OPPORTUNITIES FOR INCREASED RESOURCE SUSTAINABILITY IN HEMODIALYSIS WATER TREATMENT SYSTEMS

Presented at the NANT 21 Annual North Texas DXT

On 2022 November 13

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Opportunities for Increased Sustainability of Hemodialysis Water Treatment Systems

This presentation will:

- Identify resources that are used in hemodialysis water treatment systems
- Investigate ways to reduce those resources
- Provide a sustainable central water treatment system

Sustainability

Merriam-Webster Dictionary

- capable of being sustained

Sustainability

US EPA

- to create and maintain the conditions under which humans and nature can exist in productive harmony

Sustainability

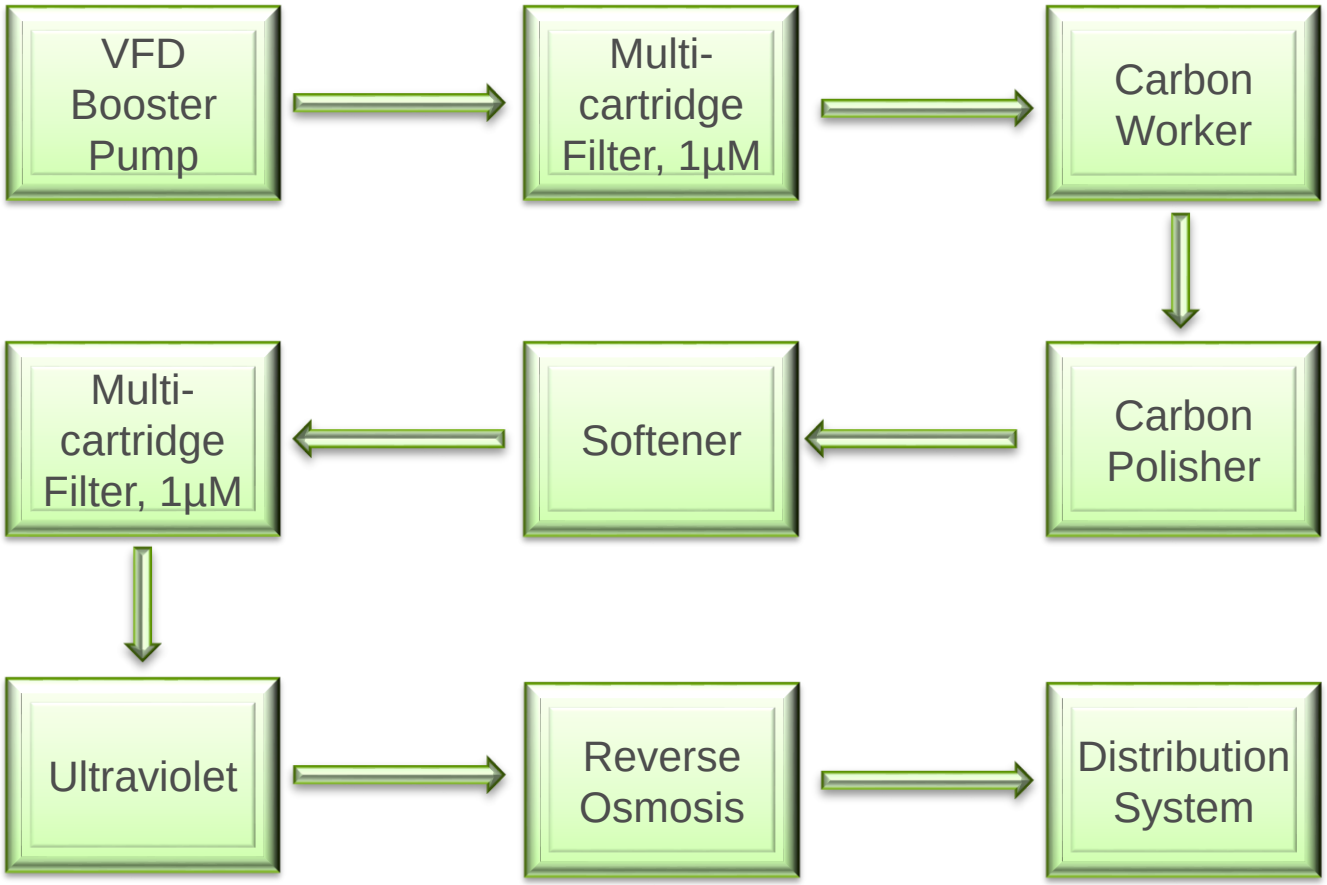
For this presentation:

Means that the natural resources used in the work that we do must be in the long-term balance with the environment that we live in.

