DEN5406: Mass Transfer and Separations Processes I

Week 6: Overview of Separations by examples in Water Processing. Comparing methods. Searching Literature.

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What we will cover

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

Start to know what you don't know

Think of alternative separation strategies

Recognize Vocabulary: Phase-change separations? Distillation, crystallization, membrane separation, centrifugation, adsorption and phase transfer,

Understand why all separations come with a cost

Start thinking of comparing and contrasting

Get familiar with the dangers but also possibilities of **drinking from a dirty pool of water**

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

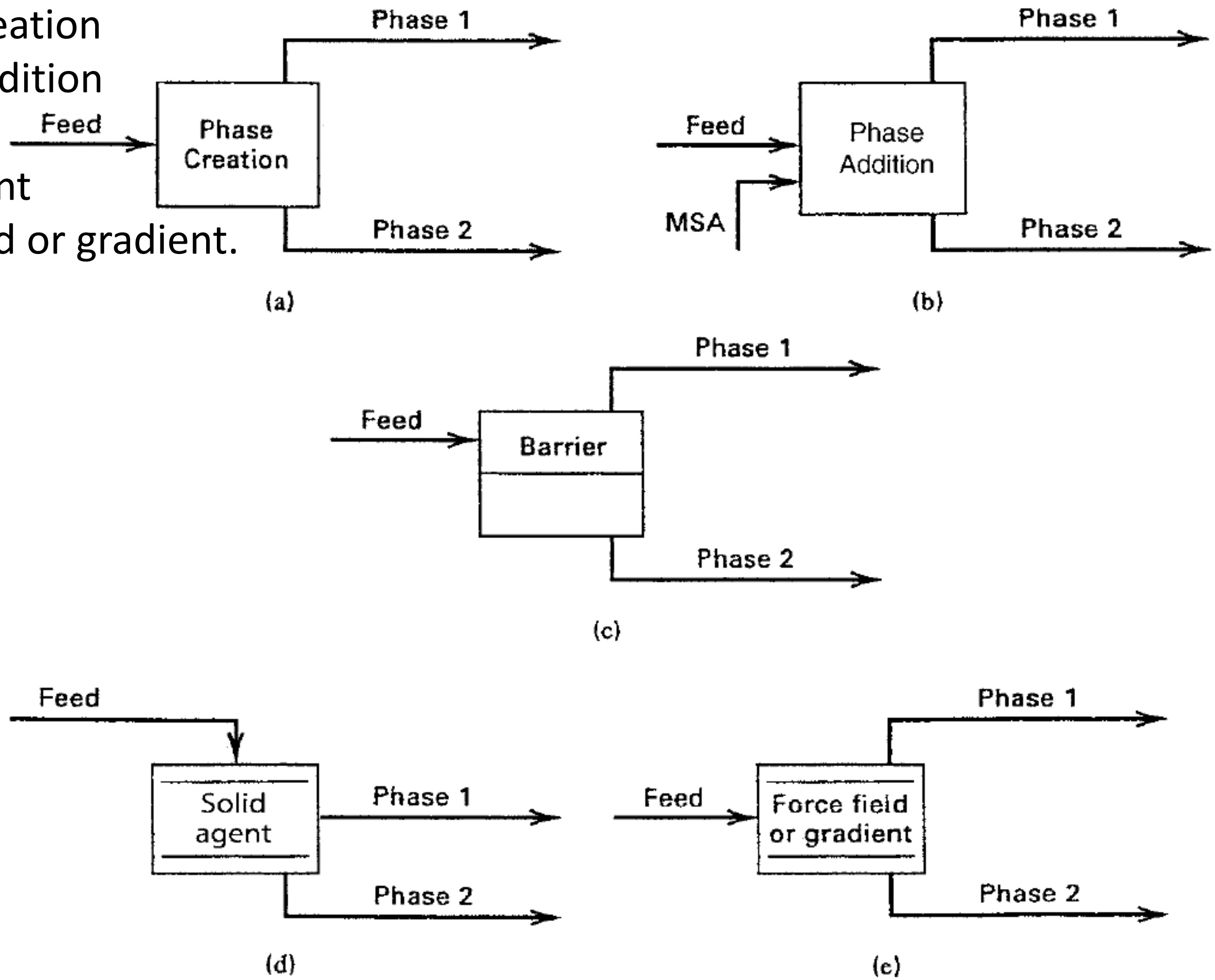
Will assign pre-class reading -> will have a chance to discuss problems in class

Applications in courseworks:
Surviving in Space,
Surviving on a desert island without fresh water
Generating power from fresh and salty water,
Etc.

Introduction

Goals: Five basic separation methods: Learn and Explain how they work.
They are (Seader, p.6) :

1. separation by phase creation
2. separation by phase addition
3. separation by barrier
4. separation by solid agent
5. separation by force field or gradient.



