T5-4 Chlorination

T5-4.1 General

Chlorine is used in various ways for odor control. See Chapter G2 for design requirements for odor control.

Dechlorination of chlorinated effluent should be provided when water quality requirements dictate the need. Capability to add dechlorination systems should be considered in all new treatment plants that will use chlorine for disinfection. The design of all disinfection facilities utilizing chlorine as the disinfectant agent should ensure that the dechlorination requirements are met.

Two problems are associated with chlorination as disinfection: effluent toxicity (chlorine residual) and safety. A dechlorination facility would address the toxicity issue and a containment and scrubbing facility would address the safety issue. The dechlorination and containment and scrubbing facilities increase the cost of chlorine-based disinfection.

T5-4.1.1 Forms of Chlorine

Dry chlorine is defined as elemental chlorine existing in the liquid or gaseous phase, containing less than 150 mg/L water. Unless otherwise stated, the word "chlorine" wherever used in this section refers to dry chlorine. Liquid chlorine in the form of sodium hypochlorite or other types is discussed in T5-5.

T5-4.1.2 Chlorine Feed Equipment

Chlorinators are used to convert the gaseous chlorine from a positive pressure to a vacuum and to regulate or meter the flow rate of the gas. The principal components of a conventional chlorinator are as follows:

- Inlet chlorine pressure-reducing valve.
- Indicating meter such as a rotameter.
- Chlorine metering orifice, changeable for various ranges of flow.
- Manual feed rate adjuster.
- Vacuum differential-regulating valve.

A few other variations also exist, such as sonic flow and remote vacuum chlorinators. Conventional vacuum-type chlorinators are most commonly utilized for dry chlorine. Liquid chlorine evaporators should be considered where manifolding multiple one-ton containers would otherwise be required to evaporate sufficient chlorine.

T5-4.1.3 Chlorine Supply

Cylinders should be considered where the average daily chlorine use is 150 pounds or less. Cylinders are available in 100- or 150-pound sizes.

One-ton containers of chlorine should be considered where the average daily chlorine consumption is more than 150 pounds.

Large-volume shipments of chlorine should be considered where the average daily chlorine consumption is more than two tons. Large volumes of chlorine can be secured by tank truck, rail car, or barge.

T5-4.1.4 Chlorine Gas Withdrawal Rates

The maximum withdrawal rate for 100 or 150-pound cylinders should be limited to 40 pounds per day per cylinder. The maximum withdrawal rate for one-ton containers should be limited to 400 pounds per day per cylinder.

T5-4.2 Design Considerations

Effective disinfection using chlorine depends upon properly sized chemical handling equipment, a reliable dosage control system, and adequate mixing and contact time with the effluent. In addition, many design considerations relate to safety; see T5-4.4.

T5-4.2.1 General

Chlorination system design should consider the following design factors:

- Contact time.
- Level of disinfection required.
- Volume of wastewater being treated.
- Concentration and type of residual.
- Mixing with the effluent.
- pH.
- Suspended solids.
- Industrial wastes.
- Temperature.
- Concentration of organisms.
- Type and age of organisms.
- Ammonia and nitrogen compounds concentration.

Design of facilities for effluent disinfection must consider the above factors such that reliable disinfection is achieved at all times.

Modifications to disinfection system designs and criteria may be considered by Ecology on a case-by-case basis. Some examples include the following:

- Applying chlorine in staged dosing, such as more than one injection point.
- Using more than one type of disinfection method, such as UV for base flows with chlorine for peaks.
- Using the effluent outfall pipe as a contact chamber.
- Batching disinfection, such as using the chlorine contact chamber as a mixed tank operated as fill-and-draw.
- Waiving redundant tankage if plant effluent flow can be stopped, such as by using lagoon systems.
- Using storage basins for intermittent or seasonal discharge of effluent.

T5-4.2.2 Capacity

Required chlorinator capacity will vary depending on the use and point of application of the chlorine. Chlorine dosage should be established for each individual situation, with those variables affecting the chlorine reaction taken into consideration. For normal wastewater at peak design flow rates, the dosing capacity listed in Table T5-2 may be used as a guide.

Table T5-2. Chlorine Dosing Capacity Guidelines

Type of Treatment	Dosage range, mg/L
Prechlorination for odor control	1.5 to 10
Primary effluent	5 to 10
Trickling filter effluent	3 to 10
Activated sludge effluent	2 to 8
Sand filter effluent	1 to 5

The design should provide adequate flexibility in the chlorination equipment and control system to allow controlled chlorination doses at both minimum and peak demands. The system should be easily expandable to increase capacity over the entire life of the treatment plant. Special consideration should be given to the operation to ensure the chlorination system is readily operable at minimum flows and low chlorine demand without overchlorination of the effluent. Several sizes of rotameters must be supplied if necessary to ensure proper dosage throughout the life of the plant. Other inplant uses of chlorine such as odor control, spray water disinfection, sludge bulking control, and scum disinfection should be added to the chlorine use and demand calculations if they are also served by the system.

