1.12: Water Treatment For Contaminate Removal

Learning Objectives

- Describe water quality characteristics
- Describe disinfection processes
- Explain chlorine disinfection
- Describe the classes of water quality
- Explain the structure of water quality characteristics

Water Quality Characteristics

Water is the universal solvent; and therefore, it carries all types of dissolved materials. Water also carries biological life forms that can cause diseases. Waterborne pathogenic organisms can cause diseases like anthrax, bacillary dysentery, cholera, gastroenteritis, salmonella, shigellosis, typhoid fever polio, amoebic dysentery cryptosporidium, and giardia.

One of the cleansing processes in the treatment of safe water is called disinfection. Disinfection is the process designed to kill or inactivate most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria. Water can be disinfected with chlorination, which is the most common method employed because of cost, availability, and reliability. Sterilization is the complete destruction of all organisms. Sterilization is not necessary for water treatment, and it is quite expensive to carry out.
Factors Influencing Disinfection

Many factors influence the disinfection of water. These factors include pH, temperature, turbidity, reducing agents, and microorganisms.

pH

The pH of the water being treated can alter the efficiency of disinfection. Chlorine disinfects water much faster and better at a pH around 7.0 rather than at a pH over 8.0.

Temperature

Temperature conditions influence the effectiveness of disinfectants. The higher the temperature of water then the more efficiently it can be treated. Water near 70 to 85°F is easier to disinfect than water at 40 to 60°F. Longer contact times are required to disinfect water at lower temperatures. To speed up the process, operators use larger amounts of chemicals. Be aware that the higher the chlorine concentration, the greater the dissipation rate of chlorine into the atmosphere. This fact can result in the production of odors and the process wastes chlorine.

Turbidity

Under normal operating conditions, the turbidity level of treated water is low by the time the water reaches the disinfection process. Excessive turbidity will greatly reduce the efficiency of the disinfecting chemical or process. Water treatment plants have demonstrated that when water is filtered to a turbidity of one unit or less, most of the bacteria have been removed.

Suspended matter can change the chemical nature of the water when the disinfectant is added. Some types of suspended solids can create a continuing demand for the disinfecting chemical, and change the effective germicidal properties of the disinfectant.

Organic Matter

Organics found in water can consume great amounts of disinfectants while forming unwanted compounds. Trihalomethanes (THMS) are an example of undesirable compounds formed by reactions between chlorine and certain organics. Disinfecting, chemicals often react with organics and reducing agents. Then if any of the chemical remains available after this initial reaction, it can act as an effective disinfectant. The reactions with organics and resulting agents, however, has a significant reducing effect on the amount of chemical available for disinfection.

Inorganic Matter

Inorganic compounds, such as ammonia (NH3) in water being treated can create special problems. In the presence of ammonia, some oxidizing chemicals form side compounds causing a partial loss of disinfecting power. Silt can also create a chemical demand. It is clear that the chemical properties of water while being treated can seriously interfere with the effectiveness of disinfecting chemicals.
Reducing Agents

Chlorine combines with a wide variety of materials, especially reducing agents. Most reactions between chlorine and reducing agents occur rapidly; however, other reactions are much slower. The side reactions complicate the use of chlorine for disinfection. The demand for chlorine by reducing agents must be satisfied before chlorine becomes available to disinfect. Examples of reducing agents in water that react with chlorine are hydrogen sulfide (H₂S), ferrous ion (Fe²⁺), manganous ion (Mn²⁺), ammonia (NH₃), and nitrite (NO₂⁻). Organic reducing agents in water also will react with chloride and form chlorinated organic materials of potential health significance.

Microorganisms

The concentration of microorganisms is important because the higher the number of microorganisms, the greater the demand for a disinfecting chemical. The resistance of microorganisms to specific disinfectants varies. Non-spore forming bacteria are generally less resistant than spore-forming bacteria. Cysts and viruses can be resistant to certain types of disinfectants.

