Water Treatment for Hemodialysis

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1404/2/9 – 29/ 4/2025

Water treatment system standards

Standards should be based upon:

- International Organization for Standardization (ISO) issued by
- American National Standards Institute (ANSI) with
- the Association for the Advancement of Medical Instrumentation (AAMI).
  - **Water quality requirements and the installation,**
  - **Disinfection,**
  - **Maintenance procedures for water treatment systems.**

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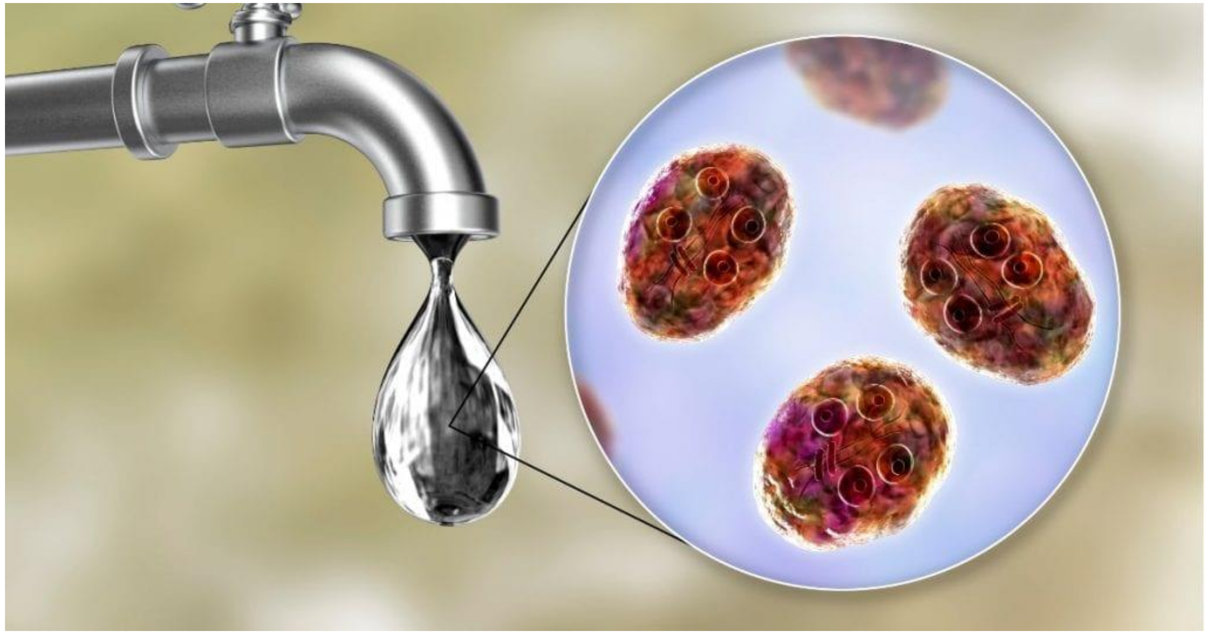
The waterborne contaminants and the safe levels in hemodialysis



water contaminants

Contaminant	ANSI/AAMI/ISO standard (mg/L)	Contaminant	ANSI/AAMI/ISO standard (mg/L)
Arsenic	0.005	Nitrate (N)	2
Antimony	0.006	Potassium	8
Barium	0.1	Selenium	0.09
Beryllium	0.004	Silver	0.005
Cadmium	0.001	Sodium	70
Chromium	0.014	Sulfate	100
Copper	0.1	Zinc	0.1

ANSI: American National Standards Institute; AAMI: American Association for the Advancement of Medical Instrumentation; ISO: International Organization for Standardization

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water contaminants…

Contaminant	ANSI/AAMI/ISO standard (mg/L)
Fluoride	0.2
Lead	0.005
Mercury	0.0002
Aluminum	0.01
Calcium	2
Magnesium	4
Total chlorine (free chlorine and chloramine)	0.1

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آزمایشگاه شرکت آب و فاضلاب استان اصفهان

Isfahan Water and WasteWater Laboratory

اصفهان - خیابان هزارجریب - خیابان جابربن حیان - شرکت آب و فاضلاب استان اصفهان

Isfahan water & wastewater Company, Jaber Ebn Hayyan St., Hezar Jerib St., Isfahan

LQS-F-708-01

Rev: 01

تاریخ انتشار: ۱۴۰۲/۱۱/۰۱

گزارش آزمون
Test Report

E03047

1403/07/23

(Test Results) نتایج آزمون

حد مجاز Specification	استاندارد مرجع Reference Standard	عدم قطعیت اندازه‌گیری (U) Uncertainty	روش آزمون Test Method	واحد Unit	نتیجه آزمون Test results	نام آزمون(پارامتر) Test Name (Parameter)
6	ISIRI 1053	22.37	SM 3112 B	µg/L	Result<1.05	Hg
10	ISIRI 1053	18.09	SM 3113 B	µg/L	Result<2.06	Pb
50	ISIRI 1053	10.43	SM 3113 B	µg/L	Result<1.9	Cr
3	ISIRI 1053	21.46	SM 3113 B	µg/L	Result<0.23	Cd
10	ISIRI 1053	20.93	SM 3114 C	µg/L	Result<2.14	As

Clinical manifestations of exposure of hemodialysis patients to water contaminants

Clinical manifestations of water contaminants

Aluminum	Neurologic deterioration, cognitive changes, encephalopathy, bone disease, anemia, death
Chlorine	Hemolysis, hyperkalemia, shortness of breath, hypoxia, cardiac arrest
Chlorine dioxide	Likely to cause methemoglobinemia and hemolytic anemia
Chloramine, (monochloramine)	Hemolysis, anemia, methemoglobinemia, cyanosis, shortness of breath, EPO resistance
Copper	Nausea, anemia, hemolysis, chills, death
Zinc	Anemia, cardiovascular events

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Clinical manifestations of water contaminants..

Fluoride	Bone disease, pruritus, chest pain, nausea, cardiac arrest (acute exposure to high concentrations)
Lead	Abdominal pain, muscle weakness, pruritus, peripheral neuropathy, cognitive changes
Nitrate	Nausea and vomiting, hypotension, methemoglobinemia
Bacteria, endotoxin	Hypotension, chills, fever, death
Sulfate	Nausea and vomiting, metabolic acidosis
Hydrogen peroxide	Cyanosis, methemoglobinemia
Silver-stabilized hydrogen peroxide	Cyanosis, methemoglobinemia

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Clinical manifestations of water contaminants..

Sodium hypochlorite	Hemolysis, hyperkalemia, shortness of breath, hypoxia, cardiac arrest
Peracetic acid	Hemolysis
Cyanotoxins	Acute illness, death
Microcystins	Acute illness, Visual disturbances, Liver failure, death,
Calcium	Nausea, vomiting, weakness, hypertension (hard water syndrome)
Magnesium	Nausea and vomiting, muscle weakness
Potassium	Cardiovascular events
Sodium	Hypertension

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Components and Monitoring of Water treatment systems

Components and Monitoring of Water Treatment Systems

1. **Booster pump**
2. **Ultrafilters, multimedia filters or sediment or depth filters**
3. **Softeners**
4. **Activated carbon beds or filters**
5. **Reverse osmosis**
6. **Deionization**
7. **Distribution system components**
8. **Disinfection**

Components and Monitoring of Water Treatment Systems

1. Booster pump

Booster pump: help regulate flow when the **water pressure** falls below predetermined levels.

