WATER TREATMENT

BY

MEMBRANE FILTRATION

PAKISTAN WATER OPERATORS NETWORK

(March-2022)

PREFACE

On behalf of All water utilities in Pakistan PWON is thankful to JICA for providing Support for ***Management of Water & Sanitation Services in Punjab against Covid-19*** through which lectures / webinars were arranged January 2022, to end March 2022, for ***Better Management of Water & Sanitation Services during Outbreak*** as well *as* ***Awareness & Preventive Measures against Covid-19*** *and* ***Preparation of in house Disinfection by Water & Sanitation Utilities*.**

On demand of PWON members, lectures for capacity building of utilities in Pakistan about various important technical topics were also added along with above lectures / webinars / seminars. All these events were well participated and appreciated by all utilities

On demand of member utilities PWON has published these lectures for capacity building and references for improvement of their day to day working for the benefit of their consumers at large. This book on the topic of **WATER TREATMENT BY MEMBRANE FILTRATION** is published by PWON for the benefit of all its members.

PWON is thankful to Capt. (R) Muhammad Hafeez for Preparing this valuable document.

Syed Zahid Aziz
CHAIRMAN
PWON, Pakistan

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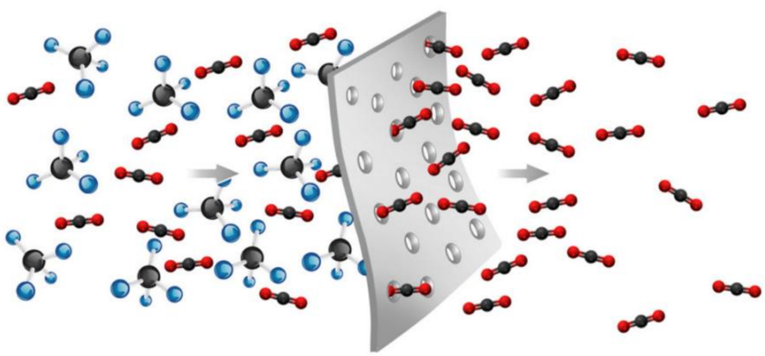
1. Every contamination has a physical body

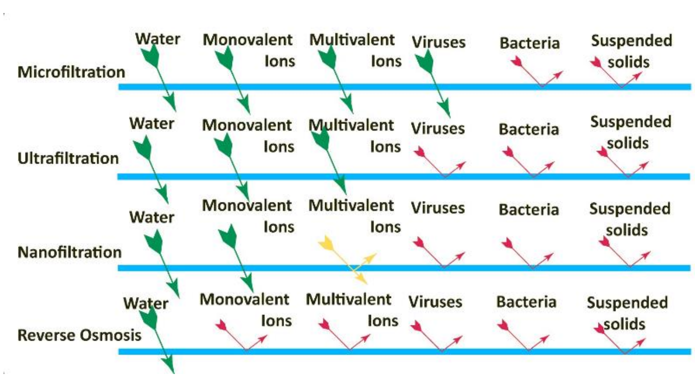
- Suspended or dissolved solids,
- Organics or Inorganics,
- color or taste causing matter
- Pathogens
- TDS: The most common chemical constituents Calcium, sodium, potassium, chloride and phosphates. Size is less than 0.001 microns.
- The size of the Giardia cyst is approximately 8 to 14 um; whereas, the Cryptosporidium oocysts are usually 4 to 6 microns. Plankton is the size of 2-85 micron.

1.2 Membranes a physical and pressure driven process



- Membrane treatment processes can be generally classified as physical processes. Membranes provide a physical barrier to contaminants.
- While water molecules are passing through tiny pores in the membranes, contaminants that are larger than the pores are rejected.
- The different types of membranes come along with a different pore size.

1.3 General categories of membranes



There are four general categories of membrane filtration systems

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

1.4 Comparison of membranes

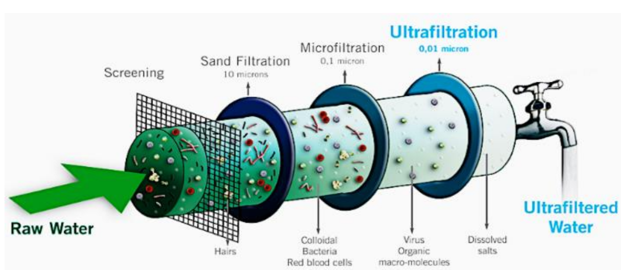
Membrane type	**Pore Size, μm**	**Operating Pressure, bar**	**Types of Materials Removed**
Microfilter	0.01-0.2	<2	Clay, bacteria, large viruses, suspended solids
Ultrafilter	0.01-0.04	1-10	Viruses, proteins, starches, colloids, silica, organics, dye, fat
Reverse Osmosis	< 0.00025	6-80	Monovalent salts

1.5 Why membrane technology is preferred now?

- No need for chemicals (coagulants, flocculates, disinfectants, pH adjustment);
- Rapid sand filtration don't filter out some contaminants completely, like
  - bacteria
  - viruses
  - industrial pollutants
  - agricultural pollutants
  - Salt
- Potable water treated with chlorine may still contain harmful organisms such as Giardia and Cryptosporidium that happen to be resistant to chlorine treatments.(These are not new organisms but these organisms have not been identified as disease causing agents until the last two decades).