Removal Processes

Pathogenic organisms can be removed from water, killed, or inactivated by physical and chemical water treatment processes. These processes are:

- Coagulation-chemical coagulation followed by sedimentation and filtration will remove 90 to 95-percent of the pathogenic organisms depending on which chemicals are used. Alum usage can increase virus removals up to 99-percent.
- Sedimentation-proper design of sedimentation processes can effectively remove 20 to 70-percent of the pathogenic microorganisms. This removal is accomplished by allowing the pathogenic organisms to settle out by gravity, assisted by chemical floc.
- Filtration-filtering water through granular filters is an effective means of removing pathogenic and other organisms from water. The removal rates vary from 20 to 99-percent, depending on the coarseness of the filter media and the type of effectiveness of pretreatment.

Disinfection Process

Disinfection destroys harmful organisms. The process does not sterilize the water. It removes pathogenic organisms from the water. The process can be accomplished physically or chemically. Physical methods can be:

- Physically remove the organisms from the water
- Introduce motion that will disrupt the cells’ biological activity and kill or inactivate them

Chemical methods alter the cell chemistry causing the microorganism to die. The most widely used disinfectant chemical is chlorine. Chlorine is easily obtained, relative inexpensive, and most importantly, leaves a chlorine residual that can be measured. Other disinfects are also used. An increased interest in disinfectant other than chlorine has occurred because of the carcinogenic compound that chlorine may form (trihalomethanes or THMs).
Ultraviolet Rays

UV light is a physical means of disinfection. It is used to destroy pathogenic microorganisms. To be effective, the rays must come in contact with each microorganism. The ultraviolet energy disrupts various organic components of the cell causing a biological change that is fatal to the microorganisms.

This system does not have a measurable residual and the cost of operation is high. The use of ultraviolet rays is limited to small or local systems and industrial applications. Oceangoing ships have used these systems for their water supplies.

Advances in ultraviolet technology and concern about disinfection byproducts produced by other disinfectants have prompted a renewed interest in UV disinfection.

Heat

Heat has been used for centuries to disinfect water. Boiling water for about 5 minutes will destroy essentially all microorganisms. This method is energy-intensive and expensive. The only practical application is in the event of a disaster when individual local users are required to boil their water.

Ultrasonic Waves

This process is used to disinfect water on a limited scale. Sonic waves destroy microorganisms by vibration. This process is not practical and is expensive.

Chemical Disinfection

Iodine

Iodine is used as a disinfectant in water but its use is limited to emergency situations. It is a good disinfectant but its cost is high. Also, a potential physiological effect on pregnant women prevents its widespread usage. The recommended dosage is two drops of iodine tincture, which is 7% available iodine, in a liter of water.

Bromine

Bromine is used on a limited basis for water treatment because of handling difficulties. Bromine causes skin burns on contact. Because bromine is a very reactive chemical residual are hard to obtain. Bromine can be purchased for swimming pool and hot tub usage.

Bases

Bases can be effective disinfectants but the high pH values leave a bitter taste in finished water. Bases like sodium hydroxide and lime can burn when left too long in contact with skin. Bases effectively kill all microorganisms: and therefore, they can sterilize water. Bases have been used to sterilize pipes.
Ozone

Ozone is used to disinfect water along with reducing taste and odors. It has limited usage because of its high cost, lack of residual, difficulty in storing, and maintenance requirements.

Although ozone is effective in disinfecting water, its use is limited by its solubility. The temperature and pressure of the water being treated regulate the amount of ozone that can be dissolved in the water. These factors tend to limit the disinfectant strength that can be made available to treat water.

Ozone destroys all microorganisms but significant residual ozone does not guarantee that water is safe to drink. Organic solids may protect organisms from the disinfection action of ozone and increase the amount of ozone needed for disinfection. In addition, an ozone residual cannot be maintained in metallic conduits for any period of time because of ozone’s reactivity. The inability of ozone to provide a residual in the distribution system is a major drawback to its usage. However, the formation of THMs by chlorine has resulted in a renewed interest in ozone as an alternative means of disinfection.

Chlorine

Chlorine is a greenish-yellow gas with a penetrating and distinctive odor. The gas is two-and-a-half times heavier than air. Chlorine has a high coefficient of expansion. One liter of chlorine liquid will expand 450 times when changing from liquid to a gas. No chlorine containers should be filled to more than 85 percent of their capacity.

Chlorine is not flammable and is non-explosive. It will support combustion. When the temperature rises, so does the vapor pressure of chlorione. When the temperature increases the pressure of chlorine gas inside a chlorine container increases. This property of chlorine is considered when feeding chlorine gas from a container or dealing with a leaking chlorine cylinder.

