Reverse Osmosis (3)

Lecture (6)

Concentration Polarization (CP) :

Selectivity of RO membranes leads to **accumulation of salt** on the brine side of the membrane.

This increase in concentration brings about **back diffusion** of the salt away from the surface and **into the bulk of the brine**.

This back diffusion is not fast enough due to the presence of the **viscous laminar boundary layer** next to the membrane surface.

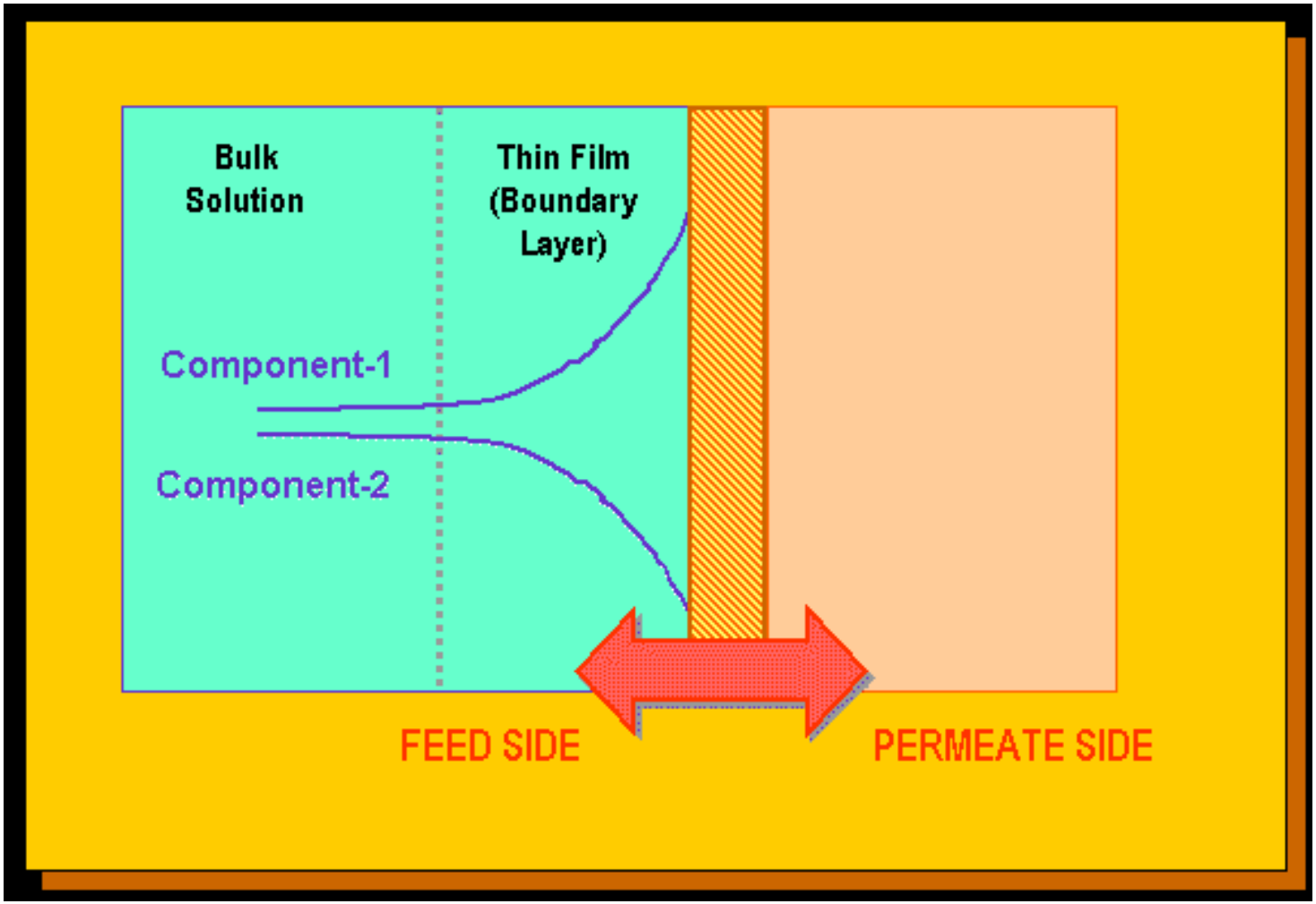
Concentration Polarization (CP):

- Because the feed solution components permeate the membrane at different rates, there is a **gradual build-up** in the concentration of **non-permeating** or slowly permeating components in the feed as **the more permeable components pass through the membrane.**
- **A layer** is formed near the surface of the membrane, whereby the **solution** immediately **adjacent** to the membrane surface becomes **depleted in the permeating part of the solution** on the feed side of the membrane, and **its concentration is lower than that in the bulk fluid.**

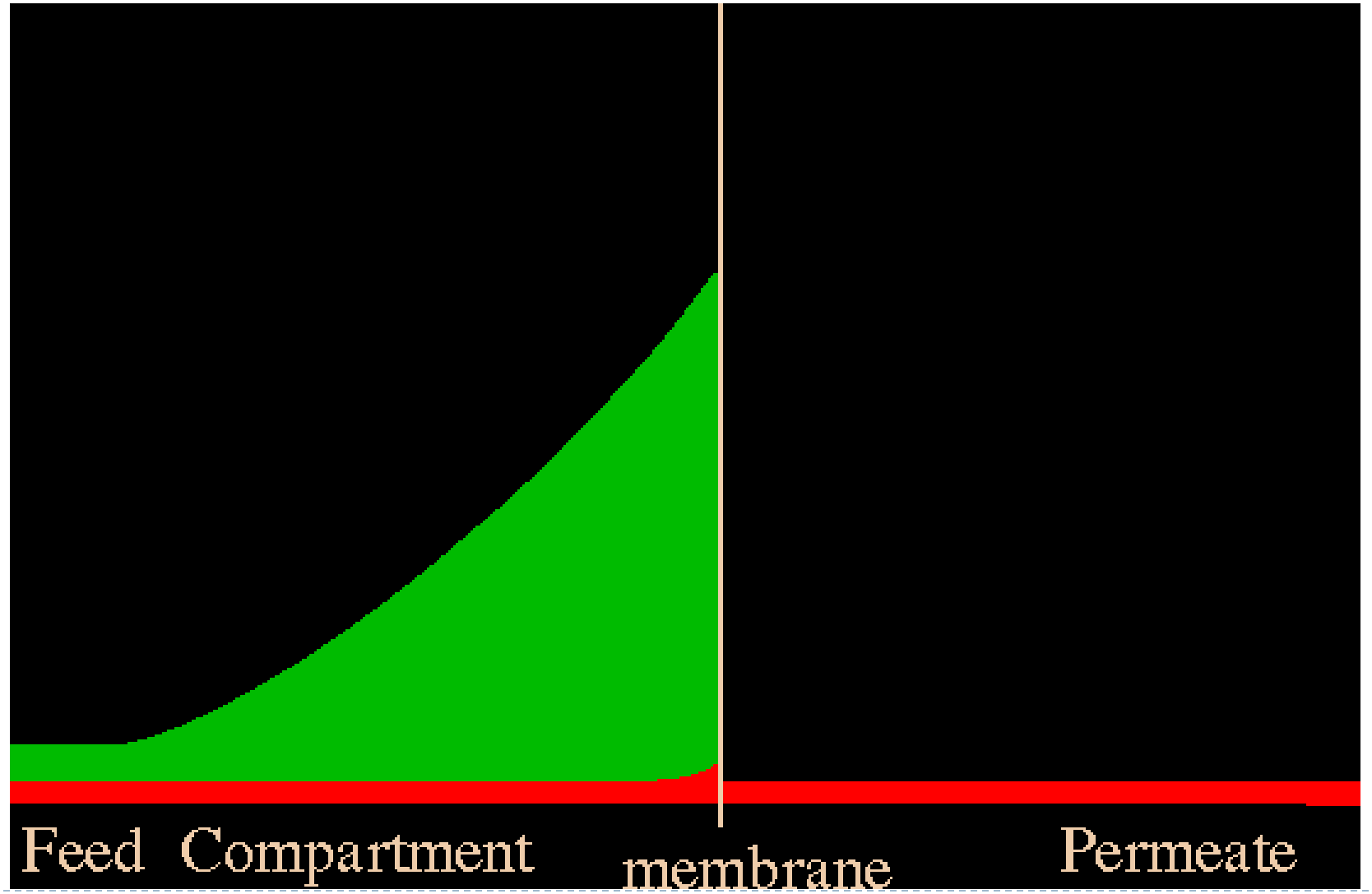
Concentration Polarization (CP):

- On the other hand, the **concentration** of the **non-permeating** component **increases** at the membrane surface.
- A concentration gradient is formed in the fluid adjacent to the membrane surface.
- **This phenomenon is known as concentration polarization (CP)** and it serves to **reduce the permeating component's** concentration difference across the membrane, thereby **lowering its flux and the membrane selectivity.**