To assure more effective removal of these tiny organisms, many utilities now require membrane filtration be part of new treatment facilities

1.6 Comparison of sand filtration with UF membrane

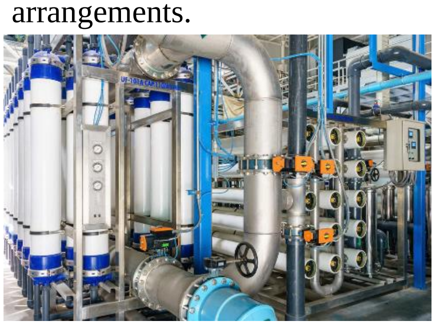


2. MICROFILTERS

- Microfiltration (MF) membranes have pore sizes that typically range from about 0.1 to 0.2 μm.
- These filters are capable of removing bacteria and cysts and typically can retain particles down to 0.1 μm in size.
- For example, Cryptosporidium oocysts range from 4 to 7 μm in size.
- Microfilters are used as prefilters in combination with RO treatment devices.

2.1 Ultrafilters

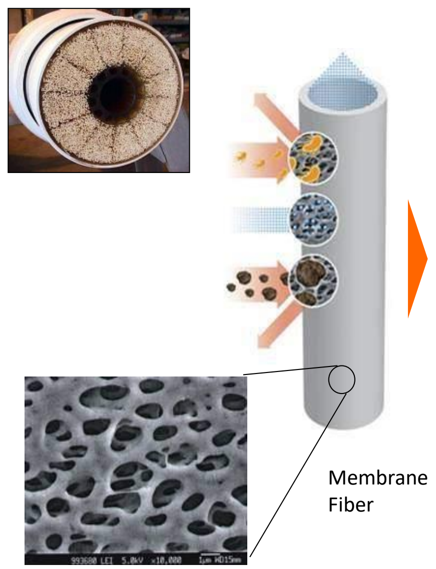
- UF membranes have pore sizes that range from about 0.01 to 0.04 μm and are capable of preventing the passage of particles including proteins and suspended solids.
- Smaller particles, such as salts, amino acids, low-weight organic compounds, inorganic acids, and sodium hydroxide, are not removed.
- UF membranes can, however, remove viruses, bacteria, and cysts.
- These filters can also be configured in flat-sheet, hollow-fiber, or tubular arrangements.



2.2 UF and MF USE Hollow Fiber Membranes

- Hollow Fiber Membranes – Bundles or Cassettes for:

- Microfiltration (MF)
  §Pressure Range: <2bar
- Ultrafiltration (UF)
  §Pressure Range: 1-10 bar
- Most are resistant to high levels of chlorine
- The pores are thousands of times smaller in diameter than a human hair



Electron microscope view of membrane surface

2.3 RO membranes types

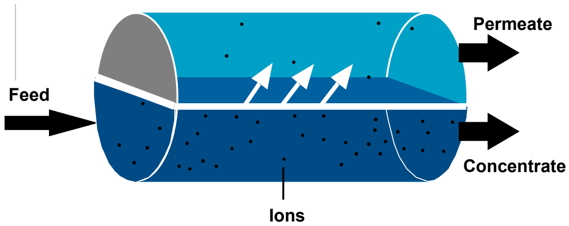
❖ The two most common RO membrane types are:
  - thin film membranes (TFMs) made of polyamide polymers
  - and cellulose acetate membranes (CAMs).

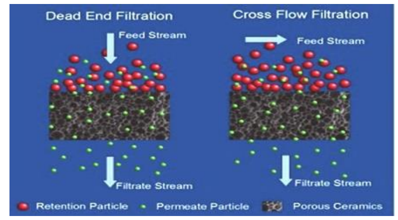
➢ CAMs are less prone to fouling than TFMs.

➢ One inherent weakness of a CAM is that it is subject to being degraded by microorganisms. While CAMs are more chlorine-resistant,

❖ TFMs are more widely used because they are more durable and can tolerate a higher range of pH.

❖ Also, their performance is better, especially in low-pressure water systems.
  - The membrane or filter typically will have a pore size between 0.00025 and 0.001 µm.
  - RO system employs cross filtration rather than standard filtration
  - typical clean water production rates are 30-40% *TDS removal is 95% to 99%*





2.4 RO,s effectiveness and weakness

- Reverse osmosis is highly effective in removing total dissolved solids (TDS), colloids, organics , asbestos, lead and other toxic heavy metals, radium, and many dissolved organics.
- RO is not effective for removal of low molecular weight (less than 100 daltons) organic compounds such as trichloroethylene, trihalomethanes, and some pesticides, and **Volatile organic compounds** (VOCs).
- RO system does not remove gases such as CO2 very well because they are not highly ionized (charged) while in solution and have a very low molecular weight.
- Because an RO system does not remove gases, the permeate water can have a **slightly lower than normal pH level depending on CO2 levels in the feed water as the CO2 is converted to carbonic acid.**

