DEN5406: Mass Transfer and Separations Processes I

Week 7: Filtration, Leaching (Extraction), Washing (& Dry Cleaning), .

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Separations and Syllabus Goals

Obtain Quantitative Understanding of the following processes:

Filtration - ✔ we started and continue! **We'll also cover this week: ✔**

Aggregation

✔ **Centrifugation**

Crystallization (controlled freezing) separation

Adsorption

Leaching (extracting metals from ores, making coffee, dry cleaning) ✔

✔ **Osmosis**

- **Forward Osmosis**
- **Reverse Osmosis**

Ion-exchange membranes

Drying

Distillation (controlled evaporation and condensation) ✔
and the many kinds of distillation

Applications: Surviving in Space, on a desert island without fresh water

What we will cover

By the end of this lecture you'll be able to:

Say what is **caking.** Other vocabulary: **washing, dewatering, feed conditioning, constant pressure filtration, Filter productivity, cycle time, Rotary vacuum drum filter, vertical disk filter, horizontal belt filter, Nutsche filter, Buchner funnel, plate-and-frame filter press**
gas filtration, impingement separators, overall on-flow area, wave-plate separators, deep bed filters, inertial and flow-line interception

Measure amount of caking and its effect on filtration
Quantify the relationship between caking and pressure drop
Different **types of filters** and their **mechanisms**

Devise strategies for mitigating **pressure loss** and prolong **filter life**

Quantitate the filtration capacity of single fibers

Efficiency and cost comparisons – Cost of material, and pressure drop
(pressure drop not only cost, e.g. max vacuum to generate by mouth in straws**)**

Recommended Reading

Available on Knovel – in the library:
De Haan & Bosch, Industrial Separation Processes, 2013, de Gruyter (Berlin)

Distillation Fundamentals and Principles, Gorak & Sorensen, eds., 2014, Elsevier

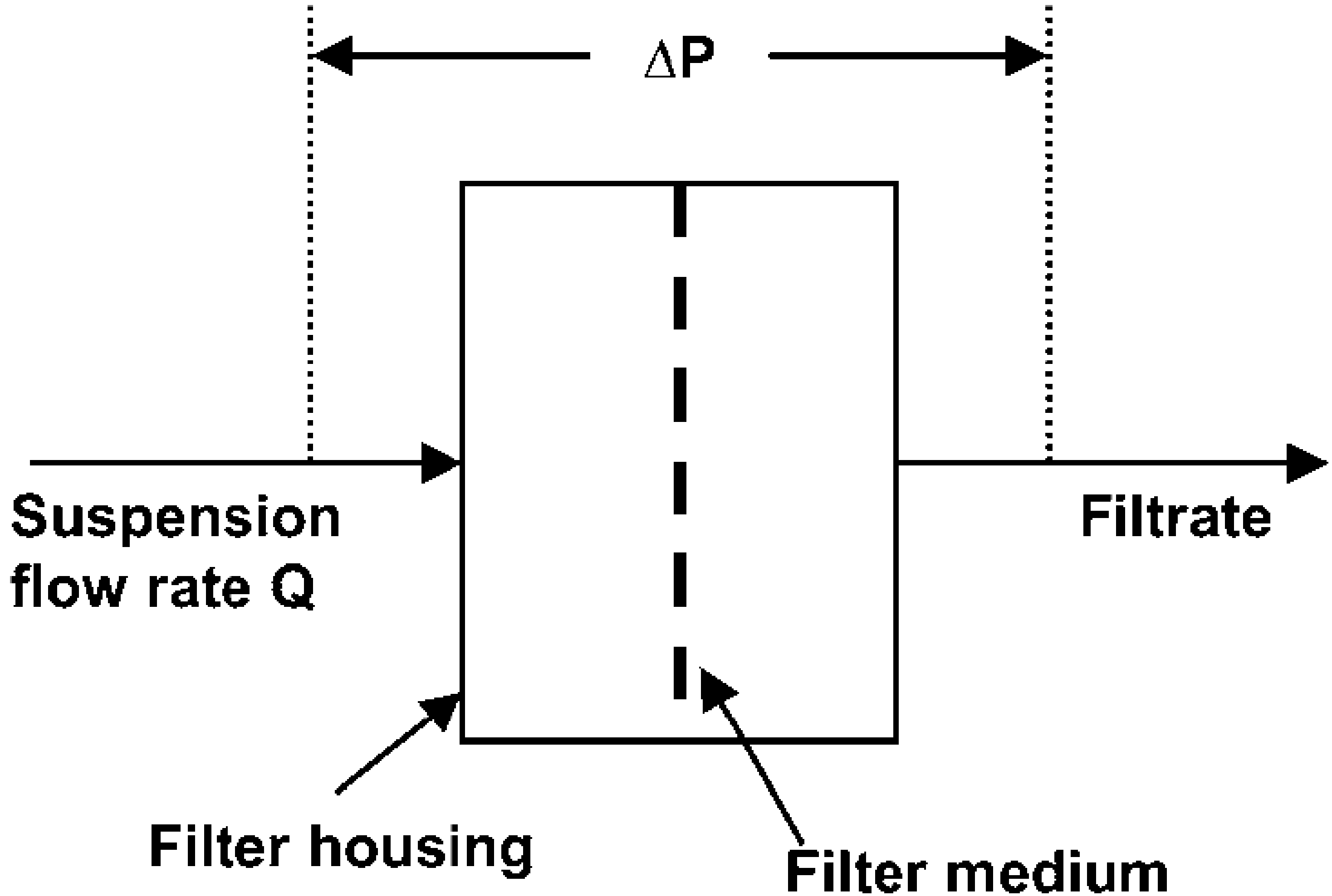
Reactive & Membrane-Assisted Separations, Lutze & Gorak, eds., 2016, de Gruyter

