Philip Andrysiak, BS, MBA, CHT; Philip M. Varughese, BS, CHT

Design Requirements for a Water Distribution System in a Hemodialysis Center

Water systems are an integral part of the dialysis facility. They are vital to the safe and effective treatment of the patient. There are a variety of components used to supply water to each dialysis machine. Part of this system of components is the piping used to distribute this water. There are specific flow velocities required that minimize bacterial adhesion to the piping system. The purpose of this article is to help with the design of a water distribution system that will maintain adequate flow velocities throughout the entire system. This article presents a new approach toward designing the water distribution system for the hemodialysis center.
This educational article has been especially designed to provide one (1) contact hour (CH) credit for registered nurses (RNs), Patient Care Technicians (PCTs), Biomedical and Equipment Technicians, and other direct-care personnel who are licensed and certified by the Board of Registered Nursing (BRN) of California. Most (not all) American states recognize and accept the California BRN-certified CHs. Thus, most American healthcare personnel can receive CHs—which are applicable for recertification or relicensure—from reading this article and then answering a post-test (see sidebar). There is ***no charge*** *to receive the CH credit. It is the reader's responsibility to contact his/her BRN, its equivalent, or other certifying bodies prior to submitting this post-test for CH credits to determine acceptability by the reader's state and/or certifying agency.*

1.0 CONTACT HOURS

Objectives

- To determine the different flow velocities needed in direct and indirect water feed systems.
- To determine the minimum flow velocity needed in a dialysis facility.
- To understand the reason for having a specific flow velocity.
- To understand the quality of water needed in a dialysis facility.
- To be able to specify the correct materials for use in a dialysis facility's water distribution system, and to specify those materials that are not appropriate.
- To understand those factors that affect the flow velocity in the water distribution system.
- To be able to calculate the flow velocity at any point in a dialysis facility.

Philip Andrysiak is a Renal Consultant based in Homestead, Florida. Philip M. Varughese is Facility Administrator, DaVita-Richmond Kidney Center, Staten Island, New York.

Ever since the early days of dialysis, transporting water has been one of the many challenges faced. From the original batch systems with 120 L of solution, to the current single-patient delivery systems that require up to 1,000 ml per minute, delivering quality water to the patients' treatment area is still a challenge.

Water systems are an integral part of any hemodialysis facility. There are various mechanical components—from the pretreatment, to the reverse osmosis (RO), to the post-treatment—that are used to provide the proper quality water for the dialysis treatment. Once it passes through the purification process, the water needs to be distributed to the dialysis equipment. There are certain requirements for distributing water to each individual station (dialysis machine, reprocessing equipment, bicarbonate filling area, etc.), as well as many drawbacks with delivering this large a quantity of water.

On the surface, it might appear to be relatively easy to supply water to each individual station. However, there are requirements that need to be met in order to ensure a safe water quality.

Each station requires a specific water flow rate, along with a minimum and maximum pressure. If only the minimum pressure and flow rate were supplied, the result would be a very low flow velocity. There would even be areas within the supply system that were completely stagnant; this is especially true with a direct distribution system (no storage tank). Therefore, it is imperative to build in extra flow capacity above what is needed, creating a "scrubbing" velocity. Along with routine disinfection, this will aid in preventing bacterial adhesion that can lead to biofilm and its consequent problems. For this reason, there are minimum flow requirements.

Loop Flow Design

Both with indirect (storage tank) and direct feed systems, the water should flow in a loop. This means that the water travels in a continuous circle throughout the facility without any branching off. The unused, expensively purified water is then returned to either the RO or the storage tank and not discarded to drain. Furthermore, with a loop design, along with proper piping size, you can achieve higher flow rates through the system, which give higher flow velocities.

Determining the Loop Flow Velocity

The flow rate is described in terms of cubic feet per minute. This then gets converted to the flow velocity in feet per second (FPS). For a direct feed system, a minimum flow velocity of 1.5 FPS is required, as measured at the "end" of the loop and during peak demand (all systems operating and drawing water). For indirect feed systems, the minimum flow velocity would be 3 FPS, with an average range of 3–6 FPS.

If the flow velocity is too high, there may be excessive noise in the system, as well as excessive heat, not to mention the increased wear and tear and electrical costs of running the pumps at an excessive speed. Consider, however, that in ultrapure applications outside of dialysis, flow velocities of 8–10 FPS are not uncommon.

