Advanced Water Treatment Concepts

Lesson 2 Appendix of Common Chemicals Used in PWS Treatment

This listing of chemicals used in the treatment of drinking water classifies them according to their purpose in water treatment. We have also listed any special properties of the chemicals and safe handling procedures of the hazardous chemicals.

D. Appendix - Common Chemicals used in Public Water System Treatment:

i. pH/Alkalinity Adjustments: A discussion of the chemicals used in pH and alkalinity adjustments exists not just because there is a desired level of pH and alkalinity in finished water, but because the pH levels and alkalinity levels of water throughout the treatment process affects the dosing and effectiveness of *other* chemicals involved in the water treatment process. For example, in the coagulation/flocculation basins the alkalinity in the water will be consumed by the formation of flocs. This means that an adequate amount of bicarbonate must be present to offset the loss of alkalinity to floc formation. There are several chemicals that can be added to offset the loss of alkalinity or to make adjustments to the pH during the water treatment process. Six chemicals that are commonly used in West Virginia plants include:

1. Sodium carbonate (Na_2CO_3): Sodium carbonate or soda ash is a very common chemical used to raise the pH levels of the water from a more acidic level into the neutral range. It is also known as a water softener. Mildly alkaline, it is produced from inexpensive and plentiful raw materials. Soda ash is a white, odorless powder with a slightly alkaline taste. The handler should follow standard safety precautions to minimize health hazards. A ventilation system is recommended to control the dust and keep operator exposure as low as possible. The dust of this compound can irritate the mucous membranes and potentially cause sores in the nasal passage. Protective gear like safety goggles and dust respirators should be worn during handling. Additionally, exposed skin surfaces should be protected with a cream or petroleum jelly. The storage containers must be designed to protect the chemical from heat and moisture.
2. Lime ($Ca(OH)_2$ and/or CaO): Lime is the generic term used to describe hydrated lime and quicklime. Calcium hydroxide (hydrated lime) and calcium oxide (quicklime) are chemicals frequently used to raise the pH of raw water before the water is treated with alum or ferric sulfates for coagulation/flocculation. Hydrated lime and quicklime are colorless crystals or white powders that are available for purchase in bags, bulk or by truckload. Care in handling of both forms should be taken since the dust can be quite irritating to the skin and eyes. Hydrated lime is commonly used by small facilities because it can be directly applied to the water treatment process. Quicklime, (in pellet form), must first be slaked, or mixed with water then heated to turn it into hydrated lime before use. When quicklime is mixed with water there is a potential for explosions due to the heat released from the chemical combinations. Lime also has reactions with alum and ferric sulfates so direct mixing should be avoided. Storage of these products should be in cool, dry places. Always wear goggles, a dust mask and protective clothing when handling lime. A face shield should be worn when inspecting lime slakers due to splattering.

3. Sodium hydroxide (NaOH): Sodium hydroxide, or caustic soda, may be available in liquid, pellet and flake form. When purchased in liquid form it is easily dispensed to raise pH values in a water system. The liquid will be in a 50% solution of sodium hydroxide and this product is a strong base that should be handled with caution. It will react violently and explosively with acids and some organic compounds. Some of the hazards include dissolving of human skin, heat generating when mixed with water, and reactive with some metals. Routine use should not be treated lightly and personal protective equipment should be worn during handling.
4. Potassium hydroxide (KOH): Potassium hydroxide or more commonly known as potash, or caustic potash, is another substance that can be added to water to raise the pH. But you must use caution! Introduction of potassium hydroxide to water may create a violent reaction and this chemical reaction will generate significant heat while forming a caustic solution. It comes in the form of a white, odorless solid, packaged in bags as flakes or pellets. It is very absorbent of moisture in the air so store potash in a cool, dry place, in a tightly closed container located in a well ventilated area. It is also a severe irritant that can cause serious damage to the upper respiratory tract; it is toxic if swallowed, and corrosive to the skin. Again, add potash slowly to water because boiling and splattering will occur therefore gloves, a respirator, goggles and protective clothing are recommended.
5. Carbon dioxide (CO_2): Carbon dioxide can be used to decrease the causticity and scale forming tendencies of supersaturated water coming from the softening process. Carbon dioxide forms carbonic acid when added to water and can be added to lower the pH of water. Carbon dioxide is odorless, colorless and heavier than air. It is obtained in bulk lots as a liquid under pressure so it must be vaporized before using. It is generated on-site, therefore safe handling considerations include the following: good ventilation and a self-contained breathing apparatus (in some instances).
6. Sodium bicarbonate ($NaHCO_3$): Adding Sodium Bicarbonate is a way to increase alkalinity or the acid neutralization ability of the water. When using salt coagulants (not polymers) this alkalinity is necessary for flocculation because it's the reaction between the coagulants and the bicarbonate (alkalinity) that bonds with the colloidal particles to form the flocs that traps the suspended matter.

