1.3: Disinfection By-Products And Alternative Disinfectants

Learning Objectives

- Explain the nature and occurrence of disinfection by-products
- Outline the Disinfection By-Products Rule
- Describe the formation of disinfection by-products
- Describe the methods of the minimization of disinfection by-products

Disinfection By-Products

Disinfection of drinking water by the addition of chlorine has long been considered a highly effective yet relatively low-cost method of preventing widespread outbreaks of waterborne diseases. In addition to reacting with disease-causing organisms in water, however, chlorine also reacts with many other types of organic materials.

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Figure \(\PageIndex{1}\): Disinfection byproducts form when disinfectants used in water treatment plants react with bromide and/or natural organic matter

Growing scientific evidence suggests that the byproducts of these chemical reactions can produce adverse health effects in humans. The highest priority health risk concern in the regulation of drinking water is the potential risk-risk tradeoff between the control of microbiological contamination (bacteria, viruses, and protozoa) on one side and DBPs on the other. This risk-risk tradeoff arises because, typically, the least expensive way for a public water system to increase microbial control is to increase disinfection (which generally increases byproduct formation) and the easiest way to reduce byproducts is to decrease disinfection (which generally increases microbial risk).

Microbiological contamination often causes flu-like symptoms; however, it can also cause serious diseases such as hepatitis, giardiasis, cryptosporidiosis, and Legionnaire’s Disease. DBPs may pose the risk of cancer and developmental effects.

THMs and HAA5s are examples of compounds formed by the reaction of chlorine with organic matter in water. THMs are suspected of being carcinogenic and have been regulated by EPA in the 1996 SDWA amendments. The MCL for TTHMs is 0.080 milligram per liter or 80 micrograms per liter, and HAA5s have an MCL of 0.060 milligrams per liter or 60 micrograms per liter.

In May 1996, EPA published the Information Collection Rule (ICR). This rule required large public water systems to undertake extensive monitoring of microbial contaminants and DBPs in their water systems. Also, some water systems conducted studies on the use of granular activated carbon and membrane processes. The data reported under the ICR were used by EPA to learn more about the occurrence of microbial contamination and DBPs, the health risks posed, appropriate analytical methods, and effective forms of treatment. The ICR data form the scientific basis for EPA’s development of the Enhanced Surface Water Treatment Rule and the Disinfectants and Disinfection Byproducts Rule.

EPA issued the Stage 1 DBPR on December 16, 1998 (Federal Register 63, No. 241). This rule set new MCLGs and MCLs for TTHMs, HAA5, bromate, and chlorite. Maximum residual disinfectant level goals (MRDLGs) and maximum residual disinfectant levels (MRDLs) have also been set for chlorine, chloramine, and chlorine dioxide.

The Stage 1 DBPR attempts to further reduce potential formation of harmful DBPs by requiring the removal of THM precursors. A treatment technique of enhanced coagulation, enhanced softening, or use of granular activated carbon (GAC) applies to conventional filtration systems. In most cases, systems must reduce total organic carbon (TOC) levels based on specific source water quality factors.

For large systems (serving more than 10,000 persons) that use surface water or groundwater under the direct influence of surface water, the compliance date for the Stage 1 DBPR was January 1, 2002. Small systems (serving fewer than 10,000) that use surface water or groundwater under the direct influence of surface water and all groundwater systems...
must have complied by January 1, 2004.

The Stage 1 DBPR has very specific laboratory and monitoring requirements. The routine monitoring requirements include the following regulated contaminants/disinfectants:

- TTHM/HAA5
- Bromate
- Chlorite
- Chlorine/chloramines
- Chlorine dioxide
- DBP precursors (TOC/alkalinity/specific UV absorbance)

Also, the Stage 1 DBPR specifies the monitoring coverage in terms of surface water, groundwater, and groundwater under direct influence (GWUDI), population served, and the type of filtration system and disinfection system. Monitoring frequency depends on the type of source water, population served, and type of treatment and disinfection system. The routine monitoring requirements are based on the regulated contaminants/disinfectants and include the MCL, MRDL, analytical method, preservation/quenching agent, holding time for sample/extract, and sample container size and type.