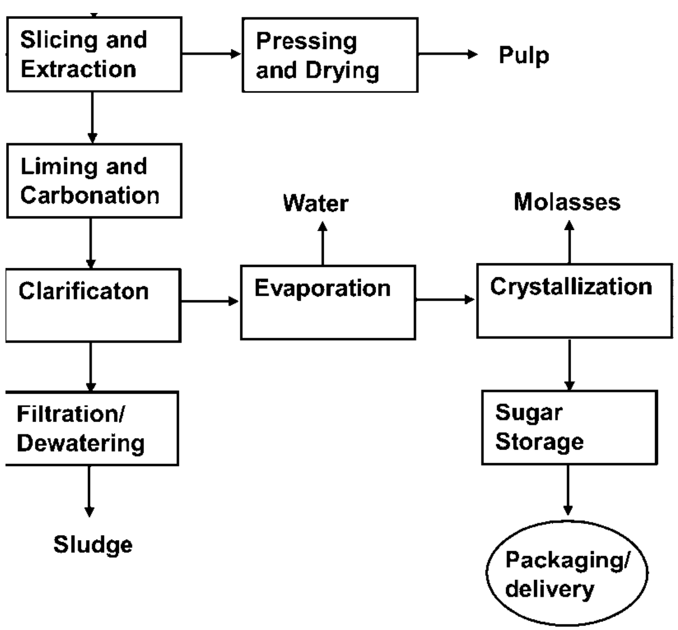
Introduction

Some important bulk thermodynamic and transport properties are:

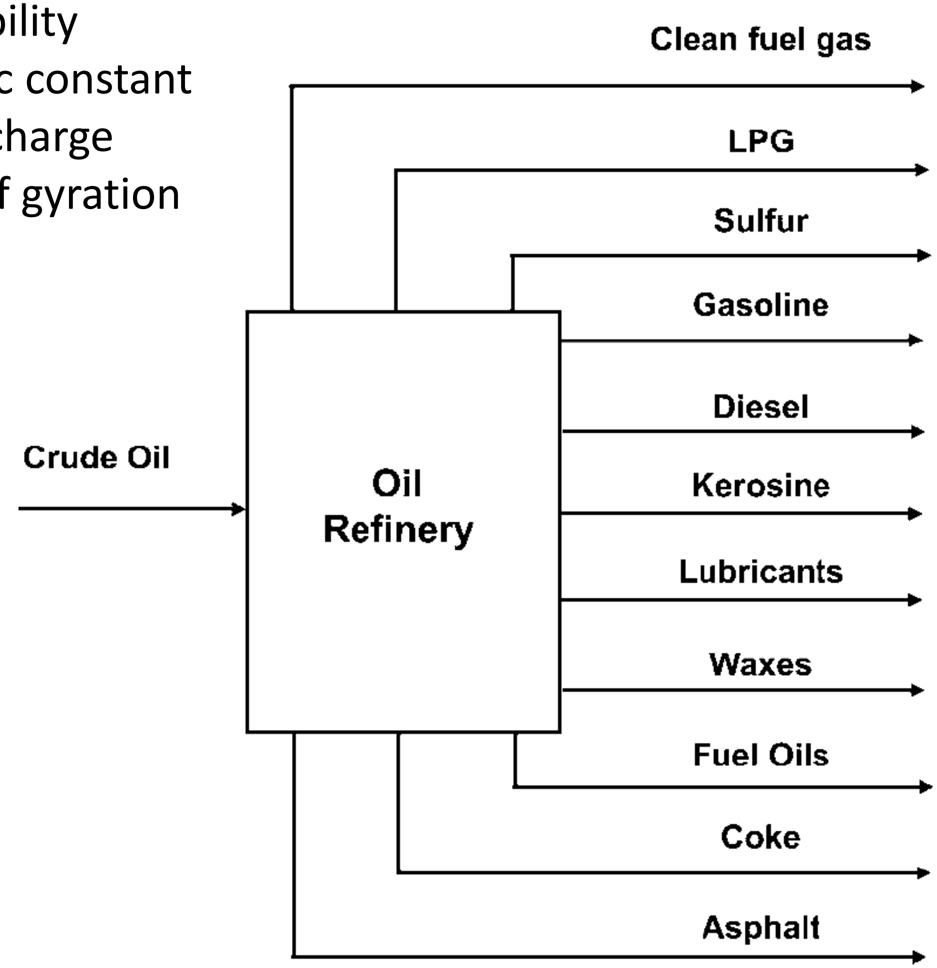
Vapor pressure, Adsorptivity, Solubility and **Diffusivity.**

Differences in bulk properties result from molecules with different properties, such as:

- Molecular weight
- Van der Waals volume
- Van der Waals area
- Molecular shape
- Dipole moment
- Polarizability
- Dielectric constant
- Electric charge
- Radius of gyration



Sugar from Sugar Beets



Oil Refinery – oil fractionation

Conceptual Framework

What do you already know about separation?

Coloring flowers – which processes involved?

Wearing face mask in polluted air?

Carrots in oil – oil is orange – why?

Phase transformation by itself – not enough – Honey freezing.

Drying foods -> solar, thermal,,, (to preserve)

What's another preservation method – salt… -> cure, pickle

We smell food, we also smell ourselves
Oil – we eat, but we also secrete.

Phase transfer - Washing – hands, hair, clothes.. Same

Conceptual Framework

What do you already know about separation?

Washing rice – with a strainer
Letting aerated water clear:
Separating fat from milk:
Boiling water out to concentrate a meal:
Selectively crystallizing something in cooking?

Purifying water: Filter, added salts + precipitation,
Filter sterilization?, Boiling? Distillation?

Sometimes components are so small, need a molecular filter.