Natural Resources used in Hemodialysis Water Treatment Systems

1. Municipal potable water
2. Sediment Filters
3. Carbon (GAC - Granulated Activated Carbon)
4. Salt
5. Electricity
6. Disinfectant

Typical Hemodialysis Water Treatment System Today



Booster Pump Section

Today almost all hemodialysis water systems use VFD pumps

- Most efficient pump system available to day (increased efficiency and reduced electrical demand typically pays for the price adder in less than two years)
- Only pumps when there is demand for water (by output pressure dropping below the preset water pressure)
- Maintains the set water pressure (for optimal operation and performance of all equipment down stream)
- Reduces pressure transients (Detrimental to life and function of down stream components)

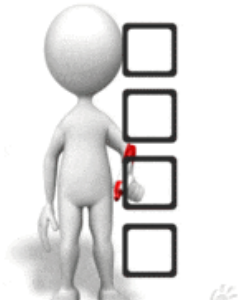
Influent Sediment Filtration Section

- Sediment continues to be the most overlooked and under-appreciated contaminate in Hemodialysis Water Treatment Systems today.
- The lack of understanding its importance is one of the major obstacles in significantly improving the sustainability of hemodialysis water treatment systems today.

Influent Sediment Filtration Section

In my NT NANT presentation in 2017, I mentioned that there are three sources of sediment:

1. Incoming municipal water;
2. Carbon fines;
3. Biological growth in situ (within the system itself).



Influent Sediment Filtration Section

The complete understanding of the sediment in incoming municipal water is critical to:

1. The most effective and efficient processes to remove it
2. The efficacy of the total water treatment system

Again, the removal of sediment from incoming municipal water is the most important process for allowing sustainable water treatment systems.