Disinfection Action

Chlorine exerts a direct action against the bacterial cell destroying it. When chlorine is added to water, several chemical reactions take place. These reactions involve water molecules. Some other reactions involve organic and inorganic substances suspended in the water.

When chlorine is added to water containing organic and inorganic materials, it will combine with these materials and form chlorine compounds. Continued addition of chlorine will reach a point where the reaction with organic and inorganic materials stops. At this point, the chlorine demand has been satisfied.

The chemical reactions between chlorine and organic and inorganic substances produce chlorine compounds. Some compounds have disinfecting properties and other compounds do not. In a similar fashion, chlorine reacts with water and produces substances with disinfection properties. The total of the compounds with disinfecting properties plus any remaining free chlorine is known as the chlorine residual. The presence of this measurable chlorine residual indicates to the operator that all possible chemical reactions with chlorine have taken place and that a sufficient available residual chlorine is left to kill any microorganisms present in the water.
When the amount of chlorine needed to satisfy the chlorine demand and the amount of chlorine residual needed for disinfection, then the chlorine dose is calculated.

- Chlorine Dosage = Chlorine Demand + Chlorine Residual

**Chlorine Reactions in Water**

In solutions that are dilute with low concentrations of chlorine and have a pH above 4, the formation of HOCl, hypochlorous acid, is nearly complete and leaves little free chlorine (Cl\(_2\)). Depending on the pH, some hypochlorous acid will disassociate and produce a hydrogen ion and a hypochlorite ion. Hypochlorous acid is a weak acid and is poorly dissociated at pH levels below 6. Below pH 6 the free chlorine is almost all in the HOCl form. Above pH 9, almost all of the free chlorine is in the OCl\(-\) form and none in the HOCl form.

In water with a pH of 7.5, approximately 50-percent of the chorine present is in the form of HOCl and 50-percent is in the form of OCl\(-\). This fact is important in that HOCl and OCl\(-\) differ in disinfection ability. HOCl has a much greater disinfection potential than OCl\(-\).

**Reactions with Substances in Water**

Hydrogen sulfide and ammonia are two inorganic substances that are found in water when it reaches the disinfection stage of treatment. Their presence can complicate the use of chlorine for disinfection purposes because they exert a chlorine demand. Hydrogen sulfide and ammonia are reducing agents and they react with chlorine to remove it from the water. They lose electrons and chlorine reacts rapidly to accept these electrons.

Hydrogen sulfide produces an odor that smells like rotten eggs. It reacts with chlorine to form sulfuric acid and elemental sulfur. Elemental sulfur is objectionable because it can cause odor problems and will precipitate as finely divided white particles that are sometimes colloidal in nature.

When chlorine is added to water containing ammonia, it reacts rapidly with the ammonia and forms chloramines. This reaction reduces the chlorine that is available to act as a disinfectant. As the concentration of ammonia increases, the disinfectant power of the chlorine drops at a rapid rate because of the chlorine demand exerted by the ammonia.

When organic material is present in water, the chemical reactions that take place with chlorine can produce suspected carcinogenic compounds (THMs). The formation of these compounds can be prevented by limiting the amount of prechlorination and by removing the organic materials before chlorination of the water.

**Hypochlorite**

The use of hypochlorite to treat potable water achieves the same result as chlorine gas. Hypochlorite can be applied in the form of calcium hypochlorite or sodium hypochlorite. The form of calcium hypochlorite that is used most frequently to disinfect water is known as High Test Hypochlorite (HTH).
Chlorine Dioxide

Chlorine dioxide (ClO₂) can be used as a disinfectant. Chlorine dioxide does not form carcinogenic compounds that can be formed by other chlorine compounds. It also is not affected by ammonia, and it is a very effective disinfectant at higher pH levels. In addition, chlorine dioxide reacts with sulfide compounds helping to remove them and eliminate their characteristic odors. Phenolic tastes and odors can be controlled with chlorine dioxide.

