



Wastewater Technology Fact Sheet Chlorine Disinfection

DESCRIPTION

The impact of untreated domestic wastewater on community reservoirs has raised several health and safety concerns. The organisms of concern in domestic wastewater include enteric bacteria, viruses, and protozoan cysts. Table 1 summarizes the most common microorganisms found in domestic wastewater and the types of human diseases associated with them. In response to these concerns, disinfection has become one of the primary mechanisms for the inactivation/destruction of pathogenic organisms. In order for disinfection to be effective wastewater must be adequately treated.

APPLICABILITY

Chlorine is the most widely used disinfectant for municipal wastewater because it destroys target organisms by oxidizing cellular material. Chlorine can be supplied in many forms, which include chlorine gas, hypochlorite solutions, and other chlorine compounds in solid or liquid form. Some alternative disinfectants include ozonation and ultraviolet (UV) disinfection. Choosing a suitable disinfectant for a treatment facility is dependent on the following criteria:

- Ability to penetrate and destroy infectious agents under normal operating conditions.
- Safe and easy handling, storage, and shipping.
- Absence of toxic residuals and mutagenic or carcinogenic compounds after disinfection.

**TABLE 1 INFECTIOUS AGENTS
POTENTIALLY PRESENT IN UNTREATED
DOMESTIC WASTEWATER**

| Organism | Disease Caused |
|--|--|
| Bacteria | |
| <i>Escherichia coli</i> | Gastroenteritis |
| <i>Leptospira (spp.)</i> | Leptospirosis |
| <i>Salmonella typhi</i> | Typhoid fever |
| <i>Salmonella</i> (=2100 serotypes) | Salmonellosis |
| <i>Shigella</i> (4 spp.) | Shigellosis (bacillary dysentery) |
| <i>Vibrio cholerae</i> | Cholera |
| Protozoa | |
| <i>Balantidium coli</i> | Balantidiasis |
| <i>Cryptosporidium parvum</i> | Cryptosporidiosis |
| <i>Entamoeba histolytica</i> | Amebiasis (amoebic dysentery) |
| <i>Giardia lamblia</i> | Giardiasis |
| Helminths | |
| <i>Ascaris lumbricoides</i> | Ascariasis |
| <i>T. solium</i> | Taeniasis |
| <i>Trichuris trichiura</i> | 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 |

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

- Affordable capital and operation and maintenance (O&M) costs.

ADVANTAGES AND DISADVANTAGES

Chlorine is a disinfectant that has certain health and safety limitations, but at the same time, has a long history of being an effective disinfectant. Before deciding whether chlorine meets the municipality's needs, it is necessary to understand the advantages and disadvantages of this product.

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 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 during disinfection.

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.

