Section 4 – Disinfection of Drinking Water

4. Disinfection of Drinking Water

The goal of water disinfection is the inactivation of microorganisms, such as viruses, bacteria and protozoa, which can cause serious illnesses and death. Although disinfection can be accomplished to a significant extent by a number of physiochemical water treatment processes, such as coagulation, sedimentation, filtration, lime-soda softening and adsorption, a specific chemical disinfection step is usually incorporated into surface water treatment process trains to prevent the transmission of waterborne diseases.

> ***Continuous disinfection is mandatory for all public water supplies***

4.1. Forms of Disinfection

Chlorine is the most commonly used chemical for disinfection. The forms most often used are chlorine gas and calcium or sodium hypochlorite. Alternative disinfectants include ozone, chlorine dioxide, chloramines, ultraviolet light, iodine, gamma irradiation, and others. The chemical or technology should be selected after due consideration of water flow rates, application and demand rates, pH of the water, cost of equipment, chemical availability, and maintenance problems.

4.2. Chlorination

4.2.1. Contact Time and Point of Application

1. Due consideration shall be given to the contact time of the disinfectant in water in relation to pH, ammonia, taste-producing substances, temperature, bacterial quality, DBP formation potential and other pertinent factors.

2. Chlorine application should be at a point, which will provide a contact time of at least 20 minutes at peak hourly flow (using the Harmon Formula or peaking table) with required free chlorine residual. All basins used for disinfection must be designed to minimize short-circuiting. Additional baffling can be added to new or existing basins to minimize short-circuiting and increase contact time.

3. The point of application shall be located in order to minimize the formation of DBPs without compromising the integrity of contact time.

4. Adding ammonia to the water shall be done only with the approval of the DOEC.

5. At plants treating surface water, provisions shall be made for applying the disinfectant to the raw water, filtered water and, water entering the distribution system. However, these practices should be optimized on a case-by-case basis in order to minimize DPB formation.

6. As a minimum, at plants treating groundwater, provisions shall be made for applying the disinfectant to the detention basin inlet and water entering the distribution system.

7. If primary disinfection is accomplished using ozone, chlorine dioxide, or some other chemical or process that does not provide a measurable residual disinfectant, then chlorine must be added as a secondary disinfectant to provide a residual disinfectant as mentioned in Section 4.2.3.

4.2.2. CT Factor and Log Inactivation

4.2.2.1. CT Factor

CT factor is one of the most important features for determining or predicting germicidal efficiency of any disinfectant. It is the best method to ensure that the water provided to customers is safe. Chemical disinfection does not remove microorganisms from water but inactivates them so they can no longer infect consumers. The CT factor is defined as the product of the residual disinfectant concentration, C in mg/L, and the contact time T, in minutes, that residual disinfectant is in contact with the water. CT tables have been developed that relate CT values to levels of inactivation under various operating conditions. Different tables exist for different disinfectants. As the CT value is increased, a greater percentage of microorganisms are inactivated by chemical disinfection. The CT, and therefore the level of inactivation, can be increased by, applying greater doses of the disinfectant or by increasing the time that the water is in contact with the disinfectant.

Various factors can affect CT values, such as pH, temperature, strength of disinfectants and types of organisms:
1. As pH increases, the CT value also needs to be increased. This can be explained by examining the effects of pH on free chlorine. As the pH increases, more of the weak disinfectant (OCl-) exists than the strong disinfectant (HOCl-), thus increasing the CT value;

2. With temperature, in general for all disinfectants, as temperature increases, effectiveness increases;

3. The strength of a disinfectant directly affects the CT. For a weak disinfectant, the CT will have to be higher than for a strong disinfectant; and

4. Different organisms have different resistances to disinfectants. If an organism has a strong resistance to a certain disinfectant, the CT will need to be higher than for an organism with a weaker resistance.

The first step in using CT Disinfection is to determine the required CT to demonstrate that enough disinfection is occurring. To determine CT, you need to know:

1. The minimum temperature of the water during disinfection. The minimum temperature of the water in the chlorine contact chamber must be monitored. Minimum temperature is used because chlorine's ability to disinfect becomes less with lower temperatures. By using the lowest temperature of the water when determining CT, we know that the disinfection that occurred was at least as good as the lowest temperature allowed.

2. The maximum pH of the water during disinfection. The maximum pH of the water in the chlorine chamber must be monitored. Chlorine's ability to disinfect becomes less as pH increases. By using the maximum pH when determining CT, we know that the disinfection that occurred was at least as good as the disinfection that occurs at the maximum pH.

3. The minimum chlorine residual in the water during disinfection. The minimum chlorine residual in the water must be monitored at the end of the disinfection chamber. We know that higher chlorine dosages disinfects better. The lowest chlorine residual is used because the water in the chlorine contact chamber has been exposed to at least that concentration of chlorine.

4. The Log reduction by disinfection must be known. The required Log reduction by disinfection is based on the raw water quality with allowances for the treatment at the water treatment plant.

With this information we use the CT tables to determine the CT required.

CT tables are used as follows:

1. Make sure you are using the correct table. The tables are specific to the target organism and the type of disinfectant. Most likely, you will use the *Giardia* inactivation table for free chlorine. Free chlorine is the most common disinfectant used. Free chlorine is more than ten times better at inactivating *Giardia* than chloramines.

2. The tables are temperature specific. You must use the table that corresponds to your measured minimum temperature.

3. The tables are divided into pH sections. Locate the section of the table that corresponds to your measured maximum pH.

4. Within the appropriate pH range, locate the disinfection Log inactivation for *Giardia*.

5. Read the CT value from the table where the chlorine residual row meets the required Log inactivation column.

6. CT is read directly from the table.

The CT tables are temperature specific for water temperatures at 5°C increments. If your temperature falls between two temperatures for which tables exist, for example 8°C, then you need to determine the CT by one of the following methods:

1. Determine the CT at both 5°C and 10°C from the corresponding tables and estimate the CT value for 8°C using the CT values for 5°C and 10°C; or

2. Use the CT table that exists for the next lower temperature. To determine CT for 8°C, use the CT value for 5°C. This will produce a value that is conservative (i.e. higher) and adds an extra measure of safety.

To determine the CT value for a pH that does not correspond to one of the given pH sections, the CT value can be estimated using the pH sections higher and lower than your measured pH or by using the CT value at the next higher pH section.

Tables 4.1, 4.2, 4.3 and 4.4, presented below, represent a few selected CT Tables for *Giardia* and viruses using free chlorine or chloramine.

Table 4.1
CT Values for 3.0 log (99.9%) Inactivation of *Giardia* Cysts by Free Chlorine
(Water Temperature of 15°C)

Free Chlorine Residual (mg/L)	pH						
	≤ 6.0	≤ 6.5	≤ 7.0	≤ 7.5	≤ 8.0	≤ 8.5	≤ 9.0
0.4	49	59	70	83	99	118	140
0.6	50	60	72	86	102	122	146
0.8	52	61	73	88	105	126	151
1.0	53	63	75	90	108	130	156
1.2	54	64	76	92	111	134	160
1.4	55	65	78	94	114	137	165
1.6	58	66	79	96	116	141	169
1.8	57	68	81	98	119	144	173
2.0	58	69	83	100	122	147	177
2.2	59	70	85	102	124	150	181
2.4	60	72	86	105	127	153	184
2.6	61	73	88	107	129	156	188
2.8	62	74	89	109	132	159	191
3.0	63	76	91	111	134	162	195

Table 4.2
CT Values for Inactivation of Viruses by Free Chlorine

| Temperature | Log Inactivation | | | | | |
| | 2.0 Log | | 3.0 Log | | 4.0 Log | |
°C	pH 6 - 9	pH 10	pH 6 - 9	pH 10	pH 6 - 9	pH 10
0.5	6	45	9	66	12	90
5	4	30	6	44	8	60
10	3	22	4	33	6	45
15	2	15	3	22	4	30
20	1	11	2	16	3	22
25	1	7	1	11	2	15

Table 4.3
CT Values for Inactivation of *Giardia* Cysts by Chloramine
Within the pH Range 6 to 9

| Inactivation | Temperature (°C) | | | | | |
	≤1	5	10	15	20	25
0.5-log	635	365	310	250	185	125
1.0-log	1270	735	615	500	370	250
1.5-log	1900	1100	930	750	550	375
2.0-log	2535	1470	1230	1000	735	500
2.5-log	3170	1830	1540	1250	915	625
3.0-log	3800	2200	1850	1500	1100	750

Table 4.4
CT Values for Inactivation of Viruses by Chloramine

| Inactivation | Temperature (°C) | | | | | |
	≤1	5	10	15	20	25
2.0-log	1243	857	643	428	321	214
3.0-log	2063	1423	1067	712	534	356
4.0-log	2883	1988	1491	994	746	497

4.2.2.2. Log Inactivation or Removal

The level of inactivation is generally referred to in terms of log inactivation since inactivation is measured on a logarithmic scale (i.e. orders of magnitude reduction). Log inactivation is a measure of the percent of microorganisms that are inactivated during the disinfection process and is defined as:

$$Log\ Inactivation\ =\ Log\left(N_O/N_T\right)$$

where: N_O = initial (influent) concentration of viable microorganisms;
N_T = concentration of surviving microorganisms; and
Log = Logarithm to base 10.

Log inactivation is related to the percent inactivation, defined as:

$$Percent\ Inactivation = \left(1 - NT/NO\right) \times 100$$

Therefore, the relationship between log inactivation and percent inactivation is as follows:

$$Percent\ Inactivation = \left(1 - \frac{1}{10^{\ Log\ Inactivation}}\right) \times 100$$

or

$$Log\ Inactivation = Log\left(\frac{100}{100 - Percent\ Inactivation}\right)$$

Log Inactivation and Percent Inactivation are presented in Table 4.5.

