Chlorine Disinfection

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Fact Sheet

Introduction

Human exposure to wastewater discharged into the environment has increased within the past 15 to 20 years with the rise in population and the greater demand for water resources for recreation and other purposes. The organisms of concern in domestic wastewater include enteric bacteria, viruses, and protozoan cysts. Some common microorganisms found in domestic wastewater and the diseases associated with them are presented in Table 1.

Table 1: Infectious Agents Potentially Present in Untreated Domestic Wastewater

Organism	Disease Caused
Bacteria	
Escherichia coli (enterotoxigenic)	Gastroenteritis
Leptospira (spp.)	Leptospirosis
Salmonella typhi	Typhoid fever
Salmonella (≈2,100 serotypes)	Salmonellosis
Shigella (4 spp.)	Shigellosis (bacillary dysentery)
Vibrio cholerae	Cholera
Protozoa	
Balantidium coli	Balantidiasis
Cryptosporidium parvum	Cryptosporidiosis
Entamoeba histolytica	Amebiasis (amoebic dysentery)
Giardia lamblia	Giardiasis
Helminths	
Ascaris lumbricoides	Ascariasis
T. solium	Taeniasis
Trichuris trichiura	Trichuriasis
Viruses	
Enteroviruses (72 types, e.g., polio, echo, and coxsackie viruses)	Gastroenteritis, heart anomalies, meningitis
Hepatitis A virus	Infectious hepatitis
Norwalk agent	Gastroenteritis
Rotavirus	Gastroenteritis

Adapted from: Crites and Tchobanoglous (1998) with permission from The McGraw-Hill Companies

Disinfection is considered to be the primary mechanism for the inactivation/destruction of pathogenic organisms to prevent the spread of waterborne diseases to downstream users and the environment.

It is important that wastewater be adequately treated prior to disinfection in order for any disinfectant to be effective.

There is no perfect disinfectant. However, there are certain characteristics to look for when choosing a suitable disinfectant for a treatment facility:

- ability to penetrate and destroy infectious agents under normal operating conditions;
- lack of characteristics that could be hazardous to people and the environment before or during disinfection;
- safe and easy handling, storage, and shipping;
- absence of toxic residuals and mutagenic or carcinogenic compounds after disinfection; and
- affordable capital and operation and maintenance (O&M) costs.

Disinfection Alternatives

The three common methods of disinfection in the U.S. are chlorination, ozonation, and ultraviolet (UV) disinfection. Chlorine, the most widely used disinfectant for municipal wastewater, destroys target organisms by oxidation of cellular material. It may be applied as chlorine gas, hypochlorite solutions, and other chlorine compounds in solid or liquid form.

Like chlorine, ozone is a strong oxidizing agent. It is an unstable gas that is generated by an electrical discharge through dry air or pure oxygen. UV radiation, generated by an electrical discharge through mercury vapor, penetrates the genetic material of microorganisms and retards their ability to reproduce.

All three disinfection methods described above can effectively meet the discharge permit requirements for treated wastewater. However, the advantages and disadvantages of each must be weighed when selecting a method of disinfection. The advantages and disadvantages of chlorine disinfection are discussed below.

Advantages

- Chlorination is a well-established technology.
- Presently, chlorine is more cost-effective than either UV or ozone disinfection (except when dechlorination is required and fire code requirements must be met).
- The chlorine residual that remains in the

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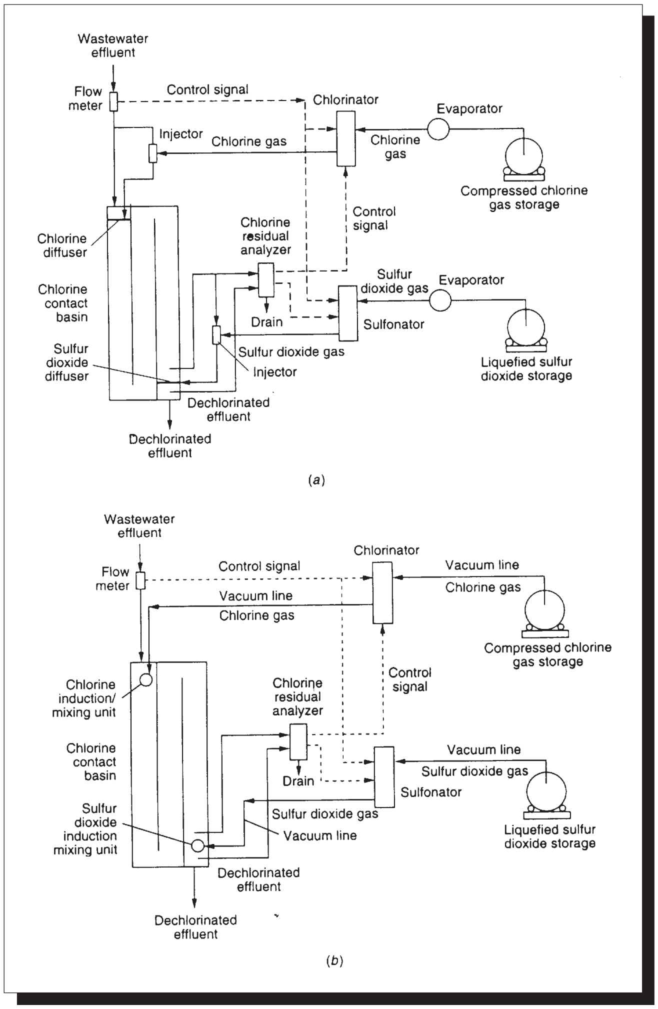

