Chapter 1

Introduction

Desalination of water

Introduction

Only 1 percent of the earth's water is liquid freshwater; 97 percent of available water resources are contaminated by salt. This makes desalination an essential component of efforts to address water shortages, especially in densely populated coastal regions. Egypt faces nowadays severe challenges to our ability to meet our future water needs, So we as a nation will need to make additional water resources available to all segments of our nation’s and provide additional water resources at a cost and in a manner that supports urban, rural and agricultural prosperity and environmental protection; Meeting these challenges may lead us to use saline water for a greater national focus on water conservation.

Earth’s water distribution

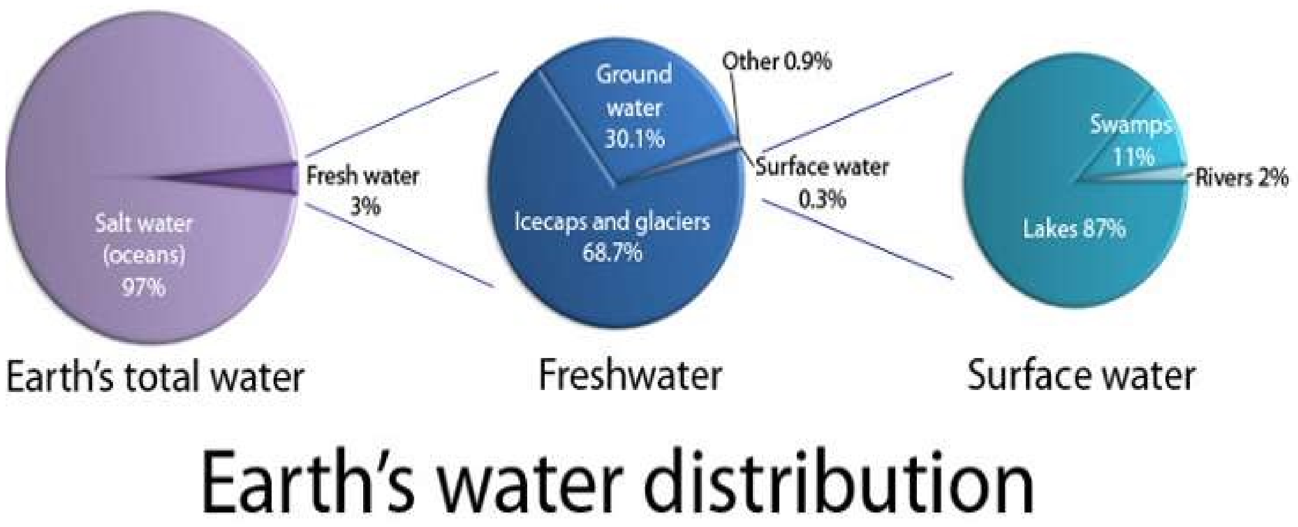


Figure 1.1

Brackish water and seawater

Brackish water is saltier than fresh water, but not as salty as seawater. Brackish water usually has a salt concentration between 5 and 20 parts per thousand (ppt) and seawater generally has a concentration of salt greater than 20 ppt. Brackish waters may also be found in aquifers.

Classification Of Water Salinity

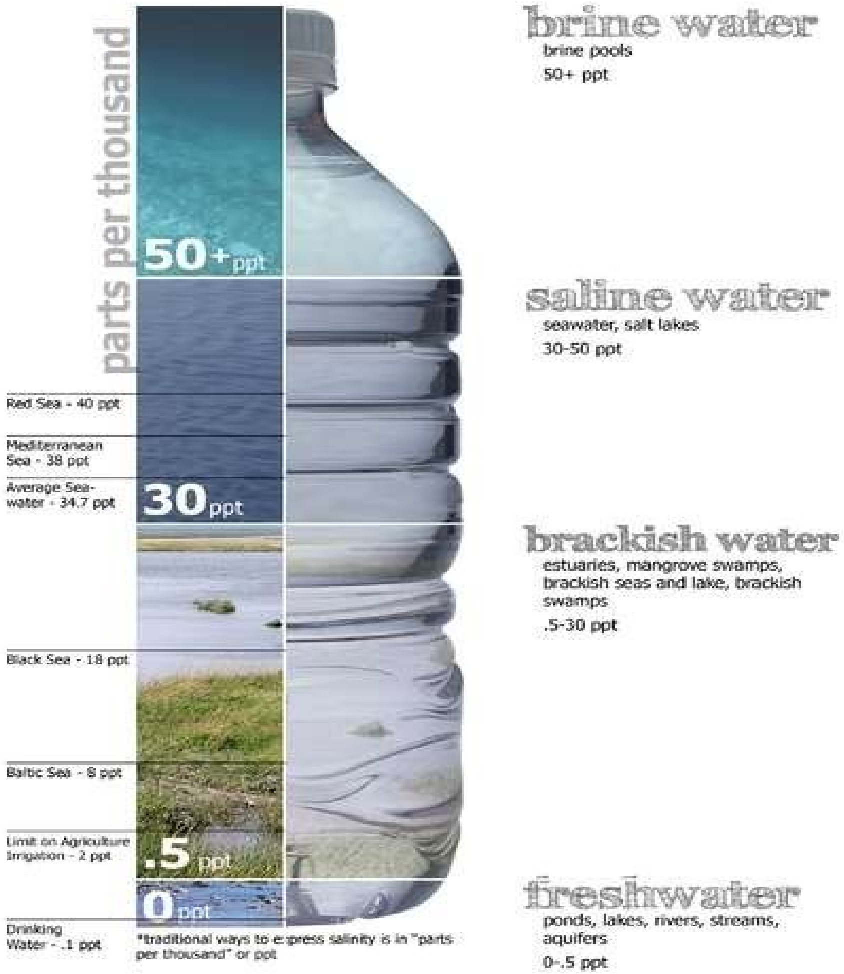


Figure 1.2

Water type and Total Dissolved Solid:

Water type	TDS(mg/l)
Sweet waters	0-1000
Brackish waters	1000-5000
Moderately saline waters	5000-10000
Severely saline waters	10000-30000
Seawater	More than 30000

Table 1.1

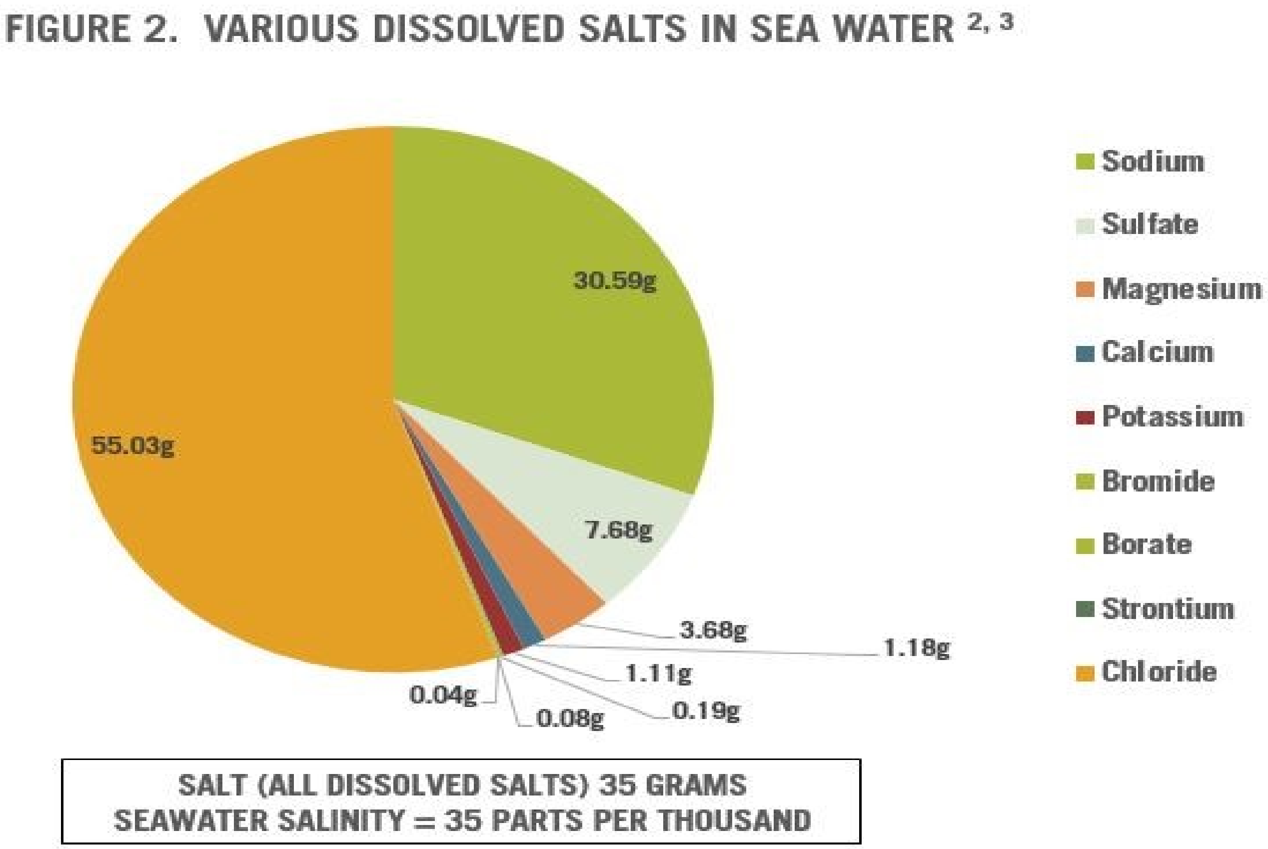


Figure 1.3

- **Significance of Desalination**

Desalination technologies will contribute significantly to ensuring a safe, sustainable, Affordable, and adequate water supply for Egypt.

- **Provide safe water:**

A safe water supply is one that meets all drinking water standards, meets all standards for use by agricultural and industrial interests, and that strives to move toward greater water security during drought, natural disasters, transport.

- **Ensure the sustainability of the nation's water supply:**

A sustainable water supply is one that meets today's needs without jeopardizing the ability to meet the needs of future generations.

- **Keep water affordable:**

An affordable water supply is one that provides water to the nation's future citizenry at rates comparable to that of today.

- **Ensure adequate supplies:**

An adequate water supply is one that guarantees local and regional availability of water.

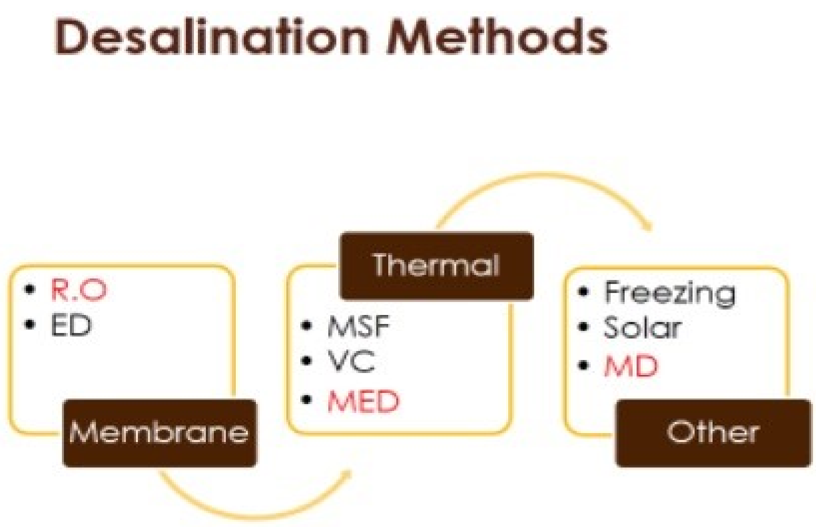


Figure 1.4

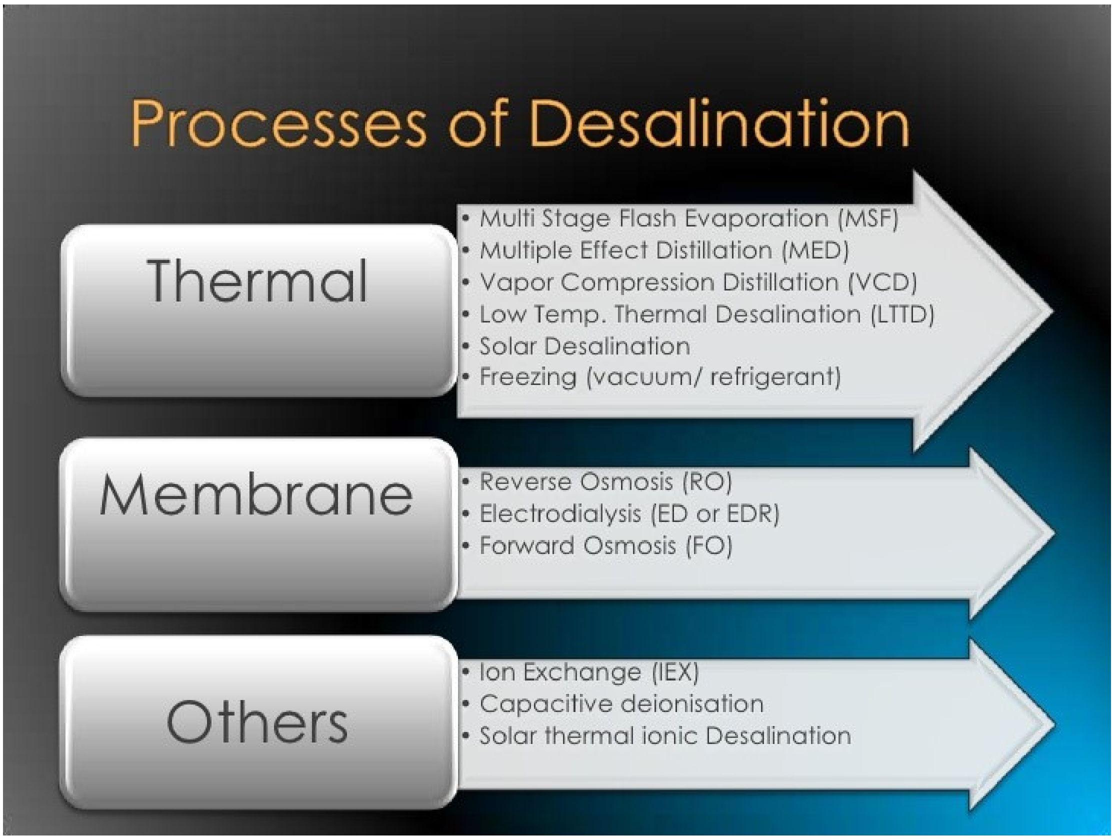


Figure 1.5

Desalination techniques

1.Distillation:

1.1Multi-stage flash distillation (**MSF**)

1.2Multiple-effect evaporator (**MED|ME**)

1.3Vapor-compression evaporation (**VC**)

Membrane processes:

2.1Electrodialysis reversal (**EDR**)

2.2Reverse osmosis (**RO**)

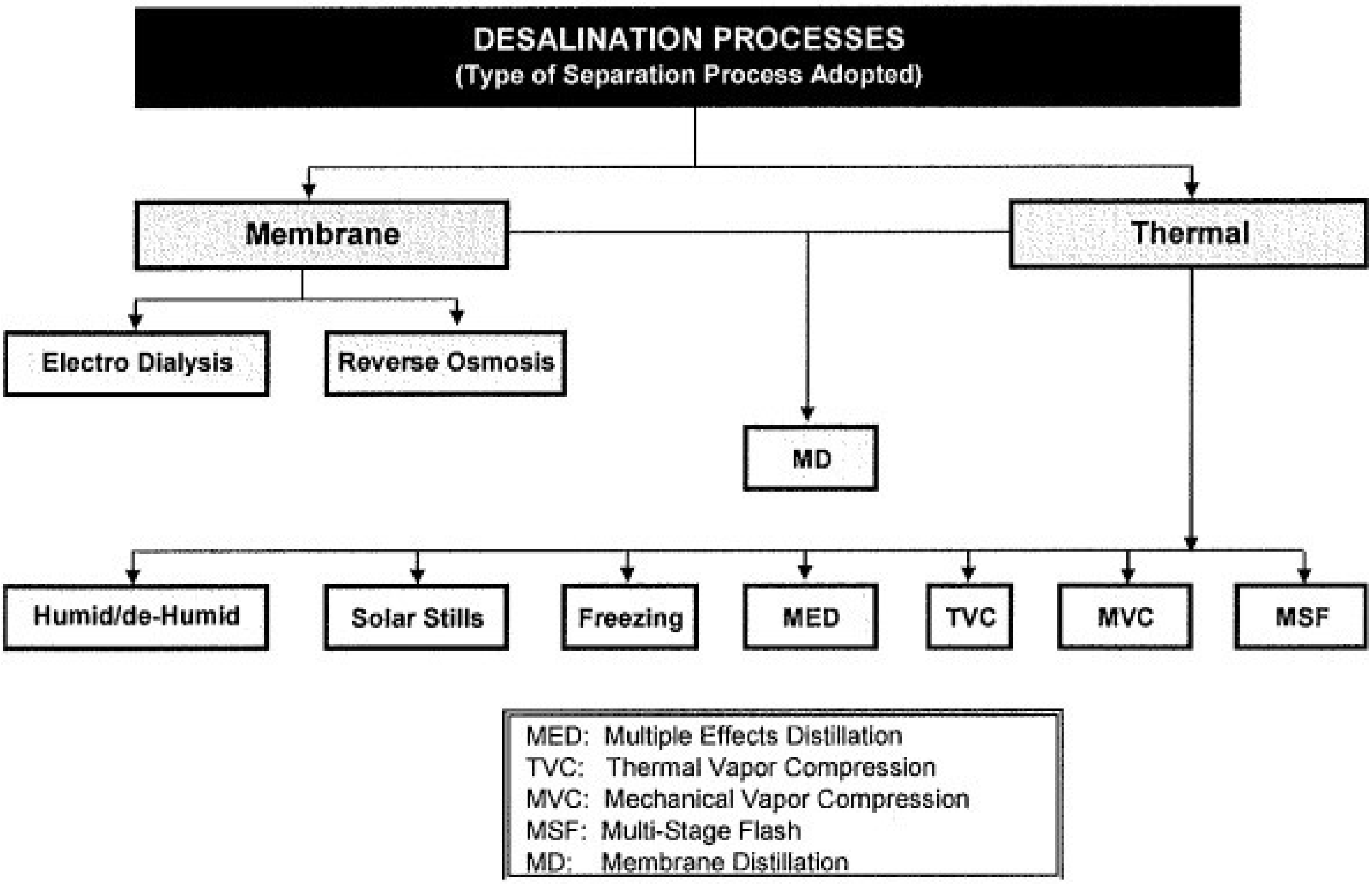


Figure 1.6

Desalination techniques:-

1. Multi-stage flash distillation (MSF)

- Multi-stage flash distillation (MSF) is a water desalination process that distills seawater by flashing a portion of the water into steam in multiple stages of what are essentially countercurrent heat exchanger. Multi-stage flash distillation plants produce [64%] percent of all desalinated water in the world, although a different type of desalinators, Reverse osmosis plants, are more numerous.

- Multi-stage flash distillation plants have been built since the late 1950s. Some MSF plants can contain from 15 to 25 stages, but are usually no larger than 15 mgd in capacity.

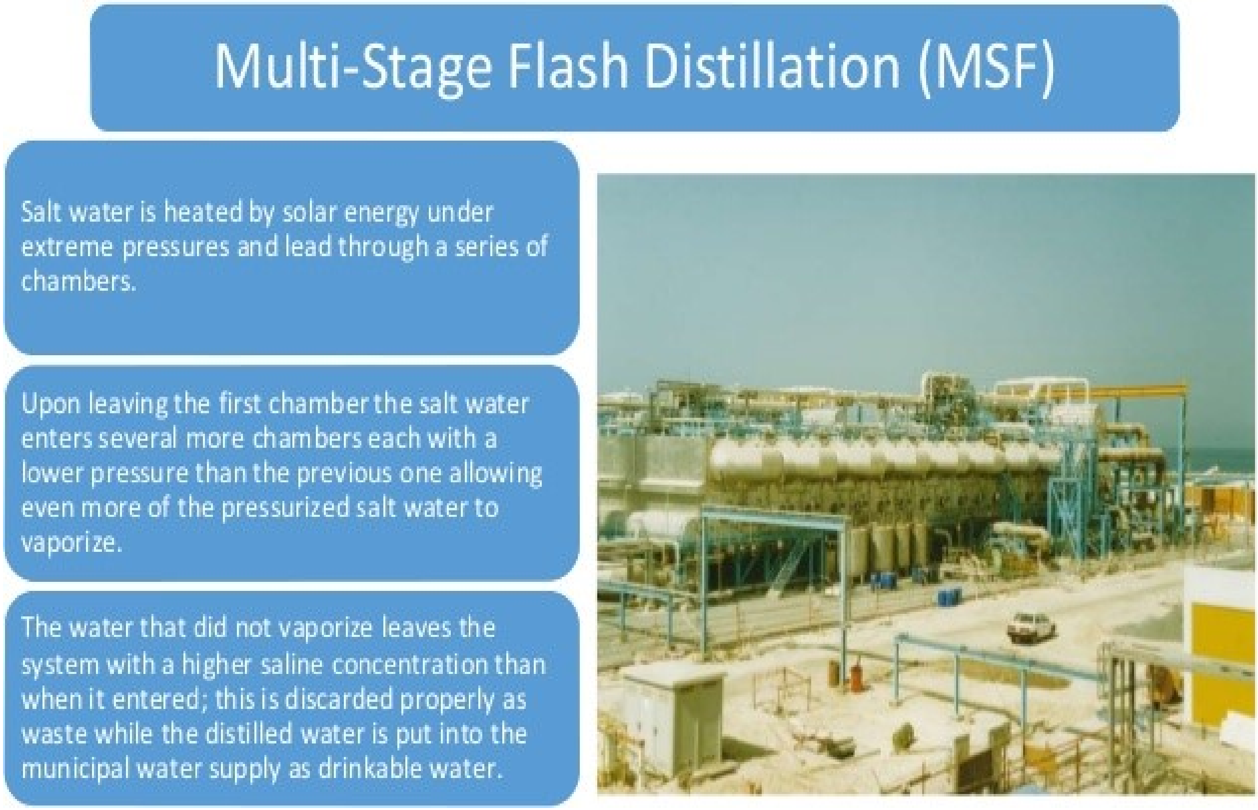


Figure 1.7

Principle :-

- The MSF system consists of three sections: heat-rejection, heat-recovery and brine heater. The heat-rejection and heat-recovery consist of a number of flash chambers (stages) connected to one another.

- This process involves the use of distillation through several (multi-stage) chambers. In the MSF process, each successive stage of the plant operates at progressively lower pressures. The feed water is first heated under high pressure, and is led into the first ‘flash chamber’, where the pressure is released, causing the water to boil rapidly resulting in sudden evaporation or ‘flashing’. This ‘flashing’ of a portion of the feed continues in each successive stage, because the pressure at each stage is lower than in the previous stage. The vapor generated by the flashing is converted into fresh water by being condensed on heat exchanger tubing that run through each stage. The tubes are cooled by the incoming cooler feed water. Generally, only a small percentage of the feed water is converted into vapor and condensed.

1.2. Multiple-effect distillation (MED)

Multiple-effect distillation is a distillation process often used for seawater desalination. It consists of multiple stages or "effects". In each stage the feed water is heated by steam in tubes. Some of the water evaporates, and this steam flows into the tubes of the next stage, heating and evaporating more water. Each stage essentially reuses the energy from the previous stage.

The tubes can be submerged in the feed water, but more typically the feed water is sprayed on the top of a bank of horizontal tubes, and then drips from tube to tube until it is collected at the bottom of the stage.

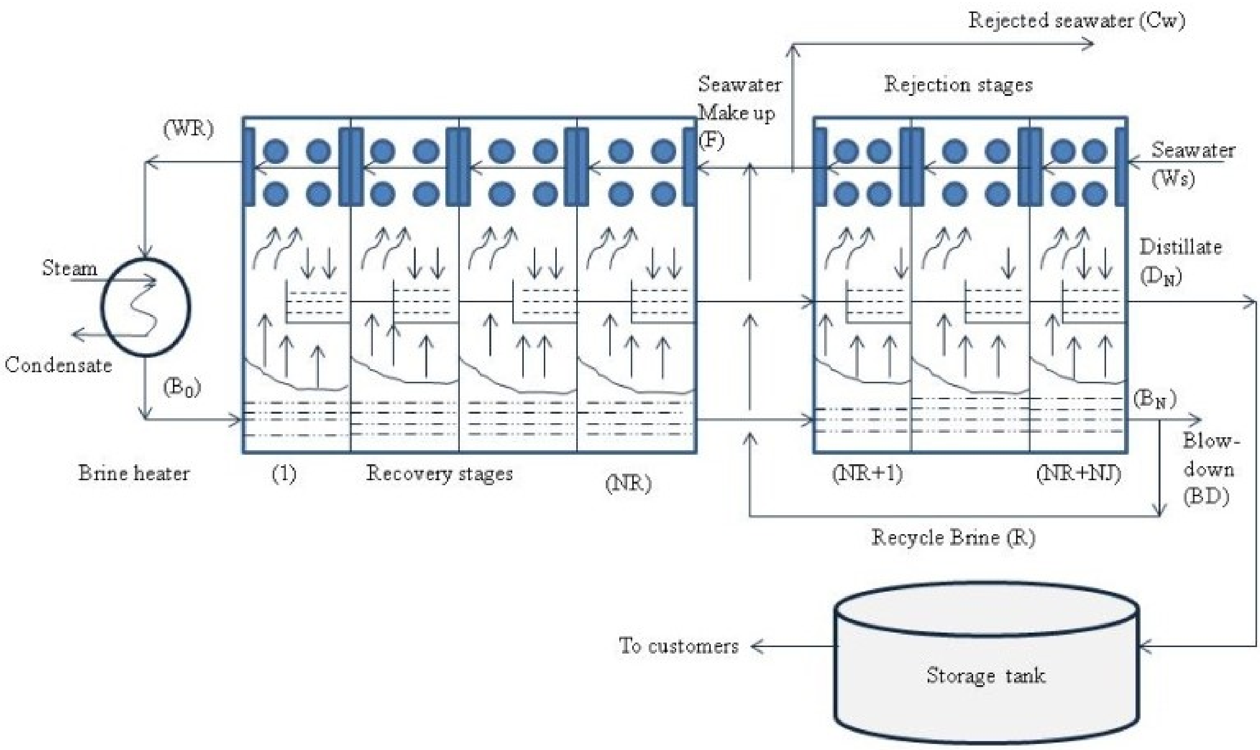


Figure1.8

Principle :-

Multi-effect distillation occurs in a series of vessels (effects) and uses the principles of evaporation and condensation at reduced ambient pressure. In MED, a series of evaporator effects produce water at progressively lower pressures. Water boils at lower temperatures as pressure decreases, so the water vapor of the first vessel or effect serves as the heating medium for the second, and so on. The more vessels or effects there are, the higher the performance ratio. Depending upon the arrangement of the heat exchanger tubing, MED units could be classified as horizontal tube, vertical tube or vertically stacked tube bundles.

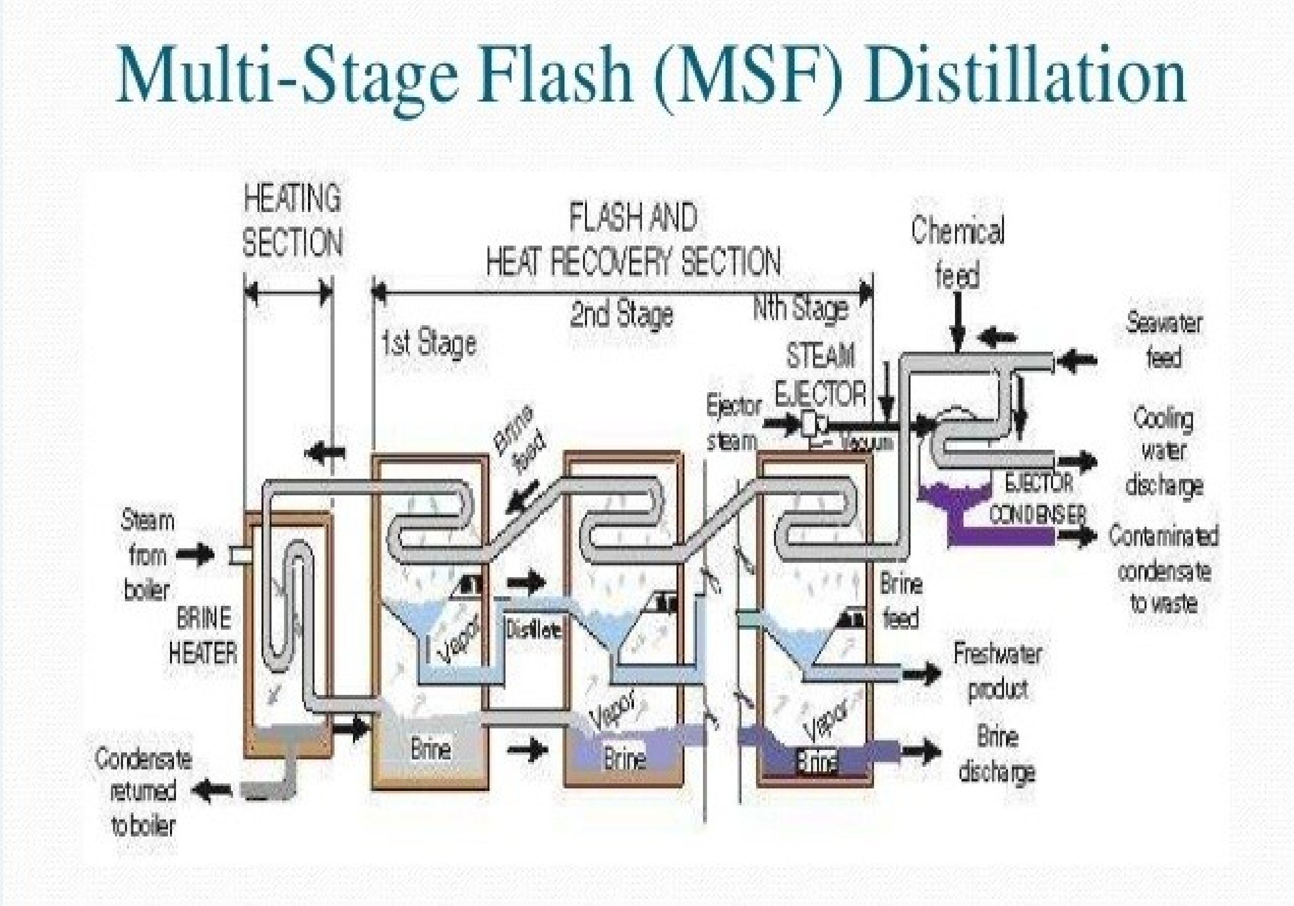


Figure 1.9

1.3. **Vapor-compression desalination (VC)**

- The VC operates mainly at a small scale, on small locations. The main mechanism is similar to MED except that it is based on compression of the vapor generated by evaporating water to a higher pressure, Which allows reuse of the vapor for supplying heat for the evaporating process.

- Vapor compression (VC) units have been built in a variety of configurations. Usually, a mechanical compressor is used to generate the heat for evaporation. The VC units are generally small in capacity, and are often used at hotels, resorts and in industrial applications.

- The compression is mechanically powered by something such as a compression turbine. As vapor is generated, it is passed over to a heat exchanging condenser which returns the vapor to water. The resulting fresh water is moved to storage while the heat removed during condensation is transmitted to the remaining feedstock.

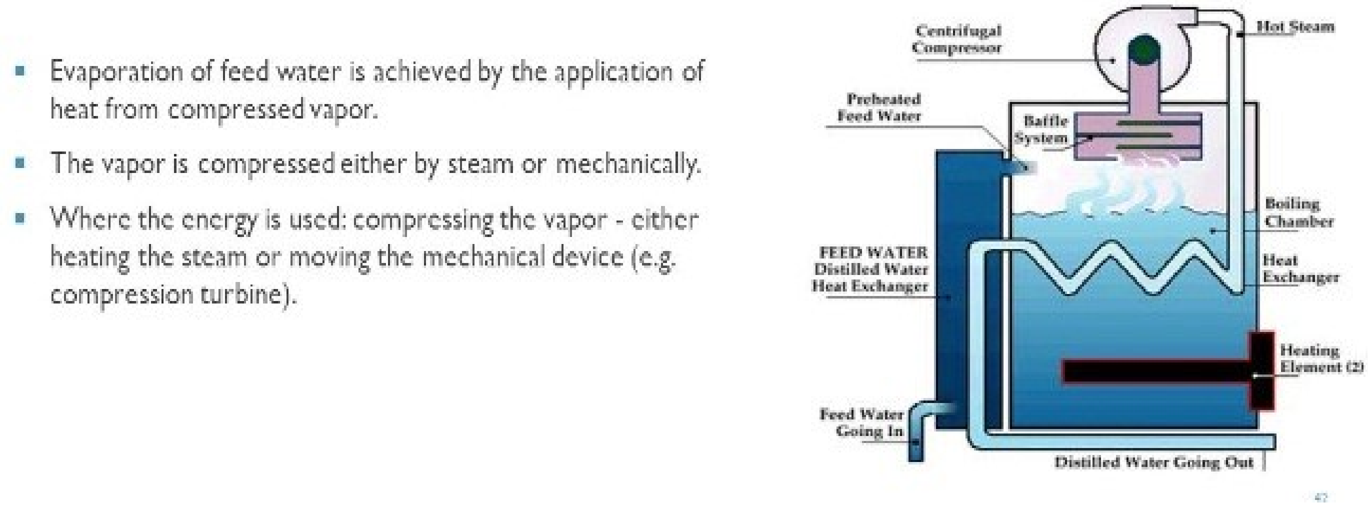


Figure 1.10

2.Membrane desalination:

2.1.Electrodialysis reversal (EDR)

- It is an electro dialysis reversal water desalination membrane process that has been commercially used since the early 1960s. An electric current migrates dissolved salt ions, including fluorides, nitrates and sulfates, through an electrodialysis stack consisting of alternating layers of cationic and anionic ion exchange membranes. Periodically, the direction of ion flow is reversed by reversing the polarity applied electric current.

- Electrodialysis reversal desalination, commonly abbreviated EDR, is a water desalination process in which electricity is applied to electrodes to pull naturally occurring dissolved salts through an ion exchange membrane to separate the water from the salts. EDR produces two effluent streams: a low salinity product water and a high salinity concentrate.

- In the reversal process, the polarity of the electrodes is switched at fixed intervals to reduce the formation of scale and subsequent fouling and allow the EDR to achieve higher water recoveries.

- EDR is used to treat brackish waters with moderate total dissolved solids (TDS) and waters that have a high scaling potential due to elevated levels of particular contaminants such as barium (Ba) and strontium (Sr). EDR is also effective on high silica (SiO_2) feedwaters.

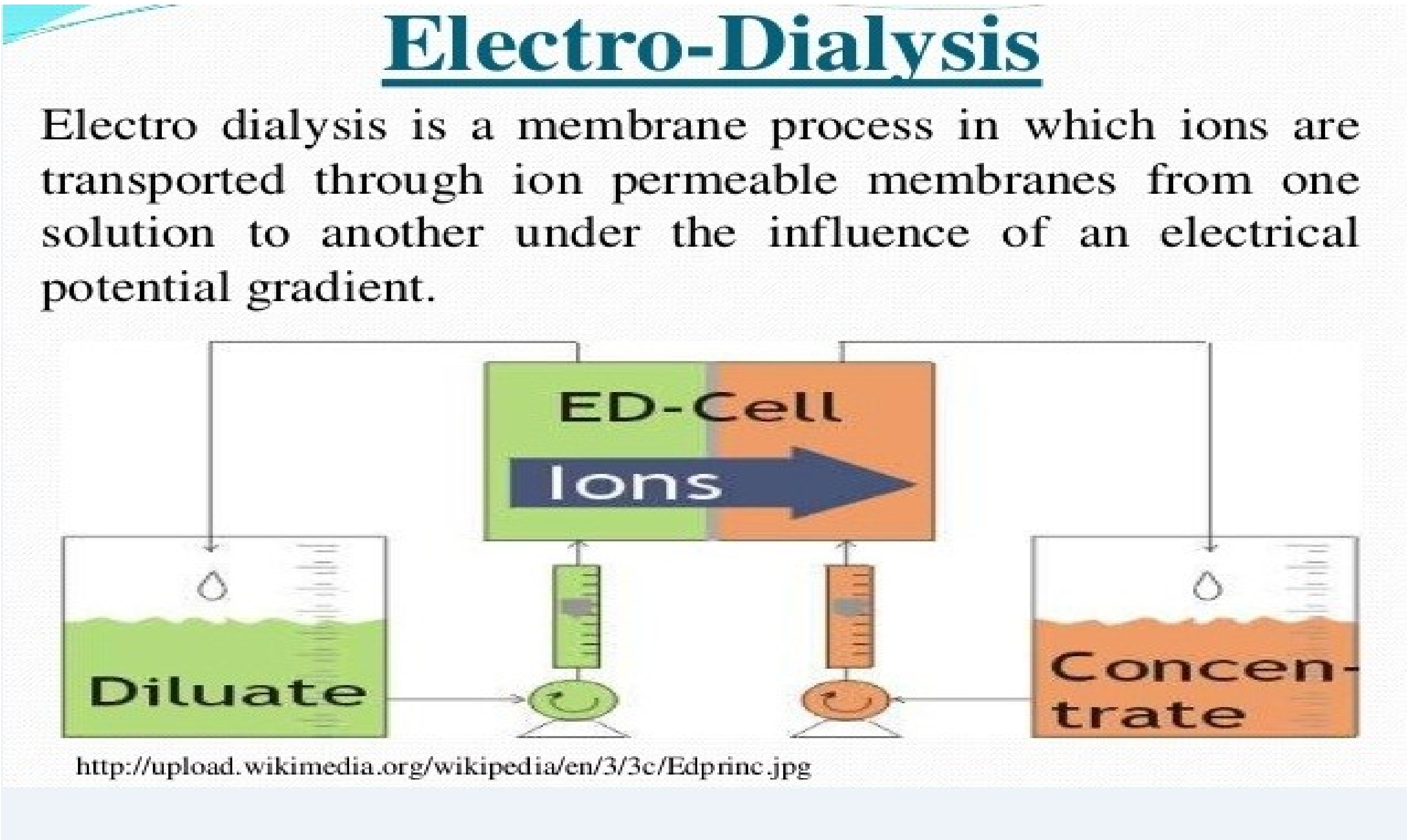


Figure 1.11

2.2. Reverse osmosis (RO)

- Reverse osmosis (RO) water desalination was conceived and laboratory-demonstrated in the late 1950s. A quantum jump to practicality was made in 1960 with the discovery of the anisotropic RO membrane which combined good desalination with adequate permeate flux at a reasonable hydrostatic pressure. Since then there has been progressive improvement in these membranes and development of ingenious means for packaging them. As a result, present day RO plants are compact and simple to operate, and can take advantage of the fact that in RO there is no phase change required. Therefore, the required energy input can approach fairly closely to the thermodynamic minimum free energy of separation, an advantage no other desalination process can surpass, and usually cannot approach. An important factor in the commercial success of reverse osmosis desalination has been the development of pretreatment methods appropriate for the particular feed brine being used. For all of these reasons reverse osmosis enjoys a leading position today in the installation of commercial water desalination.

- Reverse osmosis (RO) is a filtration method that removes many types of large molecules and ions from solutions by applying pressure to the solution when it is on one side of a selective membrane. The result is that the solute is retained on the pressurized side of the membrane and the pure solvent is allowed to pass to the other side. To be "selective," this membrane should not allow large molecules or ions through the pores (holes), but should allow smaller components of the solution (such as the solvent) to pass freely.

Principle :-

- A solution is separated from its solvent by a semipermeable membrane, one permeable to the solvent but not the solute. The natural permeation from solvent to solution is called osmosis. If hydrostatic pressure is applied increasingly on the solution side the permeation rate will decrease accordingly, stop at a hydrostatic pressure called the osmotic pressure, and reverse direction at a greater hydrostatic pressure. This is reverse osmosis (RO). Technical and Economical Relevance of Reverse Osmosis Reverse osmosis has a number of innate advantages. Because it is all-liquid and uses hydrostatic pressure as an energy source, RO modules and plants can be very compact, operation is relatively simple, and modules are readily replaced. Furthermore, the energy input can be quite low because it can approach the free energy of separation. These advantages have been realized by the necessary development of membranes having an adequately high value of the water permeation constant, A, m3 m –2 d–1 bar, thus combining relatively low hydrostatic pressures with minimization of required membrane area to obtain the lowest fresh water cost. An important and necessary factor in RO's success has been the development of customized pretreatment, suiting feed brines to membranes to increase membrane life. Starting from zero in1968 reverse osmosis now occupies a dominant position in desalination.

