3.9 Water Purifiers

3.9.1 Use and Principles of Operation

In the hospital setting it is crucial to have pure water. In many cases, the success of the laboratory depends on the quality of the water available. In the intensive care, much of the medicine delivered to patients may be mixed with water or water and salt before delivery. Even the washing of patients and the preparation of food may require water which has been purified at the hospital to some level in the developing world.

Purification is a general term used to describe the process of removing impurities from water. It can range from simple filtration to complicated multistage processing, the complexity depending on the source of the water and its eventual use. The impurities to be removed can range from parasites, bacteria, and viruses to organic compounds and ions, roughly in order of the size and difficulty of the problem. As varied as are the uses of water in a hospital, so are the requirements for the purity of water needed. Requirements can range from essentially zero tolerable contamination (for parasites) to relative indifference (for ions). Likewise, the cost of purification can range from just a few pennies a gallon to far more.

Some components are found in every purification system no matter what method of purification is being used. These components include the inlet, outlet, vent, filter, and drains. The inlet is simply where the water enters the system and the process of cleaning begins. The drains allow excess impurities to be stored or disposed of. Vents allow gas, mostly air, to exit the system. Finally, once the water has been filtered, it leaves the system through the outlet.

There are at least eight common methods of purification in developing world hospitals: 1) Distillation, 2) Ion Exchange, 3) Carbon Adsorption, 4) Filtration, 5) Ultrafiltration, 6) Reverse Osmosis, 7) Electrodeionization and 8) Ultraviolet (UV) Radiation.

Distillation

Distillation is the oldest method of water purification. The process involves heating water in a still to its boiling point and condensing the resulting steam to water again. The removal of the contaminants depends on how well the still is designed. If boiling is too vigorous, "bumping" can take place, where liquid water shoots out of the boiler directly into the condenser. Any organic compounds with boiling points lower than 100 °C cannot be removed. In fact, they can become concentrated in the process.

Stills do not need to be sophisticated. Here, a simple pot is held over a fire and covered by a large bowl of water. Three rocks hold the pot in place. The long tube allows for condensation. The condensate falls into the collection vessel in the bottom right corner.

Distillation is a robust and simple technique that has the advantage of removing a broad range of contaminants. Unfortunately, it requires careful maintenance to insure purity. Also, distillation consumes a large amount of energy and water, neither of which are in great supply in the developing world.

Ion Exchange

Ion-exchange purification is a rapid and reversible process in which impurity ions present in the water are replaced by ions released by an ion-exchange resin beads. The impurity ions are taken up by the beads, which are then periodically regenerated. The two most common ion-exchange methods are softening and deionization.

Softening is used primarily as a pretreatment method to reduce water hardness prior to reverse osmosis processing. The softeners contain beads that exchange two sodium ions for every calcium or magnesium ion removed from the "softened" water.

Deionization beads exchange either hydrogen ions for cations or hydroxyl ions for anions. The cation exchange resins will exchange a hydrogen ion for any cations they encounter. Similarly, the anion exchange resins will exchange a hydroxyl ion for any anions they encounter. The hydrogen ion from the cation exchanger unites with the hydroxyl ion of the anion exchanger to form pure water. The resin containing the charged contaminants must then be regenerated once it has exchanged all its hydrogen and/or hydroxyl ions in the water, the impurities being shunted to the drain.

Deionization removes some dissolved inorganics and most ions. It requires a relatively inexpensive initial capital investment. However, it cannot be used to remove particles, pyrogens or bacteria. In fact, deionization beds can release resin particles into the water and serve as a culture medium for bacteria growth.

Carbon Adsorption

As mentioned above, ion-exchange resins remove soluble anions and cations from raw water, but some nonionic, organic molecules can coat the resin. Such a coating will decrease the life of the resin and diminish its capacity. To remove nonionic, organic molecules and protect the ion-exchange resin, carbon filters are often placed upstream (before the ion-exchange filter).

In addition to nonionic, organic molecules, carbon also removes free chlorine and protects other purification media in the system that may be sensitive to oxidants.

The adsorption process in a carbon filter is controlled by the diameter of the pores in the carbon filter and by the diffusion rate of organic molecules through the pores. The rate of adsorption is a function of the molecular weight and the molecular size of the organics.

Carbon filters remove dissolved organics and chlorine effectively and have relatively long life. However, they can release carbon particles into the water.

Filtration

Filtration removes particles from the water based on their size. There are three types of microporous filtration approaches: 1) depth, 2) screen, and 3) surface. Each approach serves a different purpose.

Depth filters are matted fibers or materials compressed to form a matrix that retains particles by random adsorption or entrapment. Depth filters are usually used as prefilters because they are economical and can remove nearly all (perhaps 98%) of the suspended solids, protecting downstream elements from fouling or clogging.

Screen filters are single layer, uniform structures which retain all particles larger than a precisely controlled pore size. The particles are retained on one surface of the screen filter.

Surface filters are made from multiple layers of media. When fluid passes through the filter, particles larger than the specified size are retained, accumulating primarily on the surface of the filter. Surface filters are very efficient, removing almost all of the suspended solids (perhaps 99.99%). Surface filters may be used as either prefilters or clarifying filters.

Since the poor size can be specified below the size of bacteria and parasites, surface filters can be used as a partial sterilization process. Filtration requires almost no maintenance, but filters must be replaced occasionally because the flow rate drops as the retained particles clog the filter. Filtration will not remove dissolved inorganics, pyrogens, colloidals or viruses. They can be expensive to replace and cannot be reused.

