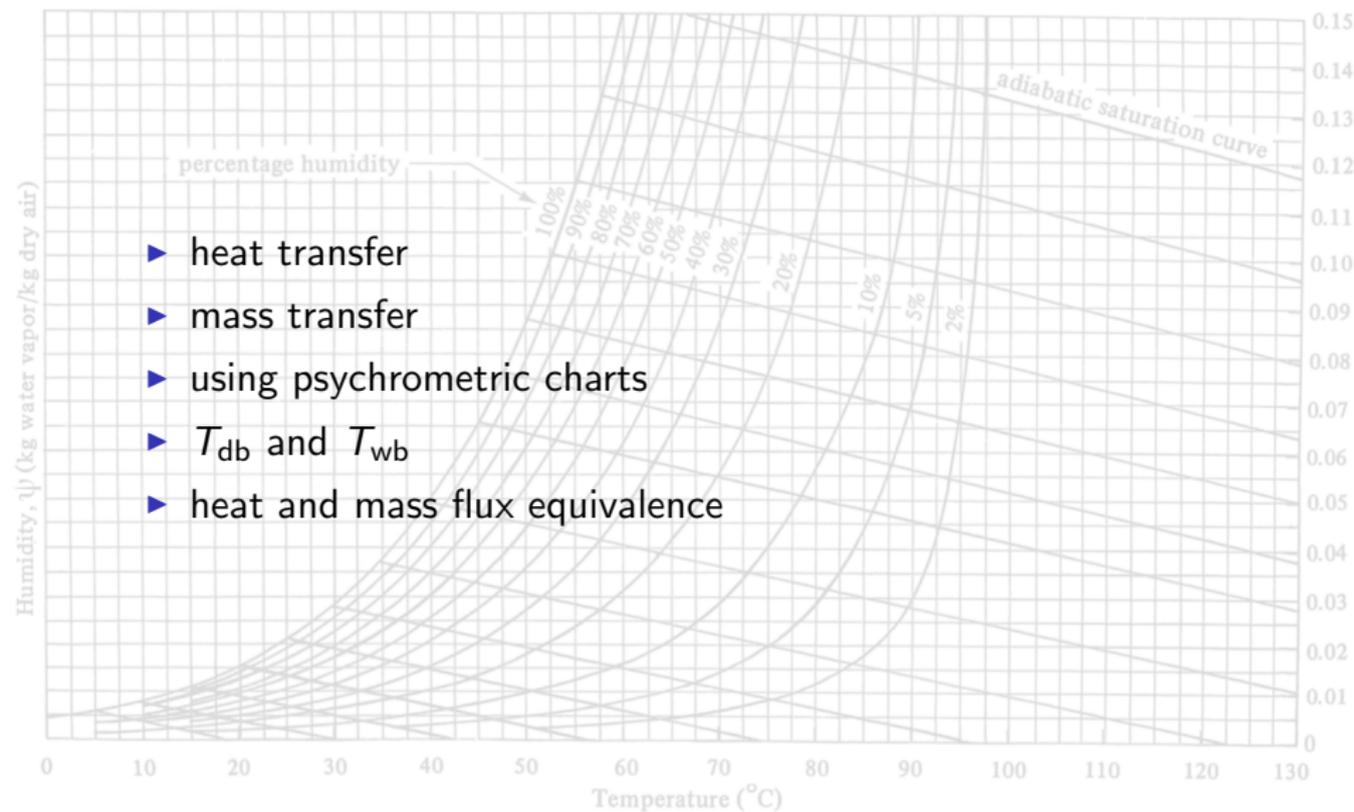
$$C_{A,S} = \frac{K_3 C_A}{1 + K_4 C_A}$$



# Supercritical fluid extraction 13A



# Drying 13A and 13B



## Common themes in all sections

- ▶ Separation factor =  $S_{ij} = \frac{x_{i,1}/x_{j,1}}{x_{i,2}/x_{j,2}}$
- ▶ Concentration of recovered compound in stream  $i$
- ▶ Recovery =  $\frac{\text{mass of desired compound recovered in stream } i}{\text{mass of desired compound in all other streams}}$
- ▶ Separating agents: mass (MSA) and energy (ESA)
- ▶ Which phases are 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** when troubleshooting problems 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  $1050 \text{ m}^3 \cdot \text{s}^{-1}$  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
- ▶ 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 guinea pigs for this 4M3 overhaul.
- ▶ In addition to it being my first time teaching this topic.
- ▶ Endured late midterms – 6 weeks – *yikes!* Sorry about that.
- ▶ 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 in person.

**Thank you.**