Engineering Fluid Solutions

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WATER TREATMENT TECHNOLOGIES

Many methods of water treatment are available. Moreover, new and better technologies appear every year. While keeping up with these advances can be a full-time affair, most methods can be categorized into one of seven general categories. These categories are broadly defined below and are assigned an abbreviation that later will be used to clarify which methods can be used to contend with specific common contaminants.

Category 1: Ion Exchange (IE)

Specific mined minerals, as well as manufactured, resin-coated polystyrene beads, have the capacity to remove dissolved cations and anions from a moving stream of water. Water softeners and deionization systems are the most commonly known examples (see Figure 2). To work properly, the media must have the ability to exchange weaker ions affixed to their surfaces for stronger ions dissolved in the water as well as be regenerated so that the stronger ions can be removed (sent to drain) and the weaker ions can be put back in their place.

In the case of a water softener, when hard water passes through the cation resin bed inside it, dissolved calcium/magnesium/potassium bicarbonate (hardness) is broken by the media's attractiveness to the mineral (cation) portion of the molecules. These cations of calcium, magnesium, and potassium are grabbed by the resin beads. In exchange, sodium is released, and a small concentration of sodium bicarbonate thereby becomes formed in the water, where hardness molecules previously existed.

In the case of deionization (DI) media, virtually all dissolved cations and anions are pulled from the water and exchanged for ions of hydrogen (H^+) and hydroxide (OH^-). When the H and OH come together in the product water, H2O (i.e., more pure water) is the resulting by-product. DI media typically is regenerated with hydrochloric acid (cation) and sodium hydroxide (anion). However, numerous other ion exchange media are available for the removal of specific minerals and contaminants.

Category 2: Oxidation/Filtration (OF)

The oxidation process involves using a chemical element or compound, such as oxygen, chlorine, chlorine dioxide, hydrogen peroxide, orozone, to rob (reduce) a water contaminant of the electrons necessary to maintain its ionic composition. In the case of dissolved minerals, oxidation often results in new chemical compounds that are less soluble (or insoluble) in water. Once they are no longer soluble, they can be removed via filtration. An example is dissolved to ferrous bicarbonate (iron). When exposed to oxygen or other chemical oxidizers, electrons within the molecule are lost, resulting in broken ionic bonds. In the case of iron, it reverts to ferric oxide (rust), which is no longer soluble and then can be captured by mechanical or medial filtration. In the case of microorganisms, oxidizing agents can be used to rob the lipids (fats) in their cell walls of electrons, thereby altering the chemical makeup of these cell walls and causing them to destruct.

Category 3: Membrane Filtration (MF)

Membrane filtration (see Figure 3), including reverse osmosis, nanofiltration, and ultrafiltration, involves pushing water under pressure through a semipermeable membrane, through which primarily only liquid water is able to flow, with virtually all other minerals and contaminants being blocked. The fact that the water is pressurized allows it to overcome the natural process of osmosis, by which water in areas of high concentrations of dissolved solids typically would flow toward areas of low concentrations to achieve an overall equilibrium. On the contrary, the addition of pressure causes water with relatively lower concentrations to flow through a membrane to an areas of higher concentration.

Ultimately, this process produces two streams of output water: a product water, or permeate, stream and a wastewater, or concentrate, stream. Just how pure the permeate stream becomes depends on the type of membrane and the amount of pressure used as well as which specific contaminants are present in the feed water.

Category 4: Media Filtration (MEF)

A very broad category, media filtration typically works by absorbing contaminants as activated carbon filters do, neutralizing or rendering harmless a contaminant as calcite and several types of phosphate filters do, or catalyzing a contaminant out of solution as template-assisted crystallization filters do. In the case of absorption filters such as activated carbon filters, the media eventually loses its capacity to absorb the contaminants and must be replaced. In the case of calcite, which is used for acid neutralization and phosphate, which is used for scale prevention, the media beds are depleted over time and must be periodically refilled. As to template-assisted crystallization, which typically is used to catalyze dissolved calcium bicarbonate out of solution and into a harmless crystalline calcium carbonate form, the media eventually can become fouled and therefore also requires periodic replacement. (See Figure 4.)

Category 5: Mechanical Filtration (MCF)

This category encompasses basket, bag, cartridge, sand, multimedia, and other forms of basic filters that are capable of removing suspended solids and microbes ranging anywhere from several hundred microns down to 0.2 microns or smaller. Notably, 0.2 micron (or 0.2 micrometer) is considered the level of porosity required to remove virtually all bacteria, viruses, and other microorganisms. While some of these units may be capable of self-cleaning by backwashing with water or air, many others are designed to be disposed of and replaced when they become too fouled to allow adequate water flow.