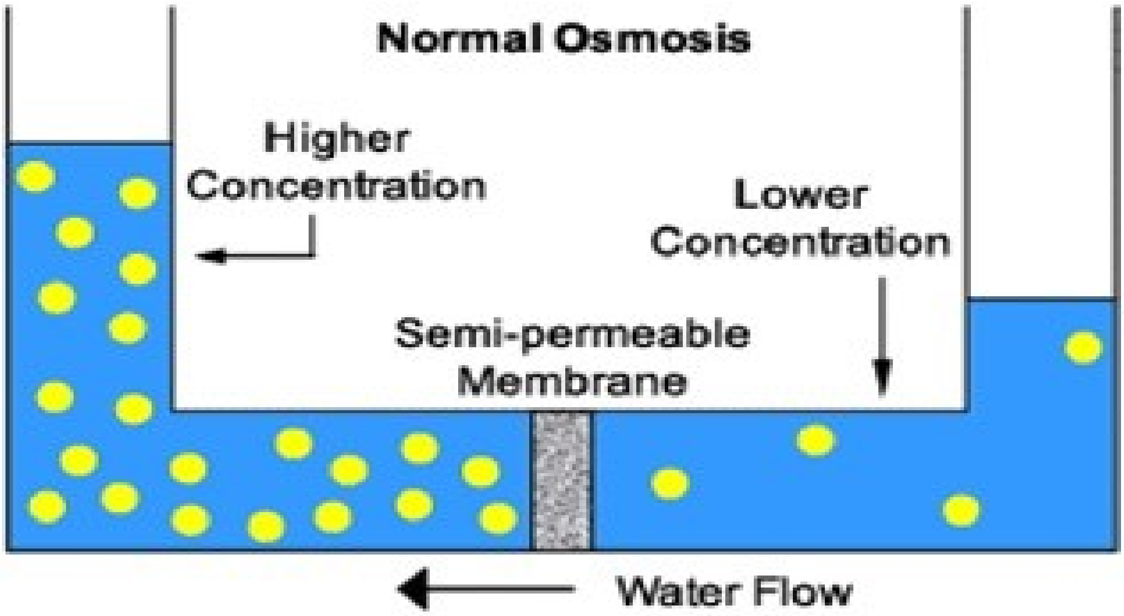


Figure 1.12

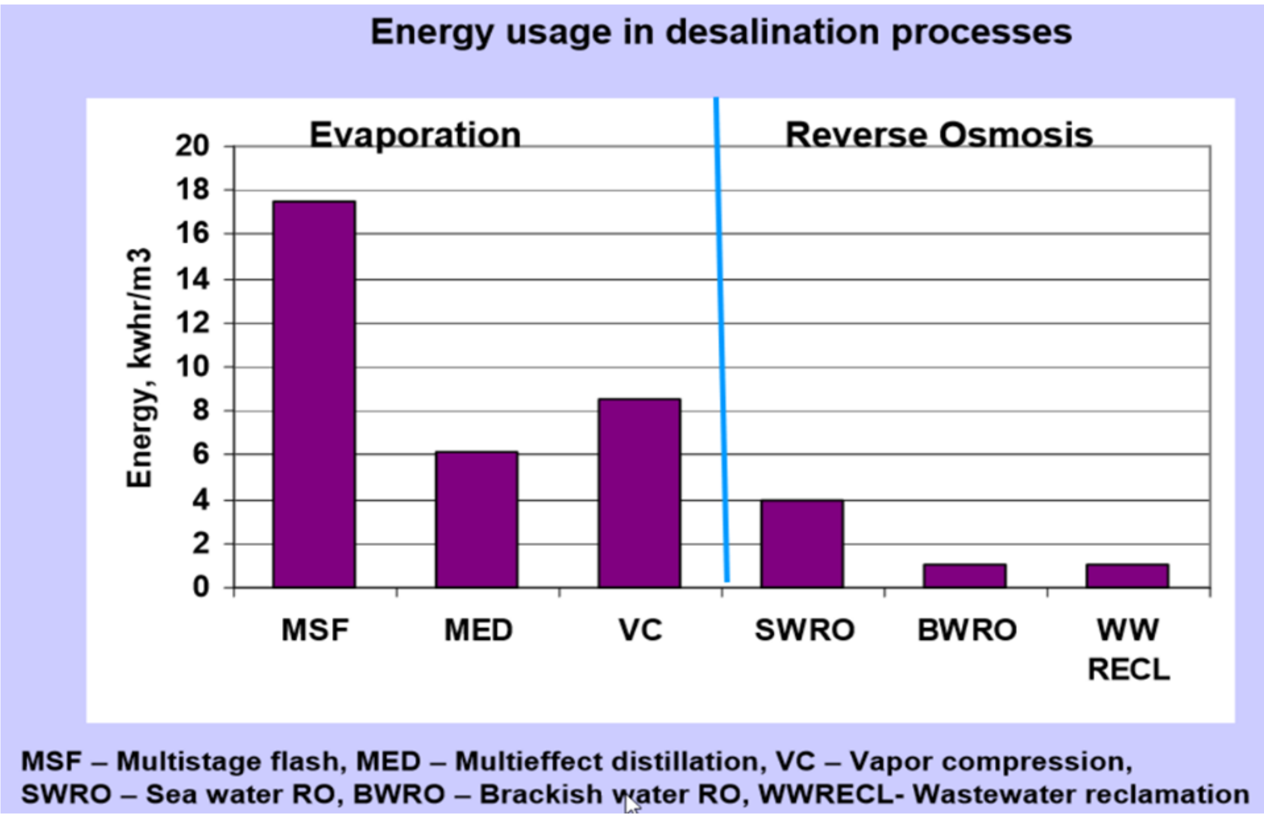


Figure 1.13

Energy consumption of seawater desalination methods				
Desalination Method >>	**Multi-stage Flash MSF**	**Multi-Effect Distillation MED**	**Mechanical Vapor Compression MVC**	**Reverse Osmosis RO**
Electrical energy (kWh/m^3)	4–6	1.5–2.5	7–12	3–5.5
Thermal energy (kWh/m^3)	50–110	60–110	None	None
Electrical equivalent of thermal energy (kWh/m^3)	9.5–19.5	5–8.5	None	None
Total equivalent electrical energy (kWh/m^3)	13.5–25.5	6.5–11	7–12	3–5.5

Table 1.2

Advantages and disadvantages of desalination techniques:

Desalination type	Usage	Advantages	Disadvantages
Multi-stage flash distillation (MSF) Desalination process that distills seawater by flashing a portion of the water into steam in multiple stages of what are essentially regenerative heat exchangers.	Accounts for 85% of all desalinated water; used since early 1950s	MSF plants, especially large ones, produce a lot of waste heat and can therefore often be paired with cogeneration	High operating costs when waste heat is not available for distillation. High rates of corrosion
Multiple-effect evaporator (MED|ME) Using the heat from steam to evaporate water. In a multiple-effect evaporator, water is boiled in a sequence of vessels, each held at a lower pressure than the last.	Widely used, since 1845	High efficiency, while relatively inexpensive	A large heating area is required
Vapor-compression evaporation (VC) Evaporation method by which a blower, compressor or jet ejector is used to compress, and thus, increase the temperature of the vapor produced.	Mainly used for wastewater recovery	Technique copes well with high salt content in water	-
Evaporation/condensation Evaporation of seawater or brackish water and consecutive condensation of the generated humid air, mostly at ambient pressure.	Widely used	Easiest method of distillation	Timeconsuming and inefficient in comparison to other techniques
Electrodialysis reversal (EDR) Electrochemical separation process that removes ions and other charged species from water and other fluids.	Widely used, since early 1960s	Long membrane lifetime and high efficiency (up to 94% water recovery, usually around 80%)	High capital and operational costs

Table 1.3

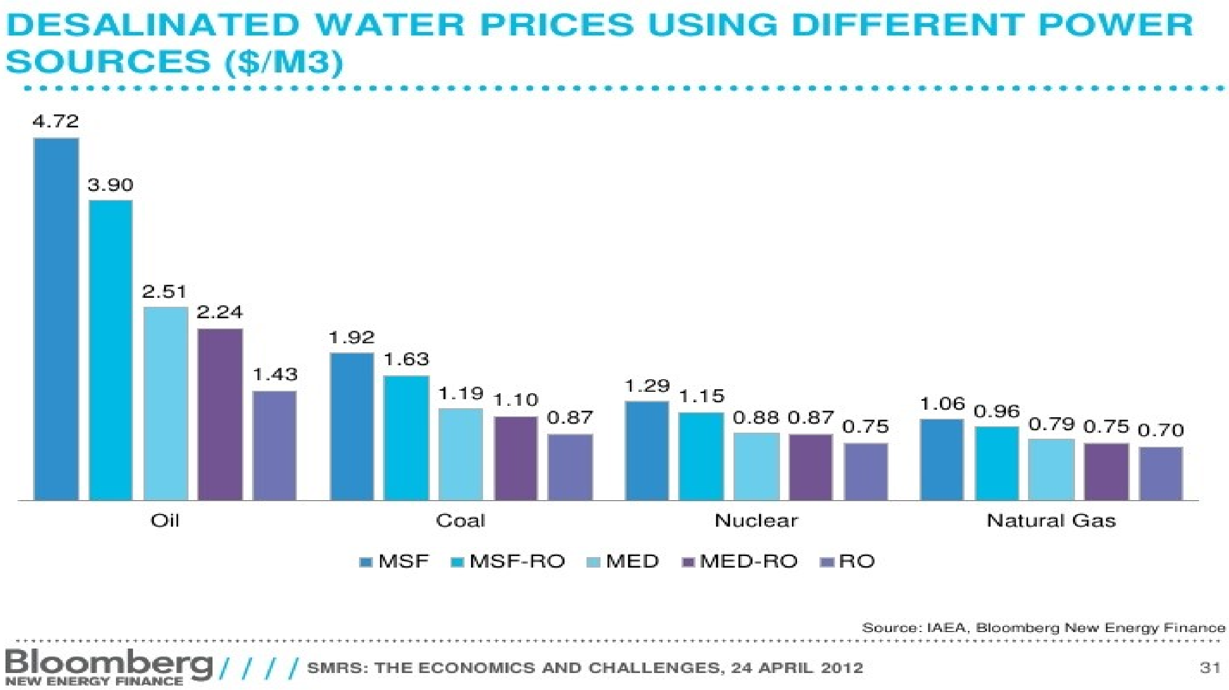


Figure 1.14

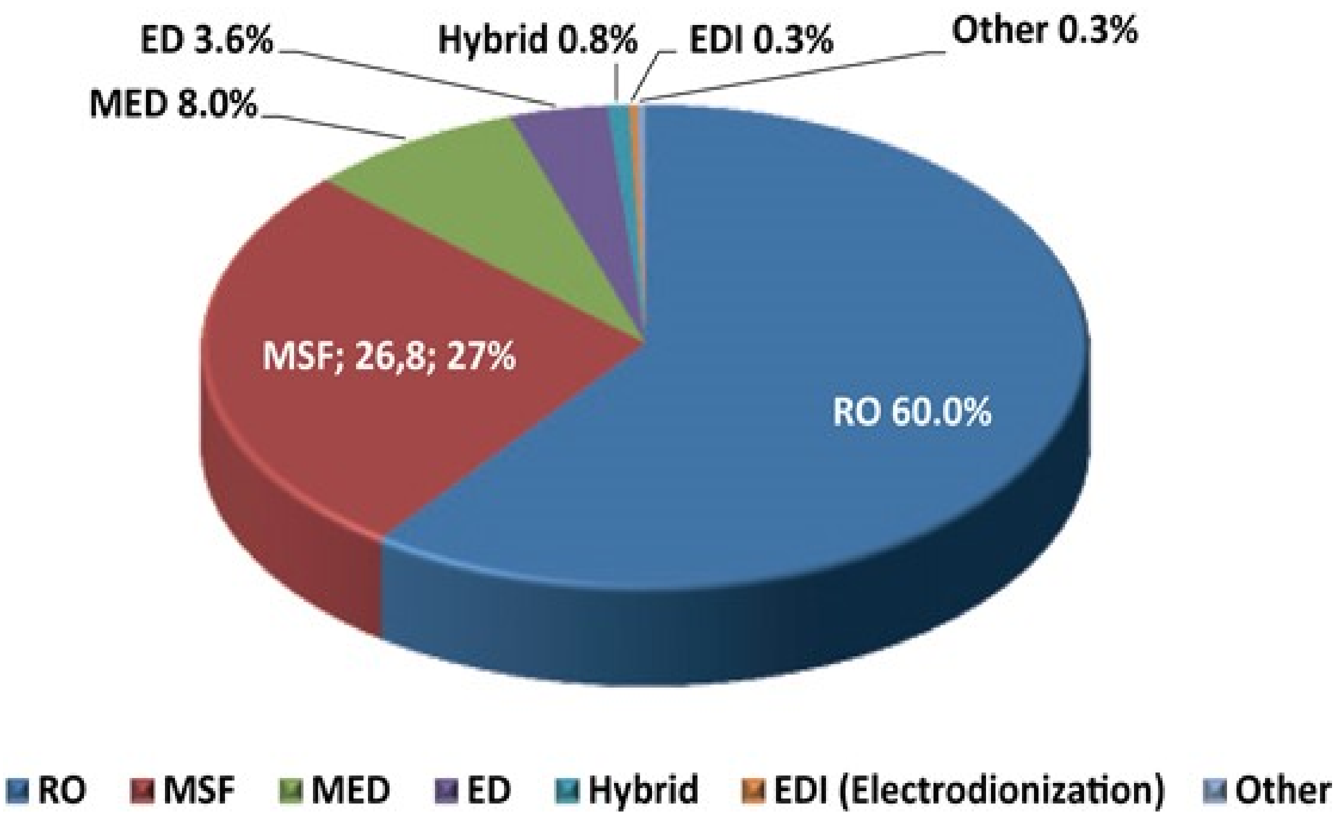


Figure 1.15

Chapter 2

Membrane

What is a membrane ?

It is defined essentially as " Barrier which separates 2 phases and restricts transport of various molecules in a selective manner ".

It is driven by :-

- Pressure
- Concentration
- Temperature
- Electrical Potential Gradients

Membrane can be :-

- Thick & Thin
- Liquid & Solid
- Symmetric & Asymmetric
- Natural & Synthetic
- Neutral & Charged
- Homogeneous & Heterogeneous

History of the membrane :-

- In 1748, Abbe Jean-Antonie Nollet; French physicist separated degassed alcohol using pig's bladder.
- In 1824, Rene-Joachim-Henri Dutrochet, French physiologist introduced " Osmosis " Movement of water through a biological membrane.
- 1846 _ Discovery of nitrocellulose (gave scope to MF).
- 1855 _ Frick discovered cellulose nitrate membranes.
- 1861, Thomas Graham (Father Of Modern Dialysis) : Coined " Dialysis " – Separated Dissolved substances based on mol.wt., n concentration.
- 1865, Moritz Traube invented first artificial membrane using copper ferrocyanide precipitates.
- 1875, Wilhelm Friedrich Philipp Pferrer : Made the membranes to withstand operational pressures.
- 1906, Bechhold devised a technique to prepare nitrocellulose membranes of graded pore size.
- 1930's-Micro porous colloidal membranes became commercially available.
- 1950's- Department n significant use of MF technology in the filtration of drinking water samples at the end of World War 2; Research effort was sponsored by US army.
- 1959, Samuel yuster made a breakthrough in RO by the invention of Lobe-sourirajan membrane at UCLA.

- By 1960-Elements of modern membrane science had been developed such as Gas Separation, Membrane Distillation etc.
- In the early 80's-Henis & Tripodi made industrial GS: economically feasible.
- Kober and coworkers developed Pervaporation. Later in 2000's modified for large scale applications.

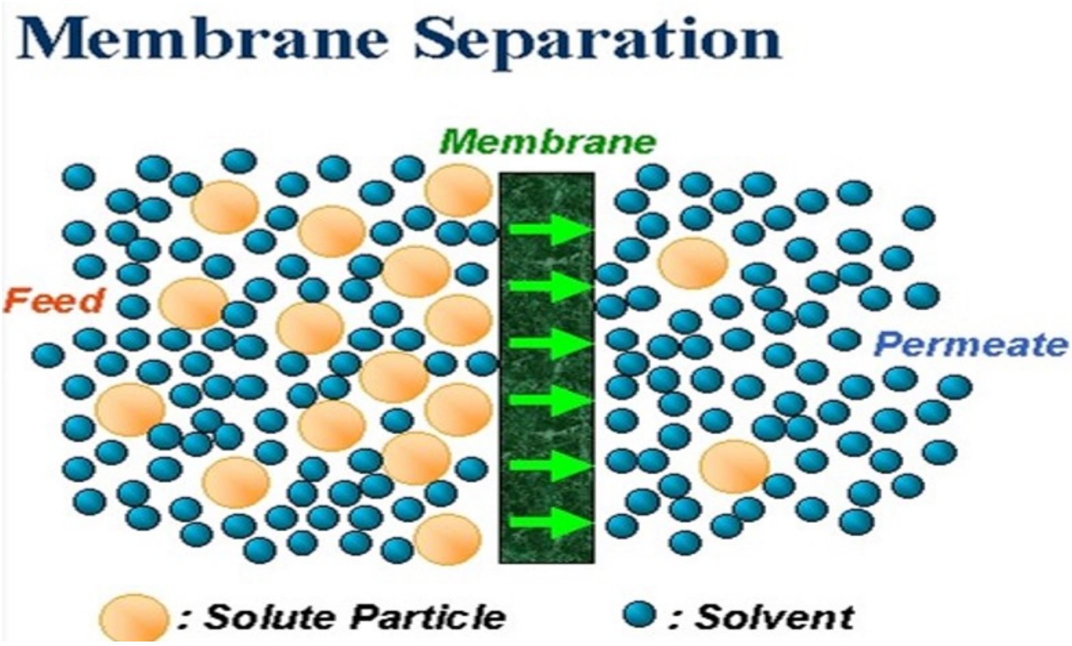


Figure 2.1

Four common types of membranes :-

1. Reverse Osmosis
2. Nanofilteration
3. Ultrafiltration
4. Microfiltration

Parameter	Microfiltration	Ultrafiltration	Nanofiltration	Reverse Osmosis
Pore Size	0.01 – 1.0 µm	0.001 – 0.01 µm	0.0001 – 0.001 µm	<0.0001 µm
Molecular Weight Cutoff	>100,000	1,000 – 300,000	300 – 1,000	100 - 300
Operating Pressure	<30 psi	20 – 100 psi	50 – 300 psi	225 – 1,000 psi
Membrane Materials	Ceramics, polypropylene, polysulfone, polyvinylidenedifluoride	Ceramics, polysulfone, polyvinylidenedifluoride, cellulose acetate, thin film composite	Cellulose acetate, thin film composite	Cellulose acetate, thin film composite, polysulfonated polysulfone
Membrane Configuration	Tubular, hollow fiber	Tubular, hollow fiber, spiral wound, plate and frame	Tubular, spiral wound, plate and frame	Tubular, spiral wound, plate and frame
Types of Materials Removed	Clay, bacteria, viruses, suspended solids	Proteins, starch, viruses, colloid silica, organics, dyes, fats, paint solids	Starch, sugar, pesticides, herbicides, divalent anions, organics, BOD, COD, detergents	Metal cations, acids, sugars, aqueous salts, amino acids, monovalent salts, BOD, COD

Table 2.1

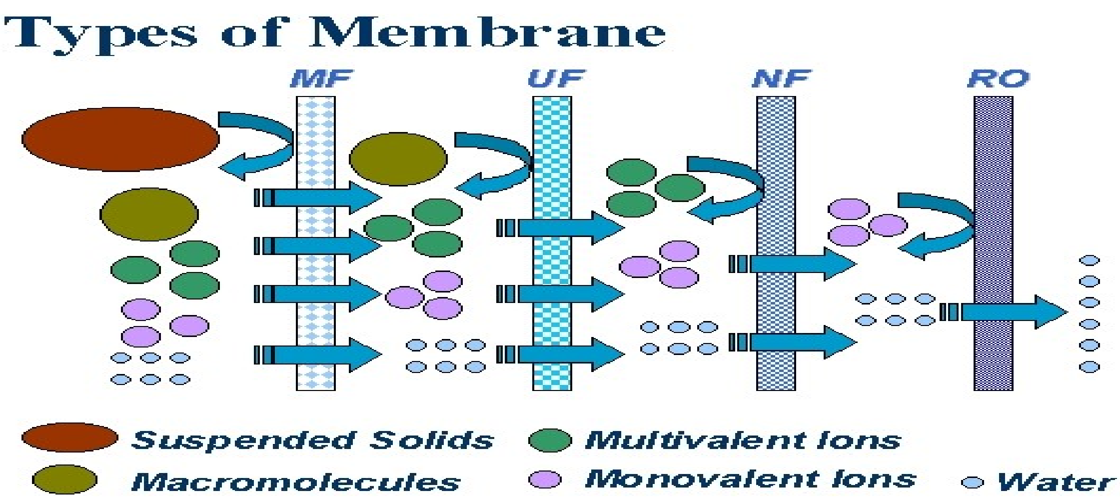
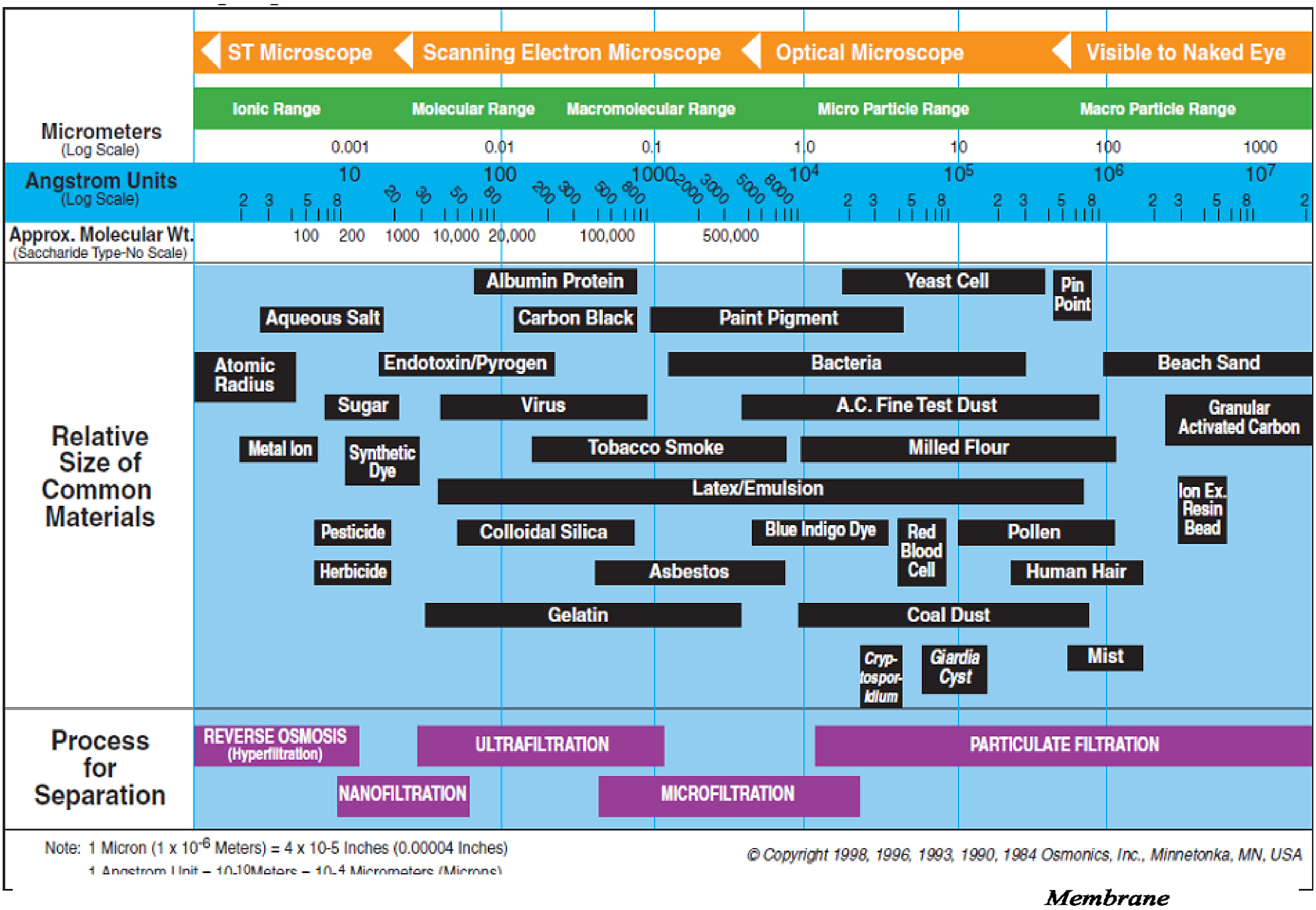


Figure 2.2


ST Microscope
Scanning Electron Microscope
Optical Microscope
Visible to Naked Eye
Micrometers (Log Scale)
Ionic Range
Molecular Range
Macromolecular Range
Micro Particle Range
Macro Particle Range
Angstrom Units (Log Scale)
Approx. Molecular Wt. (Saccharide Type-No Scale)
Relative Size of Common Materials
Albumin Protein
Yeast Cell
Pin Point
Aqueous Salt
Carbon Black
Paint Pigment
Atomic Radius
Endotoxin/Pyrogen
Bacteria
Beach Sand
Sugar
Virus
A.C. Fine Test Dust
Granular Activated Carbon
Metal Ion
Synthetic Dye
Tobacco Smoke
Milled Flour
Latex/Emulsion
Ion Ex. Resin Bead
Pesticide
Colloidal Silica
Blue Indigo Dye
Red Blood Cell
Pollen
Herbicide
Asbestos
Human Hair
Gelatin
Coal Dust
Cryptosporidium
Giardia Cyst
Mist
Process for Separation
REVERSE OSMOSIS (Hyperfiltration)
ULTRAFILTRATION
PARTICULATE FILTRATION
NANOFILTRATION
MICROFILTRATION
Note: 1 Micron (1 x 10-6 Meters) = 4 x 10-5 Inches (0.00004 Inches)
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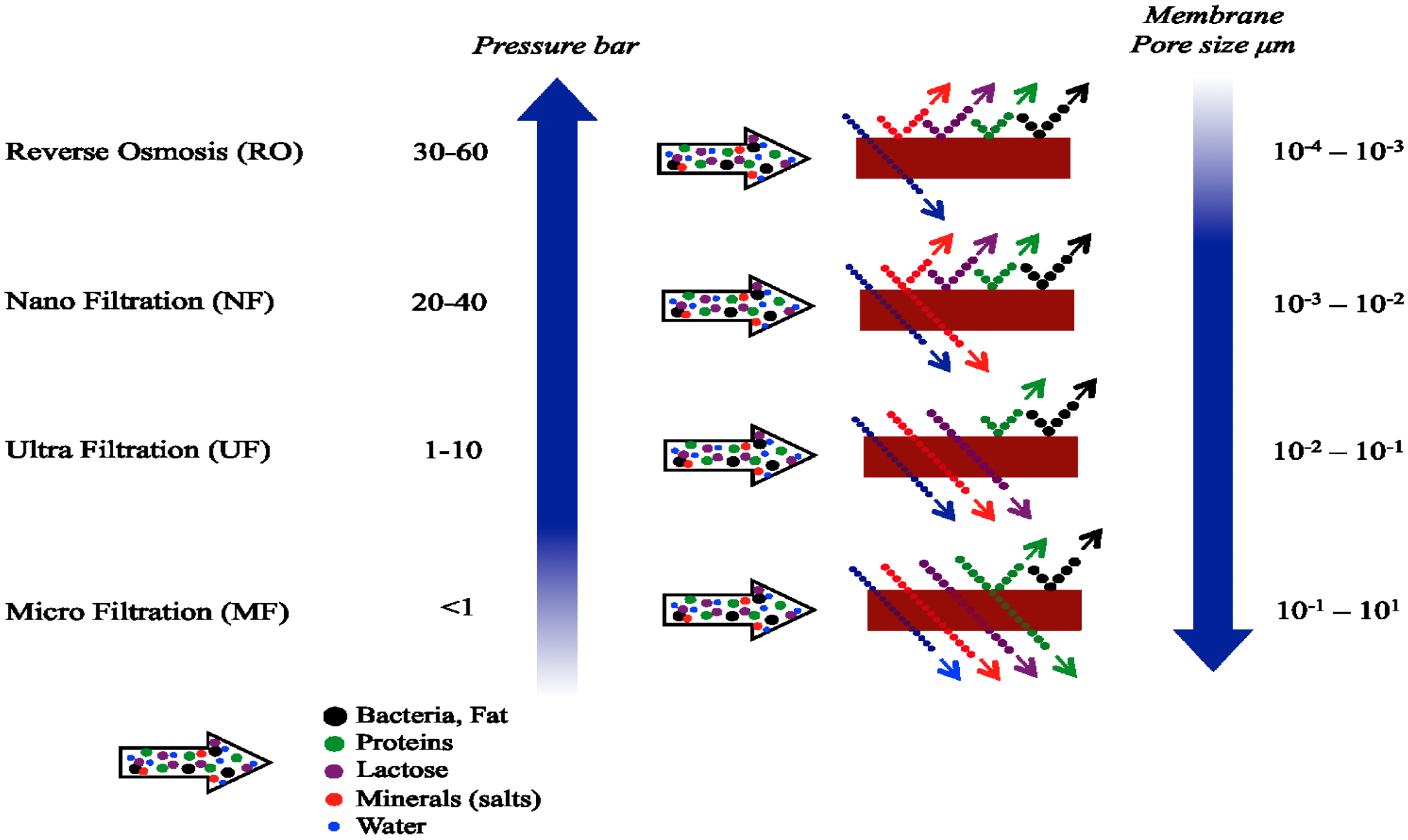

Pressure bar
Membrane Pore size µm
Reverse Osmosis (RO)
30-60
10-4 – 10-3
Nano Filtration (NF)
20-40
10-3 – 10-2
Ultra Filtration (UF)
1-10
10-2 – 10-1
Micro Filtration (MF)
<1
10-1 – 101
Bacteria, Fat
Proteins
Lactose
Minerals (salts)
Water

Figure 2.3

Figure 2.5

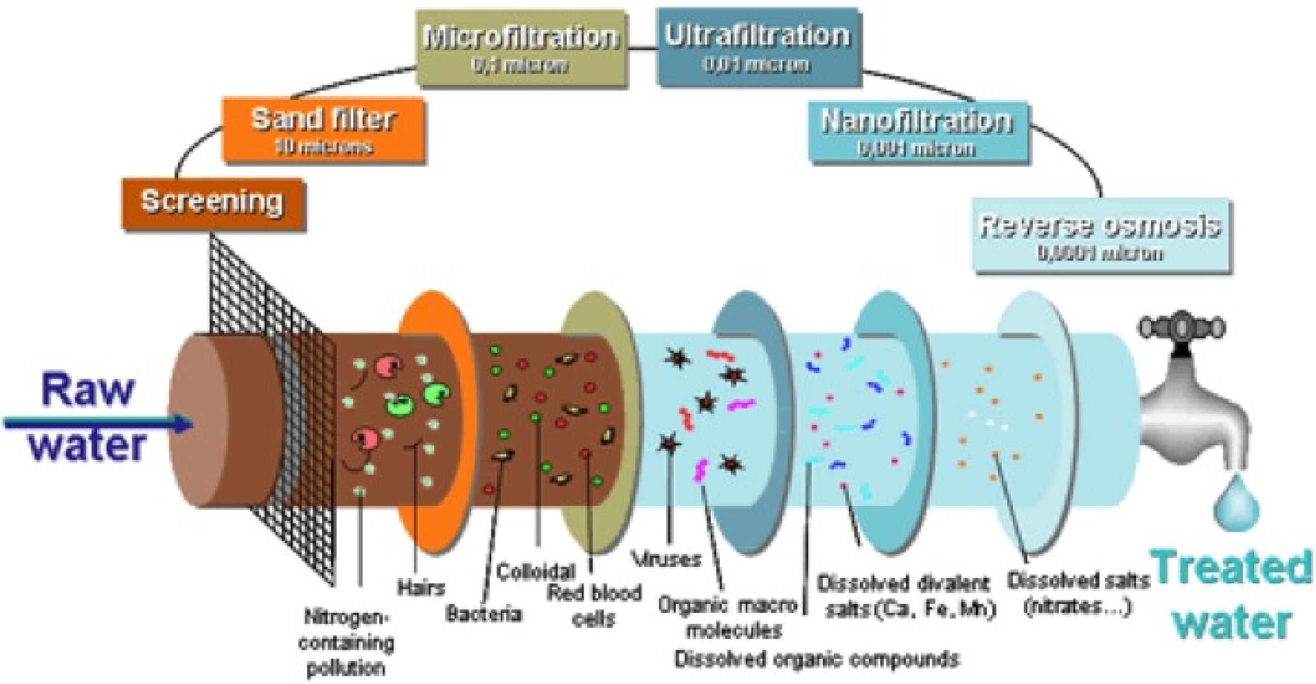


Figure 2.4

Working Mechanism :-

Membrane process : The feed stream is divided into two streams:

- Concentrate Stream
- Permeate Stream

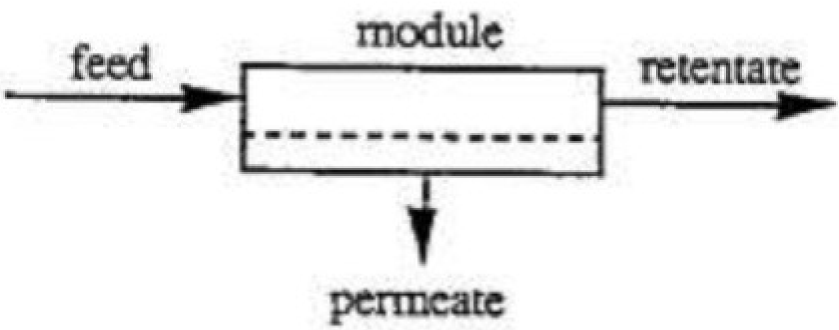


Figure 2.5

- Either the concentrate or permeate stream is the product of our interest.

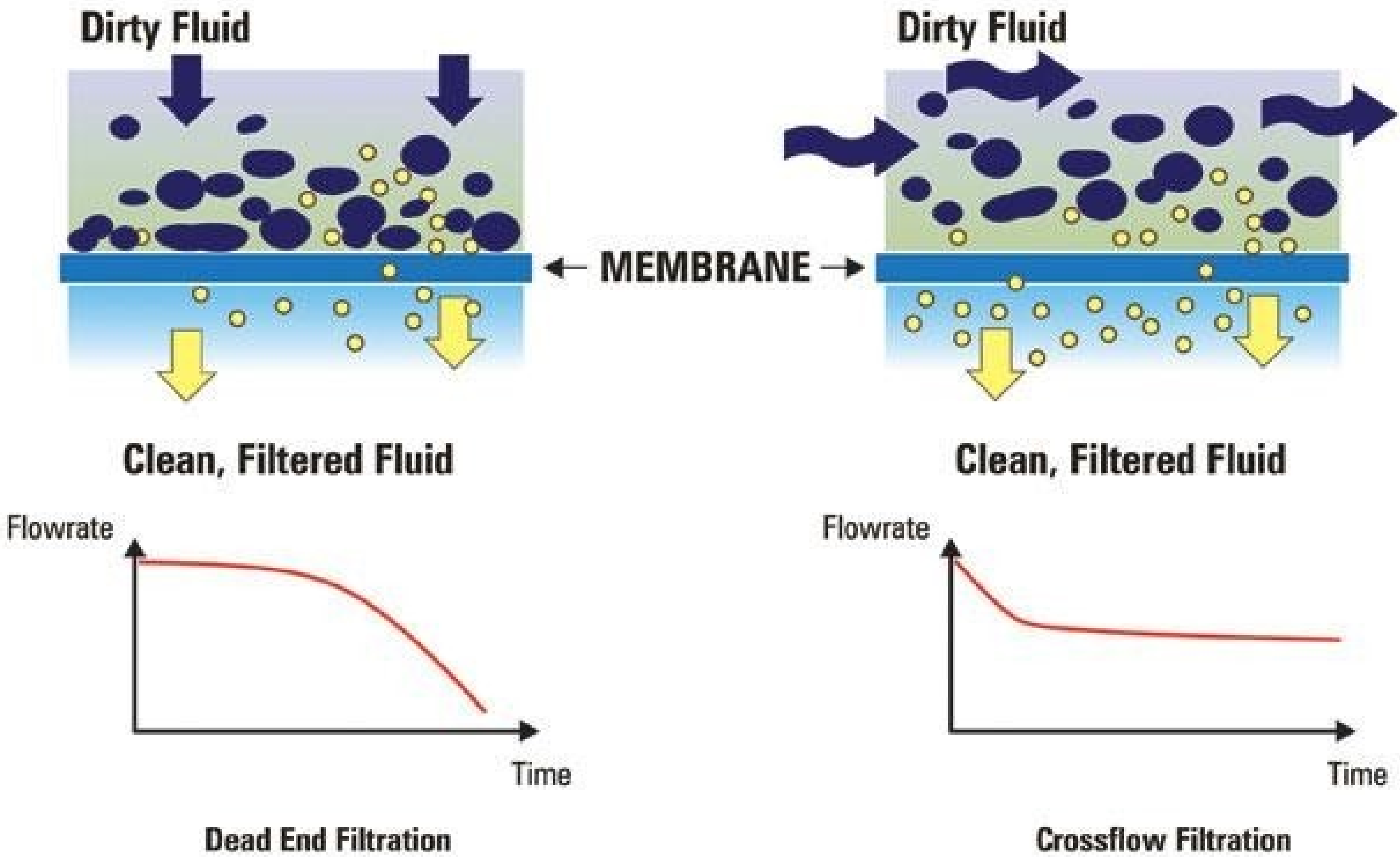


Figure 2.

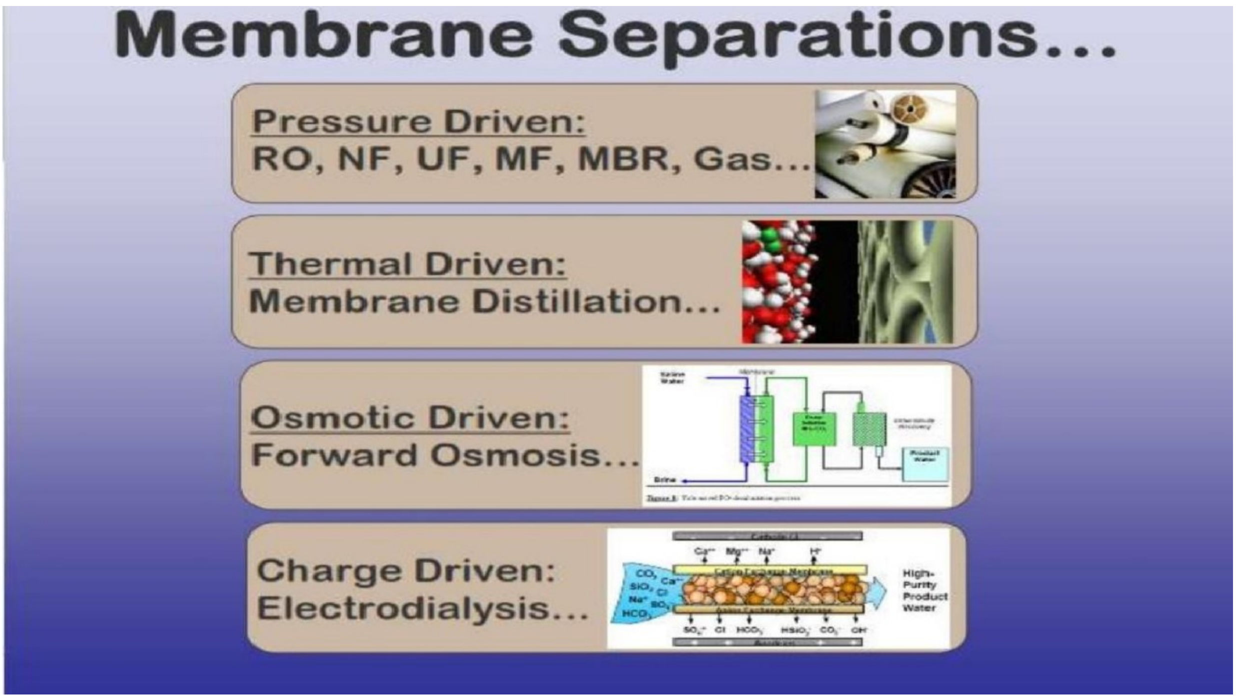


Figure 2.6

Membrane Processes :-

1. First generation membrane processes :-

1.1 Microfiltration (**MF**)

1.2 Ultrafiltration (**UF**)

1.3 Nanofiltration (**NF**)

1.4 Hyper filtration (**HF**) / Reverse Osmosis (**RO**)

1.5 Electro Dialysis (**ED**)

2. Second generation membrane processes :-

2.1 Gas Separation (GS)

2.2 Pervaporation (PV)

2.3 Membrane Distillation (MD)

1.1 Microfiltration (MF)

- Separates suspended solids and some colloidal materials (>0.1 μ) from a feed stream.

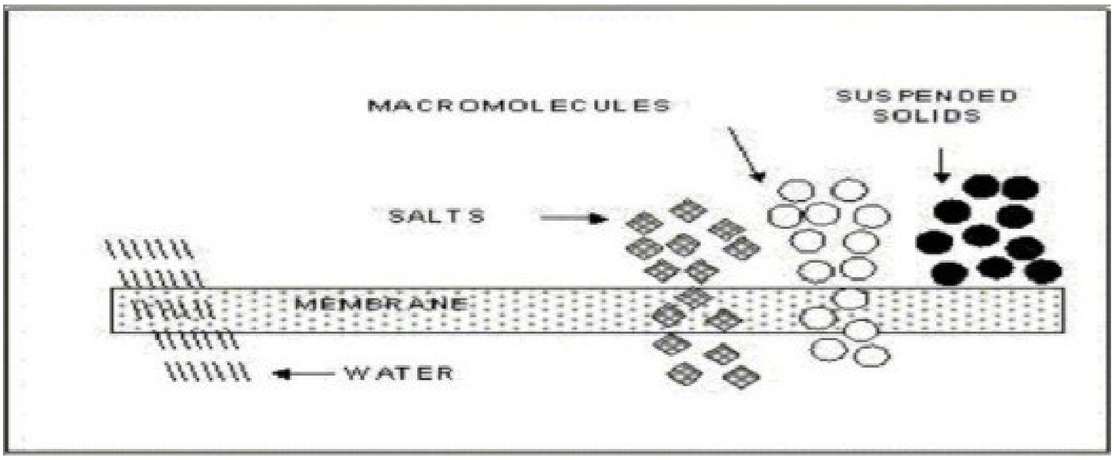


Figure 2.7

- The concentrate requires periodic removal or cleaning to prevent the eventual plugging of membrane feed passage ways.
- Pore size : (0.1 to 10.0) microns
- Pressure difference : Approx. : (10 to 500) KPa

1.2 Ultrafiltration (UF)

- Separates colloidal materials, emulsified oils, micro biological materials, and large organic molecules.
- Someone dependent on charge of the particle, and is much more concerned with the size of the particle.
- Pore Size Ranges : (10 to 1000) A : (10^-3 to 0.1) microns : most typical 0.005 μ
- Pressure difference : Approx. (0.1 to 1.0) MPa
- Typically not effective at separating organic streams.

1.3 Nanofiltration (NF)

- Used when low molecular weight solutes such as inorganic salts / small organic molecules (glucose, sucrose) have to be separated.
- Uses a membrane that is partially permeable to perform the separation (like in RO), but (NF pores >>> RO pores).
- Can operate at much lower pressures, and passes some of the inorganic salts due to larger pore size.
- Pore Size is typically 1 nm
- Pressure difference : (10 to 20) bars

1.4 Reverse Osmosis (RO) (Hyper filtration)

- Specifically used for the separation of dissolved ions from water (dissolved solids, bactreia, viruses, salts, proteins, and other germs).
- Charged ions and other materials greater than or equal to 0.001
- Essentially a pressure driven membrane diffusion process for separating dissolved solutes.
- Relatively a low energy process.
- Smallest pore structure, (5 to 15) A : (0.5 to 1.5) nm
    - Allows only the smallest organic molecules and unchanged solutes to pass through the semi-permeable membrane along with the water.

- >95-99% of inorganic salts and charged organics will also be rejected by the membrane due to charge repulsion established at the membrane surface.

1.5 Electro Dialysis (ED)

- In the ED process a semi-permeable barrier allows passage of either positively charged ions (cations) or negatively charged ions (anions) while excluding passage of ions of the opposite charge. These semi-permeable barriers are commonly known as ion-exchange, ion-selective or electrodialysis membranes.

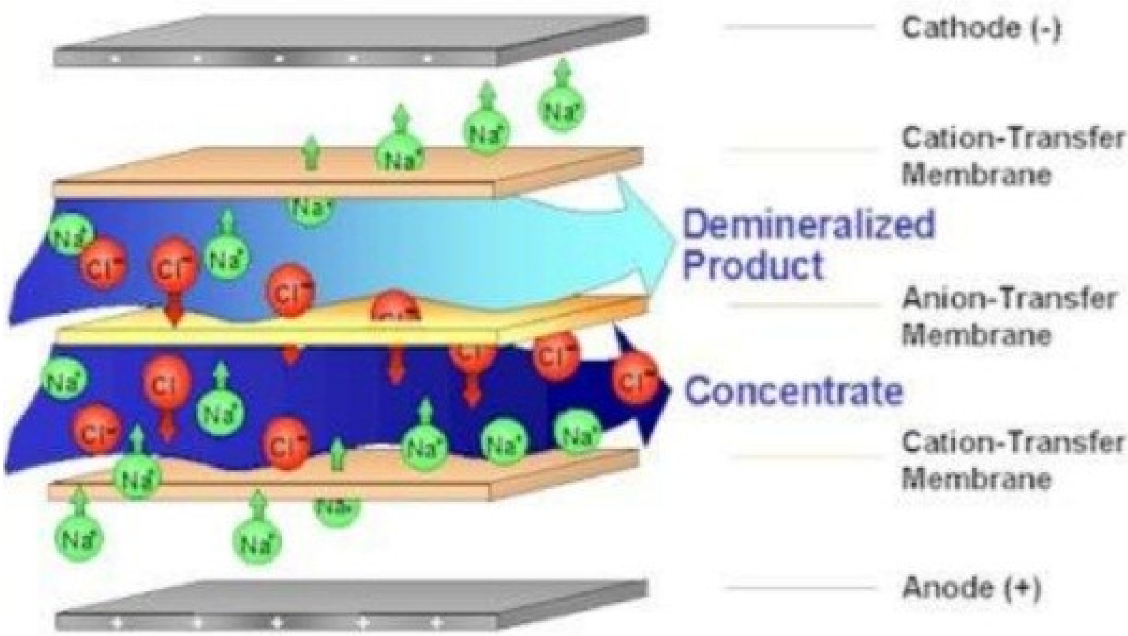


Figure 2.8

2.1 Gas Separation (GS)

- Used for separation of gas mixtures.
- Separation of gases is due to their different solubility n diffusivity in the polymer membrane.