On December 15, 2005, EPA promulgated the Stage 2 DBPR. This rule reduces potential cancer and reproductive and developmental health risks from DBPs in drinking water, which form when disinfectants are used to control microbial pathogens. This final rule strengthens public health protection for consumers by tightening compliance monitoring requirements for two groups of DBPs: TTHMs and HAA5.

The rule targets systems with the greatest risk and builds incrementally on existing rules. This regulation reduces DBP exposure and related potential health risks and provides more equitable public health protection. The Stage 2 DBPR was promulgated simultaneously with the Long Term 2 Enhanced Surface Water Treatment Rule to address concerns about risk tradeoffs between pathogens and DBPs.

Under the Stage 2 DBPR, systems will conduct an evaluation of their distribution systems, known as an Initial Distribution System Evaluation (IDSE), to identify the locations with high DBP concentrations. These locations are used by the systems as the sampling sites for Stage 2 DBPR compliance monitoring.

Compliance with the maximum contaminant levels for two groups of DBPs (TTHMs and HAA5) is calculated for each monitoring location in the distribution system. This approach, referred to as the locational running annual average (LRAA), differs from previous requirements, which determine compliance by calculating the running annual average of samples from all monitoring locations across the system.

The Stage 2 DBPR also requires each system to determine if they have exceeded an operational evaluation level, which is identified using their compliance monitoring results. The operational evaluation level provides an early warning of possible future MCL violations, which allows the system to take proactive steps to remain in compliance. A system that exceeds an operational evaluation level is required to review their operational practices and submit a report to their state that identifies actions that may be taken to mitigate future high DBP levels; particularly, those levels that may jeopardize their compliance with the DBP MCLs.
Factors Influencing Disinfection

Many factors influence successful disinfection during water treatment. These factors include pH, temperature, turbidity, reducing agents, and microorganism.

pH

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

Temperature

Temperature conditions also influence the effectiveness of the disinfectant. The higher the temperature of water, the more efficiently it can be treated. Water near 70 to 85F (21 to 29 C) is easier to disinfect than water at 40 to 60 F (4 to 16C). Longer contact times are required to disinfect water at lower temperatures. To speed up the process, operators often use larger amounts of chemicals. Be aware, though, that the higher the chlorine concentration, the greater the dissipation rate of chlorine into the atmosphere. This process can produce odors and wastes chlorine.

Turbidity

Under normal operating conditions, the turbidly level of water being treated is very low by the time the water reaches the disinfection process. Excessive turbidity will greatly reduce the efficiency of the disinfecting chemical or process. Studies in 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.

The suspended matter can also change the chemical nature of the water when the disinfectant is added. Some types of suspended solids can create a continuing demand for the chemical; thus changing 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 and HAA5s) 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 reducing agents, however, will significantly reduce the amount of chemical available for disinfection.

Inorganic Matter

Inorganic compounds, such as ammonia in water 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 the water 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 of the reactions are rapid, though other reactions are much slower. These 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 inorganic reducing agents present in water that will react with chlorine include hydrogen sulfide, ferrous ions, manganous ions, ammonia, and nitrite. Organic reducing agents in water will react with chlorine and form chlorinated organic materials that have a 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 greatly. Non-spore-forming bacteria are generally less resistant than spore-forming bacteria. Cysts and viruses can be resistant to certain types of disinfectants.

Removal Process for Microorganisms

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

- Coagulation-chemical coagulation followed by sedimentation and filtration will remove 90 to 95-percent of the pathogenic organism, depending on which chemicals are used. Alum usage can increase virus removals up to
99-percent.

- Sedimentation—properly designed sedimentation processes can effectively remove 20 to 70-percent of the pathogenic microorganisms. This removal rate is accomplished by allowing the pathogenic and non-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 and effectiveness of pretreatment.

- Disinfection—disinfection chemicals, such as chlorine, are added to water to kill or inactivate pathogenic microorganisms.

