Disinfection

Summary

Disinfection is an important step in ensuring that water is safe to drink. Water systems add disinfectants to destroy microorganisms that can cause disease in humans. The Surface Water Treatment Rule requires public water systems to disinfect water obtained from surface water supplies or groundwater sources under the influence of surface water.

Primary methods of disinfection are chlorination, chloramines, ozone, and ultraviolet light. Other disinfection methods include chlorine dioxide, potassium permanganate, and nanofiltration. Since certain forms of chlorine react with organic material naturally present in many water sources to form harmful chemical by-products, the U.S. Environmental Protection Agency has proposed maximum levels for these contaminants.

Disinfection Keeps Water Safe

Why disinfect drinking water?

Disinfection kills or inactivates disease-causing organisms in a water supply and must provide a 99.9 percent inactivation of *Giardia lamblia* cysts and enteric viruses to protect health and to comply with the U.S. Environmental Protection Agency (EPA) regulations. There are two kinds of disinfection: primary disinfection achieves the desired level of microorganism kill or inactivation, while secondary disinfection maintains a disinfectant residual in the finished water that prevents the regrowth of microorganisms.

What regulations govern it?

The EPA Surface Water Treatment Rule (SWTR) requires systems using public water supplies from either surface water or groundwater under the direct influence of surface water to disinfect.

Also, since some disinfectants produce chemical by-products, the dual objective of disinfection is to provide the required level of organism destruction and remain within the maximum contaminant level (MCL) for the SWTR disinfection set by EPA. At this time, an MCL is set for only Total Trihalomethanes, and proposed for additional disinfection by-products.

How is disinfection achieved?

Our natural environment contains numerous microorganisms. Most of these present no concerns. However, some—such as *Giardia lamblia* and various viruses, which can be present in water supplies—are extremely harmful and can cause disease in humans. These disease-causing organisms are known as pathogens.

Because pathogens can be present in drinking water supplies, disinfection is very important—the EPA requires it for surface water and groundwater under the influence of surface water. Disinfection treatment methods include chlorination, chlorine dioxide, chloramines, ozone, and ultraviolet light.

When combined with conventional treatment, such as coagulation, flocculation, sedimentation, and filtration, good results have been obtained. Direct filtration, slow sand filtration, and diatomaceous earth filtration, along with disinfection, have been just as successful.

Groundwater systems that disinfect may have to add filtration if the water contains iron and manganese. In fact, insoluble oxides form when chlorine, chlorine dioxide, or ozone are added to these systems. Both ozonation and chlorination may cause flocculation of dissolved organics, thus increasing turbidity and necessitating filtration. The effectiveness of disinfection is judged by analyzing for an indicator organism (total coliform bacteria). This organism is considered harmless, but its presence indicates that pathogens may also have survived.

Comparing Disinfectants:

Chlorination (Gas)

At normal pressures, elemental chlorine is a toxic, yellow-green gas, and is liquid at high pressures.

ADVANTAGES

Chlorine is very effective for removing almost all microbial pathogens and is appropriate as both a primary and secondary disinfectant.

LIMITATIONS

Chlorine is a dangerous gas that is lethal at concentrations as low as 0.1 percent air by volume.

PROCESS

Chlorine gas is released from a liquid chlorine cylinder by a pressure reducing and flow control valve operating at a pressure less than atmospheric. The gas is led to an injector in the water supply pipe where highly pressurized water is passed through a venturi orifice creating a vacuum that draws the chlorine into the water stream. Adequate mixing and contact time must be provided after injection to ensure complete disinfection of pathogens. It may be necessary to control the pH of the water.

EQUIPMENT

A basic system consists of a chlorine cylinder, a cylinder-mounted chlorine gas vacuum regulator, a chlorine gas injector, and a contact tank or pipe. (*See Diagram A on page 4.*) Prudence and/or state regulations would require that a second cylinder and gas regulator be provided with a changeover valve to ensure continuity of disinfection. Additional safety and control features may be required.

A gas chlorinator should be installed in a room or chamber with direct emergency access to outside air and fitted with an exhaust fan ventilation system.

Federal and state safety regulations must be observed. If not onsite, self-contained breathing apparatus and a chlorine cylinder repair kit should be available within a reasonable time frame and/or distance.