2.5 RO system needs re-mineralization

- **In fact, the reverse osmosis process removes 95-99% of beneficial calcium and magnesium from water.**
- **Calcium** is a substantial component of **bones and teeth**. In addition, it plays a role in heart and muscle contractility, intracellular information transmission.
- **Magnesium** plays an important role as a cofactor and activator of more than 300 enzymatic reactions, synthesis of proteins and nucleic acids.
- Re-mineralization required after RO
- The RO permeate coming from the existing plant is dosed with sodium bicarbonate; calcium chloride & magnesium sulphate to mineralize the RO permeate.
- Blending with bypass stream and disinfection is ok for small plants for cost effective solution for local conditions.

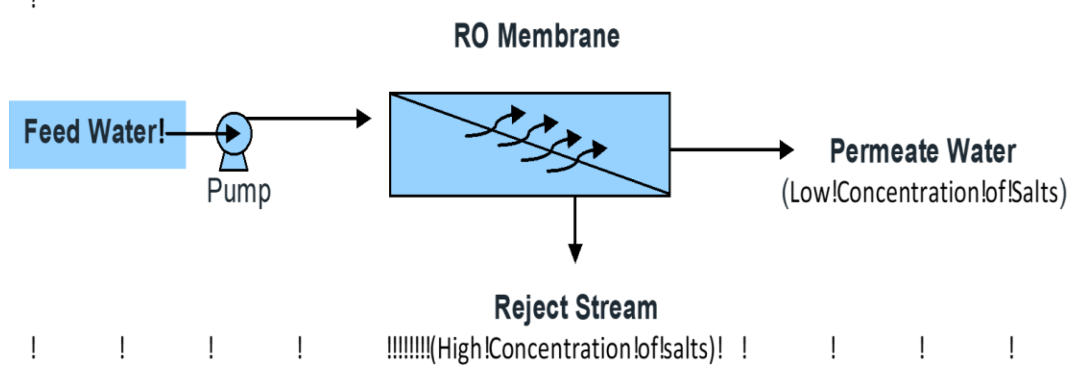
2.6 How does RO plant work?

1. **Sediment Filter:**
   To strain out sediment, silt, and dirt.
2. **Carbon Filter:**
   To remove chlorine and other contaminants as well as improve the taste and odor of your water.
3. **Reverse Osmosis Membrane:**

filter out almost all additional contaminants like sodium and impurities .

4. **Polishing Filter:**

   In a four-stage RO System, a final post filter (carbon filter) will "polish" off the water to remove any remaining taste and odor in the water.



2.7 Number of membranes

- Flux: Flux of a membrane is defined as the amount of permeate produced per unit area of membrane surface per unit time.
- J=QP/A System
- *QP* =permeate flow (L/h, and *A System* = surface area of the membrane system (m2
- Typical Flux for Brackish Wells is **23-29** L/m2.hr
- Assume permeate requirement is 2,000 l/h, take flux as 27, total active area of all membranes will be=2000/27=74.07 m2 and if each membrane (8*40 inch size) area is 37m2,
- total number of membranes will be 74.07/37=2 membranes.

2.8 Recovery & Salt Rejection

- **Percent Recovery** is the amount of water that is being ‘recovered’ as good permeate water.
- R=Qp/Qf
- Qp= Permeate flow rate produced by the membrane unit
- Qf=feed flow rate to the membrane unit
- If flow rate to membrane is 4000 liters/hr and permeate is 600 liters/hr, the recovery is=600/4000=0.15=15%
- **Salt Rejection:** (Conductivity of feed water-conductivity of permeate water)/Conductivity of feed water.
- Assume conductivity of feed water is 2000 micro Siemens and of permeate is 1920, Recovery=1920/2000=0.96=96%
- A well-designed RO system with properly functioning RO membranes will reject 95% to 99% of most feed water contaminants.
- A low salt rejection can mean that the membranes require cleaning or replacement.

2.9 Mass Balance

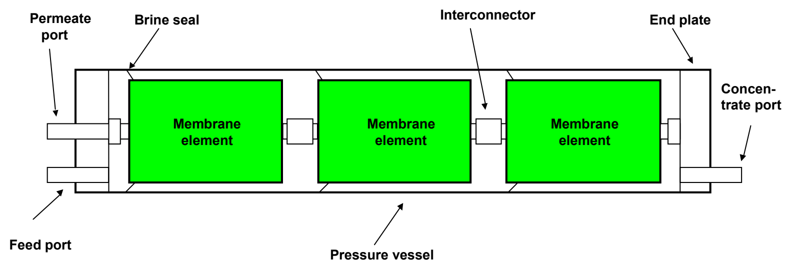
- A Mass Balance equation is used to help determine if your flow and quality instrumentation is reading properly or requires calibration.
- The mass balance equation is: (Feed flow x Feed Conductivity) = (Permeate Flow x Permeate Conductivity) + (Concentrate Flow*Concentrate Conductivity).
- For example, if you collected the following data from an RO system:
- Permeate flow=150 and its conductivity is 10, similarly feed flow is 1000 with conductivity 1200,Concentrate flow is 850 with 2000 conductivity
- Then the Mass Balance Equation would be:
- (1000 x 1200) = (150 x 120) + (850*1600)
- 1,200,000 1,378,000
- difference: 14.8%
- 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.