Table 4.5
Log Inactivation and Percent Inactivation

Log Inactivation	Percent Inactivation
0.0	0.00
0.5	68.38
1.0	90.00
2.0	99.00
3.0	99.90
4.0	99.99
5.0	99.999
6.0	99.9999
7.0	99.99999

4.2.3. Residual Chlorine and Testing

1. All water entering a water distribution system, after a minimum 20 minutes contact time at peak hourly flow, shall contain a residual disinfectant concentration of free chlorine of at least 0.3 mg/L, or equivalent CT value. A detectable free chlorine residual must be maintained in all areas of the distribution system.

2. Higher residuals may be required depending on pH, temperature and other characteristics of the water.

3. Chlorine testing should include both free and total chlorine.

4. All systems, as a minimum, should use the DPD method that utilizes the digital readout with a self-contained light source. In this regard, the equipment shall enable measurement of chlorine residuals to the nearest 0.02 mg/L in the range of 0.02 to 8.0 mg/L, and shall be the filter photometer type with digital display readout, or equivalent accuracy, and shall be compatible with the equipment used by the DOEC and the Department of Government Services

4.2.4. Chlorine Gas - Facility Design

New facilities should be designed so that there are no pits, vaults or basements where chlorine equipment or piping would have to be installed in order to add chlorine to the water system.

4.2.4.1. Capacity

1. Chlorination equipment shall be sized to provide the specified free chlorine residual after 20 minutes of contact time at the maximum design flow rate. **It shall be designed to maintain proper chlorine residual under variable chlorine demand conditions, including peak flow.**

2. Each installation should have the capability to manifold several cylinders together to satisfy the peak demand and to avoid frequent replacement. No more than 2 tonne containers should ever be manifolded together.

4.2.4.2. Standby Equipment

1. Where chlorination is required for protection of the supply, standby equipment of sufficient capacity should be available to replace the largest unit.

2. Spare parts and tools shall be made available to replace parts subject to wear and breakage. Examples of spare parts are rubber fittings, hose clamps, gaskets and glassware.

3. If there is a large difference in feed rates between routine and emergency dosages, a gas metering tube should be provided for each dose range to ensure accurate control of the chlorine feed.

4.2.4.3. Automatic Switchover

Automatic switchover capability from an empty cylinder (or tonne container) to a full one should be provided in all installations.

4.2.4.4. Automatic Proportioning and Residual Analyzer

Where flow varies, an automatic flow proportional system should be installed. If chlorine demand varies then a residual analyzer with recorder should be installed. If both the flow and the chlorine demand vary, then a compound loop system should be installed.

4.2.4.5. Chlorination Room

1. All chlorination equipment should be installed in an above ground room that is separate from the general treatment plant so that the operator entering the facility or treatment plant would not be exposed to chlorine gas resulting from a gas leak.

2. Chlorine gas under pressure shall not be permitted outside the chlorine room. Chlorination systems under vacuum shall also be confined to the chlorine room with the exception of the chlorinator, which may or may not be located in the chlorine room. If the chlorinator is to be located outside the chlorine room it shall be located on the common wall, located as close as possible to the cylinders to minimize the length of the vacuum lines. The vacuum lines shall gently slope back towards the cylinders to facilitate the return of any condensate to the cylinders.

3. The chlorination equipment room should be designed with safety in mind and should generally incorporate the following features:

    The room shall be constructed in such a manner that all openings between the room and the remainder of the facility are sealed; and

    A reinforced glazed window should be installed in an exterior door or interior wall of the chlorination room to allow for visual inspection without having to enter the room. This window should not be able to be opened and must be airtight.

4. An outside door shall be provided to the room for easy escape in the case of gas leakage. Doors should be airtight, open outwards and be equipped with panic hardware. The door shall have mounted on its exterior, a sign "DANGER CHLORINE" warning of the presence of chlorine and a reminder to turn on the fan before entering.

5. Interior access to a non-chlorine area shall only be through a pressure-ventilated vestibule.

6. The distance from any point in the room to the exit door should not exceed 4.5 m.

7. The chlorinator should be placed at least 1 m from the outside wall.

4.2.4.6. Separate Storage Room

Where possible chlorine cylinders and containers should be stored in a room separate from the chlorination equipment room and the remainder of the facility and shall not be stored with combustible materials. The cylinder storage room shall be designed similar to the chlorine room.

The chlorine and/or cylinder storage rooms should be designed to facilitate the following:

1. Easy transfer of cylinders to and from the chlorination equipment room;

2. Easy handling of cylinders within the storage room in accordance with manufacturer's recommendations;

3. Empty and full cylinders should be stored separately in an upright position held by chains, straps, etc;

4. Cylinders (or tonne containers) should not be stored near flammable materials, heating or ventilation units, elevator shafts, or on uneven or subsurface floors;

5. Full chlorine cylinders should never be stored outside;

6. Tonne containers should be shielded from direct sunlight or from overheating above 60EC (140EF) from any source either while in storage or in use;

7. The number of openings in this room should be kept to a minimum to better control heating and ventilation.

4.2.4.7. Floor Drains

Floor drains <u>should not</u> be installed in either the chlorine equipment room or the cylinder storage room. If floor drains must be provided they are to discharge to a separate sump outside the building and shall not be connected to other internal or external drainage systems.

4.2.4.8. Construction Materials

1. The material of construction of these rooms should be non-corrodible and fireproof such as concrete, bricks, etc. to minimize the damage in case of chlorine gas leak. If walls are to be painted, they should be painted with paint which chlorine cannot attack, *i.e. epoxy*.

4.2.4.9. Weigh Scales

A platform scale of proper size shall be provided for weighing cylinders. For tonne cylinders indicating and recording type are recommended. Scales should be of corrosion resistant material and accessible, either by recessing or providing a ramp for convenience of moving the cylinder on and off the scale platform.

4.2.4.10. Lighting

Both the chlorination equipment room and the cylinder storage room should be installed with proper lighting fixtures to make the inside of these rooms visible from the observation windows. About 60 foot candles lighting intensity at the chlorinator and around the cylinders should be sufficient. Lights should be explosion proof.

4.2.4.11. Emergency Ventilation

Both the chlorination equipment room, the cylinder storage room and below ground pits, vaults, basements, etc. shall be provided with air evacuation fans or a similar mechanical exhaust system, which could be turned on, manually from a safe location (outside entry door) in case of an emergency.

Air inlets shall be located so as to provide cross ventilation with air, and such that temperatures will not adversely affect the chlorination equipment. The exhaust should be routed at least one-third the height of the building above the roof or if it is to be located on an exterior wall, it must not be located in the area of the exit door or fresh air inlet. The fresh air inlet should be located at the opposite end of the room from the exhaust outlet to facilitate complete air replacement.

Emergency mechanical ventilation should be of sufficient capacity to produce one complete air change per minute. The air intake duct shall extend to within 150 mm of the floor and shall be located closest to the most likely source of leakage.

For emergency gas leaks, the gas shall be exhausted to the outside, unless conditions dictate otherwise. The location of the exhaust vent should be determined carefully so that it does not pose a health hazard to people, or damage the environment outside the building.

Vents from feeders (e.g. gas regulators) shall discharge to the outside atmosphere, above grade and to a safe location where personnel will not be endangered from the escaping gas. Vents shall not under any circumstance be located in the vicinity of an exit door or the fresh air inlet.

4.2.4.12. Warning Devices

1. The chlorination equipment room, the cylinder storage room, and below ground pits, vaults, and basements must be equipped with an automatic gas detection and related alarm equipment. The detection system should activate an emergency light and sound an alarm system that is visible and audible within the facility.

2. The alarm should have a distinct sound to be easily noticeable within the facility.

3. The exterior alarm light is to be located in an area where it can be easily seen on approach to the building.

4. A strong solution of aqueous ammonia (18 Baume or higher) should be available for use in locating the source of chlorine leaks. Dense, white clouds of ammonium chloride are formed by the reaction of the ammonia and chlorine, thus confirming the source of the chlorine leak.

5. In facilities using 1 tonne cylinders, consideration should also be given to the provision of caustic soda solution reaction tanks for absorbing the contents of leaking cylinders.

4.2.4.13. Temperature Control

The chlorination equipment, the cylinder storage room and below ground pits, vaults, and basements shall be equipped with necessary heating and ventilation equipment to maintain the temperature within the recommended range. The rate at which the gas is withdrawn from the cylinders is temperature dependent and the withdrawal rate decreases at lower temperatures. Maintenance of temperature within a narrow range, 18 to 21°C, would ensure a constant rate of gas withdrawal from the cylinders.

4.2.4.14. Cross-connection Protection

The chlorinator water supply piping shall be designed to prevent contamination of the treated water supply by sources of questionable quality. At all facilities treating surface water, pre- and post-chlorination systems must be independent to prevent possible siphoning of partially treated water into the clear well or distribution system. The water supply to each injector shall have a separate shut-off valve. No master shut-off valve will be allowed.

4.2.4.15. Chlorine Piping

1. The piping conveying chlorine gas to the chlorinator should slope gently upwards to the chlorinator to facilitate the return of any condensate to the cylinders. This precaution is especially useful for pressurized lines.

2. The chlorine gas piping between the cylinders, chlorinators and injectors, etc., should not be located on an outside wall or in a location where low temperatures may be encountered.

3. All piping should be colour coded to clearly identify their functions (see Section 3.1.13.).

4. Piping systems should be as simple as possible, manufactured to be suitable for chlorine service and with a minimum number of joints.