Also from
Seader, Henley, & Roper, Separations Process Principles, 2011, Wiley

Will assign pre-class reading -> will have a chance to discuss problems in class

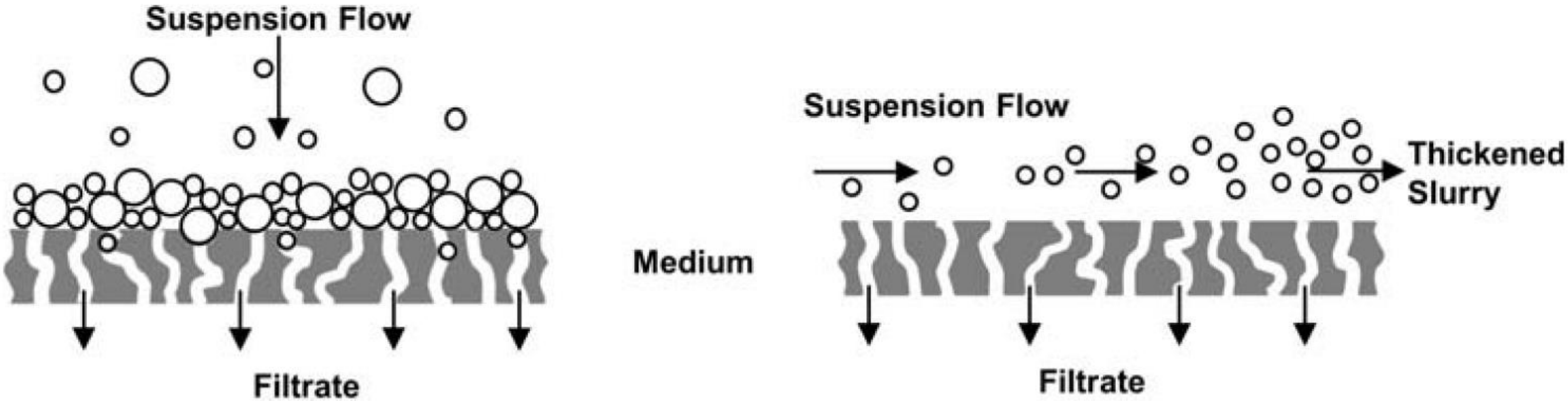
From Last Week:
Ch. 10 in
De Haan & Bosch, Industrial Separation Processes, 2013, de Gruyter (Berlin)

Filtration



Efficiency of filter = % particles retained (of a given size)
Efficiency vs. pressure drop (lower pressure is better)

