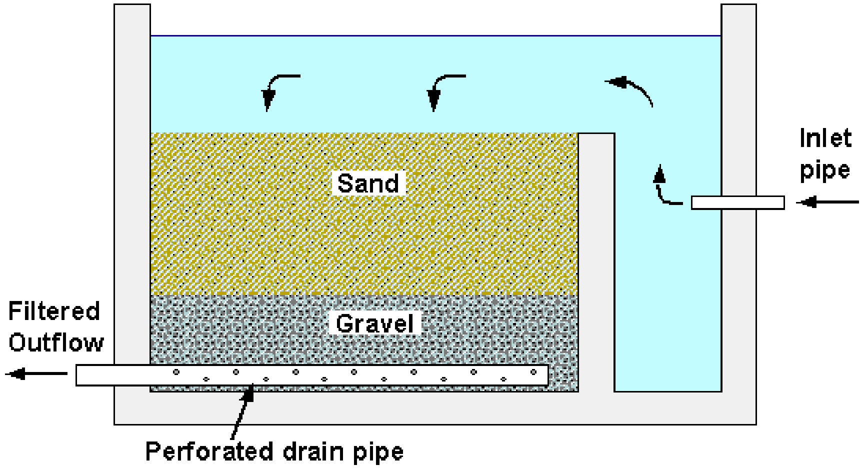
Filtration

- ✓ Filtration is a ***process of removing particulate*** matter from water / solution by forcing the water through a porous media.

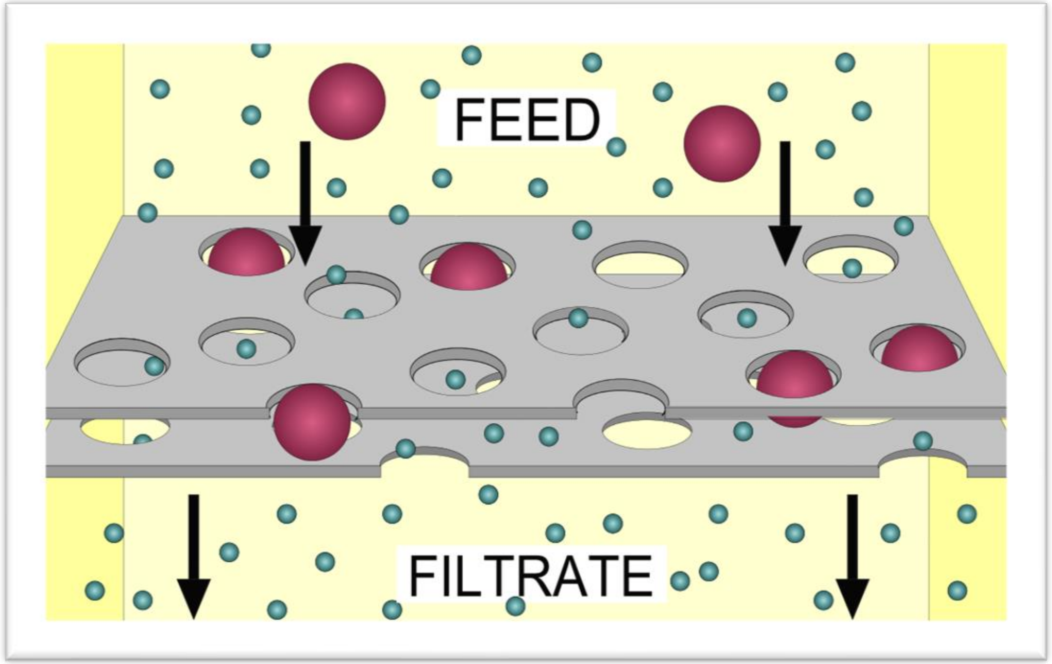
- ✓ This porous media can be natural, in the case of sand, gravel and clay, or it can be membrane wall made of various materials.

- ✓ The size of materials that can be removed during filtration depends upon the size of the pores of the filter.