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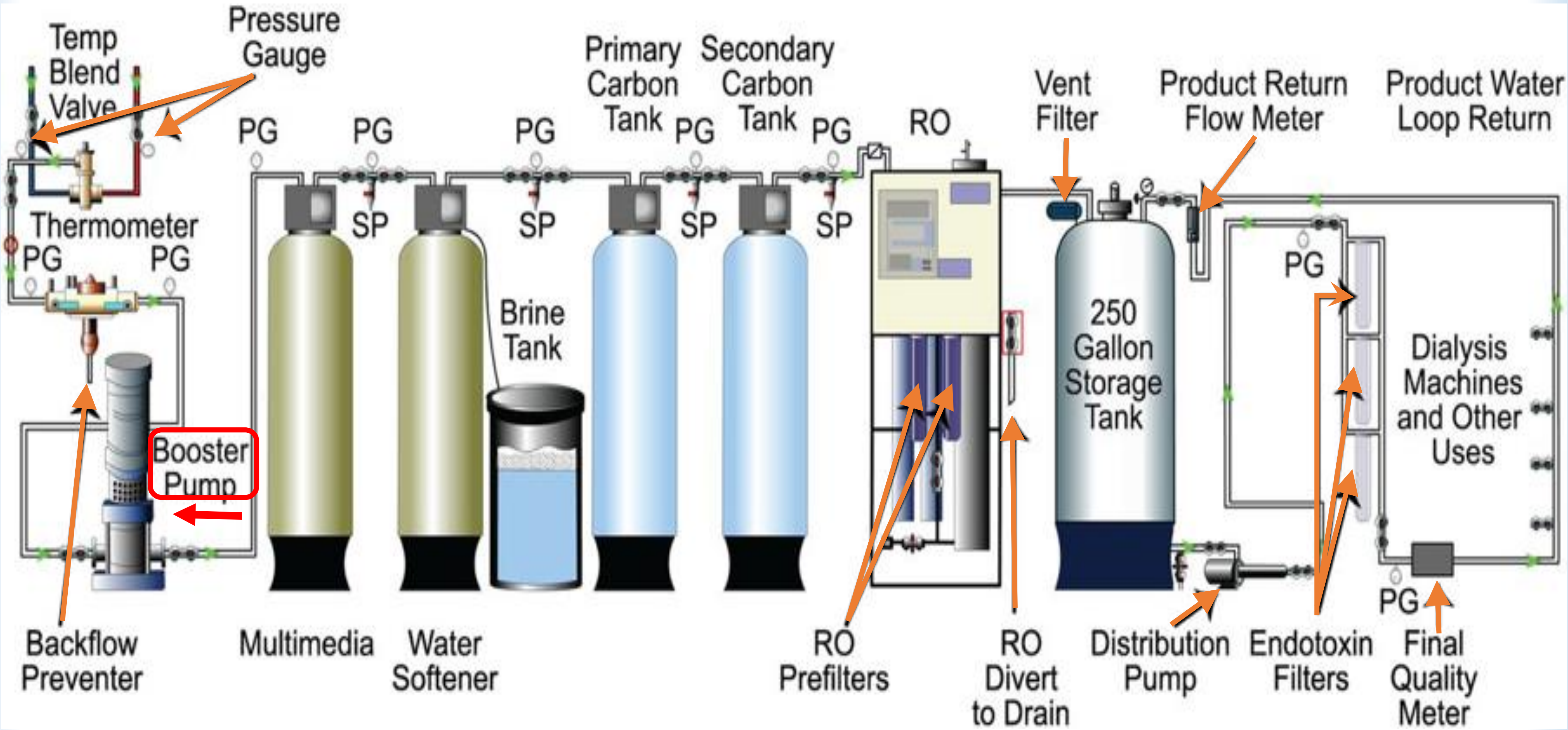
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Filter
Product Return
Flow Meter
Product Water
Loop Return
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Thermometer
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Brine
Tank
250
Gallon
Storage
Tank
PG
Dialysis
Machines
and Other
Uses
Booster
Pump
Backflow
Preventer
Multimedia
Water
Softener
RO
Prefilters
RO
Divert
to Drain
Distribution
Pump
Endotoxin
Filters
PG
Final
Quality
Meter

Water Treatment Systems

1. Booster pump
2. **Ultrafilters, particle filters, or sediment or multimedia filters**
3. Softeners
4. Activated carbon beds or filters
5. Reverse osmosis
6. Deionization
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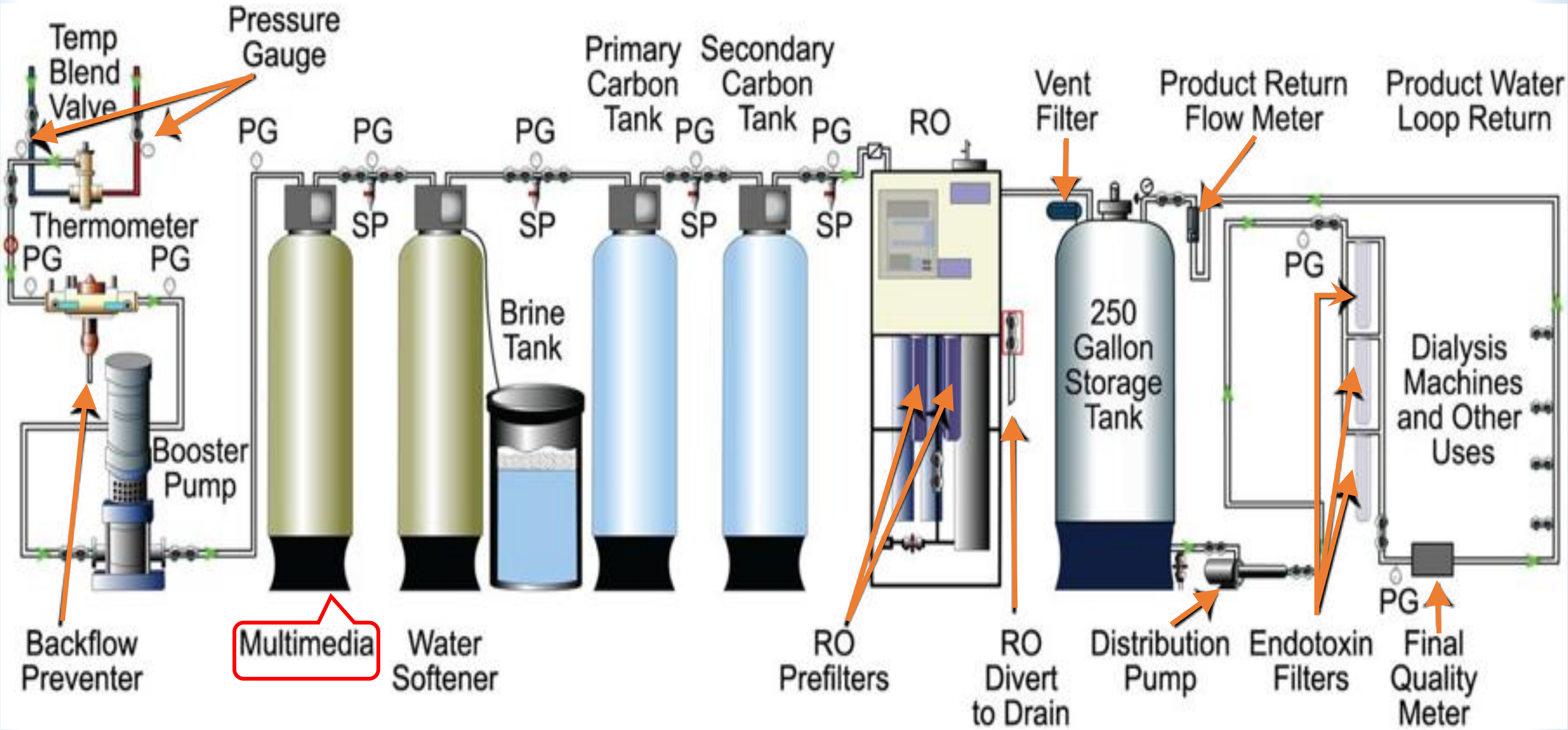
8. Disinfection



Temp Blend Valve
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Primary Carbon Tank
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Secondary Carbon Tank
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Vent Filter
Product Return Flow Meter
Product Water Loop Return
Thermometer
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SP
PG
Brine Tank
250 Gallon Storage Tank
Dialysis Machines and Other Uses
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Backflow Preventer
Multimedia
Water Softener
RO Prefilters
RO Divert to Drain
Distribution Pump
Endotoxin Filters
Final Quality Meter

2- Ultrafilters, particle filters or multimedia filters

- Filters should be **backwashed every day** when there are no patients connected to the hemodialysis machines.
- Pre- and post-filter pressure gauges should be fitted on all filters and pressure difference between the two gauges should be monitored.
- All types of filters become progressively obstructed with debris, resulting in an increase in pressure difference and/or a decrease in filtrate flow rate.