2.10 The design feed pressure (Pf)

- Pf =NDP+Po +Pd+Pp
- Pf=feed pressure,
- NDP=Net driving pressure,
- Po= osmotic pressure.
- Pd= average pressure drop along the RO system and
- Pp= permeate pressure.

- Net driving pressure(NDP)=NDP = $\Delta P - \Delta\pi - 0.5\times$ dp
- $\Delta P = Pf - Pp$,Feed & permeate pressure differential
  $\Delta\pi = \pi(Cf\ ave) - \pi(Cp)$, average osmotic pressure differential
- π (Cave), average feed osmotic pressure, π (Cp), permeate osmotic pressure Cf ave=(Cf +Cc)/2, average feed concentration.
- Osmotic pressure thumb rule= Osmotic pressure (PSI)= (TDS) ÷ 100
- For Average applied pressure of 160 psi if TDS of feed 2000, Osmotic pressure will be =20psi, if Pd=10 psi & permeate pressure 15psi
- Design feed pressure=(160-20) +20+10+15=185 psi

2.11 Membrane assembly units



- Membrane elements are installed in the pressure vessels.
- Each pressure vessel may contain from one to seven membrane elements connected in series
- In each stage pressure vessels are connected in parallel
- A high volume of feed water flows in at the start, and a relatively small volume of concentrate leaves at the end.
- The number of stages depends on the system recovery, the number of membrane elements per vessel, and the feed water quality. A general rule is to use one stage for 40%–60% recovery, two stages for 70%–80% recovery

2.12 Difference between 1 and 2 stage Reverse Osmosis

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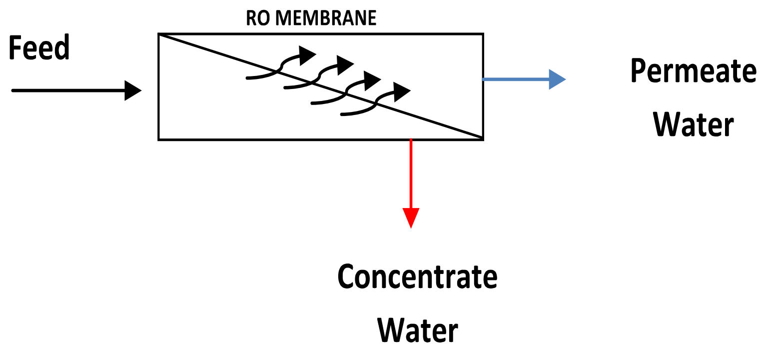
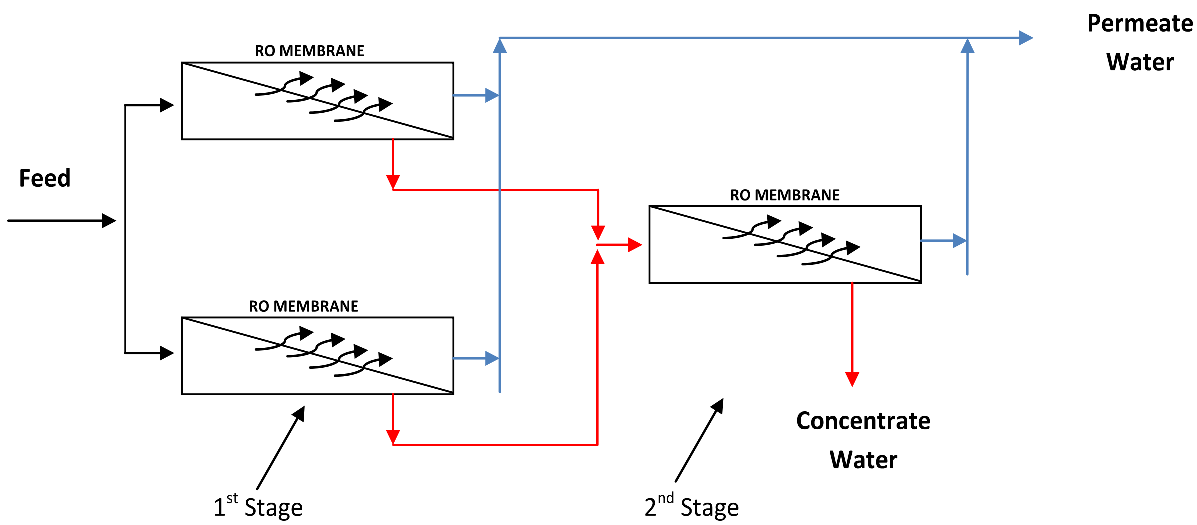
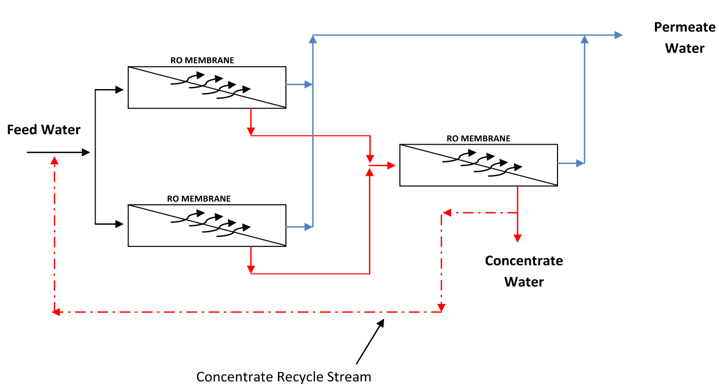