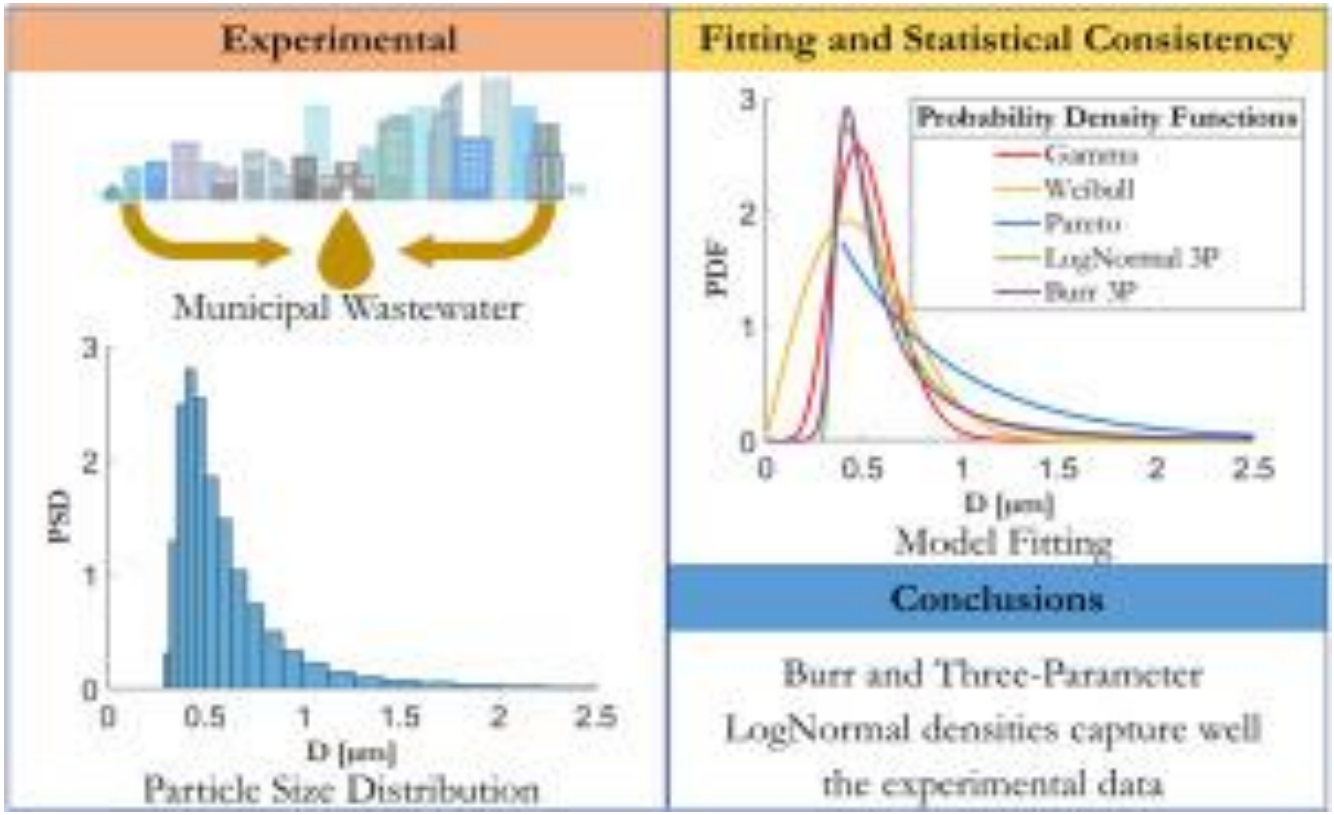
Influent Sediment Filtration Section

There are two types of sediments in municipal water

1. Inorganic – rocks, sand, micro-plastics
2. Suspended organics – decomposition of organic material such as plants

Influent Sediment Filtration Section

- Municipal water leaving the water facility plant typically has a particle distribution of 99% < 1 µm.



Environmental Technology & Innovation Volume 27, August 2022, 106638

Influent Sediment Filtration Section

- The water distribution system fed with chloramine-disinfected water at the water plant will grow nitrogen-eating bacteria in the distribution systems.
- The city will periodically switch to 100% free chlorine (0% chloramine) to kill and flush out the distribution pipe system. During this time the influent water at the hemodialysis facilities will have a suspended solids bloom that will last typically for two weeks as the decaying bacteria are being sluffed off exponentially.
- So, the initial sediment-removing section of the hemodialysis water treatment system must remove sediment that is sub-micronic and be capable of removing periodic, short-term suspended solids blooms.

Influent Sediment Filtration Section

Types of sediment filters available that are practical in the sub-micron range:

1. Polypropylene depth filters (nominal)
2. Carbon bed filters

Types of filters that are not practical in the sub-micron range:

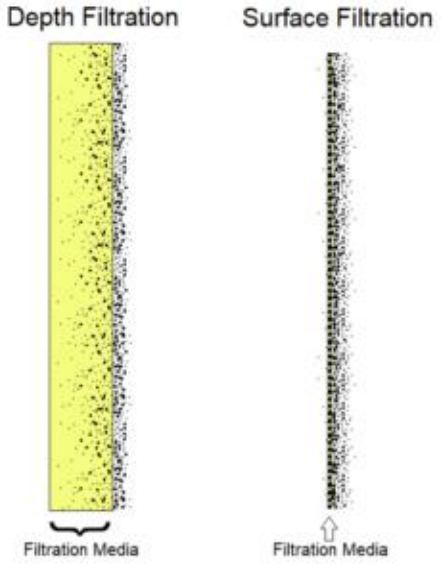
1. Multimedia bed filter (filters boulders and rocks down to 40 micron)
2. Carbon block filter (coconut carbon with almost no life due to clogging)
3. Pleated filters absolute (short life for surface water fed municipal water systems)

Influent Sediment Filtration Section

Types of sediment filters available that are practical in the sub-micron range:

1. Polypropylene cartridge depth filters (nominal)

➢Cartridge Depth filters are manufactured to have a porosity gradient across the filter with the least porosity at the exit of the filter and the greatest porosity on the outer surface. As the influent “dirty” water passes through it, the filter catches the largest size sediment first. As the water penetrates deeper into the filter, the sediment is selectively removed by the decreasing porosity size of the filter. Thus, the whole filter is used to filter out sediment, not just the surface.



Influent Sediment Filtration Section

Types of sediment filters available that are practical in the sub-micron range:

1. Polypropylene cartridge depth filters (nominal)

- Because of the economics, cartridge depth filters are very inexpensive, the depth filter should always be the first filter in municipal sources water treatment system.
- However, the filter is only as good as it is applied. Unfortunately many hemodialysis water treatment systems are put together by catalog-specification selectors who do not understand sediment filter dynamics (or forgot from their Fluids 101 course in college).
- One often hears about “channeling” in filters. There is no such thing as channeling in sediment filters. Any channels quickly get clogged with sediment, so they are self healing.