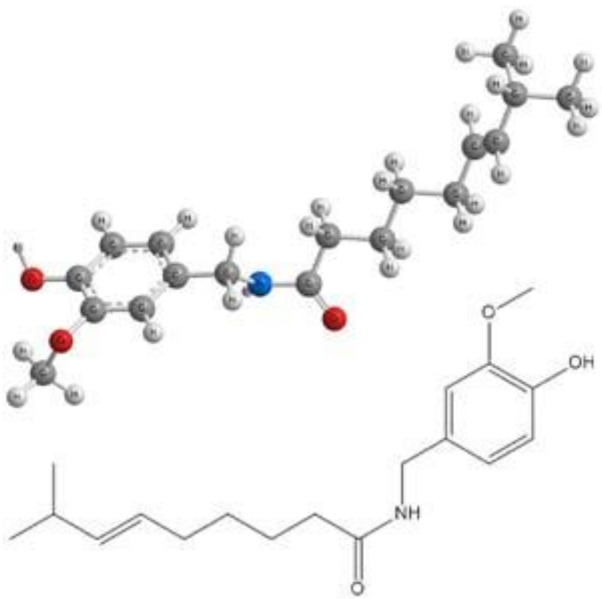
Separation of liquids by distillation

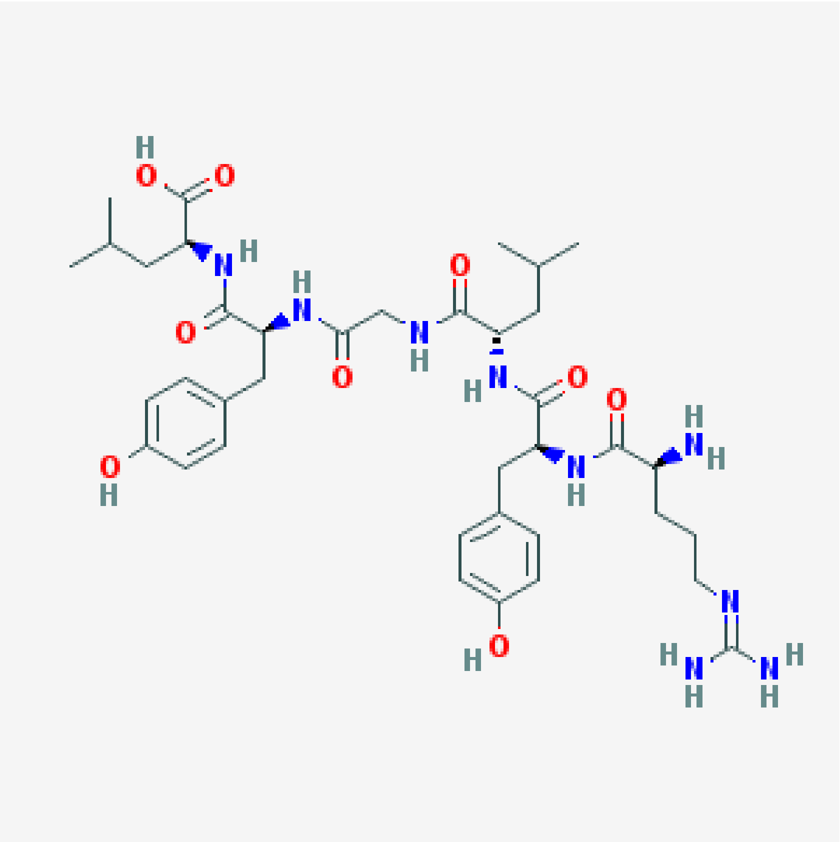
Milk? As a separator?

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

How to Deal with a Hot Meal

Molecular Structure - Capsaicin





Molecular weight[7]: 305.462 g/mol
Solubility (water)[7]: 10.3 mg/L at 25 °C
Octanol-Water Partition Coefficient (K_{ow})[7]: 3.04

Arg-tyr-leu-gly-tyr-leu; Alpha-Casein(90-95);
Molecular Formula:C38H57N9O9
Molecular Weight: 783.928 g/mol

Tutorial 1: Osmosis calculations

Pressure from differences in concentration of solute

$$\Pi_{osm} \approx c\,R\,T$$

R = 0.082 L atm K^{-1} mol^{-1}
C is in mole/L (count each ion)
Π is in atmospheres. 1atm = 10^5 Pa

Table 11.1 Osmotic pressures of various aqueous solutions [1].

Sodium Chloride Solutions			Sea Salt Solutions		Sucrose Solutions	
g mol NaCl / kg H_2O	Density (kg/m^3)	Osmotic Pressure (atm)	Wt.% Salts	Osmotic Pressure (atm)	Solute mol frac ($\times 10^3$)	Osmotic Pressure (atm)
0	997.0	0	0	0	0	0
0.01	997.4	0.47	1,00	7.10	1.798	2.48
0.10	1001.1	4.56	3.45[a]	25.02	5.375	7.48
0.50	1017.2	22.55	7.50	58.43	10.69	15.31
1.00	1036.2	45.80	10.00	82.12	17.70	26.33
2.00	1072.3	96.2				

[a] Value for standard seawatter

$$\Pi_{osm} \approx c\,R\,T = \rho\, g\, \Delta h$$

Reverse Osmosis –
Can counteract that with Hydrostatic pressure!

12% Sugar by wt (MW = 342 g/mol) Πosm=?

Osmosis – practice that could save a life

2. For blood transfusions, so your red blood cells don't explode, you need Sodium Chloride 0.9% intravenous **infusion** is an **isotonic solution**, with an approximate osmolarity of 308 mOsm/l. You have many bags of isotonic solution, but you need fresh drinking water from them.

How much minimum pressure do you need to purify this solution by reverse osmosis?

What about starting from sea water?