ii. Coagulation/Flocculation: The following chemicals are used as primary coagulants, or in some cases, coagulant aids. These coagulants cause the suspended matter in water to clump together due to either a physical texture of the chemical, or through the electrical charges of the coagulant and the colloidal particles. There are many factors in choosing a coagulant, such as its effectiveness with your source water's natural pH and alkalinity, the cost of the coagulant and any supporting chemicals it may require, and the method of delivery. Let's look at some of the chemical properties of the coagulants.

1. Aluminum sulfate ($Al_2(SO_4)_3$ or alum): Aluminum sulfate (commonly called alum) is used as a coagulant, causing colloidal particles to clump together and settle out of the water. Alum was once the most common coagulant used in West Virginia, but today it is being replaced by the more prevalent use of polymers. In order for alum to be an effective

coagulant the pH of the raw water must be between 5 and 8. There must also be sufficient alkalinity, as the alum consumes alkalinity during its reactions, so the pH and alkalinity may need to be adjusted during treatment. Alum is available in two forms: dry and liquid. Both forms should be handled with care, i.e., rubber gloves and protective clothing. Dry alum should be stored in a dry location and liquid alum should be stored in a corrosion resistant storage tank. Note: never use the same conveyer for quicklime and alum because the mixture may explode under proper conditions.

2. Ferric sulfate ($Fe_2(SO_4)_3$): Ferric sulfate is a chemical frequently used for coagulation. It forms flocs due to the sticky texture of the chemical, as well as its negative charge. Along with alum, it is a very common non-polymer coagulant. The compound produces an acidic solution when mixed with water therefore operators should use all precautions associated with handling an acid (face shield, protective clothing, neck clothes, gloves and goggles).
3. Lime ($Ca(OH)_2$ or CaO): Lime, or calcium hydroxide, is predominantly used to adjust pH, but as a softener, it can also be used as a coagulant aid. The lime bonds with the other particles and increases the size/weight of the flocs which then increases the speed with which they settle out of the water.
4. Polyaluminum chloride (PAC): Polyaluminum chloride, known as PAC, is a blend of chemicals that can achieve the same (or better) coagulant results as alum. It was manufactured to eliminate some of the pH and alkalinity adjustments that are necessary when using traditional coagulants. The cost of the PAC blend is lower than the combined cost of alum, soda ash, and lime. In addition the liquid delivery system is preferred by many.
    a. DelPAC 2020: DelPac 2020, produced by Delta Chemical Company, is the most popular of the two polymers of PolyAluminum Chloride. It is used in drinking water treatment as a primary coagulant. It has gained popularity and is replacing the use of alum.
    b. SternPAC 70: The Kemira Company produces a product called SternPac 70, which is the second PAC polymer gaining popularity over traditional alum for water treatment.
5. Polymers as filter aids: Another option in effective removal of contaminants is the use of polymers as filter aids. These polymers, used in conjunction with coagulants, improve the process in two ways. The filter aids strengthen the bonds between the particles so they don't break apart during filtering, and the filter aids also coat the filter media to improve flocs adhering to it. Filter aids should allow run times to be longer with less head loss and turbidity breakthrough.

iii. Disinfection: Chemical disinfection is required for all Public Water Systems in the state of West Virginia. Specifically a chlorine residual is required within the distribution system regardless of what other types of disinfection may be employed in the treatment process. Therefore, any discussion of disinfection includes the topic of chlorine, its properties, and its delivery methods. There are three types of chlorination that can be delivered: liquid (sodium hypochlorite/NaOCl), solid (calcium hypochlorite/$Ca(ClO)_2$), and gas (Cl_2).

1. Sodium hypochlorite: NaOCl, the liquid form of chlorine, is commonly known as liquid bleach. In a small to medium size water system, sodium hypochlorite is often the disinfectant of choice because of its ease of use and lower health hazard. It is easier to use

than solid (calcium hypochlorite) chlorine but it is more expensive than chlorine gas and prone to degradation so it can't endure long term storage.