### Disinfection Process

Disinfection destroys harmful organisms. This can be accomplished either physically or chemically. Physical methods include:

- 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, relatively inexpensive, and most importantly, leaves residual chlorine that can be measured. Other disinfectants are also used. Presently, an interest in disinfectants other than chlorine exists because of the carcinogenic compounds that chlorine can form (THMs).

### Physical Means of Disinfection

- Ultraviolet rays can be 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 microorganism. This system has not had widespread acceptance because of the lack of a measurable residual and the cost of operation. Currently, the use of ultraviolet rays is limited to small or local systems and industrial applications. Oceangoing ships use these systems for their water supply. Advances in UV technology and concern about disinfection byproducts produced by other disinfectants have prompted a renewed interest in UV disinfection.

- 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 thus expensive. However, it is the only practical treatment process for disinfection in the event of a disaster when individual local users are required to boil their water.

- Ultrasonic waves have been used to disinfect water on a limited scale. Sonic waves destroy microorganisms by vibration. This procedure is not yet practical and is expensive.

### Chemical Disinfectants Other Than Chlorine

- Iodine has been used as a disinfectant in water, but its use has been limited to emergency treatment of water supplies. Although it has long been recognized as a good disinfectant, iodine's high cost and potential physiological effects on pregnant women has prevented widespread acceptance. The recommended dosage is two drops of iodine (7% available iodine) in a liter of water.

- Bromine has been used only on a very limited scale for water treatment because of its handling difficulties. Bromine
causes skin burns on contact. Because bromine is a very reactive chemical, residuals are hard to obtain. This lack of a measurable residual also limits its use. Bromine can be purchased at swimming pool supply stores.

- Bases, such as sodium hydroxide and lime, can be effective disinfectants but the high pH leaves a bitter taste in the finished water. Bases can also cause skin burns when left too long in contact with the skin. Bases effectively kill all microorganisms (sterilize). Although this method has not been used on a large scale, bases have been used to sterilize water pipes.

- Ozone, in the United States, has been used for taste and odor control. The limited use has been due to its high costs, 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. Many scientists claim that ozone destroys all microorganisms. Unfortunately, significant residual ozone does not guarantee that treated water is safe to drink. Organic solids may protect organisms from the disinfecting action and increase the amount of ozone needed for the disinfection process. In addition, ozone residuals cannot be maintained in metallic conduits for any period of time because of ozone’s reactive nature. The inability of ozone to provide a residual in the distribution system is a major drawback to its use. However, recent information concerning the formation of THMs by chlorine compounds has resulted in a renewed interest in ozone as an alternative means of disinfection.

Chloramination

Chloramination is used as an alternative disinfection process in place of free chlorine. An operator’s decision to use chloramine in place of chlorine depends on several factors, including the quality of the raw water, the ability of the treatment plant to meet various regulations, operational practices, and distribution system characteristics. Chloramines have proven effective in accomplishing:

- Reducing the formation of THMs and other DBPs
- Maintaining a detectable residual throughout the distribution system
- Penetrating the biofilm in the pipeline and reducing the potential for coliform regrowth
- Killing or inactivating heterotrophic plate count bacteria
- Reducing taste and odor problems
Chlorine Dioxide

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

Chlorine dioxide reacts with water to form chlorate and chlorite ions:

- Chlorine Dioxide + Water
  
  Chlorite Ion + Hydrogen Ion

Reactions with impurities in water:

- Inorganic compounds-chlorine dioxide is an effective oxidizing agent with iron and manganese and does not leave objectionable tastes or odors in the finished water. Because of its oxidizing ability, chlorine dioxide usage must be monitored and the dosage will have to be increased when treating water with iron and manganese.
- Organic compounds-chlorine dioxide does not react with organics in water. Therefore, the danger of forming potentially dangerous THMs does not exist.

