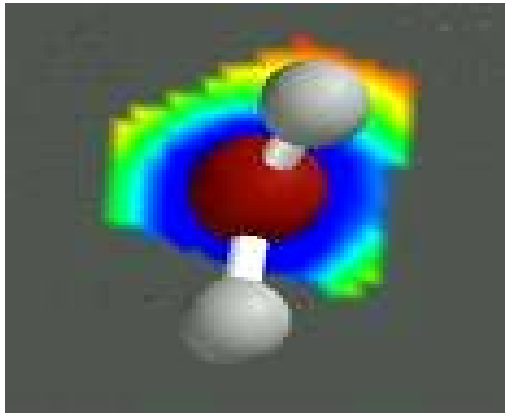
Water treatment System for Haemodialysis and Management

Certificate Renal Nursing Course 2010

Water

- Water is a complex and incompletely understood chemical compound

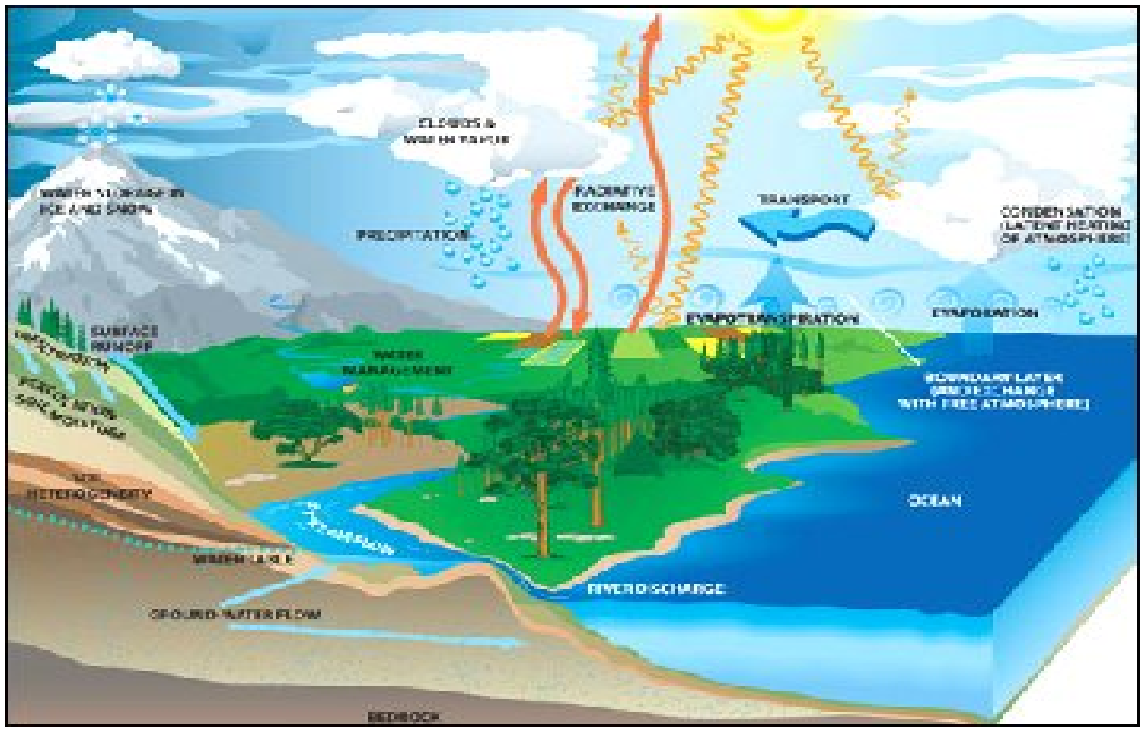


Water

- What impurities in tap water?
  - Chemical solutes
  - Bacteria or bacteria products
  - Particulate matter

Water

Cloud → Rain → Water



Water

Rain water → air → ground

\+

Carbon Dioxide / Sulfur Dioxide

\+

Limestone / Minerals

↓

Carbonic acid

Sulfuric acid

↓

Calcium bicarbonate

Magnesium carbonate

Salts

Water

Common ionic constituents

- Sodium
- Chloride
- Iron
- Aluminum
- Nitrates
- Magnesium
- Copper
- Zinc
- Iodine
- fluoride

Water

- Nonionic organic compounds
  - Proteins
  - Polypeptides
  - Phenols
  - Indoles
  - Aldehydes

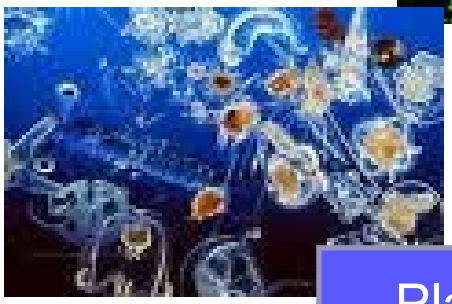
Water

- Solid particles
  - Iron
  - Sand
  - Silica

Water

- Suspension material
  - Algae
  - Plankton
  - Mud
  - Bacteria
  - Viruses
  - Dissolved gases

Algae



Plankton

Viruses

Water

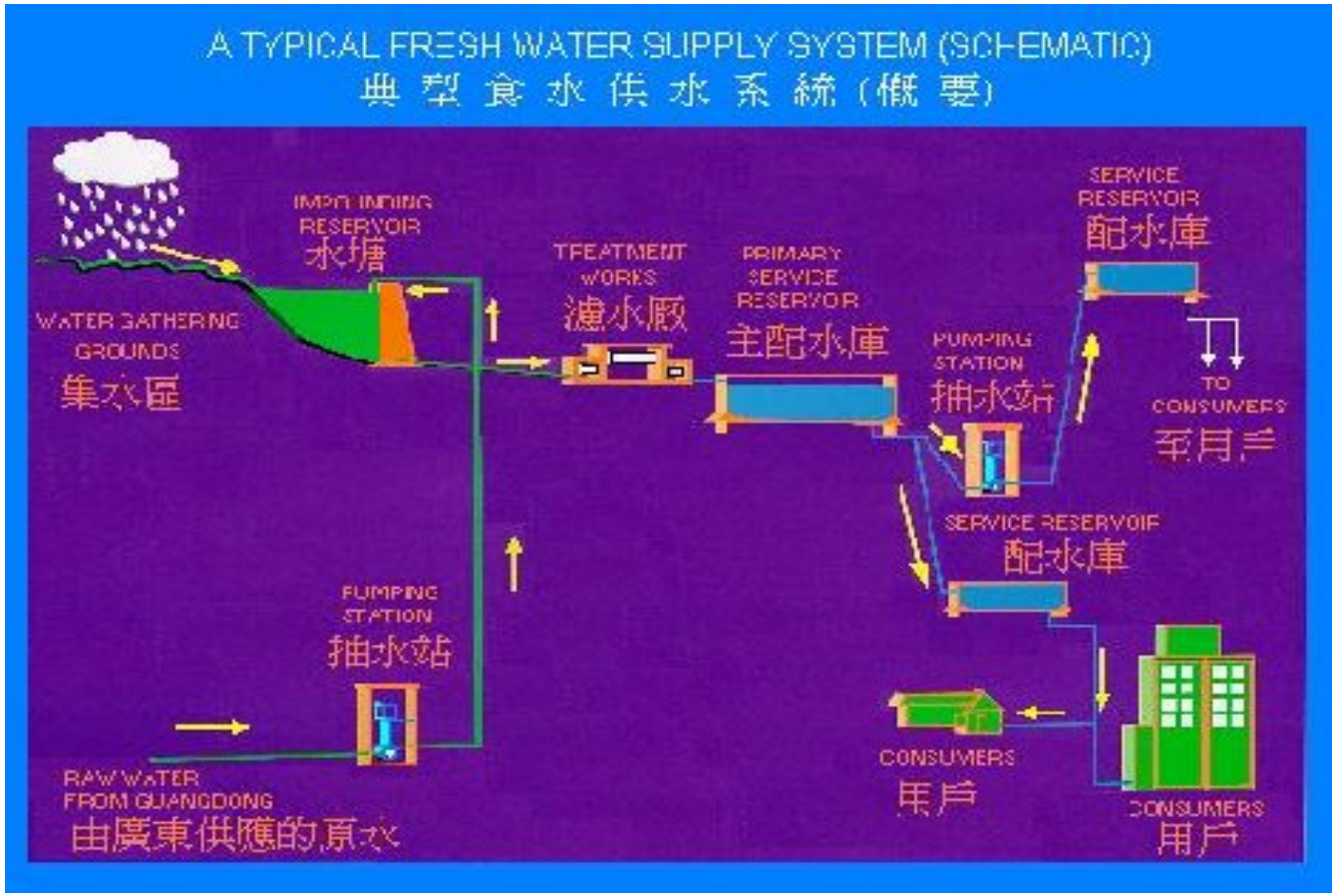
- Most water supplies contain various kinds of bacteria
  - Flavobacterium
  - Achromobacter
  - Serratia
  - Pseudomonas
  - Atypical mycobacteria

