Reverse Osmosis (2)

Lecture (5)

2.4. Concentration Factor

- The **concentration factor** is **related** to the RO system **recovery** and is an important equation for RO system design.
- The **more** water you recover as **permeate** (the higher the % recovery), the **more** concentrated **salts** and contaminants you collect in the **concentrate stream**.
- This can **lead to higher potential for scaling** on the surface of the RO membrane when the concentration factor is too high for the system design and feed water composition.

2.4. Concentration Factor

- Concentration Factor = (1 / (1-Recovery %)
- As the degree of concentration increases, the solubility limits may be exceeded and precipitate on the surface of the equipment as scale.
- Example,
- if your feed flow is 100 kg/s and your permeate flow is 75 kg/s, then the recovery is (75/100) x 100 = 75%.
- To find the concentration factor, the formula would be 1÷ (1-75%) = 4.

2.4. Concentration Factor

- A concentration factor of **4** means that the water going to the **concentrate** stream will be **4 times** more concentrated than the **feed water** is.
- If the feed water in this example was 500 ppm, then the concentrate stream would be 500 x 4 = 2,000 ppm.

2.5. Flux

$$\text{Flux} = \frac{\text{gpm of permeate x 1440 min/day}}{\text{number of RO elements in system x square footage of each RO element}}$$

- Example:
- You have the following:
- The RO system is producing 75 gallons per minute (gpm) of permeate.
- You have 3 RO vessels and each vessel holds 6 RO membranes.
- Therefore you have a total of 3 x 6 = 18 membranes.

2.5. Flux

- The type of membrane you have in the RO system is a Dow Filmtec BW30-365.
- This type of RO membrane (or element) has 365 square feet of surface area.
- Flux = $\dfrac{75 \text{ gpm} \times 1{,}440 \text{ min/day}}{18 \text{ elements} \times 365 \text{ sq ft}}$
- The flux is 16 (Gallon/square foot per day) Gfd.
- Gallon = 3.79 kg; ft = 0.3048 m
- This means that 16 gallons of water is passed through each square foot of each RO membrane per day.
- This number could be good or bad depending on the type of feed water chemistry and system design.

3. RO membranes

- Features of the RO membranes include the following:

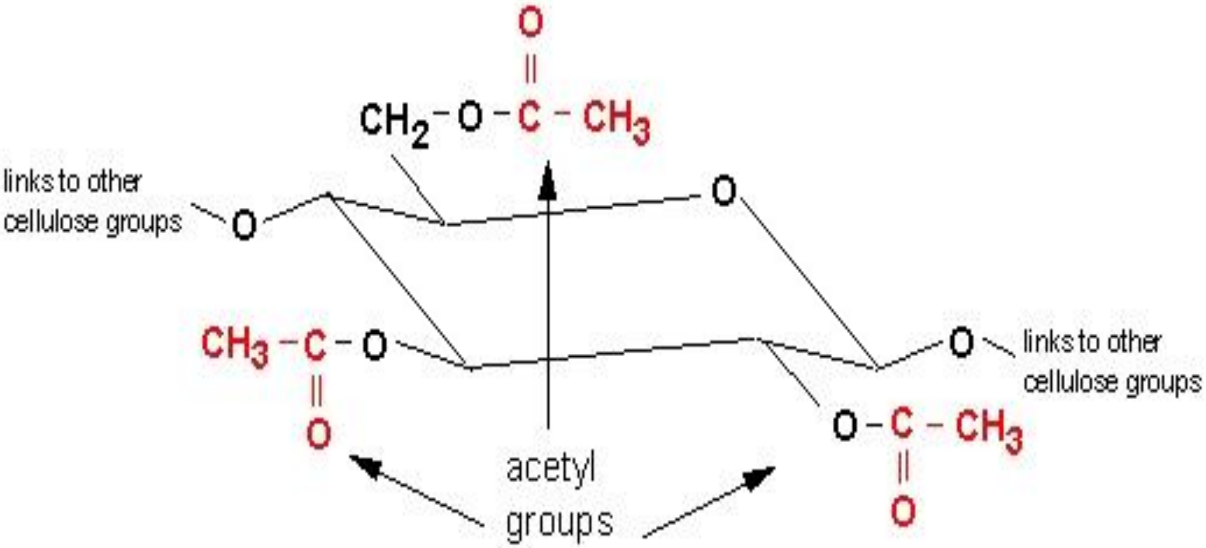
1. The membranes are formed of thin film of polymeric material several thousand Angstroms thick cast on polymeric porous material.
2. Commercial membranes have high water permeability and a high degree of semi-permeability; that is, the rate of water transport must be much higher than the rate of transport of dissolved ions.
3. The membrane must be stable over a wide range of pH and temperature, and have good mechanical integrity.