- The 2 stage RO system displayed is a 2:1 array
- which means that the concentrate (or reject) of the first 2 RO vessels is fed to the next 1 vessel.

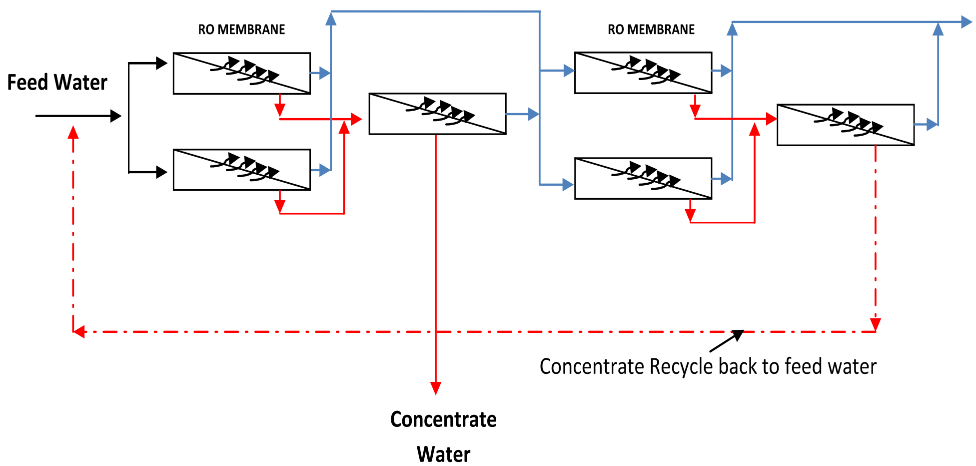
2.13 RO System with Concentrate Recycle



- With an RO system a concentrate recycle setup can be utilized where a portion of the concentrate stream is fed back to the feed water to the first stage to help increase the system recovery.

2.14 Single Pass RO vs Double Pass RO

- The difference between a single pass RO system and a double pass RO system is that with a double pass RO, the permeate from the first pass becomes the feed water to the second pass (or second RO) which ends up producing a much higher quality permeate because it has essentially gone through two RO systems.



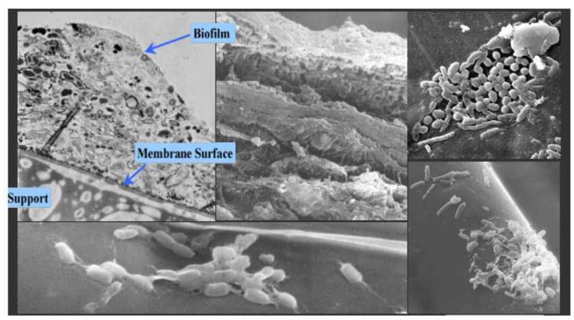
2.15 Additional treatment after RO

- If you have mixed bed ion exchange resin beds after the RO for removal of last traces of TDS & Silica.
- C02 is undesirable for this process.
- Remove carbon dioxide gas from the permeate by injecting caustic between the first and second pass.
- By adding caustic after the first pass, you increase the pH of the first pass permeate water and convert C02 to bicarbonate (HCO3-) and carbonate (CO3-2) for better rejection by the RO membranes in the second pass.
- This can't be done with a single pass RO because injecting caustic and forming carbonate (CO3-2) in the presence of cations such as calcium will cause scaling of the RO membranes.

3. MEMBRANE FOULING

- Fouling typically occurs in the front end of an RO system and results in a higher pressure drop across the RO system and a lower permeate flow. This translates into higher operating costs and eventually the need to clean or replace the RO membranes.
- Fouling can be caused by the following:
- Particulate or colloidal mater (dirt, silt, clay, etc.)
- Organics (humic/fulvic acids, etc)
- Microorganisms (bacteria, etc). Bacteria present one of the most common fouling problems
- Since RO membranes in use today cannot tolerate a disinfectant such as chlorine and therefore microorganisms are often able to thrive and multiply on the membrane surface. They may product biofilms that cover the membrane surface and result in heavy fouling.
- The most popular methods to prevent fouling are the use of multi-media filters (MMF) or microfiltration (MF). In some cases cartridge filtration will suffice.

3.1 Biofouling & Particulate fouling



- Biofouling is different from other types of fouling in that the deposit (biofilm) is not brought with the feed stream, but develops in place, by consuming nutrients found in the feed.