Chloramination

Chloramination is used as an alternative disinfection process by operators to:

- Reduce the formation of THMs and other disinfection byproducts
- Maintain a detectable residual throughout the distribution system
- Penetrating the biofilm and reducing the potential for coliform regrowth
- Killing or inactivating heterotrophic plate count bacteria
- Reducing taste and odor problems

Several factors are used to make a decision concerning the use of chloramine disinfection. These factors are the quality of the raw water, the ability of the treatment plant to meet various regulations, operational practices, and distribution system characteristics.

Three methods are used to produce chloramines for disinfection purposes. These methods include pre-ammoniation followed by chlorination, addition of chlorine and ammonia at the same time, and pre-chlorination with post-ammoniation.

Pre-ammoniation followed later by chlorination is applied at the rapid-mix unit process and chlorine is added downstream at the entrance to the flocculation basin. This approach produces lower THM levels than the post ammoniation method. Pre-ammoniation to form chloramines does not produce phenolic tastes and odors, but this method may not be as effective as post-ammoniation for controlling tastes and odors associated with diatoms and anaerobic bacteria in the source water.

Concurrent addition of chlorine and ammonia is a method that applies chlorine to the plant influent at the same time or immediately after ammonia is introduced at the rapid mix unit process. Concurrent chloramination produces the lowest THM levels of the three methods.

Prechlorination and postammoniation is a method where chlorine is applied at the head of the plant and a free chlorine residual is maintained throughout the plant processes. Ammonia is added at the plant effluent to produce chloramines. Because of the longer free chlorine contact time, this method results in the formation of more THMs, but it may be necessary to use this method to meet the disinfection requirements of the Surface Water Treatment Rule. A major limitation of using chloramine residuals is that chloramines are less effective as a disinfectant than free chlorine.
UV Disinfection and Treatment of Water

Ultraviolet (UV) rays are part of the light that comes from the sun. The UV spectrum is higher in frequency than visible light and lower in frequency compared to x-rays. The UV spectrum has a larger wavelength than x-rays and a smaller wavelength than visible light and the order of energy, from low to high, is visible light, UV, and x-rays.

UV is known to be an effective disinfectant due to its strong germicidal (inactivating) ability. UV disinfects water containing bacteria and viruses and can be effective against protozoans, such as *Giardia lamblia* cysts or *Cryptosporidium* oocysts. UV is used in the pharmaceutical, cosmetic, beverage, and electronics industries. In the United States, it is used for drinking water disinfection; however, high operating costs compared to disinfection by chlorination has limited its usage.

Because of safety issues associated with the reliance of chlorination and improvements in UV technology, UV has experienced increased acceptance in municipal water systems. Two classes of disinfection systems are certified and classified by the NSF under Standard 55, Class A and Class B Units.

- **Class A**-these ultraviolet water treatment systems must have an intensity and saturation rating of at least 40,000 uwsec/cm² and possess designs that will allow them to disinfect and/or remove microorganisms from contaminated water. Affected contaminants should include bacteria and viruses. Class A point-of-entry and point-of-use systems covered by this standard are designed to inactivate and/or remove microorganisms, including bacteria, viruses, and *Cryptosporidium* oocyst and *Giardia* cysts from contaminated water. Systems covered by this standard are not intended for the treatment of water that has obvious contamination or intentional source contamination, such as raw sewage, nor are these systems intended to convert wastewater to drinking water. These systems are intended to be installed on visually clear water.

- **Class B**-these ultraviolet water treatment systems must have an intensity and saturation rating of at least 16,000 uw-sec/cm² and possess designs that will allow them to provide supplemental bactericidal treatment of water already deemed safe, such that no elevated levels of *E. coli* or a standard plate count of less than 500 colonies per 1 ml exists. NSF Standard 55 suggests Class B UV systems are designed to operate at a minimum dosage and are intended to reduce normally occurring non-pathogenic or nuisance microorganisms only. The Class B or similar non-rated UV systems are not intended for the disinfection of microbiologically unsafe water.

The type of unit depends on the situation for use, source of water, and water quality. Transmitted UV light dosage is affected by water clarity. Water treatment devices are dependent on the quality of the raw water. When turbidity is 5 NTU or greater and/or total suspended solids are greater than 10 ppm, pre-filtration of the water is highly recommended. Normally, it is advisable to install a 5 to 20 micron filter prior to a UV disinfection system.