Filtration – Caking and membranes



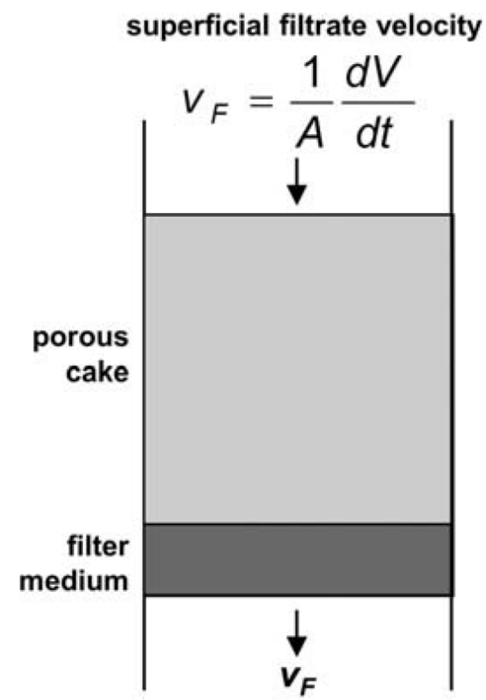
Cake vs. Cross-flow

Filter Porosity

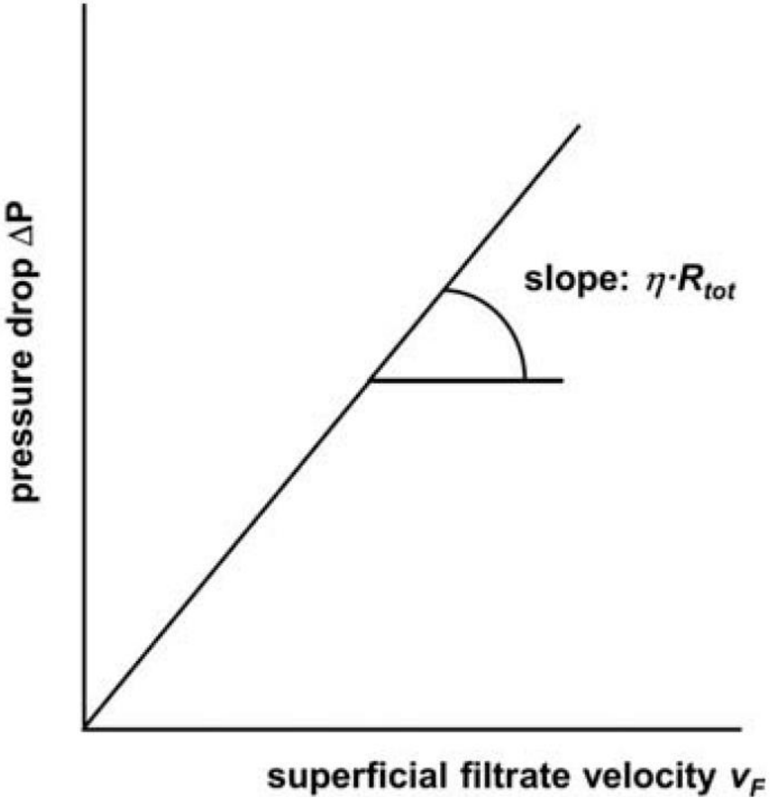
$$\varepsilon = \frac{volume\ of\ voids}{total\ bed\ volume}$$

Filtrate Velocity

$$v_F = \frac{\Delta P}{\eta\, R_{tot}}$$



Filtration – Quantitation



$$v_F = \frac{\Delta P}{\eta\,(R_M + R_C)}$$

Resistance due to filter medium
And to cake (R_M and R_C)

$$v_F = \frac{1}{A}\frac{dV}{dt}$$

$$\Delta P = \Delta P_C + \Delta P_M = \eta\,\frac{R_C + R_M}{A}\frac{dV}{dt}$$

Darcy's Law

De Haan & Bosch, Industrial Separation Processes, 2013, Ch 10.