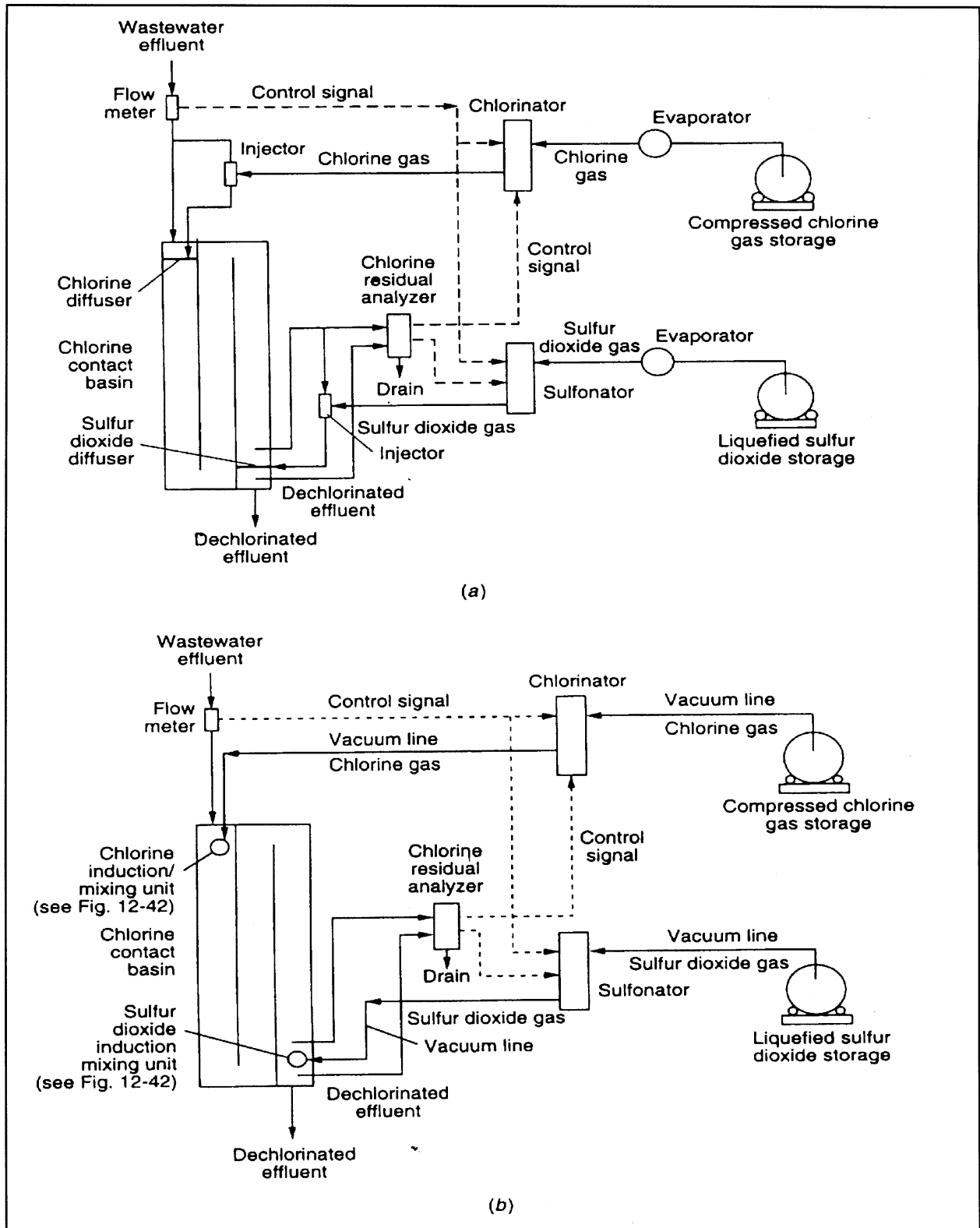
- Chlorine oxidizes certain types of organic matter in wastewater, creating more hazardous compounds (e.g., trihalomethanes [THMs]).
- The level of total dissolved solids is increased in the treated effluent.
- The chloride content of the wastewater is increased.
- Chlorine residual is unstable in the 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.
- Long-term effect of discharging dechlorinated compounds into the environment are unknown.

DESIGN CRITERIA

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

Chlorination

Figure 1 shows a flow chart 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 one second. The goal of proper mixing is to enhance disinfection by initiating a reaction between the free chlorine in the chlorine solution stream with the ammonia nitrogen. This prevents prolonged chlorine concentrations from existing and forming other chlorinated compounds.



Source: Crites and Tchobanoglous, used with permission from the McGraw-Hill Companies, 1998.

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

Another important process that contributes to optimal disinfection is contact. The contact chamber should be designed to have rounded corners to prevent dead flow areas and be baffled to minimize short-circuiting. This design allows for adequate contact time between the microorganisms and a minimal chlorine concentration for a specific period of time.

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 milligrams per liter (mg/L). Table 2 describes some of the more common wastewater characteristics and their impact on chlorine. There are several other factors that ensure optimum conditions for disinfection and they include temperature, alkalinity, and nitrogen-content. All key design parameters should be pilot tested prior to full-scale operation of a chlorine disinfection system.