Pseudomonas

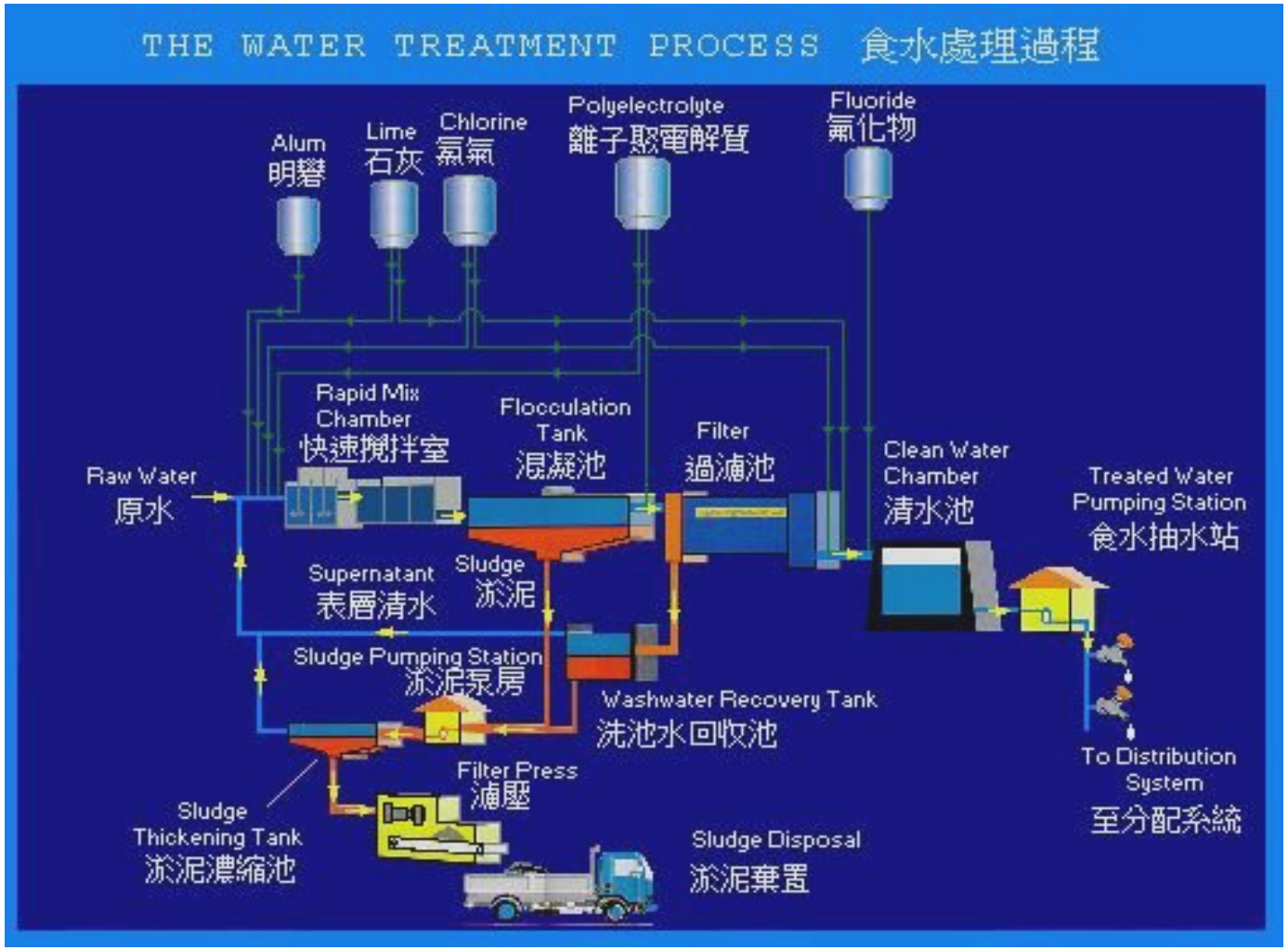
Serratia

Water

- HK Water Supplier Department



Water


THE WATER TREATMENT PROCESS 食水處理過程
Alum
明礬
Lime
石灰
Chlorine
氯氣
Polyelectrolyte
離子聚電解質
Fluoride
氟化物
Rapid Mix Chamber
快速攪拌室
Flocculation Tank
混凝池
Filter
過濾池
Clean Water Chamber
清水池
Treated Water Pumping Station
食水抽水站
Raw Water
原水
Supernatant
表層清水
Sludge
淤泥
Sludge Pumping Station
淤泥泵房
Washwater Recovery Tank
洗池水回收池
To Distribution System
至分配系統
Filter Press
濾壓
Sludge Thickening Tank
淤泥濃縮池
Sludge Disposal
淤泥棄置

Water Treatment for hemodialysis

- During hemodialysis, the patient's blood is often exposed to more than120 liters of water
- Dialysis flow (500ml/min) x 60min/hour x Duration of the treatment (5 hours)

  = 150 liter / treatment

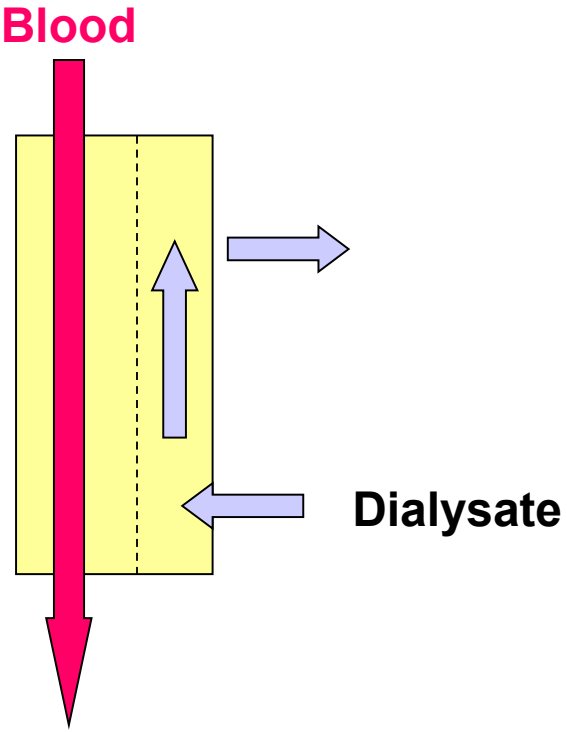
  = 30 liter / hour of hemodialysis
- Dialysis flow (800ml/min) x 60min/hour x Duration of treatment (5hours)