3. RO membranes

4. The life of commercial membranes varies between 3-5 years. This depends on the feed water quality, pretreatment conditions, and stability of operation.
5. Major types of commercial reverse osmosis membranes include cellulose acetate (CA) and polyamide (PA).
6. It should be noted that membrane choice is often governed by compatibility considerations rather than separation performance and flux related characteristics.

3.1. Cellulose acetate membranes

- The original CA membrane, developed in the late 1950's by **<u>Loeb and Sourirajan</u>**, was made from cellulose diacetate polymer.
- Current CA membrane is usually made from a blend of cellulose diacetate and triacetate.



3.1. Cellulose acetate membranes

- Cellulose acetate membranes need a residual of chlorine to protect them from biological attack.
- They also have tight pH operating requirements.
- Cellulose acetate membranes are considered uncharged because their functional groups are not polar (polyamide and polysulfone are).
- Because cellulose acetate membranes are non-polar they do not attract foulants to the surfaces as easily.
- Less fouling is observed also due to a smother surface of a cellulose acetate membrane.
- Cellulose acetate membranes are easily degraded by bio-fouling.

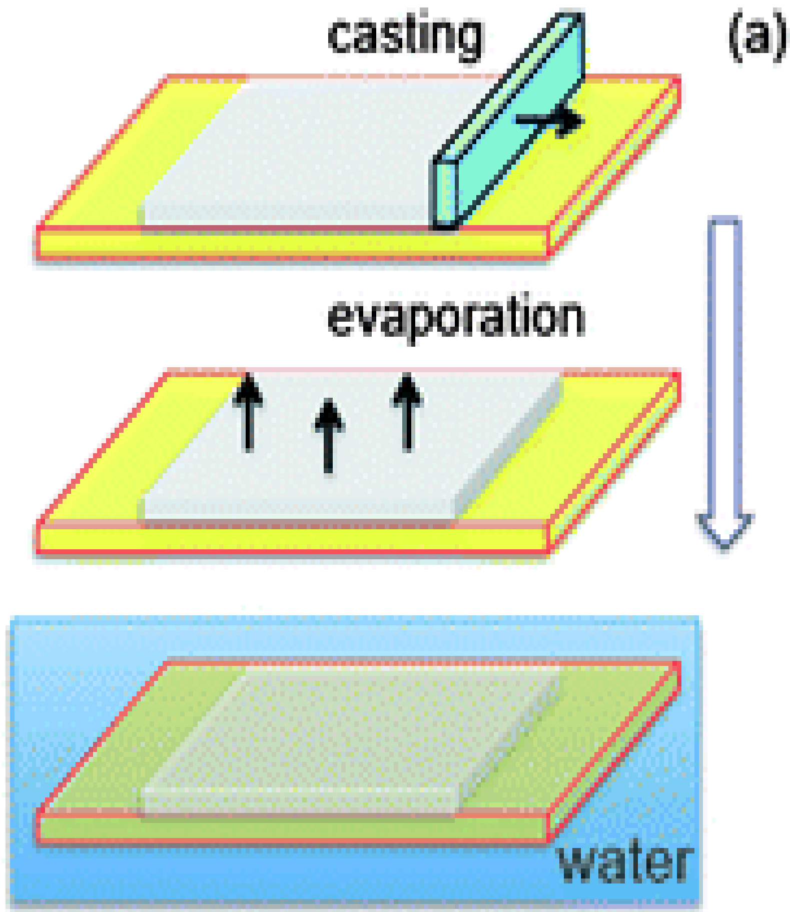
3.1. Cellulose acetate membranes

- The membrane preparation process includes
- 1. Thin film casting,
- 2. Cold bath leaching, and
- 3. High temperature annealing.
- The membrane is formed in a way such that dense top layer is allowed to evaporate rapidly followed by immersing in water during which the spongy layer is formed. Both layers are intact.
- The salt solution is made to face the rejection layer in order to reject the soluble salts and only allow the hydrophilic matrix (spongy layer) to allow the water to pass by the make and break of hydrogen bonds.