Rate of permeation :

- Proportional to pressure difference across the membrane, solubility of gas in the membrane, diffusivity of gas through membrane.
- Inversely proportional to the membrane thickness.
- Driving force : Concentration difference
- Pore Size : <1nm
- Ex : Palladium membranes -Hydrogen separation

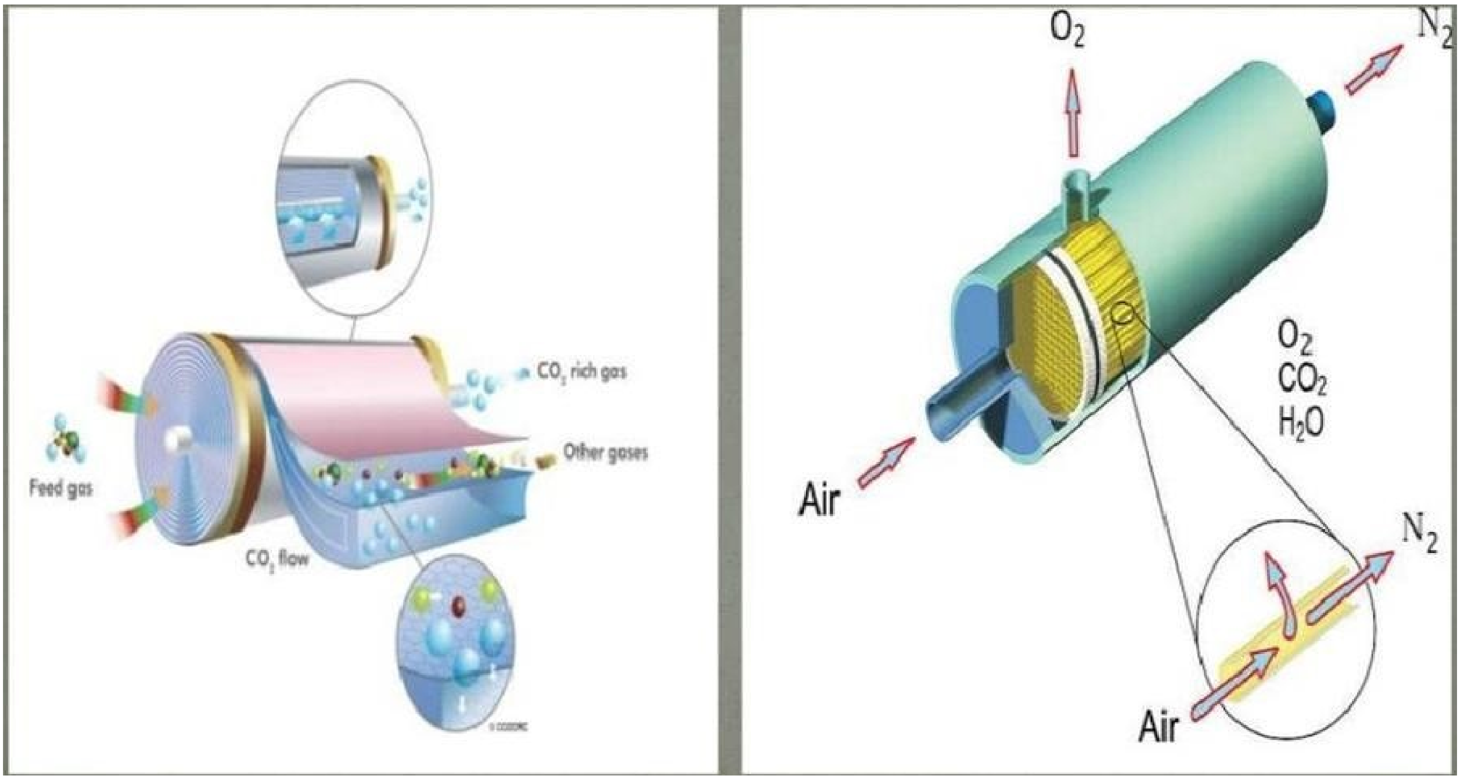


Figure 2.9

2.2 Pervaporation (PV)

- Separation of miscible liquids.
- Liquid is maintained at atmospheric pressure on the feed side of the membrane, and permeate is removed as a vapor because of a low vapor pressure existing on the permeate side.
- Differs from all other membrane processes because of the phase change of the permeate.
- Transport is affected by maintaining a vapor pressure gradient a process the membrane.
- Membrane used : Zeolite n poly Dimetyl Siloxane.

Three steps sequence :-

- Selective sorption of one of the components of the liquid into the membrane on the feed side.
- Selective diffusion of this component across the membrane.
- Evaporation, as permeate vapour, into the partial vacuum applied to the underside of the membrane.

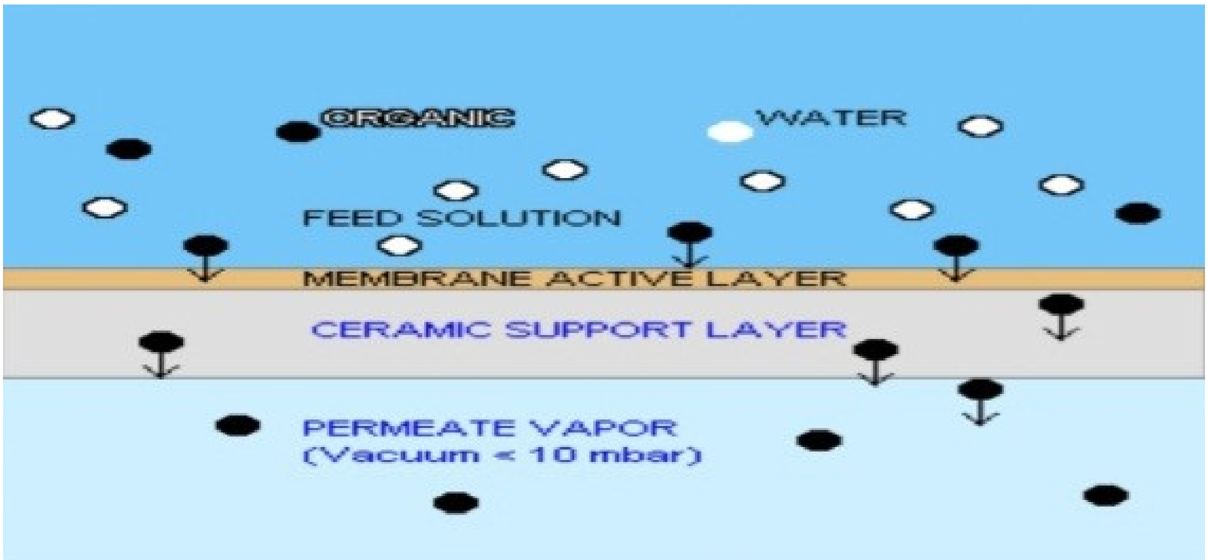


Figure 2.10

2.3 Membrane Distillation (MD)

- Is a process in which two liquid or solutions at different temperatures are separated by a porous hydrophobic membrane.
- The liquid / solution must not wet the membrane otherwise the pores will be filled for capacity force.
- Membrane distillation is a type of low temperature, reduced pressure distillation due at the use porous hydrophobic membranes.

Membrane technologies

- Reverse Osmosis utilizes the unique properties of a semi-permeable membrane to allow fluid to pass while restricting the flow of dissolved ionic material. With pressure applied to impure water on the side of such membrane materials, pure water will pass through, leaving most of the impurities behind. The rejection of the dissolved ionic material is a function of both molecular weight and ionic charge.

- Reverse osmosis membrane separations are, most importantly, governed by the properties of the membrane used in the process. These properties depend on the chemical nature of the membrane material (almost always a polymer) as well as its physical structure.

- Properties for the ideal RO membrane include that it is resistant to chemical and microbial attack, mechanically and structurally stable over long operating periods, and have the desired separation characteristics for each particular system. However, few membranes satisfy all these criteria and so compromises must be made to select the best RO membrane available for each application.

- The reverse osmosis process which uses polymeric membranes to achieve selective mass transport has become the simplest and most efficient technique to desalt the seawater and brackish water .
- The desalination performance of a RO membrane depends largely on the membrane material and the membrane structure.
- An industrially useful RO membrane must exhibit several characteristics such as high water flux, high salt rejection, mechanical stability, tolerance to temperature variation, resistance to fouling, and low cost. So far, a number of polymer materials such as cellulose acetates, polyamides, cross linked poly (furfuryl alcohol) and sulfonated polyethersulfone have been used to make RO membranes.

Of these, the following two have been the most successful :-

1. Cellulose acetate (CA) :-

- It was the first high-performance RO membrane material discovered. A typical CA membrane exhibits a flux of 0.9 m /day at 425 psi and an average NaCl rejection of 97.5% from a 2000 mg/L NaCl feed solution. The main advantage of CA is its low price and hydrophilic nature which makes it less prone to fouling.
- CA also has a good chlorine resistance up to 5 ppm. Thus, today, CA membranes still maintain a small fraction of the market. However, an inherent weakness of CA is that it can be eaten by microorganisms. It also slowly hydrolyzes over time and is generally not used above 35 o C , Operating pH of a CA membrane is limited to 4-6.

2. Thin film composite (TFC) :-

- aromatic polyamide membrane A more successful, commercially available RO membrane for desalination , the TFC membranes have dominated the water desalination market because they show both high flux and very high salt rejection. A typical membrane exhibits a NaCl rejection of 99.5 % and a flux of 1.2 m/day for a feed solution of 35,000 mg/L NaCl at 800 psi.

CTA Membrane	TFC Membrane
Advantages:	*Advantages:*
Chlorine tolerant	High Rejection High Flow
Low price	pH tolerant
Disadvantages:	*Disadvantages:*
pH intolerant	Chlorine intolerant
Medium rejection	High price
Applications:	*Applications:*
Municipal water	Low temperature water Low pressure water
Chlorinated Wells	High nitrate water High pH

Table 2.2

A typical composite reverse osmosis membrane as commercially produced today is shown schematically in Figure :

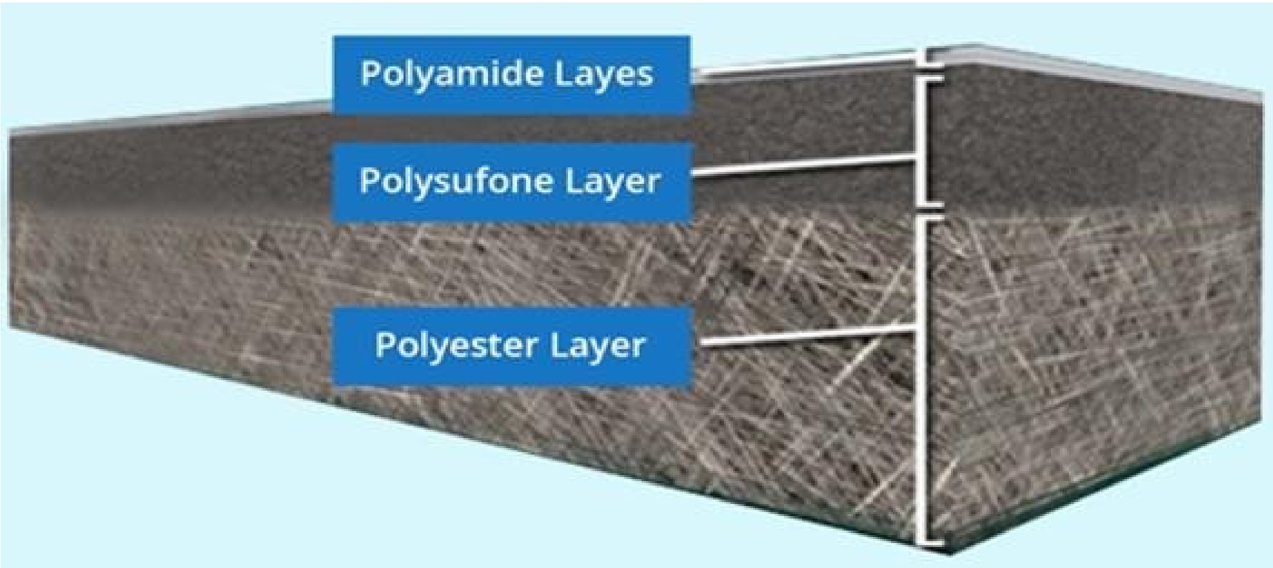


Figure 2.11

- A base layer of a woven or a nonwoven fabric is over coated with a layer of an anisotropic microporous polymer (usually polysulfone).
- The surface of the microporous support is coated with an ultrathin layer of a crosslinked aromatic polyamide.
- The porous support provides mechanical strength, whereas the separation is performed by the thin polyamide top-layer, Operating pH of a TFC membrane is limited to 2-12 , TFC also has low chorine resistance , and fair fouling tolerance.

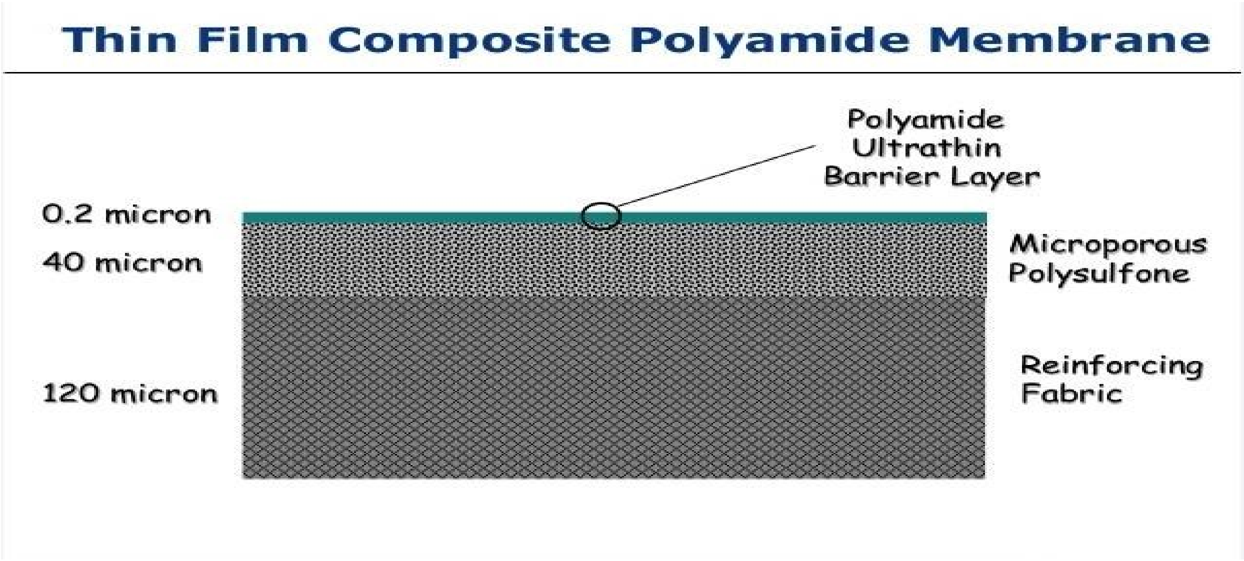


Figure 2.12

membrane manufacturing & coating

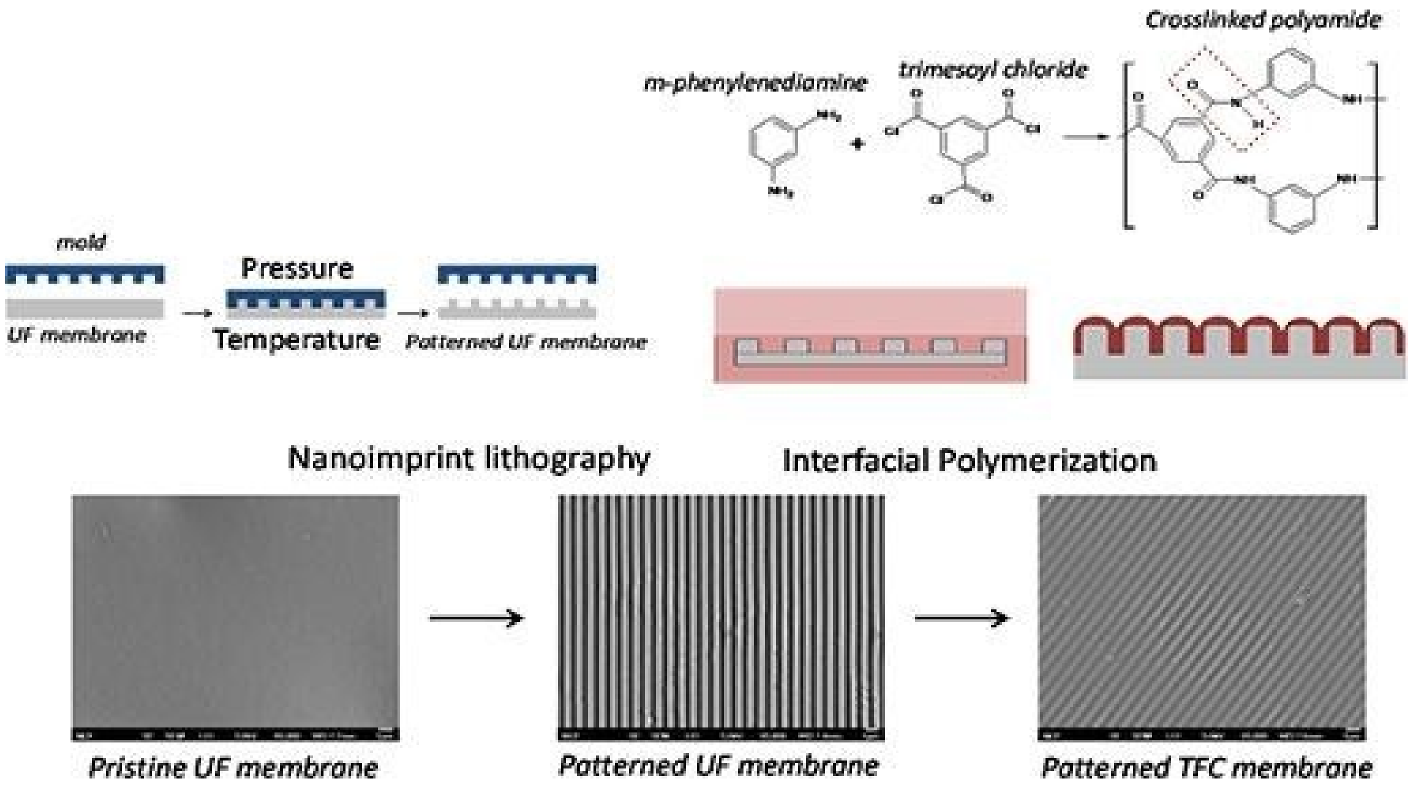


Figure 2.13

Modules:-

- A module is the simplest membrane element that can be used in practice.
- Module design must deal with the following issues :-
  1. Economy of manufacture
  2. Minimum waste of energy
  3. Membrane integrity against damage and leaks.
  4. Easy egress of permeate
  5. Permit the membrane to be cleaned

Membrane Modules :-

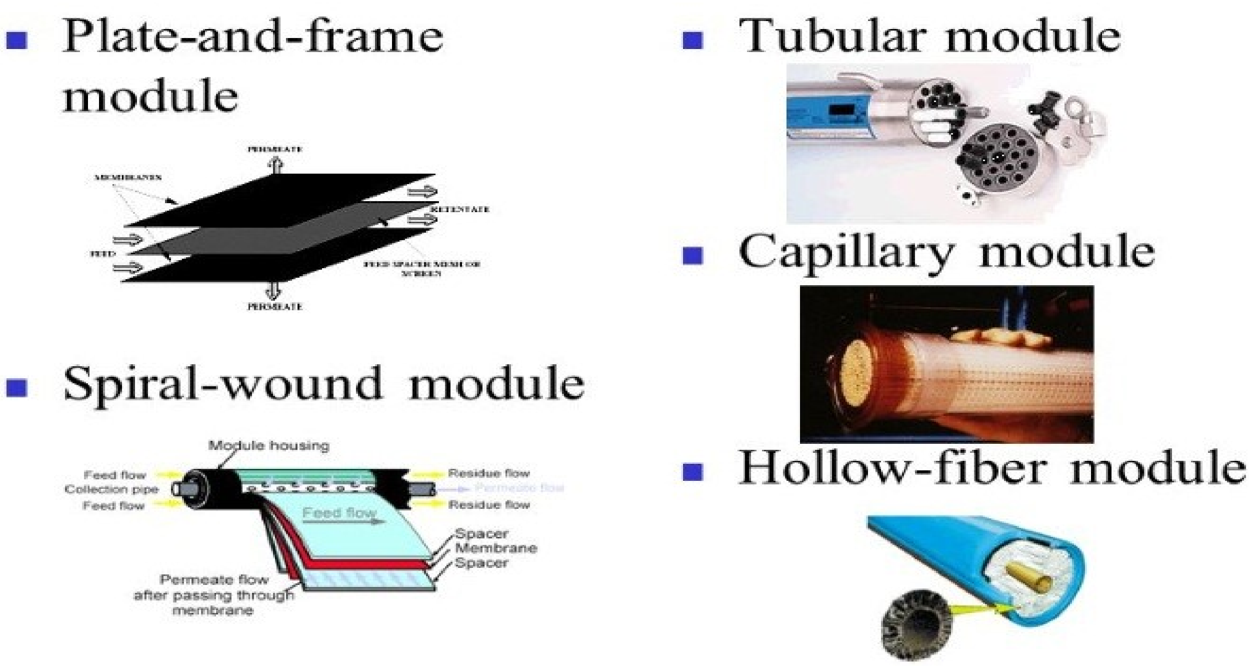


Figure 2.14

Membrane Modules

- Reverse osmosis membranes for industrial applications are typically modularized using configurations that pack a large amount of membrane area into a relatively small volume. This makes the RO system more economical to use in that the system requires a smaller footprint, and membranes can be replaced in smaller modules rather than system wide.

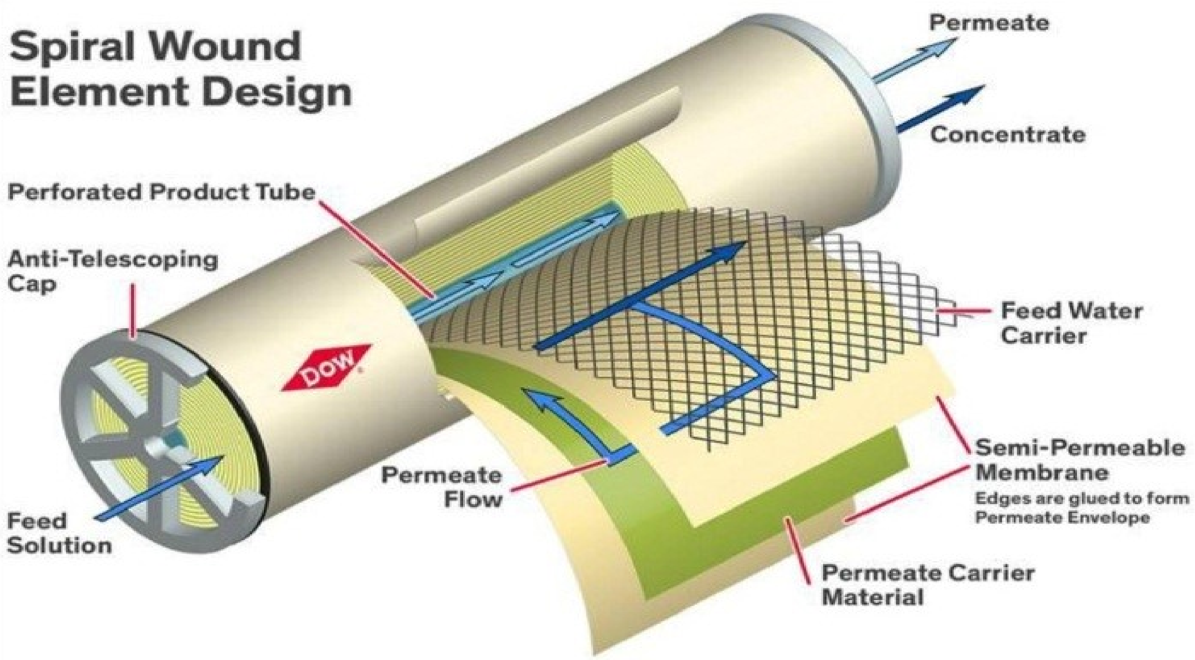
There are four basic forms for RO membrane modules :-

1. **Plate and frame**
2. **Tubular**
3. **Spiral wound**
4. **Hollow fine fiber**

Membrane module	Membrane area/unit vol. ($m^2 m^{-3}$)	Membrane costs	Control of Fouling	Application
Plate & frame Module	400 - 800	medium	good	MF, UF, RO, ED
Spiral-wound module	800 - 1200	low	good	UF, RO, GS
Tubular module	20 - 100	very high	very good	MF, UF, RO
Capillary module	600 - 1200	low	very good	UF, MF,
Hollow fiber module	2000 - 5000	very low	very poor	RO, GS

Table 2.3

Spiral wound RO membrane element



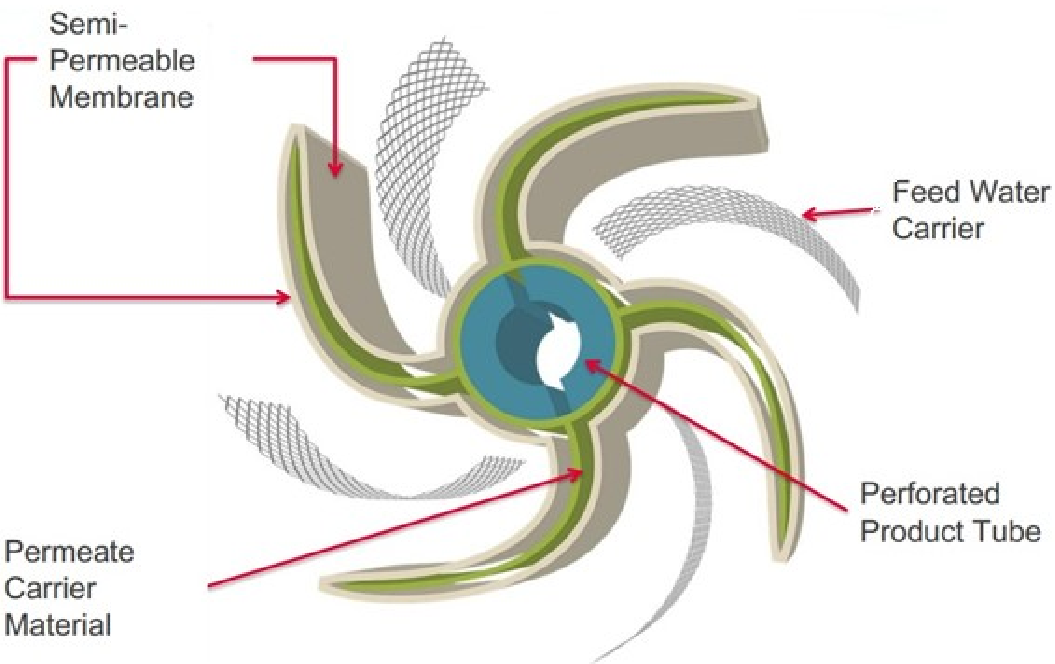


Figure 2.15

Spiral wound RO membrane mechanism & water tracing

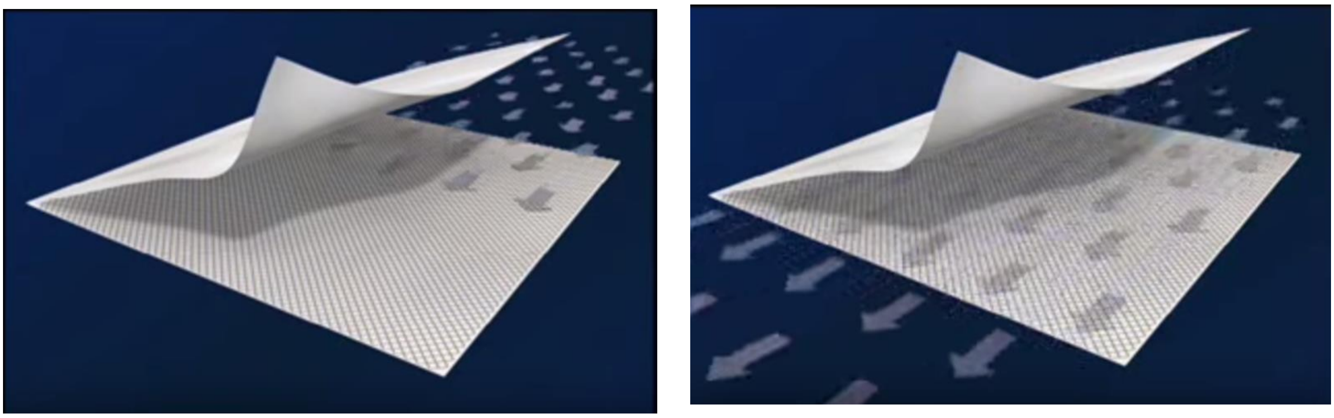


Figure 2.16

- To create our standard spiral round membranes we construct the flat sheet membranes using automated casting equipment we begin the process with a fabric support base and then coat it with a micro porous poly cell foam layer.

- this provides additional support for the top point two micron thick membrane barrier layer. This top barrier layer makes the actual separation purify the water the semi permeable polyamide layer consists of a thin film of polymeric material a few thousand angstroms thick formed on a porous supporting material.

- The semi permeable membrane skin is formed on the poly cellphone substrate by interfacial polymerization of monomers containing amine and carboxylic acid chloride functional groups.

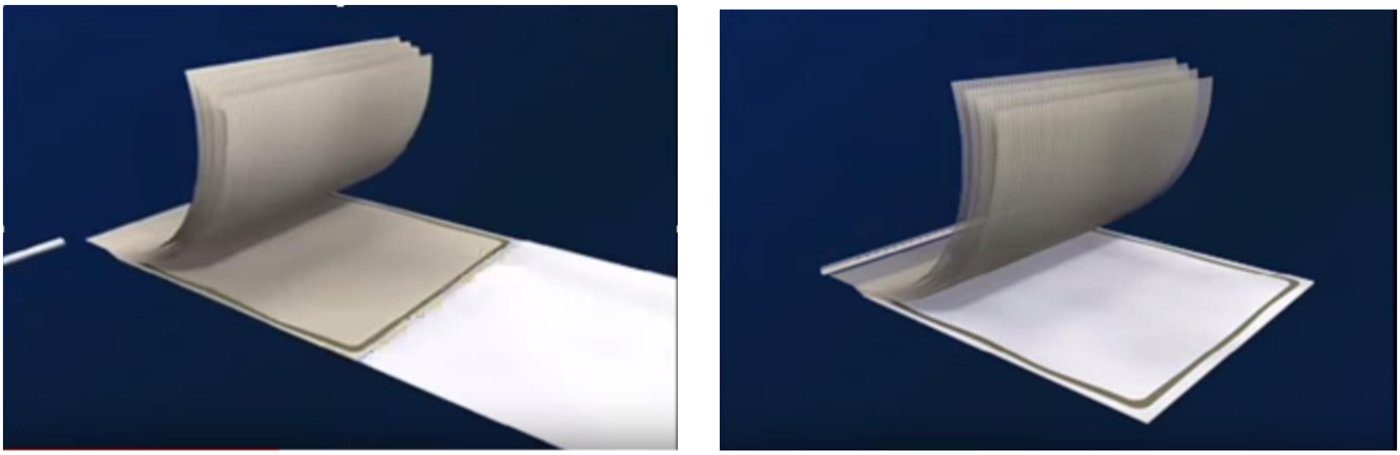


Figure 2.17

- A combination of these three layers makes a durable membrane flat that is used in each spiral wound element. The membrane flat sheet is then combined with a sheet of feed channel spacer.

- This provides turbulence and create space between the membrane sheets to allow uniform flow of the water to the entire membrane surface.

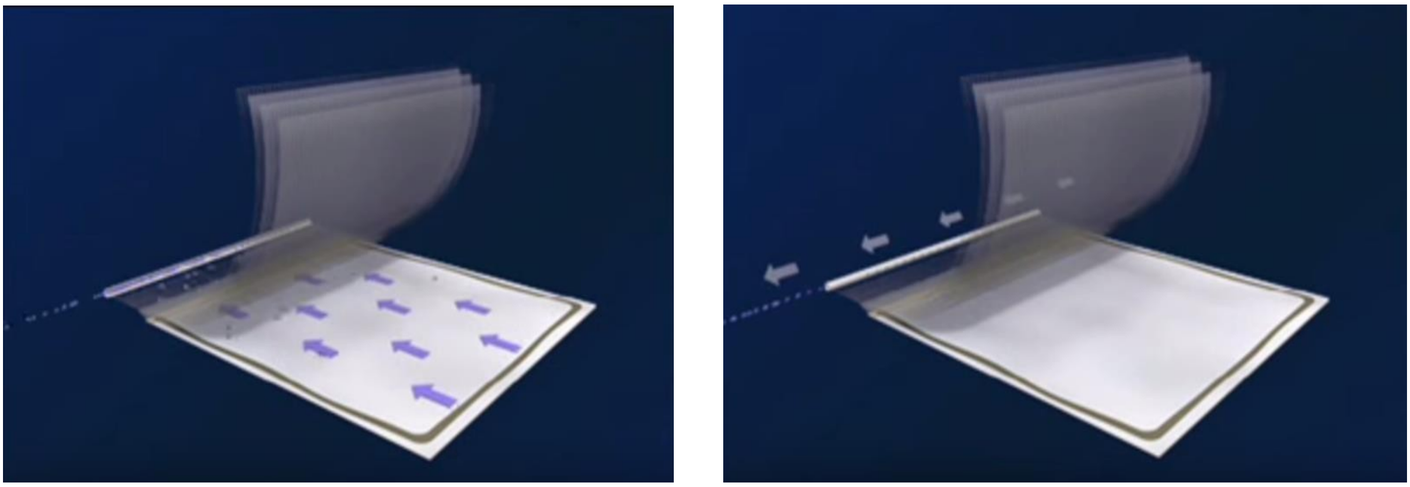


Figure 2.18

- The leaves of membrane and feed channel spacer and then combined with a sheet of permeate spacer which provides open flow channels for the permeate even under high pressure.
- The leaves are glued along each of the three exposed sides and then rolled around the core tube.

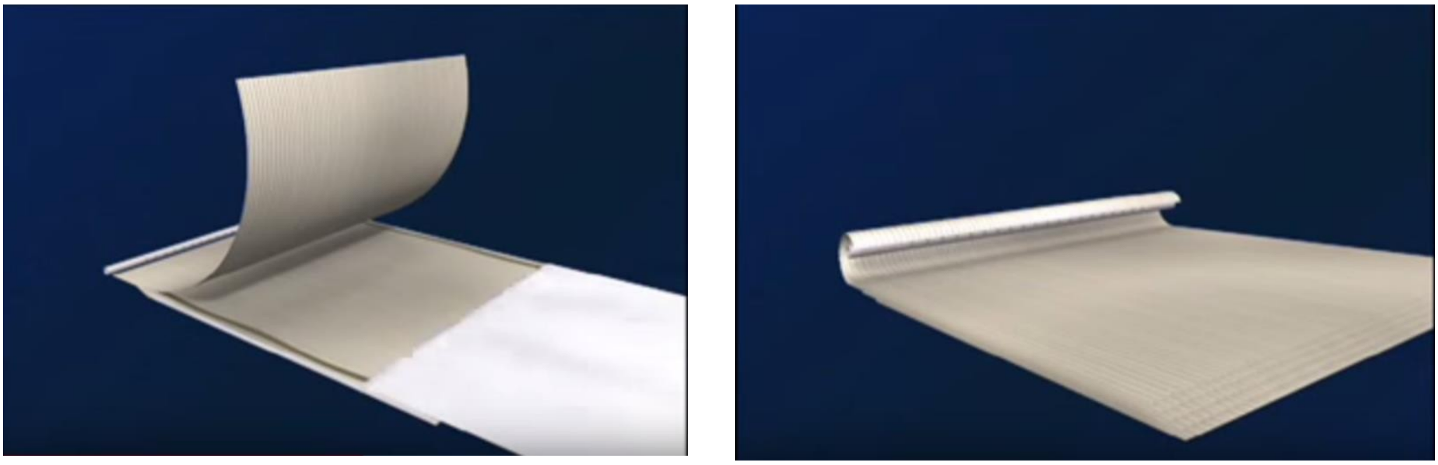


Figure 2.19

- With the back of the membrane completely sealed to the edges of the permeate spacer the feed water is forced through the feed channel spacer contacting the front or barrier layer of the membrane clean water or permeate passes through the membrane surface into the permeate channel.

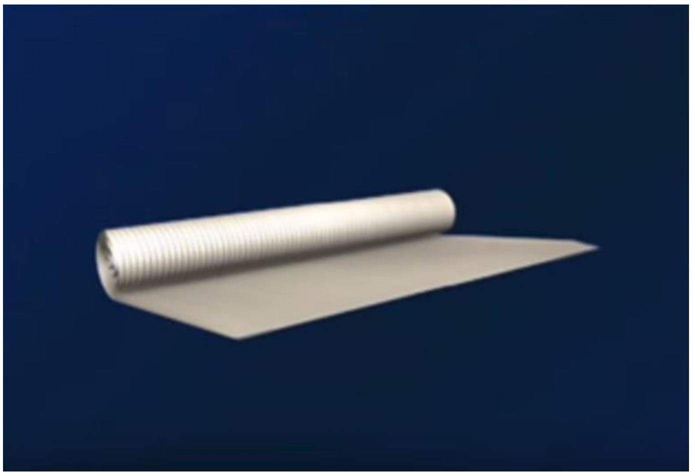
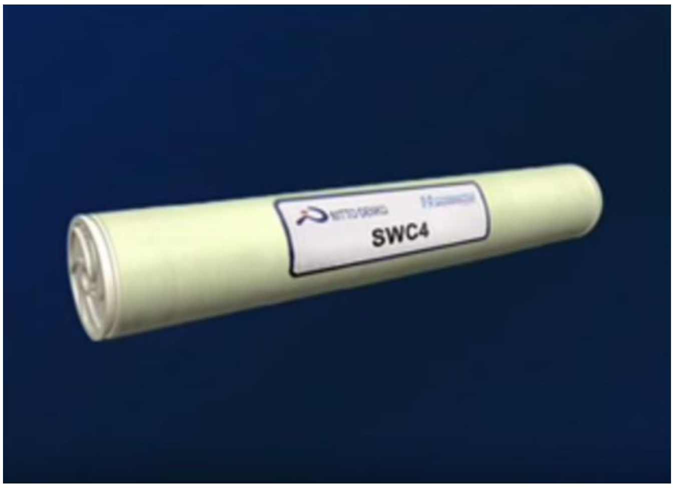



Figure 2.20

- then flows in a spiral direction to the center of the element and is collected into the core tube hydronaut expire around elements can then be loaded into pressure vessels and interconnected with additional elements to complete any number of design specifications once the end adapter is connected to the last element and the pressure vessel is sealed.



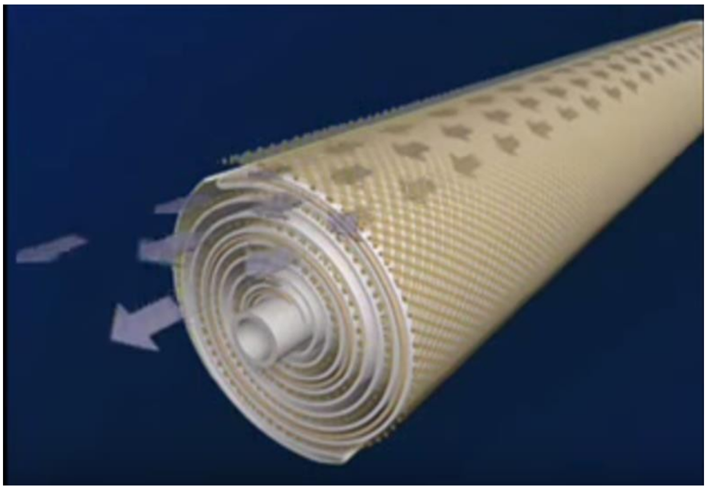


Figure 2.21

- Feed water can be introduced and then treated the feed water that does not permeate through the membrane becomes enriches in salts as it travels through the feed channel spacer due to permeate water being removed typically eight to ten percent of the water is removed in one forty inch long membrane element.

Figure 2.22

- The permeate water then flows at the end of the vessel and is collected as the product and the reject and concentrated from that vessel may then flow through another vessel producing more permeate.

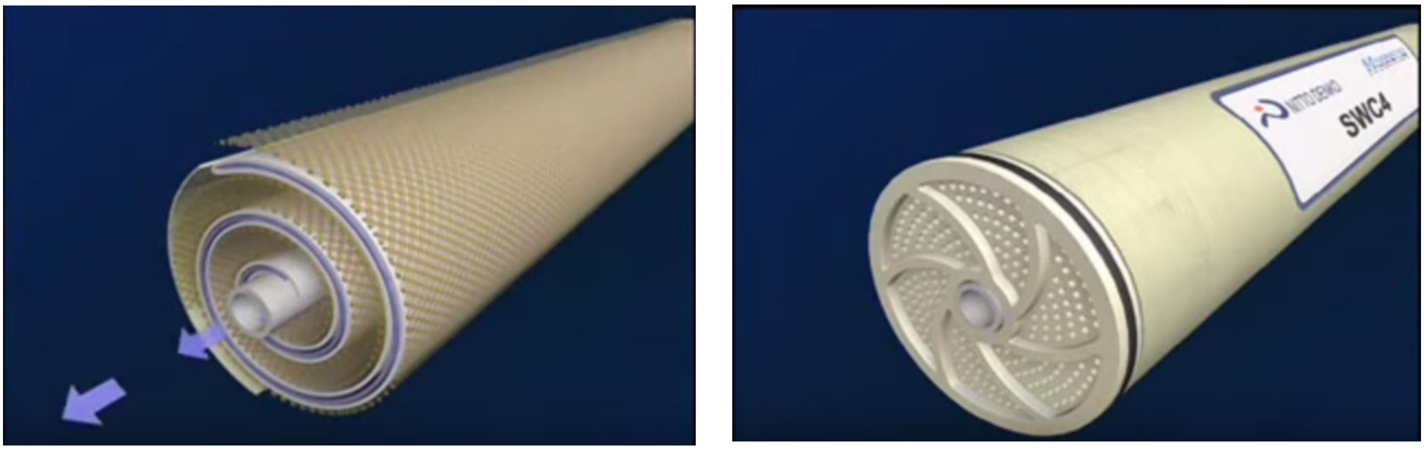


Figure 2.23

- The remaining concentrate may then be disposed of as waste or partially recycled as the feed typically 70 to 90 percent of the water can be recovered as pure product water.

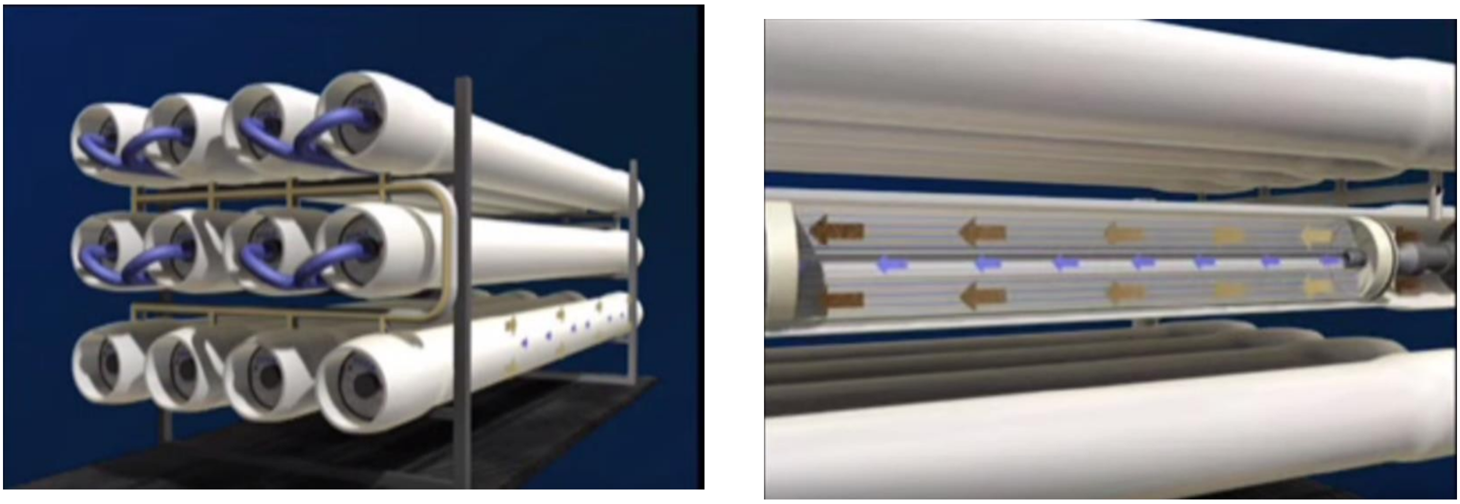


Figure 2.24

What RO can do?