Dechlorination

After disinfection, chlorine residual 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 effect on aquatic species. To minimize the effect, 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 residual 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 systems. Figure 1 shows a schematic of the chlorination/dechlorination system using sulfur dioxide.

TABLE 2 WASTEWATER CHARACTERISTICS AFFECTING CHLORINATION PERFORMANCE

| Wastewater Characteristic | Effects on Chlorine Disinfection |
|---------------------------------|---|
| Ammonia | Forms chloramines when combined with chlorine |
| Biochemical Oxygen Demand (BOD) | The degree of interference depends on their functional groups and chemical structures |
| Hardness, Iron, Nitrate | Minor effect, if any |
| Nitrite | Reduces effectiveness of chlorine and results in THMs |
| 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 |

Source: Darby et al., with permission from the Water Environment Research Foundation, 1995.

PERFORMANCE

Marsh Creek Wastewater Treatment Plant in Geneva, New York

The Marsh Creek Wastewater Treatment Plant in Geneva, New York, met stringent state permitting requirements 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 three-month study, the plant installed an ORP system to monitor and regulate 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 milliamperes 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 mandated parts 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 backup to the dechlorination operation. It performed very well and kept 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 (SO₂) 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 SO₂ concentration of 1.5 mg/L. It is also set to begin operation when the SO₂ leak detection system

automatically shuts off the SO₂ feed, or during wet weather operations when the SO₂ demand may exceed the SO₂ system's capacity.

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 to 3 to 5 mg/L, without affecting the compliance requirements. This also resulted in using less SO₂ 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%.

OPERATION AND MAINTENANCE

A routine O&M schedule should be developed and implemented for any chlorine disinfection system. Regular O&M includes the following activities:

- Disassembling and cleaning the various components of the system, such as meters and floats, once every six months.
- Iron and manganese deposits should be removed with, for example, muriatic acid.
- Booster pumps should be maintained.
- Valves and springs should be inspected and cleaned annually.
- All manufacturer's O&M recommendations should be followed.
- Equipment must be tested and calibrated as recommended by the equipment manufacturer.
- An emergency response plan for onsite storage of gaseous chlorine must be developed.

When using chlorine it is very important to properly and safely store all chemical disinfectants. The storage of chlorine is strongly dependent on the compound phase. For further details on the safe use

and storage of chlorine refer to chemical's Material Safety Data Sheets. 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.

COSTS

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, for example, tend to be more expensive than chlorine gas. On the other hand several large cities have switched to hypochlorite, despite the expense, in order to avoid transporting chlorine through populated areas. In addition to the costs incurred by the chlorination process, some municipalities will also have to consider the costs of introducing the dechlorination process. The total cost of chlorination will be increased by approximately 30 to 50% with the addition of dechlorination.

Table 3 summarizes 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%).

REFERENCES

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TABLE 3 ESTIMATED TOTAL ANNUALIZED COST FOR CHLORINATION/DECHLORINATION

| Flow (mgd) | | | Estimated Capital Costs (\$) | | | | Estimated O&M Costs |
|------------|--------|-----------------------------|------------------------------|----------------|---------|------------|---------------------|
| ADWF | PWWF | Cl ₂ Dose (mg/L) | Chlorination | Dechlorination | UFC* | Total | |
| 1 | 2.25 | 5 | 410,000 | 290,000 | 239,000 | 1,127,000 | 49,300 |
| 10 | 20.00 | 5 | 1,804,000 | 546,000 | 264,000 | 3,137,000 | 158,200 |
| 100 | 175.00 | 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 | 20.00 | 10 | 2,051,000 | 664,000 | 264,000 | 3,575,000 | 226,700 |
| 100 | 175.00 | 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 | 20.00 | 20 | 2,113,500 | 913,500 | 264,000 | 3,949,000 | 379,100 |
| 100 | 175.00 | 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

Source: Darby et al., with permission from the Water Environment Research Foundation, 1995.

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