Methods of Water Purification

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Water treatment can be defined as any procedure or method used to alter the chemical composition or natural "behavior" of a water supply. Water supplies are classified as either surface water or groundwater. The majority of public or municipal water comes from surface water such as rivers, lakes, and reservoirs. The majority of private water supplies consist of groundwater pumped from wells.

MUNICIPAL OR UTILITY WATER TREATMENT

Most municipal water found in a city or community today has been treated extensively. Specific water treatment methods and steps taken by municipalities to meet local, state, national, or international standards vary but are categorized below.

Screen prefiltration

A coarse screen, usually 50 to 100 mesh (305 to 140 microns), at the intake point of a surface water supply, removes large particulate matter to protect downstream equipment from clogging, fouling, or being damaged.

Clarification

Clarification is generally a multi-step process to reduce turbidity and suspended matter. Steps include the addition of chemical coagulants or pH-adjustment chemicals that react to form floc. The floc settles by gravity in settling tanks or is removed as the water percolates through a gravity filter. The clarification process effectively removes particles larger than 25 microns. The clarification process is not 100% efficient; therefore, water treated through clarification may still contain some suspended materials.

LIME TREATMENT

The addition of lime (Ca) and soda ash ($Na2CO3$) reduces the level of calcium and magnesium and is referred to as "lime softening." The purpose of lime softening is to precipitate calcium and magnesium hydroxides (hardness) and then clarify the water. The process is inexpensive but only marginally effective, usually producing water of 50 to 120 ppm (3 to 7 gpg) hardness.

Disinfection

Disinfection is one of the most important steps to municipal water treatment. Usually, chlorine gas is fed into the supply after the water has been clarified and/or softened. The chlorine kills bacteria. In order to maintain the "kill potential", an excess of chlorine is fed into the supply to maintain a residual. The chlorine level must be constantly monitored to assure that no harmful levels of chloramines or chlorinated hydrocarbons develop.

PH adjustment

Municipal waters may be pH adjusted to a pH of approximately 7.5 to 8.0 to prevent corrosion of water pipes, particularly to prevent dissolution of lead into the water supply. In the case of excessive alkalinity, the pH may be reduced by the addition of CO2.

ON-SITE TREATMENT

After the water is delivered from the utility or the well, there are many on-site options for further treatment to meet specific end-use requirements.

Chemical addition

- **pH adjustment.** Certain chemicals, membranes, ion exchange resins and other materials are sensitive to specific pH conditions. An example of this is to prevent acid corrosion in boiler feed water by adjusting the pH so it is between 8.3 to 9.0.
- **Dispersants.** Dispersants are added when scaling may be expected due to concentration of specific ions in the stream. Dispersants disrupt the scale formation, preventing growth of precipitate crystals.
- **Sequestering (chelating) agents.** Sequestering agents are used to prevent the negative effects of hardness, preventing the deposition of Ca, Mg, Fe, Mn and Al.
- **Oxidizing agents.** Oxidizing agents have two distinct functions: as a biocide, or to neutralize reducing agents.
- **Potassium permanganate.** Potassium permanganate ($KMnO_4$) is a strong oxidizing agent used in many bleaching applications. It will oxidize most organic compounds and is often used to oxidize ferrous iron to ferric for precipitation and filtration.
- **Reducing agents.** Reducing agents, like sodium metabisulfite ($Na_2S_2O_5$), are added to neutralize oxidizing agents such as chlorine or ozone. In membrane and ion exchange systems, they prevent the degradation of certain membranes or resins, which are sensitive to oxidizing agents.

Tank-type pressure filters

A typical filter consists of a tank to house the filter media and a valve or controller to direct the filter through its various cycles–typically service, backwash and rinse.

Easily the most critical aspect of pressure filter performance is the relationship of flow rates to filter media surface area. This relationship is the primary cause of failure or trouble in filter systems. If problems develop, the most common reason is that many filters are inaccurately "sized" for the job. Some examples of pressure filters and their applications are:

Sand filters. Sand or other filtration media are used to remove turbidity. However, the location of the fine media on top of the coarse media causes the sand filter to clog quite quickly and the coarseness of sand allows many smaller impurities to pass through.

Neutralizing filters. Neutralizing filters usually consist of a calcium carbonate calcite medium (crushed limestone or marble) to neutralize low pH water.

Oxidizing filters. Oxidizing filters use a medium treated with oxides of manganese as a source of oxygen to oxidize and precipitate iron, manganese, hydrogen sulfide, and others.