  = 240 liter / treatment

  = 48 liter / hour of haemodialysis

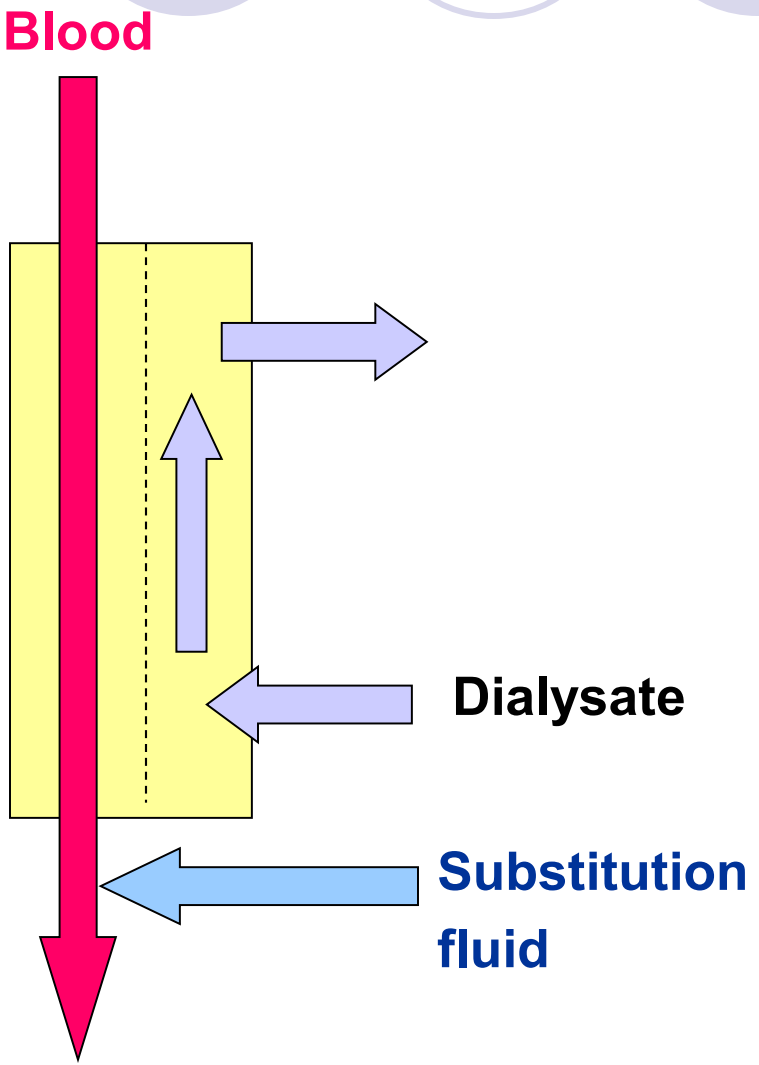
Water Treatment for hemodialysis

- Small molecular weight substances in the water have direct access to the patient's bloodstream.



Water Treatment for on-line Hemodiafiltration

- On-line HDF



Water Contaminants that have been identified as toxic in the dialysis setting and the toxic effects associated with these contaminants are:

Contaminant	Toxic effects	Min. Conc. (Mg / L)
Aluminum	Encephalopathy, bone disease	0.06
Ca / Mg	Hard water syndrome	88(Ca ++)
Chloramines	Hemolysis, anemia, methemoglobinemia	0.25
Copper	Liver demage, Hemolytic anemia	0.49
Fluoride	Osteomalacia, osteoporosis, bone disease	1.0
Nitrate	Myoglobinemia, BP↓, nausea	21(as N)
Sodium	BP↑, pulmonary edema, confusion, vomiting, headaches, tachycardia, shortness of breath,	300
Sulfate	Nausea, vomiting, metabolic acidosis	200
Zinc	Anemia, nausea, vomiting, fever	0.2
Microbiologic	Pyrogen reactions- fever, chills, nausea etc	---

Water Treatment

- Purpose
  - To remove bacteria and pyroxenes
  - To remove trace minerals like aluminum
  - To prepare water for dialysate that is sufficiently pure (free of contaminants)

Quality of water for dialysis

- Inorganic contaminants
- Microbiological contaminants
- Endotoxin contaminants

Quality standard in dialysis

COUNTRY	DOCUMENT	FLUID	LIMITS	
			CFU/ml	EU/ml
EUROPE	Ph Eur 2005	Water	$<10^2$	<0,25
SWEDEN	SLS 2007	Water	$<10^2$	<0,25
		Dialysis Fluid	$<10^2$	<0,25
FRANCE	Circ 2007:52	Water	$<10^2$	<0,25
		Dialysis fluid	$<10^2$	<0,25
GERMANY	RKI	Water	100	-
USA	USP XXX	Water	100	2
	AAMI RD52	Water	200 (50)	2 (1)
		Dialysis fluid	200 (50)	2 (1)
JAPAN	JSDT 1995	Water	100	<0,25

AAMI maximum levels of chemical contaminants

Contaminant	Conc. In raw water 11/2009	AAMI (mg/ L) Suggested maximum level
Aluminum	0.019	0.01
Arsenic	<0.001	0.005
Barium	0.025	0.1
Cadmium	<0.0002	0.001
Calcium	14	2
Chloramine	Not done	0.1
Chromium	<0.001	0.014
Copper	0.004	0.1
Fluoride	0.5	0.2

AAMI maximum levels of chemical contaminants

Formaldehyde	Not done	0
Lead	<0.001	0.005
Magnesium	1.7	4
Mercury	<0.0005	0.002
Nitrate	1.7	2
Potassium	3.2	8
Selenium	<0.005	0.09
Silver	<0.001	0.005
Sodium	8.9	70
Sulphate	20	100
Total Chlorine	0.7	0.5
Zinc	<0.01	0.1

Clinical Application of tests

- Evaluate the design and safety of water treatment systems for dialysis
- Monitor the effectiveness of water treatment
- Identify problems before patient health
- Monitor changes in water sources

Renal Centre Water Quality Schedule

Specimen	Type of Test	Frequency
RO Water	Inorganic contaminants	Half yearly
	Bacterial Culture (Post RO & Post loop)	Monthly
	Endotoxin (Post RO & Post loop)	
	Chloramines	
	Free Chlorine	Weekly
	Hardness	
Raw Water	Inorganic elements	Half yearly
Dialysate Mixed from HD	Bacterial culture	Monthly
	Na, K, HCO_3	When Batch change
Ultrapure	Bacterial culture	Monthly & before Online HDF
	Endotoxin	

Sites of water sampling

- Depend on the system structure
- Close loop system – pre + post RO
- Open loop system – post RO + each open end

Microbiological contaminants

- Microbial count
- Test should be done at least monthly
- The sites of water sampling depend on the system structure

HD	<200 cfu / ml
Online HDF	$<10^{-1}$ cfu / ml before IV Infusion into the patient's circulation