Influent Sediment Filtration Section

Types of sediment filters available that are practical in the sub-micron range:

1. Polypropylene cartridge depth filters (nominal)

- What is critical in sediment filters is the cross-sectional water velocity. Sediment filters should be applied to have the least practical velocity possible. This allows the sediment to securely be captured by the filter. Almost all inefficient sediment filters is caused by rapid cross-sectional velocities punching through sediments.
- But the best engineered sediment filter systems most often are defeated by the traditional sediment filter change as part of periodic (quarterly) PM programs.

Influent Sediment Filtration Section

Types of sediment filters available that are practical in the sub-micron range:

1. Polypropylene cartridge depth filters (nominal)

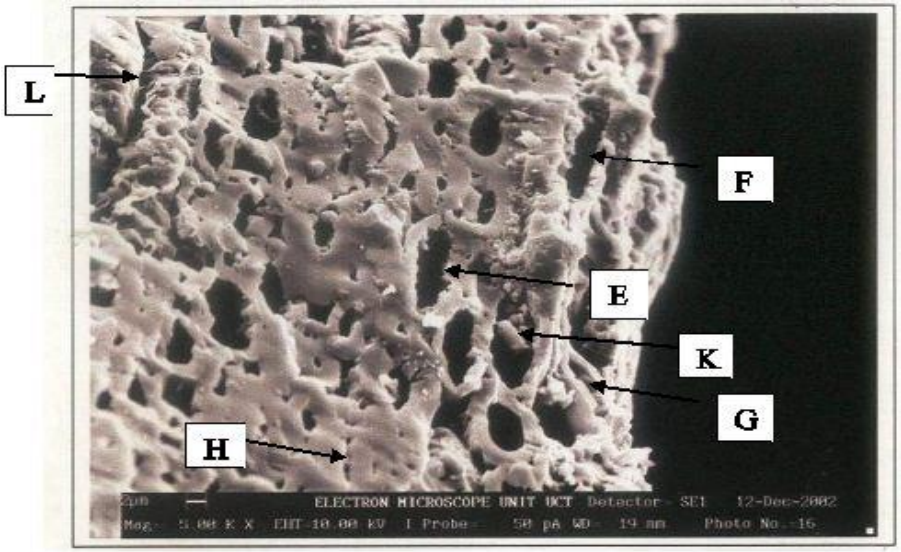
- Cartridge sediment filters increase in efficiency as the cartridges start to load up, forming a cake. The thicker the cake, the greater the efficiency of the filter.
- Sediment filter cartridges should only be replaced after the delta pressure across the filter is greater than 10 psi and when the pressure drop will start to influence the water system components downstream from it.

Influent Sediment Filtration Section

Types of sediment filters available that are practical in the sub-micron range:

2. Carbon filters

- Carbon filters are the most efficient sediment filters available. When properly installed after a multi-cartridge sediment filter, they protect the rest of the water treatment system. The large variation in pore size removes everything that arrives in the city water.



Influent Sediment Filtration Section

Types of sediment filters available that are practical in the sub-micron range:

2. Carbon bed filters

- Unlike cartridge depth filters, there is no “break-in” period while a cake is building. Thus, the carbon bed filter protects the down stream components during this period.
- In addition to being a sediment filter, carbon filters are well know for their removal of dissolved organic compounds. Thus, when used as an entry-stage filter, it removes dissolve organic components that could affect water treatment compounds downstream.

Influent Sediment Filtration Section

In summary:

- The influent sediment filtration system is the most important section to provide the opportunity to design a sustainable hemodialysis water treatment system.
- It is also the poorest designed, mis-applied, and maintained section of the typical water treatment system today.

Carbon Bed Filter Section

- Traditional hemodialysis water treatment systems today use carbon beds with top-mounted control valves.

Bed Filters with back-wash control valves

- Traditionally bed filters were sediment filters with sand or other media such as diatomaceous earth.
- Both media had a uniform pore size and thus, the sediment either settled on the top surface (if the sediment was greater than the media pore size), or passed through the media (if the sediment was less than the media pore size).
- The efficiency of these filters was not great, caused by the sediment clogging up the surface of the bed. As such, the beds would be backwashed usually by using a manual valve.

Carbon Bed Filter Section

Bed Filters with back-wash control valves

- Automatic valves such as those in use today (Fleck for example) were introduced into the market and allowed for programmed automatic back-washing.
- Carbon filters took advantage of the automatic control valves developed for the sediment filters and applied them to carbon beds.
- Just like sand sediment beds, carbon beds accumulate sediment on the top surface for large-sized debris.

Carbon Filter Section

Carbon Bed Filters

- Since these bed are so efficient at capturing sediment, the theory was that back-washing was required to remove the sediment that was captured in the media by back-washing the bed.