Activated carbon filters. Activated carbon (AC) is similar to ion exchange resin in density and porosity. It absorbs low molecular weight organics and reduces chlorine or other halogens from water, but does not remove any salts. These filters must be changed periodically to avoid bacterial growth, but are not easily reactivated in the field. Accumulated solids require frequent backwashing of the filter unless installed after reverse osmosis or ultra filtration.

Dual- or multi-media filters. Dual-media filters remove suspended solids to as low as 20 microns in size, but no dissolved solids. The top layer is a coarse anthracite followed by fine sand.

Pre-coat filters

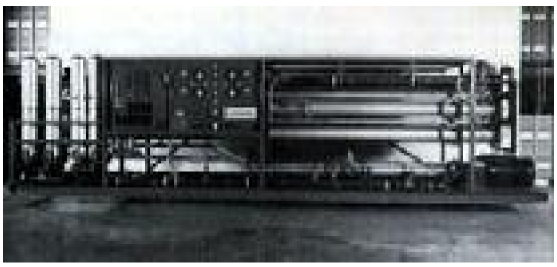
Usually with a media of diatomaceous earth, pre-coat filters remove very small particulate matter, including some bacteria. They are practical only for limited volume applications but are common for swimming pools, beverage plants, and small installations.

Cartridge filters

Cartridge filters can now be described two general ways: as depth filters or surface filters.

Depth cartridge filters. In a depth cartridge filter, the water flows through the thick wall of the filter where the particles are trapped throughout the complex openings in the media. The filter may be constructed of cotton, cellulose, synthetic yarns or "blown" micro fibers such as polypropylene. The best depth filters have lower density on the outside and progressively higher density toward the inside wall. The effect of this "graded density" is to trap coarser particles toward the outside of the wall and the finer particles toward the inner wall. Depth cartridge filters are usually disposable, cost-effective, and are in the particle range of 1 to 100 microns. Generally, they are not an absolute method of purification since a small amount of particles within the micron range may pass into the filtrate.

Surface filtration–pleated cartridge filters. Pleated cartridge filters typically act as absolute particle filters, using a flat sheet media, either a membrane or specially treated non-woven material, to trap particles. The media is pleated to increase usable surface area. Pleated membrane filters serve well as sub-micron particle or bacteria filters in the 0.1 to 1.0 micron range. Newer cartridges also perform in the ultra filtration range: 0.005 to 0.15 micron.



An Osmosis, Inc, custom-made Model OSMO-43B reverse osmosis unit used to desalt water for textile dying operation in Thailand.

Ultra filtration cartridge filters.

Point-of-use ultra filtration cartridges are used to remove progeny and other macromolecular compounds from ultra pure water. They are built in a spiral-wound configuration. This allows a cross flow mode of operation to help keep the surface clean.

Ion exchange systems

An ion exchange system consists of a tank containing small beads of synthetic resin. The beads are treated to selectively adsorb either cations or anions and exchange certain ions based on their relative activity compared to the resin. This process of ion exchange will continue until all available exchange sites are filled, at which point the resin is exhausted and must be regenerated by suitable chemicals.

Water softening.

The ion exchange water softener is one of the most common tools of water treatment. Its function is to remove scale-forming calcium and magnesium ions from hard water. In many cases soluble iron (ferrous) can also be removed with softeners. A standard water softener has four major components: a resin tank, resin, a brine tank, and a valve or controller. However, water softening is disadvantageous when high quality water is required since sodium ions will be present after the ion exchange process.

Demineralization/deionization.

Ion exchange deionizers (DI) use synthetic resins similar to those used in water softeners. Typically used on water that has already been prefiltered, DI uses a two-stage process to remove virtually all ionic material remaining in water. Two types of synthetic resins are used, one to remove positively charged ions (cations) and another to remove negatively charged ions (anions). Resins have limited capacities and must be regenerated upon exhaustion.

Two-bed and mixed-bed deionizers.

The two basic configurations of deionizers are two-bed and mixed-bed. Two-bed deionizers have separate tanks of cation and anion resins. In mixed-bed deionizers, the anion and cation resins are blended into a single tank or vessel. Generally, mixed-bed systems will produce higher quality water with a lower total capacity than two-bed systems.

Deionization can produce extremely high-quality water in terms of dissolved ions or minerals, but they do not generally remove organics and can become a breeding ground for bacteria.