Control of microbiological quality

- Sample storage
  - Immediate storage of sample at 4ºC
  - The sample should be analyzed within 24 hours
- Culture medium
  - Bacterial culture of TGEA
  - TGEA = Tryptone Glucose Extract Agar

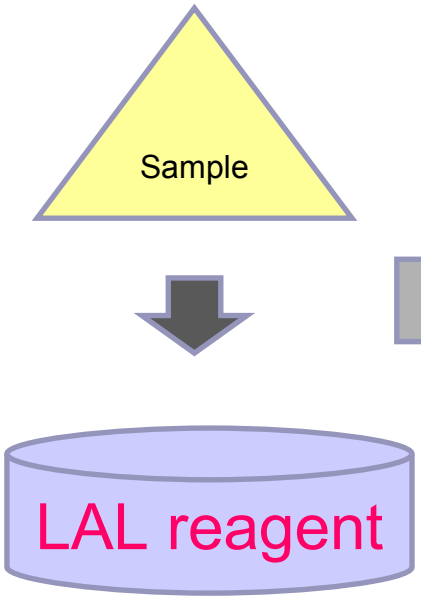
Standard Methods Agar

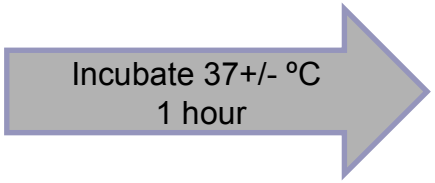
Endotoxin contaminants

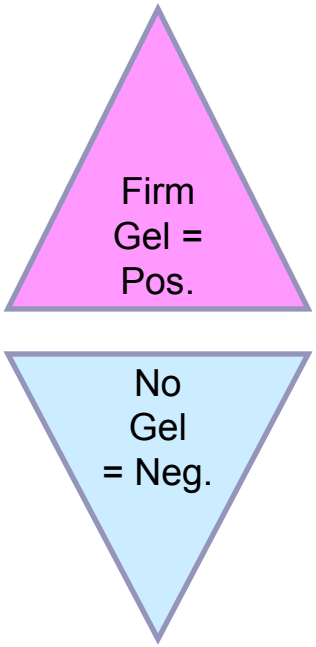
- Endotoxin (LAL)
- LAL= Limulus amoebocyte lysate test

HD	<0.25 Eu / ml
Online HDF	<0.03 Eu / ml

LAL Test


Sample
LAL reagent


Incubate 37+/- ºC
1 hour


Firm
Gel =
Pos.
No
Gel
= Neg.

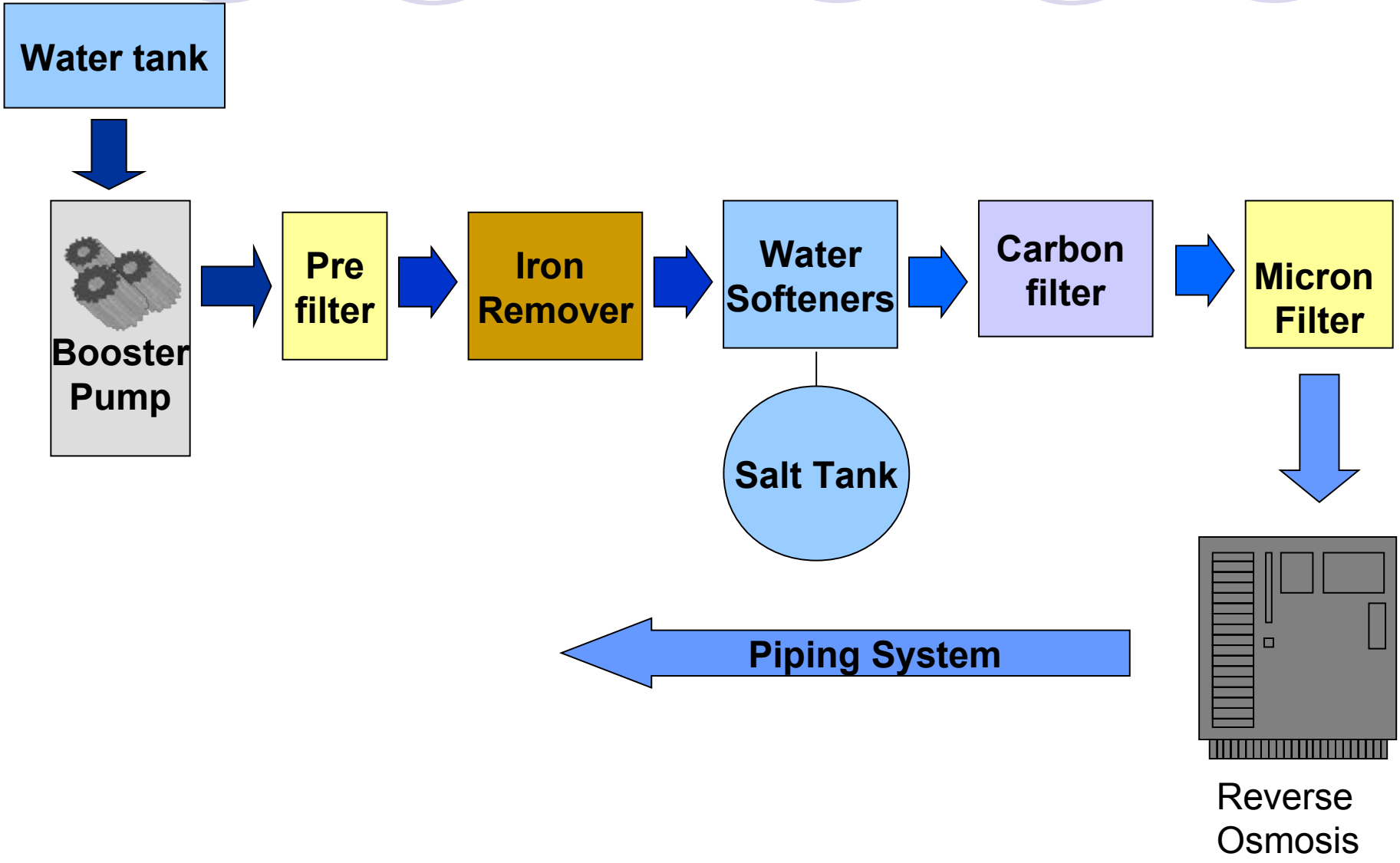
What is Water Treatment System?

- System that produces **Purified Water** for preparation of Dialysate for **Haemodialysis**

Basic components of water treatment system:

- Pre-treatment of municipal water treatment
- A purification process
- A hydraulic circuit for the distribution of purified water

Example Design of Water Treatment System



Water Tank

Water Tank Sizing

- HD machine output
- Number of HD served
- Dependent on operation need
- Rejection ratio
- Contingency

Water Tank Maintenance

- Cleaned every four month

Function of Pre treatment system

- Pretreatment is done to minimize the potential to plug reverse osmosis (RO) membrane
- To remove material that might not be removed by the RO step in water treatment

Pre-treatment system

- Booster pump
- Pre filter
- Iron remover
- Water softener
- Activated carbon filter

Booster pump

- Additional Pressure for Downstream components
- 3 phase high power pump
- Alarm at control cabinet
- Operation Lamp

Booster pump

- To ensure water pressure to reverse osmosis machine to achieve the requirement
- To be applied only if water pressure is insufficient

Particulate filter

- First line filtration
- Particulate filtration is based on size exclusion
- Particulate filters are rated by the nominal pore size for particulate exclusion and the maximum flow rate

Particulate filter

- To remove suspended particles such as mud, sand, rust, and algae
- Dissolved particles, such as ions , remain in the water