CHEMICALS

Chlorine gas is supplied as liquid in high pressure cylinders.

Chlorination (Sodium hypochlorite solution)

Sodium hypochlorite is available as a solution in concentrations of 5 to 15 percent chlorine, but is more expensive than chlorine gas (as available chlorine).

ADVANTAGES

Sodium hypochlorite is easier to handle than gaseous chlorine or calcium hypochlorite.

LIMITATIONS

Sodium hypochlorite is very corrosive and should be stored with care and kept away from equipment that can be damaged by corrosion. Hypochlorite solutions decompose and should not be stored for more than one month. It must be stored in a cool, dark, dry area.

PROCESS

Sodium hypochlorite solution is diluted with water in a mixing/holding tank. The diluted solution is injected by a chemical pump into the water supply pipe at a controlled rate. Adequate mixing and contact time must be provided.

EQUIPMENT

A basic liquid chlorination system, or hypochlorinator, includes two metering pumps (one serving as a standby), a solution tank, a diffuser (to inject the solution into the water), and tubing.

CHEMICALS

Sodium hypochlorite solution is readily available.

Sodium hypochlorite can also be generated onsite by electrolysis of sodium chloride solution in specialized proprietary equipment. The only supplies required are common salt and electricity. Hydrogen is given off as a by-product and must be safely dispersed.

Chlorination (Solid calcium hypochlorite)

Calcium hypochlorite is a white solid that contains 65 percent available chlorine and dissolves easily in water.

ADVANTAGES

When packaged, calcium hypochlorite is very stable, allowing a year's supply to be bought at one time.

LIMITATIONS

Calcium hypochlorite is a corrosive material with a strong odor that requires proper handling. It must be kept away from organic materials such as wood, cloth, and petroleum products. Reactions between calcium hypochlorite and organic material can generate enough heat to cause a fire or explosion. Calcium hypochlorite readily absorbs moisture, forming chlorine gas. Therefore, shipping containers must be emptied completely or carefully resealed.

PROCESS

Calcium hypochlorite may be dissolved in a mixing/holding tank and injected in the same manner as sodium hypochlorite. Alternatively, where the pressure can be lowered to atmospheric, such as at a storage tank, tablets of hypochlorite can be directly dissolved in the free flowing water by a proprietary device that provides flow-proportional chlorination with gravity feed of the tablets.

EQUIPMENT

The equipment used to mix the solution and inject it into the water is the same as that for sodium hypochlorite. Solutions of 1 or 2 percent available chlorine can be delivered by a diaphragm-type, chemical feed/metering pump or by tablet chlorinator.

CHEMICALS

Calcium hypochlorite can be purchased in granular, powdered, or tablet form.

All chlorine added to drinking water must meet American National Standards Institute (ANSI), and NSF *International,* formerly the National Sanitation Foundation (NSF) standards. *ANSI/NSF Standard 60: Drinking Water Chemicals—Health Effects* covers water treatment chemicals.

Chloramine

Chloramines are formed when water containing ammonia is chlorinated or when ammonia is added to water containing chlorine (hypochlorite or hypochlorous acid).

ADVANTAGES

An effective bactericide that produces fewer disinfection by-products, chloramine is generated onsite. Usually, chloramine-forming reactions are 99 percent complete within a few minutes.

LIMITATIONS

Chloramine is a weak disinfectant. It is much less effective against viruses or protozoa than free chlorine. Chloramine is appropriate for use as a secondary disinfectant to prevent bacterial regrowth in a distribution system. Nitrogen trichloride appears to be the only detrimental reaction. It may be harmful to humans and imparts a disagreeable taste and odor to the water. The use of the proper amounts of each chemical reactant will avoid its production.

PROCESS

Chlorine (gaseous solution or sodium hypochlorite) is injected into the supply main followed immediately by injection of ammonia (gaseous solution or as ammonium hydroxide). As before, adequate mixing and contact time must be provided. The mix of products produced when water, chlorine, and ammonia are combined depends on the ratio of chlorine to ammonia and the pH of the water. Chlorine-to-ammonia ratios of 5:1 should not be exceeded. If the pH drops below 5, some nitrogen trichloride may be formed.