5. The pipes carrying elemental liquid or dry gaseous chlorine under pressure must be Schedule 80 seamless steel tubing or other materials recommended by the Chlorine Institute (never use PVC). A minimum size of at least 19 mm diameter is recommended. Due to the corrosiveness of wet chlorine all lines designed to handle dry chlorine should be protected from the entrance of water or moist air. PVC tubing should not be employed for conveying chlorine from cylinders to the chlorinator unless the tubing is under negative pressure.

6. Nylon products are not acceptable for any part of the chlorine solution piping system.

4.2.4.16. Injector

1. Each injector must be selected for the point of application with particular attention given to the quantity of chlorine to be added, the maximum injection water flow, the total discharge back pressure, the injector operating pressure, and the size of chlorine solution line. Gauges for measuring water pressure and vacuum at the inlet and outlet of each injector should be provided.

2. The chlorine solution injector/diffuser must be compatible with the point of application to provide a rapid and thorough mix with all the water being treated. The centre of a pipeline is the preferred application point.

3. It is recommended that a strainer be installed on the waterline to the injector. This prevents any possible grit or foreign material from entering and blocking the injector, or causing undue wear on the injector throat and tailway.

4. If a booster pump is used in the system, the strainer should precede the pump. Also, two booster pumps shall be provided to ensure continuous operation of the chlorination system.

4.2.4.17. Methods of Dosage Control

4.2.4.17.1. *Open Loop Flow Proportional Control*

Automatic proportioned-to-flow control consists of varying the rate of chlorine feed in proportion to the flow as determined be a metering device. The dosage rate is manually set, and the control device varies the rate in relation to flowrate. The chlorinator may be either automatic or manual start and stop.

Usually over-chlorination is practised to ensure results. Invariably, such a device wastes some chlorine.

4.2.4.17.2. *Closed-Loop Flow Proportional Control (Compound-Loop Arrangement with One Chlorine Analyzer)*

Chlorine residual analyzer provides feedback to the chlorinator. Flow signal and dosage signal each separately control the added chlorine feed with a compound-loop arrangement. If the residual is above the pre-determined level, the chlorine feed rate is reduced, and vice versa. In some designs, chlorine residual is measured at one point in the system and in other designs at 2 or 3 points.

4.2.4.17.3. *Closed-Loop Flow Proportional Control (Compound-Loop Arrangement with Two Chlorine Analyzers)*

This ideal system employs quantitative as well as qualitative feed control as in the previous case. However, the qualitative control is accomplished at two points in the flow stream. One sample is automatically collected immediately downstream from the point of chlorination (diffuser) and analyzed by another chlorine analyzer, which monitors the combined residual after a given contact time and adjusts the control point on the analyzer, which controls the chlorine metering

equipment. When the residual chlorine is more than the desired (pre-set) level, the chlorine feed rate is reduced and vice versa.

4.2.4.17.4. *Required Chlorine Control Systems*

Plants with proper qualitative and quantitative control systems are known to chlorinate effectively and efficiently. However, the plants without such controls show either inadequate performance (due to under dosage) or waste chlorine unnecessarily (by undue overdose). Higher than needed chlorine residuals may result in ecological damage to the receiving waters.

Table 4.6 summarizes chlorine control guidelines.

Table 4.6
Chlorine Control Guidelines

Size of Plant	Type of Receiving Water	Recommended Control	Method of Chlorine Residual Determination
Large	All Types	Closed-loop, Flow Proportional, Two Chlorine Analyzers	Amperometric Titrator; Continuous Determination and Recording
Medium	Ecologically Sensitive Waters with Fishing Potential	Same as Large Plants	Same as Large Plants
	Waters of Public Health Importance	Closed-loop, Flow Proportional, One Chlorine Analyzer	Amperometric Titrator; Continuous Determination (Optional Recording)
Small	Ecologically Sensitive Receiving Water	Closed-loop, Flow Proportional, One Chlorine Analyzer	Amperometric Titrator; Continuous Determination
	Receiving Water of Public Health Importance	Open-loop, Flow Proportional	Starch-iodide Method Orthotolidine Method (Intermittent – Manual)

4.2.4.18. Gas Protection and Safety Equipment

1. Each facility should have, readily available, a self-contained or air supplied breathing apparatus which works on pressure demand or constant flow principle. The equipment shall be stored in a convenient location, but not inside any room where chlorine is used or stored. The unit shall use compressed air, have at least 30-min capacity, and be compatible with the units used by the fire department responsible for the facility. The air cylinder shall be purged and refilled on a regular basis in order to ensure its safe operation. Operator(s) shall be trained in the use of the breathing apparatus.

2. Safety chains should be used to retain all cylinders, either in storage or on weigh scales, in a safe, upright position, except when the cylinders are stored horizontally in cradles specially built for their storage in accordance with the manufacturer's recommendations.

3. 1-tonne cylinders must be moved by an approved lifting bar and hoist, and not by rolling them along the floor.

4.2.4.19. Eye Wash Stations and Showers

1. For facilities using cylinders, eye wash stations should be located within 4.5 m outside of the chlorine equipment room and/or chlorine storage room exit doors. An eye wash station capable of providing a continuous 15-minute flush as a minimum, using potable water or equivalent, shall be installed in a convenient location(s) within the facility.

2. For facilities using 1-tonne cylinders, then showers shall be located within 4.5 m of both the chlorine equipment room or chlorine storage room exit doors.

3. A water holding tank that will allow water to come to room temperature should be installed in the water line feeding the shower and eye washing device. Other methods of water tempering will be considered on an individual basis.

4.2.4.20. Other Protection

1. Clothing, including gloves, goggles, safety shoes, etc. should be available for personnel handling chlorination equipment.

2. Other safety equipment should include a first aid kit and a fire extinguisher.

3. Container repair emergency kits, such as Chlorine Institute Emergency Kit A for 68 kg cylinders and Kit B for tonne containers, should be available at all chlorination facilities. A contingency plan to deal with major leaks should also be in place.

All the above equipment should be located at readily accessible points, away from the areas likely to be contaminated with chlorine gas. Instructions for using, testing and replacing parts should be posted near the equipment.

A summary of emergency procedures shall be posted outside the chlorine room or chlorine storage room.

4.2.4.21. Operation

For effective operation, chlorination equipment requires care and attention. Manufacturer's recommendations and instructions should be made available and should be followed.

4.2.4.22. Fencing

The chlorination facility shall be located in a fenced enclosure to minimize vandalism and endangerment to the general public in case of a chlorine leak.

4.2.4.23. System Design and Installation

Chlorination systems should only be designed by registered professional engineers, and plans for the systems must be submitted to the DOEC for approval.

4.2.4.24. Deviation from these Guidelines

For design of facilities where the consultant considers these guidelines not to be applicable, the DOEC should be contacted directly.

4.2.5. Hypochlorination - Facility Design

4.2.5.1. Capacity

Chlorination equipment shall be sized to provide the specified free chlorine residual after 20 minutes of contact time at the maximum design flow rate. **It shall be designed to maintain proper chlorine residual under variable chlorine demand conditions, including peak flow.**

4.2.5.2. Standby Equipment

Where chlorination is required for protection of the supply, standby equipment of sufficient capacity should be available to replace the largest unit.

Spare parts and tools shall be made available to replace parts subject to wear and breakage. Examples of spare parts are rubber fittings, hose clamps, gaskets and glassware.

4.2.5.3. Application of Chlorine

Depending on the water system, the chlorination installation should have a chlorine residual analyzer with recorder to accurately record the chlorine residual continually. The recorder should be accurate, reliable and approved by the DOEC.

Chlorination equipment should be designed as to be able to feed the desired level of chlorine into the supply line on a flow proportional basis.

4.2.5.4. Automatic Proportioning

Where flow varies, an automatic flow proportional system should be installed. If chlorine demand varies then a residual analyzer with recorder should be installed. If both the flow and the chlorine demand vary, then a compound loop system should be installed.

4.2.5.5. Certification and Storage Requirements

All sodium and calcium hypochlorite must be NSF 60 (National Sanitation Foundation) certified to ensure it is suitable for use in potable water. The NSF 60 Water Treatment Program is responsible for the certification of drinking water treatment chemicals to ensure that these products do not contribute contaminants to drinking water that could cause adverse health effects.

The sodium hypochlorite shall be stored in a dark cool area to minimize loss of strength of the solution. The rate of strength loss for sodium hypochlorite doubles with every 5EC rise in temperature. In this regard a storage cabinet should be provided and shall be located away from any direct heat and light sources. Because of its shelf life consideration must be given when purchasing sodium hypochlorite, as too large quantities will be wasting money and possibly cause some impact on the adequacy of the chlorination.

Calcium hypochlorite (also known as HTH) should always be stored indoors and kept dry and covered. When it gets wet, chlorine gas can be released, and corrosive products formed. In this regard, there should not be any automatic sprinklers where it is stored. Calcium hypochlorite will not burn, but if heated above 175EC will release oxygen that will support a fire, therefore it should never be stored around combustible materials. It must also be kept away from direct contact with oil, grease or gasoline vapours. Direct contact can cause a fire.

4.2.5.6. Floor Drains

All drains shall be equipped with screens to prevent the entry of insects, birds and rodents.

4.2.5.7. Hose Bibbs and Cross-Connection Control

Most hypochlorination facilities will require a water line to supply water to the solution tank. Common practice is to use a hose bibb connection with a garden hose. In this regard a backflow prevention device, in this case, a non-removable hose connection vacuum breaker meeting or exceeding CSA 64.2, shall be attached to any hose bibb connection in order to reduce the possibility of contaminants or strong chlorine solutions entering the potable water system due to back-siphonage. The use of any other type of waterline must be protected with the appropriate backflow prevention device.