Ultrafilter for endotoxin removal

Pressure gauge

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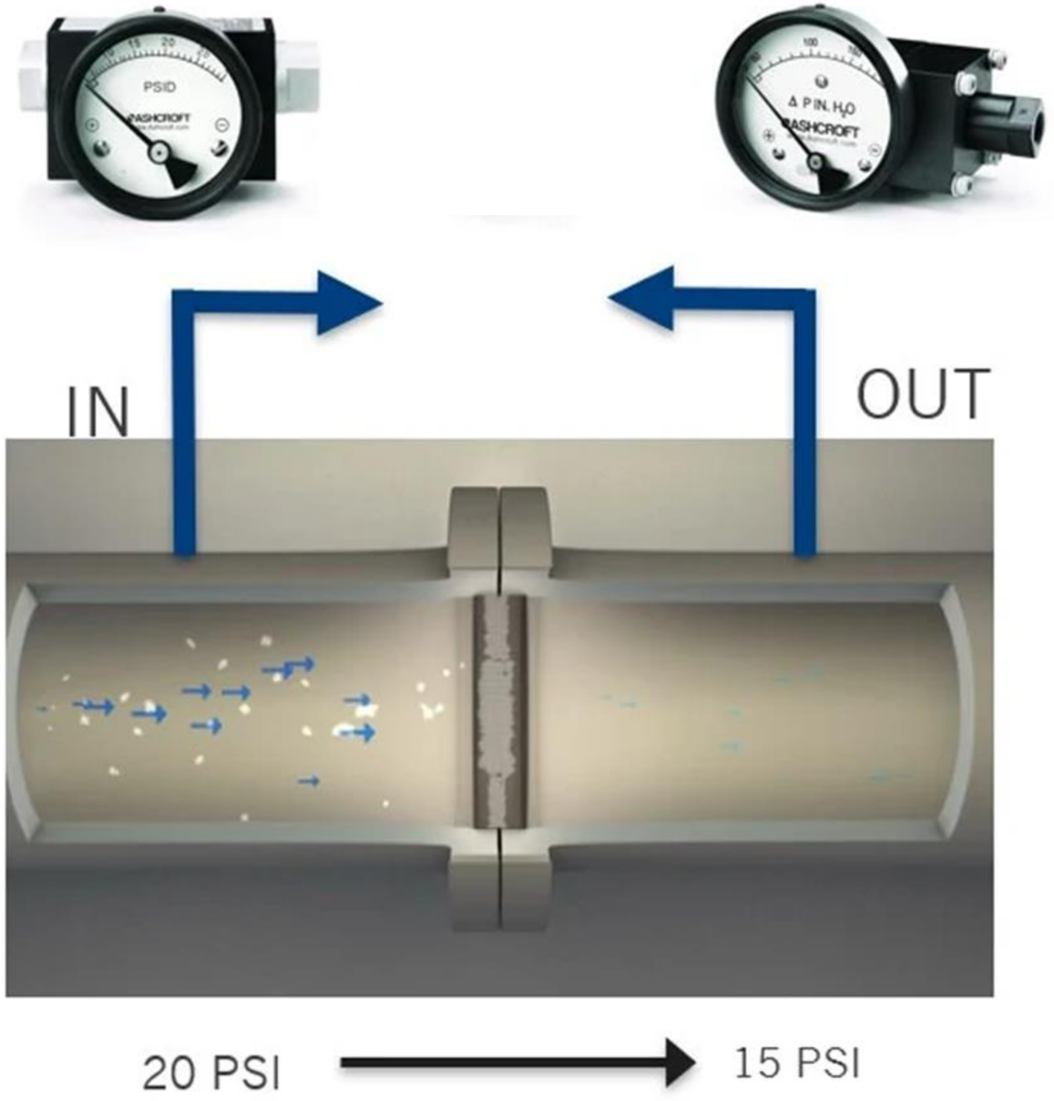
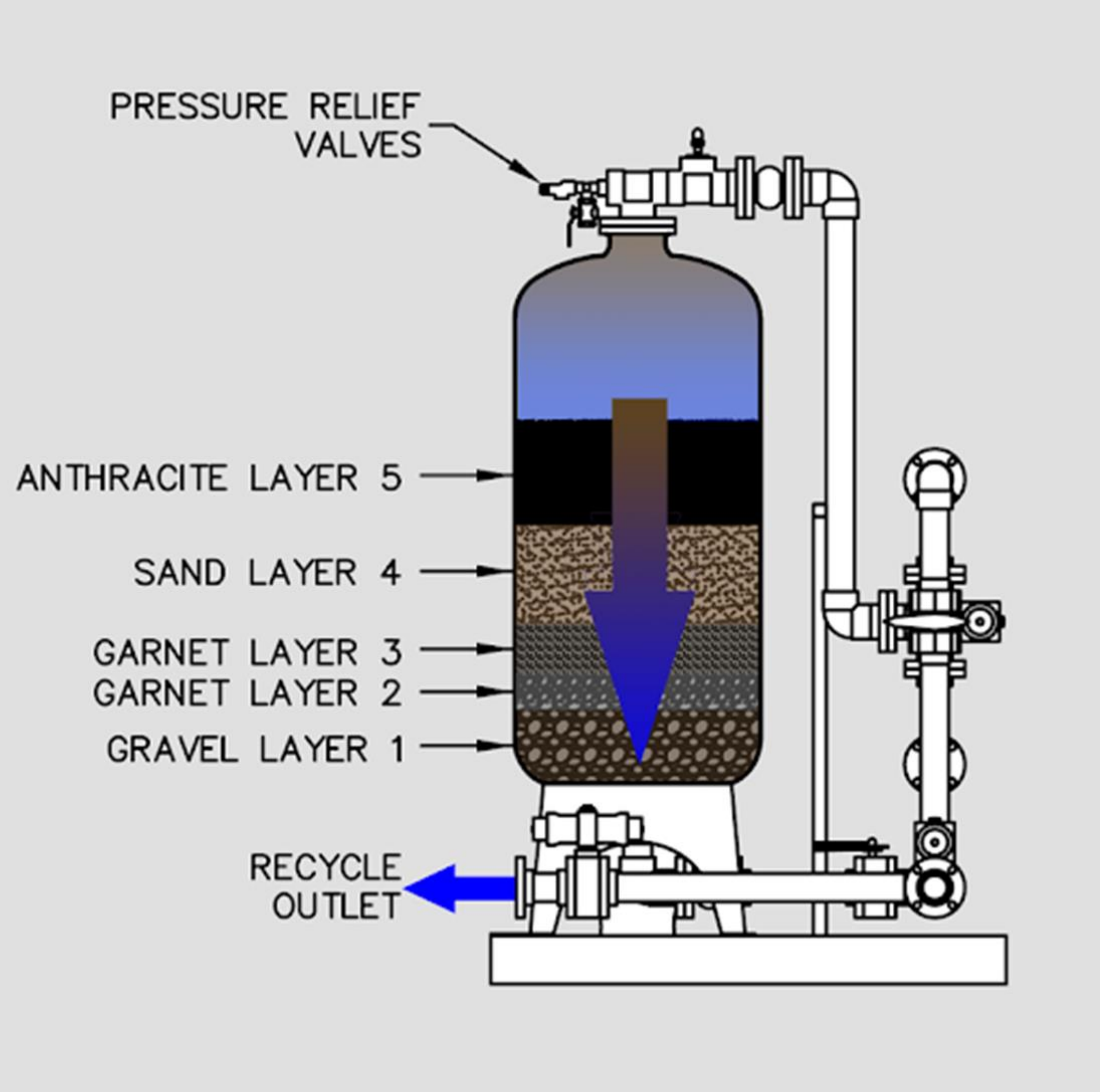

PSID
ASHCROFT
Δ P IN. H_2O
ASHCROFT
IN
OUT
20 PSI
15 PSI

MULTI-MEDIA FILTERS (MMF)
(Sediment filter)



Water Treatment Systems

1. Booster pump
2. Ultrafilters, particle filters, multimedia filters, and depth filters
3. **Softeners**
4. Activated carbon beds or filters
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3- Softeners

- In which **calcium and magnesium are exchanged for sodium ions**. When the water is "hard" due to high levels of calcium and magnesium.
- Softeners must be **regularly regenerated**.
- Regeneration on an automatic cycle **by exposing the resin to a strong brine solution**.

- To ensure that calcium and magnesium ions remove effectively, **at the end of the day**, hardness should be checked.