UV disinfection is based on the principles associated with wavelengths of light that damage the nucleic acids of waterborne pathogens. UV radiation has three wavelength zones, UV-A, UV-B, and UV-C, and it is the last region, the shortwave UV-C, that has germicidal properties for disinfection. A low-pressure mercury arc lamp resembling a fluorescent lamp produces the UV light in the range of 254 nanometers (nm). These lamps contain elemental mercury and an inert gas, such as argon, in a UV-transmitting tube, usually quartz. Traditionally, most mercury arc UV lamps have been the low pressure type, because they operate at a relatively low partial pressure of mercury, low overall vapor pressure (about 2 mbar), low external temperature (50-100o C), and low power. These lamps emit nearly monochromatic UV radiation at a wavelength of 254 nm, which is in the optimum range for UV energy absorption by nucleic acids (about 240-280 nm).
In recent years, medium pressure UV lamps that operate at much higher pressures, temperatures, and power levels have been installed. They emit a broad spectrum of higher UV energy between 200 and 320 nm.

An essential requirement for UV disinfection with lamp systems is an available and reliable source of electricity. While the power requirements of low-pressure mercury UV lamp disinfection systems are modest, they are essential for lamp operation to disinfect water. Since most microorganisms are affected by radiation around 260 nm, UV radiation is in the appropriate range for germicidal activity. UV lamps are available that produce radiation in the range of 185 nm, and they are effective in reducing microorganisms as well. They will also reduce the total organic carbon (TOC) content of the water.

For typical UV systems, approximately 95-percent of the radiation passes through a quartz glass sleeve and into the untreated water. The water is flowing as a thin film over the lamp. The glass sleeve is designed to keep the lamp at an ideal temperature of approximately 104° F.

UV radiation affects microorganisms by altering the DNA in the cells and impeding reproduction. UV treatment does not remove organisms from the water. It inactivates them. The effectiveness of this process is related to exposure time and lamp intensity, as well as general water quality parameters.

The exposure time is reported as microwatt-seconds per square centimeter (µwatt-sec/cm²), and the U.S. Department of Health and Human Services has established a minimum exposure of 16,000 µwatt-sec/cm² for UV disinfection systems. Most manufacturers provide a lamp intensity of 30,000-50,000µwatt-sec/cm². In general, coliform bacteria are destroyed at 7,000 µwatt-sec/cm².

Since lamp intensity decreases over time with use, lamp replacement and proper pretreatment are key to the success of UV disinfection. In addition, UV systems should be equipped with a warning device to alert operators when lamp intensity falls below the germicidal range.

Used alone, UV radiation does not improve the taste, odor, or clarity of water. UV light is a very effective disinfectant, although the disinfection can only occur inside the unit. No residual disinfection in the water exists to inactivate bacteria that may survive or may be introduced after the water passes by the light source. The percentage of microorganisms destroyed depends on the intensity of the UV light, the contact time, raw water quality, and proper maintenance of the equipment.

If material builds up on the glass sleeve or the particle load is high, the light intensity and the effectiveness of treatment are reduced. At sufficiently high doses, all waterborne enteric pathogens are inactivated by UV radiation. The general order of microbial resistance (from least to most) and corresponding UV doses for extensive (>99.9%) inactivation are: vegetative bacteria and the protozoan parasites Cryptosporidium parvum and Giardia lamblia at low doses (1-10 mJ/cm²) and enteric viruses and bacterial spores at high doses (30-150 mJ/cm²).
Most low-pressure mercury lamp UV disinfection systems can readily achieve UV radiation doses of 50-150 mJ/cm² in high-quality water; and therefore, efficiently disinfect waterborne pathogens. However, dissolved organic matter, such as natural organic matter, certain inorganic solutes such as iron, sulfites, and nitrites, and suspended matter (particulates or turbidity) will absorb UV radiation or shield microbes from UV radiation, resulting in lower delivered UV doses and reduced microbial disinfection. Another concern surrounding disinfecting microbes with lower doses of UV radiation is the ability of bacteria and other cellular microbes to repair UV-induced damage and restore pathogenicity, which is a phenomenon known as reactivation.