Separations and Syllabus Goals

Obtain Quantitative Understanding of the following processes:

Filtration

Aggregation

Centrifugation

Crystallization (controlled freezing) separation

Adsorption

Leaching (extracting metals from ores, making coffee)

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

Water Processing can involve all of the following:

Filtration
Aggregation
Centrifugation
Crystallization (controlled freezing) separation
Adsorption
Leaching (extracting metals from ores, making coffee)
Osmosis
- **Forward Osmosis**
- **Reverse Osmosis**

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

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

Searching Scientific Literature

Web of Science -> http://isiknowledge.com
Google Scholar -> http://scholar.google.com

Keywords
Finding reviews – new concepts and keywords
Sorting to find important articles

How to get the articles
How to read them – start with abstract (often you can stop there)

Further searching – keywords, search, repeat

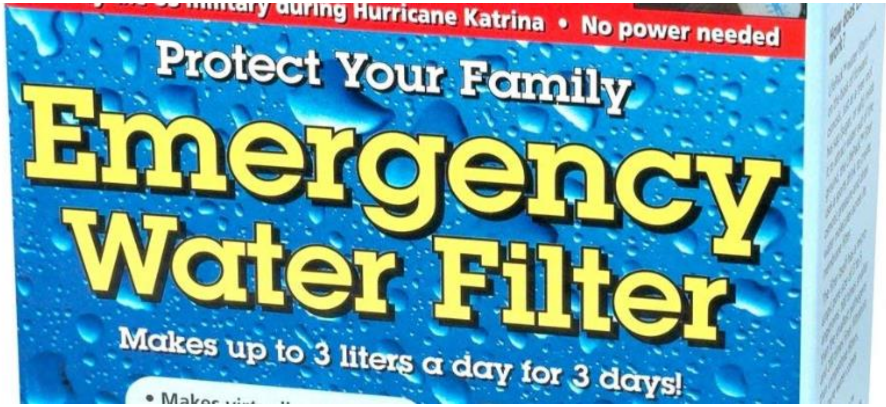
Making Products, Making a Difference

Water Purification for Disaster situations:

How to make it:
Cheap
Safe
Clear
Good-tasting
Easy to Deliver

and
Extra benefits and
Local considerations

VS.



VS.

Hydration Technology Innovations LifePack Water Filter

by Hydration Technology

☆☆☆☆☆ 9 reviews from Amazon.com

Share

Price: £124.00 + £4.38 delivery

Note: Not eligible for Amazon Prime.

1 new from £124.00

- Compact water filter that produces 3-day supply of drinking water
- Ultra-pure forward osmosis filter works with virtually any water source
- Uses sports drink syrup to add electrolytes to water; non-clogging filter design
- Includes six 2-ounce syrup charges and 60-fluid-ounce filter
- Meets or exceeds all EPA criteria for bacteria, viruses, and cysts

Report incorrect product information.

£124.00

+ £4.38 delivery

Get it as soon as 6 - 18 Dec. when you choose **Standard Delivery** at checkout. Details

Usually dispatched within 2 to 3 days.

Dispatched from and sold by MMC America Direct.

£124.00 + £4.38 delivery

Quantity: 1 ▼

WARNING!

Although we are continuing to list HTI products (at least temporarily), there is a real possibility that the company has been foreced out of business because of a fire at their manufacturiing plant. Consequently, we will not be filling orders at this time. Shipping will resume as soon as HTI is able to advise us that their difficutlieshave been rectified.

Meeting Outdoor Needs

			
HTI X-Pack Personal Water Filtration System	HTI LifePack Family Water Filtration System	HTI HydroPack Self-Hydrating Water Filter Pouches	HTI SeaPack Personal Desalination Kit
Price $57.95	**Price** $34.00	**Price** $229.95	**Price** $79.95
Qty 1	**Qty** 1	**Qty** 1	**Qty** 1
Add to Cart	Add to Cart	Add to Cart	Add to Cart
16L (10x1.6L)	9L	38.3L (108x0.355L)	4L (8x0.5L)
$3.56/L	$3.8/L	$6/L	$20/L

SEAL™ WATER FILTER

EMERGENCIES • TRAVEL • RECREATION

FOR USE IN FRESH OR SALT WATER

JUST DROP IN WATER AND LET HYDRATE FOR A CLEAN, REFRESHING SPORTS DRINK

BLOCKS ** BACTERIA, VIRUSES & CYSTS

REMOVES MORE THAN **93% OF SALT** FROM SEA WATER

NOMINAL PORE SIZE: 0.0007 MICRON

- EASY TO USE
- NON-CLOGGING
- NUTRIENTS
- HIGH RELIABILITY

DRINKANYWATER.COM

FTS H_2O™
Fluid Technology Solutions

HOW TO USE

Simply place the dry pouches in the water source. In open water, use the provided net and tether to life raft or other object. The Seal will swell over time as water flows through the membrane wall into the pouch. When finished, simply poke with the included straw and drink.

SUBMERGE DRY POUCH IN WATER SOURCE

REMOVE WHEN POUCH IS FULL

DRINK STICK STRAW IN TOP CORNER

[NOTE: UNUSED POUCH MAY BE MOIST IN PACKAGE]

⚠ CONSUME DRINK WITHIN 24 HOURS OF PLACING POUCH IN WATER. POUCH CANNOT BE RE-USED. DO NOT USE IN ANTIFREEZE. USE IN NATURAL WATERS. DO NOT USE IN INDUSTRIAL WASTE WATERS.