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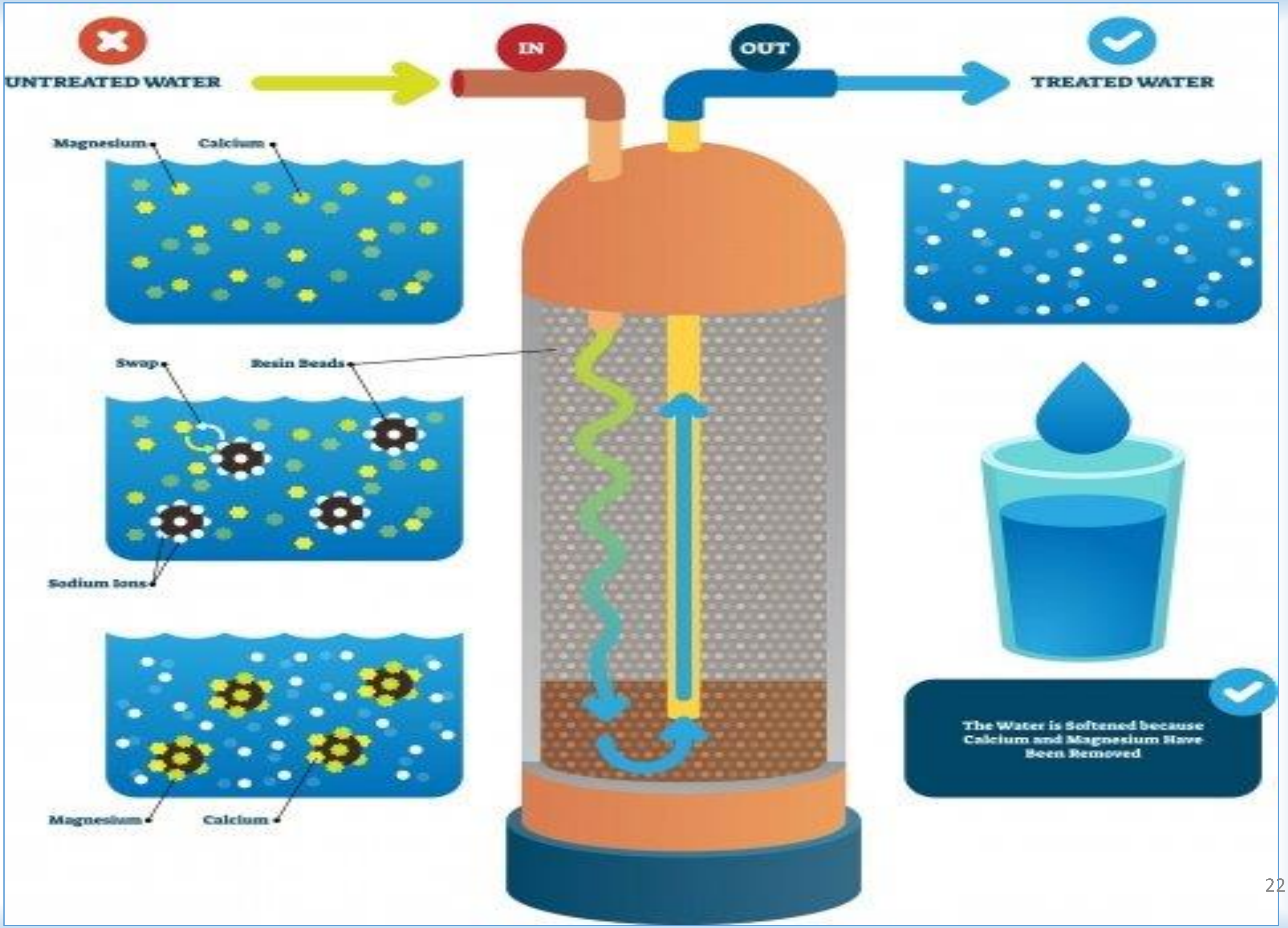
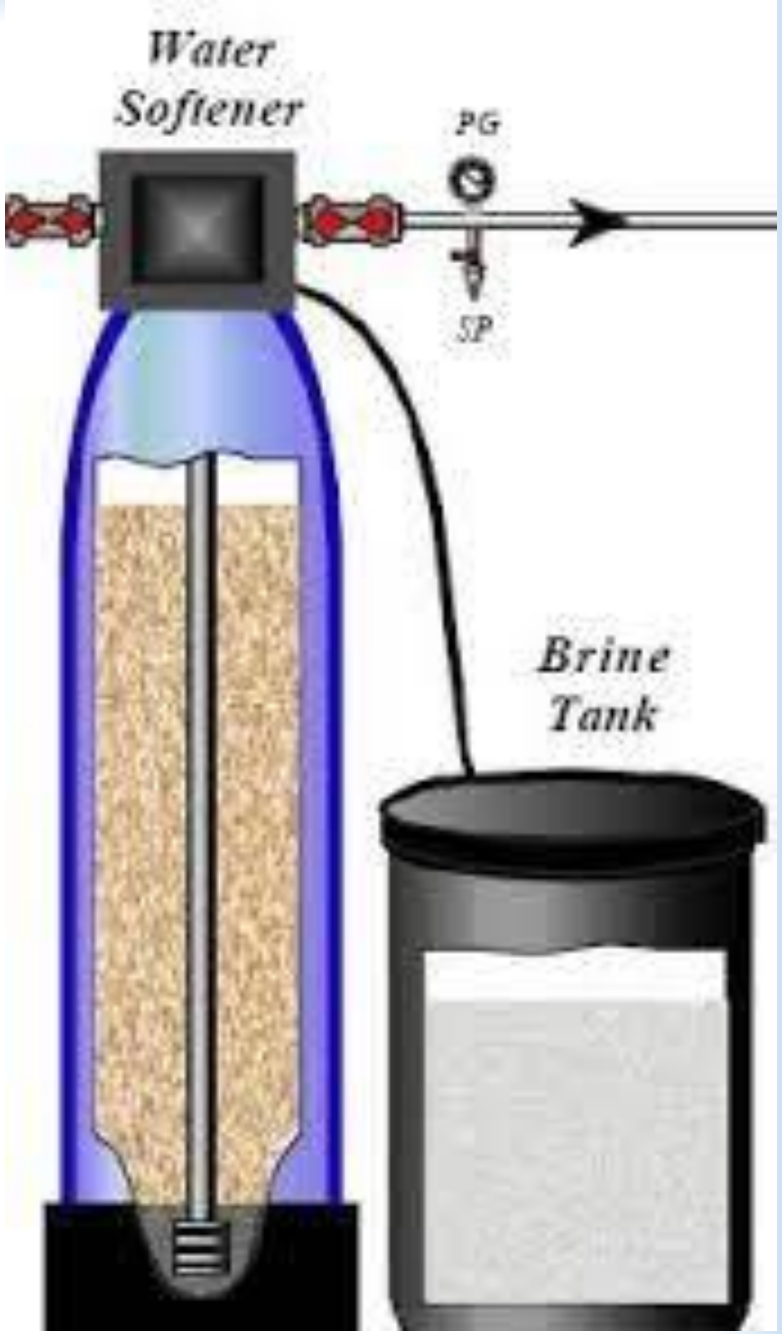
Water softener



Monitoring of Softeners

- Colorimetric test strips can also be used to measure water hardness on site.
- Softened water should have a hardness of 1 GPG (17 mg/L $CaCO_3$) or lower.

- The brine tank should be checked daily to ensure adequate quantities of sodium chloride.



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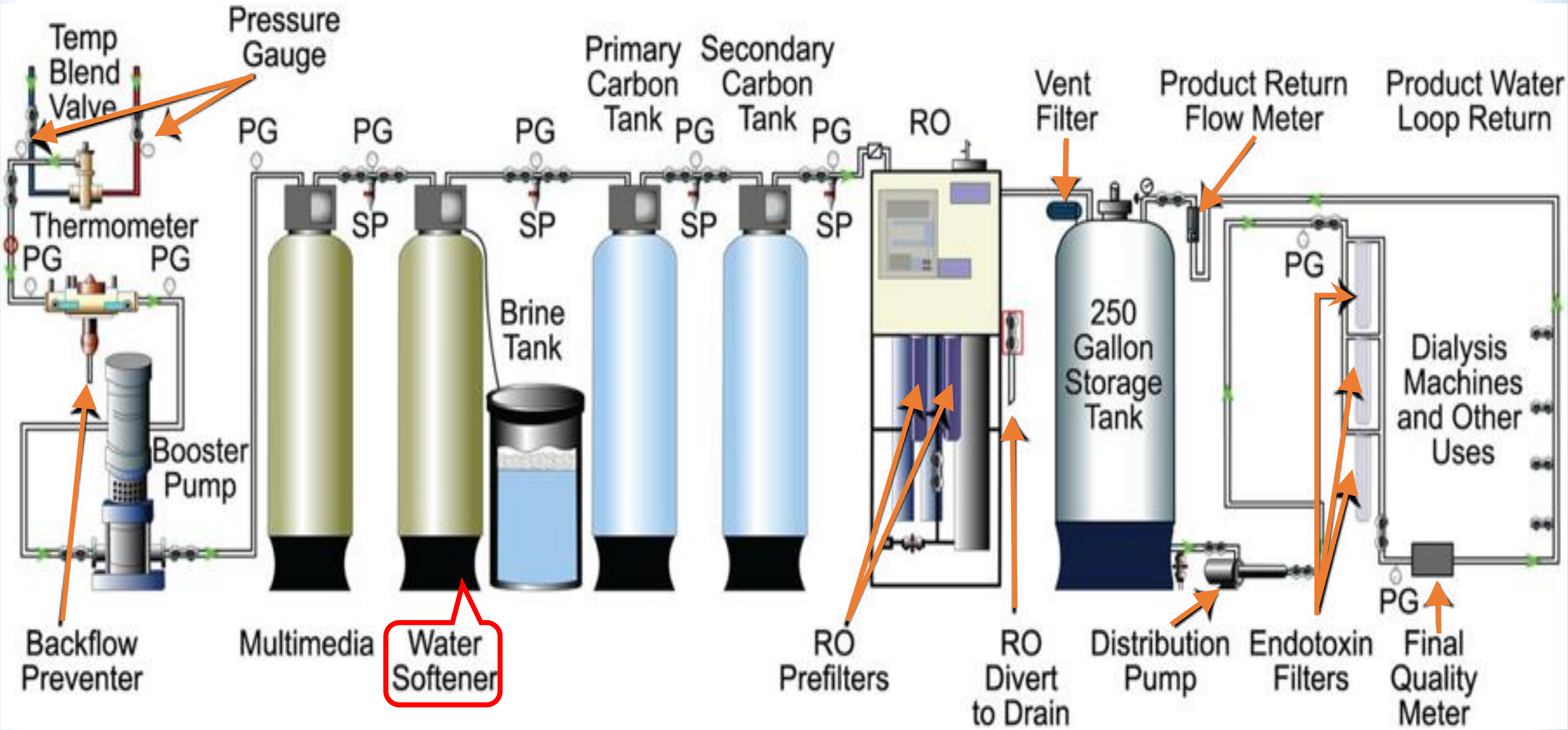