UV inactivates microbes primarily by chemically altering nucleic acids. However, the UV-induced chemical lesions can be repaired by cellular enzymatic mechanisms, some enzymes act independent of light (dark repair) and other enzymes require visible light (photo-repair or photo-reactivation). Therefore, achieving optimum UV disinfection of water requires delivering a sufficient UV dose to induce greater levels of nucleic acid damage; and thereby, overcome DNA repair mechanisms.

UV units have a maximum flowrate capacity and some equipment have minimum flowrates. If the flow is too high, water will pass through without enough UV exposure. If the flow is too low, heat may build up which can damage the UV lamp. A UV unit with minimum flow requirements should not be placed on the water line supplying pressure stations in a non-recirculating system. UV units are most often used in constant flow systems.

UV lamps do not burn out as normal florescent lamps do. Instead, the UV lamps will solarize, which reduce their intensity to about 60% of a new lamp after about one year of continuous use. When lamps are new, they will generate a dosage level near 60,000 µW-s/cm². When the dosage drops to 30,000 µW-s/cm², the minimum dosage needed to effectively kill bacteria, lamps should be replaced. Lamp life will be shortened significantly if the lamp is turned on and off more frequently than once every eight hours.

Water should be sampled and tested for bacteria counts regularly. Sample before and after the UV unit to test its performance. Water should also be sampled in the distribution since bacterial regrowth can occur downstream of the UV unit.
As water passes through the UV unit, minerals, debris and other material in the water will deposit onto the quartz or Teflon sleeve. This activity will limit the penetration of UV rays through the sleeve and into the water. To maintain high clarity, the glass around the lamp must be cleaned regularly. Cleaning frequency depends on the water quality and will be minimal with RO treatment upstream.

UV light intensity meters are available which indicate the penetration of UV light through the glass sleeve and the water. Low intensity means the UV dose is too low to provide adequate disinfection. This meter will indicate when cleaning or lamp replacement is needed.

Ozone

Ozone is one of the most powerful water treatment compounds available to system managers today. It is a technology that has been in continual commercial use for over 100 years and has distinct properties that allow disinfection of even heavily compromised water streams. With the 1996 reauthorization of the Safe Drinking Water Act, ozone was named as among the best available technologies for water system compliance with National Primary Drinking water Regulations as overseen by the US Environmental Protection Agency.

Ozone (O₃) is formed when oxygen molecules are exposed to electron flow. Ozone molecules are unstable and will lose the third oxygen atom over time. Ozone is formation characterization:

- Ozone generators provide an electron flow between dielectric and SS tubes
- Oxygen is passed through the gap between dielectrics resulting in ozone generation
- Oxygen feed gas must be dry and free of particles
- Ozone generators must be cooled, and cooling water removes .90 percent of the heat that is generated

Ozone is a powerful oxidant with high disinfectant capacity. Ozone residuals between 0.3 to 2.0 mg/L inactivate viruses. Inactivation rates range from >3.9-log to >6-log, and occur within very short contact periods, 5 seconds. Microorganisms in natural waters are very sensitive to ozone. Giardia and enteric viruses are inactivated by ozone, as a primary disinfectant, with 5 minutes of contact time. Ozone residuals of 0.5 to 0.6 mg/L result in 3-log and 4-log removals, respectively. When ozone is used as a primary treatment, the criteria for its use is based on ozone residuals, competing ozone demands, and a minimum contact time to meet the required cyst and viral inactivation requirements.

Ozone is the strongest oxidant and strongest disinfectant available for potable water treatment. This unique material can be utilized for a number of specific water treatment applications, including disinfection, taste and odor control, color removal, iron and manganese oxidation, hydrogen sulfide removal, nitrite and cyanide destruction, oxidation of organics such as phenols, pesticides, and some detergents, algae destruction and removal, and as a coagulant aid. Even though ozone is the strongest chemical disinfectant available for water treatment, some refractory organics are not oxidized, or oxidize too slowly. In such cases, ozone can be combined with UV radiation and/or hydrogen peroxide to produce hydroxyl free radicals, HO-, which is a stronger oxidant than molecular ozone, O₃. Deliberate production of hydroxyl free radicals starting with ozone has been termed ozone advanced oxidation. Groundwater that is contaminated with chlorinated organic solvents and some refractory hydrocarbons are being treated successfully with ozone advanced oxidation techniques.