Nutrition Facts

Serving Size 1 pouch (50g)

Amount Per Serving

Calories	205
Total Fat 0g	0%
Sodium 98mg	4%
Potassium 170mg	5%
Total Carbohydrate 50g	18%
Sugars 50g	
Protein 0g	

Not a significant source of calories from Fat, Saturated Fat, Cholesterol, Dietary Fiber, Vitamin A, Calcium, Iron.

*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs.

Ingredients: Dextrose, Fructose, Monopotassium Phosphate, Salt, Malic Acid, Tartaric Acid.

SINGLE USE ONLY.
DISCARD AFTER USE.
EXPIRATION DATE: 5 years after packaging date when stored continuously below 90°F (33°C). If possible, store cool and away from direct sunlight.

**In independent laboratory tests FTS filter technology meets or surpasses the 6-log bacteria (99.9999%) reduction as specified by the EPA for water purifiers.

WATER TEMPERATURE MATTERS!

Approx volume to expect at 8 hours in **SALTWATER** temperatures:

Temp	Vol (ml)
5°C	155
20°C	210
30°C	216
20°C	210
5°C	155

SEAL IN FRESHWATER AT 8 HOURS

Temp	Vol (ml)
5°C	310
20°C	365
30°C	370

FTS H_2O™
Fluid Technology Solutions
DRINKANYWATER.COM
info@drinkanywater.com

http://skallywagtactical.com/product/mariner-f20-emergency-desalinator/

1.5L (3x0.5L) = $70, so
$47/L
That is £37 / L – ok to save your life but not the kind of price you want to pay for water.

Used by the US Coast Guard and militaries around the globe

production:	500ml per use
uses:	one time
purity:	6-log bacteria reduction, 97% salt rejection
hydration time:	8 hours at 20° C
calories:	480 per use

FTSH2O™
Fluid Technology Solutions

Simple and easy emergency desalination. The Mariner F2O desalinator works by osmosis, the natural way of filtering water.

When placed in a salt water source, the nutrient powder blend inside the Mariner draws water through the pouch's membrane filter walls while blocking contaminants -- including 97% of salt.

To use, simply place the Mariner F2O directly in the sea water and tether the filter to the raft or stationary object. That's it. As water flows into the pouch by osmosis, salt and other contaminants are kept outside the filter. No pumping or manipulation is required.

The result is a clean and hydrating drink that provides 480 critical calories invaluable in survival situations at sea.

Cost of Water

Engineers sit in between studies of pure science and applications
We must understand not only

- **Focused scientific studies but**
- **Cross-disciplinary view of the problems**
- **Scale-up**
- **Process Efficiencies**
- **Economics**
- **Marketing**
- **…**
- **Applications**

Entrepreneurs: Read this and articles & patents citing it: New commercial cellulose acetate membrane for forward osmosis, Desalination 343 (2014) 187–193 http://dx.doi.org/10.1016/j.desal.2013.11.026

An Engineer can make for a £1… what any fool can make for £2!

£3.51/2000L = 0.0017 £/L

HTI LifePack Family Water Filtration System

3.0 £/L

Local Utility Cost

https://www.thameswater.co.uk/

Membrane Separation

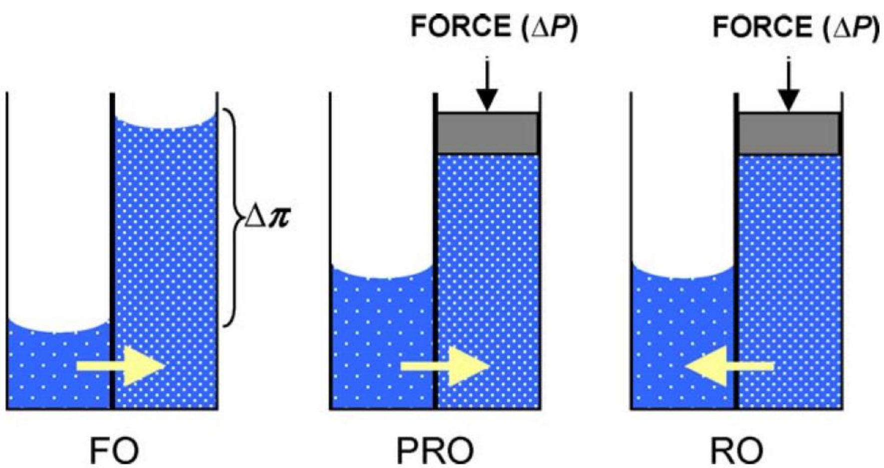
$$J_W = A\,(\sigma\Delta\pi - \Delta P)$$