When designing a system, it is important to remember that the flow rate within the piping system will vary. It will be very high at the beginning of the system and will decrease as the water moves through the pipe. The reason is that the various hemodialysis equipment demands a certain amount of water from the loop as the water passes by, decreasing the volume as each piece of equipment collects its requirement. When designing a system and loop, it is imperative to take into account the flow requirements of each individual hemodialysis machine, piece of reuse equipment, bicarbonate fill station, machine repair station, etc.

The water requirements can be calculated for the best-case and worst-case scenarios by using the Distribution Loop Flow Analysis depicted in *Table I,* and which is available on-line (*see sidebar*). For example, you can calculate the flow velocity with the reprocessing equipment either running or with it off. You can also do the same thing with the bicarbonate mixer. Keep in mind that the *minimum flow velocity is with **everything running.***

Although in current practice the diameter of the distribution piping is constant for the entire loop, the flow velocity can also be maintained by using a step-down approach. By progressively decreasing the size of the piping, a higher flow velocity can be maintained for the entire loop. This would also help to maintain consistent pressures throughout the loop. In order to accurately determine the flow velocity, you will need to know the precise diameter of the pipe, along with the initial feed flow rate. Installing a flow meter at the end of the loop will allow you to verify that the system has been designed correctly.

A word of advice: Build in space and options for future expansion of your facility so that your brand-new water system and loop are not obsolete in a few years and so that your capital investment is not lost.

Water Quality

Various agencies either regulate or recommend the quality of the water that is needed in a dialysis facility. The agencies that regulate the outpatient dialysis facilities are the state health departments and the Centers for Medicare & Medicaid Services (CMS; formerly the Health Care Financing Administration [HCFA]). They typically adopt the Association for the Advancement of Medical Instrumentation (AAMI) guidelines. AAMI is a volunteer board that recommends policies for both manufacturers and end-users alike, and their guidelines pertaining to water quality

Glossary

Flow Rate is the Volume of water delivered per unit of time (e.g., gallons per minute)

Flow Velocity is the Distance that the water travels per unit of time (e.g., feet per second)

Water **Pressure** is determined by multiplying the Flow Rate times the Resistance (measured as psi/GPM) offered by the pipe

To convert **Liters per minute (LPM) *to* Gallons per minute (GPM),** multiply by 0.2642

To convert **GPM *to* Cubic Feet per minute,** multiply by 0.1337

To convert **GPM *to* Cubic Feet per second,** divide GPM by 60 and then multiply by 0.1337

To convert the **Pipe Diameter** in inches ***to*** the **Pipe Radius** in feet, divide the Internal Diameter by 2, then divide the resulting number by 12

Cross-Sectional Area of the pipe is determined by the formula $2\pi r$ (2 x 3.14 x radius of the pipe)

Feet per Second = Cubic Feet per second divided by the Cross-Sectional Area for hemodialysis can be found in the monograph, ANSI/AAMI RD62:2001.[1,2]

The AAMI recommendation for bacteria is less than 200 colony forming units (CFU)/ml for all water used in dialysis, including the water in the distribution system, with an action level of 50 CFU/ml. If 50 CFU/ml is reported, then an action should be taken such as disinfecting the RO and/or loop and resampling. For endotoxins, the AAMI recommendation is less than 2.0 endotoxin units (EU)/ml with an action level of 1.0 EU/ml.

The European recommendations are more stringent. The European Pharmacopoeia suggests a limit of 100 CFU/ml for bacteria, with an action level of 25 CFU/ml. For endotoxins, the limit is 0.25 EU/ml, with an action level of 0.0125 EU/ml.

A properly designed water distribution system will keep to a minimum the stagnant areas in the distribution system. Along with an aggressive, routine disinfection of the RO and loop, this should keep the bacterial and endotoxin levels within an acceptable range for longer periods of time.

Endotoxins

The challenge for any hemodialysis facility is to provide water that is endotoxin free. Bacteria will not cross the dialyzer membrane unless there is a micro leak or unless bacteria are introduced during the reprocessing stage. Bacteria introduced during reprocessing are killed as a result of exposure to the disinfectant, but they will leave endotoxins in their wake.

Endotoxins reside in the cell wall of Gram-negative waterborne bacteria. When the bacteria die, they release these toxins. Endotoxins can cause pyrogenic reactions in patients (fever spikes, chills, myalgia, nausea and vomiting, hypotension). Pyrogenic or endotoxin reactions typically occur in more than one patient in a given dialysis facility at a time. They also usually occur at 1 hour to halfway into the treatment, though they may occur earlier depending upon the amount of endotoxin exposure, dialyzer efficiency, back filtration issues, underlying infection processes in the patients, and endotoxin build-up in the dialyzer as a result of multiple reuses.