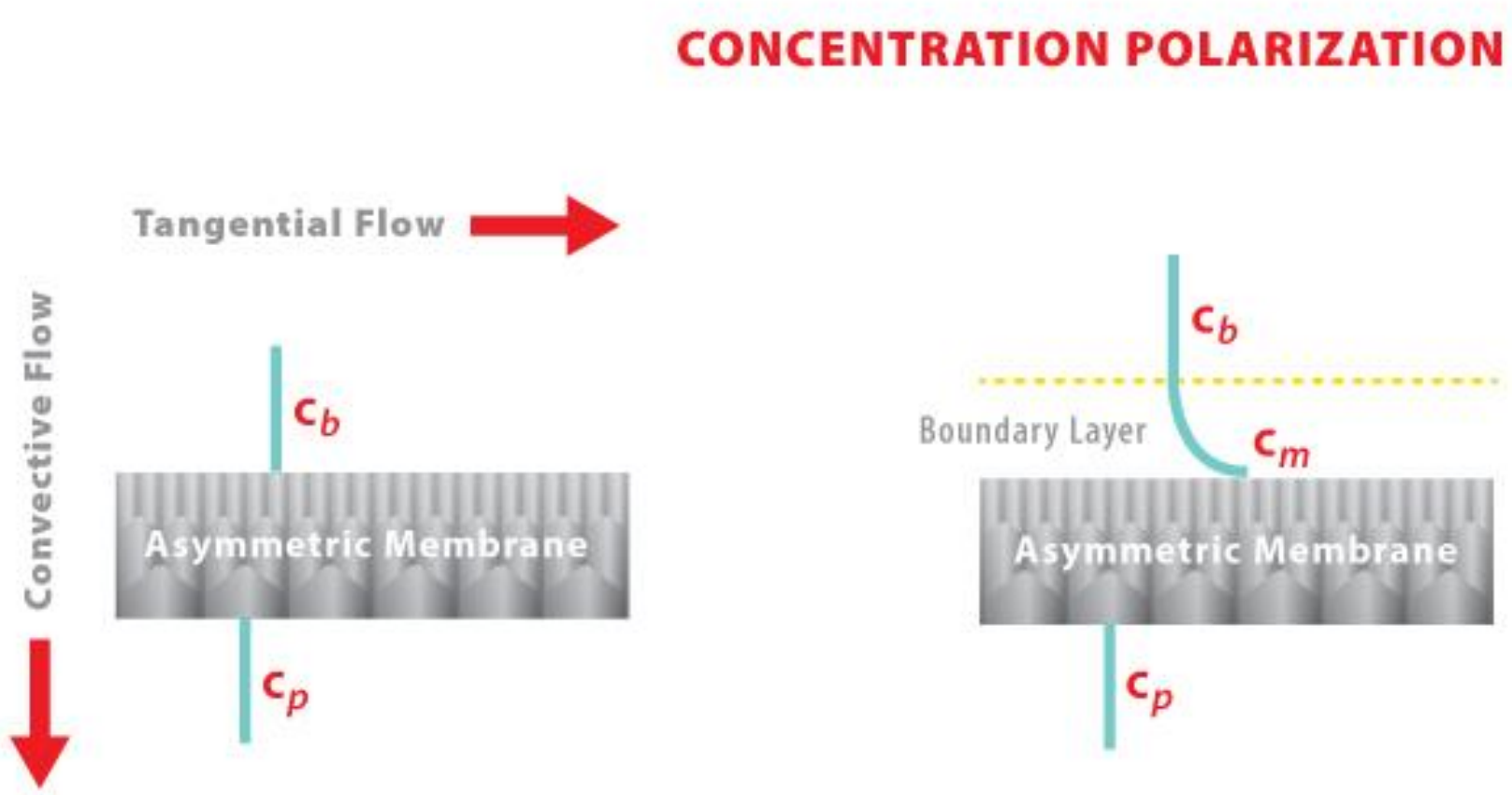
Concentration Polarization (CP):



Concentration Polarization (CP):



Concentration Polarization (CP):



Concentration Polarization (CP):

- Therefore, as desalination progresses the salinity near the membrane increases,
- therefore, osmotic pressure increases,
- therefore, $(\Delta P - \Delta \pi)$ decreases,
- therefore, water flux decreases,
- and will ultimately go to zero, i.e., **water flow will stop.**

Concentration Polarization (CP):

- In this case, polarization is used to be complete, therefore, CP is prevented by:
- 1. Increase of operating pressure.
- 2. Increase in water velocities (as high as possible).
- 3. Addition of turbulence promoters (to decrease the laminar sub-layer thickness by distributing its inertia and thus increase the rate of salt diffusion toward the bulk of the brine).

4. Membrane modules

- The two major membrane module configurations used for reverse osmosis applications are **hollow fine fiber (HFF)** and **spiral wound**.
- Other configurations, which include **tubular** and **plate and frame**, are used in the food and dairy industry.

4.1. Hollow fine fiber

- **HFF** elements represent one of **four possible** RO membrane **configurations** (other configurations are **spiral wound**, **plate and frame**, and **tubular**).
- **HFF** elements are made of **extruded cellulose acetate or polyamide material.**
- **Pressurized feed water** passes across the **outside of the fibers.**
- **Pure water permeates the fibers** and is collected at the end of the element.

4.1. Hollow fine fiber

- The fiber is **asymmetric** in structure and is **as fine as a human hair**, about **42 µm ID** and **85 µm OD**.
- **Millions of these fibers** are formed into a **bundle** and folded in half to a length of approximately **120 cm.**