3.2 Scaling & Chemical attack

- As certain dissolved (inorganic) compounds become more concentrated then scaling can occur if these compounds exceed their solubility limits and precipitate on the membrane surface as scale.
- The results of scaling are a higher pressure drop across the system, higher salt passage (less salt rejection), low permeate flow and lower permeate water quality.
- An example of a common scale that tends to form on an RO membrane is calcium carbonate ($CaCO_3$).

3.3 Chemical Attack of Chlorine

- Modern thin film composite membranes are not tolerant to chlorine or chloramines.
- Oxidizers such as chlorine will 'burn' holes in the membrane pores and can cause irreparable damage.
- The result of chemical attack on an RO membrane is a higher permeate flow and a higher salt passage (poorer quality)

3.4 Pretreatment Solutions: Pre-filtration

- Sand filters=20-30 microns.(Sand filters remove 90% particles. Remaining particles have less size than 20 micron.
- A 5-10 microns Multi-Media Filter is used to help prevent fouling of an RO system.
- It is important to have a 5 micron cartridge filter placed directly after the MMF unit in the event that the under drains of the MMF fail.
- Bio fouling of the membranes is due to bacteria that has size from o.2 to 2.0 micron in width and 1 to 10 micron in length.
- So a 1-micron filter will remove most bacteria and cysts in waters where biofouling is a concern.
- Microfiltration is effective in removing colloidal and bacteria matter and has a pore size of only 0.1- 10µm.It will also remove Giardia cyst approximately 8 to 14 um; whereas, the Cryptosporidium oocysts 4 to 6 microns and Plankton the size of 2-85 micron.

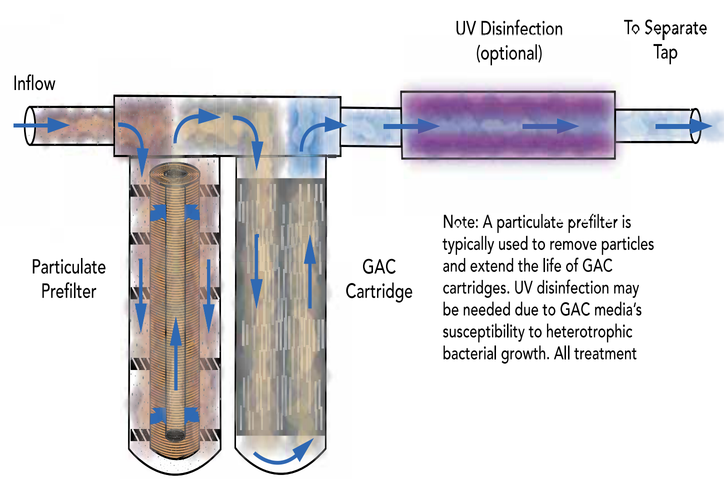
3.5 Antiscalants/Scale Inhibitors

- Before an RO unit to help reduce the scaling potential of the feed water.
- Most antiscalants are proprietary organic man-made polymers.
- Antiscalants and scale inhibitors work by interfering with scale formation and crystal growth.
- **Water Softening**
- A water softener can be used to help prevent scaling in an RO system by exchanging scale forming ions with non scale forming ions.
- As with a MMF unit, it is important to have a 5 micron cartridge filter placed directly after the water softener in the event that the under drains of the softener fail.

3.6 Granular Activated Carbon (GAC)

- GAC is used for both removing organic constituents and residual disinfectants.
- Activated carbon removes residual chlorine and chloramines.
- The disadvantage of using a GAC before the RO unit is that the GAC will remove chlorine quickly at the very top of the GAC bed.
- This will leave the remainder of the GAC bed without any biocide to kill microorganisms.
- A GAC bed will absorb organics throughout the bed, which is potential food for bacteria, so eventually a GAC bed can become a breeding ground for bacteria growth which can pass easily to the RO membranes.
- Sodium Bisulfite
- The two most common pretreatment methods for reducing chlorine levels are by activated granular carbon filter media, or by the use of a chemical reducing agent such as sodium bisulfite.

3.7 Particulate filter before GAC



3.8 Cleaning in place-(CIP)

- RO membranes will inevitably require periodic cleaning, depending on the feed water quality. Some experts suggest monthly CIP.
- As a general rule, if the normalized pressure drop or the normalized salt passage has increased by 15%, then it is time to clean the RO membranes.
- **Backwash with air/water scour**

There are many other factors involved such as flows, water temperature and quality, properly designed and sized cleaning skids and many other factors

3.9 Cleaning In Place procedure

- Removing Organics and Clays
- Heat permeate to 35-40 C and mix with chemical recommended by manufacturer and circulate solution for 30 minutes.
- Soaking for 2 hours normal however it may be for 15 hours if scale removal is not successful.
- Inorganic cleaning (With mild acid cleaner) Any reduction in PH indicates scale removal and discoloration indicates ions removal.
- Repeat 2-3 times depending upon extent of fouling.