Carbon Filter Section

Carbon Bed Filters

- However, with a well-engineered, efficiently-used pre-carbon bed sediment filter system, the carbon bed will be relatively free from debris.

Carbon Filter Section

Carbon Bed Filters, Back-wash or Not.

- We now have reached one of the most controversial topics today for hemodialysis water treatment systems.

Reasons to not back-wash carbon bed filters (after sediment filter)

1. With effective sediment pre-filtration, little to no sediment will accumulate on the surface of the bed filter
2. Sub-micron sediment will fill pores in the carbon media. As mentioned before, as the influent water passes through the bed which is a depth filter, the particle-size of the sediment gets smaller and smaller, the deeper into the bed.

Carbon Filter Section

Carbon Bed Filters, Back-wash or Not

Reasons to not back-wash carbon bed filters (after sediment filter)

3. Carbon is very abrasive. When tumbled during back-wash, it breaks apart when violently hitting other carbon. This produces carbon fines. Carbon fines are an in-situ sediment that complicates water filtration downstream.

Carbon Filter Section

Carbon Bed Filters, Back-wash or Not

Reasons to not back-wash carbon bed filters (after sediment filter)

4. During the back-wash operation, the influent water enters the most-virgin part of the bed that no sediment has reached from the top and immediately contaminates the media; and continues to do so for as long as the back-wash process continues. To ensure that the most sediment is captured, the bed is expanded as previously mentioned. Then the forward rinse compacts the bed to ensure that the newly placed sediment has a difficult path to escape. Wang Leilei in his paper noted that carbon fines were still being sloughed off after 48 hours. This is not in-situ sediment but influent sediment that has by-passed the most efficient carbon bed sediment filtration.

Carbon Filter Section

Carbon Bed Filters, Back-wash or Not

Reasons to not back-wash carbon bed filters (after sediment filter)

5. The back-wash operation on a typical 24” carbon bed (10 ft^3) uses 10 min. of back-wash at 24 gpm (240 gal), followed by 10 minutes of forward wash at 24 gpm (240 gal) for a total of 480 gal.
6. Special media manufacturers advise to never back-wash their media in a bed as it will destroy the efficiency of the media. Carbon is no different.

Carbon Filter Section

Carbon Bed Filters, Back-wash or Not

Reasons to not back-wash carbon bed filters (after sediment filter)

7. Carbon beds are used in hemodialysis water treatment systems to remove chlorine, chloramine, and other toxins that may be in the influent water. As the media removes the unwanted chemicals, it does so with a boundary phenomenon. As the water flows through the media, the media above the boundary has exhausted its ability to remove any more of the chemical. The media at the boundary is actively removing the chemical. The media below the boundary is virgin. If the media is backwashed, the boundary is destroyed and both virgin and exhausted media will be distributed throughout the bed.

Carbon Filter Section

Carbon Bed Filters, Back-wash or Not.

So why are carbon filters back-washed today?

1. CYA! (Cover your ass)
   - People are afraid of change
   - If not afraid of change, don't want to be the changer
   - Risk aversion
2. The supplying of carbon beds with back-washable control valves have been part of all hemodialysis water treatment systems that have been cleared by the FDA (510k's)
3. Hemodialysis providers will not deviate from water system supplier required use of system. (I have never seen a water system supplier that requires back-washing of carbon tanks, even though they supply the control valve on top of the bed).

Carbon Filter Section

Carbon Bed Filters, Back-wash or Not.

So why are carbon filters back-washed today?

4. Industry inertia (it's always been done this way; don't kick a sleeping dog; if it ain't broke, don't fix it; don't rock the boat; why are you a trouble maker!; you don't understand; it won't work!; are you a masochist?; don't swim against the current.

Softener Section

The softener is one of the most misused components in a hemodialysis water treatment system

It is the most inefficient component in the system, because of:

1. Misunderstanding of the purpose of the softener
2. Misinformation of when softeners are needed
3. Misunderstanding of the softness requirements of RO membranes
4. Misinformation of the necessity of media backwashing
5. Misinformation of the safety of twin-alternating control valve heads on softeners
6. Misunderstanding of membrane scaling phenomenon

Softener Section

1. Misunderstanding of the purpose of the softener
   - ❑ The softener is used to protect the RO membrane from hardness
   - ❑ It is not required to be used in a RD-62 AAMI system
   - ❑ It is not considered necessary to use for patient safety.