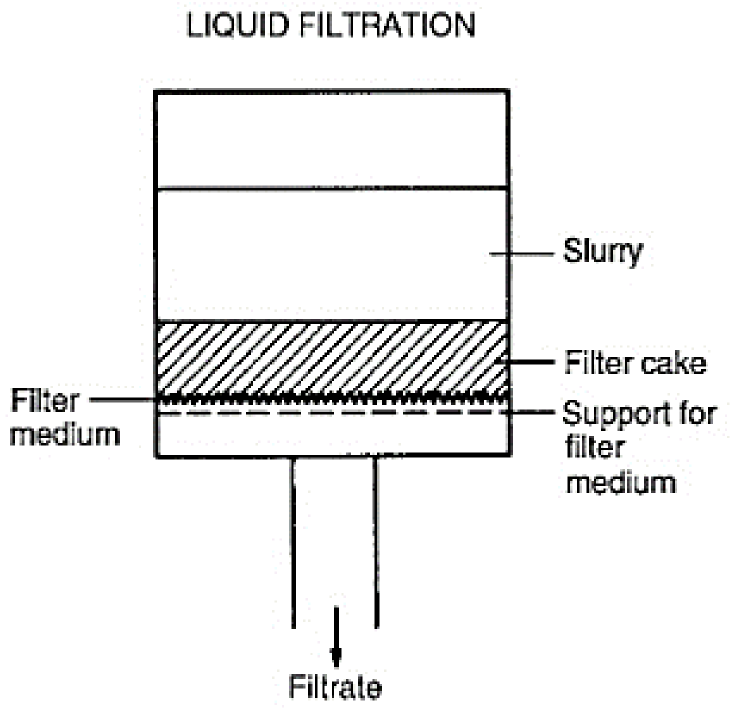


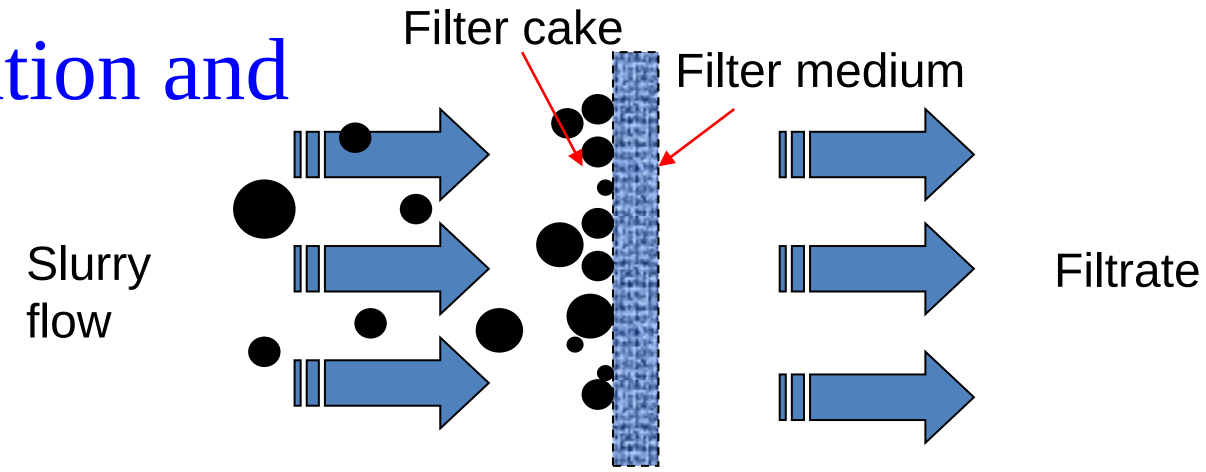
- Filtration is a physical separation process that separates solid matter and fluid from a mixture using a filter medium that has a complex structure through which only the fluid can pass.

- Solid particles that cannot pass through the filter medium are described as oversize and the fluid that passes through is called the filtrate



- Is the *removal of solid particles* from a fluid by passing it through filter medium on which solids are deposited.
- Often the feed is modified by pretreatment to increase the filtration rate
- Such as heating, re-crystallization and by addition of filter aid.





- Oversize particles may form a filter cake on top of the filter and may also block the filter lattice, preventing the fluid phase from crossing the filter, known as blinding

- The most important factors that influence the rate of filtration are:

(a) The drop in pressure across the filter medium.

(b) The area of the filtering surface.

(c) The viscosity of the filtrate.

(d) The resistance of the filter cake.

(e) The resistance of the filter medium and initial layers of cake.

Applications includes :

1) Clarify juices
2) Fruit extracts
3) Vegetable and fish oils
4) Fermented beverages
5) Recirculated cooking oil
6) Water, milk, and soy milk
7) Separate potato starch from potato fruit water
8) High-melting fats from vegetable oils in fractionation processes
9) Crystals from mother liquors
10) Chemically precipitated impurities

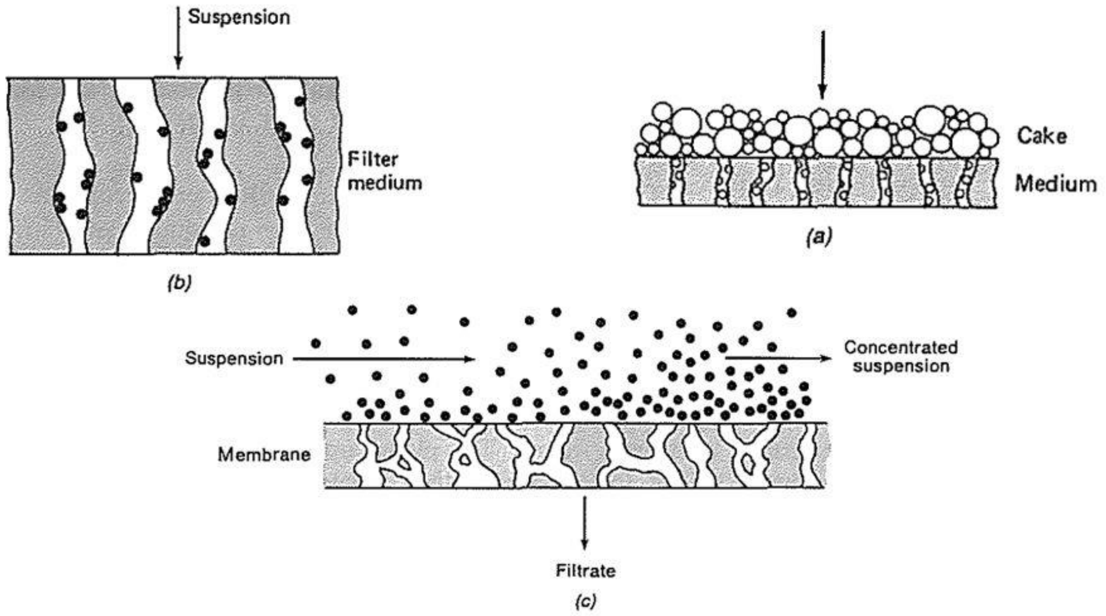
Applications …

- The coffee filter to keep the coffee separate from the grounds.
- HEPA (high efficiency particulate air) filters in air conditioning to remove particles from air.
- to clarify liquid products, by the removal of small amounts of solid particles (e.g. for wine, beer, oils and syrups)
- to separate a liquid from a significant quantity of solid material, where the overall objective of the operation is to obtain the filtrate or cake, or both, is (e.g. for fruit juices or beer)

Filters

- Cake filter – separates relatively large amount of solids
- Clarifying filter – to produce clean liquid from the slurry such as beverages
- Cross flow filter – the feed suspension flow under pressure at high velocity