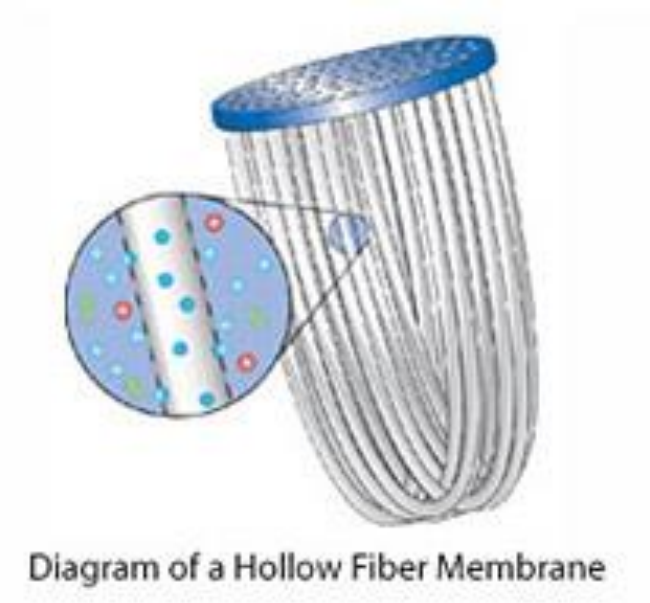


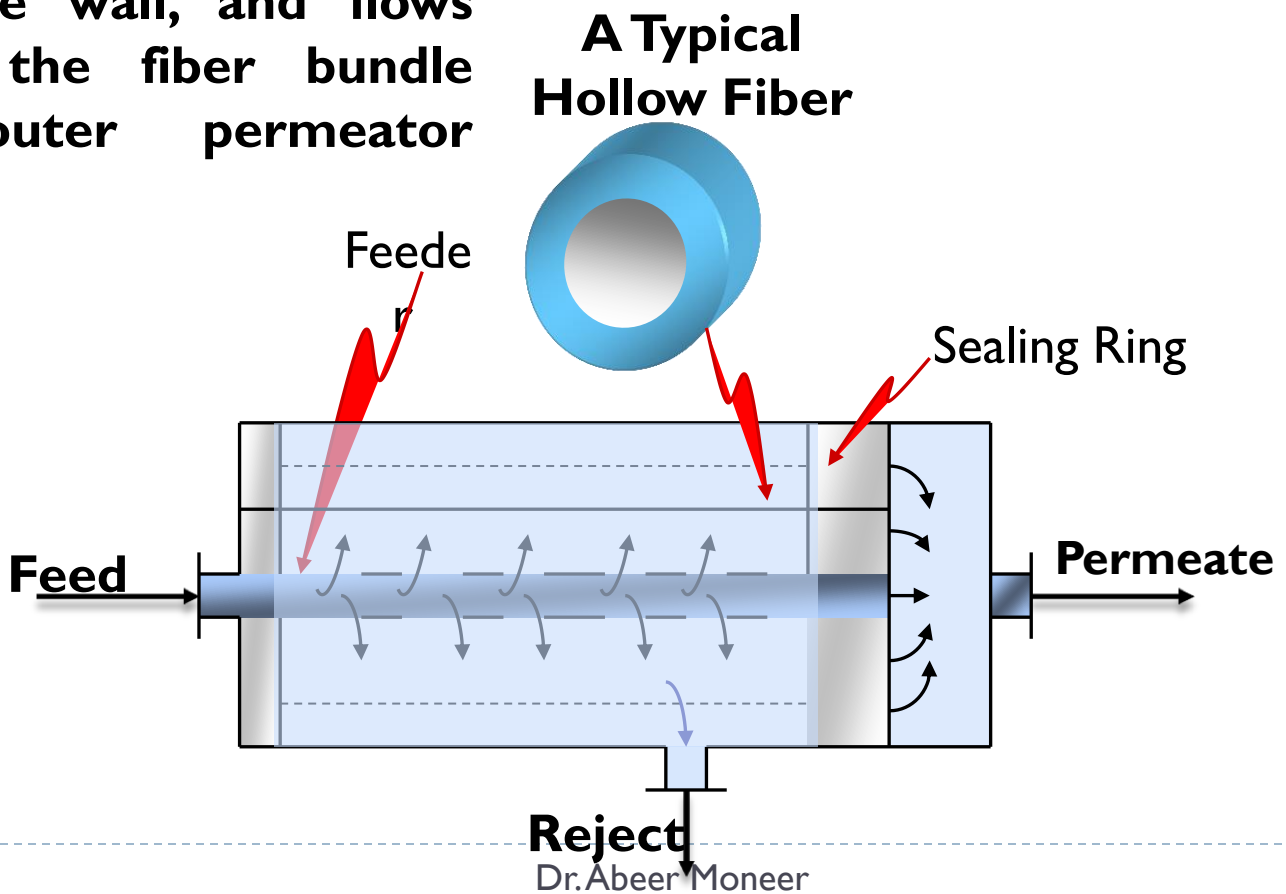
Diagram of a Hollow Fiber Membrane

4.1. Hollow fine fiber

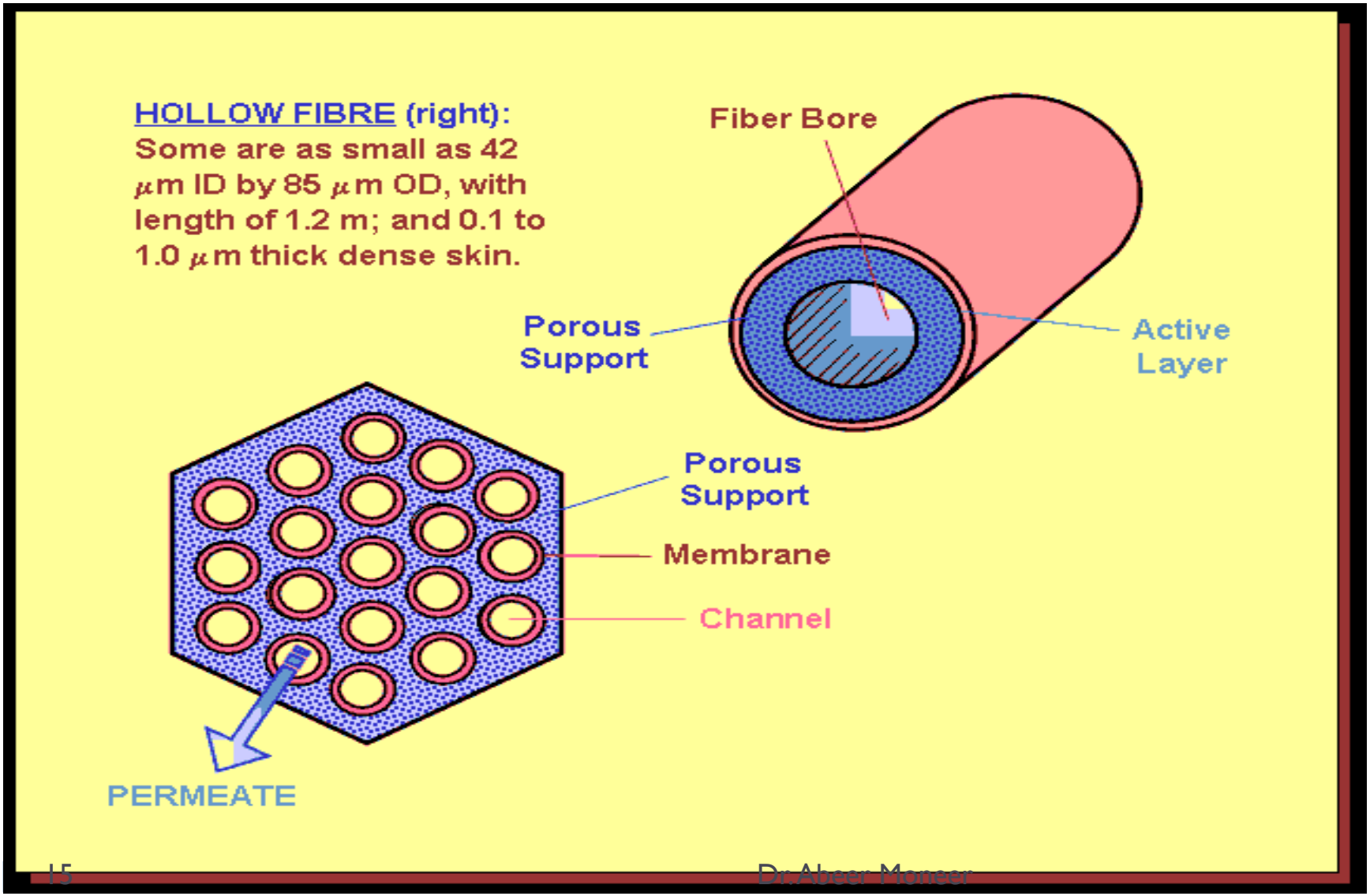
- A **perforated plastic tube**, serving as a **feed water distributor** is inserted in the center and **extends the full length of the bundle**.
- The **bundle** is **wrapped** and both ends are epoxy **sealed** to form a sheet-like **permeate tube end.**

4.1. Hollow fine fiber

The pressurized feed water enters the permeator feed end through the center distributor tube, passes through the tube wall, and flows radially around the fiber bundle toward the outer permeator pressure shell.

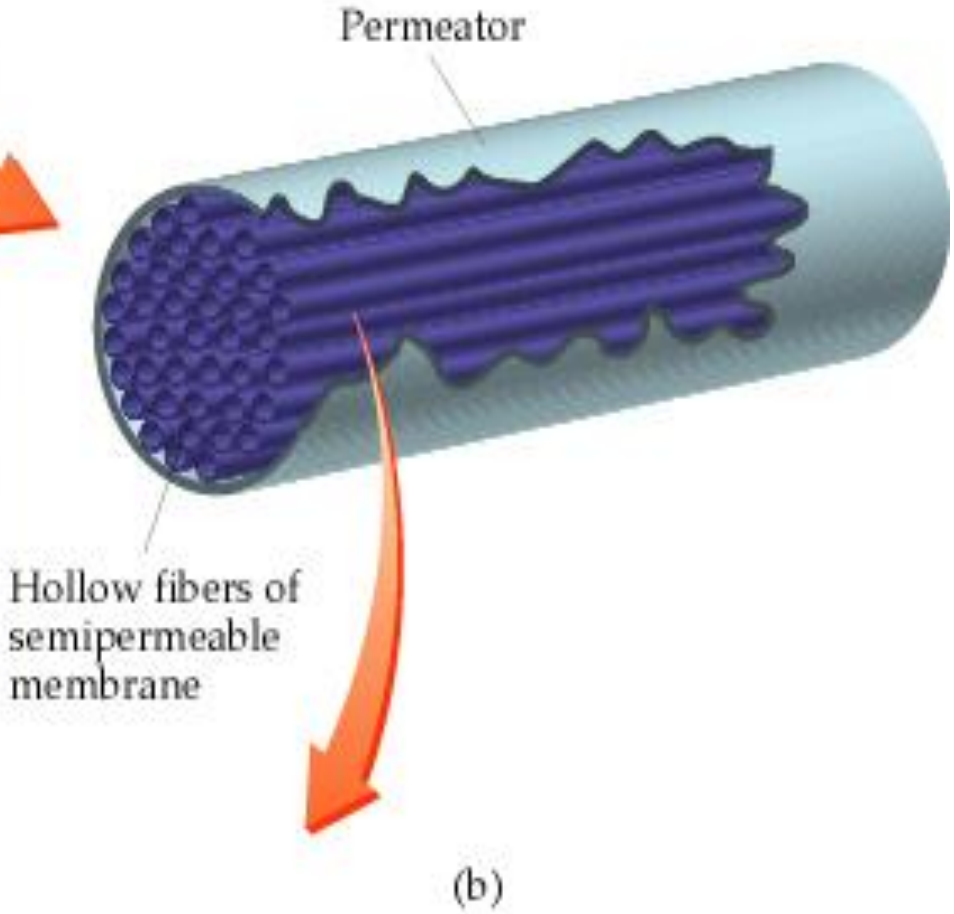


4.1. Hollow fine fiber



4.1. Hollow fine fiber

(a)



(b)

4.1. Hollow fine fiber

- The HFF membrane bundle, **10 cm to 20 cm in diameter**, is contained in a cylindrical housing or **shell** approximately **137 cm long and 15-30 cm in diameter**.
- The assembly has the **highest specific surface area,** defined as the total area per unit volume, **among all module configurations**.

4.1. Hollow fine fiber

- **Water permeates** through the **outside wall of the fibers** into the hollow core or **fiber bore**, through the bore to the tube sheet or product end of the fiber bundle, and **exits** through the product connection.
- In a HFF module, the permeate **water flow** per unit area of membrane is low, and therefore, the **CP is not high** at the membrane surface.
- The net result is that HFF units operate in a **non-turbulent or laminar flow regime.**

4.1. Hollow fine fiber

- The HFF membrane **must operate above a minimum reject flow to minimize CP** and maintain even flow distribution through the fiber bundle.
- Typically, a single hollow fiber permeator can be operated at up to **50% recovery** and meet the minimum reject flow required.
- The HFF unit allows a large membrane area per unit volume of permeator that results in **compact systems**.
- Because of very close packed fibers and tortuous feed flow inside the module, HFF modules require feed water of better quality (lower concentration of suspended solids) than the spiral wound module configuration.