Figure 1:
A compound-loop control system for chlorination with chlorine and dechlorination with sulfur dioxide: (a) injection of liquid chlorine and (b) injection of chlorine gas by induction.

Source: Crites and Tchobanoglous (1998), used with permission from The McGraw-Hill Companies

wastewater effluent can prolong disinfection even after initial treatment and can be measured to evaluate the effectiveness.
- Chlorine disinfection is reliable and effective against a wide spectrum of pathogenic organisms.
- Chlorine is effective in oxidizing certain organic and inorganic compounds.
- Chlorination has flexible dosing control.
- Chlorine can eliminate certain noxious odors while disinfecting.

Disadvantages

- The chlorine residual, even at low concentrations, is toxic to aquatic life and may require dechlorination.
- All forms of chlorine are highly corrosive and toxic. Thus, storage, shipping, and handling pose a risk, requiring increased safety regulations (especially in light of the new Uniform Fire Code).
- Chlorine oxidizes certain types of organic matter in wastewater, creating more hazardous compounds (e.g., trihalometh-anes [THMs]).
- The level of total dissolved solids is increased in the treated effluent.
- The chloride content of the wastewater is increased.
- Chlorine residuals are unstable in the presence of high concentrations of chlorine-demanding materials, thus requiring higher doses to effect adequate disinfection.
- Some parasitic species have shown resistance to low doses of chlorine, including oocysts of *Cryptosporidium parvum,* cysts of *Endamoeba histolytica* and *Giardia lamblia,* and eggs of parasitic worms.
- The long-term effects of discharging dechlorinated compounds into the environment are unknown.

Process Description

Many hypotheses have been suggested over time to explain the germicidal effects of various chlorine compounds. Some of these theories include:

- *Oxidation:* Chlorine diffuses into the cell and oxidizes the cell protoplasm.
- *Protein precipitation:* Chlorine precipitates proteins and may change the chemical arrangement of enzymes or inactivate them directly.
- *Modification of cell wall permeability:* Chlorine may destroy the cell wall membrane, allowing vital solutes and nutrients, such as nitrogen and phosphorus, to diffuse out of the cell.
- *Hydrolysis:* Chlorine hydrolizes the cell wall polysaccharides, which weakens the cell wall and can dehydrate the cell.
- *Reactions with available chlorine*

Although the theories mentioned above may all play a part in the destruction of pathogens, the primary mechanism depends on the particular type of microorganisms, the chlorine compound (or species) used, and the characteristics of the wastewater.

When chlorine gas and hypochlorite salts are added to water, hydrolysis and ionization take place to form hypochlorous acid (HOCl) and hypochlorite ions (OCl). *Free available chlorine* is defined as the concentration of chlorine existing in the form of hypochlorous acid and hypochlorite ions. Free chlorine reacts quickly with ammonia in non-nitrified effluents to form combined chlorine, principally monochloramine, which actually is the predominant chlorine species present.

See Figure 1 for a flowchart of the chlorination process using liquid and gaseous chlorine. For optimum performance, a chlorine disinfection system should display plug flow and be highly turbulent for complete initial mixing in less than 1 second. The contact chamber should have rounded corners to prevent dead flow areas and be baffled to minimize short-circuiting and allow adequate contact time.

The two important process control parameters for any chlorination system are the dose and the chlorine residual. The operational process control parameters are the contact time and the indicator bacteria results.