2. Misinformation of when softeners are needed

   Protection of membranes from hardness scale is generally only necessary when the Langelier Saturation Index (LSI) is positive. This is why the FDA requires a site water analysis be done before designing the water treatment system

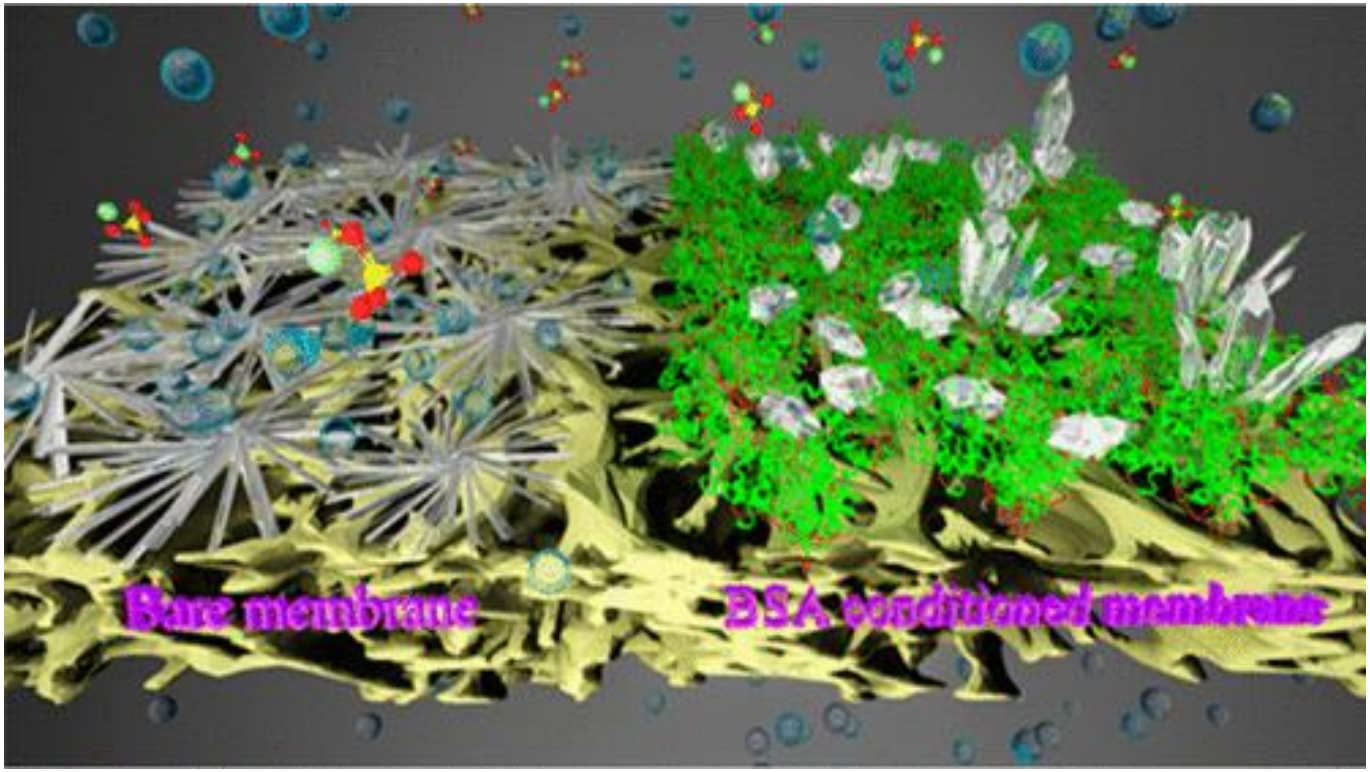
   Unfortunately, industry standard is to use a water softener without scientific verification of its necessity.

Softener Section

3. The softness requirements of RO membranes

- RO membrane manufacturers specify a hardness of 3 grains (51 mg/L) maximum hardness for influent water. That is a general rule based on a standard solution. Greater than 3 grains of hardness can cause metal salts to precipitate out.
- This occurs when the concentration of their ions in the water is greater than its saturation point of those ions. The precipitation is a global dispersion.
- The exact sclability for a specific water sample can be calculated by software (or manually, if no software is available).
- In addition, the Langelier Saturation Index (LSI) is commonly used to predict scaling for specific water samples.