4.2.5.8. Lighting

The chlorination equipment room should be installed with proper lighting fixtures. About 60 foot candles lighting intensity at the chlorinator

4.2.5.9. Ventilation

Adequate ventilation should be provided in the facility, particularly where calcium hypochlorite is used in order to control the dust from the calcium hypochlorite, which can be a potential health hazard.

4.2.5.10. Temperature Control

The chlorination equipment room should be installed with necessary heating and ventilation equipment to maintain the temperature within the recommended range, not below 13EC and not above 27EC.

4.2.5.11. Chlorine Solution Tank and Piping

Because hypochlorite solutions are corrosive, solution tanks are usually made of polyethylene or fibreglass. The solution tank should have a tight fitting corrosion resistant cover, which helps to prevent the weakening of the solution, and possible contamination.

1. All pipes and tubes should be colour coded to clearly identify their functions.

2. Piping systems should be as simple as possible, manufactured to be suitable for hypochlorination and with a minimum number of joints. Polyethylene is normally used for hypochlorination solutions.

4.2.5.12. Point of Application

1. The point of application must provide a rapid and thorough mix with all the water being treated. The centre of a pipeline is the preferred application point. A diffuser can be added at the end of the discharge line to assist in this regard. The total backpressure in the water line must also be considered.

4.2.5.13. Methods of Dosage

Refer to Section 4.2.4.17.

4.2.5.14. Eye Wash Stations

An eye wash station capable of providing a continuous 15-minute flush as a minimum, using potable water or equivalent, shall be installed in a convenient location(s) within the facility.

A water holding tank that will allow water to come to room temperature must be installed in the water line feeding the shower and eye washing device. Other methods of water tempering will be considered on an individual basis.

4.2.5.15. Other Protection

1. Clothing, including gloves, goggles, safety shoes, etc. should be available for personnel handling chlorination equipment.

2. Other safety equipment should include a first aid kit and a fire extinguisher.

All the above equipment should be located at readily accessible points. Instructions for using, testing and replacing parts should be posted near the equipment.

4.2.5.16. Operation

For effective operation, chlorination equipment requires care and attention. Manufacturer's recommendations and instructions should be made available and should be followed.

4.2.5.17. Fencing

The chlorination facility shall be located in a fenced enclosure to minimize vandalism.

4.2.5.18. System Design and Installation

Chlorination systems should only be designed by registered professional engineers, and plans for the systems must be submitted to the DOEC for approval.

4.2.5.19. Deviation from these Guidelines

For design of facilities where the consultant considers these guidelines not to be applicable, the DOEC should be contacted directly.

4.3. Ozone

Ozonation uses the same form of ozone found in the atmosphere. Ozone must be generated at the point of use, as it is highly unstable and can't be stored as a compressed gas. It is formed by passing dry clean air between two high voltage electrodes. Oxygen gas can be used and will produce approximately twice the amount of ozone at the same electrical input. Ozone is a powerful oxidant over a wide pH and temperature range. At dosage concentrations of 1.0 to 1.5 mg/L it will remove colour, taste and odours from drinking water and will inactivate disease-causing microbes including *Giardia* and *Cryptosporidium*.

Unlike chlorine, ozone disinfection dissipates quickly in water supplies. Contaminants entering an ozonated water supply after treatment has occurred will be left unaffected. Adding chlorine before treated water enters the distribution system provides residual protection straight to the tap.

Advantages
1. Ozone is more effective than chlorine in destroying viruses and bacteria;
2. Ozone is a good oxidant for removing colour;
3. Ozone is an effective oxidizer for removal of iron and manganese;
4. Ozone can improve performance of subsequent coagulation, settling, and filtration;
5. Ozonation is an effective way to remove taste and odour;
6. Ozone is recognized as an important tool in controlling halogenated disinfection by-products;
7. There is no re-growth of microorganisms after ozonation, unlike ultraviolet and chlorine disinfection; and
8. Ozone is generated onsite, and thus, there are fewer safety problems associated with shipping and handling.

Disadvantages
1. Low dosages may not effectively inactivate some viruses, spores, and cysts;
2. Ozonation is more complex than other disinfection technologies. Water treatment plant operators require additional training to operate ozonation treatment equipment;

3. Ozone is very reactive and corrosive, thus requiring corrosion-resistant material, such as stainless steel. Ozonation can also lead to increased rates of corrosion in the distribution system, requiring more frequent replacement of infrastructure;

4. Ozonation is not economical for poor quality and poorly treated water. Because of the massive amount of electricity necessary for treatment, the cost of ozonation is approximately 4 times larger than that of traditional chlorine disinfection. The cost of treatment is relatively high, being both capital and power intensive;

5. Ozone is extremely irritating and possibly toxic, so off-gases from the contactor must be destroyed to prevent worker exposure;

6. Although ozonation does not produce the harmful by-products associated with chlorine disinfection, ozonation will create bromate, a known carcinogen, if bromide is present in the water supply; and

7. There is no measurable residual to indicate the efficacy of ozone disinfection.

4.3.1. Ozone Generator

4.3.1.1. Capacity

1. The production rating of the ozone generators shall be stated in kg/day and kW-hr/kg at a maximum cooling water temperature and maximum ozone concentration.

2. The design shall ensure that the minimum concentration of ozone in the generator exit gas will not be less than 1.0%, by weight.

3. Generators shall be sized to have sufficient reserve capacity so that the system does not operate at peak capacity for extended periods of time, which can result in premature breakdown of the dielectrics.

4. The production rate of ozone generators will decrease with a variation in the supply temperature of the coolant throughout the year. Curves or other data shall be used to determine production changes due to the temperature change of the supplied coolant. The design shall ensure that the generators can produce the required ozone at maximum temperature.

5. Appropriate ozone generator backup equipment must be provided.

4.3.1.2. Electrical

The generators can be low, medium or high frequency type. Specifications shall require that the transformers, electronic circuitry and other electrical hardware be proven, high quality components designed for ozone service.

4.3.1.3. Cooling

The required water flow to an ozone generator varies with the ozone production. Normally unit design provides a maximum cooling water temperature rise of 2.8°C (5°F). The cooling water must be properly treated to minimize corrosion, scaling and microbiological fouling of the water side of the tubes. A closed loop cooling water system is often used to ensure proper water conditions are maintained. Where cooling water is treated, cross connection control shall be provided to prevent contamination of the potable water supply.

4.3.1.4. Materials

To prevent corrosion, the ozone generator shell and tubes shall be constructed of Type 316L stainless steel**.**

4.3.2. Ozone Contactors

Analyses for bromate production should be done early in the design process. Biological mediation or other by-product removal processes shall be included as a part of the ozone facility design.

The selection or design of the contactors and method of ozone application depends on the purpose for which the ozone is being used.

1. Bubble Diffusers. Where disinfection is the primary application, a minimum of two contact chambers, each equipped with baffles to prevent short-circuiting and induce counter current flow, shall be provided. Ozone shall be applied using porous-tube or dome diffusers.

2. The minimum contact time shall be 10 minutes. A shorter contact time may be approved if justified by appropriate design and CT considerations.

3. For ozone applications in which precipitates are formed, such as with iron and manganese removal, porous diffusers should be used with caution.

4. Where taste and odour control is of concern, multiple application points and contactors shall be considered.

5. Contactors should separate closed vessels that have no common walls with adjacent rooms. The contactors must be kept under negative pressure and sufficient ozone monitors shall be provided to protect worker safety. Placement of the contactors where the entire roof is exposed to the open atmosphere is recommended. In no case shall the contactor roof be a common wall with a separate room above the contactors.

6. Large contact vessels should be made of reinforced concrete. All reinforcement bars shall be covered with a minimum of 4.0 cm of concrete. Smaller contact vessels can be made of stainless steel, fibreglass or other material which will be stable in the presence of residual ozone and ozone in the gas phase above the water level.

7. Where necessary, a system shall be provided between the contactors and the off-gas destruction unit to remove froth from the air and return the other to the contactors or other location acceptable to the DOEC. If foaming is expected to be excessive, then a potable water spray system shall be placed in the contactors headspace.

8. All openings into the contactors for pipe connections, hatchways, etc. shall be properly sealed using welds or ozone resistant gaskets such as Teflon or Hypalon.

9. Multiple sampling ports shall be provided to enable sampling of effluent from each compartment and to confirm CT calculations.

10. A pressure/vacuum relief valve shall be provided in the contactors and piped to a location where there will be no damage to the destruction unit.

11. The diffusion system should work on a counter current basis such that the ozone is fed at the bottom of the vessel and water is fed at the top of the vessel.

12. The depth of water in bubble diffuser contactors should be a minimum of 6 m. The contactors should have a minimum of 1 m of freeboard to allow for foaming.

13. All contactors shall have provisions for cleaning, maintenance and drainage of the contactors. Each contactor compartment shall be equipped with an access hatchway.

14. Aeration diffusers shall be fully serviceable by either cleaning or replacement.

15. Other contactors, such as the venturi or aspirating turbine mixer contactors, may be approved by the DOEC provided adequate ozone transfer is achieved and the required contact times and residuals can be verified.

4.3.3. Ozone Destruction Unit

A system for treating the final off-gas from each contactor must be provided in order to meet safety and air quality standards. Acceptable systems include thermal destruction and thermal/catalytic destruction units. In order to reduce the risk of fires, the use of units that operate at lower temperature is encouraged, especially where high purity oxygen is the feed gas. The maximum allowable ozone concentration in the discharge is 0.1 ppm (by volume). At least two units shall be provided which are each capable of handling the entire gas flow. Exhaust blowers shall be provided in order to draw off-gas from the contactors into the destruction unit. Catalysts must be protected from froth, moisture, and other impurities that may harm the catalyst. The catalyst and heating elements shall be located where they can easily be reached for maintenance.