  (Gutch &Stoner,1993)

Iron remover

- The filter medium has the ability to oxidize and dissolved iron and manganese
- Backwashing is require to remove precipitate trapped in the filter medium
- Iron compounds could be detrimental to RO
- Principle similar to Water softener

  (Iron exchange)

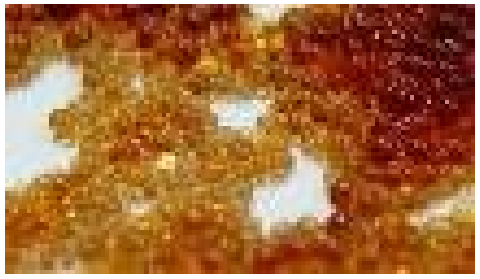
Water softener

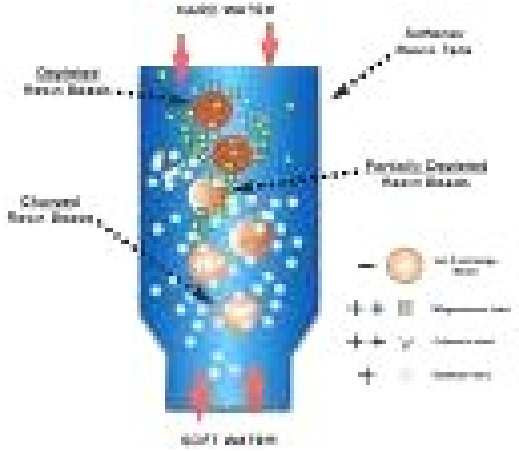
- Purpose :

  Remove hardness from the water to avoid scaling of the RO- membrane
- Hardness of water is determine by the presence of calcium and magnesium
- Softener is based on principle of ion exchange
- Connected with Salt Tanks for replenishment
- The water softening process replaces calcium and magnesium ions with sodium ions while the water passes through an exchange resin bed
- Automatic Timer for regeneration

Water softener

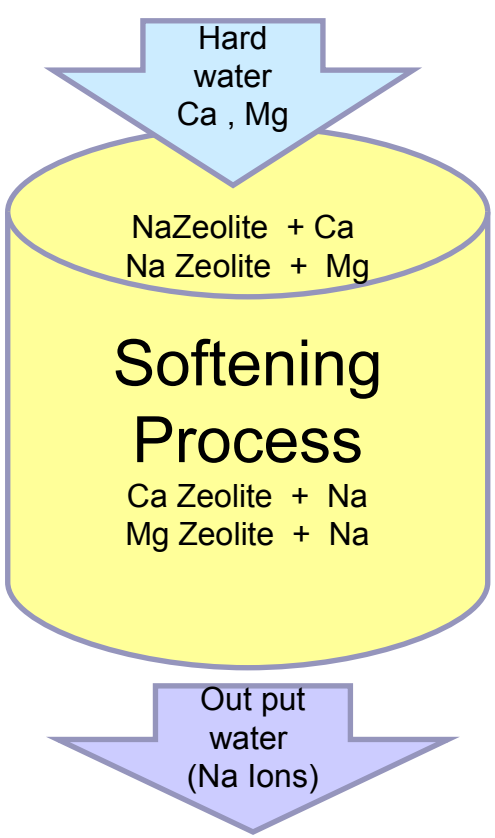
- A softener contains millions of small beads (0.2mm) of polystyrene (resin), with negative sires that are saturated with sodium ions (Na^+)
- Exchange occurs on a mill equivalent per mill equivalent basic
  - E.g.: each Ca ion (++) removed, two Na ion(+) are exchange

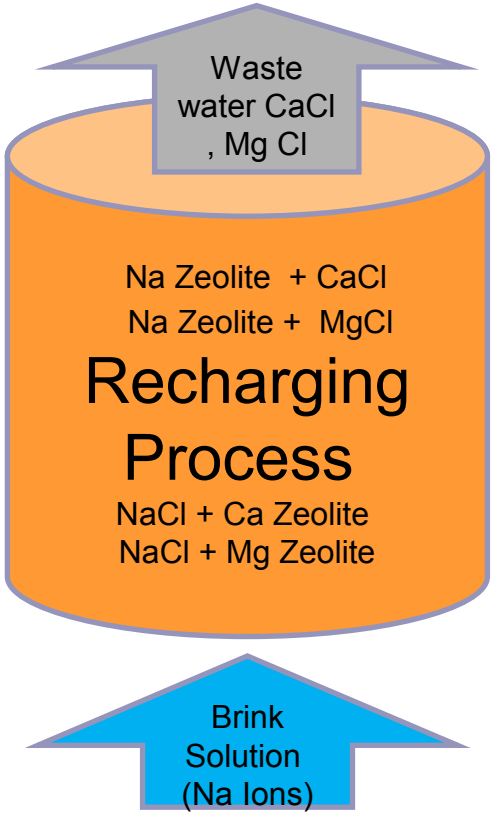




Water softener

- Ion exchange - when water passes through the filter, the resin will remove the hardness (Ca^{2+} & Mg^{2+}) in exchange for sodium(Na^{+})





Water softener

- Type of softener
  - Portable exchange
  - Permanent

Portable

Permanent

Water softener

- Portable exchange
  - Provide ready-for-use by the vendor
  - Regeneration of the media resin is performed by the vendor at a central facility

Water softener

- Permanent softener
  - Have a concentrated salt tank and valves and controls for on-site regeneration

Water Softener

- Maintenance
  - Regularly check the residual hardness with an appropriate test method
  - Check salt level in brine tank and refill when required.
  - Use salt of high quality (intended for softener regeneration). Do not use rock salt!

Water softener

- There are no on-line monitor that will indicate “hard” or “soft” water
- Commercial test kits for total hardness
- The result indicate the need for the regeneration cycle, as well as any softener malfunction
- Failure of the softener may include hard water syndrome in patient

Activated charcoal filter

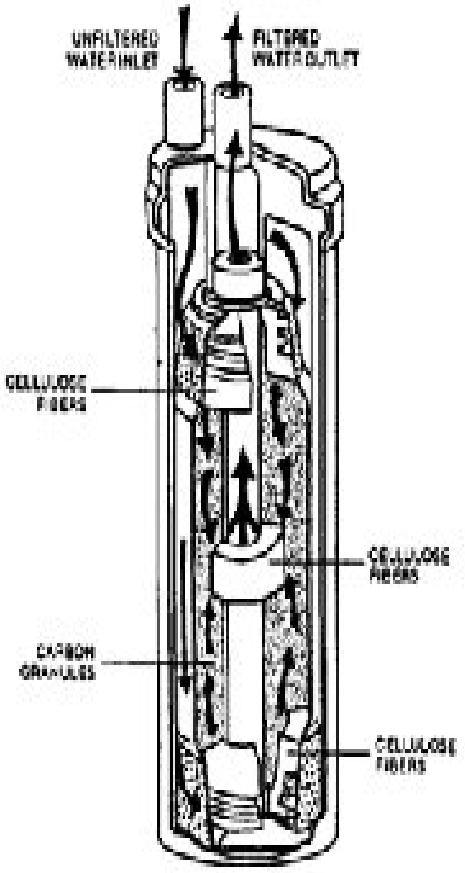
- Activated Carbon
- Removal of Chlorine and Chloramines
- Chlorine/Chloramines are NOT effectively removed by RO
- RO-membranes are oxidized by free chlorine
- To be placed before RO