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Distribution Pump
Endotoxin Filters
Final Quality Meter

Water Treatment Systems

1. Booster pump
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4- Activated carbon beds or filters

- Activated carbon bed is the principal method of removing **chlorine** and **monochloramine**, substances that:
    1. Can degrade reverse osmosis membranes, and
    2. Cause hemolysis and resistance to erythropoiesis-stimulating agents (ESAs).
- Carbon can remove a wide range of organic contaminants by adsorption.

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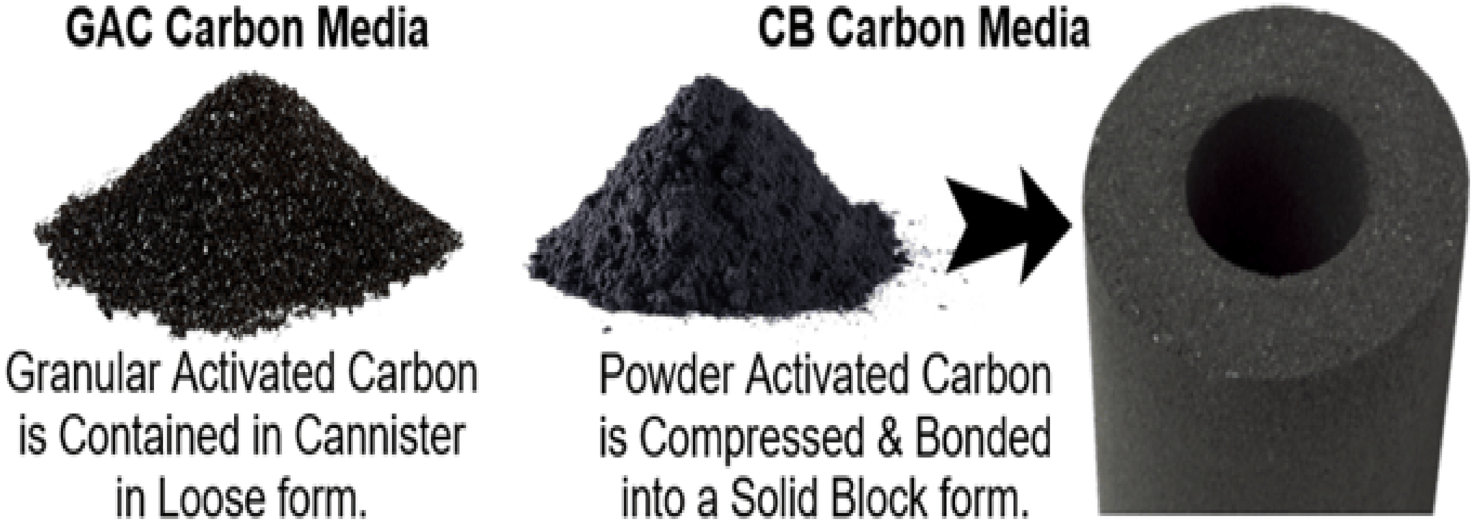
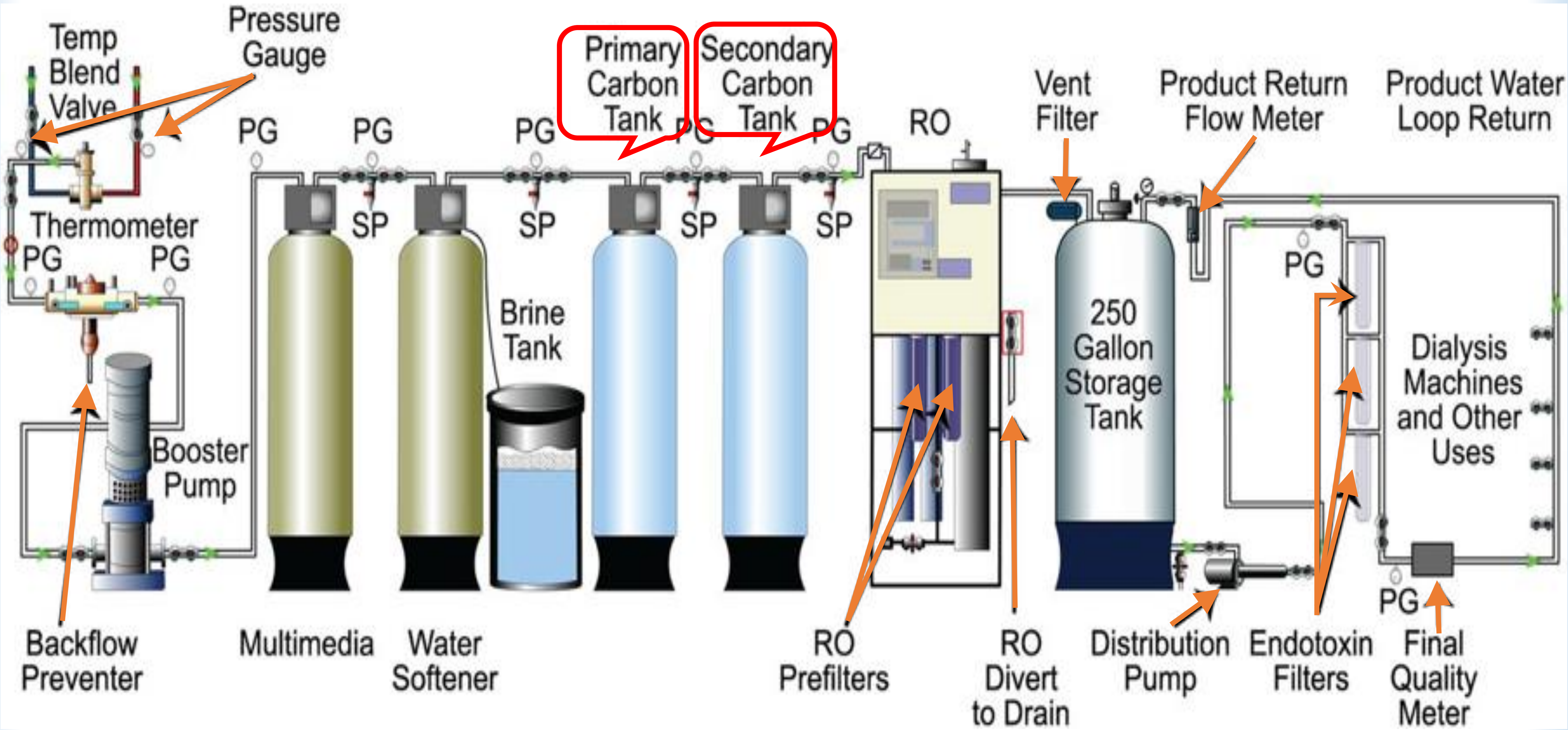

GAC Carbon Media
CB Carbon Media
Granular Activated Carbon is Contained in Cannister in Loose form.
Powder Activated Carbon is Compressed & Bonded into a Solid Block form.



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4- Activated carbon beds or filters..

Monitoring: to detect exhaustion of their capacity for removal of monochloramine and total chlorine.

- Total chlorine measurements can be made by using a "dip and read“ test strip.
- Testing should be performed **at the beginning of the day** after allowing the system **to run for 15 minutes** and then at least **every three to four hours** while patients are on dialysis.