In addition to pyrogenic reactions, there are well-documented chronic inflammatory disease processes that have been seen in patients exposed to low levels of endotoxins over time; thus, the tighter standards for endotoxins.

Reverse osmosis will remove molecules >200 MW, which will encompass almost 100% of endotoxins. However, in dialysis we are not making sterile water, and no water loop can deliver water that is bacteria and endotoxin free. For this reason, it is a good idea to incorporate an ultrafilter on each hemodialysis machine prior to the point where the dialysate enters the hemodialyzer. In this way, you are assured of dialysate going to the hemodialyzer that is endotoxin free.

Incorporating ultrafilters in the lines leading to the storage tank and in the water loop will further aid in the prevention of bacteria colonization within the loop. However, these filters will reduce the flow rate and, therefore, decrease the flow velocity; thus, they have to be carefully thought out and designed into the system. Other points of use that require ultrafiltration are the reuse equipment and the bicarbonate filling station. Ultrafilters need to be disinfected and/or replaced on a routine basis or they will grow bacteria and shed endotoxin—the very things you are trying to remove!

Construction Considerations

The way in which the water distribution system is installed is critical and requires attention to certain details that a local plumber might not understand. Typically, the material of choice in the U.S. is polyvinylchloride (PVC) schedule 80. However, there is some movement toward more pristine materials such as polyvinylidenefluoride (PVDF), polypropylene (PPE), etc. When using these types of specialty piping, you should assure that the installer understands how to correctly weld the material; otherwise, you may have wasted your money.

When using PVC, the pipe should be cut using an approved PVC pipe-cutting method (a PVC pipe cutter, for instance, looks like a knife and cuts the pipe square). The pipe should not be cut with a hacksaw, as this will leave a rough edge to which bacteria can adhere. Once the pipe is cut, a chamfering tool should be used that will round off the inner and outer diameter of the pipe. Chamfering the edges will reduce the burrs, thus allowing the glue to be more evenly distributed; it will also decrease the occurrence of stress points so that the pipe will be less likely to crack.

All solvent welds should be primed prior to the gluing process. Primer comes both with and without a blue tint. If it has a blue tint, the solvent weld can be inspected after it has been completed. Where possible, all connections should be solvent welded; however, the over-use of glue should be avoided, as the excess glue can hang down and provide places for bacteria to attach. Threaded joints also should be avoided, as they will have spaces where there will be stagnation, thus increasing the possibility for bacterial growth.

Ninety-degree turns in the loop should be accomplished through the use of two 45-degree angles. This will provide a more even flow through the turn and prevent the stagnation that occurs when a 90-degree turn is used.

The connections to the stations should be kept as short as possible. In this way, when a station is not in use the stagnant areas will be kept to a minimum. The connection to the station should be maintained at as high a flow velocity as possible. Nonetheless, it will probably not be possible to achieve the minimum flow velocity of the distribution loop for this short segment. You can, however, achieve the highest possible flow velocity by using a

Table I

Distribution Loop Flow Analysis

	A	B	C	D	E	F	G	H	I
1	**Station**	**LPM**	**GPM**	**Total GPM**	**Cu. Ft./Sec.**	**Pipe Dia. (In.)**	**Pipe Rad (Ft.)**	**Area**	**Ft./Sec.**
2	FEED	40.00	10.57	10.57	0.0235	0.95	0.0396	0.0049	4.78
3	1	0.80	0.21	10.36	0.0231	0.95	0.0396	0.0049	4.69
4	2	0.80	0.21	10.15	0.0226	0.95	0.0396	0.0049	4.59
5	3	0.80	0.21	9.93	0.0221	0.95	0.0396	0.0049	4.50
6	4	0.80	0.21	9.72	0.0217	0.95	0.0396	0.0049	4.40
7	5	0.80	0.21	9.51	0.0212	0.95	0.0396	0.0049	4.30
8	6	0.80	0.21	9.30	0.0207	0.95	0.0396	0.0049	4.21
9	7	0.80	0.21	9.09	0.0203	0.95	0.0396	0.0049	4.11
10	8	0.80	0.21	8.88	0.0198	0.95	0.0396	0.0049	4.02
11	9	0.80	0.21	8.67	0.0193	0.95	0.0396	0.0049	3.92
12	10	0.80	0.21	8.45	0.0188	0.95	0.0396	0.0049	3.83
13	11	0.80	0.21	8.24	0.0184	0.95	0.0396	0.0049	3.73
14	12	0.80	0.21	8.03	0.0179	0.95	0.0396	0.0049	3.63
15	13	0.80	0.21	7.82	0.0174	0.95	0.0396	0.0049	3.54
16	14	0.80	0.21	7.61	0.0170	0.95	0.0396	0.0049	3.44
17	15	0.80	0.21	7.40	0.0165	0.95	0.0396	0.0049	3.35
18	16	0.80	0.21	7.19	0.0160	0.95	0.0396	0.0049	3.25
19	17	0.80	0.21	6.97	0.0155	0.95	0.0396	0.0049	3.16
20	18	0.80	0.21	6.76	0.0151	0.95	0.0396	0.0049	3.06
21	19	0.80	0.21	6.55	0.0146	0.95	0.0396	0.0049	2.96
22	20	0.80	0.21	6.34	0.0141	0.95	0.0396	0.0049	2.87
23									
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smaller pipe size for this short segment. By disinfecting the RO, the loop, and all of the machines connected to the system at the same time, you will be able to disinfect the connections and the inlet hoses to the dialysis machines, which are often neglected.