- Remove purified water from a feed stream (permeate)
- Concentrate chemicals in a feed stream (reject)
- Selectively separate small ions and molecules

What RO cannot do?

- Cannot concentrate to 100%
- Cannot separate to 100%

Osmotic pressure – rule of thumb

- **Convert TDS to osmotic pressure:**

– TDS in ppm divided by 100: osmotic pressure in psi
– TDS in ppm divided by 1400: osmotic pressure in bar

- **Examples:**

– 100 ppm TDS » 1 psi osmotic pressure (» 0.07 bar)
– 1,000 ppm TDS » 10 psi osmotic pressure (» 0.7 bar)
– 35,000 ppm TDS » 350 psi osmotic pressure (» 25 bar)

Osmotic pressure

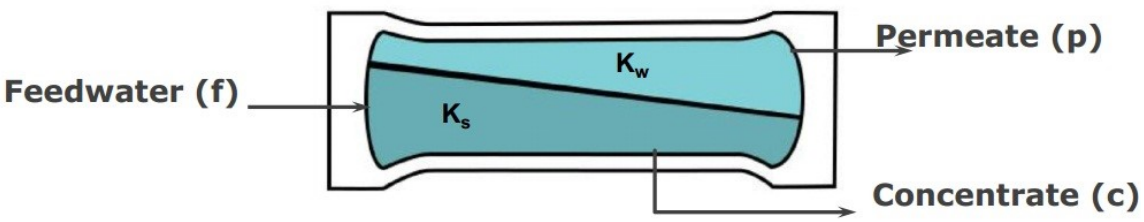
For dilute solutions, osmotic pressure is approximated using the Van't Hoff equation:

$$p = f\,C_i\,RT$$

p - osmotic pressure, atm
f - osmotic pressure coefficient
Ci - molar concentrate of the solute, mol/l
R - gas constant
T - absolute temperature (°K)

Homogenous solution diffusion model

Describes water flux, salt flux and mass-transfer in pressure-driven membrane systems



$$Fw = Kw\ (DP - Dp)$$

Fw - solvent flux [gallons per square foot per day=gfd]
Kw - solvent mass transfer coefficient [gfd/psi] (A value)
DP - transmembrane pressure differential [psi]
Dp - osmotic pressure differential [psi]

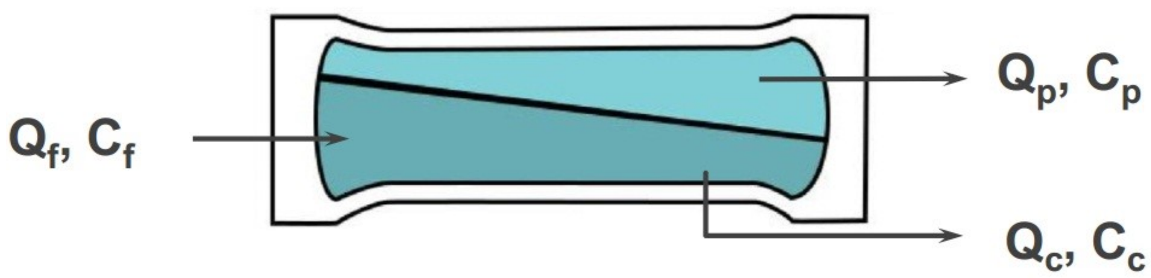
$$Fs = Ks\ (DC)$$

Fs - solute flux [pounds per square foot per day, lbfd]
Ks - solute mass transfer coefficient [gfd] (B value)
DC - transmembrane concentration differential [lb/gal]

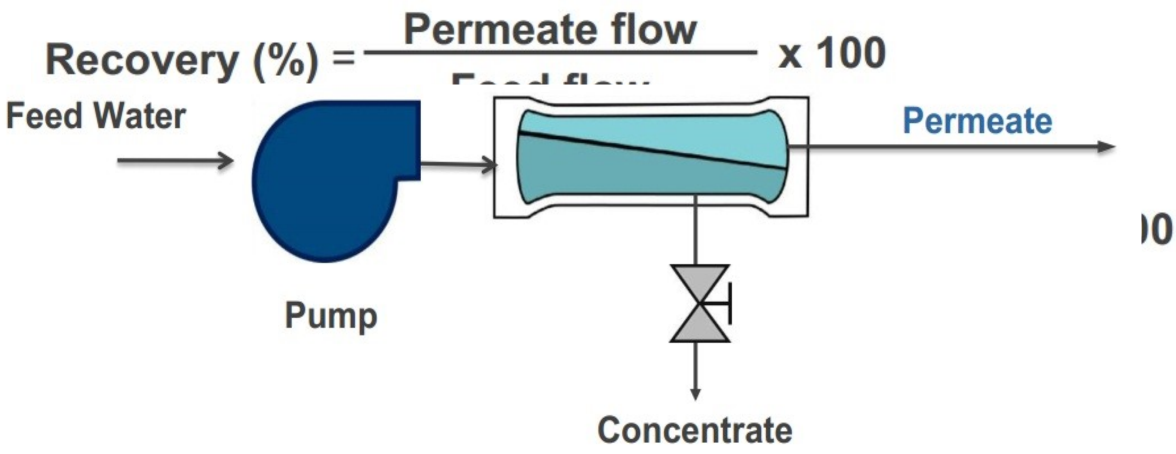
Mass balance equations

$$Qf = Qp + Qc$$
$$QfCf = QpCp + QcCc$$

Qf - feed flow [gal/min]
Qp - permeate flow [gal/min]
Qc - concentrate flow [gal/min]
Cf - feed solute concentration [lb/gal]
Cp - permeate solute concentration [lb/gal]
Cc - concentrate solute concentration [lb/gal]



Basic definitions



100 to 600 psi (brackish water)
800 to 1,200 psi (seawater)

Simplified RO system

Factors which effect membrane performance

- **Feedwater**

– Concentration
– Temperature
– Osmotic pressure
– pH

- **Operation parameters**

– Pressure
– System recovery

- **Concentration Polarization**

Affect of feedwater pressure on flux and salt rejection

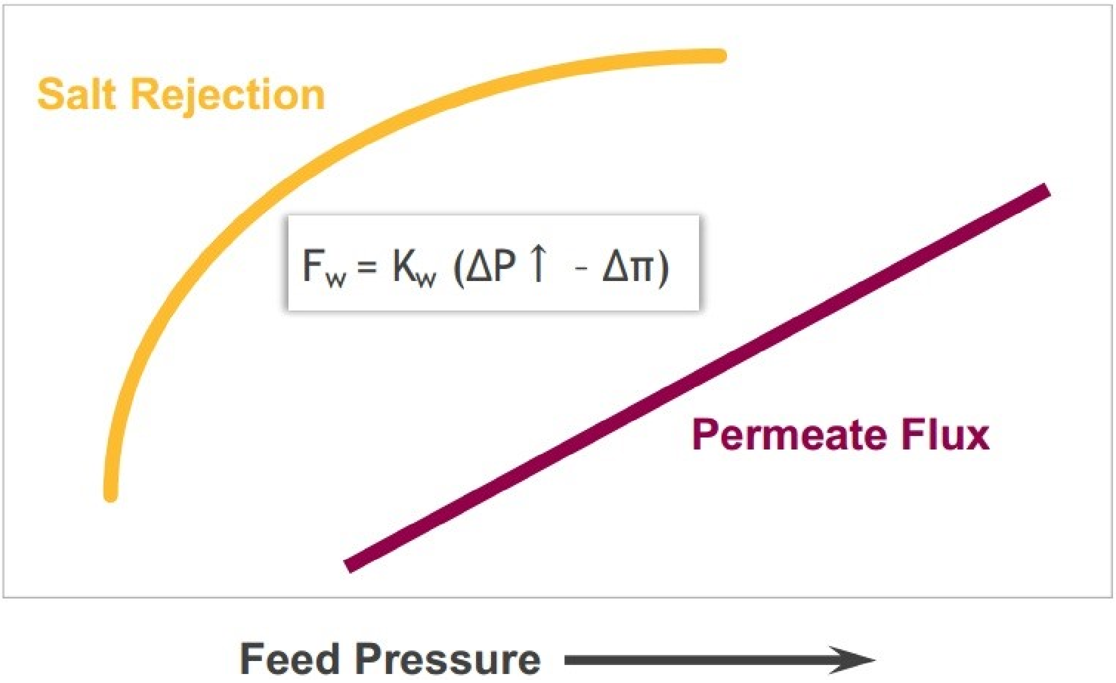
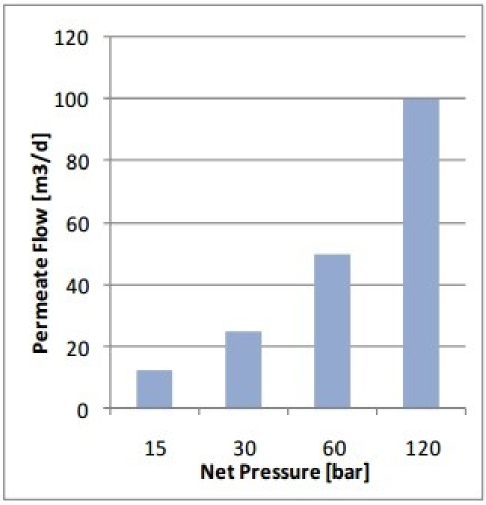


Figure 2.25

Pressure Affect



- If you double net driving pressure (NDP) to an RO unit you will double your permeate flow.
- NDP is the sum of all forces acting on the membrane

$$NDP = \Delta P - \Delta \pi$$

Feedwater temperature vs. flux and salt rejection

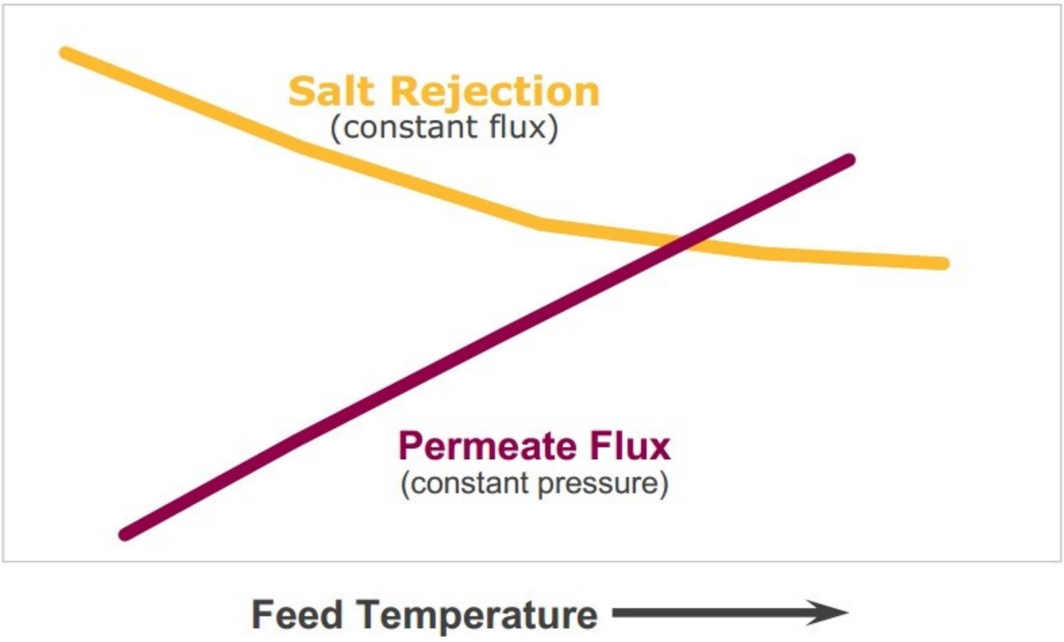


Figure 2.26

Temperature Affect

Permeate flow

• The higher the temperature the higher the permeate flow
• Why? Lower viscosity makes it easier for the water to permeate through the membrane barrier
• RULE OF THUMB – for every 1ºC the permeate flow will increase ~ 3%

Salt passage

• Rule of Thumb: salt passage increases 6% for 1ºC increase.
• Increasing temperature increases salt passage more than water passage.
• Generally you will get better rejections at lower temperatures

Salt concentration vs. flux and salt rejection

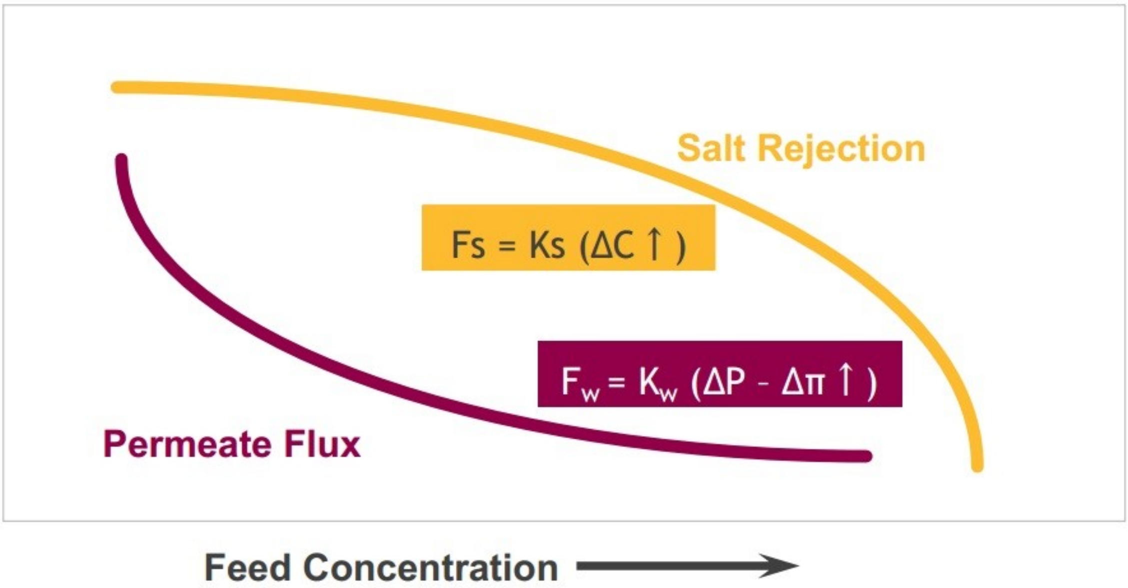


Figure 2.27

Salt concentration affect

• Salt concentration affect on permeate flow
• Higher salt concentration will decrease the permeate flow.
• Why? Because higher osmotic pressure will reduce the NDP.
• Salt concentration affect on salt passage
• Higher salt concentration will increase the salt concentration gradient and increase
the rate of salt passage.
• Salt concentration affect on permeate quality
• Overall water quality is lower for two reasons, higher rate of salt passage combined with less permeate water.

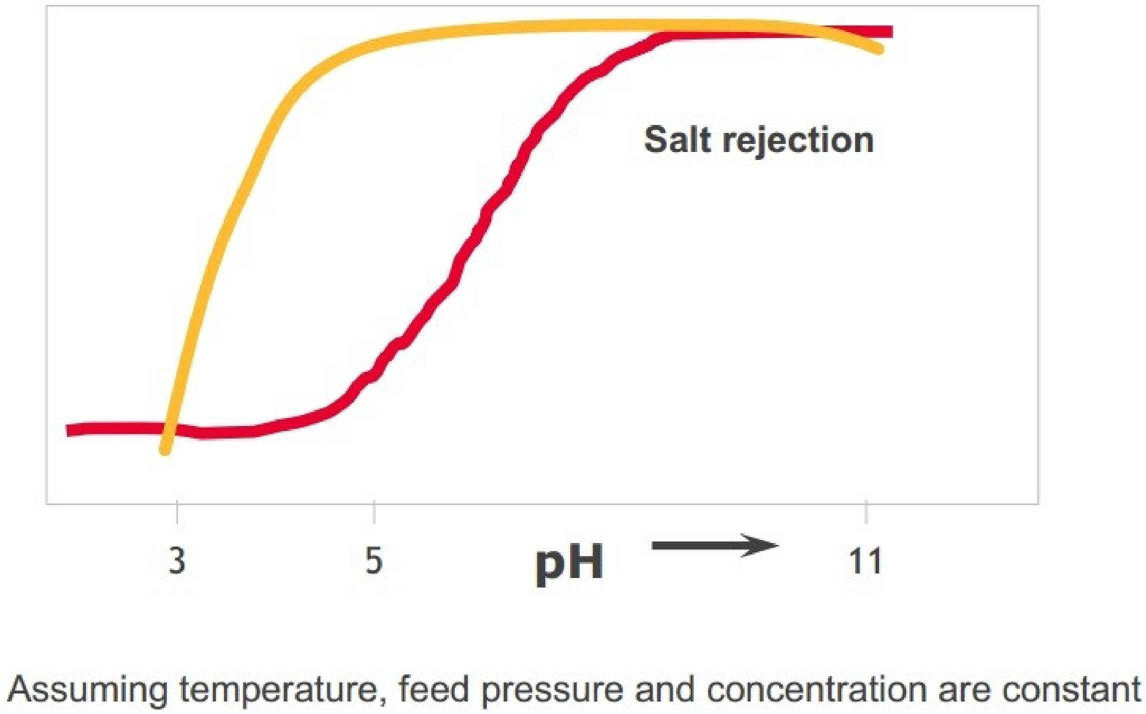
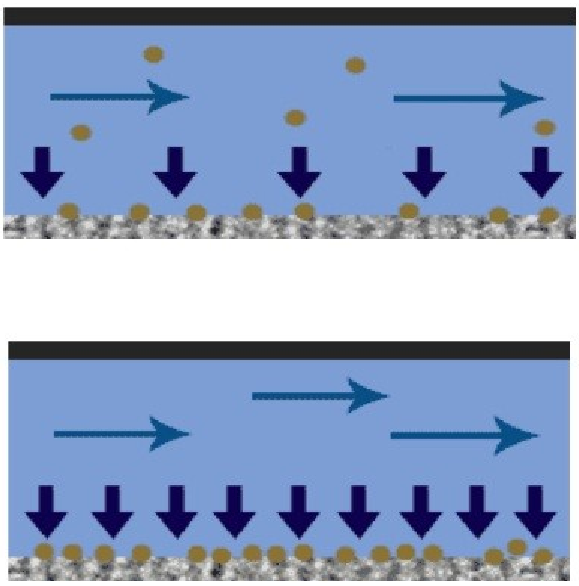


Figure 2.28

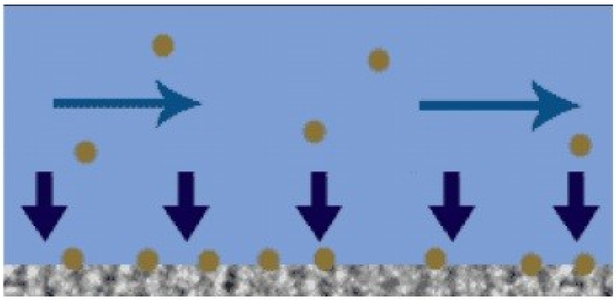
pH influence on salt rejection

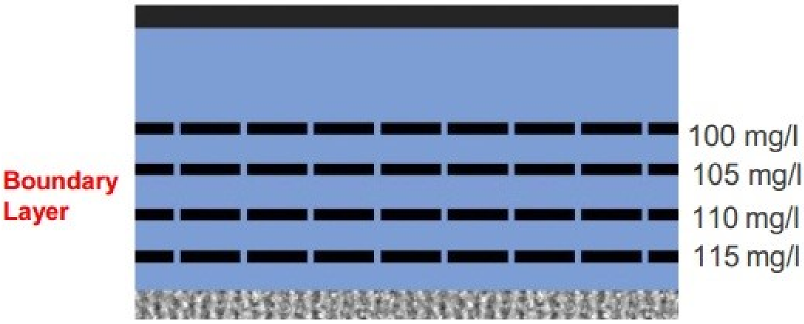
Boundary layer



- Water near the membrane surface has little to no cross flow
- Creates an area for particulates & colloids to collect and foul the membrane.
- Water flux through the membrane helps hold foulants in place.

Concentration polarization





- Concentration polarization is a function of the boundary layer.
- It results in an increased salt concentration at the membrane surface.
- The higher the flux rate through the membrane the higher the salt concentration at the membrane surface.
- Typically the TDS is 13–20% higher than the concentration in the bulk stream.

Factors affecting membranes solute rejection

Membrane type/condition

- SW30XHR NaCl 99.75%,
- XFRLE NaCl 99.4%
- NF90: NaCl 85-95%

Solute characteristics

- Charge
- Polarity and/or Degree of Dissociation
- Degree of Hydration
- Molecular weight and Degree of Branching

RO membrane problems :

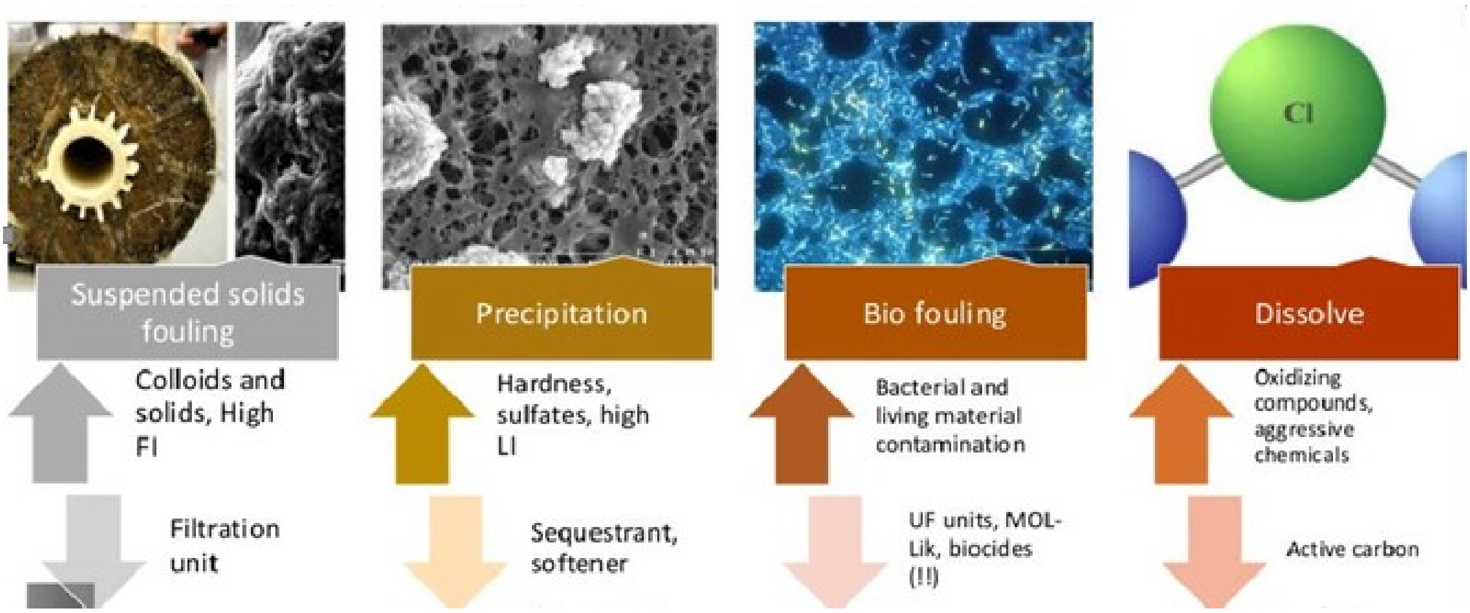


Figure 2.29

scaling

Scaling Scaling of RO membranes is a result of precipitation of saturated salts onto the surface of the membrane.

Figure 2.30

Fouling

Membrane fouling is a result of deposition of suspended solids, organics, or microbes on the surface of the membrane, typically on the feed /concentrates side.

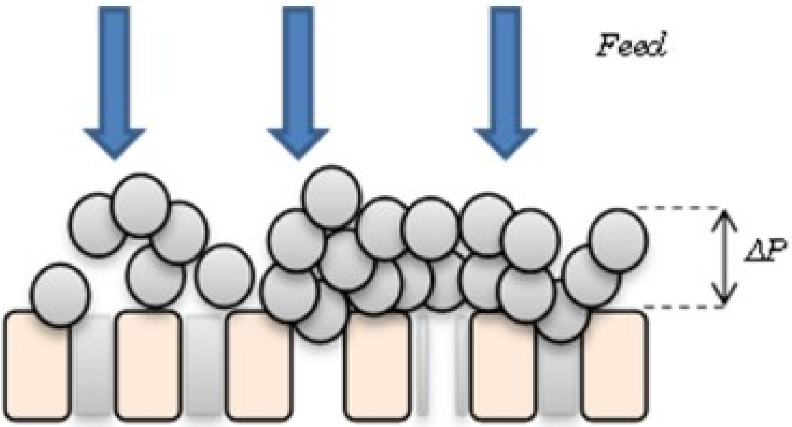


Figure 2.31

over pressure effect on membrane (mechanical damage) :

Part of the pretreatment scheme should be pre and post RO system pl umbing and controls. If 'hard starts' occur mechanical damage to the membranes can occur. Likewise, if there is too much backpressure on the RO system then mechanical damage to the RO membranes can al so occur. These can be addressed by using variable frequency drive motors to start high pressure pumps for RO systems and by installing check valve(s) and/or pressure relief valves to prevent excessive back pressure on the RO unit that can cause permanent membrane damage .

Figure 2.32

Chemical Attack

Modern thin film composite membranes are not tolerant to chlorine or chloramines. Oxidizers such as chlorine will 'burn' holes in the membra ne pores and can cause irreparable damage. The result of chemical at tack on an RO membrane is a higher permeate flow and a higher salt passage (poorer quality permeate water). This is why microorganism gr owth on RO membranes tends to foul RO membranes so easily since there is no biocide to prevent its growth.

Chapter 3

Pretreatment

Reverse Osmosis Pretreatment

Since the design of an RO system is quite standardized, we find few differences at the end of the day between two different approaches for the design of the same RO System for an specific project.

We can say that apart than being more or less aggressive on setting the Design Flux of the system, other variations are almost negligible between one design and another at equality conditions for other important characteristics as, for example, the Energy Recovery System.

Therefore, with the exception of some projects with special characteristics, we can say that the core of a smart design for a RO Plant in order to ensure its proper operation regarding quantity and quality of the Treated Water is the Selection and Design of the Pretreatment.

The performance and successful operation of an RO system depends directly on the quality of water feeding the RO. The nature of feed water constituents can influence membrane performance by causing scaling, fouling, or degradation of the membrane.

Main Factors for Pretreatment Selection:

The proper Selection and Design of the Pretreatment must take into consideration not only the Pretreatment itself but also the whole RO Plant to ensure a continuous operation and production of a Treated Water downstream the RO system complying with the required Quantity and Quality.

As a way of example, if we have a Pretreatment composed by a set of Pressurized Dual Media Filters (DMF) with an inappropriate design, means that the outlet water from these filters will have a SDI, Turbidity, Colloidal Matter and TSS higher than the calculated in the design of this Pretreatment.

Therefore, the RO membranes will suffer a fouling process much faster than predicted in the Design Calculations.

Therefore the Number of Backwash Cleanings for the DMFs will increase, the Number of Cleanings of the RO Membranes will increase and the Operating Life of the RO membranes will decrease, that means a lower time of operation in continuous than the predicted in the Design of the RO System.

Therefore, in this case, an incorrect Design of the Pretreatment brings associated an increase in the OPEX of the RO System and a decrease of the time of operation in continuous of the whole plant and therefore a decrease in the flowrate production of Treated Water.

As we can see, the Selection and Design of the Pretreatment affects not only to the Pretreatment, but also to the whole RO Plant OPEX.

Water Characteristics:-

1-TDS:-

Total dissolved solids (TDS) is found to be in a wide range of levels in drinking water.The TDS level of a drinking water supply should be less than 500 mg/L however, high level of TDS from dissolved ions is not usually considered dangerous or harmful, and at worst results in water being "hard" (hard to make soap suds),or gives it a slightly bitter or salty taste.

***And can be mesured by TDS meter**

A TDS meter is basically a electrical charge (EC) meter whereby two electrodes equally spaced apart are inserted into water, and used to measure charge. The result is interpreted by the TDS meter and converted into a ppm figure.

Figure

Level of TDS (milligrams per litre)	Rating
Less than 300	Excellent
300 - 600	Good
600 - 900	Fair
900 - 1,200	Poor
Above 1,200	Unacceptable

Table 3.1

2-Turbidity:-

Turbidity is a measurement of the cloudiness (or lack of clarity) of water. The standard for turbidity of drinking water is a value of less than 5 Nephelometric Turbidity Units (NTU). Water with readings in this range will appear to be clear. To reach low levels of turbidity during water treatment, it is sometimes necessary to remove particles or suspended particulates by filtration, screening, or flocculation.

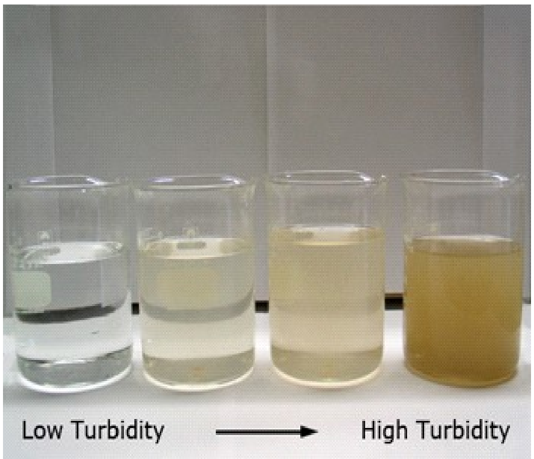


Figure 3.1

3-pH:-

pH is a measurement of how acidic or basic a water sample is. The pH scale ranges from 0 to 14. Drinking water with a pH greater than 7 is basic, and with a pH less than 7 is acidic. It is quite common for drinking water to be slightly basic (between 7 and 8.5), due to the presence of hard-water minerals. the drinking water is recommended to be in the pH range of 6.5-8.5. Because slightly acidic water can cause metal pipes to corrode, if drinking water has a pH less than 7, communities will sometimes adjust that PH to a value that is greater than 7.

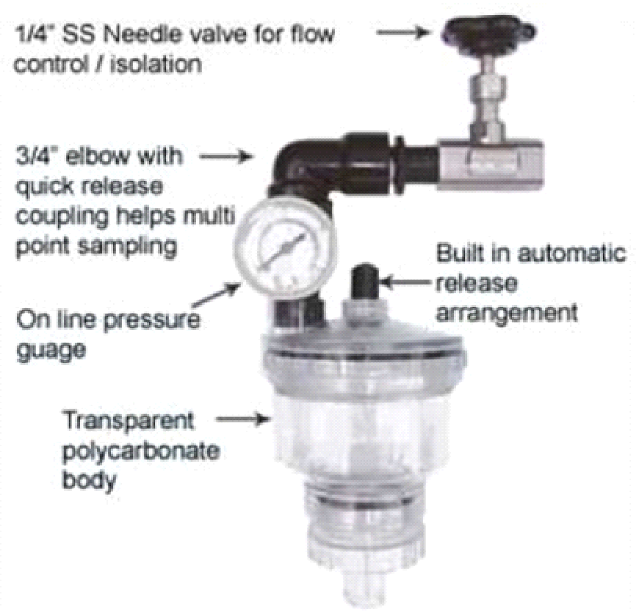
Figure 3.2

4-SDI (Silt Density Index):-

Suspended solids and colloidal materials in feed water are one of the biggest problems in reverse osmosis systems. Even though most systems have some pretreatment including 5 micron prefilters, these fine particles are responsible for fouling of reverse osmosis membranes.

In order to have some measure of the degree of this fouling problem, a concept called Silt Density Index is used. Here a 0.45 micron filter is exposed to the feed water under pressure and filtration rates are calculated.

An SDI of less than 5 is considered acceptable for the reverse osmosis systems. This means that at values of SDI of less than 5, the membranes should foul at a very low rate. Even though the concept works most of the time, there are exceptions when a lower SDI (less than 3) is desirable due to the nature of the suspended solids in that feed water.



<u>Figure 3.3</u>

<u>SDI of <5: No prefiltration is necessary.</u>

<u>SDI of 5-10: A media (sand-type) filter is required.</u>

<u>SDI of >10: A 2-stage media filtration is necessary - possibly with the aid of coagulants or settling tanks.</u>

5-Water Hardness:-

- The simple definition of water hardness is the amount of dissolved calcium and magnesium in the water. Hard water is high in dissolved minerals, both calcium and magnesium.
- Hardness can cause scaling of the membrane, which over time will defeat the whole purpose.
- It will reduce the output of the membrane itself and it will reduce the quality of water that the membrane is putting out. Essentially, it slowly kills the membrane.

Figure 3.4

The proper selection of the Pretreatment depends on the following factors:-

1-Source of Raw Water.

2-Specific Composition of Raw Water.

3-Final Application of the Treated Water.

*The main targets of a proper Pretreatment are:

1. Maximize Efficiency of the RO System.

2. Maximize Operating Life of the RO Membranes.

These two main targets are achieved by:

1-Minimizing:-

1-Fouling

2-Scaling

3-Membrane Degradation

2-Optimizing:-

1-Product Flow.

2-Product Quality (Salt Rejection).

3-Product Recovery (Product Quantity).

4-Operating & Maintenance Costs.

- Appropriate pretreatment techniques for a given RO application needs to be selected based on the quality of the influent water to be treated by RO. Some water, such as well water with low concentrations of iron and manganese, may require very little, if any, pretreatment, while other water, such as river or lake water, may require extensive pretreatment using sequenced techniques and technologies. Obtaining historical influent water quality data as well as pilot testing of proposed pretreatment unit operations are both good practice in designing and optimizing the pretreatment system.

Pretreatment Techniques

Coagulation & Flocculation

For raw waters containing high concentrations of suspended matter resulting in a high SDI, the classic coagulation-flocculation process is preferred. The hydroxide flocs are allowed to grow and settle in specifically designed reaction chambers. The hydroxide sludge is removed, and the supernatant water is further treated by media filtration.

Type of coagulants

1-Aluminum salts (alum).

2-Ferric and ferrous salts.

3-Lime.

4-Polymers.

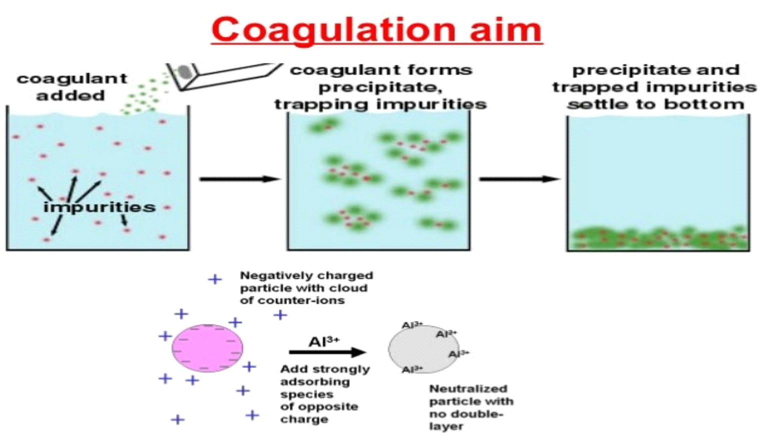


Figure 3.5

Cartridge filters

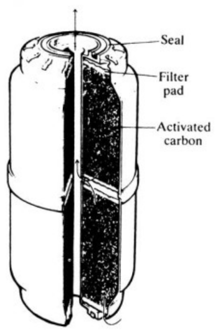
Cartridge filters are simple, modular filters that are inserted into a housing and can be used to remove particles, or sometime chemicals, from the water. Cartridge filters can be composed of a number for materials. Some may be made from wound strands of a material such as polypropylene.

Carbon Filters Activated

carbon filters are used to reduce the concentration of organics in RO feed water. These filters are also used to remove oxidants such as free chlorine from RO feed water.

Activated carbon is derived from natural materials such as bituminous coal, lignite, wood, fruit pits, bones, and coconut shells, to name a few.

Chlorine and other oxidants are removed using activated carbon by an oxidation/reduction reaction. Chlorine oxidizes the carbon while the chlorine is being reduced. Chlorine ends up forming hydrochloric acid.



Activated carbon water filter.

Figure 3.6

Melt blown

The term 'Melt blown' means the filter has been manufactured using a computer controlled process where fibres are collected in a graded pore structure about a moulded core.

*used for For Suspended solids removal.

Figure 3.7

Multimedia Pressure Filters

Multimedia pressure filters are designed to reduce turbidity and colloids (measured as SDI) in water. These filters can remove particles down to about 10 microns in size. If a coagulant is added to the fil- ter influent stream, reduction of particles down to 1-2 microns can sometimes be accomplished.

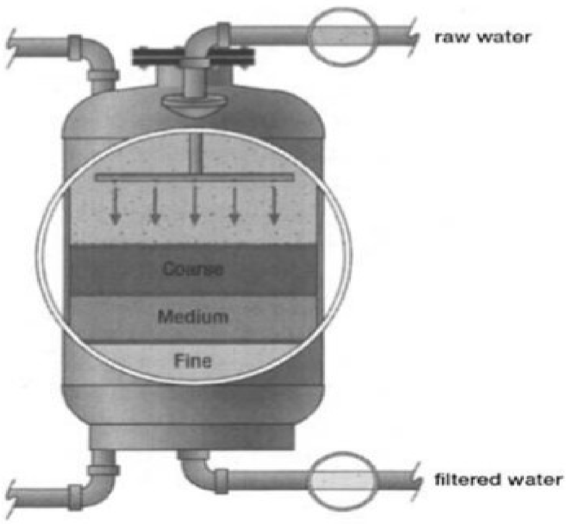


Figure 3.8

Particles are subsequently removed through the filter using physical entrapment. Larger particles are removed on top through the anthracite, while smaller particles are subsequently removed through the sand and garnet.

Iron Filters

Many well waters contain soluble iron, manganese, and hydrogen sulfide that oxidize in the presence of oxygen or chlorine to form insoluble hydroxides and elemental sulfur, all of which foul RO membranes.

Manganese Greensand Filters

Manganese greensand requires the use of oxidizers to aid in the oxidation and removal of iron, manganese, and hydrogen sulfite. Iron can be removed with the use of chlorine as the oxidizer. Manganese removal via manganese greensand requires the use of potassium permanganate to adequately oxidize the metal.

Figure 3.9

Sodium Softeners

Sodium softeners are used to treated RO influent water to remove soluble hardness (calcium, magnesium, barium, and strontium) that can form scale on RO membranes. Once known as sodium zeolite softeners, zeolites have been replaced with synthetic plastic resin beads. For sodium softeners, these resin beads are strongly acidic cation (SAC) polystyrene resin in the sodium form. The active group is benzene sulfonic acid, in the sodium, not free acid, form. Figure 8.12 shows styrene-divinylbenzene gel cation resin.

$$Ca(HCO_3)_2 + SAC\text{-}Na \Leftrightarrow 2NaHCO_3 + SAC\text{-}Ca$$

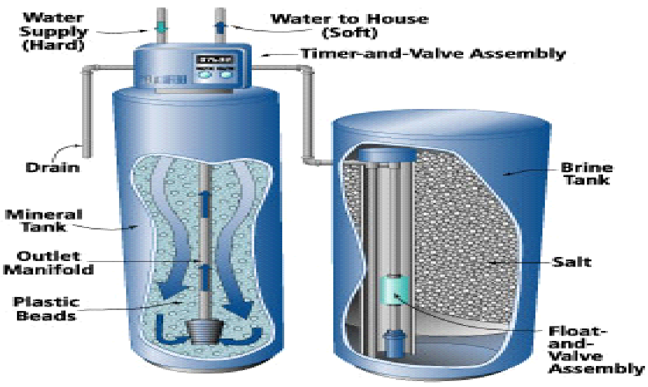


Figure 3.10

Ultraviolet Irradiation

Ultraviolet (UV) irradiation is used to destroy bacteria and reduce organic compounds (measured as TOC) as well as destruction of chlorine and chloramines. This technique involves passing water over a UV lamp that is operating at a specific wavelength of energy.

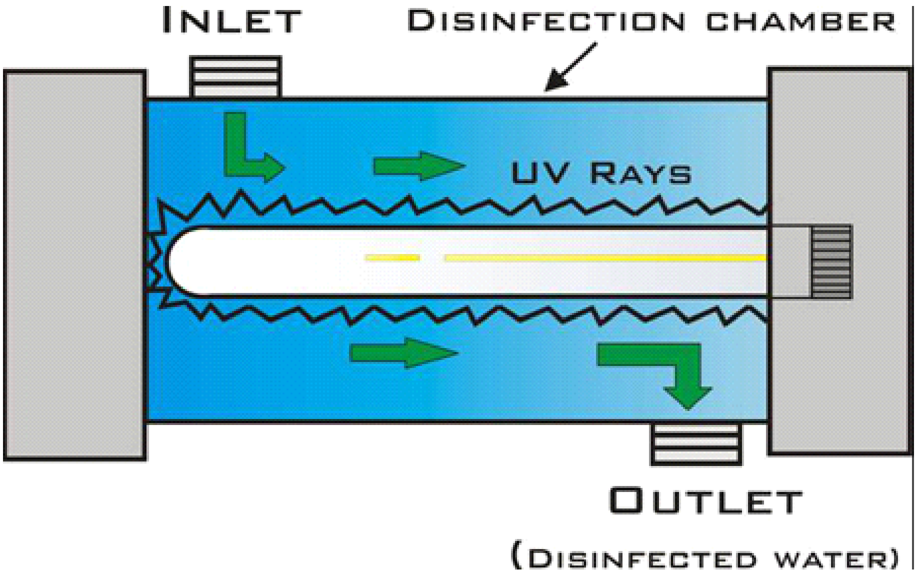


Figure 3.11

A significant advantage of UV over use of chemical oxidizers for microbial control is that no trihalomethane (THM) compounds are generated. Additionally, the need to store and feed a hazardous chemical oxidizer is avoided.

For UV to be effective, certain water conditions must be met. The water must be free of suspended solids, which can foul quartz sleeves, thereby reducing the amount of radiation reaching the water.

Chlorination

is commonly used to kill microbes in pretreatment prior to RO and to break up organics that may foul RO membranes. It is used rather than other halogens because of its higher OW. Chlorine is available in many forms, such as chlorine gas, sodium hypochlo- rite (bleach), chloramines, and chlorine dioxide. Chlorine gas and sodium hypochlorite each react with water to form hypochlorous acid, as shown in Equations 8.5 and 8.6, respectively.

$$Cl_2 + 2H_2O \Rightarrow HOCl + H^+ + Cl^-$$

$$NaOCl + H_2O \Rightarrow HOCl + NaOH$$

Dechlorination

Dechlorination of feed water to polyamide composite membranes is necessary as a polyamide membrane polymer cannot tolerate oxi- dizers of any kind. The options for dechlorination include activated carbon, sodium metabisulfite chemical feed, and UV radiation. Carbon has its own set of difficulties, as described previously, and UV radiation can be capital intensive. Sodium metabisulfite is the most commonly used technique to dechlorinate RO influent. In water, the sodium metabisulfite forms sodium bisulfite.

$$Na_2S_2O_5 + H_2O \Rightarrow 2\ NaHSO_3$$

Ozone

Ozone is a very powerful disinfectant. Its ORP is greater than that of chlorine.

Although ozone can be generated in a number of different fash- ions, the most economical method is by dielectric barrier discharge.'O This method involves the passing of a high-voltage, alternating cur- rent (6 to 20kV) through either air or pure oxygen.

When added to water, ozone quickly converts to oxygen, leav- ing behind no residual ozone. This makes it difficult for ozone to provide residual disinfection of RO feed water. Although no triha- lomethanes are produced when using ozone, side reactions have been known to form carcinogenetic compounds such as aldehydes and phthalate.

Antiscalants

Sequestering agents (also known as scale inhibitors or antiscalants) are used to minimize the potential for forming scale on the surface of an RO membrane

There are three methods of scale control commonly employed:-

1)Acidification:-

Acidification: acid addiction destroys carbonate ions, removing one of the reactants necessary for calcium carbonate precipitation. This is very effective in preventing the precipitation of calcium carbonate, but ineffective in preventing other types of scale. Additional disadvantages include the corrosivity of the acid, the cost of tanks and monitoring equipment and the fact that acid lowers the pH of the RO permeate.