Mechanisms of filtration



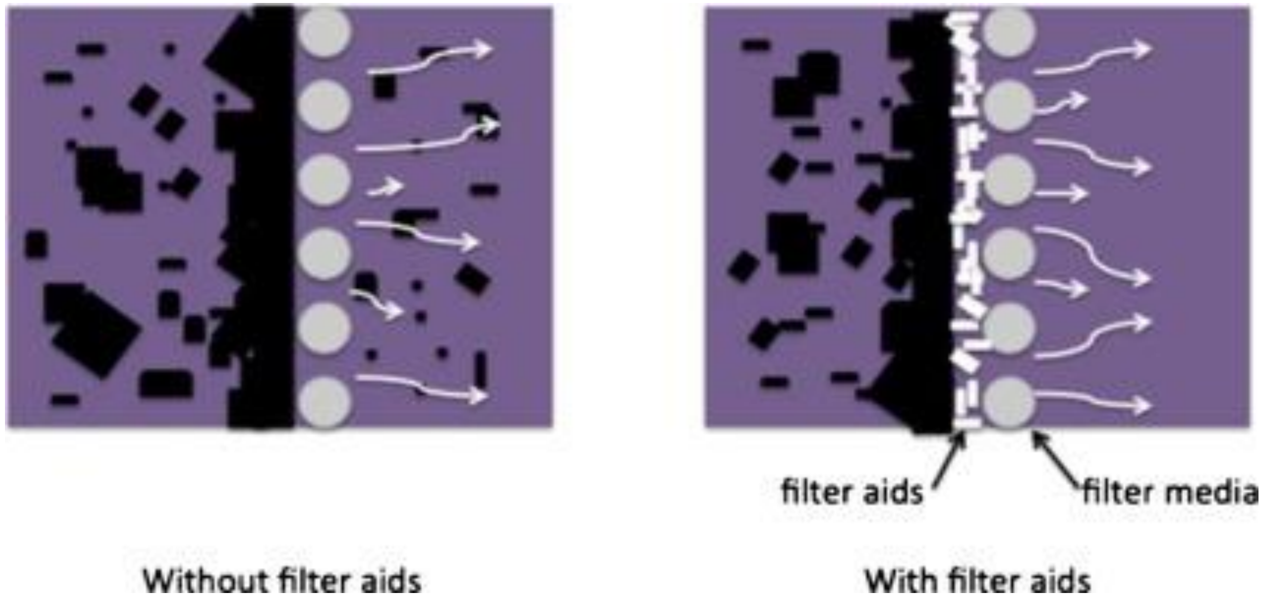
(a) cake filter; (b) clarifying filter; (c) cross flow filter.

Requirements of filter

- Must retain solids and give clear liquid
- Must not plug or clog
- Must be chemically resistant
- Strong enough to withstand process conditions
- Should not be expensive

Filter aids

- Very fine particles form a dense impermeable cake that will plug the filter.
- *Porosity of the cake needs* to be increased to permit passage of liquid.
- This is done by adding filter aid to the feed slurry, such as
  - Diatomaceous silica
  - Wood cellulose



Principle of cake filtration

- In filtration, flow resistance increase with increase in time as
  - the filter medium becomes clogged
  - a filter cake builds up
- The important parameters of filtration is
  - Pressure drop across the filter
  - Flow rate through the filter

- As the time passes either the flow rate decreases or pressure drop increases.
- Const. pressure filtration
  - Flow rate allowed to vary with time
  - Pressure drop held constant
- Const rate filtration
  - Pressure drop allowed to vary
  - Flow rate of fluid held constant

Pressure drop

- The overall pressure drop at any time is the sum of the pressure drop of cake and filter medium.

$$\Delta P = \Delta P_c + \Delta P_m$$

ΔP = Overall pressure drop

ΔP_c = Pressure drop across the cake

ΔP_m = Pressure drop across the filter medium

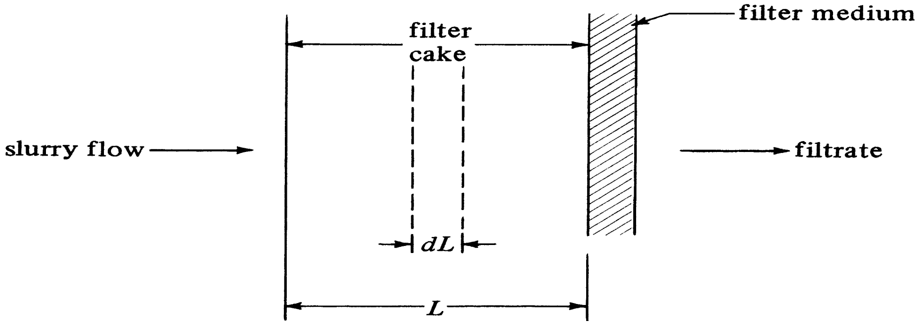
Rate of filtration

- The fluid / slurry passes through the filter medium, which gets resistance to its passage, under the influence of force

$$dv/dt = \text{Driving force / resistance}$$

Resistance = by cake + by filter medium

- Filter cake resistance = Specific resistance of filter cake x thickness of the cake.
- Filter medium resistance = specific resistance of filter medium x thickness of filter medium.
- Total resistance = filter cake resistance + filter medium resistance
- Total resistance is directly proportional to μ of the fluid



As time passes during filtration, either

- the filtrate flow rate diminishes or
- pressure drop rises

<u>Constant-pressure filtration</u>

- pressure drop is held constant
- flow rate allowed to fall with time

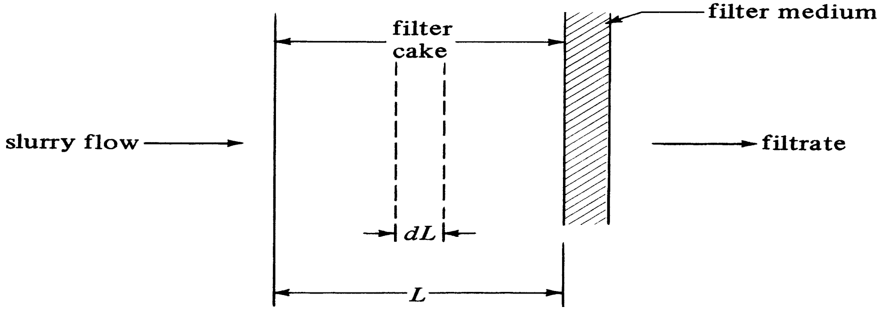
<u>Constant -rate filtration (less common)</u>

- pressure drop is progressively increased

Liquid passes through 2 resistance in series:

- cake resistance (zero at start & increases with time)
- filter medium resistance (important during early stages of filtration)

during washing, both resistances are constant, and filter medium resistance is usually negligible



Rate of filtration = driving force/resistance

$$\frac{dV}{dt} = \frac{-\Delta p A}{\mu\left(\frac{\alpha c_s V}{A} + R_m\right)}$$

where

L = thickness of cake (m)

Δp = total pressure drop = Δp_{cake} + $\Delta p_{filter\ medium}$ (N/m^2)