4.3.4. Piping Materials

Only low carbon 304L and 316L stainless steels shall be used for ozone service with 316L the preferred.

4.3.5. Joints and Connections

Connections on piping used for ozone service are to be welded where possible. Connections with meters, valves, or other equipment are to be made with flanged joints with ozone resistant gaskets, such as Teflon or Hypalon. Screwed fittings shall not be used because of their tendency to leak. A positive closing plug or butterfly valve plus a leak-proof check valve shall be provided in the piping between the generator and the contactors to prevent moisture reaching the generator.

4.3.6. Instrumentation

1. Pressure gauges shall be provided at the discharge from the air compressor, at the inlet to the refrigeration dryers, at the inlet and outlet of the desiccant dryers, at the inlet of the ozone generators and contactors and at the inlet to the ozone destruction unit.

2. Electric power meters should be provided for measuring the electric power supplied to the ozone generators. Each generator shall have a trip, which shuts down the generator when the wattage exceeds a certain preset level.

3. Dew point monitors shall be provided for measuring the moisture of the feed gas from the desiccant dryers. Because it is critical to maintain the specified dew point, it is recommended that continuous recording charts be used for dew point monitoring which will allow for proper adjustment of the dryer cycle. Where there is potential for moisture entering the ozone generator from downstream of the unit or where moisture accumulation can occur in the generator during shutdown, post-generator dew point monitors shall be used.

4. Airflow meters shall be provided for measuring airflow from the desiccant dryers to each of other ozone generators, air flow to each contactor and purge airflow to the desiccant dryers.

5. Temperature gauges shall be provided for the inlet and outlet of the ozone cooling water and the inlet and outlet of the ozone generators feed gas, and, if necessary, for the inlet and outlet of the ozone power supply cooling water.

6. Water flow meters shall be installed to monitor the flow of cooling water to the ozone generators and, if necessary, to the ozone power supply.

7. Ozone monitors shall be installed to measure ozone concentration in both the feed-gas and off-gas from the contactors and in the off-gas from the destruction unit. For disinfection systems, monitors shall also be provided for monitoring ozone residuals in the water. The number and location of ozone residual monitors shall be such that the amount of time that the water is in contact with the ozone residual can be determined.

8. A minimum of one ambient ozone monitor shall be installed in the vicinity of the contactors and a minimum of one ambient ozone monitor shall be installed in the vicinity of the generator. Ozone monitors shall also be installed in any areas where ozone gas may accumulate.

4.3.7. Alarms

The alarm/shutdown systems listed here should be considered at each installation:

1. Dew point shutdown/alarm. This system should shut down the generator in the event the system dew point exceeds -60°C (-76°F).

2. Ozone generator cooling water flow shutdown/alarm. This system should shut down the generator in the event that cooling water flows decrease to the point that generator damage could occur.

3. Ozone power supply cooling water flow shutdown/alarm. This system should shut down the power supply in the event that cooling water flow decreases to the point that damage could occur to the power supply.

4. Ozone generator cooling water temperature shutdown/alarm. This system should shutdown the generator if either the inlet or outlet cooling water exceeds a certain preset temperature.

5. Ozone power supply cooling water temperature shutdown/alarm. This system should shutdown the power supply if either the inlet or outlet cooling water exceeds a certain preset temperature.

6. Ozone generator inlet feed-gas temperature shutdown/alarm. This system should shutdown the generator if the feed-gas temperature is above a preset value.

7. Ambient ozone concentration shutdown/alarm. The alarm should sound when the ozone level in the ambient air exceeds 0.1 ppm or a lower value chosen by the water supplier. Ozone generator shutdown should occur when ambient ozone levels exceed 0.3 ppm (or a lower value) in either the vicinity of the ozone generator or the contactor.

8. Ozone destruct temperature alarm. The alarm should sound when temperature exceeds a preset value.

4.3.8. Safety

The maximum allowable ozone concentration in the air to which workers may be exposed must not exceed 0.1 ppm (by volume). Noise levels resulting from the operating equipment of the ozonation system shall be controlled to within acceptable limits by special room construction and equipment isolation. High voltage and high frequency electrical equipment must meet current electrical and fire codes. Emergency exhaust fans must be provided in the rooms containing the ozone generators to remove ozone gas if leakage occurs. A portable purge air blower that will remove residual ozone in the contactors prior to entry for repair or maintenance should be provided.

4.3.9. Construction Considerations

Prior to connecting the piping from the desiccant dryers to the ozone generators the air compressors should be used to blow the dust out of the desiccant. The contactors should be tested for leakage after sealing the exterior. This can be done by pressurizing the contactors and checking for pressure losses. Connections on the ozone service line should be tested for leakage using the soap-test method.

4.3.10. Ozone Feed Gas Preparation

Feed gas can be air, high purity oxygen, or oxygen enriched air. Air handling equipment on conventional low-pressure air feed systems shall consist of an air compressor, water/air separator, refrigerant dryer, and heat reactivated desiccant dryer, and particulate filters. Some "package" ozonation systems for small systems may work effectively operating at high pressure without the refrigerant dryer and with a "heat-less" desiccant dryer. In all cases the design engineer must ensure that the maximum dew point of -60°C (-76º F) will not be exceeded at any time. For oxygen- feed systems, dryers typically are not required.

4.3.10.1. Air Compression

1. Air compressors shall be of the liquid-ring or rotary lobe, oil-less positive displacement type for smaller systems or dry rotary screw compressors for larger systems.

2. The air compressors shall have the capacity to simultaneously provide for maximum ozone demand, provide the airflow required for purging the desiccant dryers (where required) and allow for standby capacity.

3. Air feed for the compressors shall be drawn from a point protected from rain, condensation, mist, fog, and contaminated air sources to minimize moisture and hydrocarbon content of the air supply.

4. A compressed air after-cooler and/or entrainment separator with automatic drain shall be provided prior to the dryers to reduce the water vapour.

5. A back-up air compressor must be provided so that ozone generation is not interrupted in the event of a breakdown.

4.3.10.2. Air Drying

1. Dry, dust free and oil- free feed gas must be provided to the ozone generator. Dry gas is essential to prevent formation of nitric acid, to increase the efficiency of ozone generation, and to prevent damage to the generator dielectrics. Sufficient drying to maximum dew point of –60ºC (-76º F) must be provided at the end of the drying cycle.

2. Drying for high-pressure systems may be accomplished using heatless desiccant dryers only. For low-pressure system, a refrigeration air dryer in series with heat-reactivated desiccant dryer shall be used.

3. A refrigeration dryer capable of reducing inlet air temperature to 4ºC (40ºF) shall be provided for low-pressure air preparation systems. The dryer can be of the compressed refrigerant type or chilled water type.

4. For heat-reactivated desiccant dryers, the unit shall contain two desiccant filled towers complete with pressure relief valves, two four- way valves and a heater. In addition, external type dryers shall have a cooler unit and blowers. The size of the unit shall be such that the specified dew point will be achieved during a minimum adsorption style time of 16 hours while operating at the maximum expected moisture loading conditions.

5. Multiple air dryers shall be provided so that the ozone generation is not interrupted in the event of dryer breakdown.

6. Each dryer shall be capable of venting "dry" gas to the atmosphere, prior to the ozone generator, to allow start-up when other dryers are "on-line."

4.3.10.3. Air Filters

1. Air filters shall be provided on the suction side of the air compressors, between the air compressors and the dryers and between the dryers and the ozone generators.

2. The filter before the desiccant dryers shall be of the coalescing type and be capable of removing aerosol and particulate larger than 0.3 microns in diameter. The filter after the desiccant dryer shall be of the particulate type and be capable of removing all particulate greater than 0.1 microns in diameter, or smaller if specified by the generator manufacturer.

4.3.10.4. Air Preparation Piping

Piping in the air preparation system can be common grade steel, seamless copper, stainless steel or galvanized steel. The piping must be designed to withstand the maximum pressures in the air preparation system.

4.4. UV

Ultraviolet irradiation is a process for inactivating microorganisms by irradiating them with ultraviolet light. The UV disinfection process takes place as water flows through an irradiation chamber. Microorganisms in the water are inactivated when the UV light is absorbed. A photochemical effect is created and vital processes are stopped within the cells, thus making the microorganisms harmless. UV light inactivates microbes by damaging their nucleic acid, thereby preventing the microbe from replicating. When a microbe cannot replicate, it is incapable of infecting a host. The ultraviolet light does not leave a disinfectant residual so a form of chlorine disinfection must be applied if a residual is desired. To allow the irradiation to reach the organisms effectively, the water to be disinfected must be relatively free of particles, as in filtered water.

Advantages
1. The UV light disinfection process does not use chemicals;
2. Microorganisms, including bacteria, viruses, and algae, are inactivated within seconds of UV light disinfection, but all are not equally sensitive. Generally, viruses and algae are more resistant to disinfection by UV light.
3. UV light is effective in inactivating *Cryptosporidium*, while at the same time decreasing chlorinated disinfection by-products;
4. UV disinfection is used in air and water purification, sewage treatment, protection of food and beverages, and many other disinfection and sterilization processes; and
5. One major advantage of UV light disinfection is that it is capable of disinfecting water faster than chlorine, and without the need for retention tanks or potentially harmful chemicals.

Disadvantages
1. Scaling of lamps can be an issue if dissolved organics are present and will gradually decrease the effectiveness of the UV system;
2. Turbidity or the presence of suspended particles can prevent or shadow bacteria from the UV dose. Problems typically exist in surface water applications and filtration may be required to remove turbidity to have an effective system. NSF studies have shown that the effective transmission coefficient of the water should be 75%;
3. UV may be used as a primary disinfection process but will need to be followed by a secondary disinfection process to maintain a measurable residual in the distribution network;
4. Capital and operational costs will be significantly higher than chlorine disinfection alone; and
5. Effective lamp life and replacement will require additional operational requirements in addition to power requirements.