3.10 Desalination Process

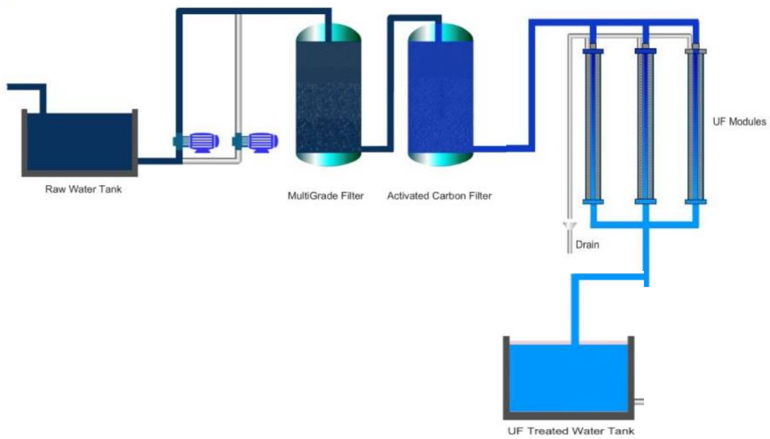
- Pretreatment with Rapid sand dual media filter complete process.
- Secondary Treatment with microfiltration
- Main process is RO Plant
- Post treatment with re-mineralization and disinfection with chlorine

3.11 Most common brine disposal methods in US

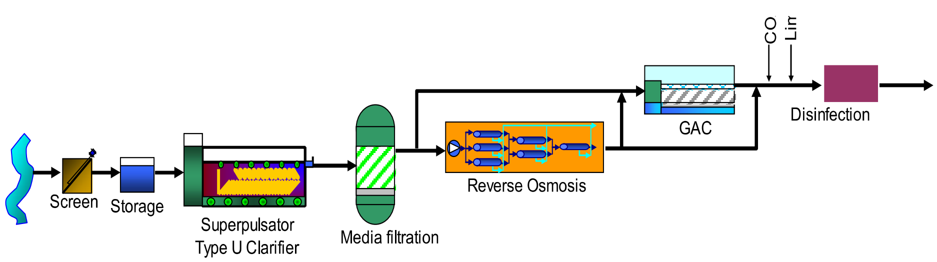
Brine disposal method	**Description**	**% of total capacity**
Deep well injection	Brine is injected into porous subsurface rock formations	13
Land application	Brine is used for irrigation of salt-tolerant crops and grasses	8
Evaporation ponds	Brine is allowed to evaporate in ponds while the remaining salts accumulate in the base of the pond	4
Sewer discharge	Discharge of brine into an existing sewage collection system	27
Seawater discharge	Brine is discharged on the surface of seawater. The most common method for all big desalination facilities worldwide	45
Seawater discharge; Submerged	Brine is discharged off shore through multiport diffusers installed on the bottom of the sea	

4. ADDITIONAL FILTERS WITH OPTIONAL UF MEMBRANE OR CHLORINATION

- Add additional filters between sand and carbon filter for following requirement:
- Arsenic Removal: Ferric hydroxide filter
- Nitrates Removal, strong base anionic resin filter
- Arsenic and Nitrates Removal both: resin and ferric hydroxide filters
- Fluoride Removal: Activated alumina filter



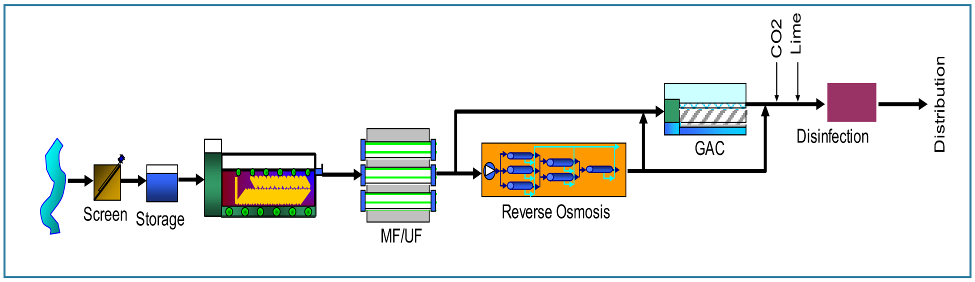
4.1 Ro & Gac After Sand Filtration



Consisting of

- Coagulation,
- Clarification,
- Media filtration(Sand Filtration),
- RO,
- GAC
- and post-treatment
- Post-treatment consisting of addition of carbon dioxide and lime for PH adjustment and disinfection using chlorine