Mineral Scaling on Reverse Osmosis Membranes:



Role of Mass, Orientation, and Crystallinity on Permeability

Meng Wang, Bo Cao, Yandi Hu*, and Debora F. Rodrigues*

Cite this: *Environ. Sci. Technol.* 2021, 55, 23, 16110–16119
Publication Date:November 17, 2021
https://doi.org/10.1021/acs.est.1c04143

Softener Section

4. Does not require backwashing

   Reason to backwash softener bed:

   None

   Reasons to not Back-wash softeners:

   - ❑ There is no sediment on top of the media to back-wash out
   - ❑ Carbon fine sediment if present is not likely to enter the bead, and if it does, is not likely to be removed by the back-washing process.
   - ❑ Wastes water. Typical 10 min. back-wash stage uses 10 min x15 gpm or 150 gal.

Softener Section

4. Does not require backwashing

   So why are softeners back-washed today?

- CYA! (Cover your ass)
  - People are afraid of change
  - If not afraid of change, don't want to be the changer
  - Risk aversion
- The supplying of softeners with back-washable control valves have been part of hemodialysis water treatment systems that have been cleared by the FDA (510k's)

Softener Section

4. Does not require backwashing

   So why are softeners back-washed today?

- Hemodialysis providers will not deviate from water system supplier required use of system. (I have never seen a water system supplier that requires back-washing of carbon tanks, even though they supply the control valve on top of the bed).
- Industry inertia (it's always been done this way; don't kick a sleeping dog; if it ain't broke, don't fix it; don't rock the boat; why are you a trouble maker!; you don't understand; it won't work!; are you a masochist?; don't swim against the current).

Softener Section

5. Mis-information about safety of twin-alternating control valve heads on softeners

Softener Section

5. Mis-information about safety of twin-alternating control valve heads on softeners
   - Twin-alternating softeners are the most efficient softeners available. They only switch tanks after the service tank bed is 90% exhausted. Therefore, all of the bed media is used every time that the beds are alternated.
   - Unfortunately early fears (based upon ignorance) about how the valves function, caused certain key specifiers of hemodialysis water treatment systems at the time to restrict this type of softener.

Softener Section

5. Mis-information about safety of twin-alternating control valve heads on softeners
   - The problem was further compounded when State inspectors were told that there must not be any copper in a hemodialysis water treatment system.
   - To ensure that softeners never run out of capacity, water system designers super size water softeners giving them much more capacity than is necessary. This guarantees that softeners are regenerated with only a partial of their capacity used.

Softener Section

6. Ignorance of membranes scaling phenomenon

   Membrane Scaling was originally thought to be a boundary wall phenomenon. But, . In 2001, Elfil and Roche showed that when the saturation index of amorphous calcium carbonate is exceeded, it will globally precipitate out of the solution (not a boundary wall phenomenon). R. J. Ferguson and A. J. Freedman published similar results in 2003.

   In hemodialysis water treatment systems today, scaling now is recognized as biological fouling. The bacterial on the surface of the membrane capture the metal salt precipitate and glue it onto the bacteria's gelatinous surface.

Softener Section

6. Ignorance of membranes scaling phenomenon

   Since the precipitate is global dispersion, it does not coat a wall but stays within the fluid solution (down the drain). The precipitate will only get stuck on the membrane if there is biofouling.

   <u>No biofouling – no scaling</u>

   Controlling biofilm also allows the membranes to:

   - work at full capacity (100% efficiency)
   - Not require cleaning as often
   - Reduce the amount of heat or chemicals for disinfection

Softener Section

QUESTION: **IS A WATER SOFTENER NECESSARY?**

ANSWER: **ONLY IF AN ANALYSIS OF THE INFLUENT WATER INDICATES SCALING POTENTIAL**

QUESTION: **IF SO, ARE THERE ALTERNATIVES TO A WATER SOFTENER?**

ANSWER: **YES**

1. Phosphate cartridges
2. Liquid Chemical Anti-scalants
3. Templet Assisted Crystallization (T.A.C.) media

Softener Section

Water softener alternatives

1. Phosphate Cartridges

Phosphate chelates the hardness ions so that as their anion and cation concentrations increase in the water, the ions are inhibited from joining together to form the solid mineral salt solid molecule.

Softener Section

Water softener alternatives

2. Liquid Anti-scalant Chemicals

Antiscalant is a pretreatment water additive for reverse osmosis system that is highly effective in preventing the membranes from scaling. Before the feed water enters the reverse osmosis membrane, an antiscalant is injected into the water and sent through the system. The chemical creates a time delay between the bicarbonate and the calcium magnesium. The delay allows the water to pass through the membrane before any chemical reaction, in which scale can form, occurs. This results in scale not forming as the water is being purified by the RO.