4.4.1. UV Reactor Design

All UV disinfection facilities must continuously monitor such parameters that allow the operator to determine that the target design 254nm-equivalent UV pass through dose or higher is being delivered, and all systems must provide failure alarms when this design dose is not being delivered.

Equipment that records test results of the continuous monitoring equipment is strongly recommended for drinking water systems using a surface water supply or a groundwater supply under the direct influence of surface water. All sensors that constitute part of the monitoring system must be calibrated at a frequency that maintains their necessary sensitivity and reliability in ensuring that the design UV dose is being achieved, or as deemed necessary by the DOEC.

Most conventional UV reactors are available in two types; closed vessel and open channel. For drinking water applications, the closed vessel is generally the preferred UV reactor for the following reasons:
1. Smaller footprint;
2. Minimized pollution from airborne material;
3. Minimal personnel exposure to UV; and
4. Modular design for installation simplicity.

Additional design features for conventional UV disinfection systems include:
1. UV sensors to detect any drop in UV lamp output intensity;
2. Alarms and shut-down systems;
3. Automatic or manual cleaning cycles; and
4. Telemetry systems for remote installations.

In addition to conventional UV systems, two other UV processes are currently being evaluated for drinking water disinfection; micro-screening/UV, and pulsed UV. Both of these systems profess to provide sufficient UV dose to inactivate *Giardia* cysts and *Cryptosporidium* oocysts.

The most common point of application for UV radiation is the last step in the treatment process train just prior to the distribution system and after filtration. The use of UV disinfection has no impact on other processes at the water treatment facility.

4.4.1.1. Hydraulic Design Considerations

The major elements that should be considered in the hydraulic design of a UV closed vessel reactor are:
Dispersion;
Turbulence;
Effective volume;
Residence time disturbance; and
Flowrate.

Dispersion is the characteristic of water elements to scatter spatially. The ideal UV reactor is plug flow, where water particles are assumed to discharge from the reactor in the same sequence they entered and each element of water passing through the reactor resides in the reactor for the same period of time. An ideal plug flow reactor has no dispersion and is approximated by a long tank with high length-to-width ratio in which dispersion is minimal.

In addition to plug flow characteristics, the ideal UV reactor has a flow that is turbulent radially from the direction of flow, to eliminate dead zones. This radially turbulent flow pattern promotes uniform application of UV radiation. A negative of having a radially turbulent flow pattern is that some axial dispersion results, thus disrupting the plug flow characteristics. Techniques such as misaligning the inlet and outlet, and using perforated stilling plates, have been used to accommodate the contradicting characteristics of plug flow and turbulence.

4.4.2. Pathogen Inactivation

UV radiation is efficient at inactivating vegetative and sporous forms of bacteria, viruses, and other pathogenic microorganisms. Electromagnetic radiation in the wavelengths ranging from 240 to 280 nm effectively inactivates microorganisms by irreparably damaging their nucleic acid. The most potent wavelength for damaging deoxyribonucleic acid (DNA) is approximately 254 nm (Wolfe, 1990).

The germicidal effects of UV light involve photochemical damage to RNA and DNA within the microorganisms. Microorganism nucleic acids are the most important absorbers of light energy in the wavelength of 240 to 280 nm (Jagger, 1967). DNA and ribonucleic acid (RNA) carry genetic information necessary for reproduction; therefore, damage to either of these substances can effectively sterilize the organism. Damage often results from the dimerization of pyrimidine molecules. Replication of the nucleic acid becomes very difficult once the pyrimidine molecules are bonded together due to the distortion of the DNA helical structure by UV radiation (Snider et al., 1991). Moreover, if replication does occur, mutant cells that are unable to replicate will be produced (USEPA, 1996).

Two phenomena of key importance when using UV disinfection in water treatment are the dark repair mechanisms and the capability of certain organisms to photoreactivate following exposure to certain light wavelengths. Under certain conditions, some organisms are capable of repairing damaged DNA and reverting back to an active state in which reproduction is again possible. The extent of reactivation varies among organisms. Because DNA damage tends to become irreversible over time, there is a critical period during which photoreactivation can occur. To minimize the effect of photoreactivation, UV contactors should be designed to either shield the process stream or limit the exposure of the disinfected water to sunlight immediately following disinfection.

4.4.2.1. Bacteria and Virus Inactivation

UV doses required for bacteria and virus inactivation are relatively low. One study determined that UV was comparable to chlorination for inactivation of heterotrophic plate count bacteria following treatment using granular activated carbon (Kruithof et al., 1989).

4.4.2.2. Protozoa Inactivation

Even though protozoa were once considered resistant to UV radiation, recent studies have shown that ultraviolet light is capable of inactivating protozoan parasites. However, results indicate that these organisms require a much higher dose than that needed to inactivate other pathogens.

4.4.3. Disinfection Efficiency

To achieve inactivation, UV should be absorbed into the microorganism. Therefore, anything that prevents UV from reacting with the microorganism will decrease the disinfection efficiency. Several factors that are known to affect disinfection efficiency of UV are:
1. Chemical and biological films that develop on the surface of UV lamps;
2. Dissolved organics and inorganics;
3. Clumping or aggregation of microorganisms;
4. Turbidity;
5. Colour; and
6. Short-circuiting in water flowing through the UV contactor.

4.4.3.1. Chemical Films and Dissolved Organics and Inorganics

Accumulation of solids onto the surface of the UV sleeves can reduce the applied UV intensity and, consequently, disinfection efficiency. In addition to biofilms caused by organic material, build-up of calcium, magnesium, and iron scales have been reported (DeMers and Renner, 1992). Waters containing high concentrations of iron, hardness, hydrogen sulphide, and organics are more susceptible to scaling or plating, which gradually decreases the applied UV intensity. Scaling is likely to occur if dissolved organics are present and inorganic concentrations exceed the following limits (DeMers and Renner, 1992):

1. Iron greater than 0.1 mg/L;

2. Hardness greater than 140 mg/L; and

3. Hydrogen sulphide greater than 0.2 mg/L.

4.4.3.2. Microorganism Clumping and Turbidity

Particles can affect the disinfection efficiency of UV by harbouring bacteria and other pathogens, partially protecting them from UV radiation, and scattering UV light. Typically, the low turbidity of ground water results in minimal impact on disinfection efficiency. However, the higher turbidity of surface water can impact disinfection efficiency. Similar to particles that cause turbidity, microorganism aggregation can impact disinfection efficiency by harbouring pathogens within the aggregates and shade pathogens that would otherwise be inactivated.

4.4.3.3. Reactor Geometry and Short Circuiting

Poor geometry within the UV contactor (which creates spacing between lamps) can leave dead areas where inadequate disinfection occurs (Hazen and Sawyer, 1992). A key consideration to improving disinfection is to minimize the amount of dead spaces where limited UV exposure can occur. Plug flow conditions should be maintained in the contactor; however, some turbulence should be created between the lamps to provide radial mixing of flow. In this manner, flow can be uniformly distributed through the varying regions of UV intensity, allowing exposure to the full range of available UV radiation (Hazen and Sawyer, 1992). As mentioned earlier, UV systems typically provide contact times on the order of seconds. Therefore, it is extremely important that the system configuration limit the extent of short-circuiting.

4.4.4. Operational Considerations

Onsite pilot plant testing is recommended to determine the efficiency and adequacy of UV disinfection for a specific quality of water. The efficiency test should involve injecting select microorganisms into influent water and sampling effluent water to determine survival rates. The National Sanitation Foundation's Standard 55 for ultraviolet water treatment systems recommends that UV disinfection systems not be used if the UV transmittance is less than 75% (NSF, 1991). If the raw water UV transmittance is less that 75%, the UV system should be preceded by other treatment processes (to increase UV transmittance) or a different disinfectant should be used. Some constituents that adversely interfere with UV disinfection performance by

either scattering and/or absorbing radiation are iron, chromium, copper, cobalt, sulphites, and nitrites. Care should be taken with chemical processes upstream of UV disinfection process to minimize increasing concentrations of these constituents since disinfection efficiency may be adversely affected.

4.4.4.1. Equipment Operation

UV disinfection facilities should be designed to provide flexibility in handling varying flow rates. For lower flow rates, a single reactor vessel should be capable of handling the entire flow rate. A second reactor vessel with equal capacity of the first reactor vessel should be provided for redundancy should the first reactor vessel be taken out of service. For higher flow rates, multiple reactor vessels should be provided with lead/lag operation and flow split capacity to balance run time for each reactor vessel, if desired, and to avoid hydraulic overloading. Valves should be provided within the interconnecting piping to isolate one reactor vessel from another. There should also be a positive drainage system to remove water from within a reactor vessel when it is taken out of service.

4.4.4.1.1. UV Lamp Aging

The output of UV lamps diminishes with time. Two factors that affect their performance are:
1. Solarization, which is the effect UV radiation has on the UV lamp that causes it to become opaque; and

2. Electrode failure, which occurs when electrodes deteriorate progressively each time the UV lamp is cycled on and off.

Frequent lamp cycling will lead to premature lamp aging. When determining the requirement for UV disinfection, a 30% reduction of UV output should be used to estimate end of lamp. Average life expectancy for low-pressure UV lamps is approximately 8,800 hours.

4.4.4.1.2. Quartz Sleeve Fouling

Fouling of the quartz sleeve reduces the amount of UV radiation reaching the water. The quartz sleeve has a transmissibility of over 90% when new and clean. Over time, the surface of the quartz sleeve that is in contact with the water starts collecting organic and inorganic debris (e.g., iron, calcium, silt) causing a reduction in transmissibility (USEPA, 1996). When determining the requirements for UV disinfection, a 30% reduction of UV transmission should be used to reflect the effect of quartz sleeve fouling.