Activated charcoal filter

- Activated charcoal acts by adsorption
- Activated carbon has a micro porous structure with a very large surface area
- Consequently a high adsorptive capacity for small organic contaminants (<300Daltons), chlorine, and chloramines

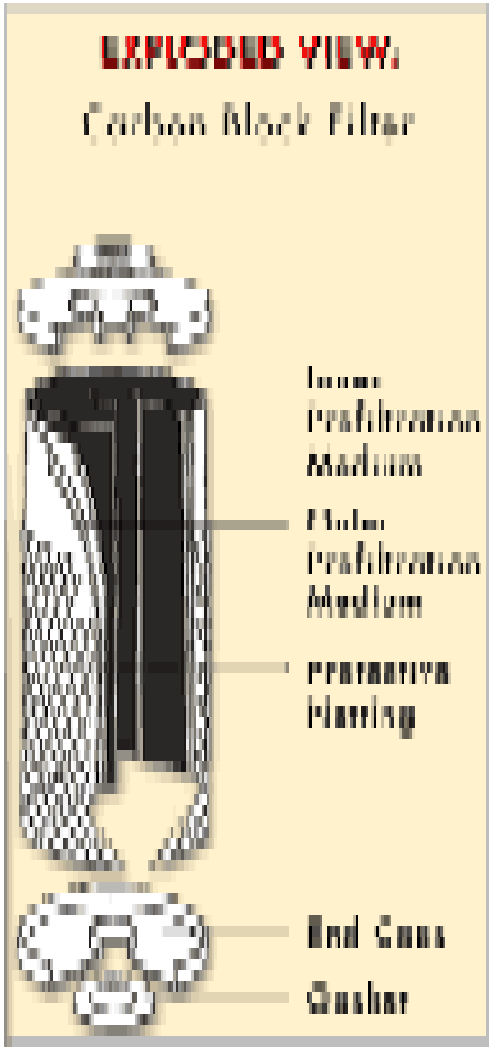
Activated charcoal filter

- Type of carbon tank
  - Portable exchange
  - “Permanent “ portable exchange



Activated charcoal filter

- Portable exchange
  - “Change out” on a cycle
  - The vendor replaces them with “New charcoal” –filled tanks



Activated charcoal filter

- “Permanent” tanks
  - Equipped with control unit that allow them to be backwashed at the facility’s discretion
  - Carbon is replaced by the vendor
  - Backwashing does not regenerate the carbon beds

Activated charcoal filter

- Maintenance
  - Regular backwash (automatic, during non-dialysis hours) loosens up the bed and flushes out contaminants
  - Test mush be performed regularly
  - Check setting of the timer regularly
  - The filter material should be exchanged when
    - Total chlorine exceeds0.1mg/l
    - The pressure drop exceeds predefined value(0.5Bar)

Activated charcoal filter

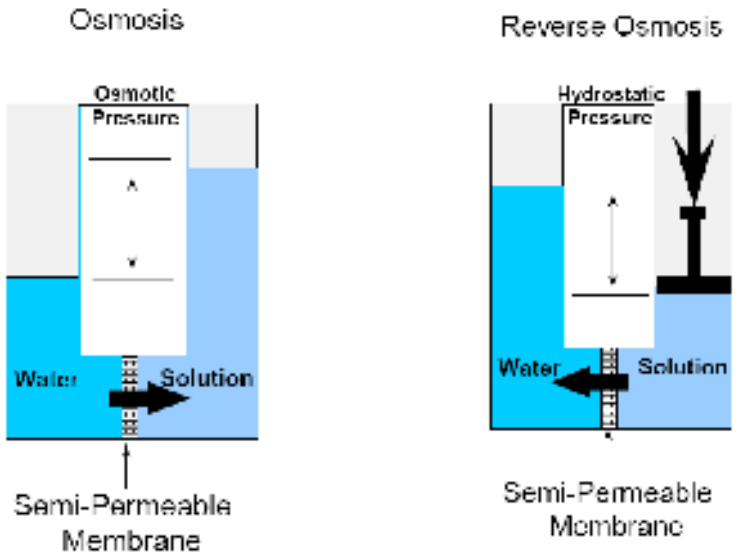
- Activated needed to be replaced when breakthrough of marker contaminants such as chlorine or chloramines is noted in the effluent
- Chloramines are replacing chlorine in many municipalities as bactericidal agents
- Even low chloramines levels (0.25mg/L) in dialysate can cause hemolysis, anemia, and methemoglobinemia

Micron Filter

- Remover finer particulates
- Protect RO from incoming / upstream particulate
- Do not remove bacterial nor endotoxin

Reverse Osmosis

- As the name implies, reverse osmosis is a process that reverses the flow of solvent due to osmosis
- The "reverse" in RO is the hydraulic force needed to overcome the osmotic back-pressure

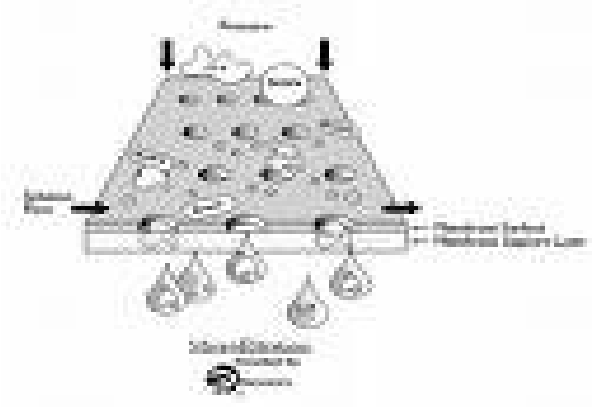


Reverse Osmosis

- This method uses a semi permeable membrane to removes both organic matter and electrolytes from the water
- With osmosis, solvent flows across a semi permeable membrane from the less conc. To the more- conc. side
- By applying a pressure that exceeds osmotic pressure, solvent flows is reversed and occurs from the more-conc. side

Reverse Osmosis

- RO have such small ”effective pore size” (under 1.0nm diameter) that transfer of even low molecular weight solutes is retarded



Reverse Osmosis

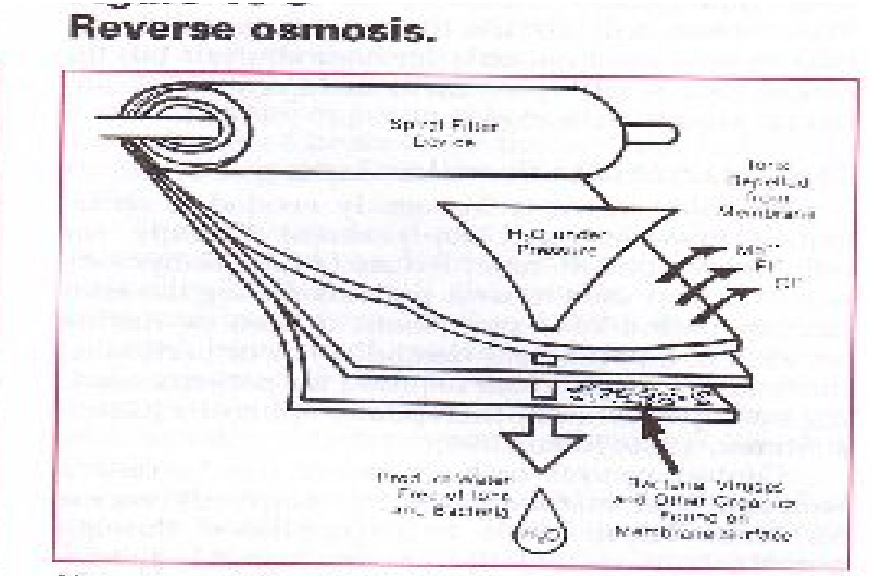
- More than 90% of impurities are removed
- Bacteria and viruses are also rejected
- Reject 90% - 98% of monovalent ions (e.g. Na)
- Remove 95 - 99% of divalent ions (e.g. Ca)
- Removal of dissolved inorganic and organic contaminants(>200daltons), bacteria, pyrogens, and particulates