2. Calcium hypochlorite ($Ca(ClO)_2$): Calcium hypochlorite is the solid form of chlorine used as a disinfectant. As with all other chemicals used in water treatment there are benefits and drawbacks to its use. The benefits of calcium hypochlorite are that it is more stable than the liquid form and it has a longer shelf life. The primary drawback in using solid chlorine is that it must be mixed with water before it can be added to the water system. This mixing process can be hazardous because of the heat generated from the chemical reaction. Additionally, avoid injecting calcium hypochlorite near sodium fluoride to keep from creating a severe crust in the water. Keep in mind that all forms of chlorine must be stored in a cool, dry location, away from sunlight, and away from combustible materials such as motor oil or gasoline.
3. Chlorine Gas (Cl_2): Chlorine gas is a greenish-yellow gas with a distinctive odor. The gas is heavier than air so the expansion properties warrant careful handling and storage. When managed properly, it is a safe and convenient method of disinfection. It is typically stored in 150 lb. cylinders, although some systems store larger, one ton cylinders. Chlorine gas is the cheapest method of chemical disinfection, but it does come with a risk. In its gaseous state, chlorine is hazardous to the respiratory system, and the compressed gas has a risk of explosion. Specifically, chlorine gas must be stored in a separate room with outside access, appropriate ventilation, heat and light.

iv. Chemical oxidizers are used in the treatment of drinking water to oxidize undesirable contaminants such as iron, manganese or arsenic, and to destroy other organics contained in the water. Oxidized contaminants form precipitates which can be removed by sedimentation or filtration.

1. Potassium permanganate ($KMnO_4$): Potassium Permanganate is primarily used to as an oxidant to precipitate out iron and manganese and effectively control taste and odor problems. It also works to inactivate harmful pathogens and viruses, although it is not technically considered a disinfectant in the water treatment system. An advantage of using potassium permanganate is that it oxidizes organic substances without producing the regulated disinfection by-products. It may be considered as a replacement for pre-chlorination if disinfection by-products are an issue for a water system. Potassium permanganate is available in powdered form and turns pink or purple when mixed with water. The chemical should be stored in closed containers on a concrete floor away from heat sources.
2. Sodium permanganate ($NaMnO_4$): Sodium Permanganate is a liquid oxidant that works much like potassium permanganate, but it dissolves more readily in water and can be fed at higher rates. This concentrated liquid oxidant is easily stored and handled, therefore feed equipment is simplified. Because it is more soluble than potassium permanganate it does find applications where very high concentrations of permanganate are sought such as the Field of Electronics. It is also used on groundwaters to degrade chlorinated solvents,

polyaromatic hydrocarbons, and organic pesticides. It must be handled very carefully therefore the operator should wear face shields, gloves, and an apron at a minimum.

3. Chlorine (as an oxidant): Chlorine, most commonly known for its disinfecting abilities, is also used as an oxidizing agent. Chlorine can oxidize and precipitate out iron, manganese and hydrogen sulfide. Using chlorine as an oxidizer helps avoid "dirty water" complaints and problems with taste and odor. The forms of chlorine most commonly used by small water treatment plants are chlorine gas, sodium hypochlorite or calcium hypochlorite.
4. Sequestering agents keep iron and manganese chemically complexed so they won't settle out in the distribution system: Potassium permanganate and sodium permanganate are listed as oxidizing chemicals that cause the precipitation of iron and manganese. In some cases, water systems are not designed to accommodate the settling out of iron and manganese but they can't be left untreated as they may precipitate out in the distribution system. If delivered to the customer it can cause the staining of clothes and hardware fixtures. If the water system cannot remove the precipitates by other means then sequestering agents can be administered to the process. Phosphates and sodium silicate can be added to the water to chemically bond with the iron and manganese. This will keep iron and manganese from precipitating in the distribution system or contributing to biofilm development (harbors microorganism growth) in the distribution system. The new chemical forms will also not allow iron and manganese to react with chlorine (bleach) or the air during consumer use which eliminates clothes and fixture staining.

v. Corrosion Control: Corrosion is a common problem in many water distribution systems. Corrosive water causes materials to deteriorate and the particles of these materials will be carried into the water. When corrosive water comes into contact with metal pipe, the pipe may slowly leach or dissolve into the water. This can result in a breakdown of the piping and may cause increased levels of iron, copper, and lead in the water which is a serious health hazard. There are many factors that contribute to a corrosive environment: pipe material (copper, lead, iron), alkalinity, stray electric currents, pH, water temperature, air temperature, water pressure, and more! External corrosion can occur if corrosive soils and moisture are in contact with the piping system. Overall, corrosion control is a very complex problem that requires considerable study and analysis of specific water data to achieve a positive outcome for your community. In this course we will be focusing on the application of orthophosphates to the distribution system as one means of assisting in corrosion control.