2)Ion exchange softening:-

this method utilizes the sodium which is exchanged for magnesium and calcium ions that are concentrated in the RO feed water, following the chemical equations:

$Ca^{2+} + 2NaZ \Rightarrow 2Na^{+} + CaZ_2$

$Mg^{2+} + 2NaZ \Rightarrow 2Na^{+} + MgZ_2$

(NaZ represents the sodium exchange resin).

When all the sodium ions have been replaces by calcium and magnesium, the resin must be regenerated with a brine solution. Ion exchange softening eliminates the need for continuous feed of either acid or antiscalant.

3)Antiscalant addiction:-

They are surface active materials that interfere with precipitation reactions in three primary ways:

Threshold inhibition: it is the ability of an antisclant to keep supersaturated solutions of springly soluble salts.

Crystal modification: it is the property of an antiscalants to distort crystal shapes, resulting in soft non adherent scale. As a crystal begin to form at the submicroscopic level, negative groups located on the antiscalant molecule attack the positive charges on scale nuclei interrupting the electronic balance necessary to propagate the crystal growth. When treated with crystal modifiers, scale crystals appear distorted, generally more oval in shape, and less compact.

Dispersion: dispersancy is the ability of some antiscalants to adsorb on crystals or colloidal particles and impart a high anionic charge, which tends to keep the crystals separated. The high anionic charge also separates particles from fixed anionic charges present on the membrane surface.

Membrane

Membrane pretreatment includes microfiltration (MF), ultrafiltra- tion (UF), and nanofiltration (NF). Microfiltration and UF membrane processes can remove microbes and algae. However, the pores of MF and UF membranes are too large to remove the smaller, low- molecular weight organics that provide nutrients for microbes. As a result, MF and UF can remove microbes in the source water, but any microbes that are introduced downstream of these membranes will have nutrients to metabolize. Therefore, chlorination along with MF and UF is often recommended to minimize the potential for microbial fouling of RO membranes. The MF or UF membranes used should be chlorine resistant to tolerate chlorine treatment. It is suggested that chlorine be fed prior to the MF or UF membrane and then after the membrane (into the clearwell), with dechlorination just prior to the RO membranes.

Micro filtration

1-Remove particles in range 0.1 to 1 micron

2-Remove SS , large colloid , Bacteria

3-Low exit turbidity

4-0.7 bar (Applied pressure)

Ultra Filtration

1-Remove particles in range 2 Nano to 0.1 Micron

2-colloid , Bacteria , Proteins , microbiological contaminants

3-Remove biological fouling

4-1-7 bar (Applied pressure)

Nano Filtration

1-Remove particles in range 1 Nano

2-Calcium , Sodium , magnesium , color , TOC

3-Softening , surface water , waste water

4-3.5-16 bar (Applied pressure)

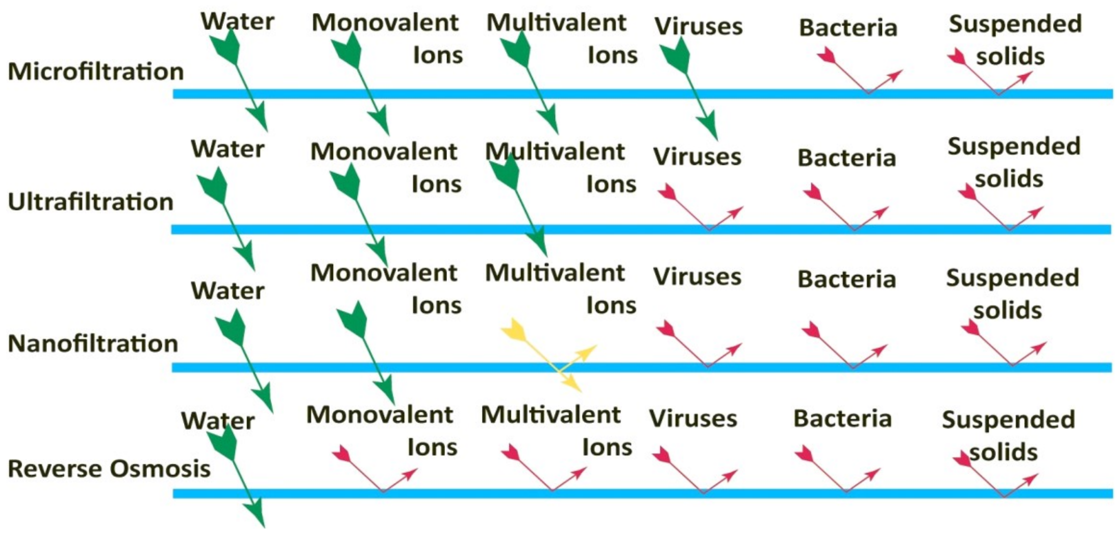


Figure 3.12

Sample reverse osmosis and pretreatment process flow diagram

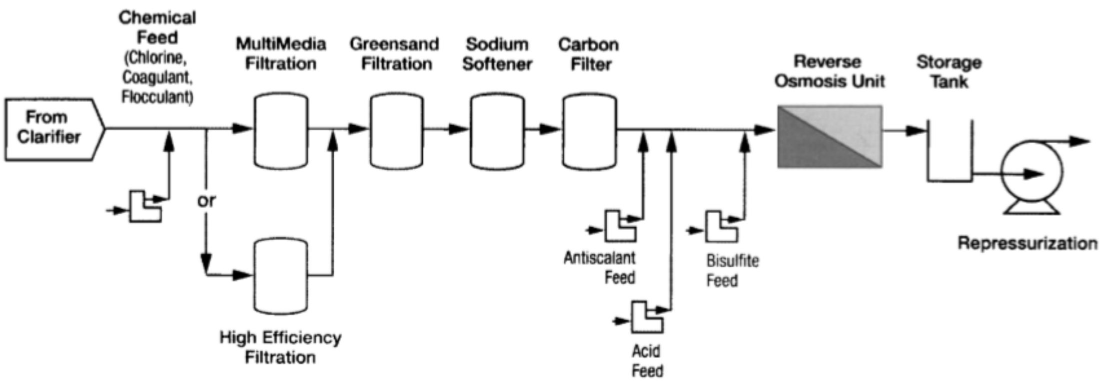


Figure 3.13

Post Treatment

Water from a desalination process is typically void of dissolved solids resulting in finish water with low hardness , low alkalinity and high amount of dissolved gases.

As a result, desalinated watear without posttreatment is corrosive toward the metal and concrete surfaces of pipelines

The aims of the post treatment:

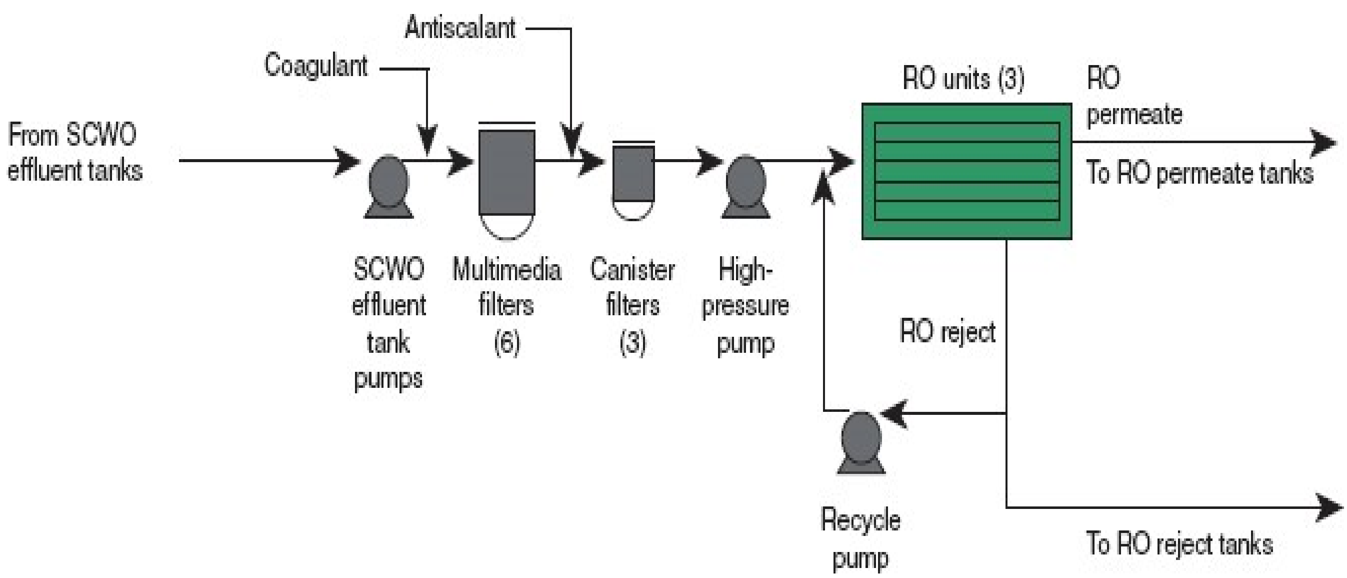
- Remove corrosion effect of water
- Make sure that the water permeate matching the specifications and standards required, such as pH

FIRST Method:

We use the Reverse Osmosis permeate Mixing with water after RO:

1- to improve their acceptability and particularly

2- to reduce their aggressive attack on materials, the major ions added are sodium and chloride.



- Post treatment technologies vary upon final application:

Which:(sodium adsorption ratio)

	Drinking water	Irrigation water	Process water
Sodium chloride	< 450 mg/L	SAR optimization	minimized
Calcium, Magnesium	Hardness 6-10°D		minimized
pH	6.5-8.5		

1- PH adjustment Reverse Osmosis (RO)

- Systems can lower the pH of Process Water by (1 - 2)points, creating slightly acidic
- water so that can pose a risk to piping and equipment of (RO) unit . The Adjustment of pH as Pre/post treatment and that depend on the applicable conditions

2- Degasification or Decarbonation

- Degasification is the removal of dissolved gases from liquids,
- The purpose of the post treatment decarbonation is to remove dissolved carbon dioxide in the reverse osmosis (RO) permeate water in order to increase the pH value.

3- Ultra violet (UV)

- Ultraviolet radiation (254 nm) Uses in pre/post treatment to disinfect water that occur when UV rays penetrate the cells of harmful bacteria and viruses in our drinking water, destroying their ability to reproduce, and same any system UV has Advantages and Disadvantages of using .

Chapter 4

Solar Energy

Introducing Solar Energy

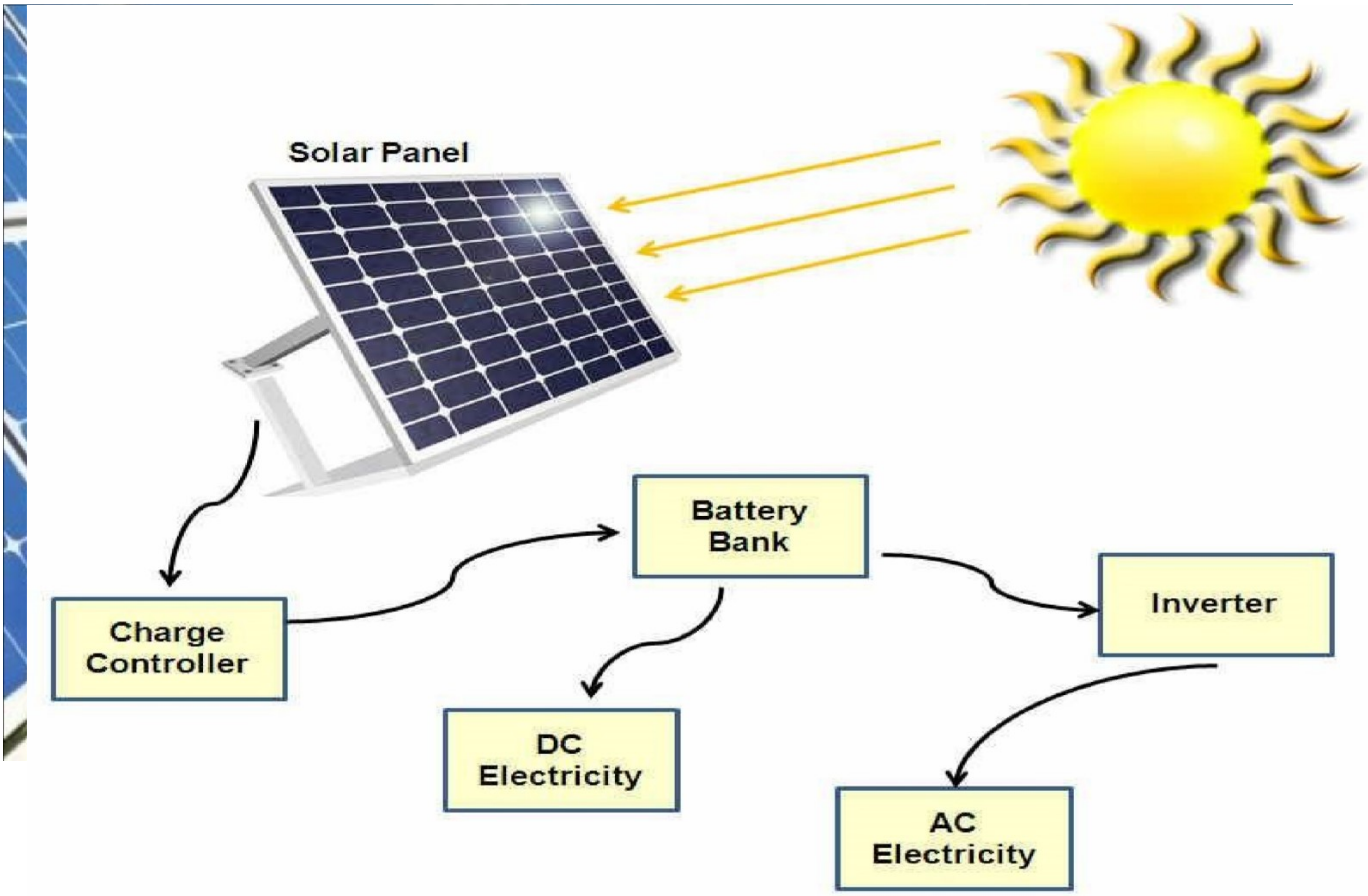


Figure 4.1

- Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis.
- Directly or indirectly, our sun provides all the power we need to exist and supports all life forms. The sun drives our climate and our weather. Without it, our world would be a frozen wasteland of ice covered rock.
- Solar electricity is a wonderful concept. Taking power from the sun and using it to power electrical equipment is a terrific idea. There are no ongoing electricity bills, no reliance on a power socket: a free and everlasting source of energy that does not harm the planet!
- It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable

thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

- The large magnitude of solar energy available makes it a highly appealing source of electricity. The United Nations Development Program in its 2000 World Energy Assessment found that the annual potential of solar energy was 1,575–49,837 exajoules (EJ). This is several times larger than the total world energy consumption, which was 559.8 EJ in 2012.
- In 2011, the International Energy Agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries' energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating global warming, and keep fossil fuel prices lower than otherwise. These advantages are global. Hence the additional costs of the incentives for early deployment should be considered learning investments; they must be wisely spent and need to be widely shared".

The source of solar power:-

- Deep in the center of the sun, intense nuclear activity generates huge amounts of radiation. In turn, this radiation generates light energy called photons. These photons have no physical mass of their own, but carry huge amounts of energy and momentum. Different photons carry different wavelengths of light. Some photons will carry nonvisible light (*infrared* and *ultra-violet*), whilst others will carry visible light (*white light*).
- Over time, these photons push out from the center of the sun. It can take one million years for a photon to push out to the surface from the core. Once they reach the sun's surface, these photons rush through space at a speed of 670 million miles per hour. They reach Earth in around eight minutes. On their journey from the sun to earth, photons can collide with and be deflected by other particles and are destroyed on contact with anything that can absorb radiation, generating heat.
- Our atmosphere absorbs many of these photons before they reach the surface of the earth. That is one of the two reasons that the sun feels so much hotter in the middle of the day. The sun is overhead and the photons have to travel through a thinner layer of atmosphere to reach us, compared to the end of the day when the sun is setting and the photons have to travel through a much thicker layer of the atmosphere.
- This is also one of the two reasons why a sunny day in winter is so much colder than a sunny day in summer. In winter, when your location on the earth is tilted away from the sun, the photons have to travel through a much thicker layer of atmosphere to reach us.

The principles of solar electricity:-

- Solar electricity refers to generating electrical power using photovoltaic solar panels. A solar panel generates electricity using the *photovoltaic effect*, a phenomenon discovered in the early 19th century when scientists observed that certain materials produced an electric current when exposed to light.
- Two layers of a semi-conducting material are combined to create this effect. One layer has to have a depleted number of electrons. When exposed to sunlight, the layers of material absorb the photons. This excites the electrons, causing some of them to 'jump' from one layer to the other, generating an electrical charge.
- The semi-conducting material used to build a solar cell is silicon, cut into very thin wafers.
- The wafers are then aligned together to make a solar cell.
- Conductive metal strips attached to the cells take the electrical current. When a photon hit the solar cell, it can do one of three things: it can be absorbed by the cell, reflected off the cell or pass straight through the cell.
- It is when a photon is absorbed by the silicon that an electrical current is generated. The more photons (i.e. the greater intensity of light) that are absorbed by the solar cell, the greater the current generated.
- Individual solar cells typically only generate tiny amounts of electrical energy. To make useful amounts of electricity, these cells are connected together to make a solar module, otherwise known as a solar panel or, to be more precise, a photovoltaic module.

Why choose a solar electric system?

There are a number of reasons to consider installing a solar electric system:

- Where there is no other source of electrical power available, or where the cost of installing conventional electrical power is too high
- Where other sources of electrical power are not reliable. For example, when power cuts are an issue and a solar system can act as a cost-effective contingency
- When a solar electric system is the most convenient and safest option. For example, installing low voltage solar lighting in a garden or providing courtesy lighting in a remote location
- You can become entirely self-sufficient with your own electrical power
- Once installed, solar power provides virtually free power without damaging the environment

Cost-justifying solar

Calculating the true cost of installing a solar electric system depends on various factors:

- The power of the sun at your location at different times of the year
- How much energy you need to generate
- How good your site is for capturing sunlight
- Compared to other power sources, solar electric systems typically have a comparatively high capital cost, but a low ongoing maintenance cost.
- To create a comparison with alternative power sources, you will often need to calculate a payback of costs over a period of a few years in order to justify the initial cost of a solar electric system.
- On all but the simplest of installations, you will need to carry out a survey on your site and carry out some of the design work before you can ascertain the total cost of installing a photovoltaic system.

In conclusion :-

- Solar electricity can be a great source of power where your power requirements are modest, there is no other source of electricity easily available and you have a good amount of sunshine.

- Solar panels absorb photons from sunlight to generate electricity.
- Direct sunlight generates the most electricity. Dull still, generate some power.

- Solar electricity is unlikely to generate enough electricity to power the average family home, unless major on buildings or mounted on the ground if economies in the household power requirements are made first.
- Larger solar electric systems have a comparatively high capital cost, but the ongoing maintenance costs are very low.
- Smaller solar electric system can actually be extremely cost-effective to buy and install, even when compared to a conventional electricity supply.
- It can be much cheaper using solar electricity at a remote building, rather than connecting it to a conventional grid electricity supply.

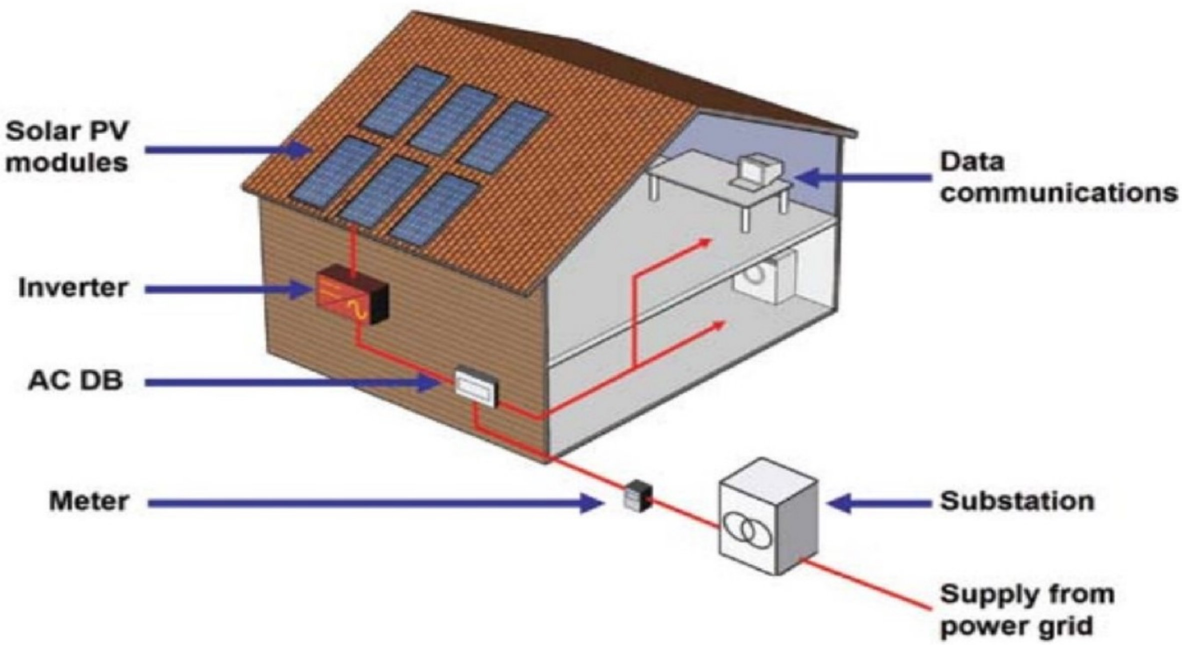
- Stand-alone solar energy systems can have a big environmental benefit if they negate the need for a connection to grid power.
- Grid-tie solar energy systems have an environmental benefit in sunny climates where typical electricity usage patterns are similar to the supply of sunlight.
- In colder regions, where electricity usage is highest when sunlight is in short supply, the environmental benefits are less certain.

Types of Solar PV System :-

- Solar PV systems can be classified based on the end-use application of the technology.
- There are two main types of solar PV systems: grid-connected (or grid-tied) and off-grid (or stand-alone) solar PV systems.

Grid-connected solar PV systems :-

The main application of solar PV in Singapore is grid-connected, as Singapore's main island is well covered by the national power grid. Most solar PV systems are installed on buildings or mounted on the ground if the land is not a constraint. For buildings, they are either mounted on the roof or integrated into the building. The latter is also known as Building Integrated Photovoltaics ("BIPV"). With BIPV, the PV module usually displaces another building component, e.g. window glass or roof/wall cladding, thereby serving a dual



purpose and offsetting some costs.

Grid-connected solar PV system configuration

Figure 4.2

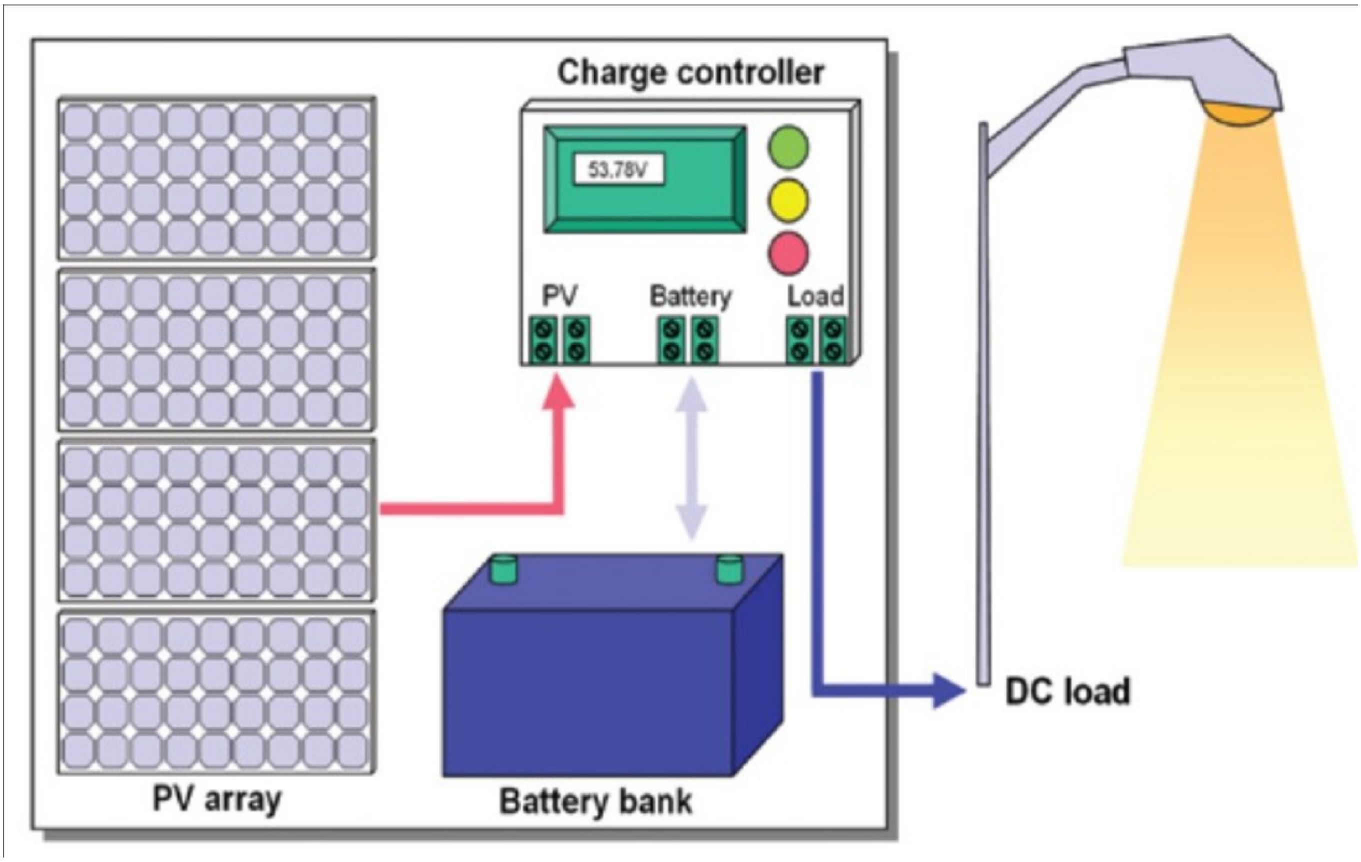
- A building has two parallel power supplies, one from the solar PV system and the other from the power grid. The combined power supply feeds all the loads connected to the main ACDB. The ratio of solar PV supply to power grid supply varies, depending on the size of the solar PV system.

- Whenever the solar PV supply exceeds the building's demand, excess electricity will be exported to the grid. When there is no sunlight to generate PV electricity at night, the power grid will supply all of the building's demand.

- A grid-connected system can be an effective way to reduce your dependence on utility power, increase renewable energy production and improve the environment.

Off-grid solar PV systems :-

- Off-grid solar PV systems are applicable for areas without the power grid. Currently, such solar PV systems are usually installed at isolated sites where the power grid is far away, such as rural areas or off-shore islands. But they may also be installed within the city in situations where it is inconvenient or too costly to tap electricity from the power grid.
- For example, in Singapore, several URA parking sign lights are powered by off-grid solar PV systems.
- An off-grid solar PV system needs deep cycle rechargeable batteries such as lead-acid, nickel-cadmium or lithium-ion batteries to store electricity for use under conditions where there is little or no output from the solar PV system, such as during the night, as shown in Figure below.



Off-grid solar PV system configuration
Figure 4.3

Solar PV Technology:-

- This section gives a brief description of the solar PV technology and the common technical terms used.

- A solar PV system is powered by many crystalline or thin film PV modules. Individual PV cells are interconnected to form a PV module. This takes the form of a panel for easy installation.

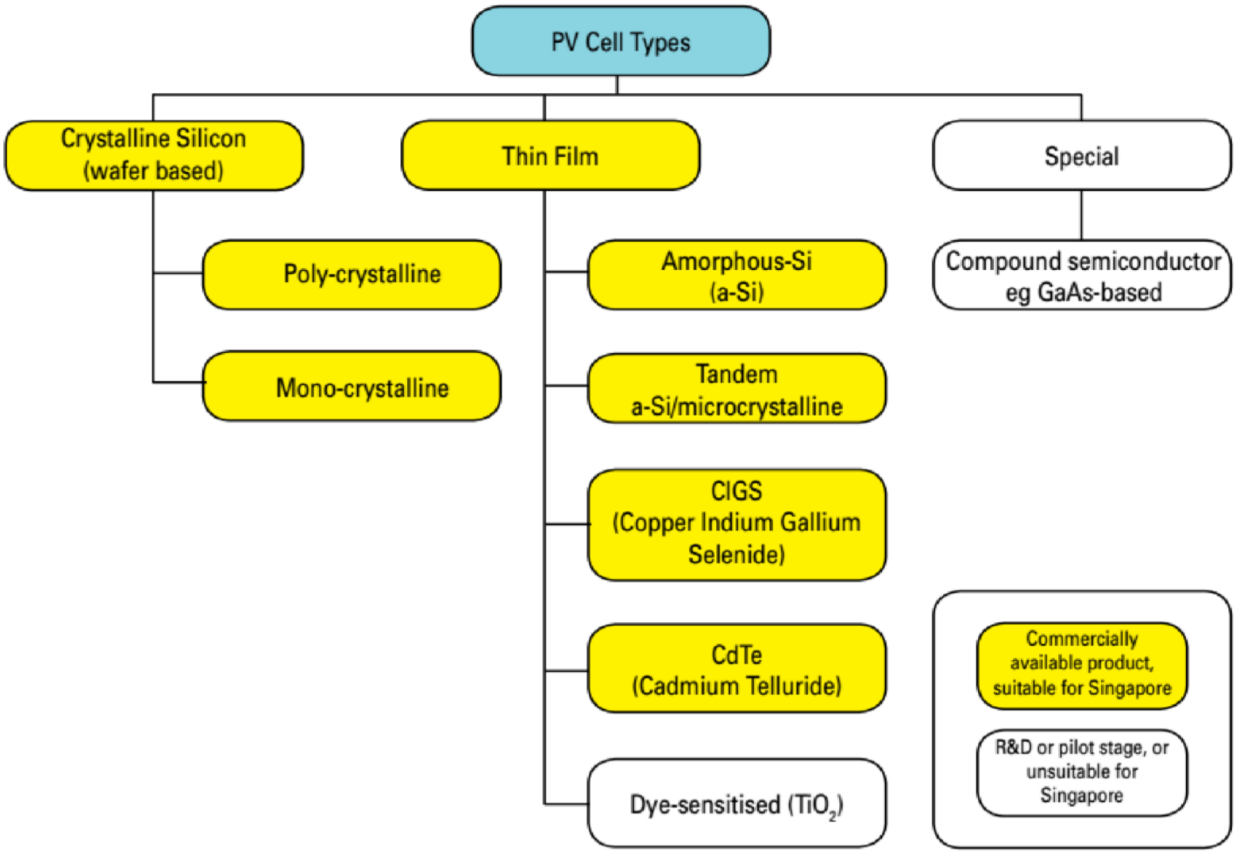
Mono-Crystalline Silicon PV Cell **Poly-Crystalline Silicon PV Cell**

Mono-and Poly-Crystalline Silicon PV Cell

Figure 4.4

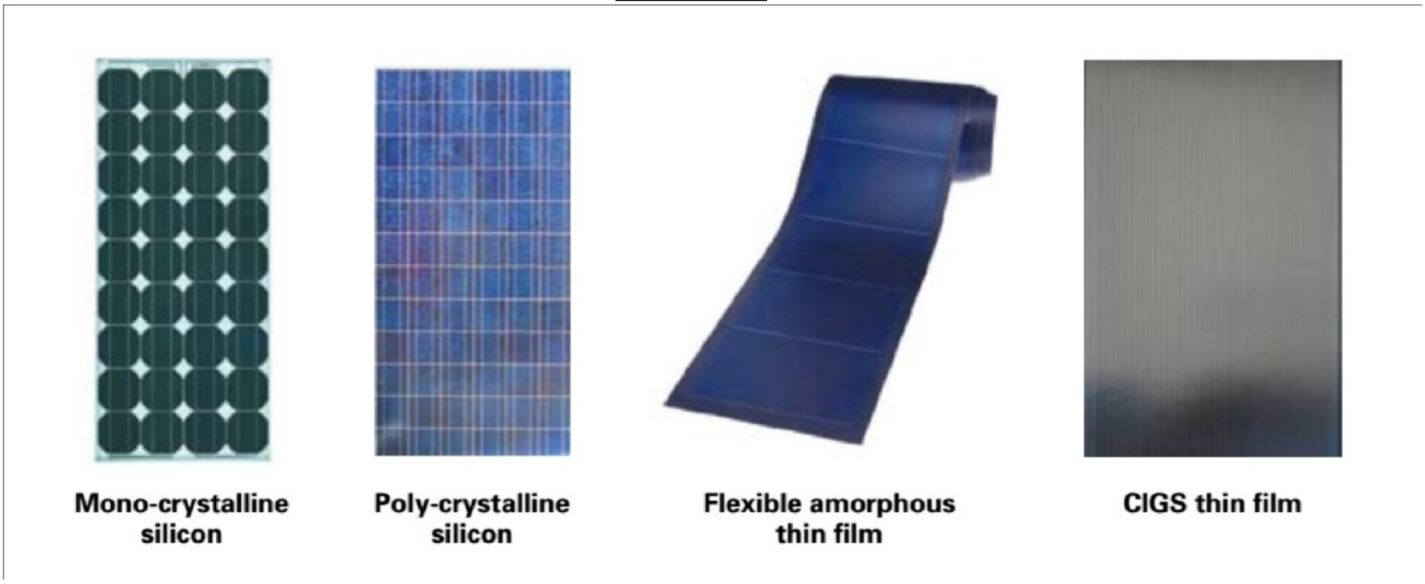
- PV cells are made of light-sensitive semiconductor materials that use photons to dislodge electrons to drive an electric current. There are two broad categories of technology used for PV cells, namely, crystalline silicon, as shown in Figure 4 which accounts for the majority of PV cell production; and thin film, which is newer and growing in popularity.

- The "family tree" in Figure below gives an overview of these technologies available today and Next Figure illustrates some of these technologies.



PV technology family tree

Figure 4.5



Common PV module technologies

Figure 4.6

Crystalline Silicon and Thin Film Technologies :-

- Crystalline cells are made from ultra-pure silicon raw material such as those used in semiconductor chips. They use silicon wafers that are typically 150-200 microns (onefifth of a millimeter) thick.
- Thin film is made by depositing layers of semiconductor material barely 0.3 to 2 micrometers thick onto glass or stainless-steel substrates. As the semiconductor layers are so thin, the costs of raw material are much lower than the capital equipment and processing costs.

Conversion Efficiency

Technology	Module efficiency
Mono-crystalline Silicon	12.5-15%
Poly-crystalline Silicon	11-14%
Copper Indium Gallium Selenide (CIGS)	10-13%
Cadmium Telluride (CdTe)	9-12%
Amorphous Silicon (a-Si)	5-7%

Conversion efficiencies of various PV module technologies

Table 4.1

- Apart from aesthetic differences, the most obvious difference amongst PV cell technologies are in its conversion efficiency, as summarized in Table 3.1

- For example, a thin film amorphous silicon PV array will need close to twice the space of a crystalline silicon PV array because its module efficiency is halved, for the same nominal capacity under Standard Test Conditions (STC) rating.

Types of Solar Cell

What Types of Solar Cells Are There?

Solar cells are more complex than many people think, and it is not common knowledge that there are various different types of cell. When we take a closer look at the different types of solar cell available, it makes things simpler, both in terms of understanding them and also choosing the one that suits you best.

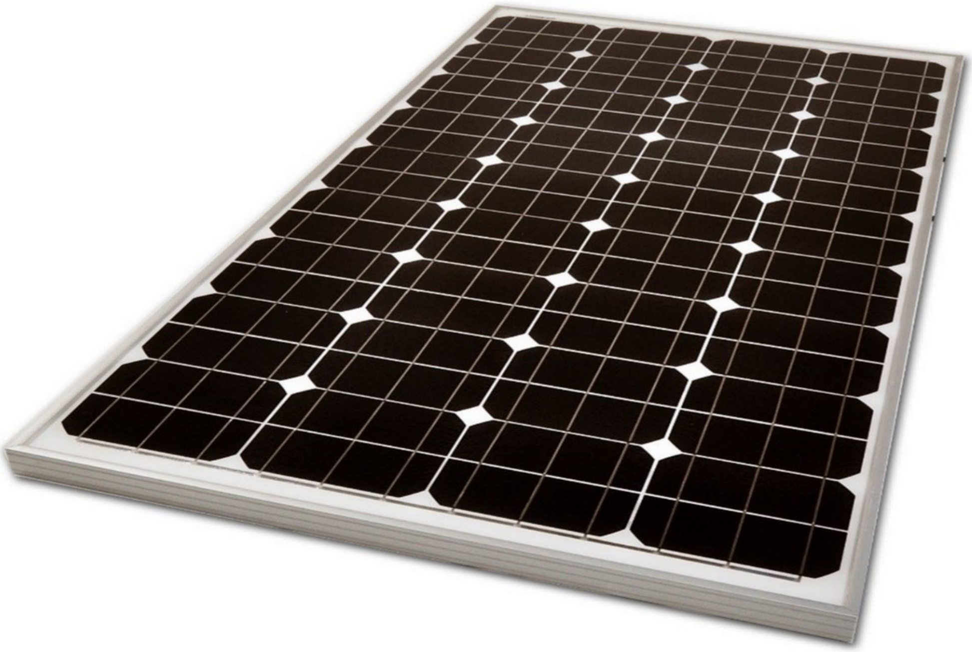
The available types :-

- Crystalline silicon cells
- Monocrystalline cells
- Polycrystalline cells
- Thin film solar cells

- Presently, around 90% of the world's photo voltaics are based on some variation of silicon, and around the same percentage of the domestic solar panel, systems use the crystalline silicon cells. Crystalline silicon cells also form the basis for mono and polycrystalline cells.
- The silicon that is in solar cells can take many different forms. However, the thing that matters most is the purity of the silicon. This is because it directly affects its efficiency. What purity means, in this case, is the way in which the silicon molecules have been aligned. The better the alignment, the purer the resulting silicon is. This, ultimately, leads to better conversion rates of sunlight into electricity.
- As previously mentioned, the levels of efficiency work alongside the purity of the silicon molecules – and purity can be quite a costly aspect to upgrade. However, it may come as a surprise to learn that efficiency is not the driving force for people who want to invest in solar energy. The cost and the amount of space it takes up tend to be the most important aspects to potential buyers.

Monocrystalline solar cells

Monocrystalline solar cells are made from single crystalline silicon. They are very distinctive in their appearance as they are often colored, and the cells hold a cylindrical shape. In order to keep the costs low and performance at optimal levels, manufacturers cut out the four sides of the monocrystalline cells. This gives them their recognizable appearance.



Monocrystalline Cells

Figure 4.7

Advantages:-

- They have the highest level of efficiency at 15-20%
- They require less space compared to other types due to their high efficiency
- Manufacturers state that this form of solar cell lasts the longest, with most giving them a 25-year warranty
- They perform better in low levels of sunlight, making them ideal for cloudy areas

Disadvantages:-

- They are the most expensive solar cells on the market, and so not in everyone's price range
- The performance levels tend to suffer from an increase in temperature. However, it is a small loss when compared to other forms of solar cell
- There is a lot of waste material when the silicon is cut during manufacture

Polycrystalline Solar Cells:-

The polycrystalline solar panels were first introduced to the public in 1981. Unlike the monocrystalline cells, polycrystalline ones do not require each of the four sides to be cut. Instead, the silicon is melted and poured into square modules. These then form perfectly shaped square cells.

Polycrystalline Cells

Figure 4.8

Advantages:-

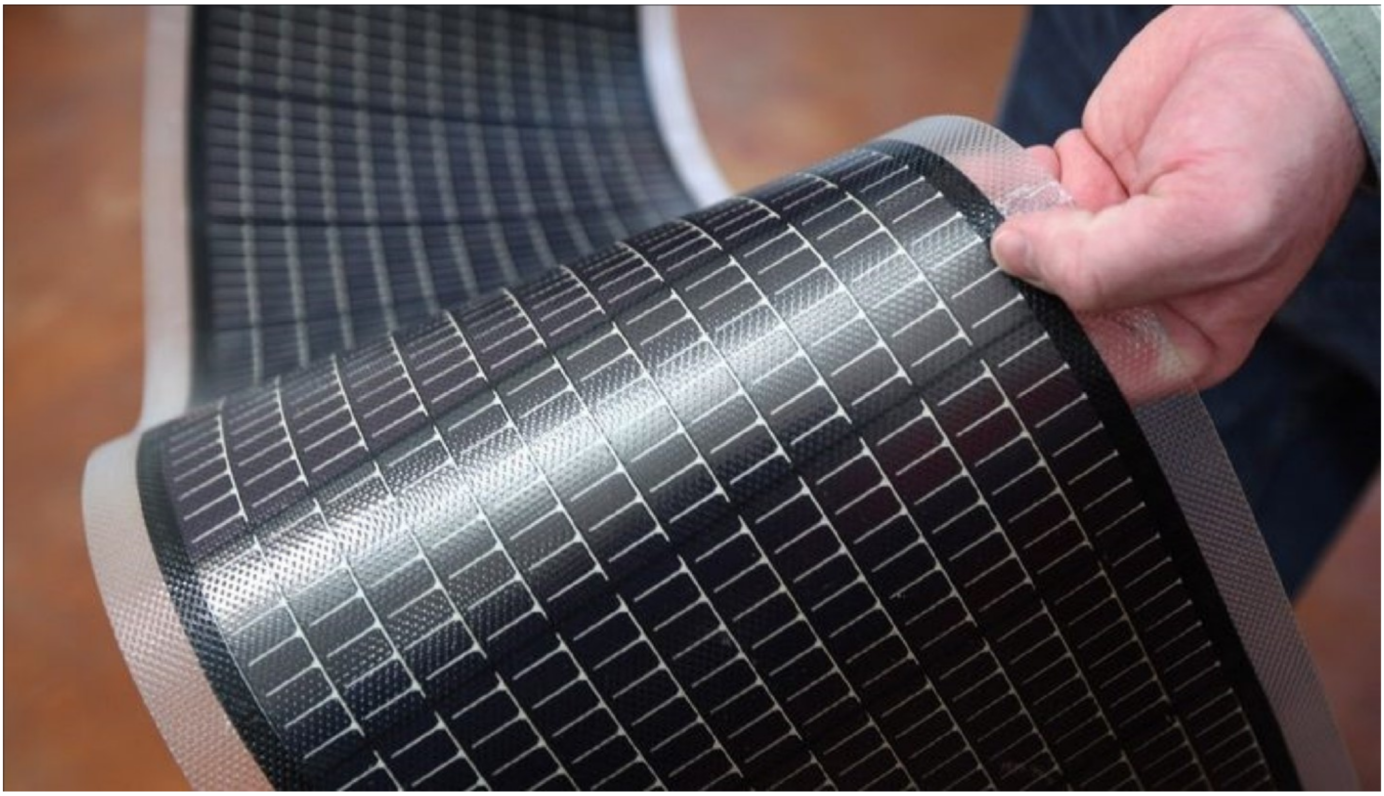
- The manufacturing process is cheaper and easier than the monocrystalline.
- It avoids silicon waste.
- High temperatures have less negative effects on efficiency compared with monocrystalline cells. This makes the polycrystalline cells more attractive to people in warmer areas as the price is lower.

Disadvantages:-

- Efficiency is only around 13-16% due to low levels of silicon purity. So they are not the most efficient on the market.
- They have lower output rates which make them less space efficient. So more roof space is needed for installation.

Thin Film Solar Cells:-

Thin film solar cells are manufactured by placing several thin layers of photovoltaic on top of each other to creates the module. There are actually a few different types of thin film solar cell, and the way in which they differ from each other comes down to the material used for the PV layers.



Thin Film Cells
Figure 4.9

The types are as follows:-

- Amorphous silicon
- Cadmium telluride
- Copper indium gallium selenide
- Organic PV cells

Depending on the technology that has been used, the efficiency rates for thin film solar cells tends to vary from 7% to 13%. Since 2002, the knowledge levels and popularity for thin film solar cells has risen dramatically, which also means that research and development have been increased. Due to this, we can expect future models to hold efficiency rates of 10-16%.