Filtration – Problem Solving 1

Filtering cold water ($\eta = 10^{-3}$ Pa.s) always topping up to 10.2 cm water, yields 250 cm^3 in 1 min. The effective coffee filter area A is 0.0025 m^2. 1bar $=10^5$ Pa= 1020 cm column of water. How many Pa is the pressure?

$$v_F = \frac{1}{A}\frac{dV}{dt}$$

What is the resistance of the coffee filter paper?
Later you pour the same height of coffee, at 80 °C, ($\eta = 0.333\text{x } 10^{-3}$ Pa.s) and collect 200 ml in 1 min.
What is the resistance of the coffee grinds?

$$v_F = \frac{\Delta P}{\eta\left(R_M + R_C\right)}$$

Try to define the quantities for the equation yourself
It's not too hard – mostly identifying the words that
Go with the symbols and plugging in.

The goal of this is literally to change your brain.
Looking at the solution does a bad job of that.

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$$v_F = \frac{\Delta P}{\eta\,(R_M + R_C)}$$

Sometimes there are no solutions – need your own but here's a hint:

$$\Delta P = \Delta P_C + \Delta P_M = \eta\,\frac{R_C + R_M}{A}\frac{dV}{dt}$$

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$$v_F = \frac{1}{A}\frac{dV}{dt} = \frac{250\ cm^3}{25\ cm^2\ min} = \frac{10\ cm}{min} = \frac{1\ cm}{6\ s} = \ldots \frac{10^3 Pa}{10^{-3} Pa.s * R_M}$$

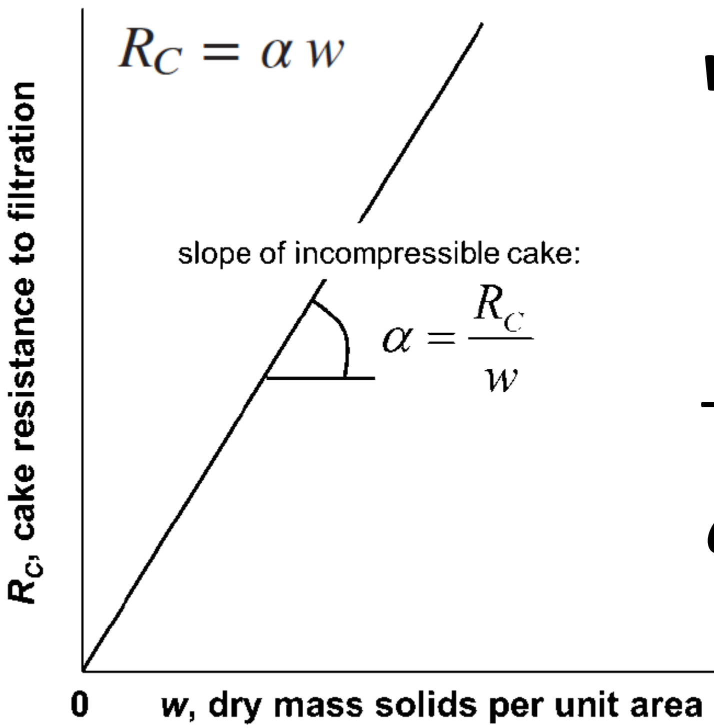
$R_M = 6\ x10^6$ /cm , so when $v_{Fcoffee}$ =0.1cm/s &

$\eta = 0.333x10^{-3}$Pa.s, $R_M+R_C=30x10^6$/cm, **$R_C=27x10^6$/cm**

Filtration – Incompressible Cake

Incompressible cake causes:

a *linear* increase in resistance $\boldsymbol{R_c}$ with *cake height*



w is mass dry solids per filter area A

$$w = \frac{c\,V}{A}$$ **[kg/m2]** where c is kg solids per volume V of suspension