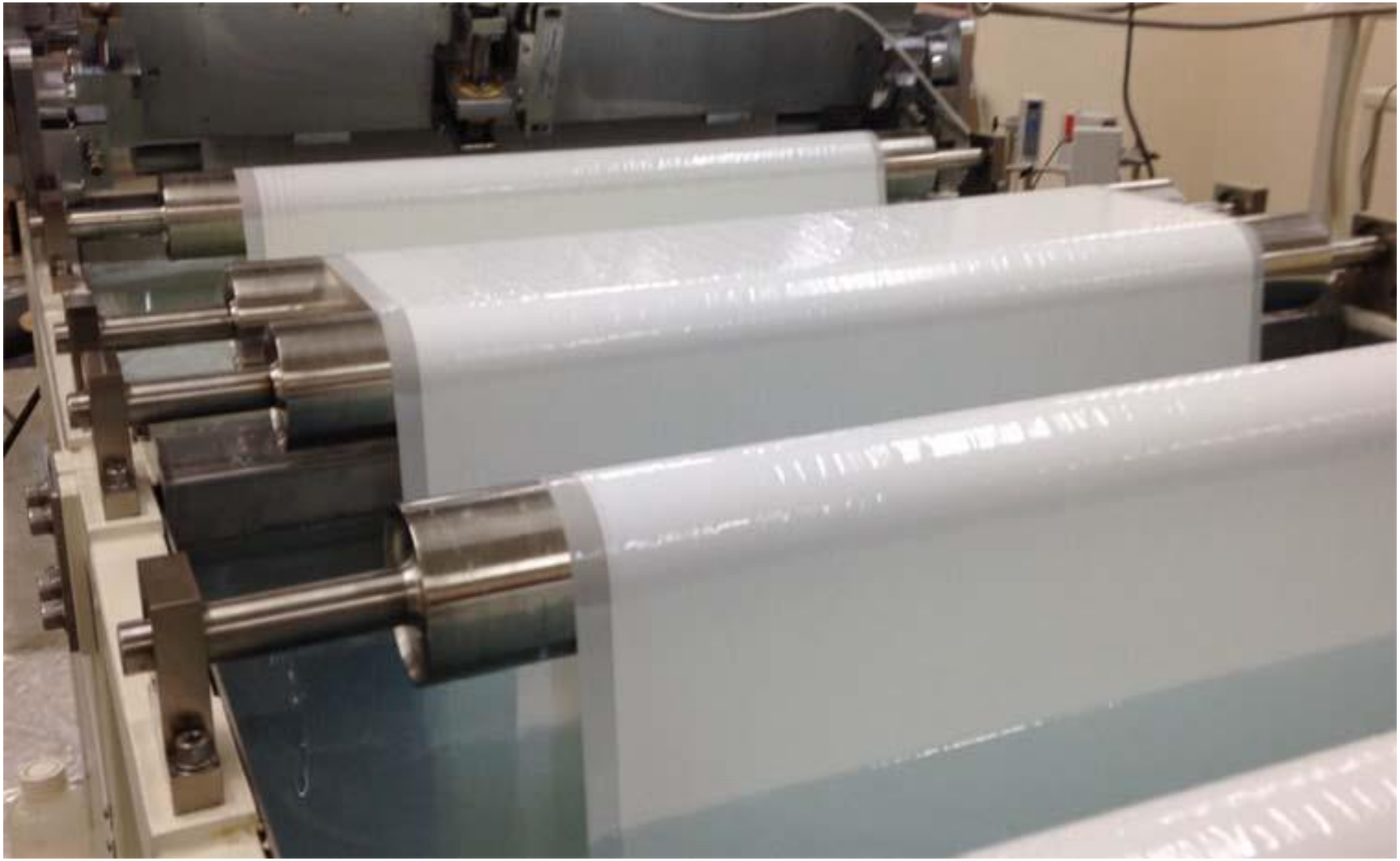
3.1. Cellulose acetate membranes

- The **casting process** is associated with **partial removal** of the **solvent** material by evaporation.
- The **cold bath** process **removes** the **remaining solvent** and other leachable compounds.
- The **annealing process** is made in a hot water bath at a temperature of 60-90°C.
- The **annealing** step **improves** the **semi-permeability** of the membrane with an increase of water transport and a significant decrease of salt passage.