Advantages:-

- They can be manufactured to be flexible, making them widely applicable to a range of situations and building types
- Mass production is easy to achieve, making them potentially cheaper to produce than crystalline solar cells
- Shading has a similar effect on their efficiency

Disadvantages:-

- They are not ideal for domestic use as thy take up a lot of space
- Low space efficiency means that they will cause further expenses in the form of enhancers, like cables of support structures
- They have a shorter lifespan and so shorter warranty periods.

Finding Your Ideal Solar Cell Type:-

- Having now presented each type of the most commonly found forms of the solar cell, including their various strengths and weaknesses, the decision process can be made a lot easier. Of course, you need to take several factors into consideration. Things like the cost, the amount of space required for installation, and the efficiency rates to name a few.
- Monocrystalline cells are arguably the best option. This is because they have the highest output rates and require a lot less space. However, it is important to remember that in many cases you may not need monocrystalline cells.
- The best thing to do is to get advice from the supplier and talk through the option with them. They can help you and give you the best solution for your situation.

How does this affect me?

The type of solar panel array you can install will depend on the size of your property, the angle of your roof and the direction it points in, as well as the affordability of the core solar panel materials

The Design Process:-

No matter what your solar energy system is for, there are seven steps in the design of every successful solar electric installation:

- Scope the project
- Calculate the amount of energy you need
- Calculate the amount of solar energy available
- Survey your site
- Size up the solar electric system
- Select the right components and work out full costs
- Produce the detailed design

The design process can be made more complicated, or simplified, based on the size of the project.

- This ensures that you will always get the best from your system

- If you are designing a grid-tie system, it can be interesting to compare the supply of solar energy with your electricity usage pattern.
- By comparing supply with demand, you can see how closely solar energy production matches your own usage and this, in turn, can be used as an indicator to identify how environmentally beneficial solar energy is for you.

- Batteries do not return 100% of the energy used to charge them. The *Charge Cycle Efficiency* of the battery measures the percentage of energy available from the battery compared to the amount of energy used to charge it.

Charge cycle efficiency :-

It is not a fixed figure, as the efficiency can vary depending on how quickly you charge and discharge the battery.

Approximate charge cycle efficiency figures are normally available from the battery manufacturers. However, for industrial quality 'traction' batteries, you can assume 95% efficiency, whilst gel batteries and leisure batteries are usually in the region of 90%.

Positioning batteries, controllers and inverters:-

It's required to identify a suitable location for batteries. This could be a room within a building, in a garage or in a weatherproof battery housing.

It is important to try to keep all the hardware close together, in order to keep the cable lengths as short as possible. By 'hardware', I am referring to the solar array itself, batteries, controller and inverter.

For the batteries, inverter and controller, you are looking for a location that fits the following criteria:

- Water- and weather proof
- Not affected by direct sunlight
- Insulated to protect against extremes of temperature
- Facilities to ventilate gases from the batteries
- Protected from sources of ignition
- Away from children, pets and rodents

Lead acid batteries give off very small quantities of hydrogen when charging. Hydrogen is explosive.

- You must ensure that, wherever your batteries are stored, the area receives adequate external ventilation to ensure these gases cannot build up.

- Because of the extremely high potential currents involved with lead acid batteries, the batteries must be in a secure area away from children and pets.

- Controllers and inverters need to be mounted as close to the batteries as possible.

The Inverter:

- The electricity generated by a solar electric system is direct current (DC). Electricity from the grid is high-voltage alternating current (AC).

- If you are planning to run equipment that runs from grid-voltage electricity from your solar electric system, you will need an inverter to convert the current from DC to AC and convert the voltage to the same voltage as you get from the grid.

- A more recent invention has been the micro inverter.

- Micro-inverters are connected to individual solar panels so that each individual panel provides a high-voltage alternating current.

- Solar panels with micro-inverters are typically only used with grid-tie systems and are not suitable for systems with battery backup. For grid-tie systems, they do offer some significant benefits over the more traditional ‘big box’ inverter, although the up-front cost is currently higher.

- The inverter is protected against overload and short-circuit. A power stage with the

- A load detection system serves to provide the smallest energy consumption and ensures a long life for the battery.

- If there is an inverter in the system, we will need to factor in the inefficiencies of the inverter. The actual figures should be available from the manufacturer but typically, you will find that an inverter is around 90% efficient.

Charge Controller:

- If you are using batteries, your solar electric system is going to require a controller in order to manage the flow of electricity (the current) into and out of the battery.

- If your system overcharges the batteries, this will damage and eventually destroy them. Likewise, if your system completely discharges the batteries, this will quite rapidly destroy them. A solar controller prevents this from happening.

- There are a few instances where a small solar electric system does not require a controller. An example of this is a small ‘battery top-up’ solar panel that is used to keep a car battery in peak condition when the car is not being used. These solar panels are too small to damage the battery when the battery is fully charged.

- In the majority of instances, however, a solar electric system will require a controller in order to manage the charge and discharge of batteries and keep them in good condition.

The Battery charger:

The built-in battery charger is capable of charging the batteries quickly and completely. A microprocessor controlled, 3 to 4 Step charging process ensures the optimum charging of the batteries.

- The desired charging current can be set.
- The battery charger can be used for lead-acid or gel batteries.

Thanks to the floating charge ability of your Solar Inverter, the batteries can remain continuously connected.

Battery Connections:

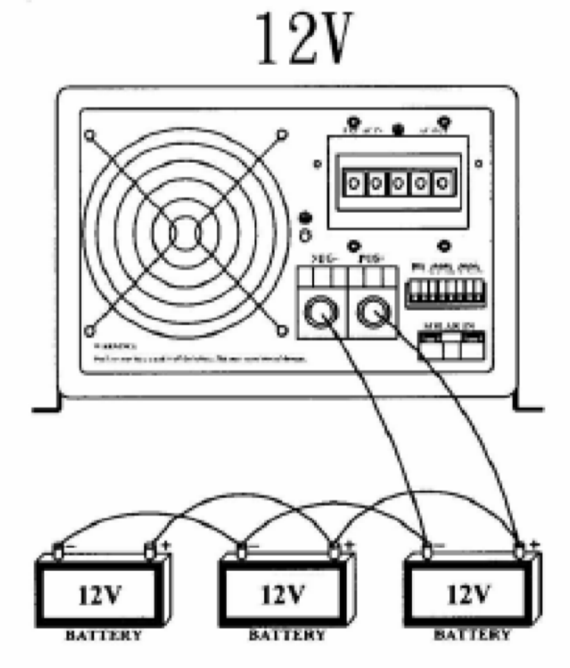
- Lead acid batteries usually come as either 6-volt or 12-volt batteries, although other voltages are also available. Batteries can be connected together in series to increase the voltage, or in parallel to keep the same voltage but increase the capacity.

- The capacity of a battery is measured in amp-hours. The amp hour rating shows how many hours the battery will take a specific drain: for instance, a 100-amp-hour battery has a theoretical capacity to power a 1-amp device for 100 hours, or a 100-amp device for 1 hour.

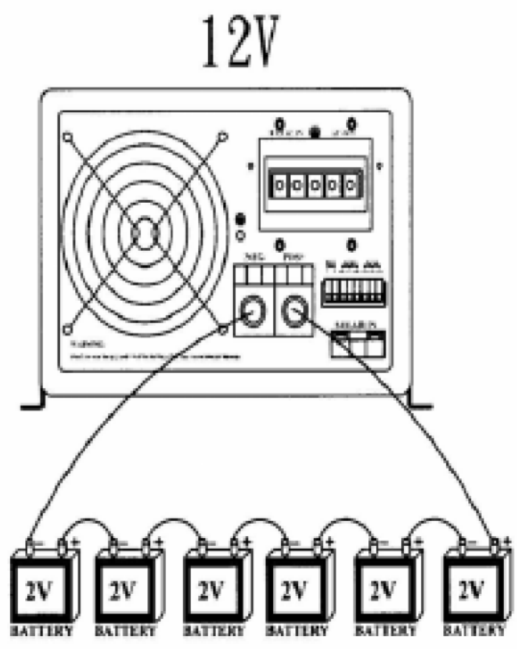
- The reality is that lead acid batteries provide more energy when discharged slowly: a 100-amp-hour battery will often provide 20–25% less power if discharged over a five-hour period, compared to discharge over a twenty-hour period. Secondly, a lead acid battery must not be run completely flat. A minimum of 20% state of charge (SOC) should be maintained in a lead acid battery at all times to ensure the battery is not damaged.

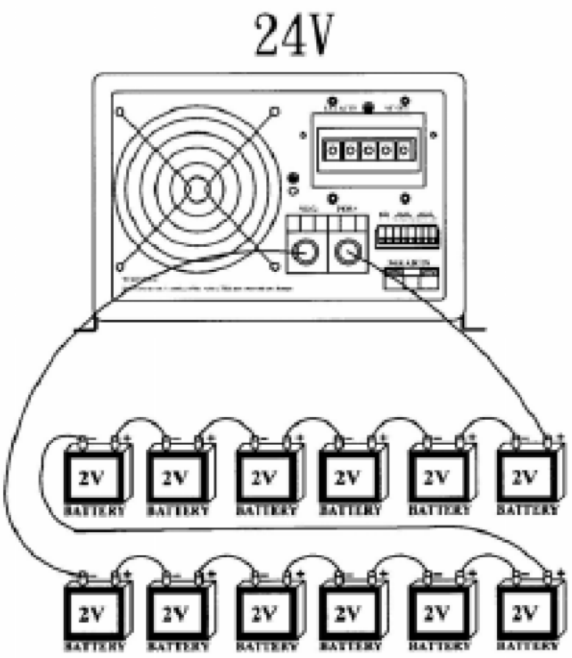
- For best overall battery life, you should design your system so that the battery charge rarely goes below 50%.

C.2.1 Parallel Connection:



C.2.2 Series Connection:





Battery Connections

Figure 4.10

Types of batteries:-

There are three types of lead acid battery:

1) **'Wet' batteries** require checking and topping up with distilled water, but perform better and have a longer lifespan than other batteries.

2) **AGM batteries** require no maintenance but have a shorter overall life.

3) **Gel batteries** are also maintenance-free, do not emit hydrogen during charging and provide a reasonable overall life. They can be placed on their side or used on the move.

- In the past, most installers have recommended industrial quality **'wet' batteries** for all solar installations. These provide the best long-term performance and the lowest cost. Often called *traction* batteries (as they are heavy-duty batteries used in electric vehicles), they can often have a lifespan of 8–10 years for a solar installation.

- A lower cost option to the industrial-quality traction battery is **the leisure battery**, as used in caravans and boats. These are typically either wet batteries or AGM batteries. Their lifespan is considerably shorter than traction batteries, often requiring replacement after 3–4 years and significantly less in intensive applications.

- The third option is **the gel battery;** These have the benefit of being entirely maintenance-free. They are also completely sealed and do not emit hydrogen gas. In the past, gel batteries have not been particularly reliable in solar installations, tending to require replacement after 1–2 years.
- However, more recently, smaller gel batteries have seen significant improvements in lifespan and they now are comparable to AGM batteries. The price has also dropped significantly.

- **Gel batteries** are not suitable for big solar applications with a power drain of more than around 400 watthours, but they can provide an excellent, zero-maintenance alternative to wet batteries for smaller applications.

- If your solar project requires batteries of 50 amp-hour capacity or less, gel batteries are a very good alternative to traction batteries.

- Not all battery makes are the same. From experience, the very best battery manufacturers for solar energy installations are Crown and Trojan, both of whom have excellent batteries specifically designed for solar installations.

- Lead-acid batteries are normally available in blocks of 2V, 6V or 12V. In most cases, to generate the necessary operating voltage and the capacity of the 8 batteries for the Solar Inverter, many batteries have to be connected together in parallel and/or in series.

- Unlike solar panels, which you can mix and match to create your array, you need to use the same specification and size of batteries to make up your battery bank. Mixing battery capacities and types will mean that some batteries will never get fully charged and some batteries will get discharged more than they should be. As a result, mixing battery capacities and types can significantly shorten the lifespan of the entire battery bank.

Chapter 5

RO Design

Reverse Osmosis Performance & Design Calculations

There are a handful of calculations that are used to judge the performance of an RO system and also for design considerations. An RO system has instrumentation that displays quality, flow, pressure and sometimes other data like temperature or hours of operation. In order to accurately measure the performance of an RO system you need the following operation parameters at a minimum:

1. Feed pressure
2. Permeate pressure
3. Concentrate pressure
4. Feed conductivity
5. Permeate conductivity
6. Feed flow
7. Permeate flow
8. Temperature

Salt Rejection %

This equation tells you how effective the RO membranes are removing contaminants. It does not tell you how each individual membrane is performing, but rather how the system overall on average is performing. A well---designed RO system with properly functioning RO membranes will reject 95% to 99% of most feed water contaminants (that are of a certain size and charge). You can determine effective the RO membranes are removing contaminants by using the following equation:

$$\text{Salt Rejection \%} = \frac{\text{Conductivity of Feed Water} - \text{Conductivity of Permeate Water}}{\text{Conductivity of Feed}} * 100$$

The higher the salt rejection, the better the system is performing. A low salt rejection can mean that the membranes require cleaning or replacement.

Salt Passage %

This is simply the inverse of salt rejection described in the previous equation. This is the amount of salts expressed as a percentage that are passing through the RO system. The lower the salt passage, the better the system is performing. A high salt passage can mean that the membranes require cleaning or replacement.

$$\text{Salt Passage \%} = (1 - \text{Salt Rejection\%})$$

Recovery %

Percent Recovery is the amount of water that is being 'recovered' as good permeate water. Another way to think of Percent Recovery is the amount of water that is not sent to drain as concentrate, but rather collected as permeate or product water. The higher the recovery % means that you are sending less water to drain as concentrate and saving more permeate water. However, if the recovery % is too high for the RO design then it can lead to larger problems due to scaling and fouling. The % Recovery for an RO system is established with the help of design software taking into consideration numerous factors such as feed water chemistry and RO pre---treatment before the RO system. Therefore, the proper % Recovery at which an RO should operate at depends on what it was designed for. By calculating the % Recovery you can quickly determine if the system is operating outside of the intended design. The calculation for % Recovery is below:

$$\%\ \text{Recovery} = \frac{\text{Permeate Flow Rate (gpm)}}{Feed\ Flow\ Rate\ (gpm)} * 100$$

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.

Concentration Factor = (1 / (1- Recovery %)

- The concept is no different than that of a boiler or cooling tower. They both have purified water exiting the system (steam) and end up leaving a concentrated solution behind. As the degree of concentration increases, the solubility limits may be exceeded and precipitate on the surface of the equipment as scale.
- For example, if your feed flow is 100 gpm and your permeate flow is 75 gpm, then the recovery is (75/100) x 100 = 75%. To find the concentration factor, the formula would be 1 ÷ (1---75%) = 4.

- 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.

Flux

$$\mathbf{Gfd} = \frac{\text{gpm of permeate} * 1{,}440\ (\frac{\text{min}}{\text{day}})}{\#\ of\ RO\ elements\ in\ system * square\ footage\ of\ each\ RO\ element}$$

For 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.
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.

To find the flux (Gfd):

$$\mathbf{Gfd} = \frac{75\ \text{gpm x}\ 1{,}440\ \text{min/day}}{18\ \text{elements x}\ 365\ \text{sq ft}}$$

$$= \frac{108{,}000}{6{,}570} = 16$$

so, The flux is 16 Gfd.

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. Below is a general rule of thumb for flux ranges for different source waters and can be better determined with the help of RO design software. If you had used Dow Filmtec LE---440i RO membranes in the above example, then the flux would have been 14. So it is important to factor in what type of membrane is used and to try and keep the type of membrane consistent throughout the system.

Table 5.1

Feed Water Source	Gfd
• Sewage Effluent	5-10
• Sea Water	8-12
• Brackish Surface Water	10_14
• Brackish Well Water	14-18
• RO Permeate Water	20-30

Mass Balance

A Mass Balance equation is used to help determine if your flow and quality instrumentation is reading properly or requires calibration. If your instrumentation is not reading correctly, then the performance data trending that you are collecting is useless.

You will need to collect the following data from an RO system to perform a Mass Balance calculation:

1. Feed Flow (gpm)
2. Permeate Flow (gpm)
3. Concentrate Flow (gpm)
4. Feed Conductivity (µS)
5. Permeate Conductivity (µS)
6. Concentrate Conductivity (µS)

The mass balance equation is:

$$\textbf{Feed flow x Feed Conductivity} = (\textbf{Permeate Flow x Permeate Conductivity}) + (\textbf{Concentrate Flow} * \textbf{Concentrate Conductivity})$$

Feed Flow = Permeate Flow + Concentrate Flow

For example,
if you collected the following data from an RO system:

• Permeate Flow	5gpm
• Feed Conductivity	500µS
• Permeate Conductivity	10 µS
• Concentrate Flow	2 gpm
• Concentrate Conductivity	1200µS

Then the Mass Balance Equation would be:
(7 x 500) = (5 x 10) + (2*1200)

3,500 = 2,450 Then find the difference:

$$\frac{\textbf{Difference}}{\textbf{Sum}} *100 = \frac{3500 - 2450}{3500 - 2450} *100 = 18\%$$

A difference of +/- 5% is ok. A difference of +/- 5% to 10% is generally adequate. A difference of > +/- 10% is unacceptable and calibration of the RO instrumentation is required to ensure that you are collecting useful data.

In the example above, the RO mass balance equation falls out of range and requires attention.

Main components of a membrane system

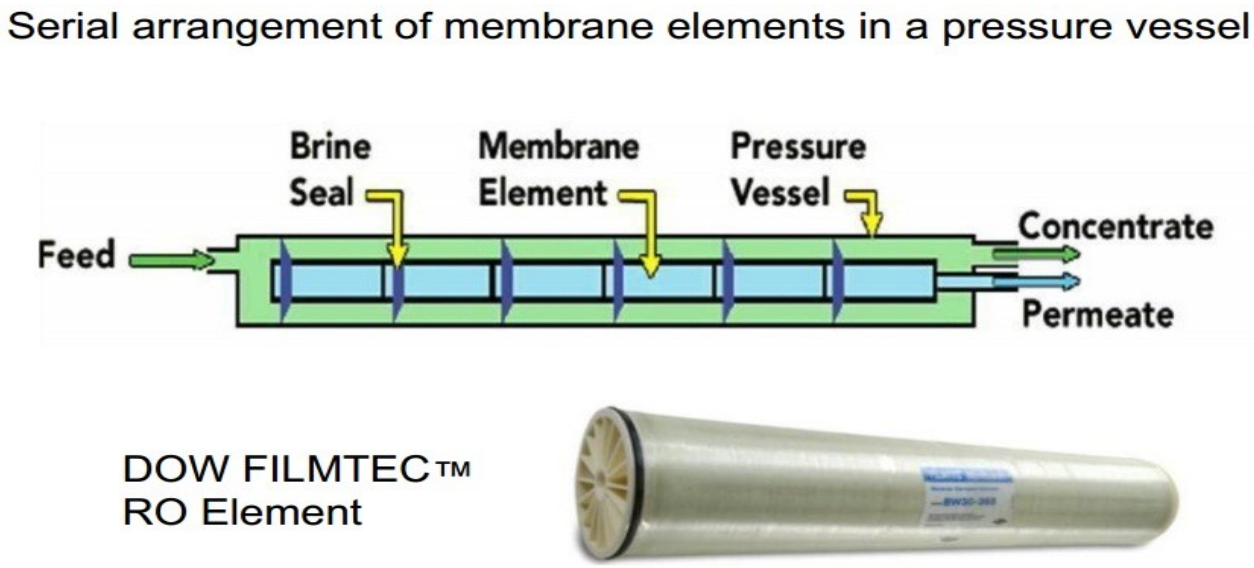


Figure 5.1

System Configuration Types

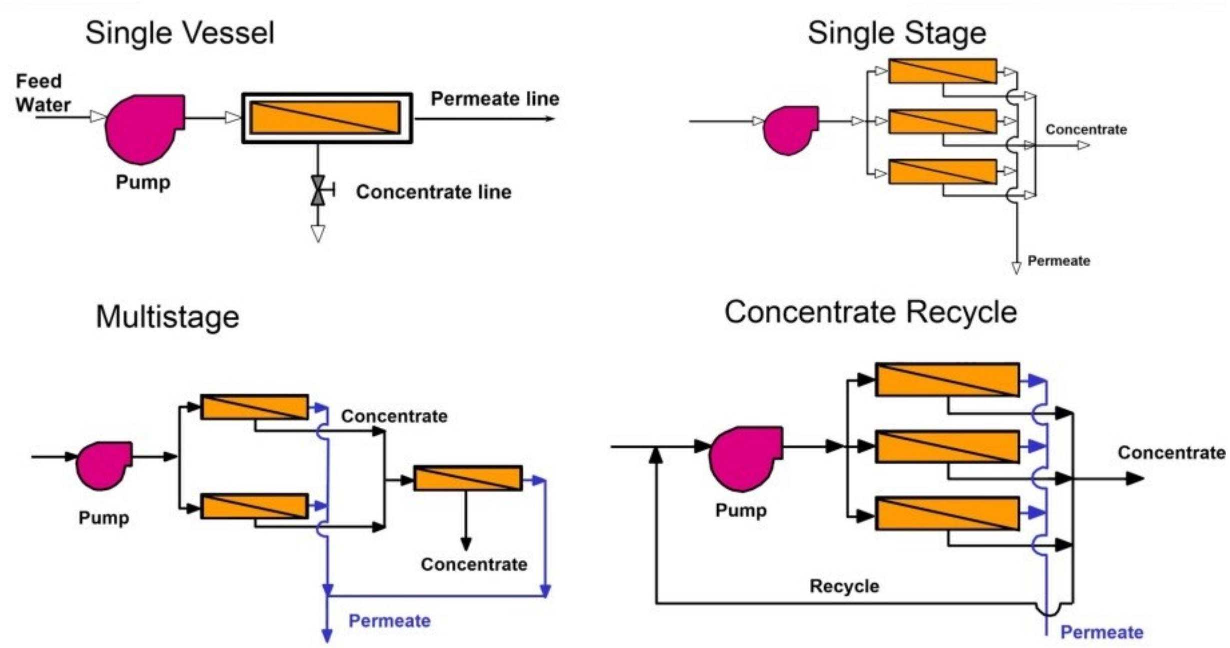


Figure 5.2

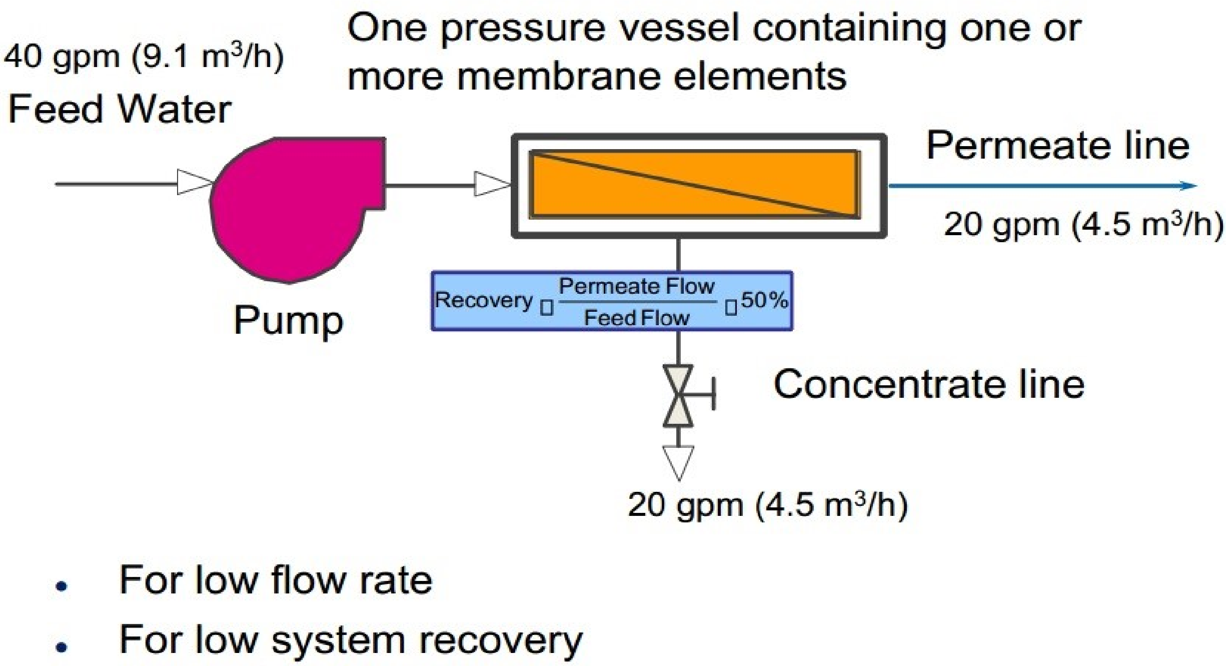


Figure 5.3

Configuration- single vessel system

Configuration- single stage system

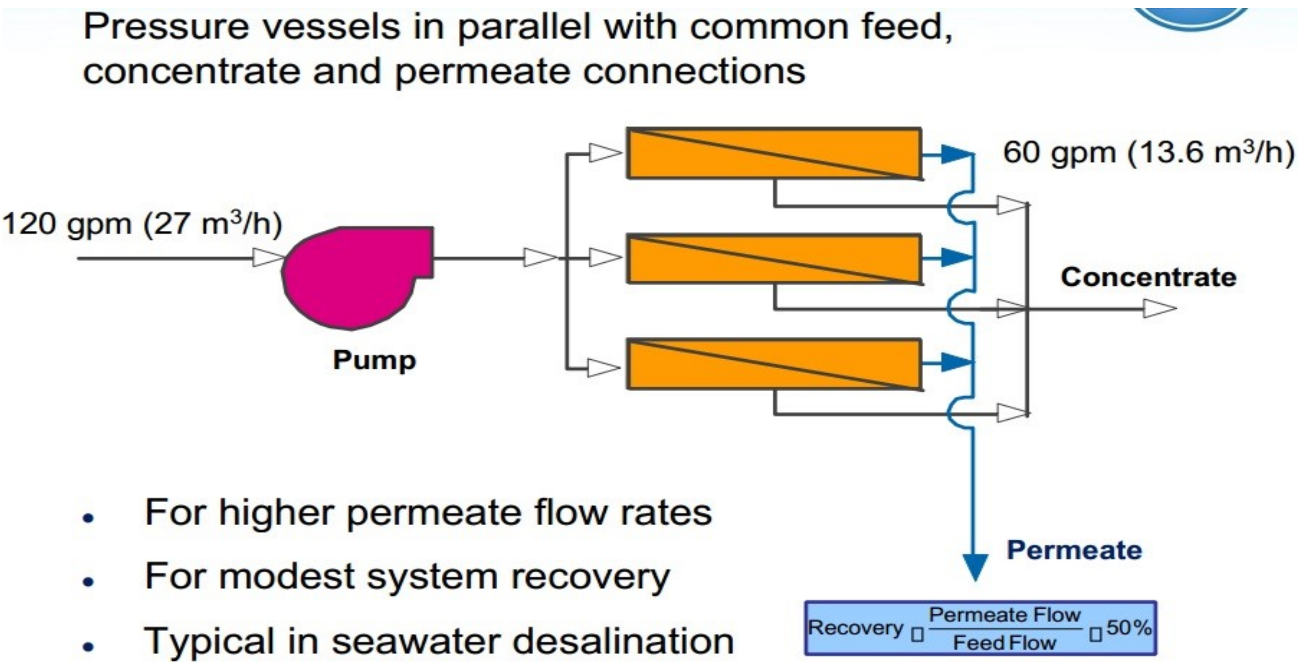
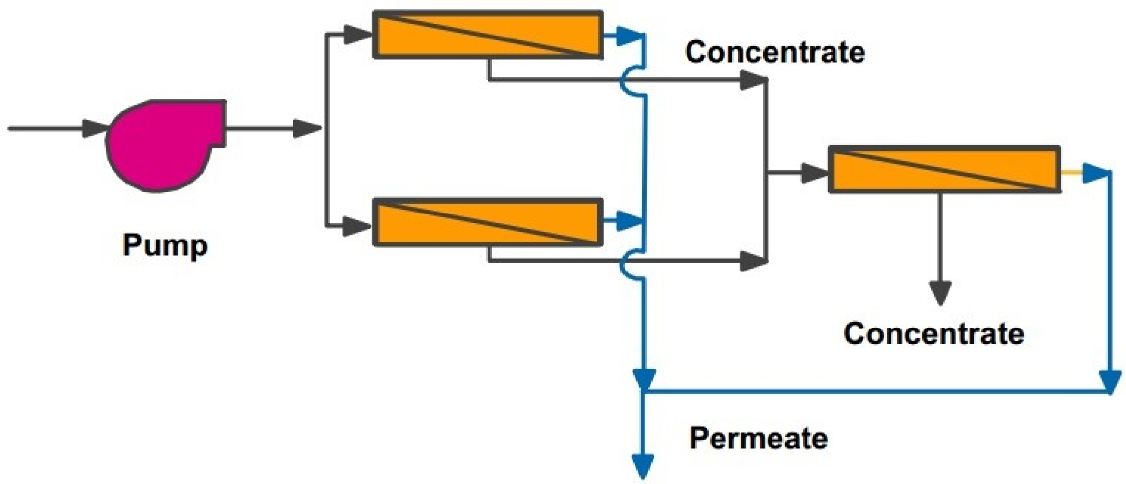


Figure 5.4

Configuration- multi-stage system

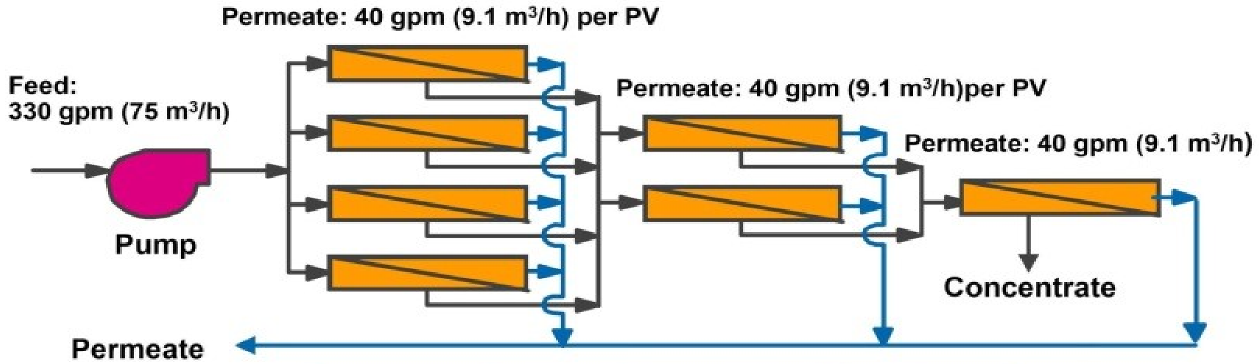
Two-stage system



- Use for higher recovery
- Typical 75% recovery with 6-element vessels

Figure 5.5

Three-stage system



$$\text{Recovery} = \frac{\text{Permeate Flow}}{\text{Feed Flow}} = \frac{160+80+40}{330} > 85\%$$

- Use for higher recovery
- Typical 85% recovery with 6-elements vessels
- Up to 90% depending on the feed water quality

Figure 5.6

Configuration – concentrate recycle

- Way to increase recovery by re-circulating reject to increase feed flow
- Typical for special / waste water applications
- Typical for single vessel systems

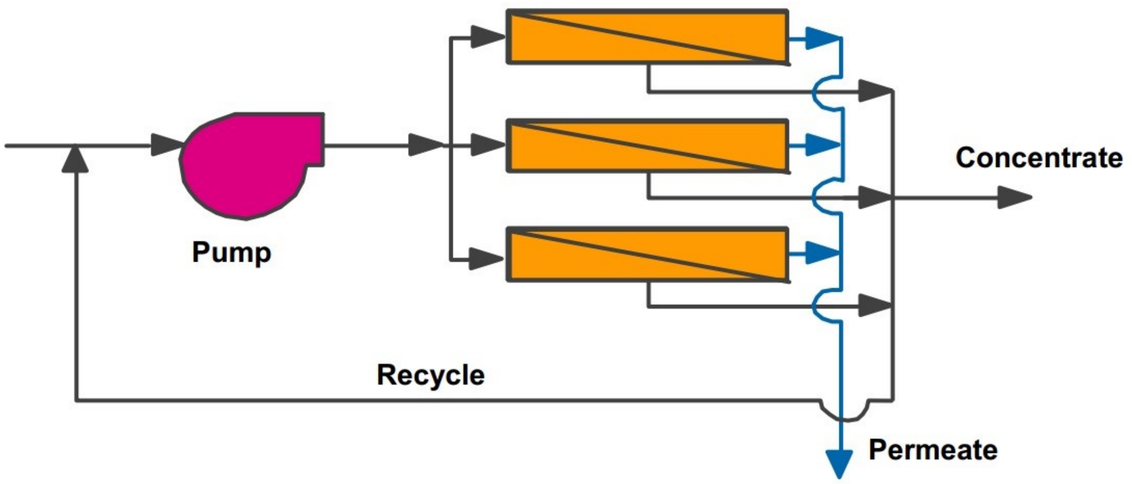


Figure 5.7

System Design Guidelines

Design guidelines for 8-Inch FILMTEC elements

	RO permeate	Well Water	Surface Water			Wastewater			Seawater		
			Dow UF	UF/MF[1]	Conventional	Dow UF	UF/MF[1]	Conventional	Dow UF	UF/MF[1] or Well	Open Intake
SDI	<1	<3	<2.5	<3	<5	<2.5	<3	<5	<2.5	<3	<5
Average flux (gfd)	21-25	16-20	16-20	13-17	12-16	11-15	10-14	8-12	9-11	8-10	7-10
Average flux (L/m²h)	36-43	27-34	27-34	22-29	20-27	18-26	17-24	14-20	15-18	13-20	11-17
Maximum element recovery (%)	30	19	19	17	15	14	13	12	15	14	13

Table 5.2

Maximum permeate flow rate per element

	RO permeate	Well Water	Surface Water			Wastewater			Seawater		
			Dow UF	UF/MF[1]	Conventional	Dow UF	UF/MF[1]	Conventional	Dow UF	UF/MF[1] or Well	Open Intake
SDI	<1	<3	<2.5	<3	<5	<2.5	<3	<5	<2.5	<3	<5
Active Membrane Area (ft^2)	Maximum permeate flow rate, gpd (m^3/d)										
365	10.200 (38)	8.500 (32)	8.500 (32)	7.200 (27)	6.600 (25)	6.300 (24)	5.900 (22)	5.200 (20)	X	X	X
380	10.700 (40)	8.900 (34)	8.900 (34)	7.500 (28)	6.900 (26)	6.500 (25)	6.000 (23)	5.200 (20)	7.900 (30)	7.600 (29)	7.200 (27)
400	11.200 (42)	9.300 (35)	9.300 (35)	7.900 (30)	7.300 (28)	6.800 (26)	6.400 (24)	5.700 (22)	8.400 (32)	8.000 (30)	7.600 (29)
440	12.300 (47)	10.300 (39)	10.300 (39)	8.700 (33)	8.000 (30)	7.600 (29)	7.100 (27)	6.300 (24)	9.200 (35)	8.800 (33)	8.360 (32)

Table 5.3

Minimum concentrate flow rate per element

	RO permeate	Well Water	Surface Water			Wastewater			Seawater		
			Dow UF	UF/MF[1]	Conventional	Dow UF	UF/MF[1]	Conventional	Dow UF	UF/MF[1] or Well	Conventional
SDI	<1	<3	<2.5	<3	<5	<2.5	<3	<5	<3		<5
Element type	Minimum concentrate flow rate[2], gpm (m^3/h)										
Brackish water (365 ft^2)	10 (2.3)	13 (3.0)	13 (3.0)	13 (3.0)	15 (3.4)	16 (3.6)	16 (3.6)	18 (4.1)	X	X	X
Brackish water (400-440 ft^2)	10 (2.3)	13 (3.0)	13 (3.0)	13 (3.0)	15 (3.4)	18 (4.1)	18 (4.1)	20 (4.6)	X	X	X
NF	10 (2.3)	13 (3.0)	13 (3.0)	13 (3.0)	15 (3.4)	18 (4.1)	18 (4.1)	18 (4.1)	X	X	X
Sea water	10 (2.3)	13 (3.0)	13 (3.0)	13 (3.0)	15 (3.4)	16 (3.6)	16 (3.6)	18 (4.1)	13 (3.0)	14 (3.2)	15 (3.4)

Table 5.4

Maximum feed flow

		RO Permeate	Well Water	Surface Water			Wastewater			Seawater		
				Dow UF	UF/MF[1]	Conventional	Dow UF	UF/MF[1]	Conventional	Dow UF	UF/MF[1] or Well	Conventional
SDI		<1	<3	<2.5	<3	<5	<2.5	<3	<5	<2.5	<3	<5
Element type	Area (ft^2)	Maximum feed flow rate, gpm (m^3/h)										
Brackish water	365 (33.9)	65 (15)	65 (15)	63 (14)	63 (14)	58 (13)	52 (12)	52 (12)	52 (12)			
NF or Brackish water	400 (37.2)	75 (17)	75 (17)	75 (17)	73 (17)	67 (15)	61 (14)	61 (14)	61 (14)			
Brackish water	440 (40.9)	75 (17)	75 (17)	75 (17)	73 (17)	67 (15)	61 (14)	61 (14)	61 (14)			
Sea water	370 (34.4)	65 (15)	65 (15)	70 (16)	70 (16)	64 (15)	58 (13)	58 (13)	58 (13)	63 (14)		56 (13)
Sea water	380 (35.3)	72 (16)	72 (16)	70 (16)	70 (16)	64 (15)	58 (13)	58 (13)	58 (13)	70 (16)		62 (14)
Sea water	400 (37.2)	72 (16)	72 (16	70 (16)	70 (16)	64 (15)	58 (13)	58 (13)	58 (13)	70 (16)		62 (14)

[1] UF/MF: Generic Ultra/Microfiltration - continuous filtration process using a membrane with pore size of <0.5 micron

Table 5.5

Choosing feedwater type

Feed water type	Description
RO Permeate SDI<1	Very-low-salinity, high-purity waters (HPW) coming from the first RO systems (double-pass RO system) or the polishing stage in ultrapure water (UPW) systems with TDS up to 50 mg/L.
Well Water SDI<3	Water from a ground source that has been accessed via well. Usually, has low fouling potential.
Surface Water with Dow Ultrafiltration SDI<2.5	Water from rivers, river estuaries and lakes. In most cases it has high TSS, NOM, BOD and colloids. Frequently, surface water quality varies seasonally.
Surface Supply SDI<3	
Surface Supply SDI<5	
Wastewater with Dow Ultrafiltration SDI<2.5	Industrial and municipal wastewaters have a wide variety of organic and inorganic constituents. Some types of organic components may adversely affect RO/NF membranes, inducing severe flow loss and/or membrane degradation (organic fouling).
Wastewater with Generic Membrane Filtration SDI<3	
Wastewater with Conventional Pretreatment SDI<5	
Seawater with Dow Ultrafiltration SDI<2.5	Seawater Dow Ultrafiltration as a pre-treatment
Seawater with Generic Membrane Filtration SDI<3	Well -water from a beach well with any type of pre-treatment Seawater any with Generic Microfiltration/Ultrafiltration as a pre-treatment
Seawater (Open Intake) SDI<5	Open intake seawater with conventional pre-treatment

Table 5.6

Ten steps to design a membrane system

• Define product flow rate and recovery (consider feed quality and required permeate quality
• Select the flow configuration
• Select the membrane element type
• Select the average membrane flux
• Calculate the number of elements needed

• Calculate the number of pressure vessels needed
• Select the number of stages
• Select the staging ratio
• Balance the permeate flow rate
• Analyze and optimize the membrane system

• Step 1 – Define scope and boundaries

• Required permeate flow rate
• Required permeate quality
• Available feed water quality
• System recovery
• Focus on capital or operation costs

Focus on capital or operation costs

Focus on minimizing capital costs (CAPEX):

Implications:
• Maximize system flux
• Minimize number of elements and vessels

Focus on minimizing operational costs (OPEX):

Implications:
• Lower system flux
• Higher number of elements and vessels
• Prefer low energy membranes

• Required permeate flow rate

• Element size
• Number of elements

• Required permeate quality

• Element selection
• Flow configuration
• Recovery

• System recovery

• Seawater recovery limits

• High osmotic pressure of brine stream
• Osmotic pressure limits recovery to 35-55%

• Brackish water recovery limits

• Brackish waters usually contain sparingly soluble salts which can cause scaling
• Recovery normally limited to 70-85%
• Softening or scaling inhibition required
• Recovery limits for non-treated and softened waters – calculated by ROSA
• Recovery limits with scale inhibitors – calculated by supplier programs
• Lower recovery for feeds with higher fouling tendency

• Permeate quality limits

• Requested permeate quality may not be achieved at very high recovery

OUR EXAMPLE

Required permeate flow rate: 1,000 gpm (227 m3/h)
Required permeate quality: TDS < 20 mg/L
Available feed water quality: Local river source, TDS = 355 mg/L
System recovery: 80%
Focus on operational costs

• Step 2 – Select flow configuration

• Continuous process is standard
• Batch process in special applications – e.g. for separation of process liquids and waste water treatment in food and pharma industries
• Concentrate recirculation – for small systems and in special application – e.g. waste water or process liquids

OUR EXAMPLE
Continuous process **Yes**
Batch process **No**
Concentrate recirculation **No**

• Step 3 – Select the membrane element type

According to:
• System capacity
• Feed water TDS
• Feed water fouling potential
• Required product water quality
• Energy requirements

According to system capacity

Element diameter for approximate system capacity
• 2.5-inch < 200 liters/h (1,270 gpd)
• 4.0-inch < 2.3 m3/h (10 gpm)
• 8.0-inch > 2.3 m3/h (10 gpm)

Element length
• Standard – 40 inches (1,106 mm)
• For small compact systems – 21 or 14 inches

According to feed water TDS (rule of thumb)

< 1,000 mg/L NF270, NF90, XLE, ECO, TW30, XFR, BW30
< 10,000 mg/L BW30, XFR
10,000-30,000 mg/L SEAMAXX, SW30ULE, SW30XLE
30,000-50,000 mg/L SW30HR, SW30XHR, SW30HRLE, SW30XLE

According to feed water fouling potential

• Standard feed spacer thickness – 28 mil
• Feed spacer thickness for feed waters with increased fouling potential – 34 mil used in BW30-365, BW30-400/34, BW30XFR-400/34, ECO-400, SW30HR-370/34
• Fouling resistant BW membrane for biofouling and organic fouling mitigation – used in BW30XFR-400/34, ECO-400

OUR EXAMPLE

According to:

• System capacity: elements of 8” x 40” (1,000 gpm, 227 m3/h)
• Feed water TDS: BW or low energy
• Feed water fouling potential: 34 mil feed spacer
• Required product water quality: BW, ECO, low energy
• Energy requirements: ECO, low energy

• Step 4 – Select the average membrane flux

Select the design flux (f) based on:

• Typical design fluxes found in Membrane System DesignGuidelines
• Feed water source (type)

OUR EXAMPLE

According to:

• Design guidelines: surface water SDI < 5; design flux range = 12-16 gfd (20-27 lmh) for pretreated river water source
• Conventional pretreatment

Step 5 – Calculate the number of elements needed

$$N_E = \frac{Q_P}{f \cdot S_E}$$

N_E	number of elements
Q_P	design permeate flow rate of system
f	flux
S_E	active membrane area of the selected element

OUR EXAMPLE

$$N_E = \frac{Q_P}{f \cdot S_E} = \frac{5{,}450(m^3/day)}{22.3(L/m^2h) \times 37.2(m^2)} \frac{1day}{24h} \frac{1000L}{1m^3} \approx 274$$

$$N_E = \frac{Q_P}{f \cdot S_E} = \frac{1{,}440{,}000(gal/day)}{13.2(gfd) \times 400(ft^2)} \approx 273$$

Step 6 – Calculate the number of pressure vessels needed

$$N_V = \frac{N_E}{N_{EpV}}$$

NV Number of vessels
NE Number of elements
NEpV Number of elements per vessel

OUR EXAMPLE

$$N_V = \frac{274}{7} = 39$$

Step 7 – Select the number of stages

Number of serial element positions should be higher for:
- Higher system recovery
- Higher fouling tendency

Number of stages depends on:
- Number of serial element positions
- Number of elements per pressure vessel

Number of stages of a brackish water system

System Recovery (%)	Number of serial element positions	Number of stages (6-element vessels)
40 – 60	6	1
70 – 80	12	2
85 – 90	18	3

Table 5.7

Step 8 – Select the staging ratio

$$R = \left[\frac{1}{(1-Y)} \right]^{\frac{1}{n}}$$

Y System recovery (fraction)
n Number stages

OUR EXAMPLE

$$R = \left[\frac{1}{(1-0.80)} \right]^{\frac{1}{2}} \approx 2.24$$

Calculate number of vessels of first stage Nv(1)

$$Nv(1) = \frac{Nv}{1 + R^{-1}}$$

For 2 stage system

$$Nv(1) = \frac{Nv}{1 + R^{-1} + R^{-2}}$$

For 3 stage system

OUR EXAMPLE

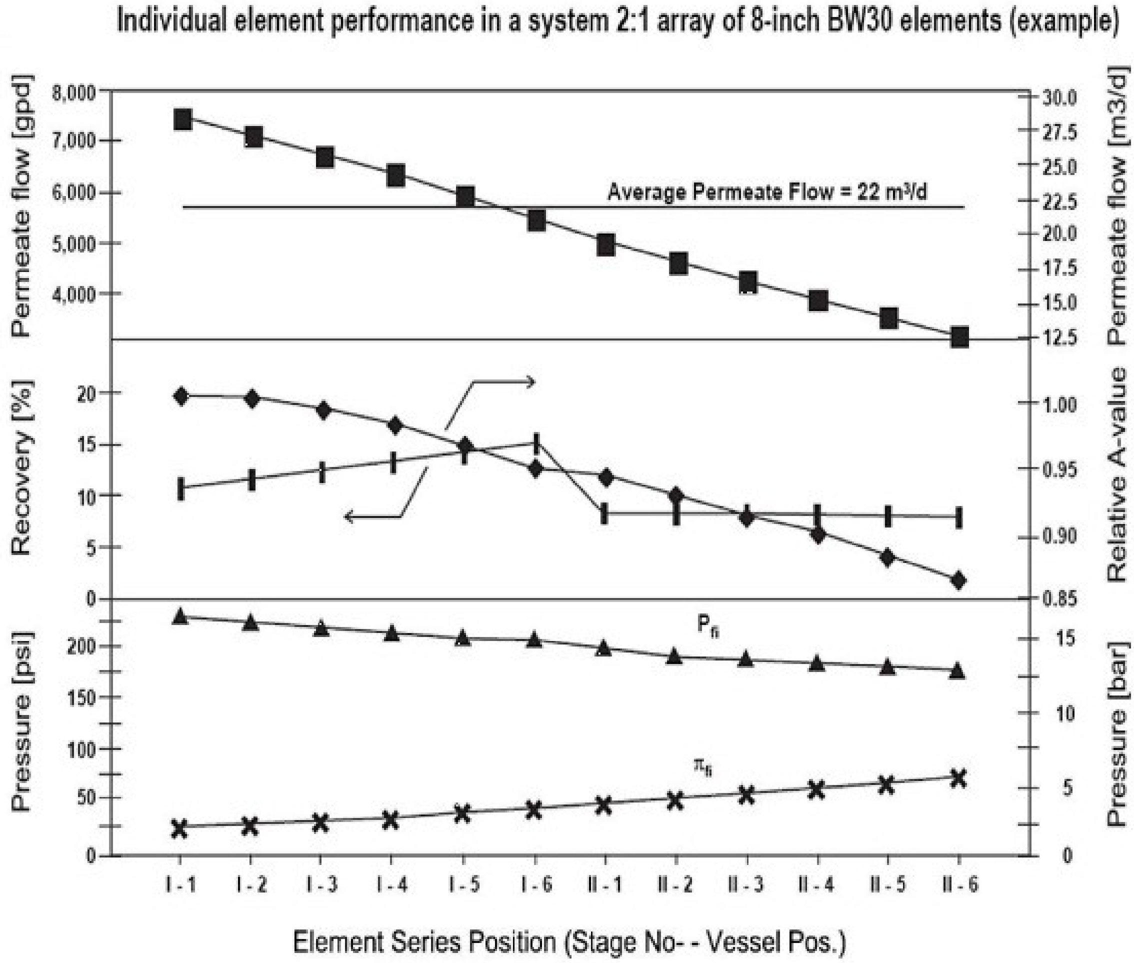
$$Nv(1) = \frac{Nv}{1 + R^{-1}} = \frac{39}{1 + 2.24^{-1}} = 26.9$$

We need approximately 26 vessels in the first stage and 13 vessels in the second stage

Step 9 – Balance the permeate flow rate

Permeate flow rate per element decreases from the feed end to the concentrate end of the system because of:

- Pressure drop in the feed/concentrate feed spacer
- Increasing osmotic pressure in the feed/concentrate stream



<u>**Figure 5.8**</u>

Imbalance of permeate flow rate predominant with:

- High system recovery
- High feed salinity
- High water temperature
- Low pressure elements
- New elements

Why balance the permeate flow rate?