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Water Treatment Systems

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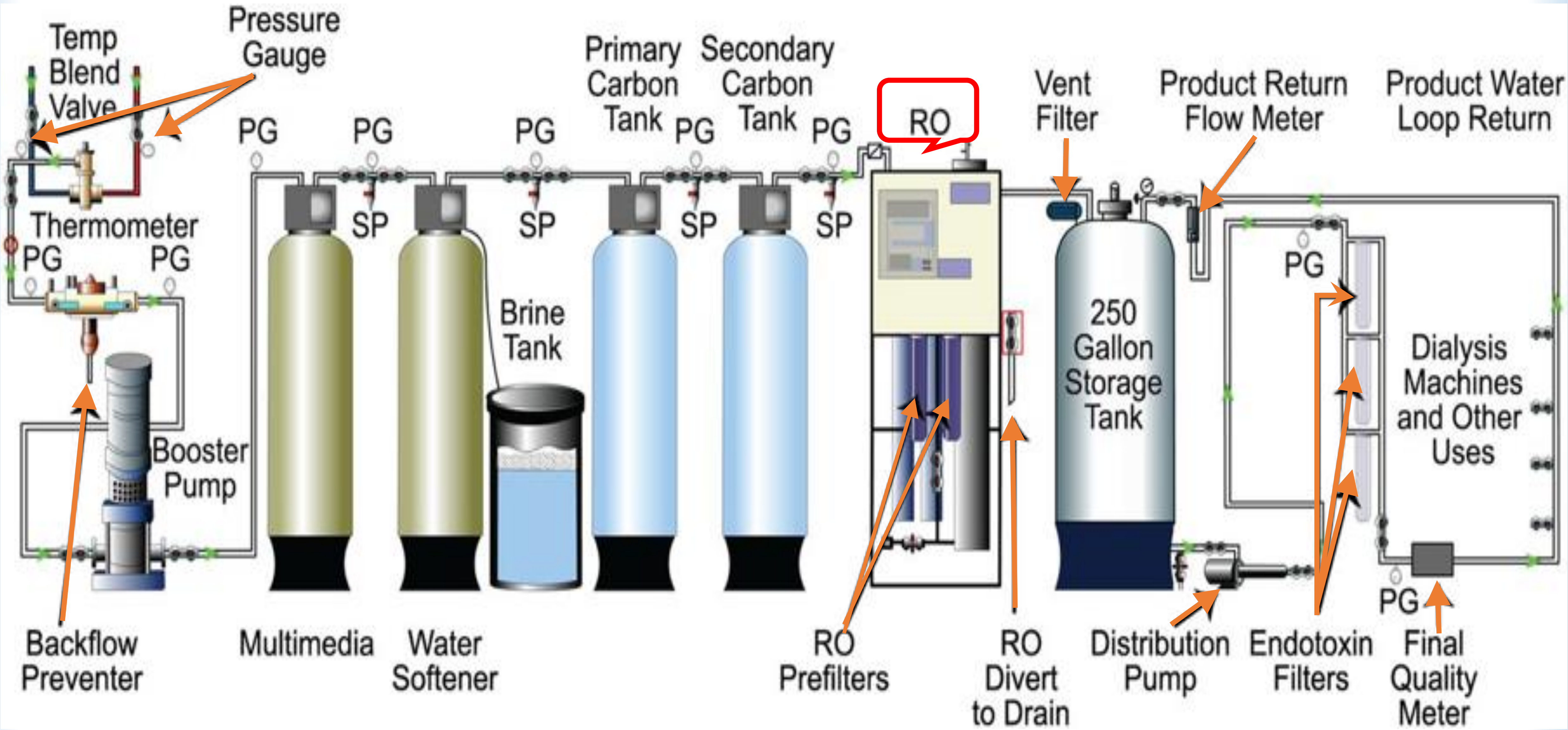

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5- Reverse osmosis

- Removes dissolved substances, such as metal ions, salts, and inorganic and organic chemicals, and microbial elements, including bacteria, endotoxins, and viruses.
- Organic contaminants with molecular weight >200 Da are effectively filtered out.
- Reverse osmosis reduces contaminant levels by using high pressure (200 to 250 pounds/in^2) to force a portion of the feed water across a semipermeable membrane.
- The remaining feed water that does not go across the membrane carries the concentrated contaminants to the drain.

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5- Reverse osmosis..

- Although there is potential for up to 75 percent of the feed water to be recovered as product water, **recovery rates of 35 to 50%** are more common
- In case of deficient feed water, a part of the reject water backs to the feed water to allow recovery of a greater quantity of product water.
- Two-stage reverse osmosis can achieve an efficiency of 90 percent or more.

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5- Reverse osmosis..

- The most common reverse osmosis membrane is made of polyamide. Polyamide membranes are sensitive to chlorine and monochloramine, and to peracetic acid (disinfectant) at a concentration of>1%.

Monitoring:

- Ensure continued removal of contaminants at the desired level
- Ensure production of sufficient product water
- Determine when the membranes should be cleaned or replaced

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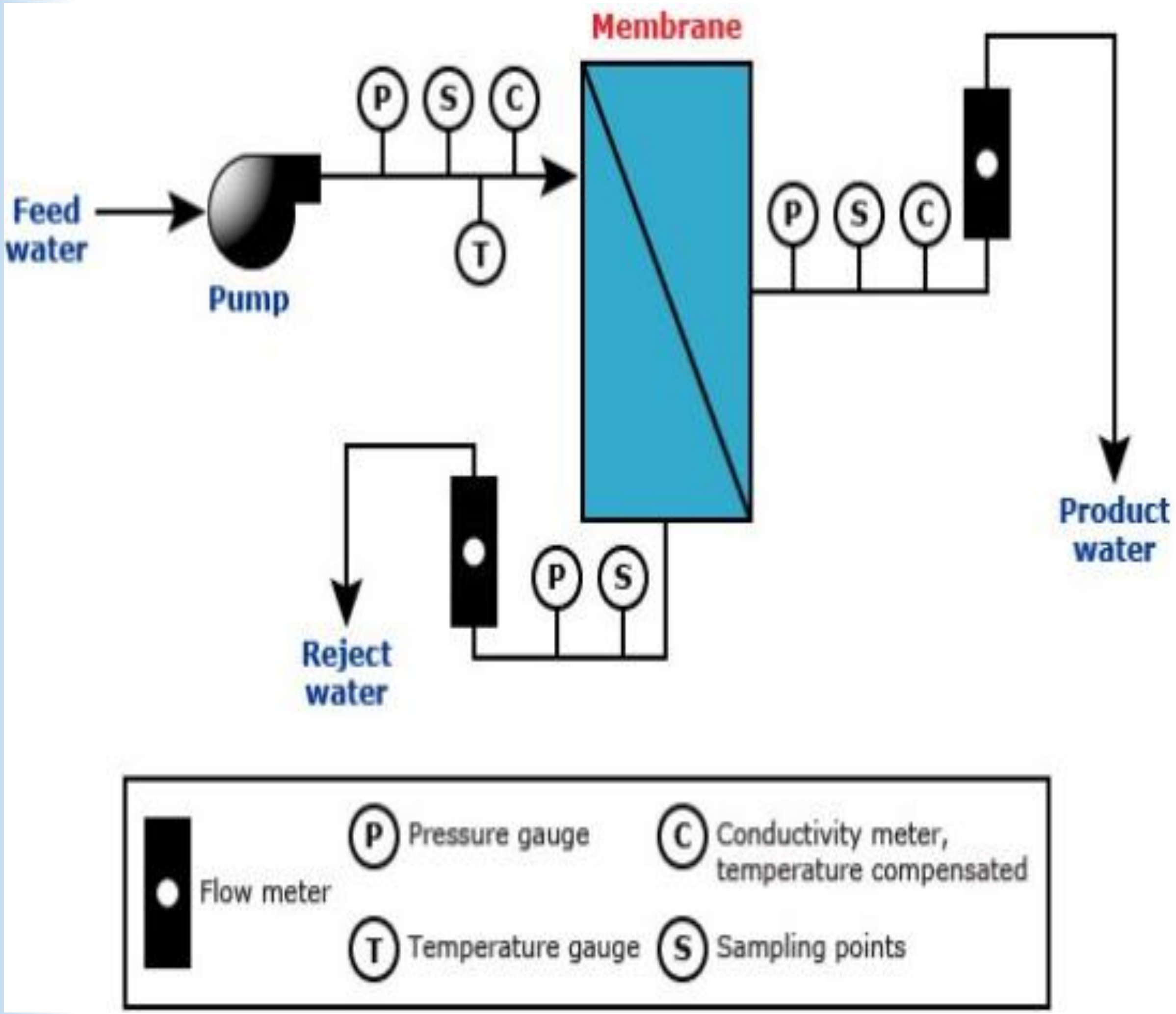
Membrane
Feed water
Pump
P
S
C
T
Product water
Reject water
Flow meter
Pressure gauge
Temperature gauge
Conductivity meter, temperature compensated
Sampling points

A


RO

B

Water Treatment Systems

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7. Distribution system components
8. Disinfection

6-Deionization

- Ion-exchange resins are used to **remove ionic contaminants** from water.
- Hydrogen ions are exchanged for cations (cationic resins) and hydroxyl ions are exchanged for anions (anionic resins).
- If feed water high contaminants and RO is insufficient, deionization can be added as secondary purification step.
- Does not remove uncharged contaminants, bacteria, or endotoxins.