4.1. Hollow fine fiber

- The **HFF** element **does not allow for turbulent flow** or **uniform flow** across the fiber surface making these elements more prone to fouling and scaling.
- Once fouled the **HFF elements are more difficult to clean** due to the inability to get the cleaning solution to the fouled area.
- HFF elements are mostly found in seawater desalination applications and limited brackish water applications where fouling potential is minimal.

4.2. Spiral wound

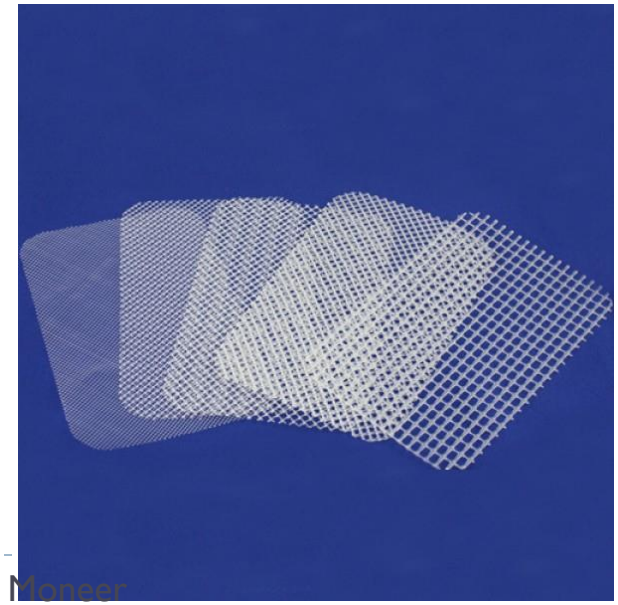
- In a spiral wound configuration **two flat sheets** of membrane are **separated** with a **permeate collector** channel material to form a **leaf.**
- This assembly is **sealed on three sides** with the **fourth side** left open for **permeate to exit.**
- A **feed/brine spacer** material sheet is **added** to the **leaf assembly**.

4.2. Spiral wound

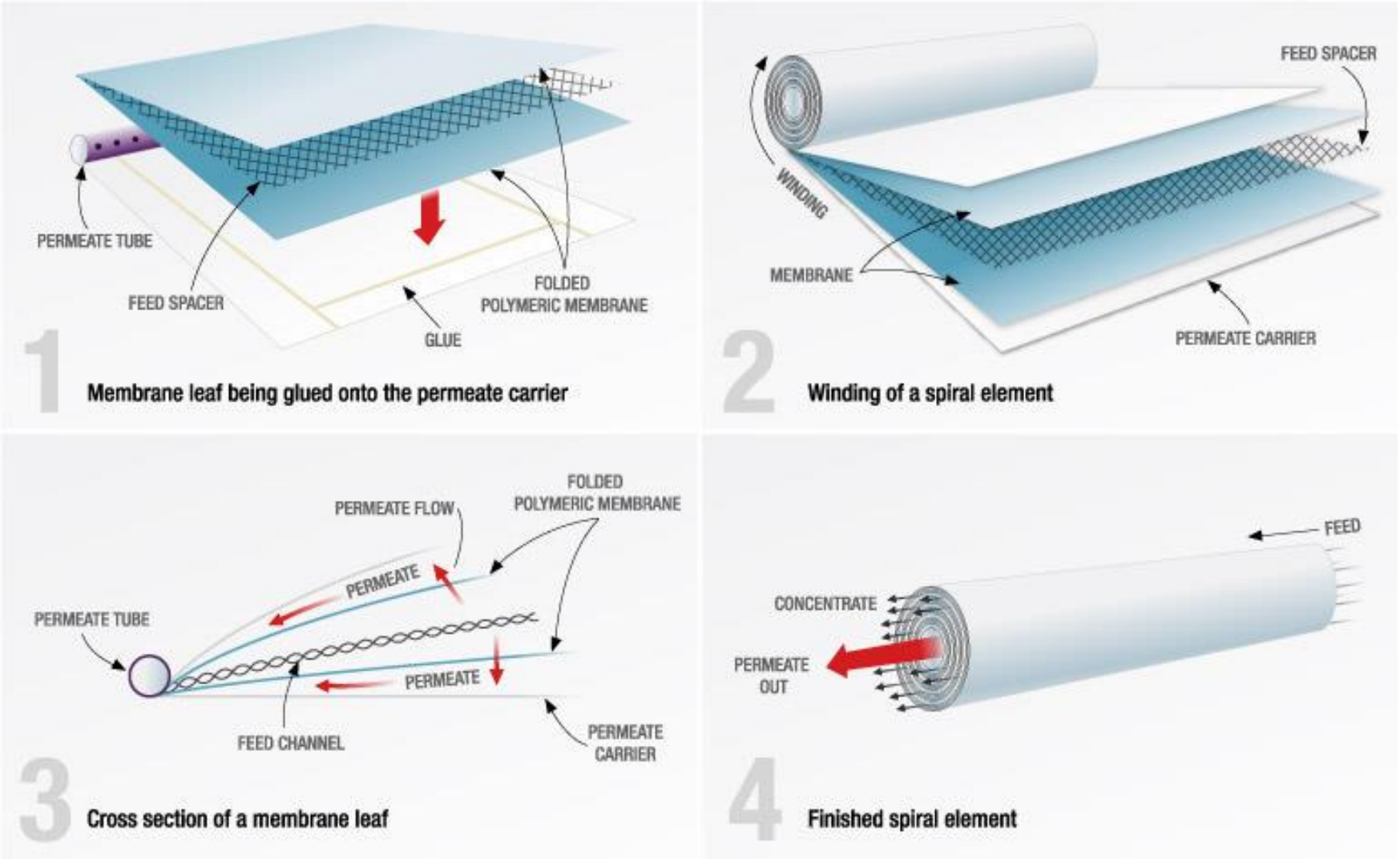
- A number of these assemblies or leaves are wound around a **central plastic permeate tube**.
- This tube is **perforated to collect the permeate** from the multiple leaf assemblies.
- The typical industrial spiral wound membrane element is approximately **100 or 150 cm long and 10 or 20 cm in diameter.**

4.2. Spiral wound

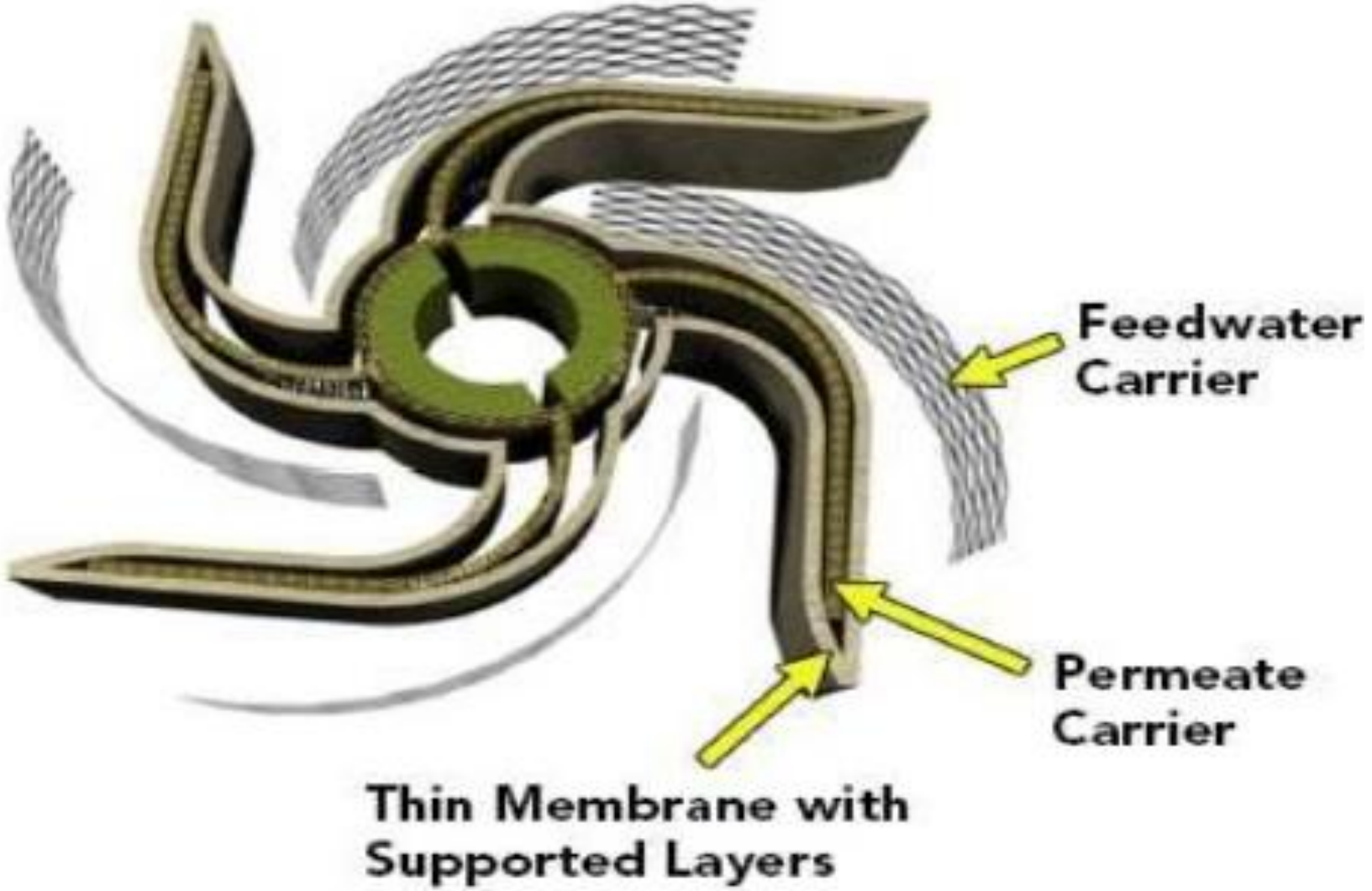
- **Feed Channel Spacer -**
- Feed channel spacers are a **netting** material placed between the flat sheets of a reverse osmosis membrane **to promote turbulence** in the feed / concentrate stream.