3.1. Cellulose acetate membranes



3.1. Cellulose acetate membranes



3.1. Cellulose acetate membranes

- The **CA** membranes have an **asymmetric** structure with a dense surface layer of about **1000-2000 A** (0.1-0.2 micron) which is **responsible** for the **salt rejection** property.
- The **rest** of the membrane film is **spongy** and porous and **has high water permeability**.
- **Salt rejection** and **water flux** of a cellulose acetate membrane can be **controlled** by **variations in temperature and duration of the annealing step**.

3.1. Cellulose acetate membranes

- **<u>Advantages of CA membranes:</u>**

1. Hydrophilicity, which is very important in minimizing fouling of the membrane.
2. Wide range of pore size can be manufactured, with reasonably high fluxes.
3. Easy to manufacture.
4. Low cost.

3.1. Cellulose acetate membranes

- **Disadvantages of CA membranes:**

1. Narrow temperature range, maximum temp. 30°C , which is a disadvantage from the point of view of flux; since higher temperatures lead to higher diffusivity and lower viscosity, both of which lead to higher flux; this temperature is particularly favorable to microbial growth. Blends of CA and CTA can tolerate temp. 35-40°C, although under carefully controlled operating conditions.

3.1. Cellulose acetate membranes

- **Disadvantages of CA membranes:**

2. Narrow pH range, most cellulose acetate membranes are restricted to pH 2-8, preferably 3-6. The polymer hydrolyzes easily under acidic conditions, since acid tends to attack the β-glucose link in the cellulose backbone, which could lead to a loss in the molecular weight and a consequent loss in structural integrity.

Highly alkaline conditions, on the other hand, cause deacetylations which will affect selectivity, integrity and permeability of the membrane.

3.1. Cellulose acetate membranes

- **Disadvantages of CA membranes:**

3. Poor resistance to chlorine, less than 1mg/L of free chlorine is suggested under continuous exposure. Chlorine oxidizes CA and weakens the membrane, opening up the pores. This results in temporary large increase of water flux, but it also leads to poor long-term operating lifetime.

3.1. Cellulose acetate membranes

- **Disadvantages of CA membranes:**

4. CA is also reported to undergo the compaction phenomenon to a slightly greater extent than other materials, i.e. gradual loss of membrane properties (most notably flux) under high pressure.
5. CA is highly biodegradable, i.e. is highly susceptible to microbial attack due to the nature of its cellulose backbone. Not being able to use the usual sanitizers such as chlorines adds to the problem.