Category 6: Chemical Injection (CI)

A wide array of applications involving the metered injection of chemicals into domestic water systems is available. Examples include disinfection (chlorine), acid neutralization (soda ash, acetic acid), scale prevention (phosphates), oxidation systems (often hydrogen peroxide) and more.

Metering pumps are widely available and typically actuated via an on/off flow switch, a proportional injection flow meter with a 4- to 20-mA signal, or an on/off timer. Of course, a plethora of anti-scalants, biocides, and other water treatment chemicals is used in commercial HVAC applications, but they do not fall within the scope of this article.

Category 7: UV and Ozone Treatment (UV, OZ)

Two very up-and-coming technologies involve treating water with powerful UVC light rays and injecting or bubbling ozone (O_3) gas into a water supply. In the case of the ultraviolet light, the 254-nanometer UVC spectrum has a powerful ability to disrupt DNA chains in microorganisms, effectively destroying them, provided the water is clear and free of suspended solids and discoloration that can block light penetration. Ozone gas, on the other hand, is one of the best and most powerful oxidizing agents on Earth and can be used to destroy microorganisms, oxidize minerals from solution, break down organic substances, remove odors, and eliminate discoloration.

When ozonated water is channeled through a UV lamp array, the two technologies together can be used to generate hydroxyl radicals, which are more effective than ozone alone. The same hydroxyl radicals also can be formed by subjecting hydrogen peroxide to UV light. Look for this category to grow in importance in coming years.

WATER QUALITY ISSUES

Water quality issues can be broadly divided into two categories: issues of desirability and issues of safety and health. Desirability revolves around aesthetic issues, including the taste, smell, feel and appearance of the water – not to mention its impact on mechanical systems and equipment. Issues of safety and health are naturally more associated with the effect of consumption or use on the human body.

Some of the more common contaminants affecting desirability and methods for contending with them follow.

Chemical Disinfectants

This most commonly includes chlorine and chloramines, with chloramines being a mixture of chlorine and ammonia commonly used in large cities to provide extended residual disinfection with minimal chlorine by-products. Beyond the obvious bad odors and taste, these chemical oxidants can cause skin irritation as well as the breakdown of piping systems and elastomers.

Treatment methods: MEF, UV

Hardness

Hardness refers to dissolved calcium bicarbonate, magnesium bicarbonate, and potassium bicarbonate. Hardness minerals are absorbed when water passes through the soil and into the water table. As a result, it is usually found in significant levels in water from deep well aquifers. Besides the hardscale it can cause in piping systems and plumbing equipment, it also can lead to issues of soap scum buildup on fixtures and poor bathing experiences (e.g., soap and shampoo residue becoming affixed to the skin or hair).

Treatment methods: IE, MEF, CI

Hydrogen Sulfide

Though often naturally occurring, hydrogen sulfide can be found in high concentrations anywhere raw sewage is present. Both corrosive and foul smelling (like rotten eggs), hydrogen sulfide can be deadly if inhaled in high concentrations.

Treatment methods: OF, MEF, OZ

Iron

The two forms of iron are ferrous bicarbonate in the non-oxygenated, dissolved form and ferrous oxide in its precipitated form. In either form, a strong metallic taste or smell may be present, in combination with fouling of plumbing systems and reddish staining of fixtures.

Treatment methods: OF, CI

Manganese (manganous bicarbonate when dissolved)

Similar to iron, yet more difficult to remove, manganese causes black staining of fixtures and can contribute to fouling of systems and equipment.

Treatment methods: OF, MF, OZ

Miscellaneous Organics

Bacteria that feed on dissolved sulfur and iron can create unsavory odors, discoloration, and bioslime. Sulfur-reducing bacteria in particular actually release hydrogen sulfide (rotten egg smell) as they metabolize sulfur from water.

Treatment methods: OF, MF, MCF, CI, UV, OZ

pH (acidic or alkaline water)

Low pH (acidic) water is best defined as any water with pH lower than 6.5. Typically, it is the result of high levels of dissolved carbon dioxide and low levels of alkaline minerals such as calcium and other bicarbonates in the soil, which can serve to neutralize this carbonic acid. High pH (alkaline) water typically is defined as anything a pH of 8.5 or 9. It is normally the result of high levels of dissolved bicarbonates (calcium, iron, etc.) absorbed from the soil. Though low pH generally is considered more destructive, leading to corrosion in plumbing systems as well as sour taste, high pH, which causes a bitter taste, also can be aggressive, particularly with metals like aluminum.

Treatment methods: IE, MEF, CI

Silica (silicon dioxide)

A colloidal substance with tiny suspended particles, silica can lead to the fouling of plumbing equipment, RO membranes, etc.