4.2 Membrane Filtration in place of rapid sand filtration



Coagulation

+ Clarification

+ Membrane Filtration

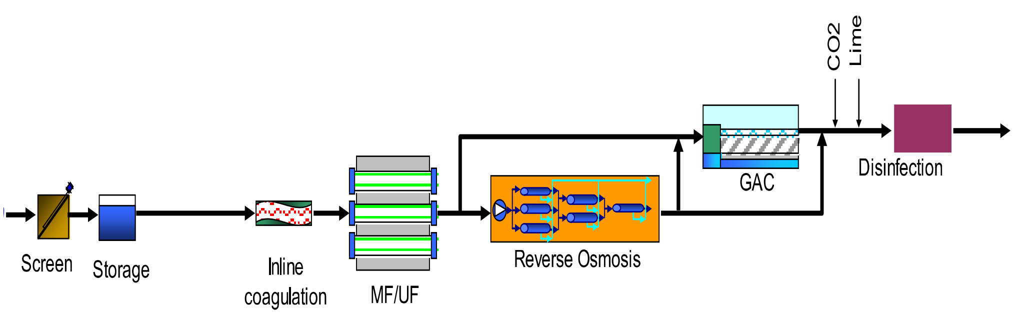
+ Reverse Osmosis

+ GAC

+ Post Treatment

4.3. Direct treatment of coagulated water (no sedimentation/clarification) with membrane filtration.

- Coagulation is added + Membrane Filtration + Reverse Osmosis + GAC + Post Treatment
- Typically, this process is economically viable when the turbidity of the raw water is low, the concentration of organic material is not high and the required coagulant doses are low.

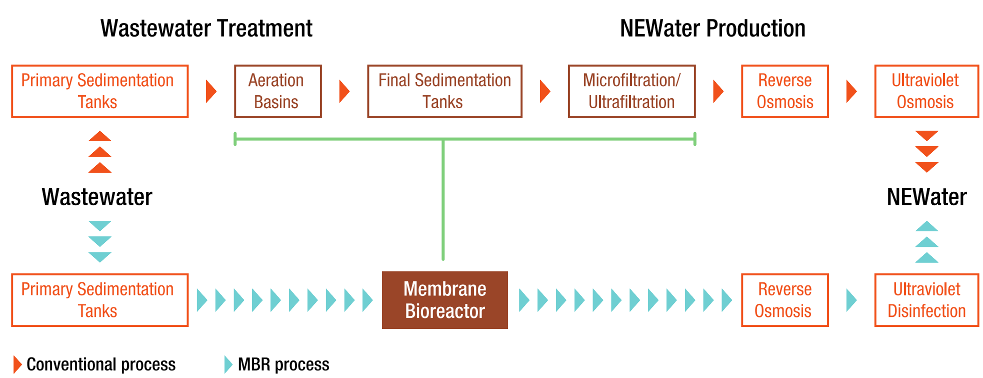


5. RECYCLING WASTEWATER THROUGH MEMBRANE TECHNOLOGY IN SINGAPORE

- In Singapore, indirect potable water reuse has been applied during the last two decades. Now, water reuse furnishes around 30%(115MGD) of the nation's water request.
- The most difficult challenge for Singapore to overcome was persuading people to drink it.
- To combat this, a dedicated communications team conducted a massive public education campaign which included a TV documentary.
- They also released the cleaned-up wastewater into reservoirs where it got re-treated along with regular tap water.
- Psychologically, this extra step was vital in helping the people of Singapore accept NEWater as drinkable water.

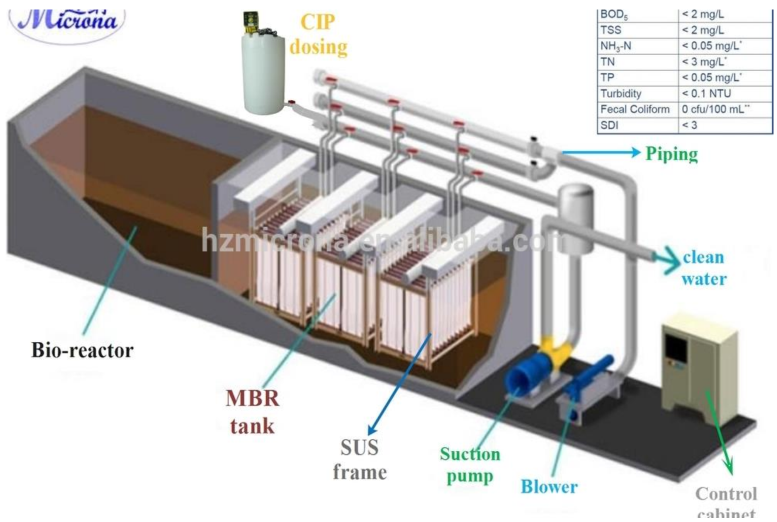
5.1 Advanced Treatment System

Incorporating a more compact aeration tank and space-efficient inclined lamella primary settling tank and eliminating the need for an additional sedimentation tank. Low sludge production



Schematic of the conventional vs MBR process for water reclamation. The MBR process offers smaller footprint, robustness, better filtrate quality, less RO fouling and higher RO fluxes.

5.2 Membrane Bioreactor for wastewater treatment



- The membranes in the system eliminate the need for secondary clarifiers.
- A more compact aeration tank and anoxic tank for simultaneous nitrification/denitrification.
- Following an Aerobic Zone where microorganisms with the help of the oxygen coming out of the FBD will digest the organics matter in the wastewater and clump together as they do so, producing a sludge.
- Sludge mixture is pumped from the bioreactor to the submerged Membrane that will separate the solids and microorganisms from water.

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