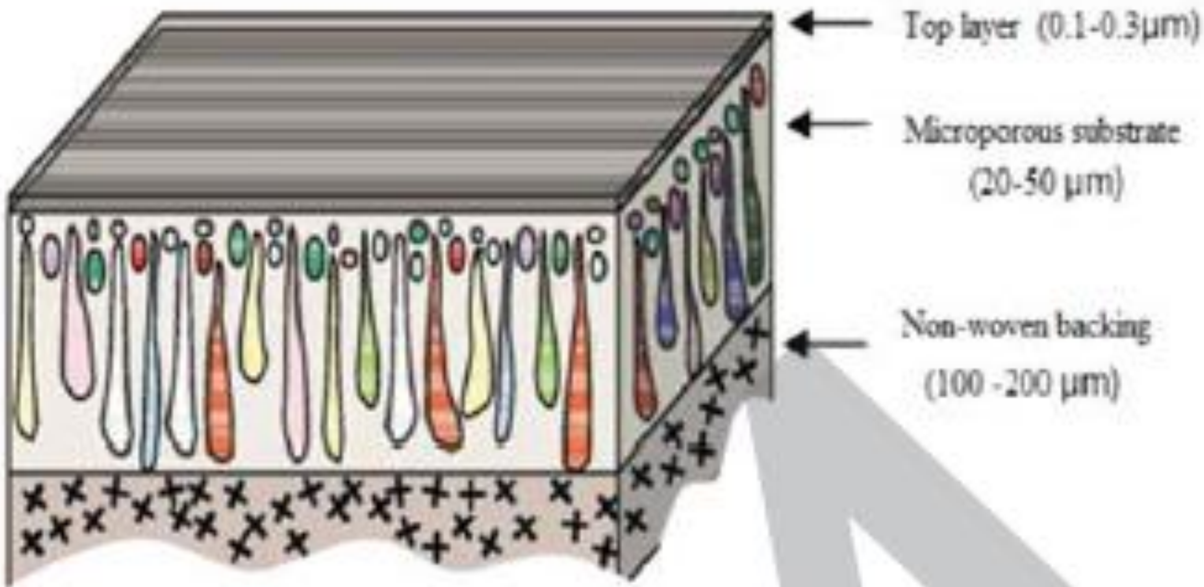
3.2. Composite polyamide membranes

- A **composite membrane** is made of 2 separate layers placed above each other.
- The **top layer** is a weak **ultra-thin membrane** placed **above a porous spongy support** for **supporting the ultra-thin** membrane and **allowing water flow through it.**
- Ultra-thin membranes are cast onto a water surface and the composite membrane has the advantage of matching for optimization of rejection properties and compaction resistance properties.

3.2. Composite polyamide membranes

- The composite polyamide membranes are formed of two layers, the first is a porous polysulfone support and the second is a semi-permeable layer of amine and carboxylic acid chloride functional groups.
- This manufacturing procedure enables independent optimization of the distinct properties of the membrane support and salt rejecting skin.
- The resulting composite membrane is characterized by higher specific water flux and lower salt passage than cellulose acetate membranes.