A = filter cross section area (m^2)

α = specific cake resistance (m/kg)

μ = viscosity of filtrate (Pa.s)

c_s = dry mass of cake deposited per unit volume of filtrate (kg solids/m^3 filtrate)

V = Volume of filtrate (m^3)

R_m = resistance of filter medium to filtrate flow (m^{-1})

$$\frac{dV}{dt}=\frac{-\Delta pA}{\mu\left(\frac{\alpha c_s V}{A}+R_m\right)}$$

CONSTANT PRESSURE FILTRATION (BATCH)

$t/V = (K_p/2)V + B$ → plot as a graph

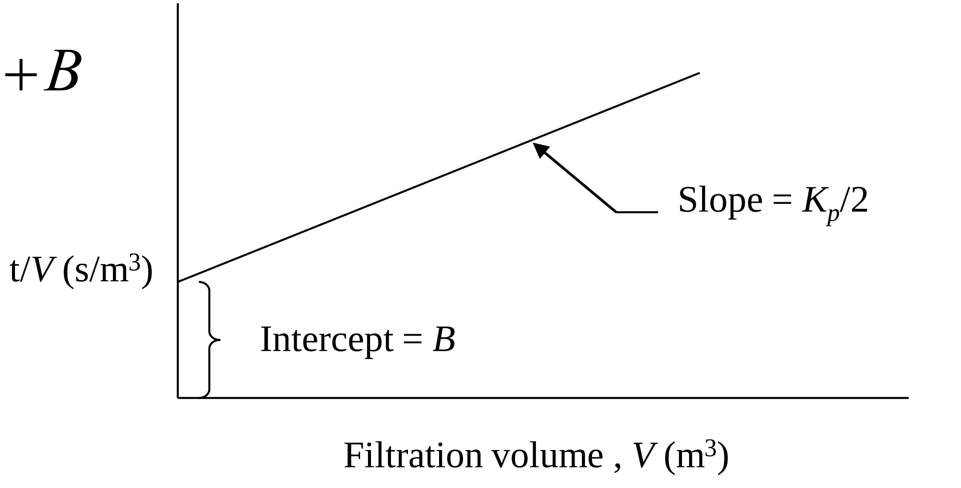
$$\frac{dt}{dV}=\frac{\mu\alpha c_s}{A^2(-\Delta p)}V+\frac{\mu}{A(-\Delta p)}R_m=K_pV+B$$

Time of filtration: $$t=\frac{K_pV^2}{2}+BV$$

where

$$K_p=\frac{\mu\alpha c_s}{A^2(-\Delta p)}$$

$$B=\frac{\mu}{A(-\Delta p)}R_m$$



Determination of constants in a constant-pressure filtration run

Δp = total pressure drop = Δp_{cake} + Δp_{filter} (N/m^2)

A = filter cross section area (m^2)

α = specific cake resistance (m/kg)

μ = viscocity of filtrate (Pa.s)

c_s = dry mass of cake deposited per unit volume of filtrate (kg solids/m^3 filtrate)

V = volume of filtrate (m^3)

R_m = resistance of filter medium to filtrate flow (m^{-1})

- If you know the volume of liquid with its solid content, the thickness of filter cake (L_c) is

$$L_c = w\,V/\,A$$

w = fractional solid content

V = volume of the liquid

A = surface area of the filter

- The rate of filtration

$$\frac{dV}{dt} = \frac{-\Delta pA}{\mu\left(\frac{\alpha c_s V}{A} + R_m\right)}$$

This is the fundamental equation of filtration.

Filtration equation for Constant Rate filtration

- In early stages of filtration, filter medium resistance is large when compare with cake resistance.
- So resistance offered to flow is constant and filtration proceeds more or less at constant rate.

$$\Delta P = V/At \times \mu r[w(V/A) + L]$$

Filtration equation for Constant Pressure Filtration

- Once the cake being built up then the pressure drop will be constant and flow rate will be changing

$$\frac{t}{(V/A)} = [\frac{\mu r w}{2\Delta P}] \text{ x } (V/A) + \frac{\mu r L}{\Delta P}$$

If filter medium thickness is negligible

$$\frac{t}{(V/A)} = [\frac{\mu r w}{2\Delta P}] \text{ x } (V/A)$$

$\text{t} = \frac{\mu r w v^2}{2A^2\Delta P}$ the time required to filter a given volume of fluid when a constant pressure is maintained

Design considerations

Volume

Surface area of the filter

Time of filtration

Feed rate

Initial and final solid content

Filter medium resistance

Filter cake resistance

Pressure drop

Thickness of filter medium and cake

Viscosity of fluid

Number of leafs

Rotational speed

Bed height and diameter

A liquid is filtered at a pressure of 200 kPa through a 0.2 m^2 filter. Initial results indicate that 5 min is required to filter 0.3 $m^3$of liquid. Determine the time that will elapse until the rate of filtration drops to $5x10^{-5}m^3/s$.

determine μrw from equation $t = \frac{\mu r w v^2}{2A^2 \Delta P}$ = $53.33x10^6$ kg/m^3s