T5-4.2.3 Reliability

For reliability it is necessary to have redundant chlorine feed equipment (such as a minimum of two chlorinators and two evaporators). Generally the chlorine demands should be divided into disinfection and nondisinfection uses, and separate equipment provided for each group. Appropriate piping and controls shall be provided so that the equipment used for nondisinfection purposes may also serve as backup for the disinfection equipment.

Five criteria must be met to ensure reliable chlorine supply at all times:

(1) Adequate reserve supply to meet demands and delays in delivery.

(2) Scales to accurately weigh chlorine inventory and monitor use rate.

(3) Manifolded system to handle high demands and to utilize backup equipment.

(4) Automatic switchover from empty containers to full ones.

(5) Alarms to alert operators of an imminent loss of supply.

Additional reliability criteria relating to other parts of the chlorine system include:

(1) Standby power to keep the evaporators, pumps, and controls functioning normally.

(2) Standby equipment available to be put into service promptly.

(3) Spare parts on hand for repairs.

(4) Water supply for injector(s).

(5) Backup residual analyzer.

(6) A means of operating the system manually if necessary.

T5-4.2.4 Mixing

All chlorination systems shall include a way to thoroughly mix the chlorine solution with the effluent water stream. Mixing will significantly influence coliform destruction and achieve viral and pathogen kills. Mixing will also help minimize chlorine use. The mixing may be accomplished in almost any type of hydraulic vessel (such as open channel, closed pipe, tank, or baffled chamber).

The mixing of chlorine (in water solution) and wastewater effluent can be accomplished by hydraulic or mechanical mixing. Hydraulic mixing should be done according to the following criteria:

A. Pipe Flow

- A Reynolds number of greater than or equal to 1.9×10^4 is required. Hydraulic jumps for baffles may be used to create turbulence.
- A diffuser with orifice velocities of 15 ft/sec (minimum) to 26 ft/sec at peak flows must be used.
- The diffuser must be set as deep as possible and at least two feet below minimum wastewater level at low flows.
- Turbulent flow after mixing must be prevented in order to avoid chlorine volatilization.

B. Open Channel Flow

A hydraulic jump with a minimum Froude number of 4.5 is necessary to provide adequate hydraulic mixing. The point of chlorine injection should be just upstream of the hydraulic jump because the location of the jump itself will change with variations in flow rate. A Parshall flume is not a satisfactory location for hydraulic chlorine mixing.

C. Mechanical Mixing

Mechanical mixing should be done according to the following criteria:

- A mixer-reactor tank is necessary that provides 0.1 to 0.3 minutes contact time.
- Inject chlorine just upstream from the mixer with a diffuser.
- Mixer speed should be a minimum speed of 50 revolutions per minute (rpm).
- The diffuser should be set at least 2 feet below the minimum water flow level at low flow rate.
- Turbulent flow after complete chlorine mixing must be prevented in order to avoid chlorine stripping.

D. Mixing Reactor

The mixing reactor shall be a completely mixed tank(s) with hydraulic retention and mixing energy values as shown in Table T5-3.

Table T5-3. Mixing Energy Values

Retention Time, sec.	Mixing Energy, G (Mechanical)
1	3,000
2	2,500
3	2,000
4	1,500

Design features should be provided as follows:

- All of the effluent flow shall pass through the mixing reactor.
- The mixing energy may vary as flow rate (hydraulic retention time) varies in accordance with Table T5-3. The maximum time in the mixing reactor should be 4 seconds at average annual flow rate.
- A combination of mixing devices may be employed.
- The mixing reactor tank shall contain inlet and outlet baffles to prevent short-circuiting and high axial velocities.
- Tank geometry shall be as near to 1:1:1 (L:W:D) as possible.
- If a closed pipe is used as a mixing reactor, a sampling point (manhole) shall be provided prior to the flow entering the chamber.
- Multiple mixing reactor tanks in parallel may be used if necessary to minimize hydraulic head losses, accommodate specific mechanical mixing equipment, or to allow for shutdown/maintenance of a unit.
- Chlorine solution shall be introduced with a diffuser or by means of a flash mixer.

T5-4.2.5 Contact Period

Contact chambers shall be sized to provide a minimum of 1-hour detention at average daily design flow or 20 minutes detention at peak daily design flow, whichever is greater. Contact chambers should be designed so detention times are less than 2 hours for initial flows.