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6-Deionization..

- The resins provide a good environment for bacterial proliferation and often worsen the microbiologic quality of water passing through them.
- A bacteria- and endotoxin-retentive filter to prevent contamination.

<u>Monitoring:</u>

- Measure of the concentration of ions in the water continuously.

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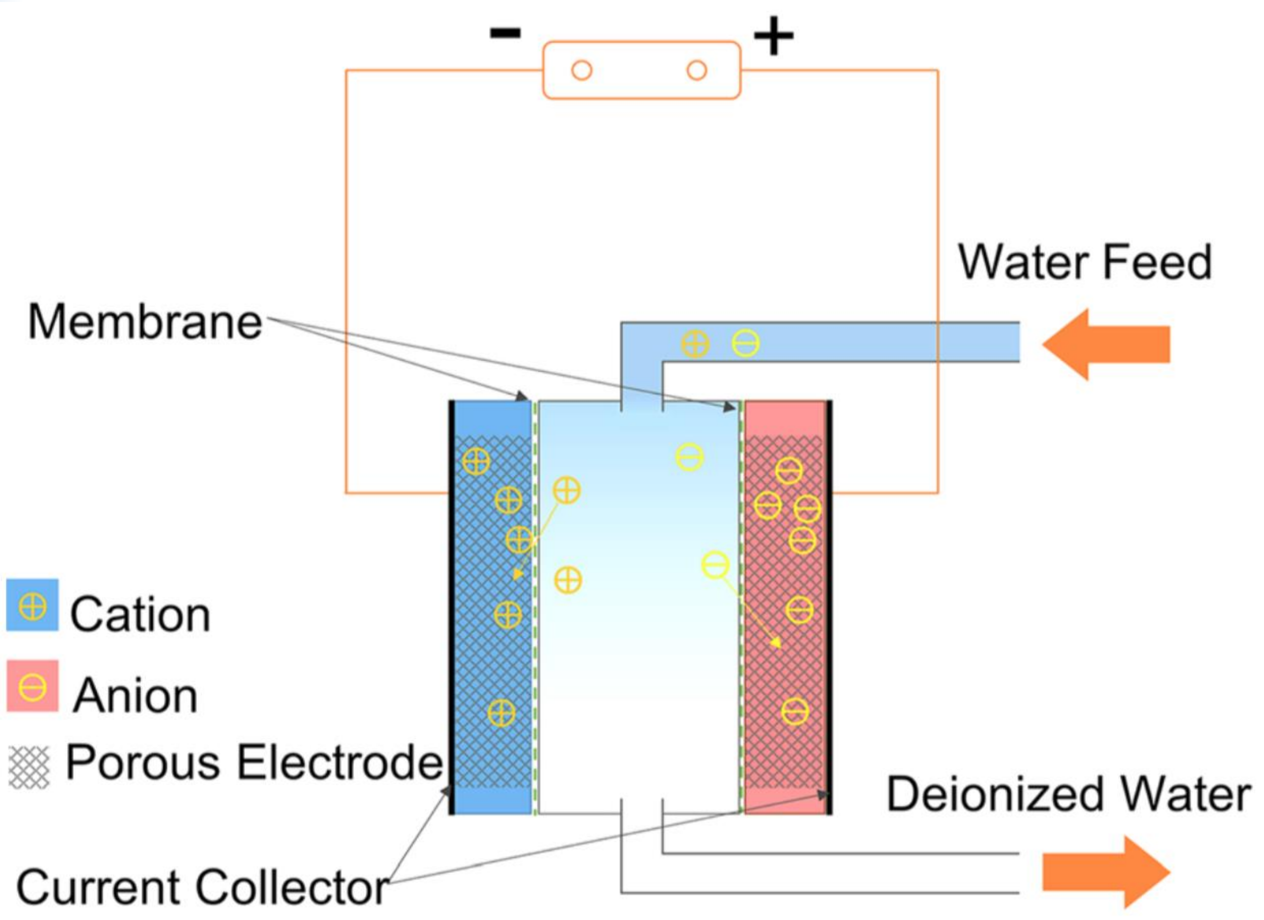

water treatment for hemodial

Water Treatment Systems

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7- Distribution system components

- Metals and chemicals leach from materials to water.
- Surfaces in contact with treated water must be fabricated with inert materials.
- No brass, aluminum, or galvanized metal parts can be used.
- Commonly used materials include cross-linked polyethylene (PEX), polyvinylchloride (PVC) and Stainless Steel.
- If hot water is used as the sterilant for the distribution system, PVC should not be used due to its degradation following repeated hot water exposure.

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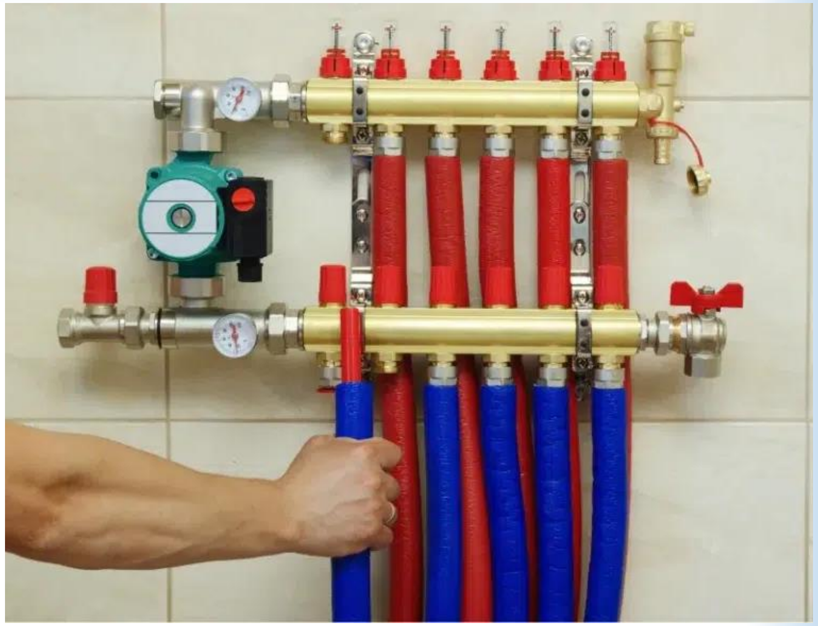
Polyethylene (PEX) Tube



PVC pipes

Stainless steel pipe

7- Distribution system components..

- **Drinking water** supply source independent from other water supply sources on site.
- **The storage tank** provides a reserve, the pressure in an indirect-feed system can be increased. Bacterial control is easier in a direct-feed system.
- A tight-fitting lid and conical or bowl-shaped base; drain from its lowest point; venting through a 0.45 micrometer hydrophobic air filter.

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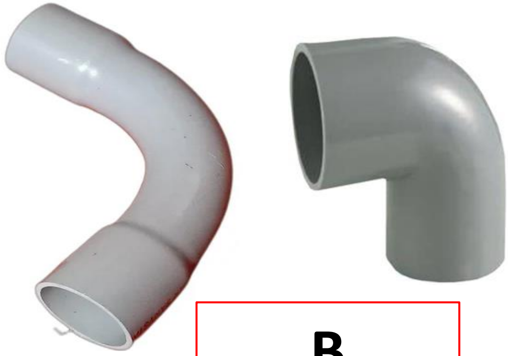
7- Distribution system components..

- The joints not to create any rough areas that can act as a focus for bacterial proliferation.
- The number of fittings in the circuit and abrupt changes in the direction of flow should be minimized as much as possible to prevent pockets of stagnant flow in the circuit.
- All surfaces within the distribution loop should be as smooth as possible .

Butt Fusion Pipe

A



B

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8. **Disinfection**

8- Disinfection

The risk of microbial recontamination in the distribution system is high due to no chlorine and monochloramine in the treatment water.

Frequency of disinfection: at a minimum should be performed **quarterly** even the **action level have not been breached**.

Disinfection:

1. **Chemicals:** sodium hypochlorite (bleach) or mixture of peracetic acid and hydrogen peroxide (compatible with the PVC).
2. Disinfection is more effective if pipes are first treated with a descaling agent.
3. **Ozonated water** or **hot water** is preferred over chemical disinfectants: lengthy period of rinsing required to remove residual disinfectant, no chemical residues (hot water) or residues with a short half-life (ozone), can be daily or weekly.