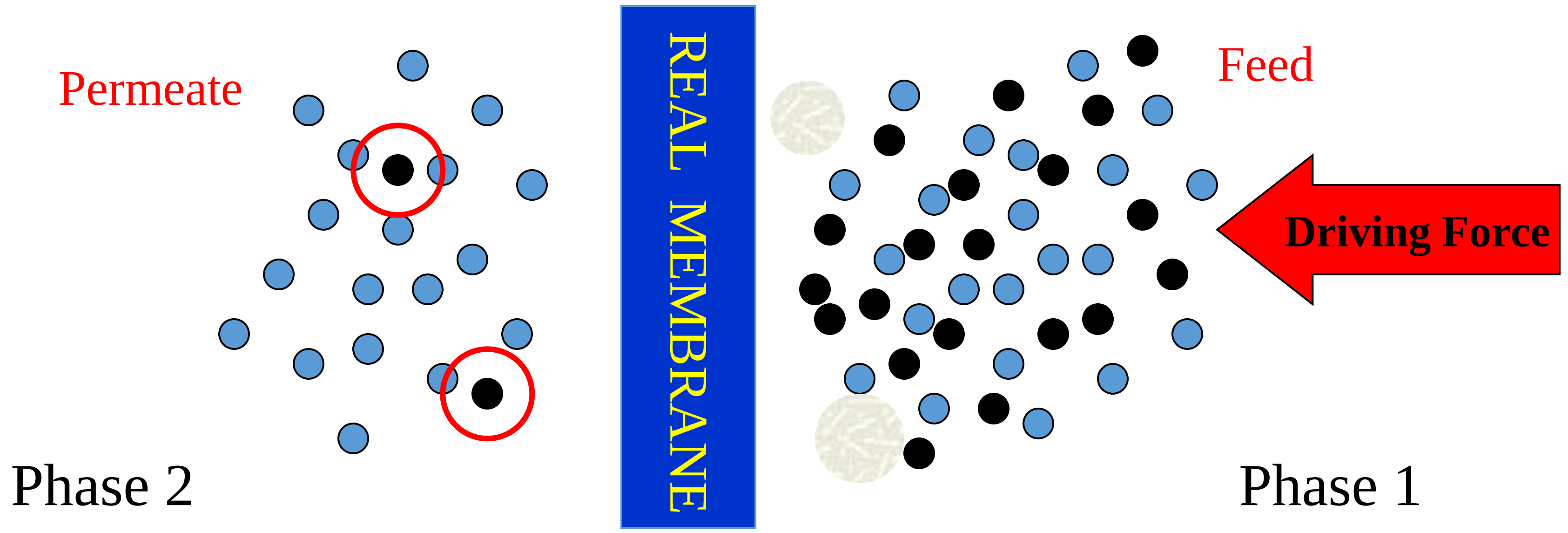
Using $\frac{dv}{dt} = \frac{A\,\Delta P}{(\mu r\,(wV/A) + L))}$ find V (L is negligible) V= 3 m^3

Find time when rate of filtration drops to $5x10^{-5}m^3/s$

$$t = \frac{\mu r w v^2}{2A^2 \Delta P}$$ = 500 min or 29998 sec

Membrane as filtration medium

A membrane can be defined as a barrier (not necessarily solid) that separates two phases as a selective wall to the mass transfer, making the separation of the components in a mixture possible.

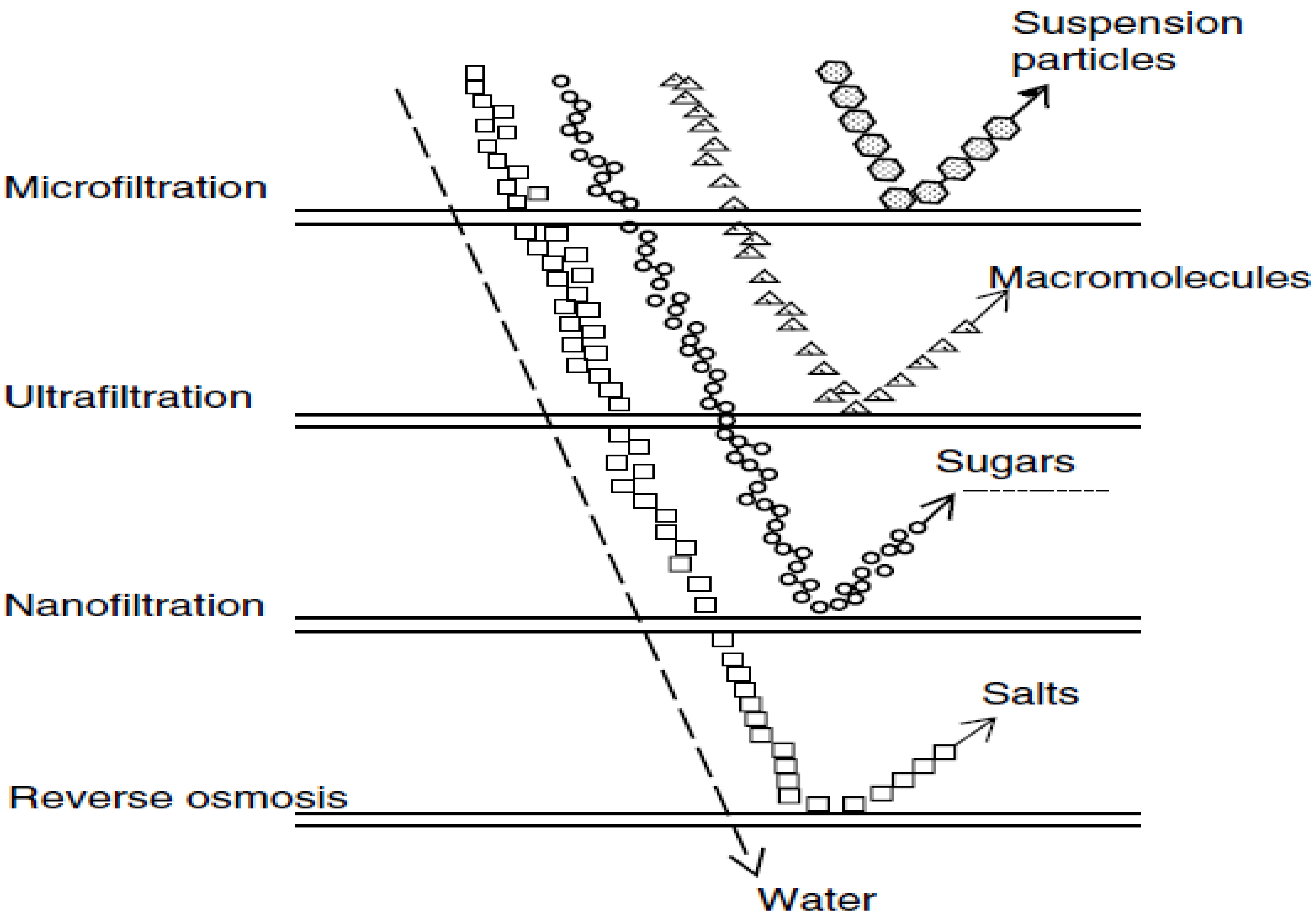


Driving Forces

A driving force can make the mass transfer through the membrane possible; usually, the driving force can be a pressure difference (ΔP), a concentration difference (Δc), an electrical potential difference (ΔE). Membranes can be classified according their driving forces:

ΔP	Δc	ΔT	ΔE
Microfiltration	Pervaporation	Thermo-osmosis	Electrodialysis
Ultrafiltration	Gas separation	Membrane distillation	Electro-osmosis
Nanofiltration	Vapour permeation		Membrane electrolysis
Reverse osmosis	Dialysis		
Piezodialysis	Diffusion dialysis		

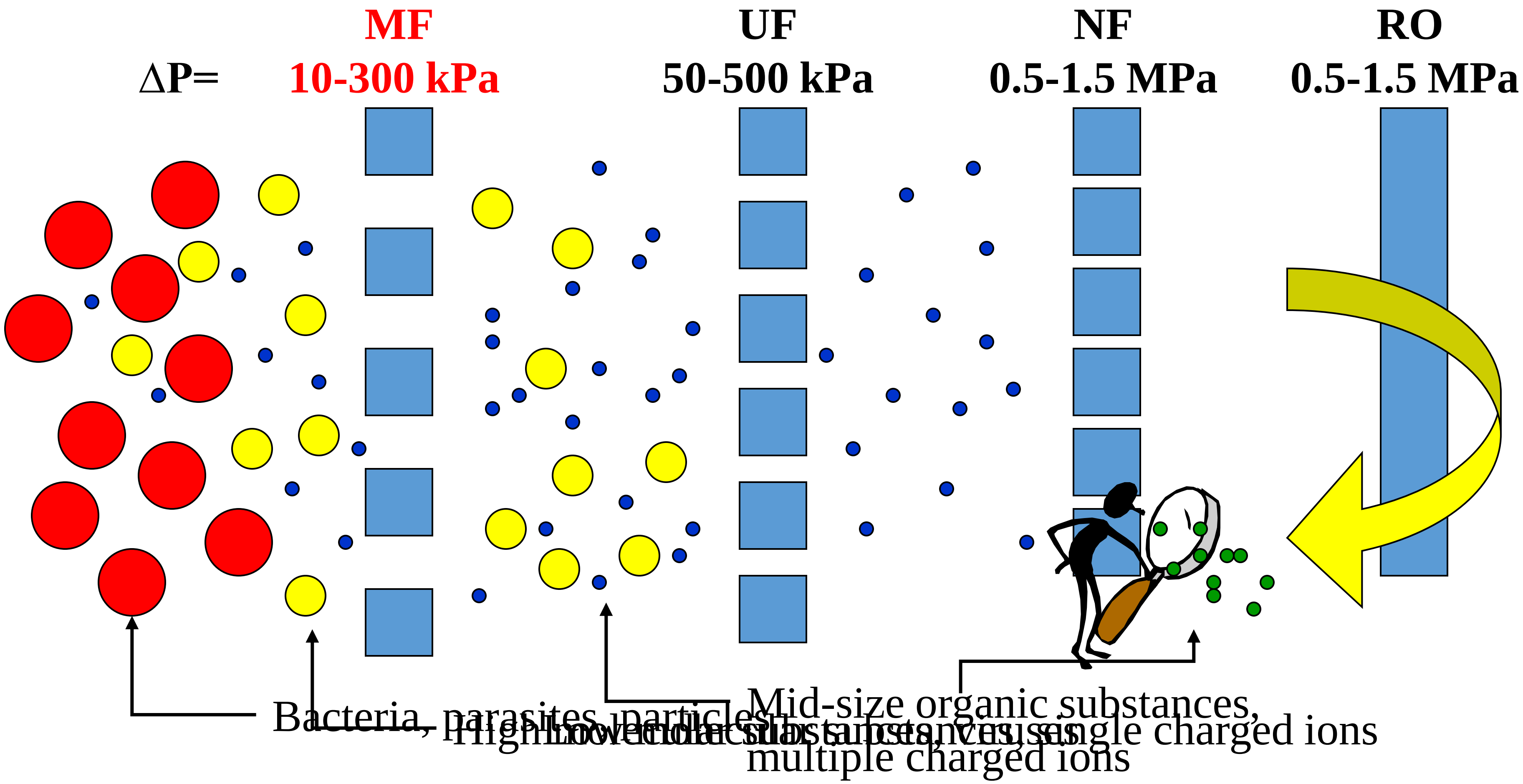
Classification of the separation processes according to the particles retained



Size of materials retained, driving force, and type of membrane

Process	**Size of materials retained**	**Driving force**
Microfiltration	0.1 - 10 µm microparticles	Pressure difference (0.5 - 2 bar)
Ultrafiltration	1 - 100 nm macromolecules	Pressure difference (1 - 10 bar)
Nanofiltration	0.5 - 5 nm molecules	Pressure difference (10 - 70 bar)
Reverse Osmosis	< 1 nm molecules	Pressure difference (10 - 100 bar)

Pressure driven processes



Microfiltration

- ✓ **Is used to remove particles larger than 0.2 µm**
- ✓ **Micro-organisms cannot pass through them**
- ✓ **Operated at low pressure differences**
- ✓ **May or may not be asymmetric**
- ✓ **Used to remove bacteria and other spoilage microorganisms**

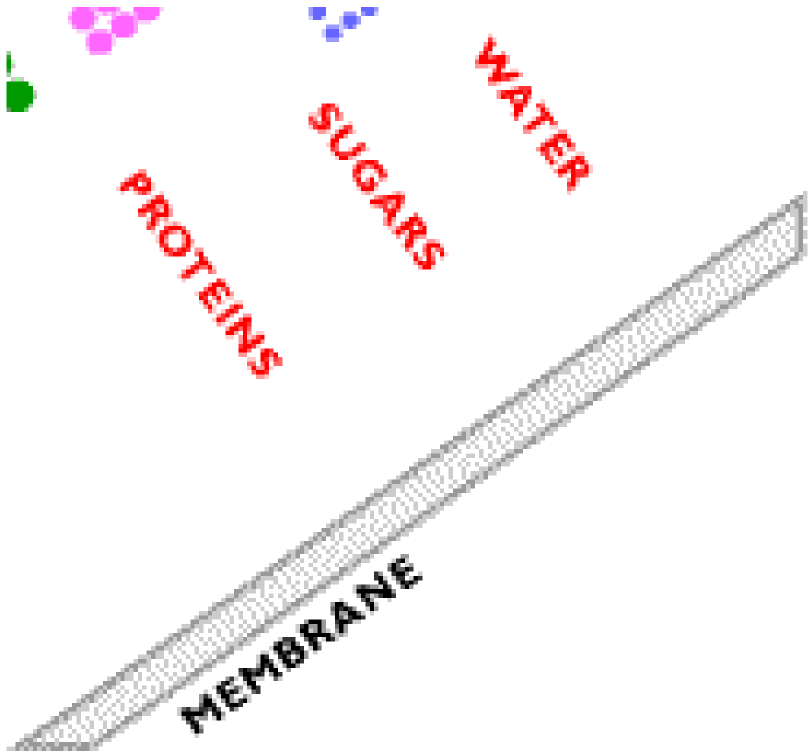
Microfiltration	0.1 - 10 µm microparticles	Pressure difference (0.5 - 2 bar)