Ultraviolet Systems

Ultraviolet light (UV) is found just beyond the visible light spectrum. When UV light is absorbed by cells of microorganisms, it damages the genetic material in such a way that the organisms are no longer able to grow or
reproduce, and ultimately, it kills them. Today with growing concern about the safety aspects of handling chlorine and the possible health effects of chlorination byproducts, UV disinfection is gaining in popularity. UV technology can also provide inactivation of Cryptosporidium and Giardia, which are resistant to common disinfectants like chlorine or ozonation.

The combination of UV technology and chlorination allows an efficient disinfecting system by killing or inactivating a larger range of microorganisms than using only one disinfectant. The UV disinfection process is particularly adapted to water with a good quality. The efficiency of UV disinfection depends on the quality of water and on the treatment stages upstream. Raw water with low turbidity and with low levels of color favor the penetration of UV light and improves disinfection efficiency.

Corrosive water can damage UV systems, and technological advances are being made. Several manufacturers produce UV disinfection systems for water and wastewater applications. As operating experience with installed systems increases, UV disinfection may become a practical alternative to the use of chlorination at water treatment plants.

UV Lamp Types

Each UV lamp assembly consists of a UV lamp enclosed in an individual quartz sleeve with the ends appropriately sealed using an O-ring and a quartz end plug. All lamps within a UV system are identical type, length, diameter, power, and output. Three types of electrode-type lamps are used to produce UV radiation, and these types are:

- Low-pressure, low-intensity
- Low-pressure, high-intensity
- Medium-pressure, high-intensity

Figure (a): UV Disinfection Unit – Image by the EPA is in the public domain
Operation

The operation of UV disinfection systems requires little operator attention. To prevent short-circuiting and ensure that all microorganisms receive sufficient exposure to the UV radiation, the water level over the lamps must be maintained at the appropriate level. Water levels in channels can be controlled by weirs or automatic control gates.

Proper water depth must be maintained in the UV channel to ensure acceptable disinfection levels over the entire range of design flows. The UV channel water level control device must be regulated by the operator to:

- Minimize variation of the channel’s water level
- Maintain the channel’s water level at a defined level
- Keep the UV lamps submerged at all times
- Prevent excessive water layer thickness above the top lamp row

Monitoring Influent and Effluent Characteristics

Care must be taken not to exceed the maximum design turbidity levels and flow velocities when using these types of equipment. Suspended particles will shield microorganisms from the UV light and protect them from their destructive effects. Flows should be somewhat turbulent to ensure complete exposure of all organisms to the UV light, but flow velocity must be controlled so that the water is exposed to UV radiation long enough for the desired level of disinfection to occur.

Because ultraviolet rays leave no chemical residual as chlorine does, bacteriological tests must be made frequently to ensure that adequate disinfection is being achieved by the ultraviolet system. In addition, the lack of residual disinfectant means that no protection is provided against recontamination after the treated water has left the disinfection facility. When the treated water is exposed to visible light, the microorganism can be reactivated. Microorganisms that have not been killed have the ability to heal when exposed to sunlight. The solution to this problem is to design UV systems with a high efficiency for killing microorganisms.

Ozone Systems

Ozone (O3) is an alternative treatment process for disinfecting water. Ozone is produced when oxygen molecules are exposed to an energy source and converted to the unstable gas, ozone, which is used for disinfection. Ozone is a very strong oxidant and virucide.

The effectiveness of ozone disinfection depends on the susceptibility of the target organism, the contact time, and the concentration of the ozone. After generation, ozone is fed into a down-flow contact chamber containing the water to be disinfected. The purpose of the contact chamber is to transfer ozone from the gas bubble to the water while providing sufficient contact time for disinfection. Because ozone is consumed quickly, it must be exposed to the water uniformly in a plug-flow-type contactor. An ozone disinfection system strives for the maximum solubility of ozone in water because disinfection depends on the transfer of ozone into the water. The amount of ozone that will dissolve in water at a constant temperature is a function of the partial pressure of the gaseous ozone above the water or in the gas feed.
stream. All ozone disinfection systems should be pilot tested and calibrated before installation to ensure they meet the disinfection requirements for their particular sites.