Reverse Osmosis

- Membranes for RO use must be:
  - **Freely permeable to water**
  - **Highly impermeable to solutes**
  - **Able to tolerate very high operating pressure**

Reverse Osmosis

- Cellulose acetate membrane
- Polyamide membrane
- Thin film composites
- High-flux, chlorine -resistance

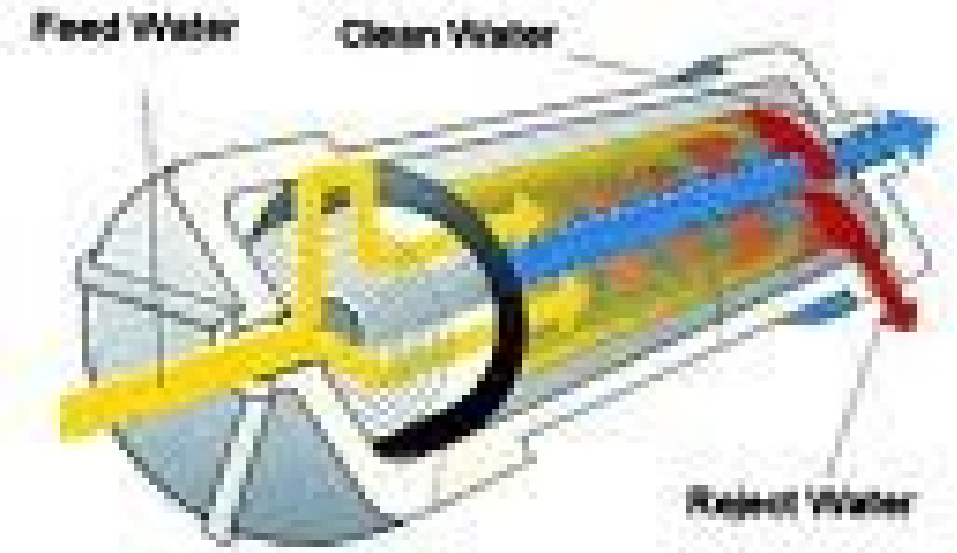


Reverse Osmosis

- Configuration of reverse osmosis modules are used :
  - A large membrane surface area
  - A tolerance for very high pressure
  - Good flow characteristics
  - A low pressure drop

Reverse Osmosis

- Configurations in use for hemodialysis water are:
  - Spiral-wound or spiral-wrap
  - Hollow-fiber modules



Reverse Osmosis

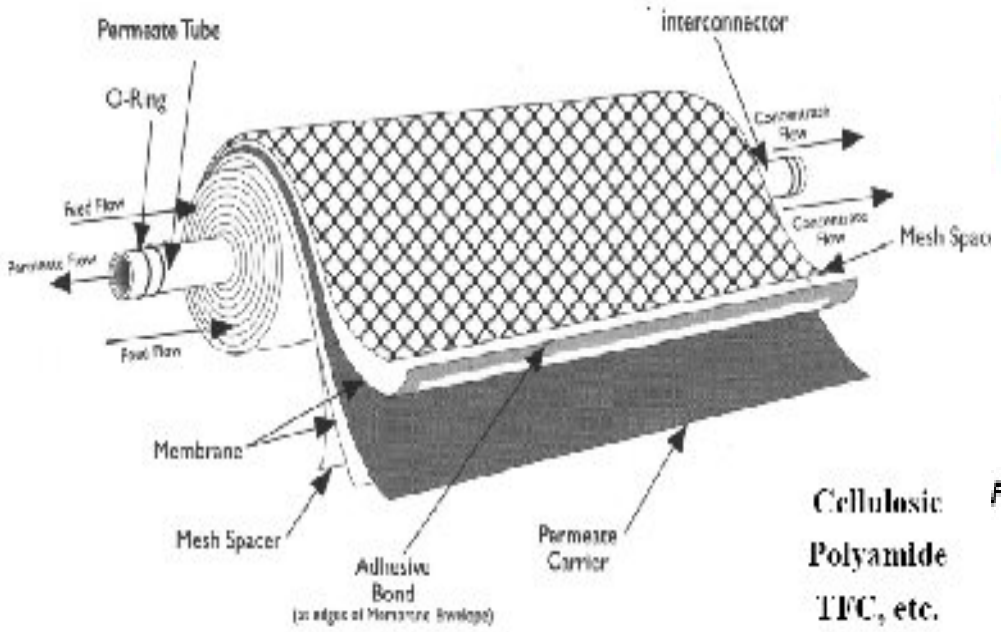
- Spiral-wound unit
  - Consist of two layers of membrane with a fabric material fastened between, sandwich fashion
  - The membrane-sandwich sheet, along with a plastic mesh separator, is wrapped in a spiral around a central perforated tube in a manner
  - The central fabric conducts this filtered water to the central tube

Reverse Osmosis

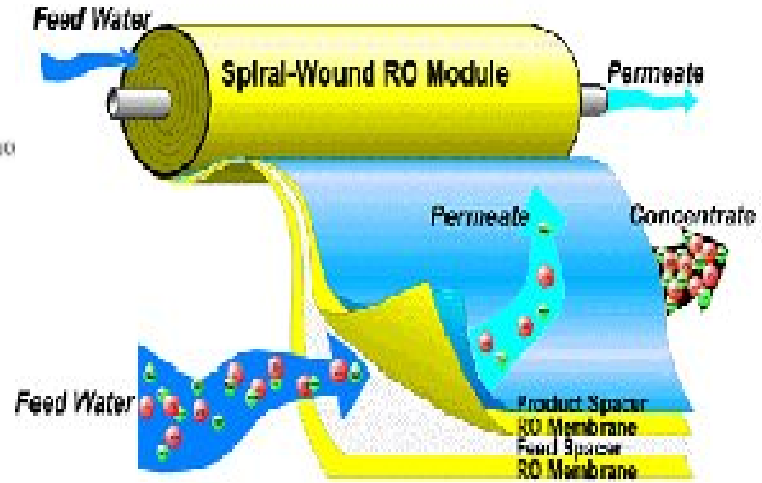
- Thin –Film composite RO membranes
  - Ultra Thin Membrane
    - Polyamide composition made of varying materials
    - Pore structure 100-200 daltons (5 – 15 A, 0.5 -1.5 nm)
  - Polysulfone Layer
    - Substrate between web and membrane
    - Web layer to irregular and porous tom provide a proper substrate
  - Web Layer
    - Provides major structural support
    - Produced to provide a hard, smooth surface free of loose fibers
    - Polyester material

Reverse Osmosis

Anatomy of a Spiral Wound Membrane



RO-spiral-wound membrane



Reverse Osmosis

- Hollow fiber units
  - Formed as capillary fibers of 80to 250μm inside diameter
  - Several thousand of these fibers are bundle inside a high-pressure cylinder
  - Pressurized feed water surrounds and permeates the hollow fibers

Reverse Osmosis

Feed Flow Rate = Produce Flow Rate + Reject Flow Rate

Amount of water entering RO	Amount of purified water exiting the RO	Amount of waste water exiting the RO