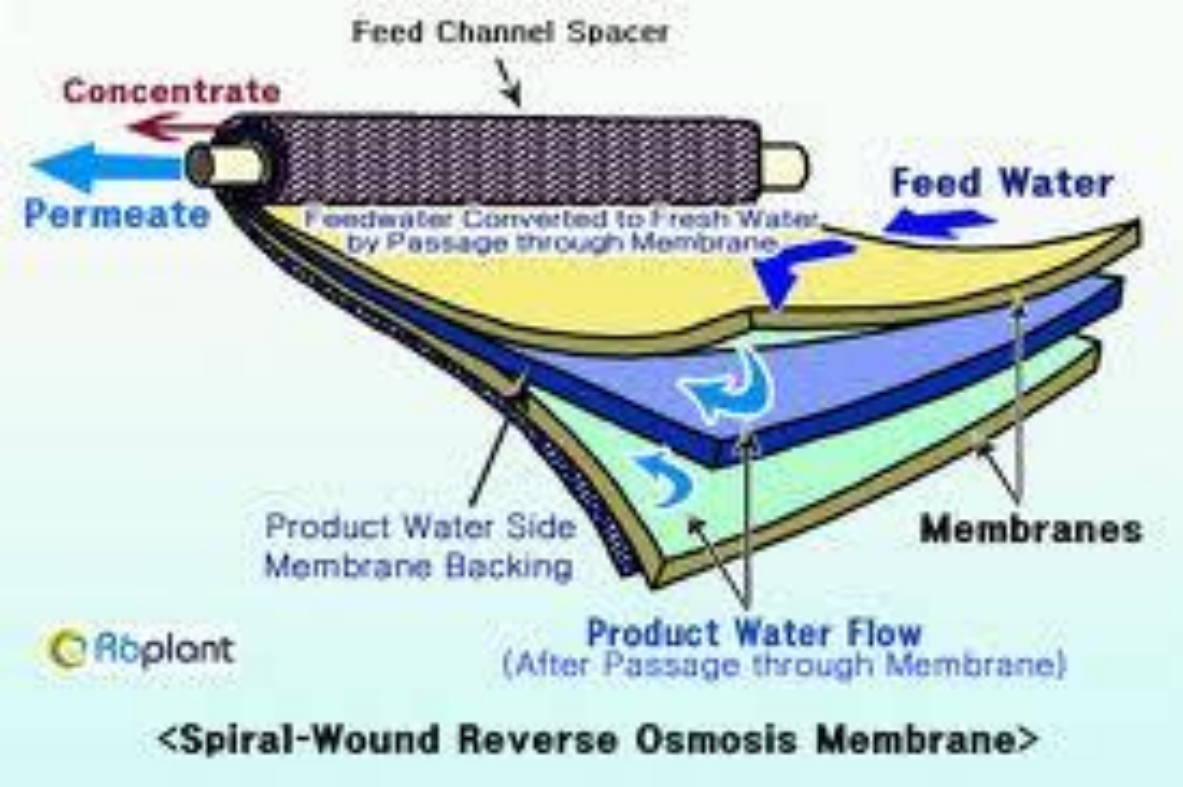
4.2. Spiral wound



4.2. Spiral wound

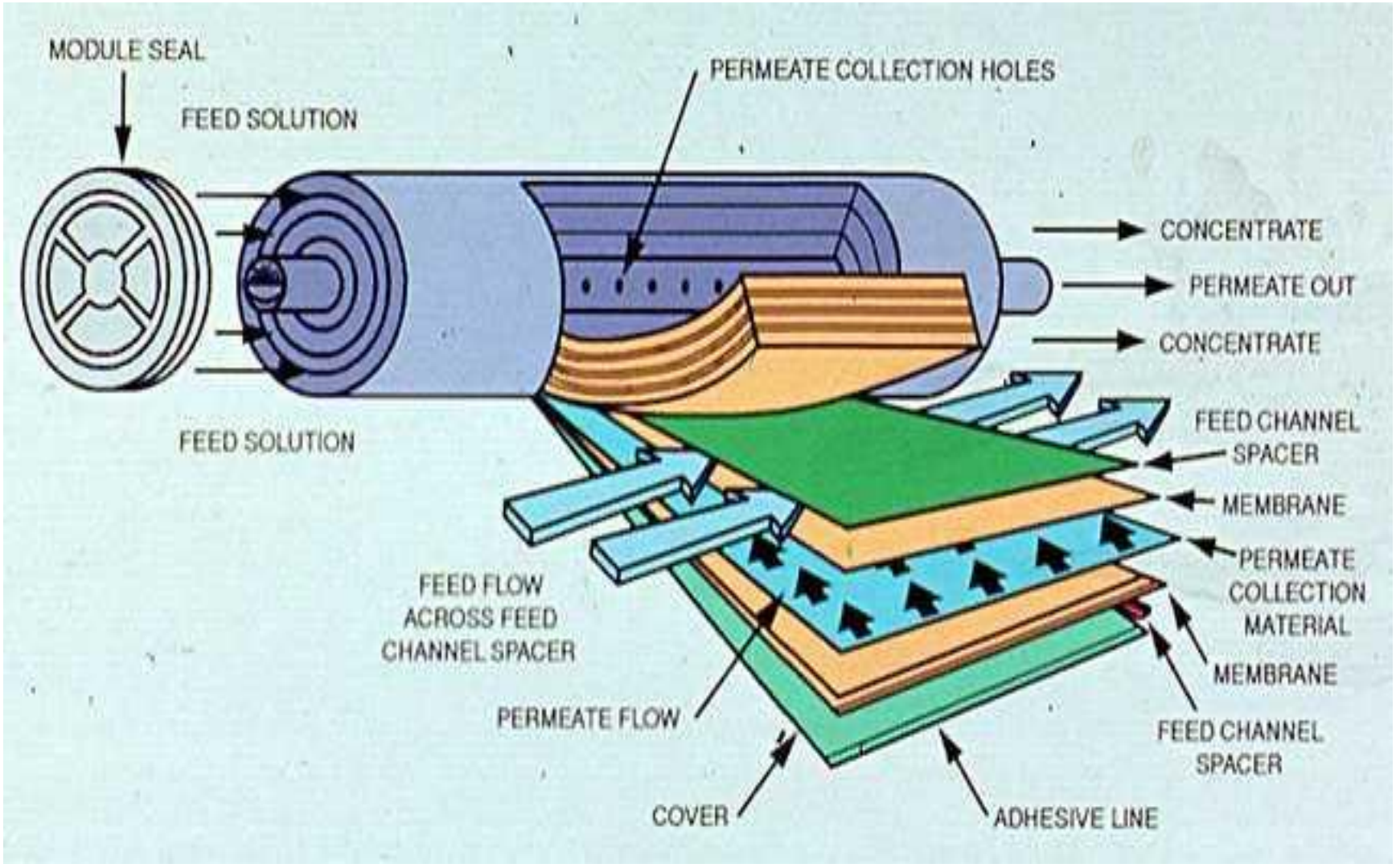


4.2. Spiral wound

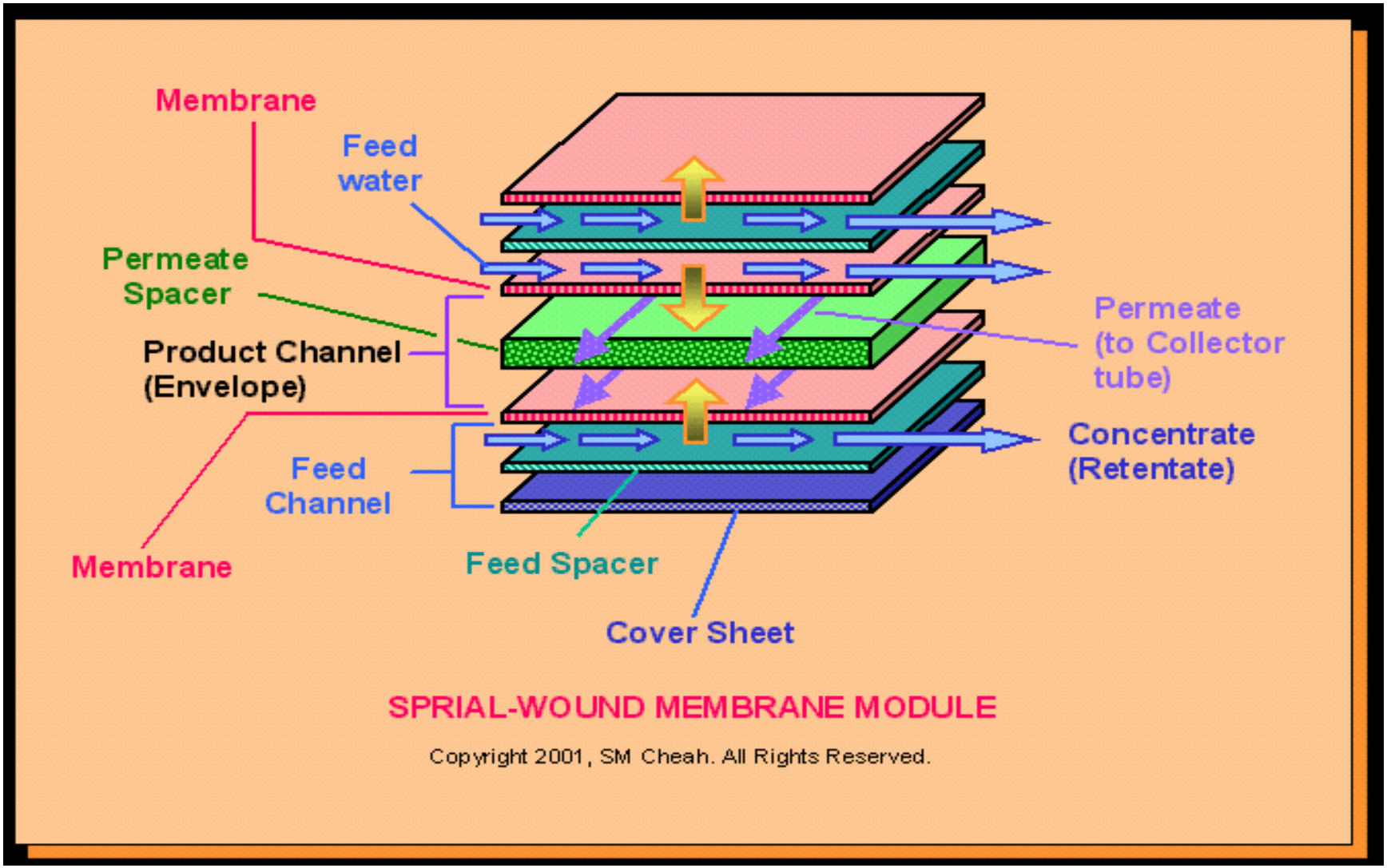


<Spiral-Wound Reverse Osmosis Membrane>

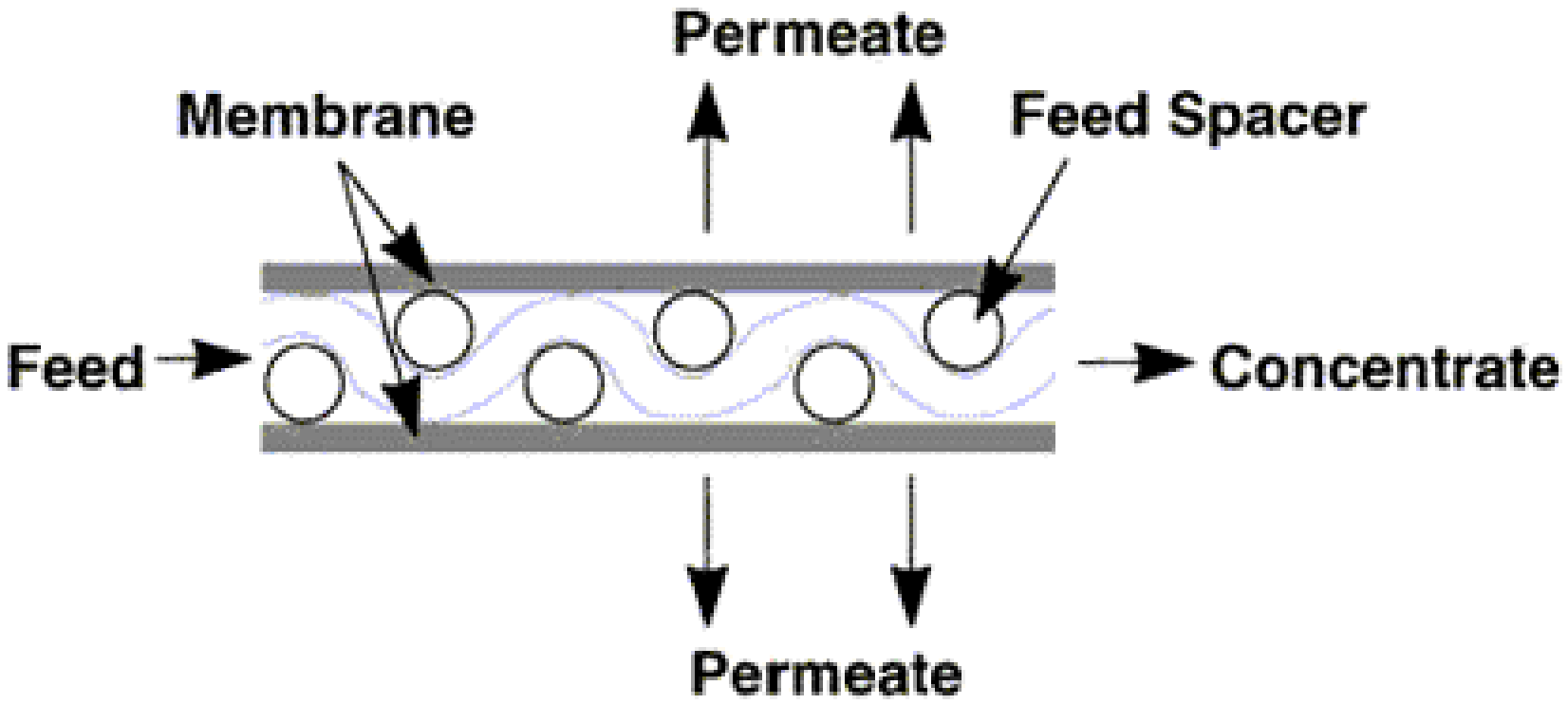
4.2. Spiral wound



4.2. Spiral wound



4.2. Spiral wound



4.2. Spiral wound

- The feed/brine flow through the element is a **straight axial path** from the **feed end** to the **opposite brine end**, running **parallel to the membrane** surface.
- The **feed channel spacer induces turbulence** and **reduces concentration polarization**.
- Manufacturers specify brine flow requirements to control CP by limiting recovery per element to 10-20%.
- Therefore, recovery is a function of the feed-brine path length.