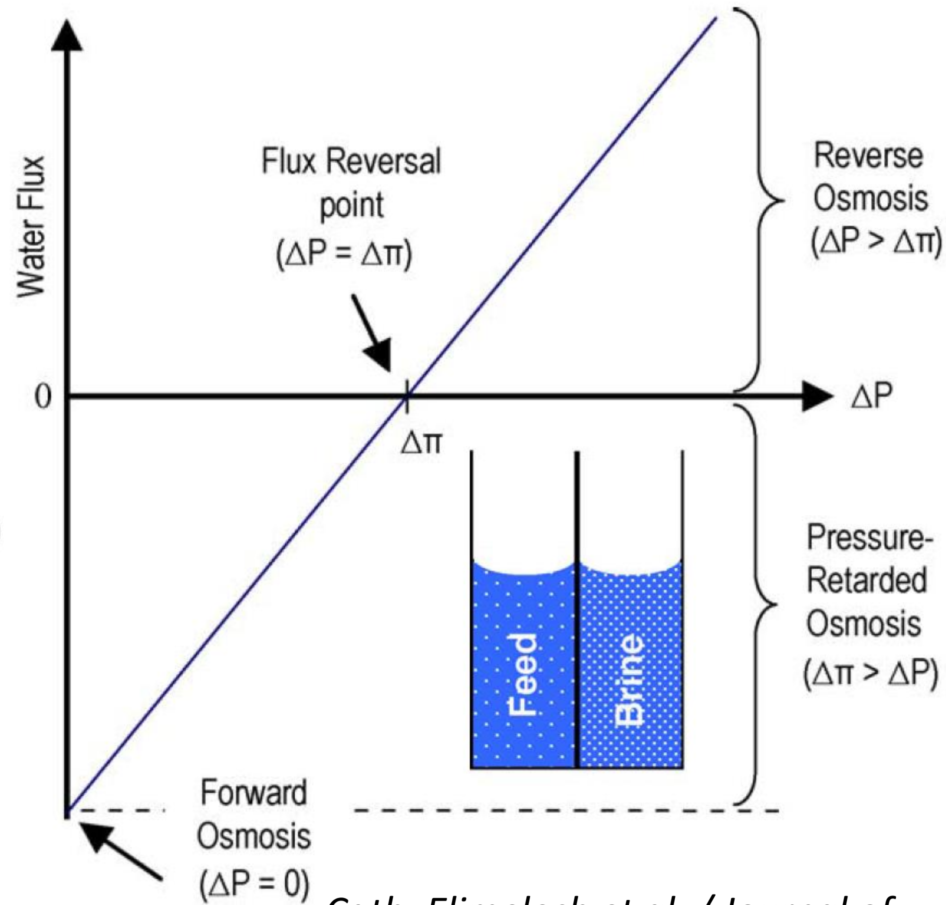
Where Jw is the water flux, A – membrane area, σ – reflection coefficient, $\Delta\Pi$ osmotic pressure and ΔP operating pressure

For Forward Osmosis $\Delta P = 0$

For Reverse Osmosis $\Delta P > \Delta\pi$

For Pressure-retarded Osmosis (PRO) $\Delta\pi > \Delta P$





Cath, Elimelech et al. / Journal of Membrane Science 281 (2006) 70–87

Forward Osmosis

$$J_W = A\,(\sigma\Delta\pi - \Delta P)\text{, where } \Delta P = 0$$

Where Jw is the water flux, A – membrane area, σ – reflection coefficient, ΔΠ osmotic pressure and ΔP operating pressure

$$J_W = A\,(\sigma\Delta\pi)\text{, and}$$

$$\Delta\pi = \mathrm{c\;R\;T}\text{, so}$$

$$J_W = A\;\sigma\;\mathrm{c\;R\;T}$$

If *A and* σ are constant, and a bag fills at 25 ^{o}C in 4 hrs, how long it would take to fill at 20 ^{o}C?

HTI Sea Pack Crew instructions say:
Hydration complete at 10 hrs at 20 ^{o}C and
15 hrs at 5 ^{o}C.
What does this say about σ?

Centrifugation

$$v_g = \frac{d^2\ (\rho_p - \rho_l)}{18\ \eta}\ g$$

Stokes flow of particle with diameter (d) determines **sedimentation velocity**
Driven from difference in densities, + depends on fluid viscosity (η) and acceleration (g)
ρ_p , ρ_L are the particle and liquid densities.

$\boldsymbol{g = r\ \omega^2}$, where r = radius of rotor, and
ω is angular velocity (rpm or Hz)

If we need to settle something to the bottom of a 1cm vial, then instead of velocity, we need **settling time**. $\boldsymbol{S}_{settle} = \boldsymbol{V}_g * \boldsymbol{t}_{settle}$

$$\boldsymbol{T}_{settle} = \boldsymbol{S}_{settle} / \boldsymbol{V}_g = \frac{18\ \eta\ \boldsymbol{S}_{settle}}{\boldsymbol{d}^2\ (\rho_p - \rho_L)\ \boldsymbol{g}}$$

Centrifugation - Practice

What is the **sedimentation velocity**
Of an oil droplet with size 100 microns.
ρ_p, ρ_L are 900 and 1000 kg/m^3 (oil & water)