Ultrafiltration

- ✓ **Is used to separate macromolecules and small particles from solvents, ions and small molecules**
- ✓ **Has smaller pores than microfiltration membranes**
- ✓ **Driving force → pressure differential (2-10 bars to 25-30 bars)**
- ✓ **Used to separate species with pore sizes 10-1000 Å (103-0.1 microns)**

Ultrafiltration	1 - 100 nm macromolecules	Pressure difference (1 - 10 bar)

- ✓ To separate a solution; mixture of desirable and undesirable components
- ✓ Has smaller pores than microfiltration membranes
- ✓ Driving force → pressure differential (2-10 bars to 25-30 bars)
- ✓ Used to separate species with pore sizes 10-1000 Å (103-0.1 microns)
- ✓ Asymmetric; the pores are small



The flux rate through an ultrafiltration membrane can be obtained

$$N = KA\Delta P$$

- ΔP is pressure difference across the membrane,
- K is membrane permeability constant (kg/[m^2 kPa s]), and
- A is membrane surface area (m^2).

The concentration of whey is being accomplished by using an ultrafiltration membrane to separate water. The 10 kg/min feed stream has 6% total solids and is being increased to 20% total solids. The membrane tube has a 5 cm inside diameter, and the pressure difference applied is 2000 kPa. Estimate the flux of water through the membrane and the length of the membrane tube when the permeability constant is 4×10^{-5} kg water/(m^2 kPa s).

Solution:

Mass Balance : Feed = filtrate (N) + filtered product (Np)

10 (0.06) = Np (0.2) …….Np=3kg/min

N = 10-3 = 7 kg/min

w.k.t $N = KA\Delta P$ ------------------------- $A = \frac{N}{K\Delta P} = 1.46\ m^2$

$A = \pi\, d\, l \Rightarrow d = 5cm, L = ?$

$L = 9.28\ m$

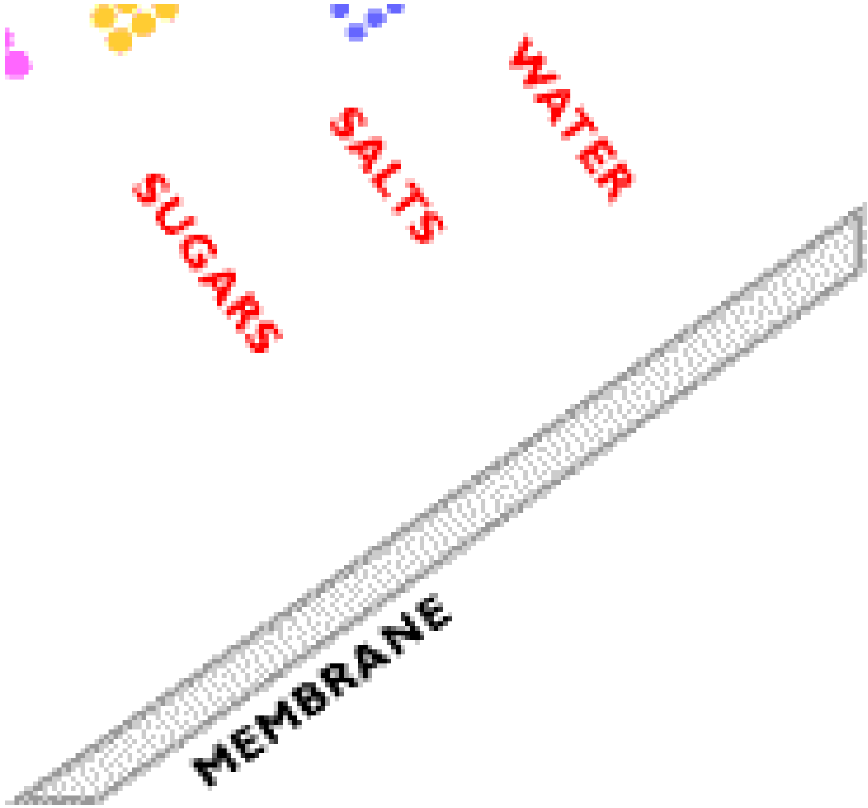
An ultra filter used to filter water from orange juice slurry. The 50 kg/min feed stream has 16% total solids and is being increased to 35% total solids. The pressure difference across the membrane is 3000 kPa. Estimate the flux of water through the membrane and area of the ultra filter when the permeability constant is 6×10^{-5} kg water/(m^2 kPa s).