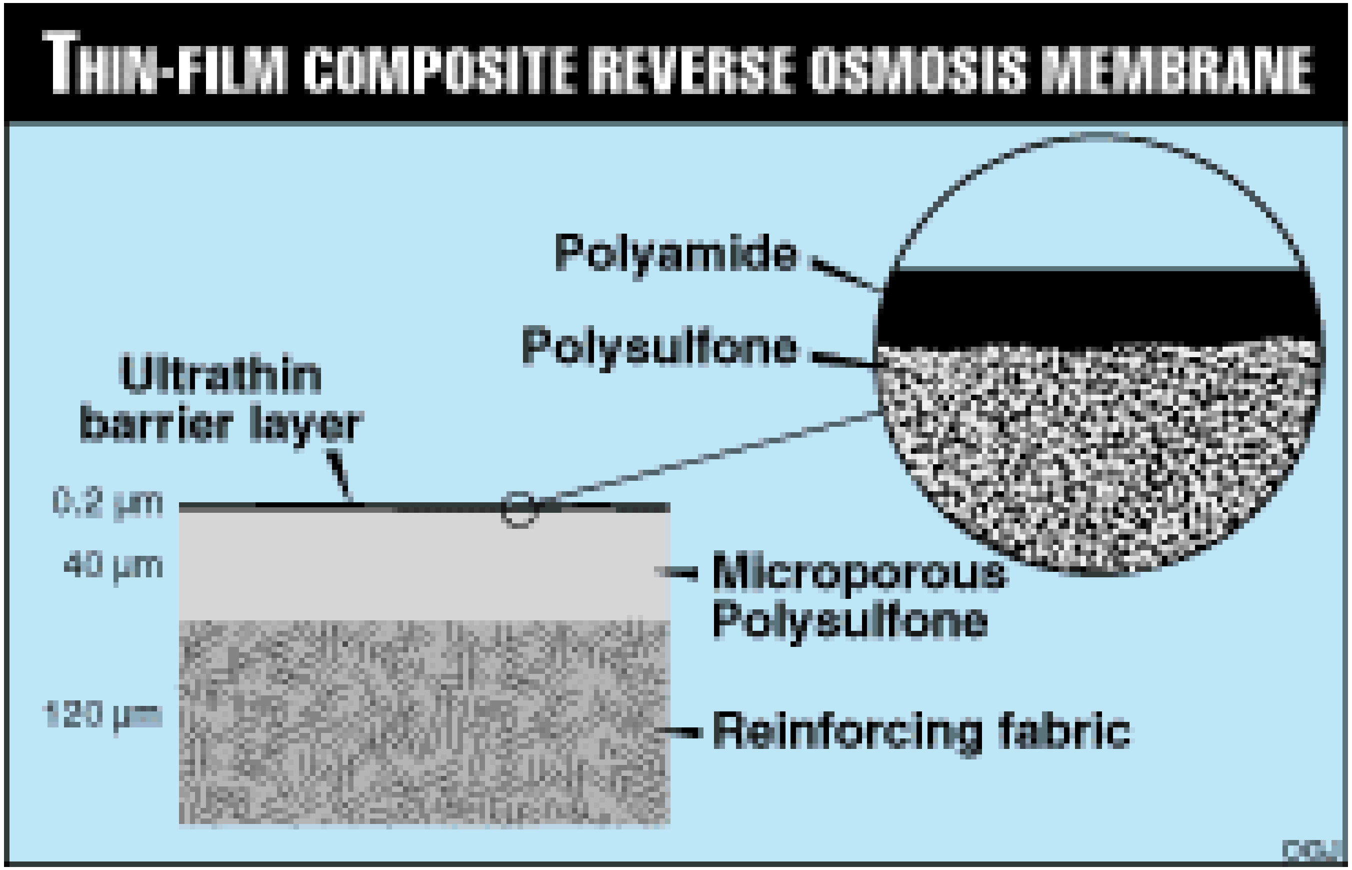
3.2. Composite polyamide membranes



Top thin selective layer + **Microporous substrate** → **Can be tailored separately** →

- High flux
- High solute rejection
- Mechanical stability
- Thermal stability (0 - 45 °C)
- Wide pH tolerance (2 - 11)

3.2. Composite polyamide membranes



3.2. Composite polyamide membranes

- Polyamide composite membranes are stable over a wider pH range than CA membranes.
- However, polyamide membranes are susceptible to oxidative degradation by free chlorine, while cellulose acetate membranes can tolerate limited levels of exposure to free chlorine.
- Compared to a polyamide membrane, the surface of cellulose acetate membrane is smooth and has little surface charge.
- Because of the neutral surface and tolerance to free chlorine (to some extent), cellulose acetate membranes will usually have a more stable performance than polyamide membranes in applications where the feed water has a high fouling potential, such as with municipal effluent and surface water supplies.

New membrane materials

- New polymers used in the manufacture of membrane filters:
- Polyacrylonitrile (PAN)
- Polycarbonate (PC)
- Polymethylmethacrylate (PMMA)
- Polypropylene (PP)
- Polystyrene(PS)
- Polytetrafluoroethylene (PTFE)
- Polyvinylalcohol (PVA)
- Polyvinylchloride (PVC)
- Polyvinylidenefluoride (PVDF)

Questions

- Answer with Yes or No, and correct the false ones:

1. The concentration factor is not related to the RO system recovery.
2. As the concentration factor increases, the potential for scaling increases.
3. Cellulose acetate membranes are considered charged because their functional groups are not polar.
4. The dense surface layer of CA membrane is 0.1-0.2 micron.

Questions:

5. Salt rejection and water flux of a CA membrane can not be controlled by variations in temperature and duration of the annealing step.
6. Polyamide membranes are not susceptible to oxidative degradation by free chlorine.

Questions:

- <u>Complete the following statements with the proper word:</u>

1. In Commercial membranes, the rate of ------- transport must be much higher than the rate of transport of ------.
2. The life of commercial membranes varies between ------ years.
3. Major types of commercial reverse osmosis membranes include -------- and --------.
4. Current CA membrane is usually made from a blend of ------- and ---------.
5. The function of the spongy layer of the membrane is----.

Questions:

Answer the following questions:

1. **Discuss briefly** the membrane casting process and the benefit of each step in this process.
2. **Explain** the structure of the composite membrane, using schematic representation.
3. **Compare** between the CA membranes and composite membranes from the following aspects: stability to pH ranges, susceptibility to oxidative degradation and surface charge of the membrane.
4. cellulose acetate membranes will usually have a more stable performance than polyamide membranes in applications where the feed water has a high fouling potential, **Give reason.**