- Avoid excessive flux of lead elements
- Reduce fouling rate of first stage
- Improve product water quality
- Make better use of tail end elements
- Reduce number of elements

Methods to balance the permeate flow rate:

- Boosting the feed pressure between stages
- Permeate backpressure to first stage only
- Elements with lower water permeability in the lead positions; elements with higher water permeability in the tail positions

Step 10 – Analyze and optimize the reverse osmosis system

The chosen system should then be analyzed and refined using the Reverse Osmosis System Analysis (ROSA) computer program.

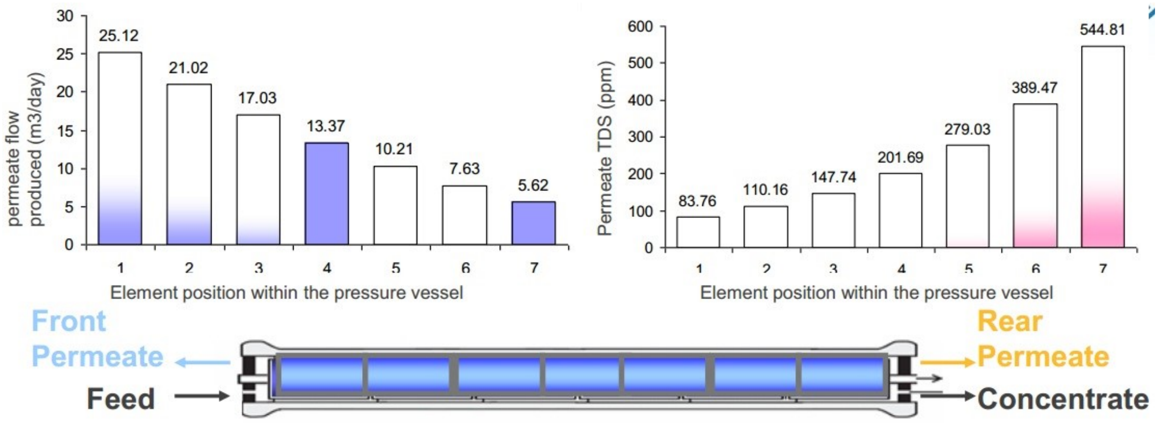
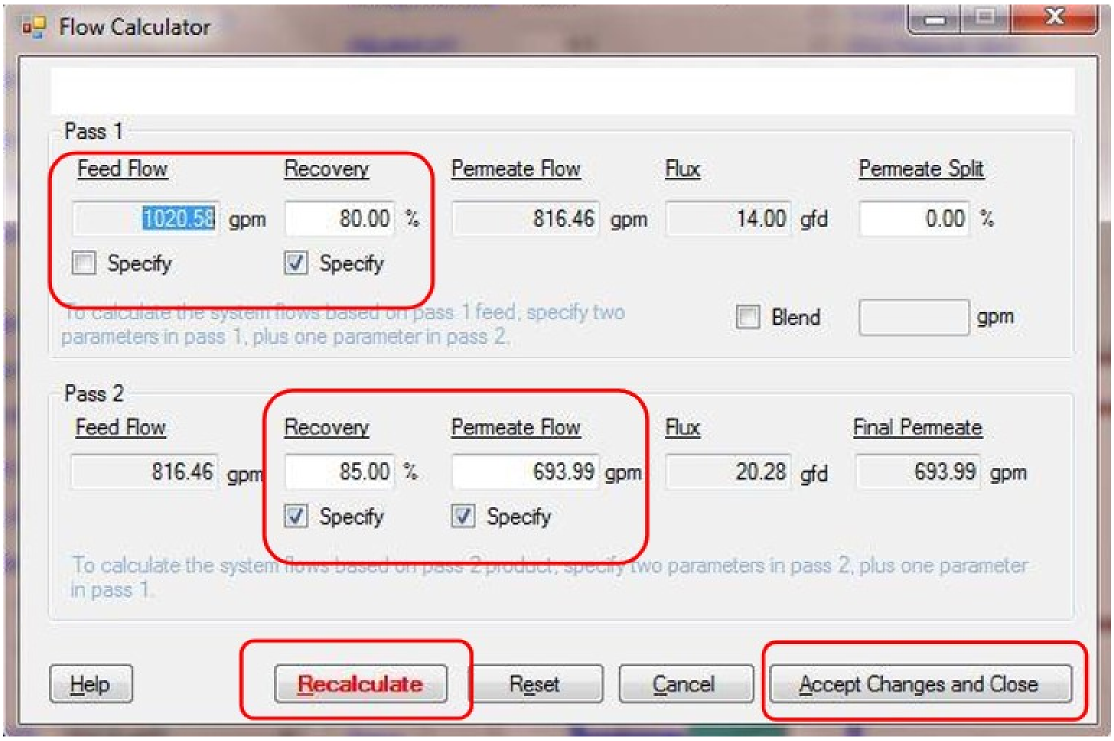
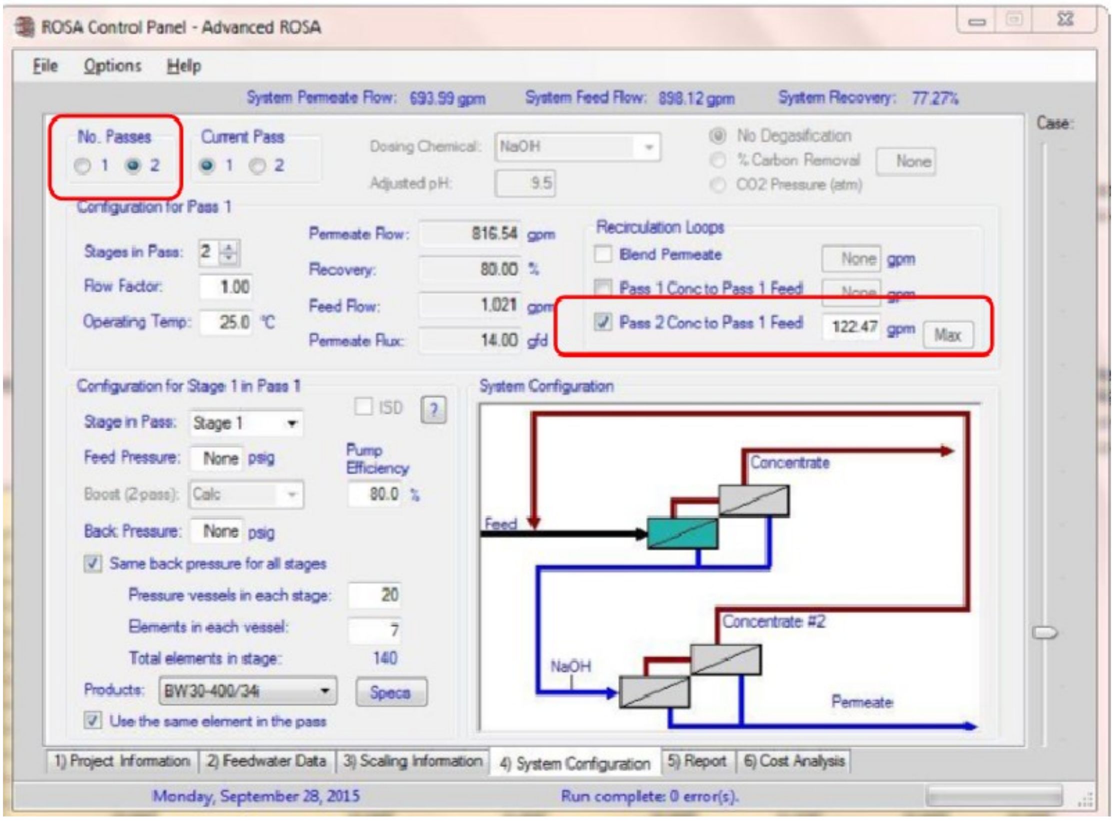


Figure 5.9

ROSA : REVERSE OSMOSIS SOFTWARE ANALYSIS





DATA SHEET OF ROSA

System Details -- Pass 1

Feed Flow to Stage 1	1020.59 gpm	Pass 1 Permeate Flow	816.56 gpm	Osmotic Pressure:	
Raw Water Flow to System	898.12 gpm	Pass 1 Recovery	80.01 %	Feed	17.28 psig
Feed Pressure	156.37 psig	Feed Temperature	25.0 C	Concentrate	81.01 psig
Flow Factor	1.00	Feed TDS	1793.34 mg/l	Average	49.15 psig
Chem. Dose	None	Number of Elements	210	Average NDP	104.19 psig
Total Active Area	84000.00 ft²	Average Pass 1 Flux	14.00 gfd	Power	86.80 kW
Water Classification: Well Water SDI < 3				Specific Energy	[illegible] kWh/kgal
System Recovery	77.27 %			Conc. Flow from Pass 2	122.47 gpm

Stage	Element	#PV	#Ele	Feed Flow (gpm)	Feed Press (psig)	Recirc Flow (gpm)	Conc Flow (gpm)	Conc Press (psig)	Perm Flow (gpm)	Avg Flux (gfd)	Perm Press (psig)	Boost Press (psig)	Perm TDS (mg/l)
1	BW30-400/34i	20	7	1020.59	156.37	0.00	392.37	141.69	628.26	16.16	0.00	0.00	17.95
2	BW30-400/34i	10	7	392.37	141.69	0.00	204.06	130.69	188.30	9.68	0.00	0.00	68.03

Pass Streams (mg/l as Ion)

Name	Feed	Adjusted Feed		Concentrate		Permeate		
		Initial	After Recycles	Stage 1	Stage 2	Stage 1	Stage 2	Total
NH4+ + NH3	0.11	0.11	0.10	0.26	0.49	0.01	0.01	0.01
K	10.00	10.00	8.95	23.10	44.02	0.11	0.43	0.18
Na	443.00	443.00	398.39	1028.58	1960.65	4.82	18.51	7.98
Mg	70.00	70.00	62.13	160.96	308.11	0.41	1.51	0.66
Ca	160.00	160.00	141.98	367.89	704.25	0.90	3.38	1.47
Sr	1.80	1.80	1.60	4.14	7.92	0.01	0.04	0.02
Ba	0.01	0.01	0.01	0.02	0.04	0.00	0.00	0.00
CO3	1.65	1.65	2.28	9.85	25.05	0.00	0.00	0.00
HCO3	200.00	200.00	182.94	463.91	871.22	2.56	9.15	4.08
NO3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cl	934.40	941.75	842.67	2178.46	4158.80	8.43	32.41	13.96
F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO4	160.00	160.00	141.61	367.35	704.22	0.62	2.29	1.01
SiO2	12.00	12.00	10.67	27.62	52.82	0.09	0.31	0.14
Boron	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	3.41	3.41	2.00	4.04	7.57	2.46	5.01	3.05
TDS	1992.98	2003.33	1793.34	4632.16	8837.60	17.95	68.03	29.49
pH	7.80	7.80	8.00	8.02	7.96	6.22	6.44	6.32

System Details -- Pass 2

Feed Flow to Stage 1	816.56 gpm	Pass 2 Permeate Flow	693.99 gpm	Osmotic Pressure:	
Raw Water Flow to System	898.12 gpm	Pass 2 Recovery	84.99 %	Feed	0.38 psig
Feed Pressure	202.72 psig	Feed Temperature	25.0 C	Concentrate	2.49 psig
Flow Factor	0.85	Feed TDS	37.01 mg/l	Average	1.44 psig
Chem. Dose (100% NaOH)	4.82 mg/l	Number of Elements	112	Average NDP	175.94 psig
Total Active Area	49280.00 ft²	Average Pass 2 Flux	20.28 gfd	Power	90.02 kW
Water Classification: RO Permeate SDI < 1				Specific Energy	2.16 kWh/kgal
System Recovery	77.27 %				

Stage	Element	#PV	#Ele	Feed Flow (gpm)	Feed Press (psig)	Recirc Flow (gpm)	Conc Flow (gpm)	Conc Press (psig)	Perm Flow (gpm)	Avg Flux (gfd)	Perm Press (psig)	Boost Press (psig)	Perm TDS (mg/l)
1	BW30-440i	12	7	816.56	202.72	0.00	274.13	168.99	542.43	21.13	0.00	0.00	0.17
2	BW30-440i	4	7	274.13	168.99	0.00	122.58	131.58	151.56	17.71	0.00	0.00	0.47

Pass Streams (mg/l as Ion)

Name	Feed	Adjusted Feed	Concentrate		Permeate		
			Stage 1	Stage 2	Stage 1	Stage 2	Total
NH4+ + NH3	0.01	0.00	0.02	0.03	0.00	0.00	0.00
K	0.18	0.18	0.55	1.22	0.00	0.00	0.00
Na	7.98	10.75	31.95	71.32	0.03	0.11	0.05
Mg	0.66	0.66	1.96	4.39	0.00	0.00	0.00
Ca	1.47	1.47	4.38	9.78	0.00	0.01	0.00
Sr	0.02	0.02	0.05	0.11	0.00	0.00	0.00
Ba	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO3	0.00	1.14	5.58	15.26	0.00	0.00	0.00
HCO3	4.08	7.14	19.02	39.60	0.03	0.09	0.04
NO3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cl	13.96	13.96	41.49	92.62	0.04	0.14	0.06
F	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO4	1.01	1.01	3.00	6.70	0.00	0.00	0.00
SiO2	0.14	0.14	0.41	0.91	0.00	0.00	0.00
Boron	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	3.05	0.00	0.01	0.01	0.00	0.00	0.00
TDS	29.49	37.01	109.24	242.89	0.17	0.47	0.24
pH	6.32	9.50	9.70	9.75	8.62	8.82	8.67

Case Study

Design Solar Powered Reverse Osmosis Desalination unit

design of a desalination plant for a well integrated salt and the use of desalinated water in agriculture and drinking purposes, which includes :

- Design of the desalination plant .
- Selection and location of the well .
- testing of the quality of water in the well .
- Selection of the final treatment to ensure adequate desalinated water to the specifications and standards required WHO (posttreatment)

The station has been designed based on several factors:

- Cost .
- Availability of materials in the local market .
- Age of equipment and materials default .
- Maintenance services and parts availability .
- Quality parts and equipment, and enable them to achieve the desired goals, Ease of use and handling

Selection of the well

- good water quality inside the well and free of contaminants that are difficult to remove.
- easy to get rid of waste water in the dry valleys
- Low salinity of the well compared to other salt wells .

water tests and analysis

showing tests of water constitutes such :

- Bicarbonate
- Calcium
- Carbonate
- Chloride
- Electrical conductivity
- Hardness
- Magnesium
- Nitrate
- Nitrite
- Potassium
- Sodium
- Sulfate
- PH
- Fe
- Turbidity

These are the most important constitutes of water for reverse osmotic process and that must be check for knowing the **suitable pretreatment process** and for the osmotic pressure and other objects .

In our well selection :

Name	Bicarbonate	Calcium	Carbonate	Chloride	E.C	Hardness	Magnesium	Nitrate	Nitrite	Sulfate
Unit	mg/L	mg/L	mg/L	mg/L	Us/cm	mg/L	mg/L	mg/L	mg/L	mg/L
Sample 1	361.12	272.14	3.5	537.47	3150	1103	103.12	0.81	<.2	793.44
Sample 2	363.56	260.92	3.5	518.66	3140	1060	99.59	0.59	<.2	774.72
Sample 3	367.22	278.56	3.5	521.14	3140	1131	106.04	3.34	<.2	746.88
AVG	363.97	270.54	3.50	525.76	3143.33	1098.00	102.92	1.58	<.2	771.68

Turbidity	Potassium	Sodium	Sulfate	pH	Fe
NTU	mg/L	mg/L	mg/L	unit	mg/l
9.3	19.16	282.9	793.44	7.40	4.00
9	18.77	279.22	774.72	7.29	4.00
9.1	19.94	292.79	746.88	7.08	4.10
9.13	19.29	284.97	771.68	7.26	4.03

- The reasonable productivity of 50-65 m3^hr
- TDS DESIGIN (Cf) = 2380 PPM
- Q in (Qp) = 55 m3/h
- Q permeate = 41 m3/h
- Recovery (Y) = 0.75 %
- Membrane type >> hydronautic (Cpa3) Active membrane area (SE) = 37.1 m2
- Avg permeate flux (F) = 37 L/m2/s
- Nominal P drop (Pd) = 0.3 bar
-

Pumps selection

For solving the well water suction and movement and provide the suitable pressure for treatment process and adding the chemicals for the water, so after doing pump selection process we decide these kinds of pumps :

- **Source intake pump**
- **Feed pump**
- **High pressure pump**

Source intake pump

For solving well water suction and by doing calculations of Source intake pump selection , the suitable pump model " lowara 6z-855/09 "

Pump characteristics * :

Q in	65 m3 / hr
H	305 m
Kw	66
HP	90
Number of pumps	1
Number of stage	8
D OUT	203.3mm

Feed pump

By knowing the amount of water required & the resistance in pipes and pretreatment filters

For solving the water flow in the plant and by doing calculations of feed pump selection the suitable pump model " Lowara FHE50 - 200/110 "

Pump characteristics *:

Pump name	Lowara FHE50-200/110
Q_{Max}	72 m3 / hr
Q_{in}	65 m3 / hr
H	42 m
K_w	10.5
HP	15
Number of pumps	2
Efficiency	71.5 %
D_{IN}	65 mm = 2.5 in
D_{OUT}	50 mm = 2 in

Design calculation steps :

$NE = \frac{QP}{F.SE}$ = 29.8 membrane elements so assume 30 membrane elements

- Calculate the number of pressure vessels needed $Nv = \frac{Ne}{Nev}$ (Nv) = 30 / 5= 6
- assume 5 element / vessel = Nev

- select staging ratio (R) :

assume 2 stages ; n = 2 (75 % recovery) ; y = 0.75

- select the staging ratio :

$R = (\frac{1}{1-y})^{1/n}$ = 2 R = 2 : 1

- number of pressure vessels needed in first stage $Nv1 = \frac{Nv}{1+R^{-1}}$ = 4 vessels

- number of pressure vessels needed in second stage (Nv2): so (Nv2) = Nv – Nv1 = 6 – 4 = 2

- Temperature correction

Since the system temp between (22 c-26 c) so no correction factor need

- Posm = (T +273) x ∑ MI

where T = Temperature , R = gas constant (8.3145)

summation of molar concentration of all concentrations in the solution approximatlly (1000 ppm) TDS equal about (0.77) bar or (11)psi of osmotic pressure

as AFS = 1632 ppm NACL so

P osm = (AFS *0.77)/ 1000 = 1.25 bar

- NDP = NET DRIVING PRESSURE FOR CALCULATING HIGH PRESSURE PUMP HEAD

NDP = P feed – Posm – (Pdrop/2)

= 15.5 – 1.25 -0.5 *0.3 = 14.1 bar

- **System Feed pressure = NDP + Posm + 0.5 (Pd)+ Pp**

= 11.7 + 5.5 + 0.5 (2)- 0 = 17.77 bar

High pressure pump

By doing calculations of high pressure pump selection , the suitable pump model " Nochhi VLR 46-100 "

Pump characteristics * :

Q_{Max}	60 m^3 / hr
Q_{in}	55 m3 / hr
H	174 m ; H = pump head
K_w	37
Hp	50 ; hp = pump horse power
Number of pumps	1
Efficiency	73 %
D_{IN}	80 mm = 3 in
D_{OUT}	80 mm = 3 in

Sometimes we need a booster pumps & dosing pumps to inject chemicals but there power is low compared with the other three main pumps .

Solar Energy

solar photovoltaic system **or** Solar power system **is one of** renewable energy system **which uses PV modules to convert sunlight into electricity. The electricity generated can be either stored or used directly, fed back into grid line or combined with one or more other electricity generators or more renewable energy source. Solar PV system is very reliable and clean source of electricity that can suit a wide range of applications such as residence, industry, agriculture, livestock, etc.**

Major system components

Solar PV system includes different components that should be selected according to your system type, site location and applications. The major

components for solar PV system are solar charge controller, inverter, battery bank, auxiliary energy sources and loads (appliances).

- PV module **– converts sunlight into DC electricity.**
- Solar charge controller **– regulates the voltage and current coming from the PV panels going to battery and prevents battery overcharging and prolongs the battery life.**
- Inverter **– converts DC output of PV panels or wind turbine into a clean AC current for AC appliances or fed back into grid line.**
- Battery **– stores energy for supplying to electrical appliances when there is a demand.**
- Load **– is electrical appliances that connected to solar PV system such as lights, radio, TV, computer, refrigerator, etc.**
- Auxiliary energy sources **- is diesel generator or other renewable energy sources.**

Solar PV system sizing

1. Determine power consumption demands

The first step in designing a solar PV system is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system as follows:

1.1 Calculate total Watt-hours per day for each appliance used.
Add the Watt-hours needed for all appliances together to get the total Watt-hours per day which must be delivered to the appliances.

1.2 Calculate total Watt-hours per day needed from the PV modules.
Multiply the total appliances Watt-hours per day times 1.3 (the energy lost in the system) to get the total Watt-hours per day which must be provided by the panels.

2. Size the PV modules

Different size of PV modules will produce different amount of power. To find out the sizing of PV module, the total peak watt produced needs.

The peak watt (Wp) produced depends on size of the PV module and climate of site location. We have to consider "panel generation factor" which is different in each site location. For Thailand, the panel generation factor is 3.43. To determine the sizing of PV modules, calculate as follows:

2.1 Calculate the total Watt-peak rating needed for PV modules

Divide the total Watt-hours per day needed from the PV modules (from item 1.2) by 3.43 to get the total Watt-peak rating needed for the PV panels needed to operate the appliances.

2.2 Calculate the number of PV panels for the system

Divide the answer obtained in item 2.1 by the rated output Watt-peak of the PV modules available to you. Increase any fractional part of result to the next highest full number and that will be the number of PV modules required.

Result of the calculation is the minimum number of PV panels. If more PV modules are installed, the system will perform better and battery life will be improved. If fewer PV modules are used, the system may not work at all during cloudy periods and battery life will be shortened.

3. Inverter sizing

An inverter is used in the system where AC power output is needed. The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage as your battery.

For stand-alone systems, the inverter must be large enough to handle the total amount of Watts you will be using at one time. The inverter size should be 25-30% bigger than total Watts of appliances. In case of appliance type is motor or compressor then inverter size should be minimum 3 times the capacity of those appliances and must be added to the inverter capacity to handle surge current during starting.

For grid tie systems or grid connected systems, the input rating of the inverter should be same as PV array rating to allow for safe and efficient operation.

4. Battery sizing

The battery type recommended for using in solar PV system is deep cycle battery. Deep cycle battery is specifically designed for to be discharged to low energy level and rapid recharged or cycle charged and discharged day after day for years. The battery should be large

enough to store sufficient energy to operate the appliances at night and cloudy days. To find out the size of battery, calculate as follows:

4.1 Calculate total Watt-hours per day used by appliances.
4.2 Divide the total Watt-hours per day used by 0.85 for battery loss.
4.3 Divide the answer obtained in item 4.2 by 0.6 for depth of discharge.
4.4 Divide the answer obtained in item 4.3 by the nominal battery voltage.
4.5 Multiply the answer obtained in item 4.4 with days of autonomy (the number of days that you need the system to operate when there is no power produced by PV panels) to get the required Ampere-hour capacity of deep-cycle battery.

Battery Capacity (Ah) = Total Watt-hours per day used by appliances x Days of autonomy
(0.85 x 0.6 x nominal battery voltage)

5. Solar charge controller sizing

The solar charge controller is typically rated against Amperage and Voltage capacities. Select the solar charge controller to match the voltage of PV array and batteries and then identify which type of solar charge controller is right for your application. Make sure that solar charge controller has enough capacity to handle the current from PV array.

For the series charge controller type, the sizing of controller depends on the total PV input current which is delivered to the controller and also depends on PV panel configuration (series or parallel configuration).

According to standard practice, the sizing of solar charge controller is to take the short circuit current (Isc) of the PV array, and multiply it by 1.3 Solar charge controller rating = Total short circuit current of PV array x 1.3

1. Determine power consumption demands

Total appliance use = 116.25kw per day

Losses=.3

Total power factor=1.3

Total PV panels energy needed = 116.25 x 1.3

= 151.125kw per day

2. Size the PV panel

2.1 Total Wp of PV panel capacity needed	**= 151.125*1000 / 3.4**
	= 44448.5 Wp
2.2 Number of PV panels needed	**= 44448.5 / 110**
	= 403.8 modules

Actual requirement = 404 modules
So this system should be powered by at least 404 modules of 110 Wp PV module.

3. Inverter sizing
Total Watt of all appliances = 116.25*1000 W
For safety, the inverter should be considered 25-30% bigger size.
The inverter size should be about 139.5*1000 W or greater.

4. Battery sizing
Total appliances use = 116.25*1000 w
Nominal battery voltage = 12 V
Days of autonomy = 3 days

Battery capacity = $\frac{(116.25*1000] \times 3}{(0.85 \times 0.6 \times 12)}$
Total Ampere-hours required 56985.2 Ah
So the battery should be rated 12 V 56986 Ah for 3 day autonomy.

5. Solar charge controller sizing
PV module specification
Pm = 110 Wp
Vm = 16.7 Vdc
Im = 6.6 A
Voc = 20.7 A
Isc = 7.5 A
Solar charge controller rating = (4 strings x 7.5 A) x 1.3 = 39 A
So the solar charge controller should be rated 40 A at 12 V or greater.

Chapter 6

Prototype

REVERSE OSMOSIS SYSTEM

RO System Components :

Stage 1: Sediment Filter

5 µ Sediment Filter Removes Bactria, dirt, sediments, sand, and other suspended physical particles.

Stage 2: Granular Activated Carbon

Granular Activated Carbon Reduces chemicals such as chlorine, and other volatile organics from the water. The removal of chlorine improves the taste and odor of the water and maintains the integrity of the membrane.

Stage 3: Carbon Block Filter

It absorbs the organic matter, colour, and odor and dissolved gases like chlorine and disinfection by-products (chloramines, THM, TCE), Volatile Organic Compounds (V.O.C)from the water which is left out from GAC filter.

Stage 4: Reverse Osmosis

Reverse Osmosis 0.0001 micron Membrane75 gallons per day thin film composite reverse osmosis membrane removes 93-97% of total dissolved solids (TDS) and a full spectrum of contaminants that could be present in your water as inorganic, minerals, lead, cysts, dissolved metals, chemicals, and more.

Stage 5: GAC Post Carbon Filter

A final polishing process that enhances and clarifies your drinking water by rejecting any Volatile Organic Compounds (V.O.C), , Nitrates, , tastes, odor.That may have slipped through the membrane, plus, adsorbs any odors that may come from the pressure storage tank. Gives water a clean refreshed taste on the way to your tap. We are using NSF approved post carbon to guarantee the taste of water.

Stage 6: Bio-ceramic filter

pH Alkalinity Neutralizer Filtration to raise pH neutral and eliminate acidity, by addition healthy minerals, such as Calcium, Magnesium, Sodium, Potassium and others readily found in many natural mineral waters.

Stage 7:Far-Infra Red

This Infra-Red filter can activates water molecules in our body and improves oxygen level in our body. Warming and eliminating fats, chemicals and toxins from our blood and thus smoothening the flow of blood.

Figure 6.1

Type	Stage No	Duration
Sediment filter	Stage 1	2-3 Months
Granular Carbon filters	Stage 2	6 months
Block Carbon filter	Stage 3	6 months
Reverse Osmosis Membrane	Stage 4	2 Years
GAC Post Filter	Stage 5	2 Years
Bio-ceramic filter	Stage 6	2 Years
Far-Infra Red Filter	Stage 7	2 Years

Table 6.1

1. Pre-Filter :-

Once the water enters the system, they first get filtered by a number of pre-filters that are generally the sediment filters. These filters remove the sand, stones and other sediments commonly present in the water. Post that they also pass the water through the carbon filters to remove all the chlorine if present in the water.

Figure 6.2

2. reverse osmosis membrane:-

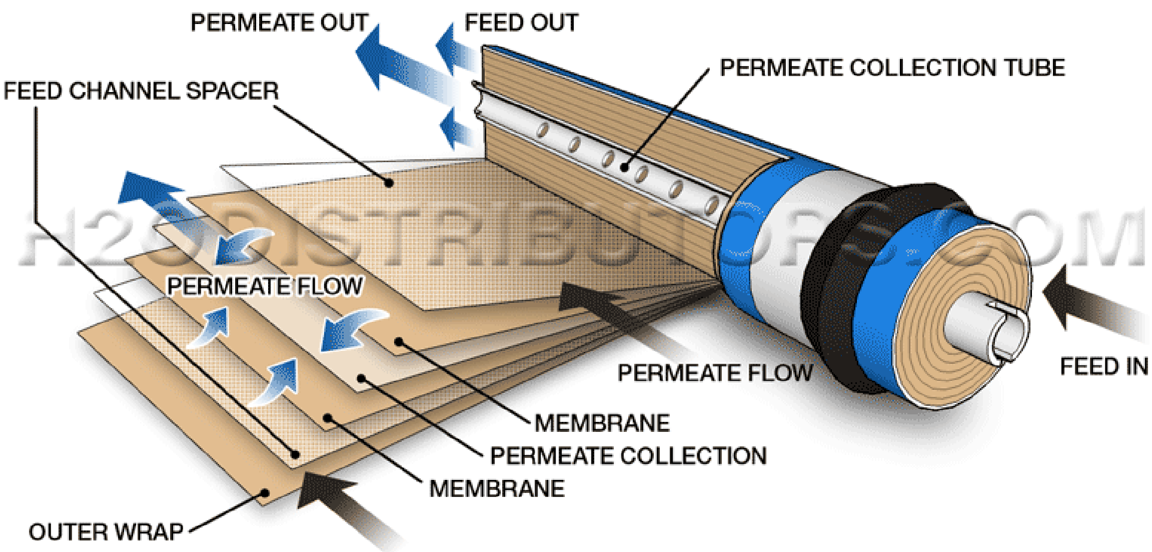


Figure 6.3

This is the main membrane of the system that are two separate spiral wounds out of which one is CTA (cellulose tri-acetate) which tolerates chlorine and the other is TFC/TFM (thin film composite/material) which does not tolerate chlorine.

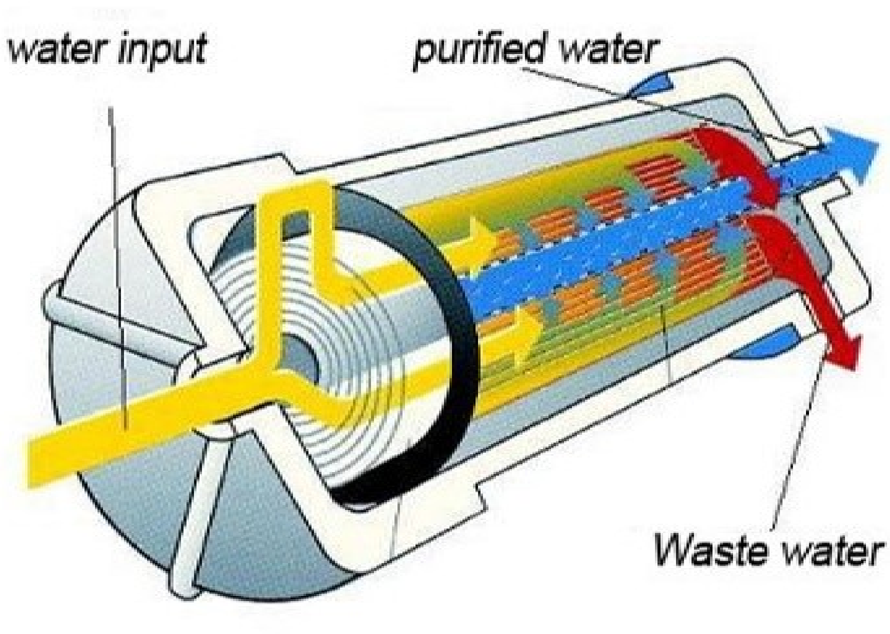


Figure 6.4

3. Post filter :-

Once the membrane passes the water, there is a final filtration to remove the remaining taste and odours in the water through a carbon filter.

4. Automatic shut off valve :-

ASOV is automatic shut-off valve. This valve allows your system to turn off the water supply, using pressure from the pure water side of the system. It will turn off the water supply to the unit, whenever there is sufficient pressure on the pure water side of your system. ASOV is a must. It saves water, extends filter life, and improves the performance of your unit. As the storage tank fills the pressure inside increases, when the pressure equals ½ to 2/3 your feed water pressure, the water to the system is shut off. No waste. Since you subtract the storage pressure from the operating pressure, the storage pressure needs be limited.

Figure 6.5

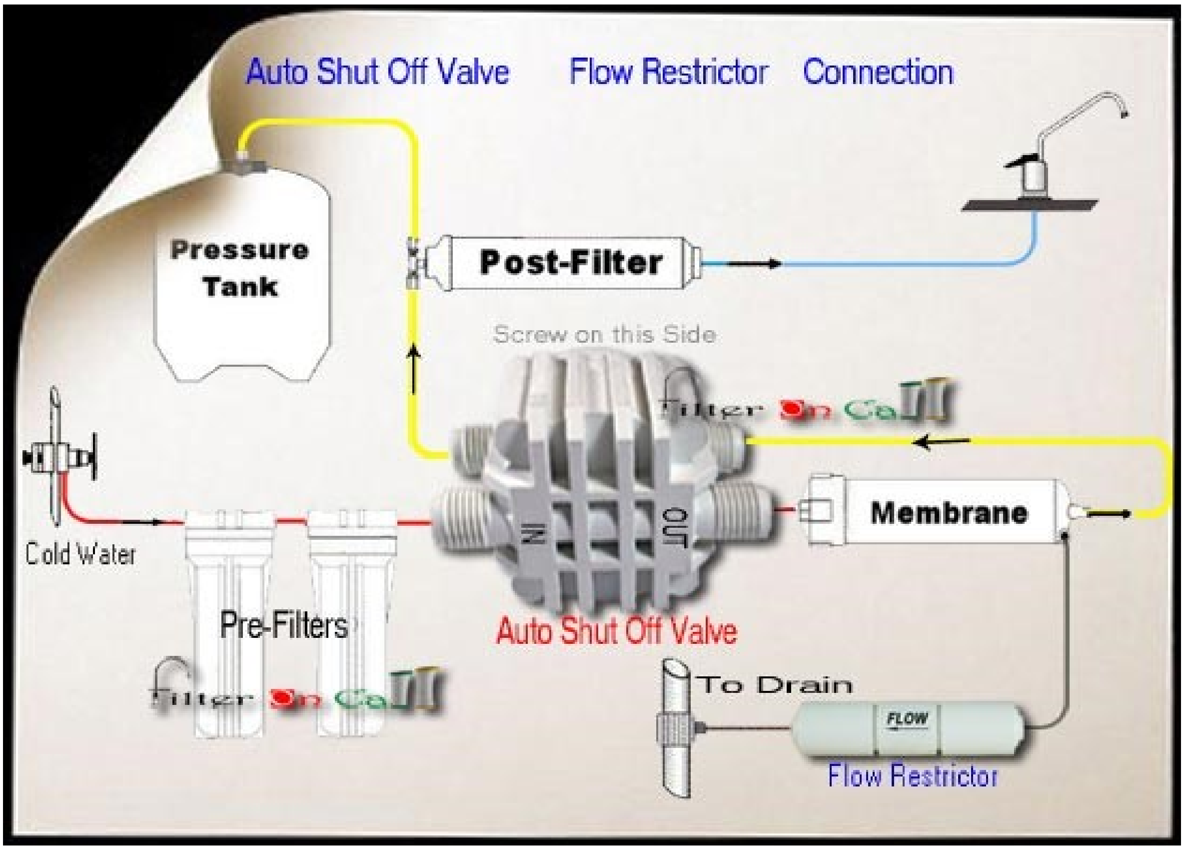


Figure 6.6

5. Flow restrictor :-

Flow Restrictor Purpose Flow Restrictors (also known as Flow Controls or Capillaries) are required for all reverse osmosis systems. The Flow Restrictor must be properly sized to the RO membrane capacity. Flow Restrictors create pressure throughout the reverse osmosis membrane element and maintain a desired ratio of reject flow (to drain) and permeate (product) flow.

It is recommended that you replace the Flow Restrictor each time you replace your reverse osmosis membrane to keep your system operating at peak efficiency. The number on the flow restrictor indicates the flow rate, in milliliters per minute. The flow restrictor should match your reverse osmosis membrane's production rate.

Flow restrictors are rated by a flow rate expressed as milliliters/minute (ml/min). The following table gives a guideline for selecting an inline flow restrictor for your RO membrane.

RO Membrane Size (Gallons Per Day)	Use Flow Restrictor (ML Per Minute)
8-20 GPD	150
21-25 GPD	250
36 GPD	350
50 GPD	500
75 GPD	750
100 GPD	1000
150 GPD	1200

Table 6.2

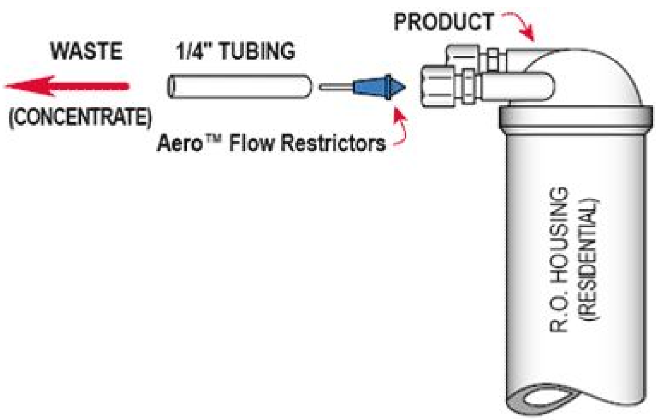


Figure 6.7

Irrespective of the incoming water flow from the tap, the flow restrictor regulates the flow of water when it reaches the main membrane in order to achieve 100% filtration of the water. This is required because variable water flow could damage the membrane and its functionality.

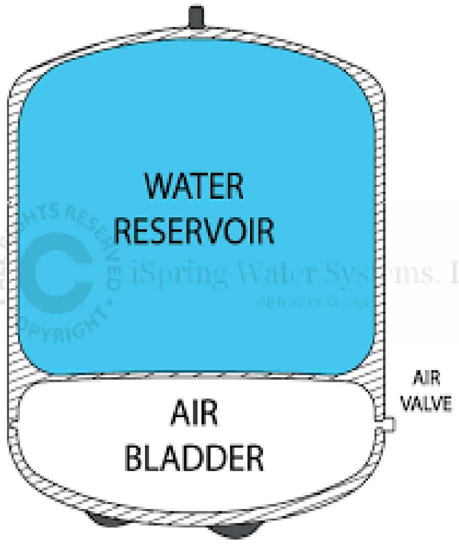
6. Storage tank :-

A pressurized storage tank for reverse osmosis product water is recommended for its ability to deliver reverse osmosis water to the faucet using air pressure within the tank. The system shut-off valve (sold separately), will automatically turn the RO system on and off as needed.