**Equipment**

Ozone is normally generated on-site because it is very unstable and decomposes to elemental oxygen in a short time after generation. Ozonation equipment consists of four major parts:

- Gas preparation unit
- Electrical power unit
- Ozone generator
- Contactor

**Gas Preparation**

The gas preparation unit to produce dry air usually consists of a commercial air dryer with a dew point monitoring system. This portion of the system is the most critical part of the system.

**Electrical Supply Unit**

This unit is normally a very special electrical control system. The most common electrical supply unit provides low frequency, variable voltage. For large installations, medium frequency, variable voltage is used to reduce power costs and because it allows for higher outputs of ozone.

**Ozone Generator**

This unit consists of a pair of electrodes separated by a gas space and a layer of glass insulation. Oxygen-containing gas is passed through the empty space as a high-voltage alternating current is applied. An electrical discharge occurs across the gas space and ozone is formed when a portion of the oxygen is ionized and then becomes associated with non-ionized oxygen molecules.

**Ozone Contactor**

This unit is a mixing chamber for the ozone-rich material and the process water. The objective is to dissolve enough ozone in the water to achieve disinfection at the lowest possible cost. These units are available in many configurations:

- Multi-Stage Porous Diffuser
  - Single application of an ozone-rich stream
  - Application of ozone to second state
- Educator System
For disinfection purposes, the diffuser-type ozone contactor is the most commonly used design. The off gases must be treated before release to the atmosphere. The most common method of treatment is the use of activated carbon and dilution.

Ozone Residuals

Residual ozone is measured by the iodometric method. The procedure is:

1. Collect an 800 ml sample in a 1-liter wash bottle
2. Pass pure air or nitrogen through the sample and then through an absorber containing 400 mL KI solution. Continue for 5 to 10 minutes at a rate of 1.0 liter/minute to purge all ozone from the sample
3. Transfer KI solution to another vessel
4. Add 20 mL 1 N sulfuric acid to reduce the pH to 2
5. Titrate with a 0.005 N sodium thiosulfate solution
6. Add several drops of starch
7. The end point is reached when the purple color is discharged and solution becomes colorless
8. Repeat this test using a blank or distilled water
9. Calculation

   • \( O_3 \), mg/L = \( \frac{(A + B) \times N \times 24,000}{V_{sample}} \) mL where...
     - \( A \) = mL of titrant for sample
     - \( B \) = mL of titrant for blank (positive if turned blue and negative if had to back titrate blank)
     - \( N \) = normality of sodium thiosulfate
     - \( V_{sample} \) = volume of the sample

Continuous inline ozone residual analyzers are available similar to the continuous inline chlorine residual analyzers.

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**Safety**

Ozone is a toxic gas that is a hazard to plants and animals. Ozone irritates nasal passages in low concentrations. When ozone breaks down in the atmosphere as a result of photochemical reactions, the resulting atmospheric pollutants can be very harmful. However, ozone is less of a hazard than gaseous chlorine because chlorine is normally manufactured and delivered to the plant site. Ozone is produced on the site, it is used in low concentrations, and it is not stored under pressure. Problem leaks can be stopped by turning the unit off.

Ozone production equipment has various fail-safe protection devices that will automatically shut off the equipment when a potential hazard develops.

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**Maintenance**

Electrical equipment and pressure vessels should be inspected monthly by trained operators. A yearly preventive maintenance program should be conducted by a factory representative or by an operator trained by the manufacturer. Lubrication of the moving parts should be done according to the manufacturer’s recommended schedule.

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**Applications of Ozone**

In addition to using ozone after filtration for bacterial disinfection and viral inactivation, ozone may be used for several other purposes in treating drinking water. Ozone may be used before coagulation for treating iron and manganese, helping flocculation, and removing algae. When ozone is applied before filtration it may be used for oxidizing organics, removing color, or treating tastes and odors.