$$V_g = \frac{d^2 \ (\rho_p - \rho_l)}{18\ \eta}\ g$$

$\boldsymbol{g = r\ \omega^2}$, your centrifuge runs at $\omega = 2000$ rpm

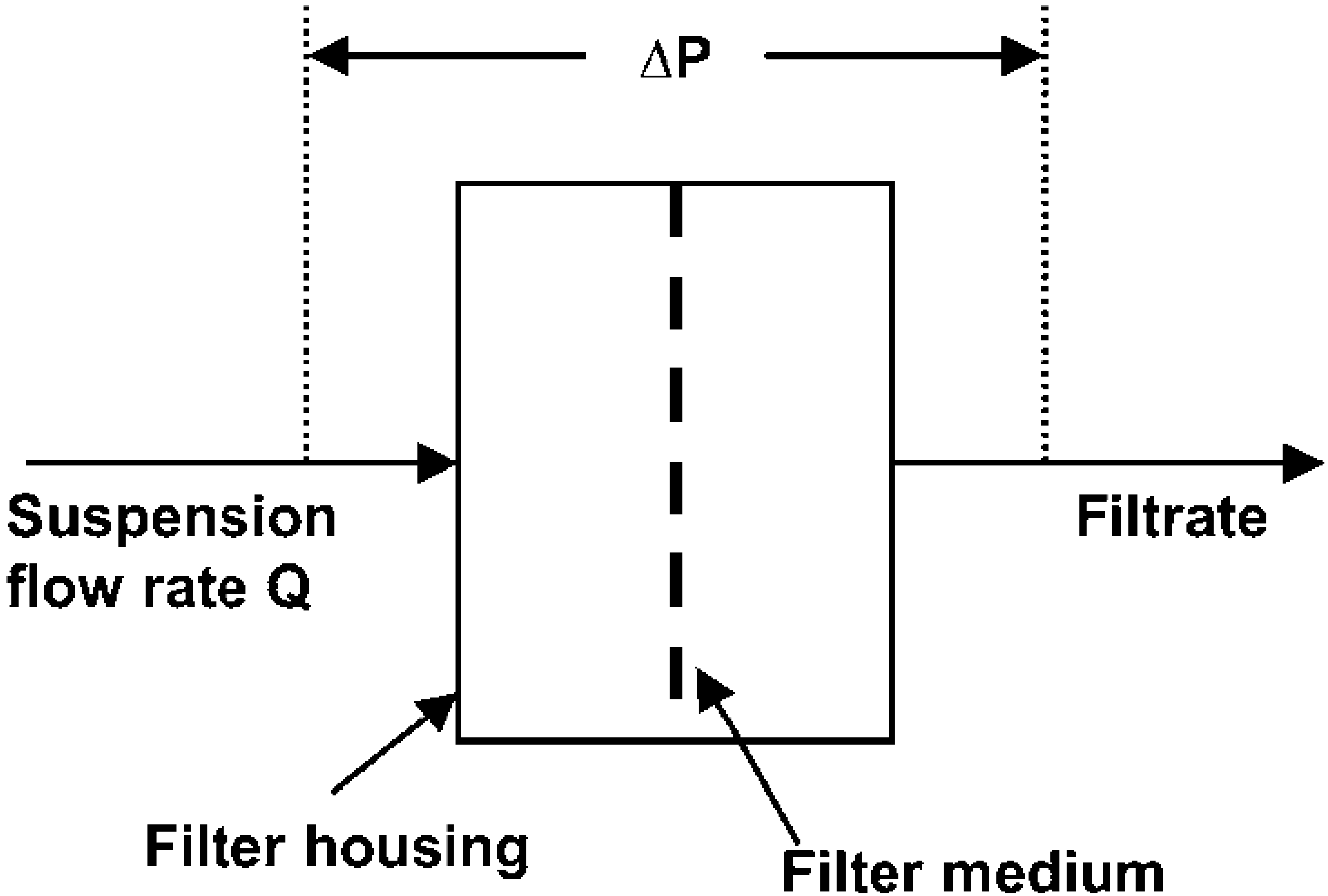
And $\boldsymbol{S}_{settle}$= 1cm. How much time do you need?

$$\boldsymbol{T}_{settle} = \boldsymbol{S}_{settle} / \boldsymbol{V}_g = \frac{18\ \eta\ \boldsymbol{S}_{settle}}{\boldsymbol{d}^2\ (\rho_p - \rho_L)\ \boldsymbol{g}}$$

What if d = 10 μm?

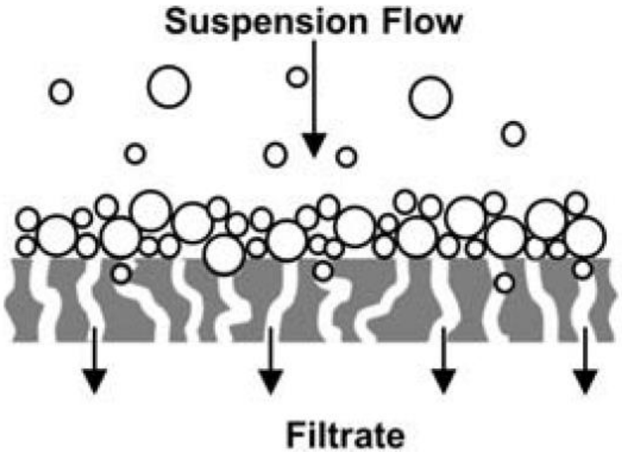
What about d = 1 μm?

Filtration



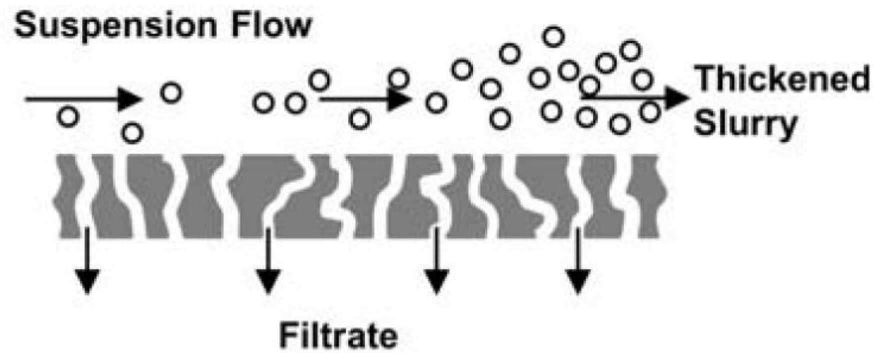
Efficiency of filter = % particles retained (of a given size)
Efficiency vs. pressure drop (lower pressure is better)

Filtration – Caking and membranes



Cake

vs.