The use of any metals in the system other than a high-grade stainless steel (316L) is not appropriate. Other metals (brass, copper, aluminum) can leach into the water and cause harm to the patient. The materials used in the system—including O-rings and pump seals—must be compatible with the disinfectants used. Nitrile rubber, for example, is not compatible with peracetic acid. Where this disinfectant is used, the preferred material would be a fluorocarbon elastomer or ethylene propylene.

Calculating the Flow Velocity

This article provides you with the spreadsheet program needed to calculate the flow velocity of a dialysis center's water distribution system. The spreadsheet program is available on-line (see sidebar). An example of a completed spreadsheet is shown in *Table I.* The entries found in the various columns are the result of mathematical derivations performed automatically once key information is inputted into selected cells. The net result is the flow velocity, shown in the far-right column in feet per second.

Column A is the station number.

Column B is the flow rate in liters per minute. The initial flow rate is entered, and then the flow rate for each machine is entered (which is automatically subtracted from the initial flow rate). Each station's flow rate will then be subsequently subtracted.

Column C converts liters per minute to gallons per minute. This is the gallons per minute for that specific machine, or for the initial input.

Column D is the total gallons per minute after that station.

Column E converts first to cubic feet per minute, and then to cubic feet per second.

Column F is the actual pipe diameter in inches.

Column G converts the pipe size from inches to feet, and also converts diameter to radius.

Column H is the cross-sectional area of the pipe in square feet.

Column I is the final answer—the flow velocity—in feet per second. It takes the cubic feet per second and divides it by the area of the pipe.

Now you can enter the specifics for your facility. What you need is the flow at the beginning of the system in liters per minute (LPM) and the flow requirements of the hemodialysis equipment, dialyzer reprocessing equipment, and bicarbonate mixing station. These will be entered in **column B**.

You will also need to know the size of the pipe in the system. Remember, all pipes will have an actual size that is different from the stated pipe size. A 1″ pipe, for instance, will have an internal diameter of less than 1″. The pipe size will be entered in **column F.**

Table I is what a 20-station facility would look like with a 40-LPM flow rate into the beginning of the loop, with hemodialysis equipment that uses 800 ml per minute. By using this method, you can determine the flow velocity of a system *before* you begin construction. You will not have to install a distribution piping system and then measure the flow velocity; you can determine the flow velocity before construction even begins.

Conclusion

You can have the best RO system in the world, but if the loop is poorly designed, or if an old loop is left in place when installing a new water treatment system, you will have a biofilm problem. Remember, too, that if the best-designed water treatment system and loop are installed yet not properly maintained, you will still have a biofilm problem.

A combination of proper water system design coupled with aggressive cleaning and disinfection is your best bet against bacteria build-up in the system.

References

1. *AAMI Standards and Recommended Practices for Dialysis.* Arlington, VA: Association for the Advancement of Medical Instrumentation, 2001.
2. Luehmann DA, Keshaviah PR, Ward RA, Klein E. *Water Treatment for Hemodialysis.* Rockville, MD: U.S. Department of Health and Human Services, Public Health Service, Food and Drug Administration, Center for Devices and Radiological Health, 2002.