1. Orthophosphates-corrosion control: One method of controlling corrosion involves adding orthophosphates to help control lead formation. The process works by injecting chemicals, such as orthophosphates, that will form a protective coating over the site of the corrosion activity. This is termed "inhibiting" corrosion. The orthophosphates are added to the water after filtration and thus the lead-phosphate compound that is formed gets transmitted throughout the water lines. A successful inhibitor will need to provide a coating all over the distribution system. The orthophosphate residual must remain in the distribution system all the way to the user's tap water. For optimal treatment, it is important to make sure the pH of the water is between 7.2 and 7.8. Why is there so much

attention placed on reducing lead in the distribution system? Lead can cause serious health problems if too much enters the body from drinking water. It can cause damage to the brain and kidneys and it can interfere with the production of red blood cells. Controlling lead exposure is one of the primary health concerns of the EPA and they place much emphasis on reducing and eliminating lead from public water supplies. The EPA established the Lead and Copper Rule to help gain compliance from water treatment plants. This rule established an action level of 0.015 mg/L of lead and 1.3 mg/L of copper, based on the 90th percentile level of tap water samples. If these levels are exceeded then it puts into motion other requirements that water treatment plants would prefer to avoid. In essence, water treatment plants are encouraged to meet the action levels to avoid additional costly treatment techniques and requirements.

vi. Fluoride-tooth decay prevention: We've spent some time talking about removing chemicals or particulates from a water supply. Now let's discuss the addition of a chemical to a water supply. The discussion of adding fluoride to water supplies came after some observations made by a Colorado Springs dentist who noted an endemic of brown stains and chalky deposits on his patient's teeth. This dentist reported the reason for the mottled tooth enamel as excessive fluoride (2 to 13 mg/L) in the water supply. On the flip side, these mottled teeth had significantly fewer dental caries or cavities. This discovery prompted controlled fluoridation studies for the purpose of determining whether or not lower concentrations of fluoride in water might prove beneficial instead of creating adverse health effects. The studies were carried out from 1945 to 1955 by adding fluoride to the public water supplies in Grand Rapids, Michigan, and in Newburgh, New York. According to the results there was a 60% reduction in cavities and decay in the children that drank the fluoridated water. Soon after these studies released their findings the recommended addition of fluoride to water supplies became an official policy of the U.S. Public Health Service. As of 2006, over 60% of Americans receive fluoridated water. One ppm is the recommended concentration of fluoride in drinking water, whereas, the secondary maximum contaminant level is 4.0 ppm. The three most common compounds used to fluoridate water are sodium fluoride, hydrofluosilicic acid, and sodium silicofluoride.

1. Sodium fluoride (NaF): Sodium fluoride is a white, odorless solid form of fluoride used for water fluoridation. Using sodium fluoride can be a convenient fluoridation chemical because it maintains a relatively constant solubility rate which works well for continuous, automatic, liquid feeding systems. Small water systems are likely to use this method of fluoridation. Examples of packaging include 50 lb bags, 125 or 400 lb drums, or 2000 lb sack. The dust from this power can be very noxious and it may cause sneezing and irritation of the nose and throat. To avoid accidental ingestion of the dusts a respirator should be worn whenever large quantities are being handled. Rubber gloves should be worn when handling sodium fluoride and contact with the bare skin should be avoided.
2. Hydrofluosilicic acid (H_2SiF_6): Recently designated fluorosilicic acid as the current terminology requested by the American Water Works Association that replaces the technical designation of hydrofluosilicic acid. Fluorosilicic acid is a high purity source of fluoride. It is simpler to use because in the liquid form it can be accurately measured and

fed with a minimum amount of equipment. It presents no dust problems, no measuring problems and handling has minimum labor requirements. Tank cars and tank trucks can deliver it or it can be supplied in 15 gallon carboys or 55 gallon drums. It comes in solution that can be fed from these shipping containers directly into the water supply. It is the most widely used form of fluoride in water systems throughout the United States. On the flip side it is extremely hazardous to handle under any conditions. The acid is shipped in polyethylene containers because it has been shown to deteriorate glass. The acid is colorless, transparent, fuming and corrosive. Always use complete protective equipment and have a safety shower readily available.

3. Sodium silicofluoride (Na_2SiF_6): Sodium silicofluoride, or sodium fluorosilicate, is a fluoridation compound processed from hydrofluosilicic acid. It is manufactured by adding soda ash to dilute hydrofluosilicic acid and filtering off the resultant precipitate. It is a white, dry crystalline powder that is both odorless and tasteless. Similar to sodium fluoride this dust can be noxious and inhalation or ingestion of the powder dust should be avoided with proper handling procedures followed at all times. Unlike sodium fluoride, sodium silicofluoride has a low solubility rate in water thus gravimetric dry feeders are used to administer this chemical. Gravimetric feeders are very accurate devices for administering powdered sodium silicofluoride, but the feeders can be expensive and space consuming over solution feeders.