Organic scavenging

Organic scavengers, or traps, are ion exchange resins that contain strong-base anion resin regenerated with sodium chloride brine. Since most naturally occurring organics have a slightly negative charge, they are absorbed by the anion resin. After the resin is loaded, the organics can be displaced by high concentrations of Cl during regeneration.

Distillation

Distillation is the collection of condensed steam produced by boiling water. Most contaminants do not vaporize and, therefore, do not pass to the condensate (also called distillate).

With a properly designed still, removal of both organic and inorganic contaminants, including biological impurities and pyrogens, is attained. Distillation involves a phase change which, when properly carried out, removes all impurities down to the range of 10 parts per trillion, producing water of extremely high purity.

Careful temperature monitoring is required to ensure purity and avoid contamination of the purified water. Organics with a boiling point near that of water are very difficult to remove due to carry over into the vapor. In these situations a double distillation system is often required for complete pyrogen removal.

Electro dialysis

Electro dialysis (ED) and electro dialysis reversal (EDR) employ specially prepared membranes which are semipermeable to ions based on their charge, and they employ electrical current to reduce the ionic content of water. Two flat sheet membranes, one that preferentially permeates cations and the other anions, are stacked alternately with flow channels between them. Cathode and anode electrodes are placed on each side of the alternating stack of membranes to draw most ions through the membranes. This leaves much lower concentrations of ions in the water of the alternate channels. Recent developments have improved the efficiency of ED by reversing the polarity of the electrodes periodically. This is called EDR and has reduced the scaling and fouling problems common to ED.

Cross flow filtration systems

Cross flow (also called tangential flow) filtration is the pressurized flow of the feed water, or influent, across a membrane, with a portion of the feed permeating the membrane and the balance of the feed sweeping tangentially along the membrane to exit the system without being filtered. The filtered stream is called the "permeate", because it has permeated the membrane. The second stream is called the "concentrate" or "reject", because it carries off the concentrated contaminants rejected by the membrane. Because the feed and concentrate flow parallel to the membrane instead of perpendicular to it, the process is called "cross flow" or "tangential flow." Depending on the size of the pores engineered into the membrane, cross flow filters are effective in the range of reverse osmosis, nano filtration, ultra filtration and more recently micro filtration.

Cross flow membrane filtration allows continuous removal of contaminants, which under normal filtration would "blind" (cover up) or plug the membrane pores very rapidly.

Reverse osmosis. Reverse osmosis (RO) was the first cross flow membrane separation process to be widely commercialized. RO removes virtually all organic compounds and 90 to 99% of all ions. A large selection of reverse osmosis membranes are available to meet varying rejection requirements.

RO can meet most water standards with a single-pass system and the highest standards with a double-pass system. RO rejects 99.9+% of viruses, bacteria and pyrogens. Pressure, on the order of 200 to 1,000 psig (13.8 to 68.9 bar), is the driving force of the RO purification process. It is much more energy efficient compared to heat-driven purification (distillation) and more efficient than the strong chemicals required for ion exchange. No energy-intensive phase change is required.

Nanofiltration. (NF) equipment removes organic compounds in the 300 to 1,000 molecular weight range, rejecting selected salts (typically divalent), and passing more water at lower pressure operations than RO systems. NF economically softens water without the pollution of salt-regenerated systems and provides unique organic desalting capabilities.

Ultrafiltration. Ultra filtration (UF) is a similar process to RO and NF, but is defined as a crossflow process that does not reject ions. UF rejects contaminants in the range of 1000 dalton (10 angstrom) to 0.1 micron particles. Because of the larger pore size in the membrane, UF requires a much lower operating pressure: 10 to 100 psig (0.7 to 6.9 bar). UF removes organics, bacteria, and pyrogens while allowing most ions and small organics, such as glucose, to permeate the porous structure.

Microfiltration. Microfiltration (MF) membranes are absolute filters typically rated in the 0.1 to 2 micron range. Traditionally available in polymer or metal membrane discs or pleated cartridge filters, microfiltration is now also available in crossflow configurations. Operating pressures of 1 to 25 psig (0.07 to 1.7 bar) are typical.

Crossflow microfiltration substantially reduces the frequency of filter media replacement required in normal flow MF, because of the continuous self-cleaning feature. Typically, crossflow MF systems have a higher capital cost than MF cartridge filter systems. However, operating costs are substantially lower.