Water is stored in a bladder within the tank vessel opposite pressurized air. As the bladder fills, the back pressure increases until it reaches a pre-set pressure limit (as determined by the shut-off valve, sold separately), causing the shut-off valve to cut off the feed supply to the reverse osmosis system.

Water will remain in the bladder until the faucet is opened, the air pressure surrounding the bladder will force the water out of the storage tank and a directed point of use. As water is used, the pressure will drop until the shut-off valve disengages, allowing feed water to the RO system to resume until the tank is refilled.

Figure 6.8



7. Pressure switches :-

- RO High Pressure Switch (HPS) for All kinds of RO System Suited for common RO water filter Purifiers available in India,Compatible with many RO Brands and Models-Can be used in multiple water purifier Models-Counter Top,Desk Top,Stand Mounted,Wall Hanging,Under Sink,most of the RO Model cabinets.

- Save RO motor from Overloading due to Blockage of Water in the RO Unit.If the Back Pressure is High,this switch will act and turn off the power supply to Booster Pump thus saving the Pump from Overloading.

- This HP switch is fitted on the output side of RO booster pump and will turn off the power supply to the pump when the water back pressure increases as a result a blockage in the Reverse Osmosis system.This will help to avoid overload of the Booster Pump and Prevents Burning of the Coils inside the Pump All the leading RO manufacturer recommend this product for the RO Units.

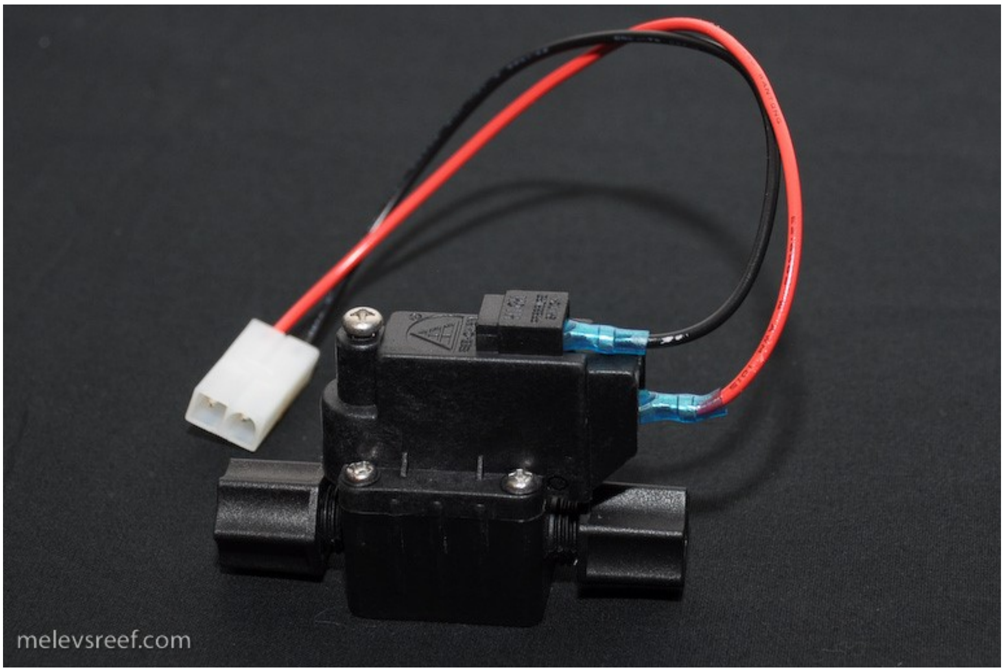


Figure 6.9

8. Booster Pumps :-

The purpose of the reverse osmosis booster pump is to increase water pressure going into the RO unit.

Reverse osmosis is a pressure-driven process. Small residential RO units will theoretically operate on very low pressure--down to 35 psi, according to some membrane makers--but the reality is, you won't get a lot of water and the product water quality will be compromised if the unit runs below 45 psi. Low inlet pressure makes the unit produce more reject water, produce less drinking water, fill the storage tank more slowly, and produce lower quality water.

RO units run well on typical city water pressure of 60 psi, but they run even better with a small pump to boost the pressure to 80 psi or higher.

The picture above shows the three essential elements of the RO booster pump. The white object at left is the transformer. It plugs into a standard wall outlet and converts to the voltage (most commonly 24 volts) required by the pump. The large object is the pump itself. The third device is the pressure switch. It monitors the water pressure in the RO unit's storage tank and turns the pump off and on in response to storage tank pressure. The most common shutoff pressure for undersink home RO units is 40 psi.

Figure 6.10

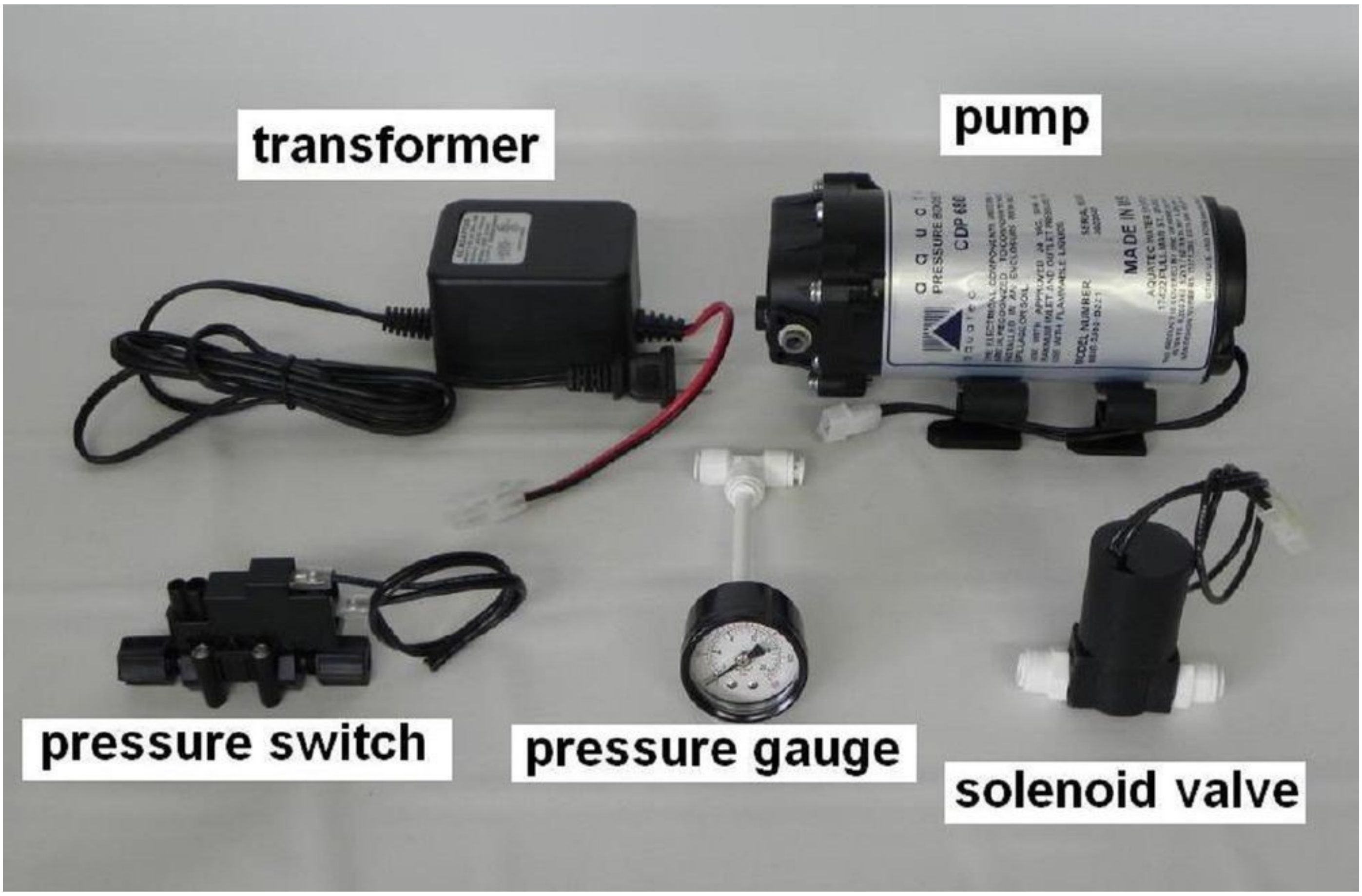


Figure 6.11

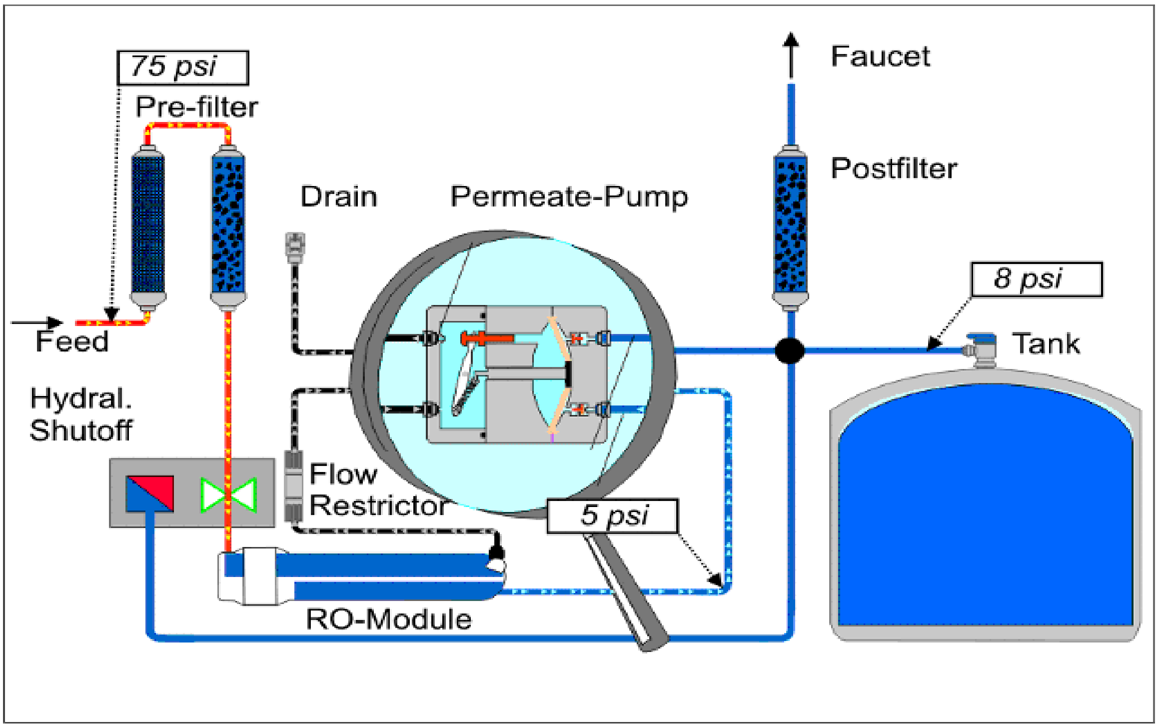


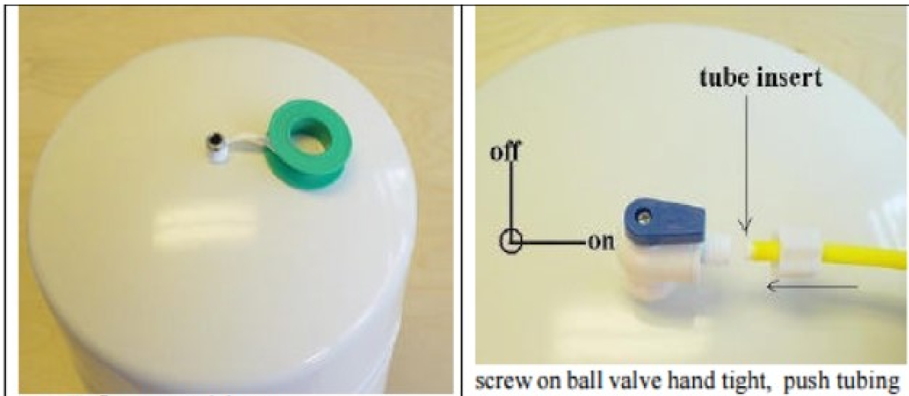
Figure 8.12

System Installation

Storage Tank:

As the RO system makes water it pushes it into a tank to store it, and a pressurized bladder in the tank pushes it back out (through the same opening) when requested (such as opening the faucet). The large male threaded fitting on one end of the tank is the inlet and outlet of the tank.

A pressure valve on the side of the tank (usually covered with a blue screw-on cap) is used **only** for checking and adding air to the bladder. The tank is shipped with 4-6psi of air pressure in the bladder, and is sufficient in most cases. Pressure may be increased to no higher than 10psi ***when the tank is empty***, this will cause water to come out of the faucet a little faster if so desired. NOTE: As the tank is emptied, pressure from the faucet will decrease, this is normal.



put Teflon tape, 6-8 turns

screw on ball valve hand tight, push tubing through the nut, put tube insert, screw on the nut

Figure 6.13

To Prepare the Tank:

1. Wrap the threaded nipple on the end of the tank with 6-7 wraps of Teflon tape.
2. Install tank ball valve on prepared nipple, tightening hand tight only. Once your system is connected, your tank line will connect to this fitting

Feed Water Installation:

1. The feed water assembly consists of a 1/2" slip joint adapter with 2 washers and an angle ball valve. Locate these parts in the installation kit. If space permits, the angle valve should be installed into the slip joint adapter before connecting the assembly to the feed water line

2. (Note: Teflon tape must be used on angle valve to prevent leaks).

3. Locate cold-water angle shut off valve underneath the sink, usually on the right side, and turn it off. Open cold water faucet to release the pressure. On single handle faucets, the hot water may need to be turned off to prevent any hot water from crossing over. If water continues to come out of the faucet with angle valve turned off the main water supply will have to be turned off.

4. The slip joint adaptor is usually installed on the cold water faucet shank, but may be installed on the cold water shut off valve. (Figure 2) If installing on the cold water shut off valve, an adapter will most likely be required. Use the following instructions for your particular plumbing type.

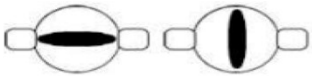
5. Once the system is ready to be hooked up, the feed water line will connect to the angle ball valve. To connect, place the nut and ferrule (white plastic ring) over the feed water line, insert the line into the angle valve, and tighten the nut. Alternately, if your angle ball valve has a stem on it, slide the nut over the feed water line, push the line onto the stem, and tighten the nut down (no ferrule is used).

System Start Up

After all the connections have been made it is time to prepare the system for use. If the system has a UV filter, plug the wire coming from the UV filter into the transformer and plug the transformer into any standard 110v outlet. When the UV bulb is working you will see a purple glow from the end of the UV filter. NOTE: When first plugged in the UV filter may take a minute or two before it lights up, this is normal. Once plugged in the light will remain on and should not be unplugged except to change the bulb, this ensures effective treatment.

Preparing the system for use:

Note: Ball valves are open when the handle is inline (parallel) with the tubing



Open Closed

1. Turn on feed water: **Slowly, turn on your Cold water supply. Open the Needle Valve (turn** counterclockwise**) to allow the raw water to enter the system.** Check for leaks!
2. **Open tank valve**: Open the tank's ball valve to allow water to enter the tank. The tank's valve is "**On**" when the valve handle is parallel (in the same direction) with the valve's outlet (see Fig. 12).
   Check for leaks!
3. **Wait for tank to fill**: Before usage, allow the tank to fill. Tank normally takes **2-3 hours** to fill.
   When the tank is filled, the RO will shut off automatically.
4. **Drain Tank**: Do not use the first tank of water! Drain it out to flush the system and
   new filters. Lift the faucet lever up into a locked position to drain tank. Let the
   tank refill again and the pure water is ready for use.
5. **Clean up area**: Allow the system to run while cleaning up tools and work area.
6. **Check for leaks!** Make sure **no leaking** at joints, fittings, valves, and tubing connections.

System Maintenance

Filters:

Filters need changed regularly to ensure protection of the membrane and high purity water production.

The replacement filter set you need depends on the optional filters you have. With average usage and normal water conditions filters should be changed every 6 months. The more water you use or the dirtier your water the more often you will want to change filters. If the first filter (sediment filter) gets dirty quickly it may need changed more often than the rest, part number for the individual sediment filter is SED105. All filters (excluding the membrane) should be changed at least every 12 months. The UV bulb can be checked to determine if it is still on by looking at the end with the wire coming out, it should glow purple. If it is not then the bulb has burnt out. Average life on the bulb is 12-18 months, though it is recommended to change it every 12 months to ensure effective filtration, as the bulb intensity diminishes over time. To change, simply pull on the wire and the bulb will slide out.

System	Filter Set	Filters Included
5-stage 6-stage w/ UV	ROFK5	Sediment, GAC, Carbon Block, Post Filter
6-stage w/ pH	ROFK6	Sediment, GAC, Carbon Block, Post Filter, Inline pH
7 Stage (UV & DI)	ROFK7	Sediment, GAC, Carbon Block, Post Filter, Inline DI
8-Stage (UV, DI, pH)	ROFK8	Sediment, GAC, Carbon Block, Post Filter, Inline DI, Inline pH
UV Bulb	UVB1	Standard 6W UV Bulb

Table 6.3

How to change filters:

1. Turn off the feed water supply. This is done by closing either the angle ball valve or the feed water ball valve. The valve is closed when the handle is at a 90° angle to the tubing (when handle is NOT parallel to tubing). If saving water from the tank, do so after closing the valve.
2. Shut the ball valve on the tank. The valve is closed when the handle is at a 90° angle to the tubing (when the handle is NOT parallel to the tubing).
3. Open the faucet to release any remaining pressure.
4. Pull the system out to where it can be easily worked with. If the system was installed with enough tubing to do so, simply pull it out to where it can be worked on. If the system does not have enough tubing, you will need to disconnect the lines to pull it out. (When changing filters, it helps to have a towel handy, as some water may leak out.) Make note of which tube goes where to ensure the system will be hooked up the same way it was.
5. Remove the first filter housing. To remove, use the filter housing wrench supplied with your system. When looking down at the top of the system, the filter housing will turn clockwise to loosen, counterclockwise to tighten. Once the filter housing has been removed, pull the filter out and replace with the new one. At the top of each housing is an O-ring, when changing filters it is recommended to remove the O-ring and check for any damage such as nicks, gouges, or kinks. If damage is found, replace before continuing, otherwise, use a silicon based lubricant (vegetable oil can be used if no silicone lubricant is available) and lubricate the O-ring, place it in

the filter housing and screw the housing back in place. This will help prevent leaks.

6. Repeat step 5 with each housing, replacing the old filter with the similar new filter and checking the O-rings. If any of the filters have only one gasket (the middle filter on most systems will have only one gasket) the filter will need to be installed with the gasket at the top of the housing, unless dictated otherwise by the filter itself.
7. Once the pre-filters (the filters in the housings) have been changed, it is time to change the inline filter(s) (the post filter, as well as the DI & pH/Mineral filter if the system has them.) To replace them, remove the tubing and/or fittings from each end of the filter (refer to section on quick connect fittings near the beginning of the manual if you are unsure how to do this) and replace in the new filter, paying careful attention to the direction of flow as indicated on the filter, and ensuring the new filter is installed in the same direction as the old filter. Do this with each inline filter your system has.
8. If the system was unhooked to change the filters, hook it back up now. Open the angle ball valve or feed water ball valve on the feed water line, and open the tank ball valve.
9. Open the faucet, and tilt the system back and forth and side to side to help work the air out of the lines
10. Allow the system some time to start producing water from the faucet, depending on the system and water pressure this may take up to 30 minutes. When the water first comes out it may be black as the carbon fines in the post filter rinse out, this is normal. Once you are getting a steady flow of water (anything from a steady drip to a small stream, depending on membrane size and water pressure), shut the faucet off.
11. Allow the system to fill the tank. Depending on the system and water pressure, this can take anywhere from 1 - 5 hours.
12. Once the tank has filled, open the faucet, allowing all the water to drain until flow from the faucet is down to the slow drip or stream seen in step 10. This flushes the system, cleaning the filters and preparing them for use.
13. Repeat steps 11-12 at least once to ensure thorough flushing of the new filters.
14. Your filters are now changed and the system is ready to use again.

Membrane:

The RO membrane will last an average of 2 –4 years, depending on water quality, water usage, frequency of filter changes, and quality of filters used. Reduced water quality, reduced production rate, or no production can be an indication of a fouled membrane, but there may not always be these signs to tell you the membrane is bad. The best way is to monitor the rejection rate of the membrane using a TDS meter. A functioning membrane should be removing a minimum of 90% of contaminates under normal conditions. To test this, simply compare the TDS of your tap water to the TDS of the water from the membrane (before it goes to any other filters). For example, if your tap water has a TDS of 400ppm, after the membrane your TDS should be 40ppm or less.

If you do not wish to use a TDS meter, it is recommended that you change your membrane at least every 4 years.

To change the membrane:

1. Turn off the feed water supply. This is done by closing either the angle ball valve or the feed water ball valve. The valve is closed when the handle is at a 90° angle to the tubing (when handle is NOT parallel to tubing). If saving water from the tank, do so after closing the valve.
2. Shut the ball valve on the tank. The valve is closed when the handle is at a 90° angle to the tubing (when the handle is NOT parallel to the tubing).
3. Open the faucet to release any remaining pressure.
4. Pull the system out to where it can be easily worked with. If the system was installed with enough tubing to do so, simply pull it out to where it can be worked on. If the system does not have enough tubing, you will need to disconnect the lines to pull it out. (When changing the membrane, it helps to have a towel handy, as some water may leak out.) Make note of which tube goes where to ensure the system will be hooked up the same way it was.
5. Disconnect the tube feeding the membrane (the tube going to the single fitting on the membrane housing cap). If unsure how to disconnect the quick connect fittings, refer to the section on quick connect near the beginning of the manual.
6. Remove the membrane housing cap (when looking at the fitting on the cap it will turn counterclockwise to loosen).
7. Remove the membrane from the housing. A pair of needle nosed pliers may be needed to grip the end of the membrane. To remove, gently pull with a twisting motion and the membrane should slide out.
8. Lubricate the O-rings on the membrane with a silicon based lubricant (vegetable oil may be used if silicon lubricant is not available), and push back into the housing.
9. Lubricate the O-ring on the membrane housing (some housings have 2) and screw the membrane housing cap back onto the housing.
10. Push the tubing back into the fitting on the membrane cap.
11. If the filters need changed, now is a good time to do so, since the system is turned off.
12. If the system was unhooked to change the filters, hook it back up now. Open the angle ball valve or feed water ball valve on the feed water line, and open the tank ball valve.
13. Open the faucet, and tilt the system back and forth and side to side to help work the air out of the lines.
14. Allow the system some time to start producing water from the faucet, depending on the system and water pressure this may take up to 30 minutes. Once you are getting a steady flow of water (anything from a steady drip to a small stream, depending on membrane size and water pressure), shut the faucet off.

15. Allow the system to fill the tank. Depending on the system and water pressure, this can take anywhere from 1 - 5 hours.
16. Once the tank has filled, open the faucet, allowing all the water to drain until flow from the faucet is down to the slow drip or stream seen in step 14. This flushes the system, cleaning the membrane and preparing it for use.
17. Repeat steps 15-16 at least once to ensure thorough flushing of the new filters.
18. Your membrane is now changed and the system is ready to use again.

O-rings:

The filter housings on the system utilize O-rings (black rubber washers, located in a grove right below the threads on the housing) to seal themselves.

To prevent leaks it is recommended to check the Orings every time the housings are opened. Ensure there are no nicks, kinks, or gouges in the O-ring. If damage is found, replace before continuing, otherwise, use a silicon based lubricant (vegetable oil can be used if no silicone lubricant is available) and lubricate the O-ring before replacing the housing.

DO NOT USE VASELINE! This will damage the o-rings and void any warranty on the system. We are not responsible for any damaged caused by using Vaseline or other petroleum lubricants. To ensure a good seal and minimize any possibility of leaks, it is recommended you replace your O-rings periodically, usually every 1-2 years.

TROUBLESHOOTINGS :

- **Leaking around filter housing (O-ring too small or not in place)**
First of all, please check if all filter cartridges are sitting upright inside the canister. Then, check if Oring is properly in place. The o-rings may be a little too small, please stretch it out and put it back inside the groove. You may over-stretch a little so when it is back to the canister, it will shrink and fit just right. Then insert the cartridge to the top cap, screw the canister all the way up. MAKE SURE ORINGS are staying in place during this process. Then use a wrench to tighten (no need to over tighten it).

- **Little water out of faucet, tank is heavy and appears full of water, but the stream turns very weak after a few seconds**
If there is no change in the supply water pressure, the problem is very likely from the tank. It could be due to low tank pressure or broken bladder. Perform the following steps first?
• Shut off main water supply
• Get a bucket under the tank and remove tank by disconnecting the ball valve.
• Dump the water from the tank by turning it upside down (through the top stem). You may add air from the front valve to help emptying the water.
• Use a gauge at the front air valve to check tank pressure. It should be within 7-10 PSI. If too low, you can use a bicycle pump to add more pressure to the tank.
• Re-connect tank to the system and turn on the water supply.

- **Low water pressure at the RO faucet or output location**
● Have you given the system enough time to fill up the tank? If you just installed the system, give it 1.52 hours to fill the tank.
● What is the total distance between the tank and the output location? If it is over 15 feet or going vertically, the pressurized tank is struggling to push out the water at an adequate pace. Shorten the distance beetween the tank and output location, or add a delivery/demand pump to assist with the output. Do not confuse this with a Booster Pump which is only for raising the INPUT pressure.
● The stage 5 Post Carbon Filter is clogged and needs to be replaced.
● If you are dispensing the RO water through your refrigerator, remove the filter that is currently installed in your fridge.
● What is the incoming water PSI to your home? If it is below 45 PSI, we recommend getting a system with a booster pump so the reverse osmosis process can be performed correctly. If you water pressure is below 45 PSI, there will not be enough water pressure to push the water through the RO

membrane on a continous basis.
● Incorrect air pressure in the tank. Shut off the main water supply to the system, and open the faucet to drain the tank. After the faucet stops dripping, close the tank valve, remove the connected yellow tube, and take the tank outside or somewhere that can get wet. Remove the tank valve from the top of the tank, and turn it upside down to drain out any remaining water. Then, use a standard tire pressure gauge to check the air pressure at the nozzle on the bottom half of the tank. The air nozzle is under a screw off blue cap. If the pressure is not between 710 PSI, use a bicycle pump to get the air pressure within that range and reconnect the tank to the system.
● If the tank feels full and no water is coming from the faucet, the tank bladder could be broken. You can verify this by measuring the tank's PSI and it being zero.

Continuous drain

All RO systems create drain water. The drain water should run only when the system is making water. The ratio of drain water to RO water is about 0.8-3:1 for our RO systems (Pumped, Side-Flow systems have lower ratio). For a regular residential household, the waste water per day is about 3 more flushes of toilet, which is not too bad. The drain should stop after the tank is full. Allow 3 hours for the tank to fill up. If the drain is still running, the problem might be caused by the following reasons?

• Faulty automatic shut-off valve (ASV, the white square valve that connects to 4 tubings),
• Faulty check valve (at the pure water outlet of the membrane housing),
• Faulty flow restrictor (the small tube that marks "flow 300" and connects to the drain line).
• Low tank pressure.

- **High TDS level in RO water**

  The RO system should produce a TDS rejection rate of about 85-95%. Check the following first?
  • What is tap water TDS reading? Is there a sudden increase in tap water TDS level.
  • Has the RO membrane been installed? It is packed in a vacuum plastic bag and in blue color, located in the accessory box.
  • Possibility of reverse drain line and pure water line. Compare your tubing connection to the diagram on the manual and check.

Quick Troubleshooting Guide

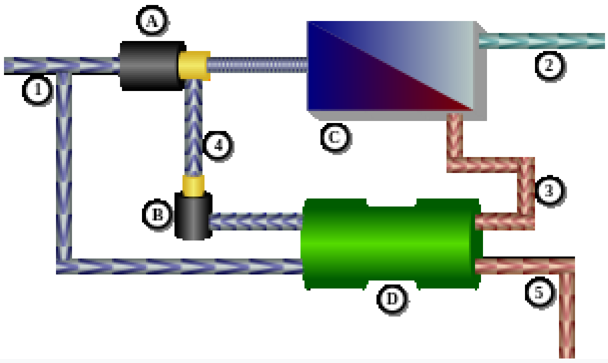
Problem	Possible Cause	Solution
No Water Production*	No Water Supply	Ensure water supply is turned on
	Insufficient Pressure	Minimum 40psi required, if less, add booster pump
	GAC Filter Upside Down	Any filter with only one gasket needs to be installed with the gasket facing up
	Clogged filters	Replace filters
	Fouled Membrane	Replace membrane
	Defective Check Valve	Replace check valve
	Defective Auto Shut Off	Replace auto shut off valve
	Defective Flow Restrictor	Replace flow restrictor
	Permeate Pump Connected Wrong/Defective	Verify pump connection, replace pump
	Obstruction In Line	Ensure all valves are open and lines are not kinked
		Trace flow of water to pinpoint cause
Waste Water Runs Constantly**	Insufficient Pressure	Minimum 40psi required, if less, add booster pump
	Clogged filters	Replace filters
	Fouled Membrane	Replace membrane
	Defective Check Valve	Replace Check Valve
	Defective Auto Shut Off	Replace auto shut off valve
	Defective Flow Restrictor	Replace flow restrictor
	Obstruction In Line	Ensure all valves are open and lines are not kinked
		Trace flow of water to pinpoint cause
Tank Not Holding Water***	No Pressure in Tank	Check pressure in tank, min. pressure 4psi, max. pressure 10psi, **with tank empty.**
	Defective Check Valve	Replace check valve

Table 6.4

Energy recovery

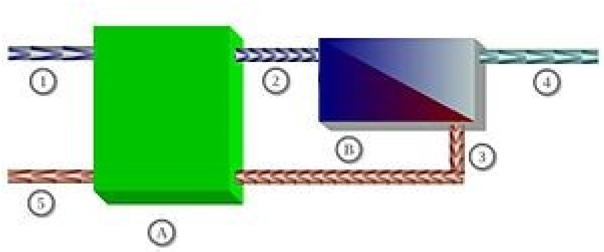
Energy recovery can reduce energy consumption by 50% or more. Much of the high pressure pump input energy can be recovered from the concentrate flow, and the increasing efficiency of energy recovery devices has greatly reduced the energy needs of reverse osmosis desalination. Devices used, in order of invention, are:

- Turbine or Pelton wheel: a water turbine driven by the concentrate flow, connected to the high pressure pump drive shaft to provide part of its input power. Positive displacement axial piston motors have also been used in place of turbines on smaller systems.
- Turbocharger: a water turbine driven by the concentrate flow, directly connected to a centrifugal pump which boosts the high pressure pump output pressure, reducing the pressure needed from the high pressure pump and thereby its energy input, similar in construction principle to car engine turbochargers.



Schematics of a reverse osmosis desalination system using a pressure exchanger.
1: Sea water inflow,
2: Fresh water flow (40%),
3: Concentrate flow (60%),
4: Sea water flow (60%),
5: Concentrate (drain),
A: Pump flow (40%),
B*: Circulation pump,*
C*: Osmosis unit with membrane,*
D*: Pressure exchanger*

- Pressure exchanger: using the pressurized concentrate flow, in direct contact or via a piston, to pressurize part of the membrane feed flow to near concentrate flow pressure. A boost pump then raises this pressure by typically 3 bar / 50 psi to the membrane feed pressure. This reduces flow needed from the high-pressure pump by an amount equal to the concentrate flow, typically 60%, and thereby its energy input. These are widely used on larger low-energy systems. They are capable of 3 kWh/m^3 or less energy consumption.



Schematic of a reverse osmosis desalination system using an energy recovery pump.
1: Sea water inflow (100%, 1 bar),
2: Sea water flow (100%, 50 bar),
3: Concentrate flow (60%, 48 bar),
4: Fresh water flow (40%, 1 bar),
5: Concentrate to drain (60%,1 bar),
A: Pressure recovery pump,
B*: Osmosis unit with membrane*

- Energy recovery pump: a reciprocating piston pump having the pressurized concentrate flow applied to one side of each piston to help drive the membrane feed flow from the opposite side. These are the simplest energy recovery devices to apply, combining the high pressure pump and energy recovery in a single self-regulating unit. These are widely used on smaller low-energy systems. They are capable of 3 kWh/m^3 or less energy consumption.

Example:

Seawater Flowrate: 100 m3/h
Applied Pressure: 75 bar
R.O. Recovery: 40%
Permeate Flowrate: 40 m3/h

Power required without energy recovery devices: 300 kW
Specific Energy: 300/40 = 7.5 kWh/m3

Power required with Energy Recovery Turbine: 177 kW
Specific Energy: 177/40 = 4.4 kWh/m3

Power required with Pressure Exchanger: 140 kW
Specific Energy: 140/40 = 3.5 kWh/m3

Turbine

The hydraulic to mechanical-assisted pumping (see Figure 1-2) uses a turbine, which is attached to a shaft that is connected to a pump and a motor. The shaft operates on the main feed. The pump, to which the shaft is connected, may be of two types— a kinetic centrifugal type or a positive displacement type. Other devices used earlier include the Pelton wheel turbines and the Francis turbines, which are also referred to as reverse running pumps. The main shortcoming of the hydraulic to mechanical-assisted 5 pumping system is that it involves double energy conversion. The first conversion occurs when hydraulic energy of the brine is converted to mechanical energy of a rotating shaft. The second conversion occurs when the mechanical energy of the shaft is then converted to the hydraulic energy of feed

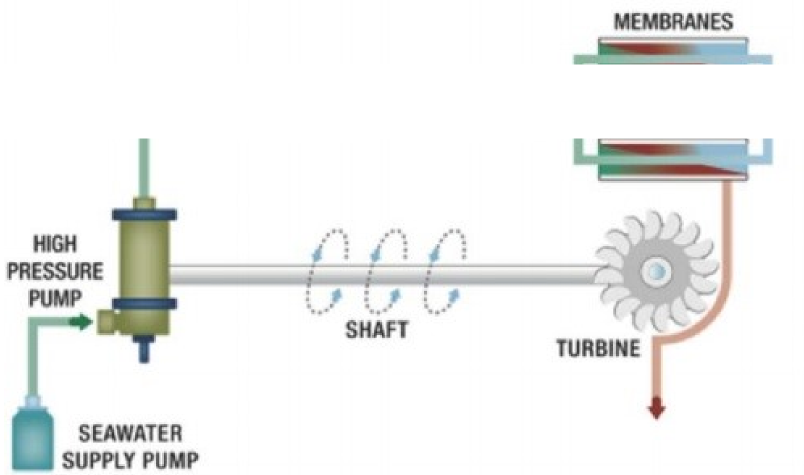


Figure 1-2: Hydraulic to Mechanical Assisted Pumping

This system of hydraulic to mechanical-assisted pumping is highly inefficient and does not significantly lower the costs associated with the process. Therefore, the search was still on for a more efficient ERD. Devices based on newer designs and technologies were then introduced. These devices drove a secondary assisting pump, thereby reducing the load on the main feed pump. In spite of its utility in reducing load and energy consumption, the reduction was not significant enough to make a considerable difference in the costs incurred during the process.

Turbo charger

The hydraulically driven pumping in series belongs to the second class of ERDs. It has an impeller and a turbine, which are coupled to a shaft within the same casing. The main feed pump and the impeller and runner are placed in series. PEI's "hydraulic 6 turbocharger", Grundfos' "Pelton-drive pump" and FEDCO's "hydraulic pressure booster HPB" are examples of the second class of ERDs. These gained significant acceptance among consumers, especially in small and midsized desalination plants. Their fullfledged use in larger systems, like the plants in the Mediterranean and the Middle East for instance, was limited because of their size limitations. Moreover, these systems failed to address the problem of converting energy from hydraulic to mechanical and then back to hydraulic, thereby hindering the efficiency of operation. They were, however, an improvement over the first class of ERDs.

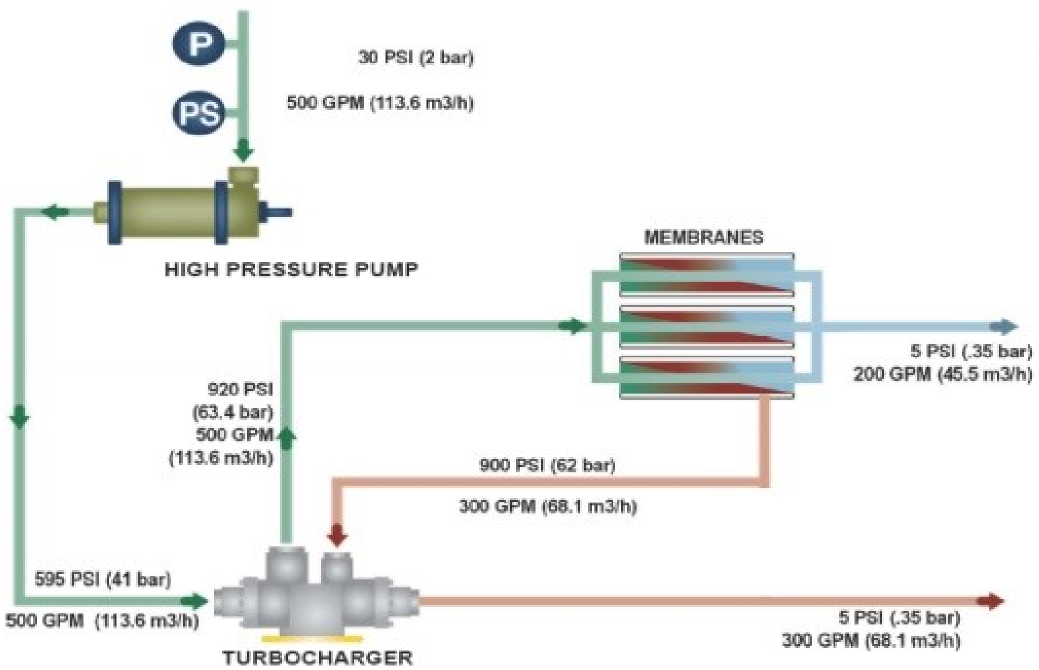


Figure 1-3: Hydraulically Driven Pumping in Series

Pressure exchanger

The late 1980s saw the emergence of a new technology that functioned on the "theory of work exchange". It involved a direct transfer of hydraulic energy of brine to hydraulic energy of feed, lacking the "drag" that would have resulted from the passage of the water throughthe shaft. This brought the technology closer to 90% efficiency

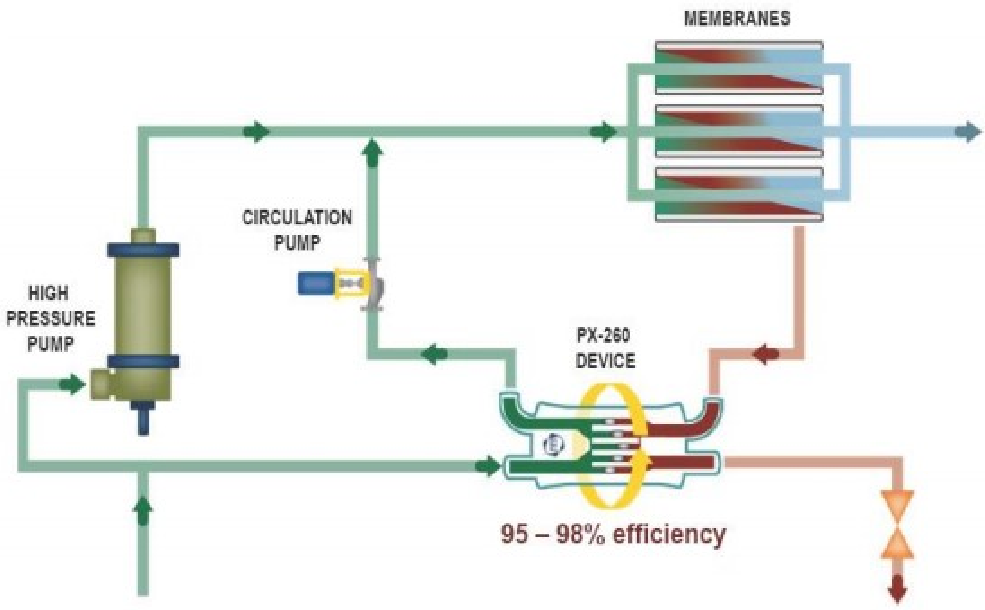


Figure 1-4: Hydraulically Driven Pumping in Parallel

This "theory of work exchange" led to the development of the third class of energy recovery devices, namely, hydraulically driven pumping in parallel. It employs the pumping of a 'buffer separating feed' or of freely reciprocating pistons. The main feed pump is placed in parallel to the device and operates on a portion of the feed, which is equal to the amount of the permeate. The device operates on the other portion of the feed whose amount is equal to the spent brine. This is based on the concept of "work exchange". In these ERDs, the hydraulic energy of brine is directly converted to hydraulic energy of feed, leading to over 90% energy efficiency. A new work exchanger device was developed based on a technology in which the number of stationary channels is fixed. A piston divides each of these channels into two working volumes, one of which is in association with brine and the other (opposing one) is in association with the feed. An exchange process ensues in these partitions, which is synchronized using 8 valves. A similar process is employed in other work exchangers wherein multiple channels are connected to a spinning rotor. The PX (pressure exchanger) is one such work exchanger. This device is also based on the same principle, in which, hydraulic energy of brine is directly converted to hydraulic energy of feed via direct contact between the two. This design disposes the requirement of valves, as there is no need for synchronizing the brine and the feed. The spinning rotor acquires a speed of 1500 rpm due to the angular momentum induced by the fluid. Because of the high speed, the fluid transit time is only 1/30th of a second, which is much less, to allow the mixing of the feed and the brine. This is thus an advantageous process. The intermixing of the feed and brine is further eliminated with the help of feed buffer. Along with the rotor's rotation, the feed buffer in the channel also reciprocates. The mixing decreases with an increase in the size of the buffer. Furthermore, the cyclic amount of feed and brine flowing through the device also decreases. By increasing the speed of the rotor, the flow rates of the brine and the feed can be increased. This increase is dependent on the conditions of the system, apart from the design of the rotor. Thus, the device's performance is limited to a small capacity, with very narrow feed and brine conditions.

SOLAR PUMPING SYSTEM

Solar pumping system is a pump running on electricity generated by photovoltaic panels as opposed to grid electricity or diesel generator water pumps.

The operation of solar pumping system is more economical manly due to the lower operation, maintenance costs and less environmental impact than pumps powered by an internal combustion engines.

Solar System Components:

Stage 1: Solar Panels

Solar panels absorb the sunlight as a source of energy to generate electricity or heat.

Stage 2: Inverter

A **power inverter**, or **inverter**, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC).

Stage 3: Battery

An electric **battery** is a device consisting of one or more electrochemical cells with external connections provided to power electrical devices such as pump

Solar panels

Simply put, a solar panel works by allowing photons, or particles of light, to knock electrons free from atoms, generating a flow of electricity. Solar panels actually comprise many, smaller units called photovoltaic cells. (Photovoltaic simply means they convert sunlight into electricity.) Many cells linked together make up a solar panel.

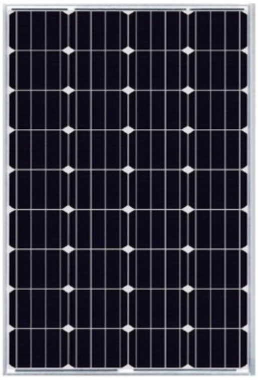


Figure 6.14

The Solar Panel Properities:

Pmax	**256.20 w**
Voc	**37.79 v**
Vpm	**30.62 v**
Ipm	**8.37 A**
Isc	**8.94 A**

Table 6.5

Inverter :-

The input voltage, output voltage and frequency, and overall power handling depend on the design of the specific device or circuitry. The inverter does not produce any power; the power is provided by the DC source.

Figure 6.15

Inverter Properities:

- Power Inverter Fully Automatic DC-AC: 1500W
- DC12V - AC220V

Battery :-

A Solar Battery Charger circuit is designed, built and tested. It acts as a control circuit to monitor and regulate the process of charging several batteries ranging

from 4 volts to 12 volts, using a photovoltaic (PV) solar panel as the input source for the battery charging process.

Figure 6.16

Battery Properities:

12volt
100Ah
Initial current: 30A
Standby use: 13.6-13.8V