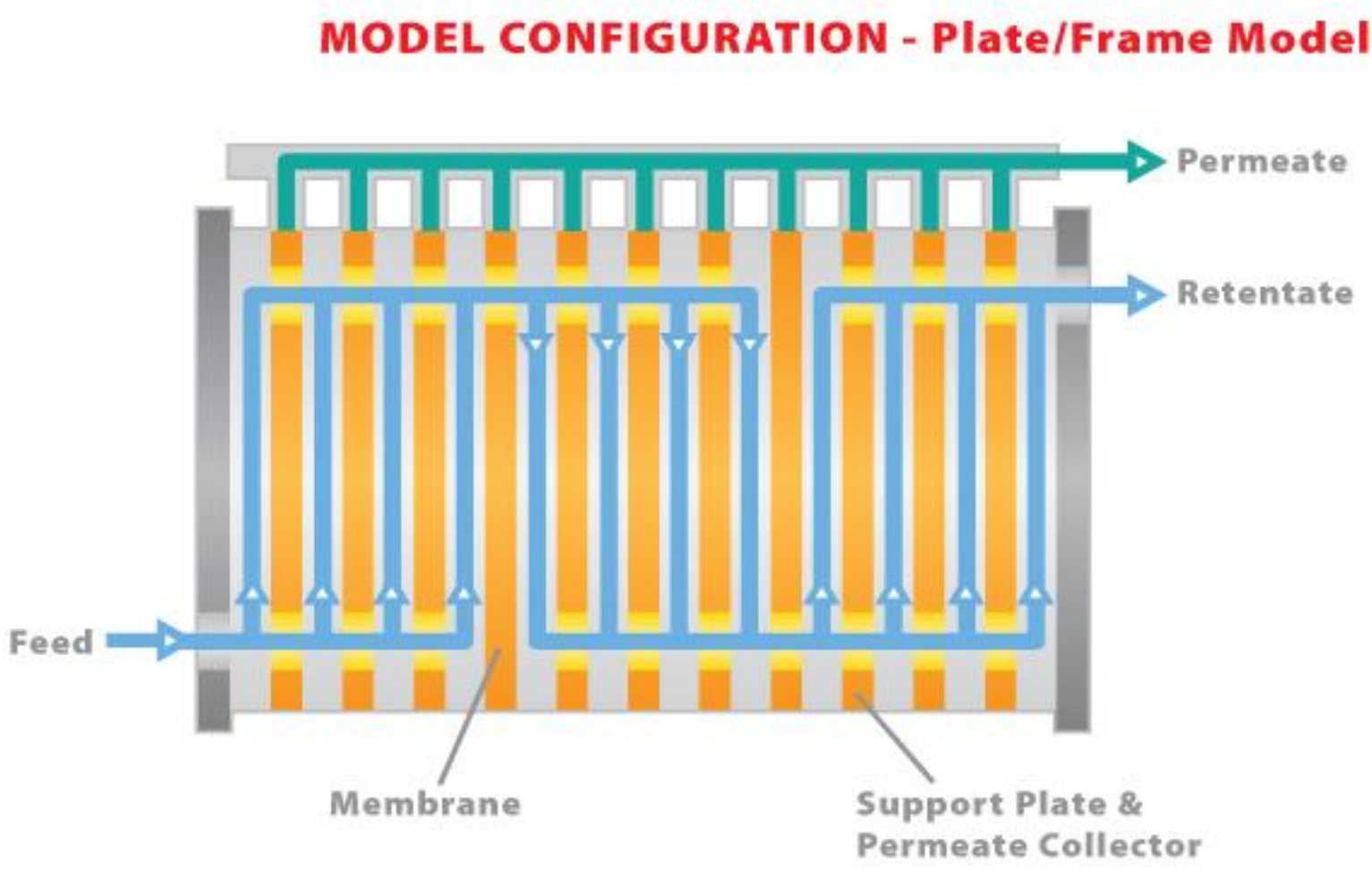
4.2. Spiral wound

- In order to operate at acceptable recoveries, spiral systems are usually staged with **three to six membrane elements connected in series** in a pressure tube.
- The **brine** stream **from the first element** becomes the **feed to the following element**, and so on for each element within the pressure tube.
- The brine stream from the last element exits the pressure tube to waste.
- The **permeate from each element** enters the permeate collector tube and exits the vessel as a **common permeate stream**.

4.2. Spiral wound

- A single pressure vessel with four to six membrane elements connected in series can be operated at up to **50% recovery** under normal design conditions.
- Spiral wound elements are most commonly manufactured with flat sheet membrane of either a **cellulose di-acetate and tri-acetate (CA) blend or a thin film composite.**

Plate and Frame RO



RO system configurations

- The RO modules can be used in different configuration in the reverse osmosis plants as follows:
- One stage RO system, and
- Two stages RO systems
- RO system with concentrate recycle.

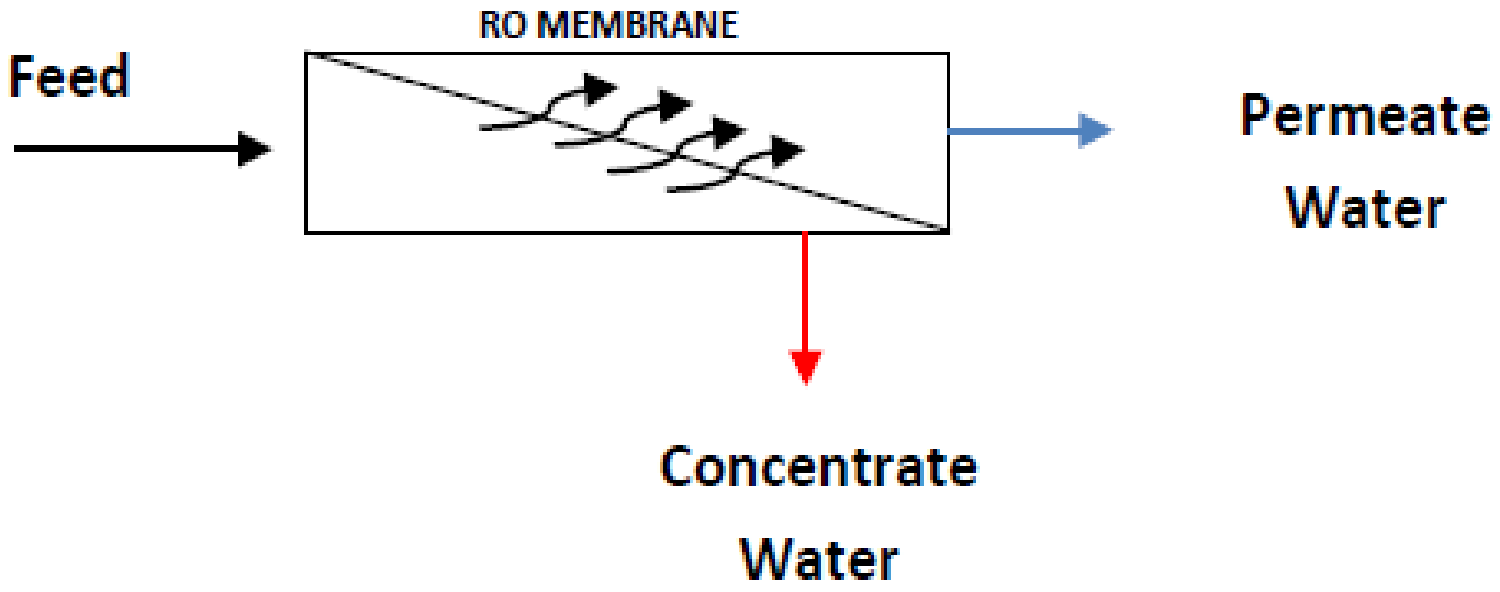
5.1.Difference between a 1 and 2 stage RO System

- In a one stage RO system, the feed water enters the RO system as one stream and exits the RO as either concentrate or permeate water.
- In a two-stage system the concentrate (or reject) from the first stage then becomes the feed water to the second stage.
- The permeate water is collected from the first stage is combined with permeate water from the second stage.
- Additional stages increase the recovery from the system.

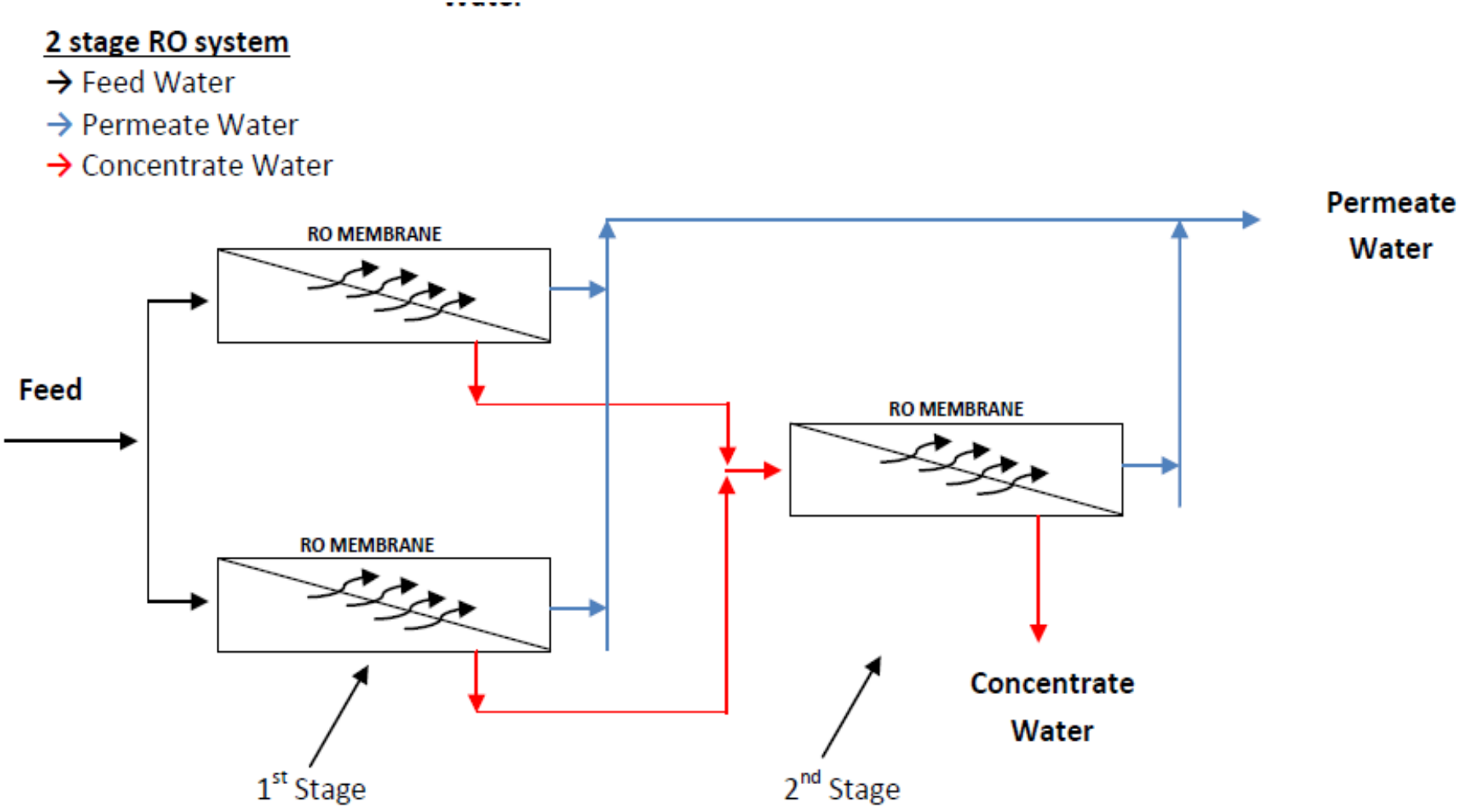
5.1. Difference between a 1 and 2 stage RO System