- **Wide range of applications of ultra filtrations**
  - **Oil emulsion waste treatment**
  - **Treatment of whey in dairy industries**
  - **Concentration of biological macromolecules**
  - **Electrocoat paint recovery**
  - **Concentration of heat sensitive proteins for food additives**
  - **Ultraflitration of milk**
  - **Bioprocessing (separation and concentration of biologically active components)**
  - **Protein harvesting**
  - **Refining of oils**

Nanofiltratıon

- ✓ **Less pore sizes than ultrafiltration membranes**
- ✓ **Operates at lower pressures(10-30bar)**
- ✓ **Can typically operate at higher recoveries; conserving total water usage due to a lower concentrate stream flow rate (advantage over reverse osmosis)**
- ✓ **Not effective on small molecular weight organics (e.G.Methanol)**

Nanofiltration	0.5 - 5 nm molecules	Pressure difference (10 - 70 bar)



- ***Less pore sizes than ultrafiltration membranes***
- ***The mass transfer mechanism is diffusion & separate small molecules from the solution (asymmetric)***
- ***Cellulosic acetate and aromatic polyamide type membranes (salt rejections; 95% for divalent salts to 40% for monovalent salts)***
- ***Can typically operate at higher recoveries; conserving total water usage due to a lower concentrate stream flow rate (advantage over reverse osmosis)***
- ***Not effective on small molecular weight organics (e.G.Methanol)***

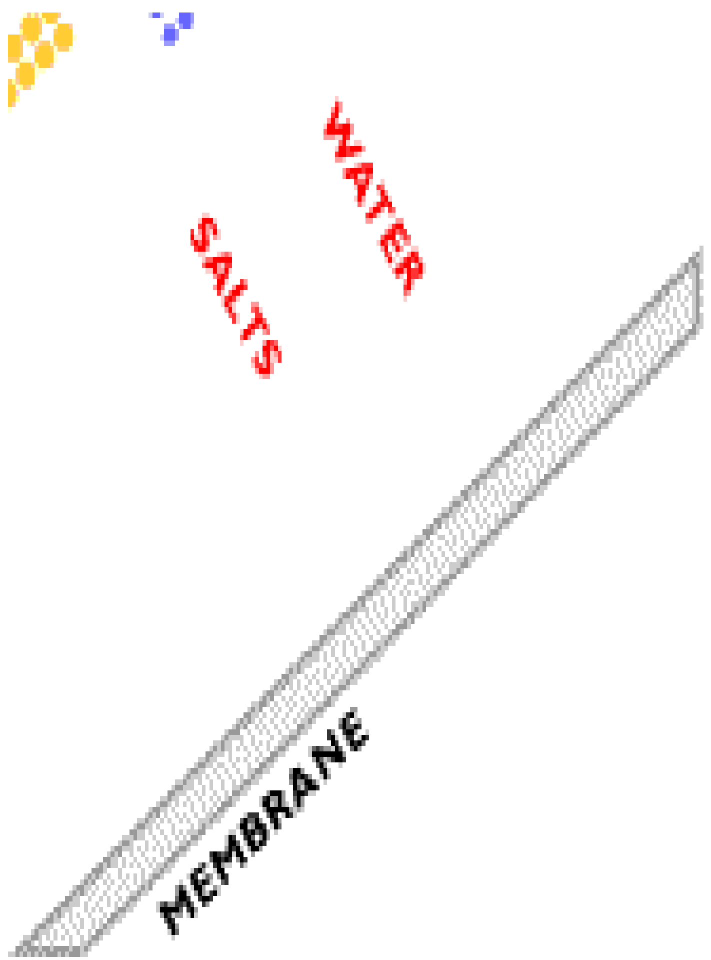
- **Typical applications:**
    - ***Desalination of food, dairy and beverage products or byproducts***
    - ***Partial desalination of whey, UF permeate or retentate as required***
    - ***Desalination of dyes and optical brighteners***
    - ***Purification of spent clean-in-place (CIP) chemicals***
    - ***Color reduction or manipulation of food products***
    - ***Concentration of food, dairy and beverage products or byproducts***
    - ***Fermentation byproduct concentration***

Reverse osmosis

- ✓ **Only remove some suspended materials larger than 1 micron**
- ✓ **Ro operates at pressures 35-100bar**
- ✓ **eliminates the dissolved solids, bacteria, viruses and other germs contained in the water**
- ✓ **Only water molecules allowed to pass via very big pressure**

Reverse Osmosis	< 1 nm molecules	Pressure difference (10 - 100 bar)

- ✓ *Only remove some suspended materials larger than 1 micron*
- ✓ *The process eliminates the dissolved solids, bacteria, viruses and other germs contained in the water*
- ✓ *Only water molecules allowed to pass via very big pressure*
- ✓ *Assymmetric type membranes (decrease the driving pressure of the flux)*
- ✓ *Almost all membranes are made polymers, cellulosic acetate and matic polyamide types rated at 96%-99+% nacl rejection*



- The osmotic pressure Π of a dilute solution can be obtained by Van’t
- Hoff’s equation

$$\Pi = \frac{cRT}{M}$$

where

- Π is osmotic pressure (Pa),
- c is solute concentration (kg/m^3) of solution,
- T is absolute temperature (K),
- R is gas constant, and
- M is molecular weight.

Estimate the osmotic pressure of orange juice with 11% total solids at 20°C.

Concentration of solids 11% =0.11 kg solids/kg product

Temperature 20°C = 293 K

The density of orange juice is estimated based on density of carbohydrates (glucose) at 1593 kg/m³.

$\rho = 0.11\ (1593) + 0.89\ (998.2) = 1063.63\ kg/m^3$

$c = 0.11\ [kg\ solids/kg\ product] * 1063.6\ [kg\ product/m^3 product]$

$\quad = 117\ kg\ solids/m^3 product$

$$\Pi = \frac{117\ [kg\ solids\ /\ m^3\ product] * 8.314[m^3\ kPa\ /\ (kgmol\ K)] * 293[K]}{180[kg\ /(kgmol)]}$$

$\Pi = 1583.5\ kPa$

Estimate the osmotic pressure of a 20% sucrose solution at a temperature of 10 C.

$\rho = 0.2\ (1600) + 0.8\ (1000) = 1120\ kg/m^3$

$c = 0.2$ [kg solids/kg product] $*1120$ [kg product/m^3 product]

$= 224$ kg solids/m^3 product

$$\Pi = \frac{224\ [kg\ solids\ /\ m^3\ product] * 8.314[m^3\ kPa\ /\ (kgmol\ K)] * 283[K]}{342[kg\ /(kgmol)]}$$

= 1541 kpa

- **EXTENSIVE APPLICATIONS OF RO**
  - ***Portable water from sea or brackish water***
  - ***Ultrapure water for food processing and electronic industries***
  - ***Pharmaceutical grade water***
  - ***Water for chemical, pulp & paper industry***
  - ***Waste treatment***
  - ***Municipal and industrial waste treatment***
  - ***Process water for boilers***
  - ***De-watering of feed streams***
  - ***Processing high temperature feed- streams***