At ambient temperatures, ozone is an unstable gas, partially soluble in water; generally, more soluble than oxygen. Due
to its instability, ozone quickly reverts to oxygen. Ozone cannot be produced at a central manufacturing site, bottled, shipped, and stored prior to use. It must be generated and applied on-site. The installation of an ozone production plant requires storage of pure oxygen on-site as the feed gas. Ozone is generated for commercial uses using corona discharge or ultraviolet radiation. The UV technique produces low concentrations of ozone, whereas corona discharge produces ozone concentrations in the range of 1 – 4.5 % when dry air is fed to the ozone generator. When concentrated oxygen is used as the feed gas, gas phase ozone concentrations of up to 14 to 18% can be produced. Since ozone is only partially soluble in water, once it has been generated it must be contacted with the water to be treated in such a manner as to maximize the transfer of ozone from the gas phase into water. For this purpose, many types of ozone contactors have been developed. However, as higher concentrations of ozone gas are employed, contacting system designs become more critical because of the lower gas to liquid ratios.

The use of oxygen as the feed gas can result in oxygen supersaturation of the treated water causing operational problems and corrosion in the distribution system. Ozone contacting system options include atmospheric tall towers or pressurized gas to liquid mass transfer processes. Fine bubble diffusers, static mixers, or venturi injectors can be used to mix the gas with the water to be treated in full flow or side stream configurations. Once dissolved in water, ozone is available to act on water contaminants to accomplish its intended purposes of disinfection and/or oxidation. At pH levels of 3-6, ozone is present primarily in its molecular form (O3). However, as the pH rises, the decomposition of ozone to produce the hydroxyl free radical (HO-) becomes increasingly rapid. At pH 7 about 50% of the ozone transferred into water produces HO-. At pH >10, the conversion of molecular O₃ to HO- is virtually instantaneous.

Because ozone is such a powerful oxidant/disinfectant, the trick to applying it to solve water treatment problems is to do so in a manner that is effective for water treatment, yet at the same safe for the people in the vicinity. Ozone safety issues are handled easily by using proper ambient ozone monitoring, tank venting, and ozone destruction. In the case of systems driven solely by a pumping/injector system, ozone may be produced under vacuum, which ensures no leakage of ozone into the operating environment.

The five basic components of an ozone system include:

- Gas preparation—either drying gas to a suitable dew point or using oxygen concentrators
- A suitable electrical power supply
- A properly sized ozone generator(s). For corona discharge ozone generation, it is critical to feed the generator a clean and dry oxygen-containing gas.
- An ozone contacting system

Ozone off-gas destruction or suitable venting system.

Moisture in the feed gas causes two operating problems:

- The amount of ozone produced by the application of a given electrical energy level is lowered as relative humidity rises. Consequently, it is usually cost-effective to dry the air to a recommended dew point of minus 65°C (-65°C or -76°F) or lower.
- Ozone generated using air in the presence of moisture allows small amounts of nitrogen oxides to react with the moisture to produce nitric acid. In this instance, gas condensation at the cooling/heat transfer surfaces produces a corrosive compound that can cause corrosion problems in the ozone generation equipment with concomitant increases in equipment maintenance requirements.
Because of the high oxidative qualities of gas-phase ozone and the chance of moisture from a failing feed gas unit, system managers must take extra care to make certain that all components in the ozone generator, ozone supply line, ozone gas to liquid mass transfer equipment and the contact vessel are ozone-compatible.

For large scale ozone systems, the equipment for cleaning and drying feed gases can become quite complex. For example, effective air drying can involve multiple treatment steps including air filtration, compression, cooling, desiccation, and final filtration prior to passage into an operating corona discharge ozone generator.

A need exists for efficient ozone contacting and destruction of excess ozone in contactor off-gases. Absent an effective ozone off-gas destruct unit, excess ozone would be present for people in the vicinity to breathe, which is not recommended because of its strong oxidizing nature. Additionally, ozone is heavier than ambient air, and can settle in the vicinity, and attack oxidizable materials. Destruction of contactor off-gas ozone is readily accomplished thermally (370°C), catalytically, thermal-catalytically, and by passing the off-gas through granular activated carbon. Care should be exercised in selecting an ozone destruct method whenever very high concentrations of ozone will be encountered.