Reverse Osmosis

- Performance of RO system
  - Daily record – pressure gauge reading, resistively /conductivity or other relevant measurement
  - Staff of dialysis centre can be alerted immediately on abnormal performance of RO system if the system alarm can be connected to the central station

Reverse Osmosis

- Performance of RO system
  - Rejection ratio should be checked and record during maintenance 3-monthly
  - All essential performance parameters (including sensor function and rejection ratio) of the RO System should be checked 6-monthly

(Quality Initiative Recommendation in The Provision of Renal Services, H K College of Physicians & Central Renal Committee)

Reverse Osmosis

- Advantage
  - Bacteria, viruses, and pyrogen materials are rejected by the intact membrane. In this respect RO Water approaches distilled water in quality
  - Available units are relatively compact and require little space. They are well suited to home dialysis
  - In average use, the membrane has a life of a little over 1 to 2 years before replacement is necessary

Reverse Osmosis

- Disadvantage
  - the membranes have a limited service life
  - As with hemodialysis membranes, leaks are possible
  - Product water is 25-50% of feed water. The remaining 50-75% goes to waste
  - The membrane must be kept continually wet throughout its entire life
  - When not in operation, the unit should be held in a sterilant-filled state

Reverse Osmosis

Portable RO

Pressure Pump

UV irradiation

- Facility for killing bacteria
- Irradiance:
  - UV at wavelength of 254 nm
  - Dosage at 30 mWs/cm^2

How to promote bacterial growth in the system?

- Favorable environment
  - **Nutrients**
  - **Water**
  - **Temperature**
- Undisturbed environment
  - **No flow**
  - **Poor disinfection**
- Surface for biofilm formation
  - **Uneven**
  - **Rough**
  - **Joints**

Water distribution system

- Material
  - PCV
  - Stainless steel
  - PP (Polypropylene)
  - PEX (Crosslinked polyethvlene)
- Piping architecture
  - Continued loop (Recommended by AAMI)
  - Non-returning lines (Direct to drain)

Water distribution system

- Speed up water velocity up to two meter per second in ring piping during disinfecting process and standby mode (night mode)
- Prevent Bio-film growth in ring piping wall

What is a Bio-film?

- Bio-film: a sticky substance secreted by bacteria which protects them from disinfectants and allow them to adhere to surface

Development of a bio-film

- **Step 1.**
  Surface conditioning
- **Step 2.**
  Adhesion of ‘pioneer’ bacteria
- **Step 3.**
  Glycocalyx or ‘slime’ formation
- **Step 4.**
  Secondary Colonizers
- **Step 5.**
  Fully Functioning Bio-film

Bio-film

- One of the problem in dialysis centre
- Easily form in pipes, water distribution system and dialysis machine

Water distribution system

- The system should be designed to avoid rough joints, dead-end pipes, and stagnant areas
- Only piping or tubing of medica-grade stainless steel, polyvinylchloride(PVC) used to carry the product water

Water distribution system

- Water leakage monitoring
- Storage tanks must be of such material. If exposed to air , ultra pure water will quickly absorb and react with carbon dioxide

Disinfection

- Chemical:
  - RO
  - Ring piping
- Hot :
  - ring piping

Chemical Disinfection

- **Disinfectant should be used as recommended by manufactures**
  - **Formaldehyde**
  - **Pursteril**
- **Only well trained nurses attendants in the dialysis centre are allowed to carry out the procedure**
- **Disinfectant should preferably be done while the centre is not in service**
- **The dwell time recommended by the manufacturers should be followed**

Chemical disinfection

- The disinfection procedure should preferably be done as recommended by the manufacturer

Chemical Disinfection

- Rinsing process
  - Testing methods for residual disinfectant
  - Written documentation upon completion of testing residual disinfectant is mandatory

(Recommendations on safe haemodialysis practice in HA Hospital)

Heat disinfection

- Daily
- Initiated by operator

  (Auto start at present time)

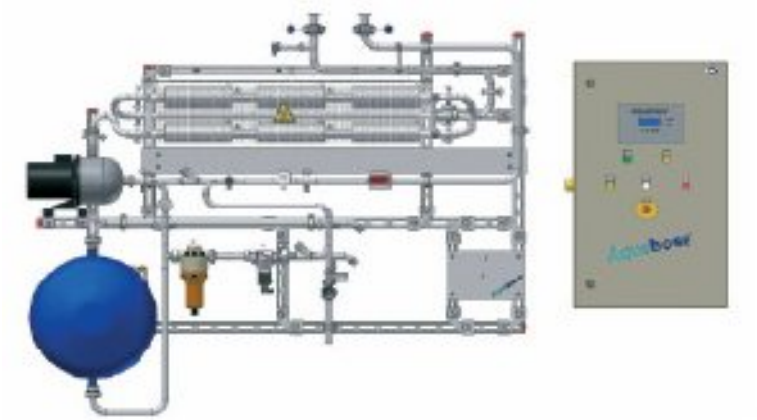
Heat disinfection

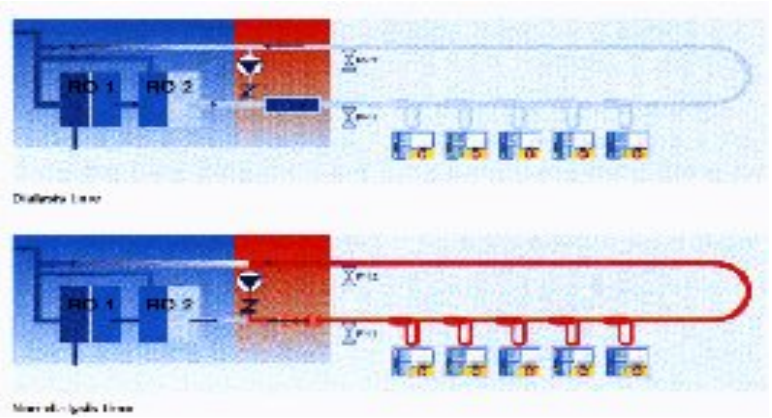
- Three temperature sensors located in ringing piping
- To make sure hot water reach 80~90 C in start point and end point of ring piping
- The third temperature sensor for safety feature. Make sure no hot water back to RO units
- Heat disinfection can be interrupt at anytime . The RO system can be resume operation within 20 min

(FMC)

Heat disinfection

- Heat disinfection just allow to active on standby mode (night mode)





Safety Procedure Guidelines

- Water treatment & distribution loop
  - **Disinfection procedure guidelines for Reverse Osmosis Machine and loop**
  - **Written documentation of absence of disinfectant for RO and loop post disinfection**
  - **Daily recording of pressure gauge reading of either resistivity or conductivity of the RO machine if pressure gauge available**
  - **Center station monitor or alarm system for water treatment plant**

Safety Procedure Guidelines

- 3–monthly checking of rejection rate of R.O. water and accuracy of timer of the pre R.O. system
- At least 6-monthly checking of inorganic contaminants in RO system
- At least monthly microbial count of Treated water

(Quality Initiative Recommendation in the Provision of Renal Services)

Water Treatment System for Haemodialysis and management

- Reference
  - Clinical Dialysis (Third Edition) International Edition
  - Core Curriculum for Nephrology, Fourth Edition American Nephrology Nurses' Association 2001
  - Contemporary Nephrology Nursing

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  - Quality Initiative Recommendation in the Provision of Renal Services
  - Electrical and Mechanical Services Department

Thanks