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**Advantages and Limitations of Ozone**

The advantages include:

- Ozone is more effective than chlorine in destroying viruses and bacteria
• The ozonation process uses a short contact time (10 to 30 minutes)
• No harmful residuals that need to be removed after ozonation are produced or are present
• After ozonation, no regrowth of microorganisms occurs, except for those organisms protected by the particulates in the water stream
• Ozone is generated on-site, and fewer safety problems associated with shipping and handling exist
• Removes color, odor, and tastes (phenols)
• Oxidizes iron, manganese, sulfide, and organics

The limitations include:

• Low dosage may not effectively inactivate some viruses, spores, and cysts
• Ozonation is a more complex technology than chlorination or UV disinfection, requiring complicated equipment and efficient contacting systems
• Ozone is very reactive and corrosive, and requires corrosion-resistant materials such as stainless steel
• Ozonation is not economical for water with high levels of suspended solids, biochemical oxygen demand, chemical oxygen demand, or total organic carbon
• Ozone is extremely irritating and possibly toxic, so off gases from the contactor must be destroyed to prevent exposure
• The cost of treatment can be relatively high in capital and power costs

Ozone can be an effective disinfectant, however, the capital costs and the O&M costs of ozone may not be competitive with available disinfection alternatives.

Review Questions

1. Describe disinfection byproducts.
2. Explain the Disinfection Byproducts Rule.
3. Describe the formation of disinfection byproducts.

Test Questions

1. The MCL for TTHMs is ________, and HAA5s have an MCL of ________.
   1. 0.080 milligram per liter, 0.060 milligrams per liter
   2. 0.10 milligrams per liter, 0.080 milligrams per liter
   3. 80 milligrams per liter, 60 milligrams per liter
   4. 60 micrograms per liter, 40 micrograms per liter

2. Compliance with the maximum contaminant levels for two groups of DBPs in the Stage II Disinfection Byproducts Rule (TTHMs and HAA5) is calculated for ________ in the distribution system. This approach, referred to as the locational running annual average (LRAA), differs from previous requirements, which determine compliance by calculating the running annual average of samples from all monitoring locations across the system.
   1. random sites
   2. each monitoring location
3. Temperature conditions influence the effectiveness of the disinfectant. The higher the temperature of water, the ______ efficiently it can be treated.
   1. less
   2. no change in how
   3. more
   4. none are correct (more factors influence the efficiency and temperature efficiency cannot be determined)

4. ________ are an example of undesirable compounds formed by reactions between chlorine and certain organics. Disinfecting chemicals often react with organics and reducing agents.
   1. Benzene
   2. Chlorite
   3. Trihalomethanes (THMs and HAA5s)
   4. Chlorate

5. ______ does not form carcinogenic compounds that may be formed by other chlorine compounds.
   1. Gas chlorine
   2. Sodium hypochlorite
   3. Calcium hypochlorite
   4. Chlorine dioxide

6. ______ can be used to destroy pathogenic microorganisms. To be effective, the rays must come in contact with each microorganism.
   1. X-rays
   2. Radium
   3. Ultraviolet light
   4. Radon

7. The inability of ______ to provide a residual in the distribution system is a major drawback to its use.
   1. ozone
   2. chloramines
   3. chlorine dioxide
   4. calcium hypochlorite

8. _______ have proven effective in accomplishing reducing the formation of THMs and other DBPs and maintaining a detectable residual throughout the distribution system.
   1. UV light
   2. Ozone
   3. Heat
   4. Chloramines

9. _______ can be used as a disinfectant. It does not form carcinogenic compounds that may be formed by disinfectants. Also, it is not affected by ammonia, and it is a very effective disinfectant at higher pH levels.
   1. UV light
2. Ozone
3. Chlorine dioxide
4. Sodium hypochlorite

10. In addition to using _____ after filtration for bacterial disinfection and viral inactivation, it may be used for several other purposes in treating drinking water. It can be used before coagulation for treating iron and manganese, helping flocculation, and removing algae, and when it is applied before filtration it may be used for oxidizing organics, removing color, or treating tastes and odors. However, it does not produce a residual that is carried into the distribution system.

1. UV light
2. Ozone
3. Chlorine dioxide
4. Chloramines