The required degree of disinfection can be achieved by varying the dose and the contact time for any chlorine disinfection system. Chlorine dosage will vary based on chlorine demand, wastewater characteristics, and discharge requirements. The dose usually ranges from 5 to 20 mg/L.

Common wastewater characteristics and their impact on chlorine are listed in Table 2.

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Also, other factors—such as temperature, alkalinity, and nitrogen-containing compounds—determine the effectiveness of the chlorination process. All key design parameters should be pilot tested prior to full-scale operation of a chlorine disinfection system.

Table 2: Wastewater Characteristics Affecting Chlorination Performance

Wastewater Characteristic	Effects on Chlorine Disinfection
Ammonia	Forms chloramines when combined with chlorine
Biochemical oxygen demand (BOD)	Organic compounds can exert a chlorine demand. The degree of interference depends on their functional groups and chemical structures
Hardness, Iron, Nitrate	Minor effect, if any
Humic materials	Reduces effectiveness of chlorine
Nitrite	Oxidized by chlorine
pH	Affects distribution between hypochlorous acid and hypochlorite ions and among the various chloramine species
Total suspended solids	Shielding of embedded bacteria and chlorine demand

Adapted from: Darby et al. (1995) with permission from the Water Environment Research Foundation

Types of Chlorine

The different forms of chlorine used in wastewater treatment plants are listed below.

- *Gas (Cl_2):* Also known as elemental chlorine, it is the most commonly used form of chlorine. This toxic, yellow-green gas is stored as a liquid under pressure.
- *Sodium hypochlorite solution (NaOCl):* This solution is clear, light yellow, highly alkaline, and corrosive with a strong chlorine odor. It is often referred to as liquid bleach and contains 5 to 15% chlorine.
- *Calcium hypochlorite ($Ca(OCl)_2$):* This highly corrosive compound is a white, dry solid containing 70% chlorine. It is commercially available in granular, powdered, or tablet form.
- *Bromine chloride (BrCl):* This compound is the combination of one atom of chlorine and one atom of bromine, with bromine being the active element. It is supplied commercially as a containerized, dark-red liquid under pressure. Bromine residuals are less lethal to aquatic life than that of chlorine compounds.

Dechlorination

After disinfection, chlorine residuals can persist in the effluent for many hours. Most states will not allow the use of chlorination alone for pristine receiving waters because of its effects on aquatic species. To minimize these effects, chlorinated wastewater must often be dechlorinated.

Dechlorination is the process of removing the free and combined chlorine residuals to reduce residual toxicity after chlorination and before discharge. Sulfur dioxide, sodium bisulfite, and sodium metabisulfite are the commonly used dechlorinating chemicals. Activated carbon has also been used.

The total chlorine residuals can usually be reduced to a level that is not toxic to aquatic life. Chlorination/dechlorination systems are more complex to operate and maintain than chlorination alone. For a schematic of the chlorination/dechlorination system using sulfur dioxide, see Figure 1 on page 2.

Application

Marsh Creek Wastewater Treatment Plant in Geneva, New York

The Marsh Creek Wastewater Treatment Plant in Geneva, New York, met a stringent requirement for residual chlorine and fecal coliforms by adopting a new chlorine control strategy. The strategy was devised to monitor the plant's changing chlorine demand and to feed the required chlorine by measuring the oxidation reduction potential (ORP).

After conducting a 3-month study, the plant installed an ORP system to monitor and respond to the amount of chlorine present in solution. The control system measured the chlorine demand and regulated the amount of chlorine needed to achieve and maintain the ORP setpoint parameters. The system was calibrated to maintain the total chlorine control limit between 0.2 and 0.1 mg/L.

An electrode, placed about 300 feet upstream from the injection point, measured the ORP, which was then converted to a 4 to 20 milliampere signal. Based on the signal, the control system drove the chlorinator and matched the feed rate to the changing chlorine demand in the system. A second electrode was used on the discharge fallout line to monitor the accuracy of the chlorine control system.

The treatment plant was then able to meet the fecal coliform limits and maintain an effluent chlorine residual of less than 0.25 mg/L. In addition to meeting the permit requirements, the plant significantly lowered the chlorine consumption cost. At the time of the study, it was estimated that the ORP control system could be paid for in approximately 30 months due to the reduction in the chlorine consumption cost.

East Bay Municipal Utility District's Wastewater Plant in Oakland, California

The East Bay Municipal Utility District in Oakland, California, owned and operated a wastewater treatment plant with a design flow of 310 million gallons per day (mgd), where chlorination and dechlorination were a mandated part of the treatment process. With this requirement, optimizing the dechlorination system was a critical part in meeting the National Pollution Discharge Elimination System permit limit of no chlorine residual during dry and wet weather operations.