EQUIPMENT

The generation of chloramines requires the same equipment as chlorination (gaseous or aqueous hypochlorination), plus equipment for adding ammonia (gaseous or aqueous).

CHEMICALS

Chemicals used to generate chloramine from ammonia and chlorine gas depend on the ammonia-based chemical used. Anhydrous ammonia is the least expensive, while ammonium sulfate is the most expensive.

Ozonation

Ozone, an allotrope of oxygen having 3 atoms to each molecule, is a powerful oxidizing and disinfecting agent. It is formed by passing dry air through a system of high voltage electrodes.

ADVANTAGES

Requiring shorter contact time and dosage than chlorine, ozone is widely used as a primary disinfectant in many parts of the world—but is relatively new to the U.S. Ozone does not directly produce halogenated organic materials unless a bromide ion is present.

LIMITATIONS

Ozone gas is unstable and must be generated onsite. A secondary disinfectant, usually chlorine, is required because ozone does not maintain an adequate residual in water.

PROCESS

The five major elements of an ozonation system are:

- air preparation or oxygen feed;
- electrical power supply;
- ozone generation—usually using a corona discharge cell consisting of two electrodes;
- ozone contact chamber; and
- ozone exhaust gas destruction.

EQUIPMENT

Ozonation equipment includes air preparation equipment; an ozone generator, contactor, destruction unit; and instrumentation and controls. The capital costs of ozonation systems are relatively high. Operation and maintenance are relatively complex. Electricity represents 26 to 43 percent of total operating and maintenance costs for small systems.

CHEMICALS

For many applications, pure oxygen is a more attractive ozone feed gas than air because:

- it has a higher production density,
- it requires lower energy consumption,
- it doubles the amount of ozone that can be generated per unit, and
- it requires smaller gas volumes for the same ozone output, thus lowering costs for ancillary equipment.

Ultraviolet Light (UV)

Ultraviolet (UV) radiation is generated by a special lamp. When it penetrates the cell wall of an organism, the cell's genetic material is disrupted and the cell is unable to reproduce.

ADVANTAGES

UV radiation effectively destroys bacteria and viruses. As with ozone, a secondary disinfectant must be used to prevent regrowth of micro-organisms. UV radiation can be attractive as a primary disinfectant for small systems because:

- it is readily available,
- it produces no known toxic residuals,
- it requires short contact times, and
- the equipment is easy to operate and maintain.

LIMITATIONS

UV radiation may not inactivate *Giardia lamblia* or *Cryptosporidium* cysts, and should be used only by groundwater systems not directly influenced by surface water—where there is virtually no risk of protozoan cyst contamination. UV radiation is unsuitable for water with high levels of suspended solids, turbidity, color, or soluble organic matter. These materials can react with or absorb the UV radiation, reducing the disinfection performance.

PROCESS

The effectiveness of UV radiation disinfection depends on the energy dose absorbed by the organism, measured as the product of the lamp's intensity (the rate at which photons are delivered to the target) and the time of exposure. If the energy dosage is not high enough, the organism's genetic material might only be damaged instead of destroyed. To provide a safety factor, the dosage should be higher than needed to meet disinfection requirements.

EQUIPMENT

UV lamps and a reactor (*See Diagram B on page 4.*)

CHEMICALS

No chemical oxidant required; therefore, microorganisms can be killed without generating by-products of chemical oxidation or halogenation.

How do you control disinfection by-products?

A number of factors can affect the formation of disinfection by-products. These include the types and concentrations of organic materials present when chlorine is added, the dosage of chlorine, the temperature and pH of the water, and the reaction time.

To control the formation of halogenated by-products (compounds formed by the reaction of a disinfectant, such as chlorine with organic material in the water supply) during chlorination, EPA has identified these three strategies:

1. Remove the by-products after they are formed, which can be difficult and costly.
2. Use alternative disinfectants that do not produce undesirable by-products, which is often the most cost-effective strategy.
3. Reduce the concentration of organics in the water before oxidation or chlorination to minimize the formation of by-products. This will provide the highest quality finished water.