Ultrafiltration

Ultrafiltration is a process like screen filtration but pore sizes lie in the range 0.001-0.02 µm (100 to 10 times smaller than typical screen or surface filters). Most of the ultrafiltration membranes used in water purification have a hollow fiber configuration, and are non-biodegradable. Ultrafilters are capable of removing 1) particulates, 2) micro-organisms, including all parasites and bacteria and some viruses, 3) inorganic colloids and 4) large organic molecules including pyrogens. Smaller molecules, such as solvents and ionized contaminants pass through the filtrate. Ultrafilters can be used either for pre-treatment or 'polishing' duties in water purification systems.

Ultrafiltration produces the highest quality of water for the least amount of energy and it can be regenerated. However, it will not remove dissolved inorganics, such as calcium, sodium and chloride.

Reverse Osmosis

Reverse osmosis is the most economical method of removing 90% to 99% of all contaminants. Reverse osmosis is a process like filtration and ultrafiltration, but the pore structure of reverse osmosis membranes is even finer than ultrafiltration. Reverse osmosis membranes are capable of rejecting 1) practically all particles, 2) bacteria, 3) viruses, and 4) any organics greater than 300 Daltons in molecular weight.

In order to understand the process of reverse osmosis, it is helpful to understand the process of osmosis in general. Osmosis occurs when solutions with two different concentrations are separated by a semi-permeable membrane. Osmotic pressure drives pure water to dilute the more concentrated solution. The pressure exists until enough water flows that the two solutions are equally concentrated. In water purification systems, the process is driven in reverse. Hydraulic pressure is applied to the concentrated solution to oppose the osmotic pressure. Pure water is driven from the concentrated solution and collected on the other side of the membrane.

Reverse osmosis rejects nearly all of the strongly ionized ions and most of the weakly ionized ions like sodium. Reverse osmosis membranes are very restrictive and therefore yield very slow flow rates so storage tanks are required to produce an adequate volume in a reasonable amount of time. Reverse osmosis can be the most economical and efficient method for purifying tap water.

Electrodeionization

This new technology is a combination of electrodialysis and ion exchange. The process consists of a number of "cells" sandwiched between two electrodes. Each cell consists of a polypropylene frame onto which are bonded a cation-permeable membrane on one side, and an anion-permeable membrane on the other. The space in the center of the cell, between the ion-selective membranes, is filed with a thin bed of ion exchange resins. The cells are separated from one another by a screen separator.

The source water entering the module is split into three parts. A small percentage flows over the electrodes, 65-75% of the source water passes through the resin beds in the cell, and the remainder passes along the screen separator between the cells. The ion-exchange resins capture dissolved ions in the source water at the top of the cell. The potential on the electrodes pulls the ions out of the resin beds. The ions travel towards the electrodes until they reach the adjacent ion-selective membrane, which is of the opposite charge. The ions remain in the space between the cells until they are flushed out of the system to the drain.

Electrodeionization effectively deionizes water. The ion exchange resins are continuously regenerated by the electric current in the unit increasing the time between maintenance calls for the purifier. The result is a deionization approach that is relatively inexpensive to operate. However, electrodeionization requires prefiltration to prevent clogging of the cells.

Ultraviolet (UV) Radiation

Ultraviolet radiation is beginning to be a widely used method for the sterilization of water in the developing world. In most systems, mercury, low-pressure lamps generate 254 nm of ultraviolet light. Exposure to intense UV light of this wavelength destroys the DNA and other proteins in the bacteria, parasites and viruses, rendering the water sterile.

Some lamps generate both 185 nm and 254 nm UV light. This combination of wavelengths is capable of photo-oxidation of additional organic compounds.

The UV technique can kill micro-organisms and, in some cases, photo-oxidate organic compounds into smaller fragments. However, the organisms are not removed from the water. Therefore, particles or clumps of microorganisms can cause shadowing, which may affect the efficiency of disinfection by the ultra-violet light. Water with significant amounts of color and organic compounds will also reduce the intensity of the light and therefore its efficiency.

3.9.2 Common Problems

Water purifiers can be complicated, multi-stage machines. In many cases you will not be able to affect a repair without specialized tools. However, there are a few common problems which can be diagnosed and repaired in the field.

One of the most common problems is clogged filters, typically indicated by a low flow rate. Some filters can be cleaned by backflushing them (running water from the following stage through them backwards – discarding the results). Don’t use upstream water for this purpose. However, if possible, the filters should be replaced.

Leaks are also common. Check all tubing, glass, and reservoirs for cracks or leaks. If the leak is in the inlet to the systems, it can be repaired with epoxy or a silicone sealant. Once the water enters the system, the solvents from glues and adhesives can contaminate the water. Replace the tubing or component rather than repairing it.

When the deionizer fails, the electrical conductivity of the water will increase. When this happens, check the resin bed and see if the beads need to be replaced or regenerated.

Older systems can accumulate deposits which are not being removed in the drains. If deposits are found, scrape them from the system and flush those components with the purest water available.

3.9.3 Suggested Testing

Most users will not know how to determine if the water purifier is working. Furthermore, unlike other clinical laboratory equipment, there is not typically one person using the water. Therefore, the burden is upon the engineer to test the water purifier. Unfortunately, in the developing world, the necessary testing equipment may be unavailable, leaving the engineer few options.

If flow rate was the reason for the initial call, then this can be easily checked with a measuring cup or graduated cylinder and a watch. However, after any work, the purifier should be checked for the purity of the water exiting the system. This can be done by measuring the protein content in a spectrophotometer and the ion content by measuring the conductivity. Sterility can be insured by culturing. However, all or some of these measurements may not be possible in a developing world hospital. Despite the fact that this testing should be performed by the engineer, you may have no choice but to resort to a discussion with the laboratory personnel as your best alternative to testing. They should be able to indicate what the problem was that initiated the call for repair in the first place, and therefore, they should be able to determine if the problem has been fixed.