1 stage RO system

- Feed Water
- Permeate Water
- Concentrate Water



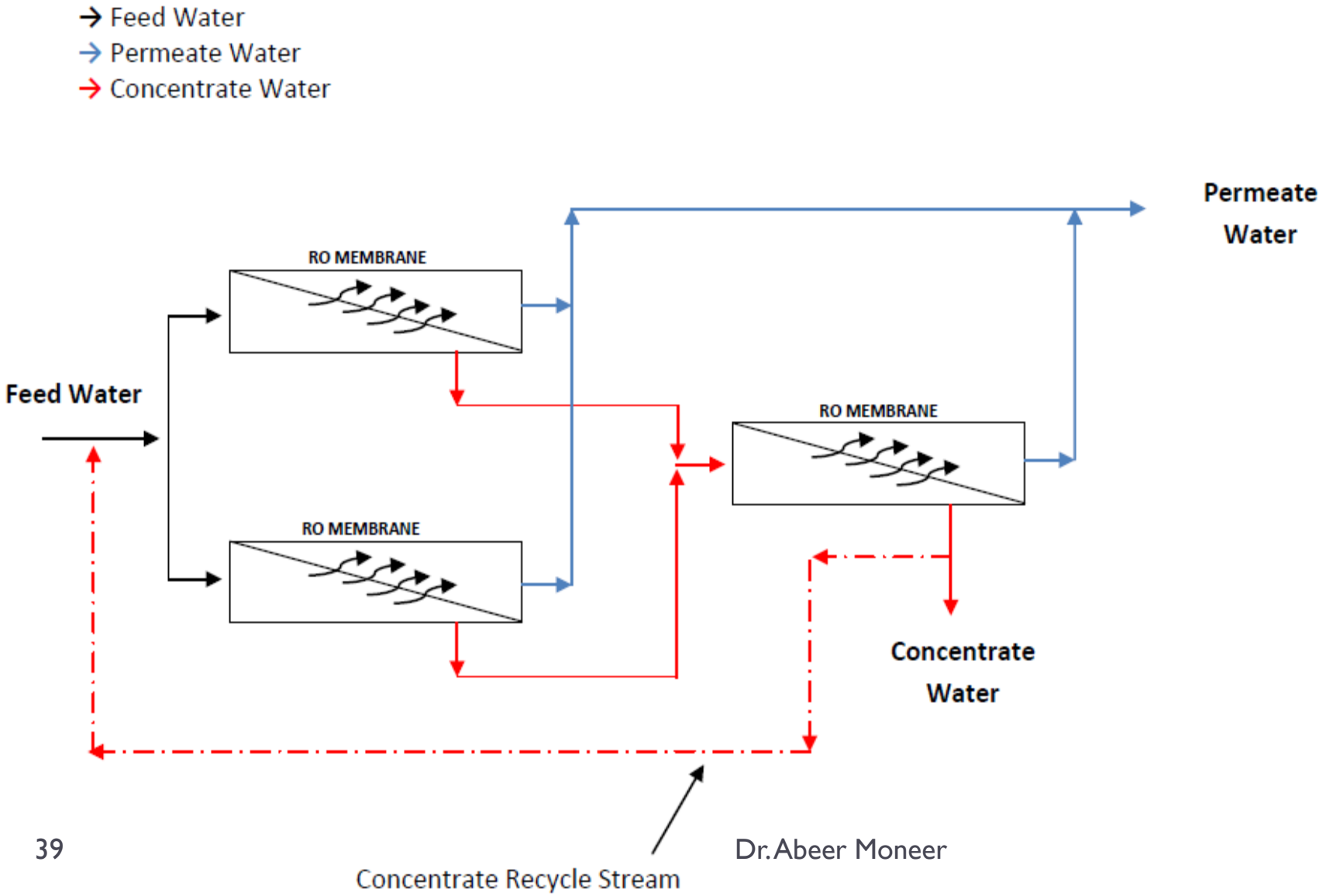
5.1. Difference between a 1 and 2 stage RO System



5.2. RO System with Concentrate Recycle

- With an RO system with Concentrate Recycle where the feed water chemistry allows for it, a concentrate recycle setup can be utilized where **a portion** of the **concentrate** stream **is fed back** to the feed water **to the first stage** to help increase the system recovery.

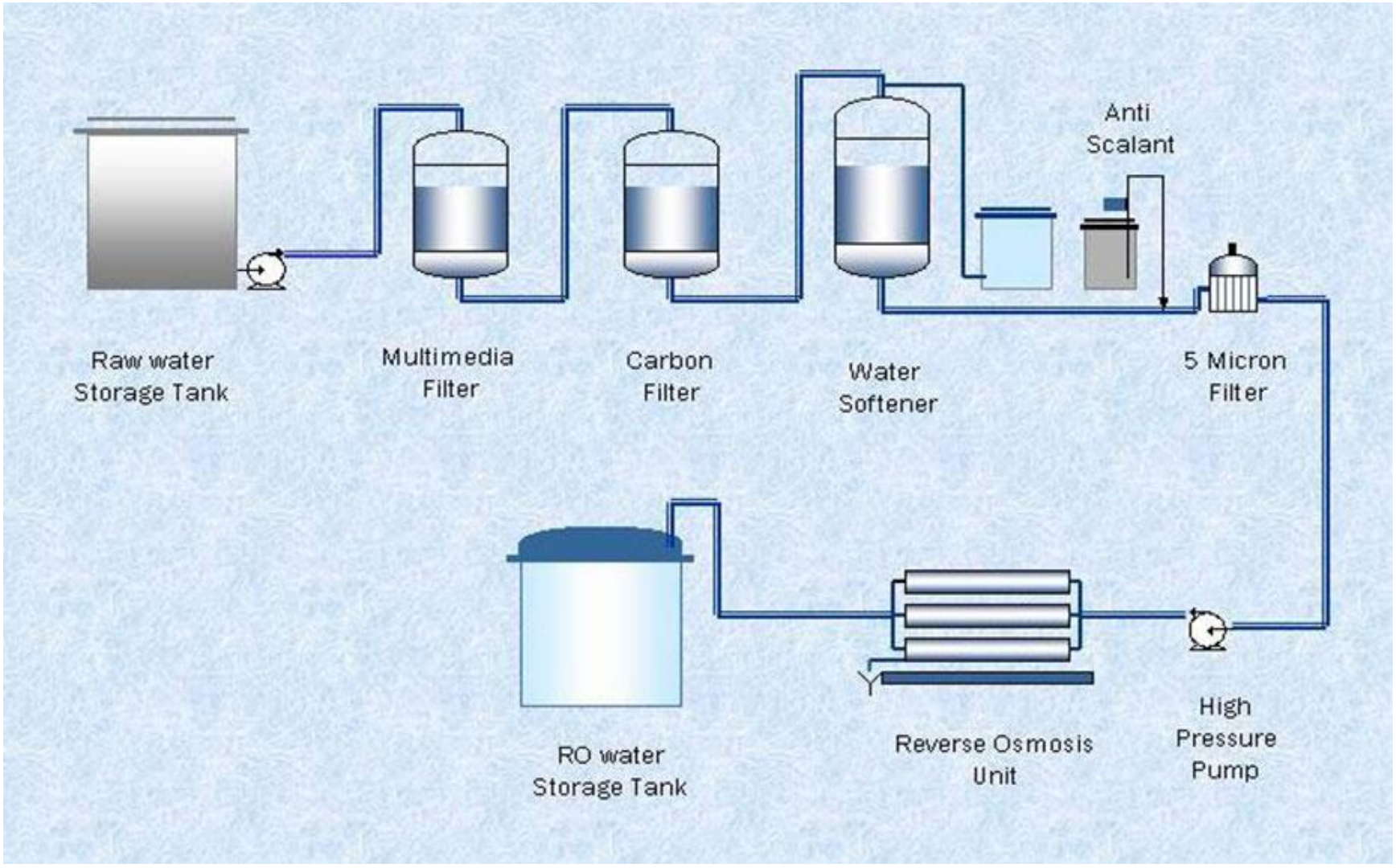
5.2. RO System with Concentrate Recycle



RO systems

- The RO systems may consist of the following basic components:
- - Feed water supply unit
- - Pretreatment system
- - High pressure pumping unit
- - Membrane element assembly unit
- - Instrumentation and control system
- - Permeate treatment and storage unit
- - Cleaning unit

RO systems


Raw water
Storage Tank
Multimedia
Filter
Carbon
Filter
Water
Softener
Anti
Scalant
5 Micron
Filter
RO water
Storage Tank
Reverse Osmosis
Unit
High
Pressure
Pump

Questions

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

1. The HFF has the highest specific surface area, defined as the total area per unit volume, among all module configurations.
2. HFF units operate in a turbulent flow regime.
3. A single hollow fiber permeator can be operated at up to 80% recovery.
4. HFF are available for brackish and seawater applications.
5. Membrane materials for HFF are cellulose acetate blends only.
6. The HFF module contains a feed channel spacers.

Questions

7. The feed channel spacer in spiral wound module of RO induces turbulence and reduces concentration polarization.

Answer:

1. The RO modules can be used in different configuration in the reverse osmosis plants, Explain.