Diagram B
Ultraviolet Water Purifier

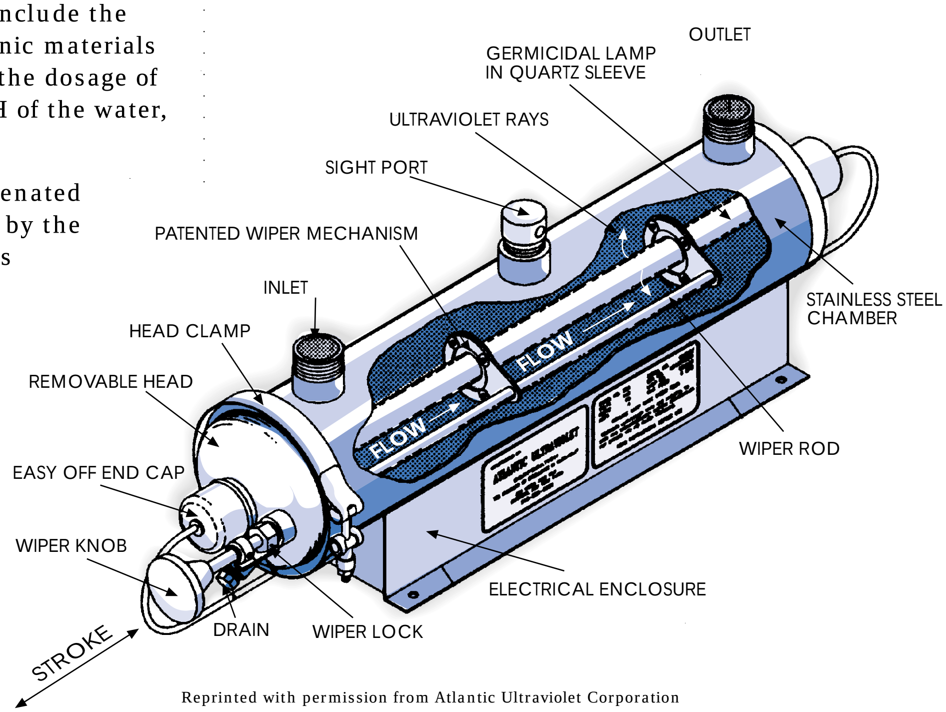

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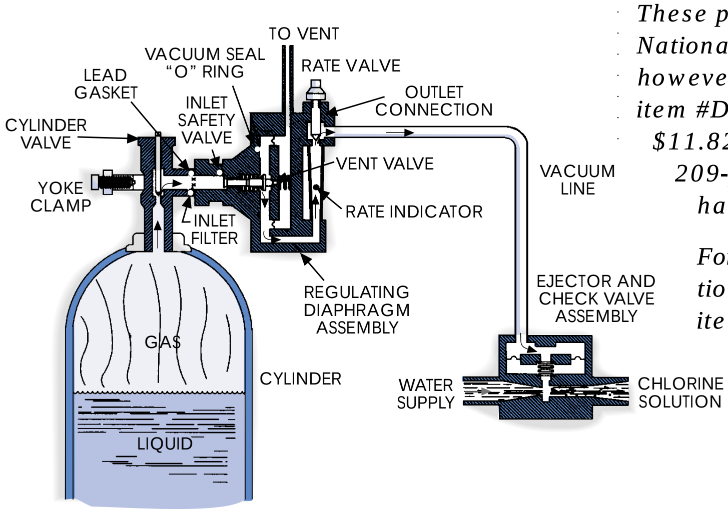
Diagram A
Cylinder-Mounted Chlorinator



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Where can I find more information

Information on disinfection was primarily obtained from two sources: Environmental Pollution Control Alternatives: Drinking Water Treatment for Small Communities, *EPA/625/5-90/025; and* Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities, *EPA/625/4-89/023. Both can be ordered free from the EPA Office of Research and Development at (513) 569-7562.*

These publications also can be ordered from the National Drinking Water Clearinghouse (NDWC); however, copying costs apply. The first book, item #DWBKGN09, an 82-page publication, costs $11.82; and the second, item #DWBKDM04, a 209-page book, costs $30.05. Shipping and handling charges apply.

For further information or to order additional copies of "Tech Brief: Disinfection," item #DWBRPE47, or the above publications call the NDWC at (800) 624-8301.