A sodium bisulfite (SBS) system was added as a backup to the dechlorination operation and performed very well in keeping the plant in compliance. This system is similar to a typical liquid chemical addition facility with a storage system, feed pump, metering system, control valve, and injection device.

The SBS system was integrated into the overall dechlorination operation by control set points on the sulfur dioxide (SO_2) residual analyzer and set to maintain a concentration of 3 to 4 mg/L. The SBS system is set to kick in at a calculated SO_2 concentration of 1.5 mg/L. It is also set to begin operation when the SO_2 leak detection system automatically shuts off the SO_2 feed, or during wet weather operations when the SO_2 demand may exceed the SO_2 system's capacity.

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The treatment plant also had to optimize chemical usage with the continued increase in chemical costs. The original chlorine dose was 15 mg/L, where 5 to 6 mg/L was consumed with 9 to 10 mg/L as a residual. The residual chlorine was then gradually lowered from 9 to 10 mg/L, down to 3 to 5 mg/L, without affecting the compliance requirements. This also resulted in using less SO_2 in addition to the reduction in chlorine usage.

By adopting a strategy to increase the focus on controlling costs through process optimization, the treatment plant was able to reduce its chemical costs by more than 30%.

Table 3: Estimated Total Annualized Costs for Chlorination/Dechlorination

Flow (mgd)		Cl_2 Dose	Estimated Capital Costs ($)			Estimated Cost ($)	
ADWF	PWWF	(mg/L)	Chlorination	Dechlorination	UFC*	Capital	O&M
1	2.25	5	410,000	290,000	239,000	1,127,000	49,300
10	20	5	1,804,000	546,000	264,000	3,137,000	158,200
100	175	5	10,131,000	1,031,000	788,000	14,340,000	660,000
1	2.25	10	441,000	370,000	239,000	1,260,000	59,200
10	20	10	2,051,000	664,000	264,000	3,575,000	226,700
100	175	10	10,258,000	1,258,000	788,000	14,765,000	721,800
1	2.25	20	445,000	374,000	239,000	1,270,000	76,600
10	20	20	2,113,500	913,500	264,000	3,949,000	379,100
100	175	20	10,273,000	1,273,000	788,000	14,801,000	1,311,000

* UFC = Uniform Fire Code (Costs include provisions to meet Article 80 of the 1991 UFC.)
ADWF = average dry weather flow PWWF = peak wet weather flow

Adapted from: Darby et al. (1995) with permission from the Water Environment Research Foundation

Operation and Maintenance

Chlorine is relatively simple to apply and control. It is introduced into the wastewater by solution feeders or gas injectors. Chlorine gas is normally stored in steel containers (150-pound or 1-ton cylinders) and transported in railroad cars and tanker trucks. Sodium hypochlorite solution must be stored in rubber-lined steel or fiberglass storage tanks. Calcium hypochlorite is shipped in drums or tanker trucks and stored with great care.

Because chlorine is hazardous, safety precautions must be exercised during all phases of shipment, storage, handling, and use. Emergency response plans are needed for onsite storage of gaseous chlorine. Several large cities have switched to hypochlorite to avoid the transport of chlorine through populated areas.

A routine O&M schedule should be developed and followed for any chlorine disinfection system. Regular O&M involves disassembling and cleaning the various components, such as meters and floats, once every 6 months. Iron and manganese deposits can be removed with muriatic acid. Booster pumps have the same maintenance requirements as any other pump. Valves and springs should also be inspected and cleaned annually. All manufacturer's O&M recommendations should be followed, and equipment must be tested and calibrated as recommended by the equipment manufacturer.

Cost

The cost of chlorine disinfection systems is dependent on the manufacturer, the site, the capacity of the plant, and the characteristics of the wastewater to be disinfected.

Hypochlorite compounds are more expensive than chlorine gas. The total cost of chlorination will be increased by approximately 30 to 50% with the addition of dechlorination.

Listed in Table 3 are the results of a 1995 study conducted by the Water Environment Research Federation for secondary effluents from disinfection facilities at average dry weather flow rates of 1, 10, and 100 mgd (2.25, 20, and 175 mgd peak wet weather flow, respectively). The annual O&M costs for chlorine disinfection include power consumption, cleaning chemicals and supplies, miscellaneous equipment repairs, and personnel costs. The costs associated with the Uniform Fire Code requirements can be high for small facilities (as high as 25%).

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