Ozone is a critical process for non-reverse osmosis purification. It is usually coupled with biologic activated carbon filtration. The process reduces TOC and trace chemical pollutants, removes protozoans, kills viruses, and is a flocculation aid. Ozone treatment is an oxidation process used as a disinfection and oxidant prior to biologic activated carbon filtration.

Instrumentation and controls for ensuring effective and safe operation of ozone systems are concerned with applying ozone effectively and affordably. System processes control ozone generation, oxygen usage, drying, ozone injection and diffusing, and ozone destruction.

The instrumentation monitors each step, and each step has an alarm associated with the process.

**Review Questions**

1. List the factors that affect the chlorination of drinking water?
2. Describe disinfection as a process in drinking water treatment.
3. What is the purpose of Chloramination in drinking water?
4. What is the ozonation of drinking water?
5. How does UV light effect microorganisms?
6. Describe the primary reason that chlorine may not be used for drinking water disinfection at a particular drinking water facility.

**Chapter Quiz**

1. _________ is the process designed to kill or inactivate most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria.
   1. Sterilization
   2. UV treatment
3. Application of chlorine
4. Disinfection

2. Which of the diseases listed is not caused by a waterborne pathogenic organism?
   1. Gastrointestinal anthrax
   2. Shigellosis
   3. Polio
   4. All of these are waterborne diseases

3. The chemical reactions between chlorine and organic and inorganic substances produce chlorine compounds. Chlorine reacts with water and produces substances with disinfection properties. The total of the compounds with disinfecting properties plus any remaining chlorine is known as the __________.
   1. Chlorine dose
   2. Chlorine demand
   3. Free chlorine
   4. Chlorine residual

4. __________ is a gas that does not form carcinogenic compounds like those compounds formed by chlorine disinfection. It also is not affected by ammonia, and it is a very effective disinfectant at higher pH levels. It is also used to diminish taste and odor problems in the distribution system. It is especially useful in inhibiting Legionella.
   1. Chloramination
   2. Chlorine dioxide
   3. Hydrogen peroxide
   4. Potassium permanganate

5. Because of safety issues associated with the reliance of chlorination and improvements in __________ technology, it has experienced increased acceptance in municipal water systems. Two systems are certified and classified by the NSF under Standard 55. The type of unit depends on the situation for use, source of water, and water quality. The dosage is affected by water clarity. When turbidity is 5 NTU or greater and/or total suspended solids are greater than 10 ppm, pre-filtration of the water is highly recommended. It is advisable to install a 5 to 20 micron filter prior to the disinfection system.
   1. Ozone
   2. Chloramination
   3. Ultraviolet light
   4. Chlorine dioxide

6. __________ is the strongest oxidant and strongest disinfectant available for potable water treatment. This unique material can be utilized for specific water treatment applications, including disinfection, taste and odor control, color removal, iron and manganese oxidation, hydrogen sulfide removal, nitrite and cyanide destruction, oxidation of organics such as phenols, pesticides, and some detergents, algae destruction and removal, and as a coagulant aid.
   1. Ozone
   2. Chloramination
   3. Ultraviolet light
   4. Chlorine dioxide

7. A major problem with disinfection using __________ is that bacterial regrowth can occur downstream of the application site in the distribution.
1. Ozone
2. Chloramination
3. Ultraviolet light
4. Both 2 and 3 are correct

8. Several factors are used to make a decision concerning the use of __________ disinfection. These factors are the quality of the raw water, the ability of the treatment plant to meet various regulations, operational practices, and distribution system characteristics.
   1. Ozone
   2. Chloramination
   3. Ultraviolet light
   4. Chlorine dioxide

9. __________ is a critical process for non-reverse osmosis purification. It is usually coupled with biologic activated carbon filtration. The process reduces TOC and trace chemical pollutants, removes protozoans, kills viruses, and is a flocculation aid. It is an oxidation process used as a disinfection and oxidant prior to biologic activated carbon filtration.
   1. Ozone
   2. Chloramination
   3. Ultraviolet light
   4. Chlorine dioxide

10. Which of the listed factors does not have an influence on the disinfection of water with chlorine?
   1. pH
   2. Reducing agents
   3. Hardness
   4. Temperature