The size of the contact chamber may be determined by any of the following four methods:

(1) If breakpoint chlorination will be practiced, the contact chamber shall be sized to provide a minimum of 15 minutes of detention time at peak design flow and at least 60 minutes at average design flow, whichever is more stringent.

(2) If breakpoint chlorination is not practiced, the contact chamber shall be sized to provide a minimum combined contact time and chlorine dose.

(3) The contact chamber shall be designed to minimize short-circuiting and to maximize plug flow characteristics.

(4) Other design approaches to be considered on a case-by-case basis include:

- Field testing of existing or similar contact chambers to demonstrate the hydraulic characteristics. This may include tracer studies.
- Computer modeling using appropriate analytical methods and supported by calibration data.

T5-4.2.6 Contact Chambers

Contact chambers should be designed to minimize short-circuiting and back mixing of the chlorinated water to such an extent that plug flow is approached. It is recommended that baffles be constructed parallel to the longitudinal axis of the chamber with a minimum length-to-width ratio of 40:1. For a serpentine baffled tank, the total length of the channel created by the baffles should be at least 40 times the distance between the baffles. Side water depths should be between 6 and 15 feet. Shallow channels should not be used. Velocities at minimum flow should be at least 0.2 fps. Alternate baffle arrangements will be considered, based on tracer tests indicating a modal value greater than 0.6. The modal time occurs at the highest point of the tracer residence time distribution curve. The modal value is the number derived when the modal time is divided by the theoretical time.

Provision shall be made for removal of floating and settleable solids from chlorine contact tanks or basins without discharging inadequately disinfected effluent. To accomplish continuous disinfection, the chlorine contact tank should be designed with duplicate compartments to permit draining and cleaning of individual compartments. A sump or drain within each compartment, going to a plant inlet, should be provided for dewatering, sludge removal, and maintenance. Flushing hydrants should be located nearby for washdown use. Tank drains shall not discharge into the effluent disposal pipeline. A scum skimmer should be provided to prevent the discharge of floating material.

Unless otherwise approved by Ecology, all wastewater disinfection shall be accomplished with two reactor/contactor tanks in series. The first tank shall be designed to introduce the chlorine into the effluent stream, mix it thoroughly, and accomplish the initial chlorine demand reactions. The second tank shall be a plug-flow-type contact chamber in which the disinfectant accomplishes germicidal action. The designs for these tanks must be conservative enough to ensure that adequate disinfection is achieved during most normal fluctuations in the plant processes without relying on operator intervention or exceptionally high chlorine doses. Seasonal process variations or other short-term extreme conditions (e.g., peak wet weather flow, plant upsets, or industrial wastes) must be manageable by simple operator adjustments to the system.

A readily accessible sampling point shall be provided at the outlet end of the contact chamber. If automated feed dosage controls are used, chlorine residual monitoring points shall be provided at other appropriate locations in the tank.

In some instances, the effluent line may be included as part of the chlorine contact tankage provided that the conditions set forth above are met. The effluent pipe may be used to provide contact time during extraordinarily high peak flows. In addition, pipe design and construction must preclude infiltration and exfiltration and must be a full-pipe flow under all conditions.

T5-4.2.7 Dechlorination

The design of dechlorination facilities should be coordinated with the chlorination facilities so that thorough effluent disinfection is accomplished prior to adding sulfur dioxide, a dechlorinating agent. See T5-6 for requirements for dechlorination.

T5-4.2.8 Sampling, Instrumentation, and Control

- An automated dosage control system shall be used for all treatment facilities. The controls should adjust the chlorine dosage rate within an appropriate lag time to accommodate fluctuations in effluent chlorine demand and residual due to changes in flow and water characteristics. This may be accomplished using either closed-loop or feedback control methods. These facilities should also utilize continuous chlorine residual monitoring.
- All sample lines should be designed so that they can be easily purged of sediments, attached growths, and other debris.
- Alarms and monitoring equipment are required to promptly alert the operator in the event of any malfunction, hazardous situation, or inadequately disinfected effluent relating to the chlorine supply, metering equipment, leaks, or other problems.
- Design of instrumentation and control equipment should allow operation at initial and design flows.
- Technology-based maximum chlorine levels should not be exceeded if more stringent water-quality-based standards are not applicable.
- Technology-based standards for total residual chlorine in the effluent are 0.5 mg/l average monthly value and 0.75 mg/l weekly average value.
- Monitoring equipment should be capable of measuring total residual chlorine within the necessary range required by permit limits.

T5-4.2.9 Residual Chlorine Testing

Equipment should be provided for automatically measuring chlorine residual. The ability to easily take grab samples is required. Where the effluent discharge occurs in environmentally sensitive areas, the installation of facilities for continuous automatic chlorine residual analysis and recording devices shall be required. Where dechlorination is used, additional testing requirements may apply as defined in T5-6.