POST-TEST

1) Which of the following are appropriate water distribution systems?
- a) indirect systems
- b) direct systems
- c) storage tank systems
- d) all of the above

2) For a direct feed system, the minimum flow velocity should be:
- a) 0.5 feet per second
- b) 1.0 feet per second
- c) 1.5 feet per second
- d) 3.0 feet per second

3) The minimum flow velocity for a system should be measured at the:
- a) beginning of the loop
- b) middle of the loop
- c) end of the loop
- d) at all points of the loop

4) The flow velocity in a direct

feed system is:
  a) higher at the beginning of the loop
  b) higher at the end of the loop
  c) highest at the middle of the loop
  d) the same at all points of the loop

5) The purpose of maintaining flow velocity in the distribution system is to:
  a) lower endotoxins
  b) reduce biofilm
  c) provide adequate flow to the machines
  d) all of the above

6) The most common material for distribution piping used in dialysis is:
  a) polyvinylchloride (PVC)
  b) polyvinylidenefluoride (PVDF)
  c) polypropylene (PPE)
  d) none of the above

7) The material that is unacceptable to use in the distribution system is:
  a) copper
  b) brass
  c) galvanized steel
  d) all of the above

8) If the dialysate flow rate of the hemodialysis equipment is increased, the flow velocity will:
  a) stay the same throughout the system
  b) be lower at the beginning of the loop
  c) be lower at the end of the loop
  d) be lower at all points in the system after the first machine
  e) answers c and d

9) A minimum flow velocity in the distribution system will:
  a) prevent bacterial adhesion
  b) prevent endotoxin adhesion
  c) provide adequate flow to the hemodialysis equipment
  d) answers a and b

10) The following will affect the flow velocity in the distribution system:
  a) initial flow rate
  b) pipe diameter
  c) hemodialysis equipment dialysate flow rate
  d) all of the above D&T

Obtaining Contact Hours

The certifying agent for these contact hours (CHs) is Hemodialysis, Inc. (Hi), a Southern California healthcare corporation. Hi—in conjunction with *Dialysis & Transplantation*—makes these CHs available as a **free** perquisite to the readers of this educational product. Those healthcare personnel who wish to receive a certificate for one (1) CH are required to correctly answer and submit the 10-question post-test that can be found elsewhere in this article. All post-tests for this article must be received in Hi's offices prior to August 16, 2004.

Download from the Web: This article and the post-test—as well as the Excel® spreadsheet discussed within the article—can be downloaded directly from Hi's Web site: www.Hemodialysis-Inc.com. A link can also be found on *D&T*'s Web site, www.eneph.com. For any specific questions pertaining to the use of the Excel spreadsheet, contact Philip Andrysiak at PHA160@aol.com.

Disclaimer: With few exceptions, other states' nursing organizations, as well as other certifying bodies, recognize California Board of Registered Nursing (BRN) CHs. It is the reader's responsibility to contact those organizations to verify that they accept California BRN CHs. We make no claim or representation that the earned CHs are applicable outside of California. Since 1998, Hemodialysis, Inc., has published nursing literature containing CHs. These educational instruments have been purchased by dialysis and other nursing personnel in most, if not all, of the 50 American states, as well as overseas and in Canada. Letters from purchasers whose state or country does not have a BRN nor a requirement for CHs have indicated that employers use and value these CHs for the evaluation of employees for the purposes of promotion and salary enhancement. Thus, these CHs have substantial value even if they cannot be applied toward recertification or relicensure.

Photocopy, Complete, and Mail This Post-Test Form To:

Hemodialysis, Inc.
ATTN: Water Distribution System Post-Test
1560 E. Chevy Chase Dr., Ste. 435
Glendale, CA 91206-4175 (USA)

A self-addressed business-size envelope (9″ x 4 1/4″) with first-class postage affixed ***must*** be enclosed with the post-test.
No request for CHs will be processed without this requirement.
All Post-Tests for this educational article must be received in Hi's offices prior to 5:00 p.m., August 16, 2004.
For any questions, please call Hemodialysis, Inc., at 818/956-5357.

Name (first and last) ____________________

Street Address (include Apt. #) ____________________

City, State, Zip Code ____________________

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❒ RN ❒ LVN ❒ PCT ❒ MD ❒ PhD ❒ Other (specify) ____________________

License or Certificate No. ____________________

State of Licensure, Date of Licensure ____________________

Post-Test Answer Form (circle the correct response)

1) A B C D

2) A B C D

3) A B C D

4) A B C D

5) A B C D

6) A B C D

7) A B C D

8) A B C D E

9) A B C D

10) A B C D

Signature ____________________

Date Form Sent ____________________

WATER DISTRIBUTION DESIGN