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Water Monitoring systems

Water system monitoring 1

Water treatment system component	Sampling site	Test	Acceptabl e level	Recommended frequency of measurement
Feed water	Sampling port in the feed **line to the water treatment** system	Chemical analysis	Variable depending	**Every 3 months** or when the water provider changes the composition of the feed water or when the source of that water changes
Multimedia filters and/or beds	Pressure gauge before and after the filters and/or beds	**Inflow versus outflow pressure difference and comparison with baseline pressure difference**	>10 mmHg above baseline	**At the end of every day**
Softener	at the outflow of the softener	Hardness	<1 GPG (17 PPM)	**At the end of every day**

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Water system monitoring 2

Water treatment system component	Sampling site	Test	Acceptable level	Recommended frequency of measurement
Carbon beds and filters	between the first and second carbon bed	Total chlorine Monochloramine	≤0.1 PPM	**At the start of the day and every 4 hours**
Reverse osmosis	N/A	Percent rejection	Based on water analysis, usually >90%	**Continuously** (measured by reverse osmosis system).
Deionizer	N/A	DI resistivity	>1 megaohm•cm	**Continuously** (measured by dionizer)
Ultraviolet irradiator	N/A	Ultraviolet energy output	>30 mW•s/cm (>16 mW•s/cm if UV calibrated meter)	**Daily**, or in accordance with the manufacturer's recommendations if otherwise indicated

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Water system monitoring 3

Water treatment system component	Sampling site	Test	Acceptable level	Recommended frequency of measurement
Dialysis water	Sampling port **prior to the distribution loop**	**Chemical analysis**	Variable, depending	**Every 3 months** or when: The quality of the feed water demonstrates changes in the measured chemical contaminants. The reverse osmosis membranes are changed. The reverse osmosis percent rejection drops below 90%.
	in the **return line of the distribution loop** in the distribution loop **outlet to each treatment station**	Colony count or total viable **microbial count**	**<100 CFU/mL** with an action level of 50 CFU/mL	From the return line of the distribution loop: **monthly** From the outlet of each treatment station: **annually**
	in the **return line of the distribution loop**, in the distribution loop **outlet to each treatment station**	**Endotoxin**	**<0.25 EU/mL** with an action level of 0.125 EU/mL	From the return line of the distribution loop: **monthly** From the outlet of each treatment station: **annually**

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Revista de la Sociedad Española de Nefrología
www.revistanefrologia.com

Review

Towards zero liquid discharge in hemodialysis. Possible issues

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Center of Hemodialysis 2 Mars, Casablanca, Morocco

ARTICLE INFO

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ABSTRACT

Scarcity of water and energy, and legal requirements for discharge of waste and wastewater are forcing hemodialysis facilities to change their approach to a more integrated concept of connecting the residual output (in terms of waste, wastewater and energy loss) to the input (in terms of water and energy). Zero liquid discharge is an expanding water treat-

- **Every drop of water** conserved **reduces energy consumption** and associated **carbon emissions**.
- Water use means energy use, therefore conserving water means conserving energy.
- The carbon footprint of kidney care is high and estimated to be 27 million tonnes of carbon dioxide per year worldwide.

N E F R O L O G I A 2 0 2 1 ;4 1(6):620–624

International Urology and Nephrology (2022) 54:1059–1065
https://doi.org/10.1007/s11255-021-02981-w

NEPHROLOGY - REVIEW

Advanced hemodialysis equipment for more eco-friendly dialysis

Adelheid Gauly[1] · Nicole Fleck[2] · Fatih Kircelli[1]

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Abstract
Healthcare in general and dialysis care in particular are contributing to resource consumption and, thus, have a notable environmental footprint. Dialysis is a life-saving therapy but it entails the use of a broad range of consumables generating waste, and consumption of water and energy for the dialysis process. Various stakeholders in the healthcare sector are called upon to develop and to take measures to save resources and to make healthcare and dialysis more sustainable. Among these stakeholders are manufacturers of dialysis equipment and water purification systems. Dialysis equipment and consumables, together with care processes need to be advanced to reduce waste generation, enhance recyclability, optimize water purification efficiency and water use. Joint efforts should thus pave the way to enable delivering green dialysis and to contribute to environmentally sustainable health care.

- It can be anticipated that with a dialysate flow of 500 ml/min for 4 h not only the 120 L water for dialysis fluid are required,
- But up to 480 L of water, taking also reject water into account.
- Additional water is used during the preparation and disinfection cycle adding to the water need by the actual treatment.

International Urology and Nephrology (**2022**) 54:1059–1065

Water implications in dialysis therapy, threats and opportunities to reduce water consumption: a call for the planet

Check for updates

OPEN

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Water is a dwindling natural resource, and potable water is wrongly considered an unlimited resource. Dialysis, particularly hemodialysis, is a water-hungry treatment that

Because of climate change, access to potable water is, and will be, a big challenge,[1] posing unprecedented threats to human health.[2] Traditionally, humans use water

Kidney International (**2023**) 104, 46–52; https://doi.org/10.1016/ j.kint.2023.04.008

Hemodialysis: a water-hungry treatment

- The global annual water use of hemodialysis is approximately **265** million m3/yr.
- "**3R**" concept:
  - **Reduce** (dialysis need, dialysate flow, optimize RO)
  - **Reuse** (reuse wastewater as potable water),
  - **Recycle** (dialysis effluents for agriculture and aquaponics use).
- Water consumption in hemodialysis is approximately 0.5 m3/session based on the that two-thirds of this water is RO reject water discharged into the drain.
- Delaying dialysis initiation: for every patient-month of dialysis delay, the amount of water spared is approximately 6000 L (12 sessions x 500 L).

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POINTS OF VIEW

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Hemodialysis water reuse within a circular economy approach. What can we add to current knowledge? A point of view

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Abstract

The ongoing climate change and the ecological challenges call for sustainable medicine and, in our field, sustainable kidney care. Dialysis is life-saving and resource-consuming, and high water consumption is one of the main concerns. Circular water economy, meaning reuse and recycling of water, and recovering resources can help reducing emissions and enhancing resilience to climate change. Several actions are possible including reusing reverse osmosis reject water, employable for gardening, aquaponics or even simply for toilet flushing, or in sterilization settings, reusing spent dialysate, at least for toilet flushing, but with wider use if microbiologically purified, recovering thermal energy from spent dialysate, that can probably be done with simple devices, or using phosphate-rich spent dialysate for producing fertilizers, namely struvite. All these options may be economically sound, and all help reducing the final dialysis carbon footprint. There is room for open-minded innovative approaches to improve water-related sustainability in hemodialysis, ultimately reducing ecological impact and increasing availability.

- Thermal energy is lost in dialysis units worldwide, could heat approximately 140,000 homes in a european country for one year.
- Spent dialysis effluent, which has a high saline content and is a potential source of infectious contamination, is systematically discharged.
- Since an excessive salt level can have a negative effect on plant growth, mixing reverse osmosis reject water with water from other sources (rain, wells) allows us to dilute salts to a safe level for use in farming.
- Reverse osmosis and nanofiltration, are effective in reducing not only salt content but also an array of micropollutants and pathogens, including viruses, drugs and drug metabolites.

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Case cost studies of reject reverse osmosis water reuse in hemodialysis

	Canterbury Hospital NHS—UK [9]	Countess of Chester Hospital NHS—UK [10]	Lister Hospital NHS—UK [11]	Maidland Hospital Ireland [12]	Sultan Abdul Halim Hospital Malaysia [13]
Reuse option	Toilet flushing	Toilet flushing, Laundry and other uses	Hot water	Toilet flushing	Acquaponics and horti-culture
Volume of saved water	800 Liters / hour	1460 M^3/year	3140 m^3/ year	5240 m^3/ year	12,000 liters/day
Implementation costs	19,000 $ (15,000 £)	14,000 $ (11,030 £)	7600 $ (6000 £)	13,100 $ (12,000 €)	$1047 (MYR 5000)
Financial savings (USD/year)	9530 $ (7500 £)	3990 $ (3143 £)	8000 $ (6300 £)	13,600 $ (12,500 €)	$524 (MYR 2500)
Payback period (months)	24	42	12	12	24

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Take home messages

1. The major components of water treatment system include: multimedia or sediment filter, water softener, carbon filter and RO.
2. **Multimedia filter** removes particles > 20 micron
3. **Water softener** removes calcium and magnesium.
4. **Carbon filter** removes chlorine and monochloramine.
5. **Reverse osmosis** removes metal ions, salts, inorganic, organic chemicals and microbial elements.
6. Materials of distribution system should be from PEX, PVC or stainless steal.

Take home messages

7. Bacterial analysis from outlet of each dialysis machine annually.
8. Feed and distribution water chemical analysis every 3 months.
9. Bacterial analysis of dialysis water every months.
10. Sediment filter, softener monitoring at the end of every day.
11. Carbon filter at the beginning and every 4 hours.
12. Water consumption in hemodialysis is approximately 0.5 m3/session.
13. The carbon footprint of kidney care is high and estimated to be 27 million tonnes of carbon dioxide per year worldwide.