Treatment methods: IE, CI

Tannins (humic acid)

The result of rotting leaves and vegetation, tannins most commonly are found in surface waters and shallow wells located near bodies of surface water. They are most prevalent in the spring and fall and can cause a tart, somewhat rotten taste. Commonly mistaken for iron, they cause a yellowish discoloration, which can sometimes appear like root beer when in large lakes and streams.

Treatment methods: IE, MF, OZ

TDS (total dissolved solids)

A very broad category, TDS is a blanket measurement that encompasses virtually any substance dissolved in water. While there is no enforced limit on levels, the U.S. Environmental Protection Agency encourages treatment for water with more than 500 parts per million of TDS. Obviously, the effects of high TDS levels are determined by what specific substances are dissolved. However, the general effects of high TDS commonly include bad taste, high corrosivity, and fouling of pipes and equipment.

Treatment methods: IE, MF

Turbidity

The result of suspended, rather than dissolved, substances, turbidity causes cloudy looking water. Most suspended solids can be removed with basic filtration. However, high levels of oxygen in water can cause turbidity-like effects. How can you tell if the effect is caused by oxygen? If the cloudiness disappears when the water sits in the open for a period of time, the cause is a high level of oxygen.

Treatment method: MCF

Some of the more common contaminants affecting safety and health and methods for contending with them include the following:

Arsenic (Type III and V)

A naturally occurring inorganic substance, arsenic is a human carcinogen that naturally leaches into groundwater. Arsenic contamination may be more of an issue in areas where mining or metallurgical operations are prevalent.

Treatment methods: OF, MEF, MF

Bacteria and Viruses

Examples are E. coli, Legionella, Salmonella, Rotavirus, and others. Their presence can be naturally occurring or may be the result of water coming into contact with human, animal or other waste products. Common reactions include gastrointestinal distress, pulmonary issues, and flu-like illnesses.

Treatment methods: MF, MCF, CI, UV, OZ

Copper

While copper is a necessary nutrient to the human body, excessive levels of copper in drinking water can lead to liver damage and anemia. Copper also has been known to cause blue or green staining of hair, teeth, and fingernails. Though some copper is naturally occurring, excessive levels are typically the result of leaching brass and copper pipe and fittings.

Treatment method: IE, MF, MEF

Lead

Though lead is a naturally occurring substance, most lead contamination is the result of leaching from piping and other plumbing system components. Lead causes afflictions of the brain, nervous system, kidneys and blood cells, and it is particularly harmful to young children.

Treatment methods: MF, MEF

Mercury (inorganic methyl mercury)

Mercury is a result of industrial manufacturing and the burning of coal, and long-term consumption and the burning of coal, and long-term consumption of water contaminated with mercury can lead to kidney damage and/or failure.

Treatment methods: MF, MEF

Nitrates and Nitrites

Essentially the same (as nitrates actually become nitrites in the human body), these contaminants are usually the result of human and animal waste or agricultural fertilizers entering the water supply. The most common side effect of excessive nitrate consumption is a reduction in the ability of red blood cells to absorb oxygen. This problem can be especially acute in young children.

Treatment methods: IE, MF

Pechlorates

An industrial by-product of firework, explosive, flare and rocket propellant production, pechlorates are believed to be present in approximately 4 percent of U.S. water supplies. Pechlorates are known to have a detrimental effect on the functioning of the thyroid gland.

Treatment methods: IE, MF

Protozoa (Giardia, Cryptosporidium)

Usually the result of contact with animal waste, these single-cell organisms often exist in a dormant, cyst form in water and cause severe gastrointestinal problems when they become active in the human body.

Treatment methods: MF, MCF, UV, OZ

Radionuclides (radium, uranium)

These naturally occurring radioactive substances are considered carcinogenic and toxic to various organs in the human body.

Treatment methods: IE, MF

THMs and Other VOCs (trihalomethanes and other volatile organic compounds)

These cancer-causing and organ-damaging chemical pollutants generally are the result of industrial waste infiltration or the reaction of chemical disinfectants with various organics in the water. Their list is very long!

Treatment methods: MF, MEF, OZ

Of course, this list of treatment techniques and contaminants is by no means comprehensive- again, it is only a sampling of some of the more common variants. A great deal more information is available from organizations such as the Water Quality Association (wqa.org). When in doubt, always refer to a water treatment specialist. They can ensure that the proper equipment is selected and sized, and those who operate in the commercial and industrial arenas are usually quite good at supplying the necessary specifications, drawings and submittals to make the engineer's task much easier.

RESOURCES

1) Water Quality Association: wqa.org
2) McGowan, Wes, Water Processing, Residential, Commercial, Light Industrial, Water Quality Association, February 2009.