The proportionality slope $\boldsymbol{R_c / w}$ is

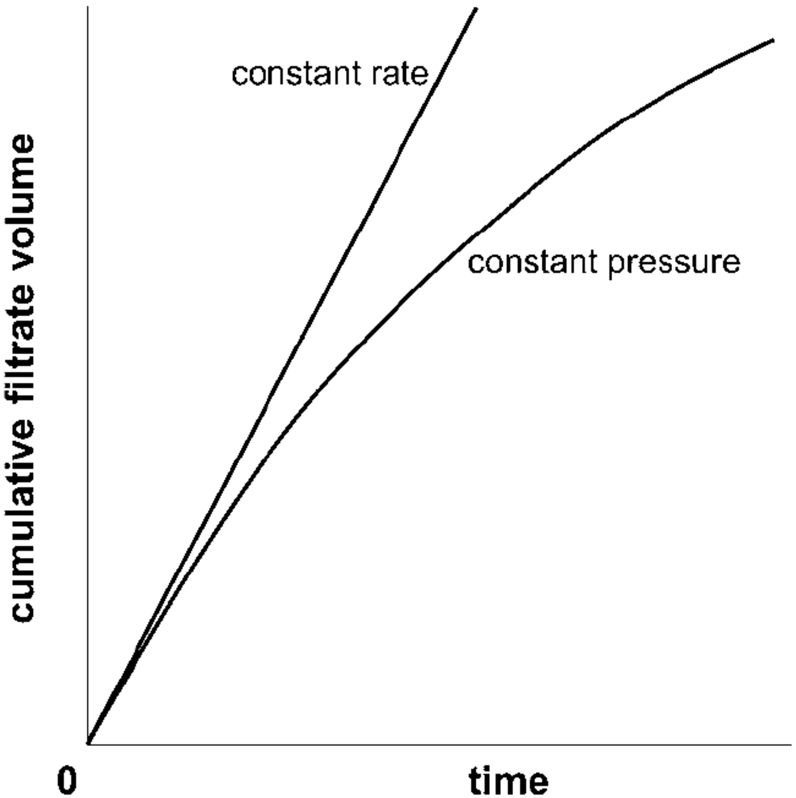
α - the **specific cake resistance** **[m/kg]**

Darcy's Law with specific resistance:

$$\eta\,\frac{R_C + R_M}{A}\,\frac{dV}{dt} \Rightarrow \Delta P = \frac{\eta\, c\, \alpha}{A^2}\, V\, \frac{dV}{dt} + \frac{\eta\, R_M}{A}\,\frac{dV}{dt}$$

Filtration – Incompr. Constant Pressure

Incompressible cake



Graph ***t/V* vs. *V*** to get:
the specific cake α and
filter medium resistance $\boldsymbol{R_M}$.

Constant pressure filtration,

After subsituting in Darcy's law and integration,

$$\int_0^t dt = \frac{\eta\, c\, \alpha}{A^2\, \Delta P}\int_0^V V\, dV + \frac{\eta\, R_M}{A\, \Delta P}\int_0^V dV$$

this yields the
Linearized parabolic rate law:

$$\frac{t}{V} = \frac{\eta\, c\, \alpha}{2\, A^2\, \Delta P}\, V + \frac{\eta\, R_M}{A\, \Delta P}$$

Filtration – Problem Solving 2

A slurry is filtered with a laboratory leaf filter with a filtering surface area of 0.05 m^2, using a vacuum pressure difference of 0.7 bar.
The slurry contains 5 vol% of solids (density 3000 kg/m^3)
Filtrate viscosity is 10^{-3} Pa.s (viscosity of water at room temp).
The volume of filtrate collected in the first 5 min was 250 cm^3 and, after a further 5 min, an additional 150 cm^3 was collected.
Determine the specific cake and cloth resistance.

A bit harder – but still …
Try to define the quantities for the equation yourself

The brain is a hard thing to change.
I'll guide you through this problem, do more yourself.

Filtration – Incompr. Constant Rate

<u>Incompressible cake</u>

$$\Delta P = \frac{\eta\, c\, \alpha}{A^2}\, V\, \frac{dV}{dt} + \frac{\eta\, R_M}{A}\, \frac{dV}{dt}$$

Characteristic Plot:

ΔP

vs V.

slope and intercept from such a graph provide the specific cake α and filter medium resistance R_M.

<u>Constant rate filtration</u>, subsituting in Darcy's law

$$\frac{dV}{dt} = \frac{V}{t} = \text{constant}$$

yields the

Pressure change with time:

$$\Delta P = \left(\frac{\eta\, c\, \alpha}{A^2}\,\frac{V}{t}\right) V + \left(\frac{\eta\, R_M}{A}\,\frac{V}{t}\right)$$