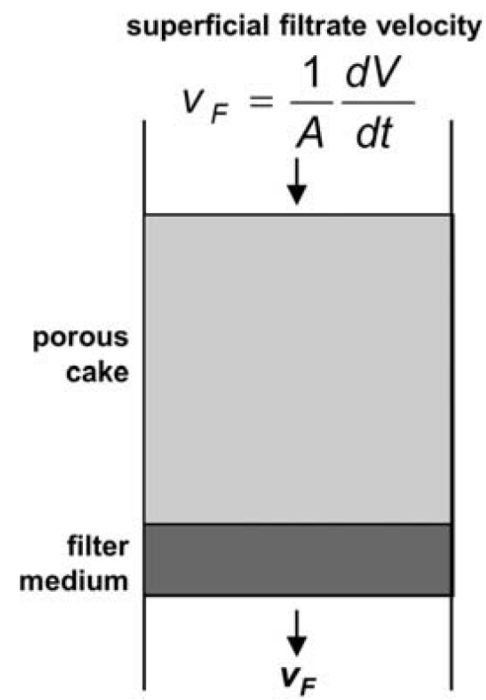
Cross-flow

Filter Porosity

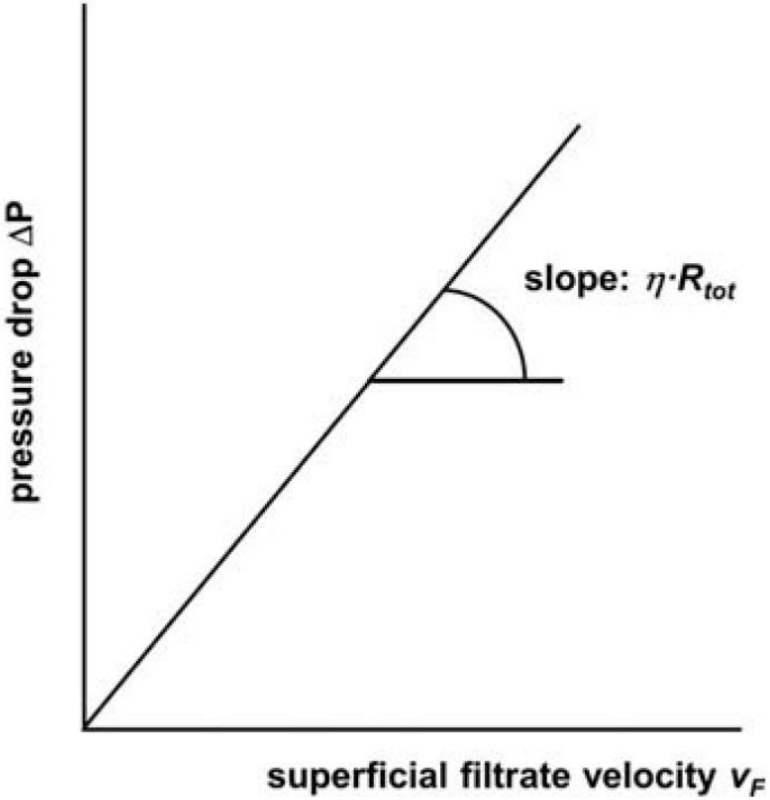
$$\varepsilon = \frac{volume\ of\ voids}{total\ bed\ volume}$$

Filtrate Velocity

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



Filtration – Quantitation



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

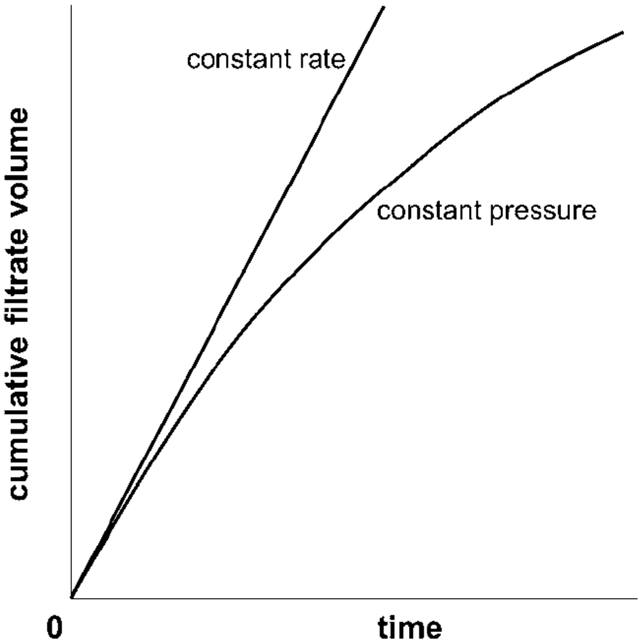
Resistance due to filter medium
And to cake (R_M and R_C)

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

Darcy's Law

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

Filtration – Quantitation



Constant pressure and constant rate filtration.

Resistance due to caking
Increases pressure, or
At constant pressure – decreases flow

Let's find how quickly our filters will cake so we cannot get water out of them anymore.

For next time, read Ch. 10 of
De Haan & Bosch, Industrial Separation Processes, 2013, de Gruyter (Berlin)