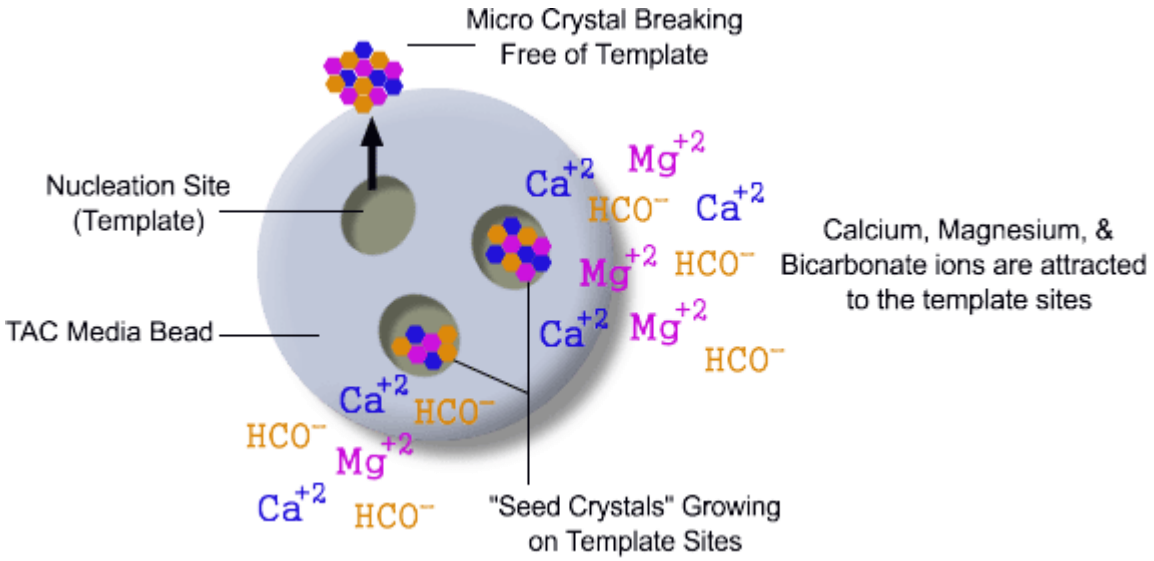
From Applied Membranes website

Softener Section

Water softener alternatives

3. Template Assisted Crystallization T.A.C Anti-scalant Media

T.A.C is a media designed to reduce the negative effects of scaling from hard water without using salt and without removing the healthy minerals from the water.



Softener Section

Thus, based upon today's knowledge, there are many sustainable opportunities to protect the RO membranes in hemodialysis water treatment systems.

If an end user insists on using a softener or on those rare occasions where a softener is required, the use of a twin-alternating softener is the most efficient choice.

Natural Resources used in Hemodialysis Water Treatment Systems

- 1. Municipal potable water
- 2. Sediment Filters
- 3. Carbon (GAC - Granulated Activated Carbon)
- 4. Salt
- 5. Electricity
- 6. Disinfectant

Natural Resources used in Hemodialysis Water Treatment Systems

HEMODIALYSIS WATER TREATMENT SYSTEM SUSTAINABILITY				
RESOURCE	**SUSTAINABILITY**	**RES REDUCTION**	**FREQUENCY**	**ANNUAL QTY**
WATER	No Softener	320 gallons	6 times/wk	99,840 g/yr
WATER	No BW Carbon Beds	480 gallons	6 (2x3times)/wk	149,760 gal/yr
WATER	No BW Softener Beds	300 gallons	6 times/wk	9300 gal/y
WATER	Clean Membranes	25%*	-	
SEDIMENT FILTERS	Change after 10 psi press drop	Sediment filters	-	
GAC CARBON	Change media upon breakthrough	GAC media	20 ft^3/yr**	20 ft^3
SALT	TA softener	50%, 5 bags***	daily	1,560 bags/yr
ELECTRICITY	RO with 100% efficient membranes	25%		
DISINFECTION	Minimal requirement	?		

Note:

* Estimated, based upon typical efficiency drop due to biofouling

** Based upon two 10-ft3 annual carbon re-beds

*** Bases upon 10 ft3 softener bed

Sustainability

Here's a free tip

- Sustainability ain't going away! It is becoming more important each year. All companies worldwide are recognizing that it is a critical part of their survival.
- Volunteer to be part of this program within your company. You will enhance your visibility within the company and become recognized as being a valuable asset in the company's future.

OPPORTUNITIES FOR INCREASED RESOURCE SUSTAINABILITY IN HEMODIALYSIS WATER TREATMENT SYSTEMS

QUESTIONS & ANSWERS