4.4.4.2. Equipment Maintenance

4.4.4.2.1. UV Lamp Replacement

Adequate space should be provided around the perimeter of the reactor vessels to allow access for maintenance and replacement of UV lamps. With modular electrical fittings, lamp replacement consists of unplugging the pronged connection of the old lamp and plugging in the new.

4.4.4.2.2. *Quartz Sleeve Cleaning*

Quartz sleeve cleaning may be accomplished by physical or chemical means. Physical alternatives include:
1. Automatic mechanical wiper;
2. Ultrasonic devices;
3. High water pressure wash; and
4. Air scour.

Chemical cleaning agents include sulphuric or hydrochloric acid. A UV reactor vessel may contain one or more physical cleaning system with provision for an occasional chemical cleaning.

4.4.4.2.3. *Miscellaneous*

Effective maintenance of a UV system will involve:
Periodic checks for proper operation;
Calibration of intensity meter for proper sensitivity; and
Inspect and/or clean reactor vessel interior.

4.5. Chlorine Dioxide

Chlorine dioxide has been generally recognized as a treatment for tastes caused by industrial wastes, such as phenols. However, chlorine dioxide can be used in the treatment of any taste and odour that is treatable by an oxidizing compound. Chlorine dioxide disinfects by oxidation, not substitution as with chlorine. The molecule oxidizes other compounds and forms the chlorite ion, which can subsequently reduce to chlorate and chloride.

Advantages
1. Chlorine dioxide is more effective than chlorine and chloramine for inactivation of viruses and protozoan;
2. Oxidizes iron, manganese and sulphides;
3. Can enhance clarification process;
4. Control of taste and odour problems from algae and decaying plant material can be achieved;
5. Halogenated by-products - THM formation is prevented as long as the generation system does not allow for the release of free chlorine;
6. Biocidal effectiveness is not affected by pH; and
7. Chlorine dioxide provides residual disinfection and can be used as a primary disinfectant.

Disadvantages
1. Chlorine dioxide forms DBPs of chlorite and chlorate;
2. Some generation technologies are difficult to maintain optimum yield and prevent excess chlorine from escaping unreacted;
3. Costs associated with chlorite, chlorate and training can be high;
4. Chlorine dioxide must be generated on site;
5. Chlorine dioxide decomposes in sunlight;

6. Extended storage of chlorine dioxide solution can contribute to by-product formation; and
7. Chlorine dioxide can produce noxious odours in some systems.

4.5.1. Safety Issues

Firstly, there are safety issues associated with chlorine dioxide as a gas. Chlorine dioxide can be an explosive gas at concentrations above 10% by volume. Due to its instability, it must be generated on site. The generator chosen must be designed in such a way that gaseous chlorine dioxide cannot accumulate. Most generation systems are designed with safety features, which will automatically shut the system down if catastrophic failures occur, such as the loss of dilution water.

The construction of a chlorine dioxide generator is not difficult. Commercially available generators are relatively simple, with pumps to move the precursors. For these types of systems, the safety aspects of the design have to be built in. That is, various controls are installed which are designed to work in case of a problem.

More elegant designs include those systems which are eductor driven. Such systems are relatively safe. Loss of dilution water leads to loss of vacuum and the generation of ClO_2 is interrupted. These systems rely on simple check valves to prevent the backflow of precursors. The system should be designed so that the concentration of chlorine dioxide does not exceed its solubility limit at any point in the system.

The second safety aspect is the storage of the precursors on site. For those plants desiring to eliminate gaseous chlorine storage, a three chemical feed approach would be appropriate. Storage of precursors can be done safely. However, of all the incidents which have arisen out of the use of chlorine dioxide, the largest number have been a result of improper storage or handling of the sodium chlorite solution. Attention to proper equipment selection and installation would solve these problems.

The third safety aspect is the operation of equipment by plant operators. Although modern generators can be made with proper safeguards, some knowledge of the generation process is required. An operator who operates the generator part time, and then only intermittently, will not be as alert to problems as compared to one who operates the unit as his/her primary responsibility.

4.5.2. Disinfection

When using chlorine dioxide for disinfection purposes, consideration must be given to the overall demand and should account for the following parameters:
1. Seasonal;
2. Variability;
3. Temperature; and
4. Application point.

For chlorine dioxide, pH has no effect on disinfection ability, unlike chlorine. Studies have demonstrated variations on the effectiveness of chlorine dioxide, but to what degree is still uncertain. Studies have shown that as pH increases the relative strength against *Giardia*, *Cryptosporidium* and viruses increases.

Disinfection capability decreases with a decrease of temperature. Changes in temperature to below 4°C can have a great affect on the ability to disinfect as at this point chlorine dioxide exists as a dissolved liquid and diffusion through the fluid is slower.

Suspended and colloidal materials greatly affect the disinfection ability of chlorine dioxide. Particles can hide bacteria from disinfection. It can increase the required CT by a factor of 3 depending on the microorganisms and the actual turbidity.

4.5.3. Taste and Odour Control

A common application for chlorine dioxide is to reduce the taste and odours present as a result of decaying plant material (algae). It is also capable of controlling the phenolic compounds that contribute to taste and odour problems. Taste and odour application points can typically be made after initial sedimentation or at the beginning of the plant where turbidity is low (< 10 NTU).

4.5.4. Oxidation of Iron and Manganese

Chlorine dioxide reduces to chlorite when oxidizing iron and manganese.
1. Iron oxidation - 1.2 mg/mg iron;
2. Manganese oxidation - 2.5 mg/mg manganese; and
3. Sulphite reduction - 5.8 mg/mg H_2S

4.5.5. Dosage Requirements

The following are the typical chlorine dioxide dosages that are required for various treatment methods:
Iron removal - 1.2 mg/mg iron – immediate;
Manganese removal - 2.5 mg/mg manganese – immediate;
Sulphide removal - 5.8 mg/mg H_2S;
Taste and odour - 1 - 2.5mg/L 10 minutes contact time;
Bacteria inactivation - 1 to 5 mg/L 5 minutes contact time;
Giardia - 1.5 to 2.0 ppm 60 minutes contact time; and
Cryptosporidium - approximately 8-16 times *Giardia*.

4.5.6. CT Value Enhancement

Chlorine dioxide has been studied extensively to provide CT values for viral, bacterial and protozoan removal. CT studies have shown proof that chlorine dioxide can be used to increase the credit given for removal of these pathogens.

4.5.7. On-site Generation

Chlorine dioxide cannot be stored for long periods of time and its reactivity when concentrated does not allow it to be transported. Generation on-site occurs through one of the following methods:
1. Acid/chlorite combination - two chemicals;
2. Chlorine gas method – three chemicals; and
3. Electrolytic membrane system - one chemical.

4.5.8. Disinfection By-products

The following items should be considered regarding chlorine dioxide and DBP formation:
1. Initial dosage/oxidation demand;

2. Blending ratios of sodium chlorite and chlorine in generation;

3. Exposure of chlorine dioxide to sunlight;

4. Reaction between chlorine and chlorite, if chlorine is used as a secondary disinfectant; and

5. Levels of chlorate in feedstock solutions.

Incomplete reactions in chlorine-based technologies can lead to chlorinated DBPs and chlorate as a result of the reaction between chlorite and chlorine. Interaction/oxidation of biological material increases overall demand and as a result increases DBP formation potential.

Generation methods that require subsequent storage of chlorine dioxide also produce DBPs in the form of chlorite and chlorate under influence of sunlight. Typically 50-70% of all chlorine dioxide applied to the water for disinfection will be reduced to chlorite, the remaining 30% will reduce to chlorate by means of other reactions with chlorine, pH dependence, and sunlight.

DBPs must be monitored on a basis determined by the exceedance of set guideline limits. Chlorine dioxide levels must also be monitored in the water leaving the plant by prescribed methodologies.

Typically, 70% of the initial dose of chlorine dioxide is converted to chlorite. Therefore if initial demand and dosage is kept below 1.4 ppm, then no DBP formation over the set guidelines will be experienced. Guideline for chlorite formation is 1.0 ppm. If a system does have a problem with chlorite formation, the level of chlorite in the system can be reduced using the following methods:
1. GAC or PAC application;
2. Adding reducing salts; ferrous chloride and ferrous sulphate; or
3. Adding reduced sulphur compounds; sulphur dioxide or sodium sulphite.

Option #3 is not prescribed as the process is effective at lower pH levels, thus the formation of chlorate can be a problem.

4.6. Chloramines

Chloramines are formed by the reaction of ammonia with aqueous chlorine. The use of chloramines was first considered after observing that disinfection by chlorine occurred in two distinct phases. During the initial phase, chlorine-reducing compounds (i.e., demand) caused the rapid disappearance of free available chlorine. However, when ammonia was present bactericidal action was observed to continue, even though the free chlorine residual was dissipated. The subsequent disinfection phase occurs by the action of the inorganic chloramines.

Initially in the early 1900's, chloramines were used for taste and odour control, however, it was soon recognized that chloramines were longer lasting and more stable, but a less powerful disinfectant than free chlorine. Because of this, chloramines were found to be effective for controlling bacterial re-growth in the distribution system. Ammonia shortage during World War II caused the popularity of chloramination to decline, however, concern during the past two decades over chlorinated organics (e.g., THM and HAA formation) in water treatment and distribution systems, increased interest in chloramines because they form very few disinfection by-products (DBPs).

4.6.1. Advantages and Disadvantages

The following list highlights selected advantages and disadvantages of using chloramines as a disinfection method for drinking water. Because of the wide variation of system size, water quality, and dosages applied, some of these advantages and disadvantages may not apply to a particular system.

Advantages

1. Chloramines are not as reactive with organics as free chlorine in forming DBPs. Use of chloramines may reduce total THM concentrations reaching consumers because chloramines do not form THMs on contact with natural organic matter in the water, although it may form other by-products;

2. The monochloramine residual is more stable and longer lasting than free chlorine or chlorine dioxide, thereby providing better protection against bacterial re-growth in systems with large storage tanks and dead end water mains;

3. Chloramines do not tend to react with organic compounds, therefore many systems will experience fewer incidences of taste and odour complaints when using chloramines;

4. Chloramines are inexpensive; and

5. Chloramines are easy to make.

Disadvantages
1. The disinfecting properties of chloramines are not as strong as other disinfectants, such as chlorine, ozone, and chlorine dioxide, and should be considered as a secondary disinfectant only;

2. Use of chloramines may provide less protection from contamination of the distribution system through cross-connections, watermain breaks and other causes;

3. Chloramines cannot oxidize iron, manganese, and sulphides;

4. When using chloramines as the secondary disinfectant, it may be necessary to periodically convert to free chlorine for biofilm control in the water distribution system;

5. Excess ammonia in the distribution system may lead to nitrification problems, especially in dead ends and other locations with low disinfectant residual;

6. Monochloramines are less effective as disinfectants at high pH rather than at low pH;

7. Dichloramines have treatment and operation problems; and

8. Chloramines must be made on-site, but unlike most substances added to water for treatment purposes, chloramines cannot be prepared at high concentrations. It can only be made by the addition of ammonia to lightly pre-chlorinated water, or chlorine to water containing low concentrations of ammonia. Contact between high concentrations of chlorine and ammonia or ammonium salts must be avoided because the sensitive and violently explosive substance, nitrogen trichloride, may be formed.

4.6.2. Converting Treatment Plants to Chloramines

Municipalities that wish to modify disinfectant practices by using chloramines must show the DOEC clear evidence that bacteriological and chemical protection of consumers will not be compromised in any way and that aspects of chloramination mentioned below are considered in any permit application.

Planning
Project planning and preparation are essential to ensure an efficient changeover, to maintain a dependable and safe system, and to preserve the public confidence in the water purveyor. Planning and preparation should consider the following aspects:
1. Raw water composition and suitability to chloramination;
2. Treatment plant and distribution system attributes and monitoring program;
3. Employee training;
4. Public notification and education; and
5. Environmental affects from chloraminated water.

Preliminary Analysis

A bench scale study is necessary to identify the water characteristics and to determine if chloramination is suitable. Some of the study objectives and variables to consider are as follows:

Organic nitrogen in the water;

Ammonia residual desired in the distribution system; and

Chloramine residual type and concentration required in the distribution system.

4.6.3. Potential Operational Impacts of Chloramination

4.6.3.1. Pre-treatment

Ammonia in excess of the required chlorine can promote the growth of nitrifying bacteria in filter beds (i.e., rapid sand filters). The excess ammonia acts as a nutrient and causes the growth of nitrifying bacteria, which convert the excess ammonia to nitrates and nitrites. Excessive levels of nitrate in drinking water may cause serious illness and sometimes death in infants less than six months of age.

4.6.3.2. Nitrification

Nitrification in chloraminated drinking waters is usually partial. Partial nitrification occurs when the chloraminated water has excess ammonia present in the distribution system. Partial nitrification can have various adverse effects on water quality, including a loss of total chlorine and ammonia residuals and an increase in heterotrophic plate count (HPC) bacteria concentration.

4.6.3.3. Taste and Odour

If the chlorine to ammonia-nitrogen ratios are between 3:1 and 5.5:1, disagreeable tastes and odours should be evaluated at the consumer tap. Fishy tastes and odours (e.g., from source waters and return washwater from the washwater treatment system) can be controlled by a 1-hour contact time with free-chlorine residual of 2 mg/L prior to the addition of ammonia. This pre-chlorination eliminates the fishy taste and odour but may increase the THM concentrations at the plant effluent.

4.6.4. Special Considerations for Chloramination Facilities

4.6.4.1. Organic Nitrogen

Concentrations of organic nitrogen and ammonia nitrogen as low as 0.3 mg/L may interfere with the chloramination process. The monochloramine residuals will hydrolyze with the organic nitrogen to form organochloramines, which are non-germicidal. This reaction would take about 30 to 40 minutes. After the monochloramine residuals disappear, free ammonia nitrogen reappears. Free ammonia nitrogen is a powerful biological nutrient. Its presence promotes

biological instability in that portion of the distribution system. Biological instability usually results in foul tastes and odours plus dirty and/or coloured water at the consumers tap.

The free chlorine residual or chloramine residual method may be used to clean an area with biological instability. Of the two methods, the free chlorine residuals method is superior. Free chlorine residuals restore distribution system stability quicker (i.e., a few days for free chlorine versus weeks for chloramines), the clean-up process can be monitored, and the clean up is complete when the free chlorine residual concentration reaches 85 % of the total chlorine concentration.

4.6.4.2. Mixing

Thorough and reasonably rapid mixing of chlorine and ammonia in the main plant stream shall be arranged so as to avoid formation of odorous dichloramine. Also, mixing at the point of application can greatly affect the bactericidal efficiency of the chloramine process. When the pH of the water is between 7 and 8.5, the reaction time between ammonia and chlorine is practically instantaneous. If chlorine is mixed slowly into the ammoniated water, organic matter, especially organic matter prone to bleaching with chlorine solution, may react with the chlorine and interfere with chloramine formation.

4.6.4.3. Blending Waters

When chlorinated water is blended with chloraminated water, the chloramine residual will decrease after the excess ammonia has been combined and monochloramine is converted to dichloramine and nitrogen trichloride. The entire residual can be depleted. Therefore, it is important to know how much chlorinated water can be blended with a particular chloraminated water stream without significantly affecting the monochloramine residual. Blended residual curves should be developed for each specific blend.

4.6.4.4. Corrosion

Chloramination and corrosion control can limit bacterial biofilm development in the distribution system. If optimum corrosion of iron pipes is not controlled, the chloramination efficiency may be impacted. Corrosion inhibitors with higher phosphate concentrations may reduce corrosion rates.

4.6.4.5. Formation of Nitrogen Trichloride

If water in the distribution system tends to form nitrogen trichloride, the finished water should be subjected to post-aeration, which readily removes nitrogen trichloride. Nitrogen trichloride is also readily destroyed by sunlight.

4.6.4.6. Human Health and the Environment

Users of kidney dialysis equipment are the most critical group that can be impacted by chloramine use. Chloramines can cause methemoglobinemia and adversely affect the health of kidney dialysis patients if chloramines are not removed from the dialysate water. Chloramines can also be deadly to fish as chloramines in water are considerably more toxic to fish and other aquatic organisms than free chlorine. The residuals can damage the gill tissues, enter the red blood cells, and cause an acute blood disorder. Chloramine residuals should be removed from the water prior to the water contacting any fish. As such, fish hobbyists should be notified, along with pet stores and aquarium supply establishments.

4.6.5. Ammonia Feed Facilities

Ammonia feed facilities can be located on-site at the water treatment plant or at remote locations in the distribution system. Most ammonia feed facilities use either gaseous (anhydrous ammonia) or liquid (aqueous) ammonia. Though anhydrous ammonia is a gas at ambient temperature and pressure, it is commonly stored and transported as a liquid in pressure vessels. In this phase, ammonia is highly soluble in water. Storage facilities and handling equipment should be kept dry

4.6.5.1. Anhydrous Ammonia

Anhydrous ammonia is stored in portable cylinders or stationary tanks. Portable cylinders are similar to chlorine cylinders and are available in 45, 68, and 364 kg sizes. The cylinders are rated for a minimum service pressure of 3300 kPa (480 psi). Stationary tanks are typically 3800 L vessels that can be used on-site and are refilled by tanker trailers (not used in the province).

Anhydrous ammonia is applied using an ammoniator. An ammoniator is a self-contained modular unit with a pressure-reducing valve, gas flow meter, feed rate control valve, and miscellaneous piping for controlling the flow of ammonia. Automatic paced ammoniators are available.

4.6.5.2. Aqueous Ammonia

Aqueous ammonia is not used in the province so it is not discussed in this document. Please contact the DOEC for requirements.

4.6.5.3. Piping and Valving

For anhydrous ammonia, the typical piping materials for both direct and solution feed systems are stainless steel, PVC, and black iron. Stainless steel or black iron pipe is used in the high-pressure (i.e., greater than 103 kPa (15 psi)) portions of the feed system. PVC pipe is used only in the low-pressure portion of the feed system, after the ammoniators.

4.6.6. Safety Provisions for Chloramine Generation Facilities

A chloramination facility should include safety provisions to prevent the formation of nitrogen trichloride and the vaporization of ammonia at ambient temperatures. The possible formation of nitrogen trichloride at a chloramination facility should be considered when selecting sites for the ammonia and chlorine storage facilities.

Chlorine gas and ammonia gas should never be stored in the same room. The ammonia gas application points should be located at least 1.5 m away from chlorine feed solution lines. Anhydrous ammonia is lighter than air, so any leaking vapour will rise quickly. Under pressure, anhydrous ammonia is a liquid. Great amounts of heat are absorbed when the pressurized liquid reverts to a gas. If the storage tanks and/or chemical feed equipment are installed indoors, ventilation and vapour detection devices should be located at high points in the room. Ammonia gas storage tanks should be protected from direct sunlight or direct sources of heat to avoid pressure increases in the tank. Otherwise, ammonia gas may be released into the atmosphere through the pressure relief valves.

4.6.7. Points of Application

The formation of monochloramine can be accomplished by first adding ammonia and then chlorine, or vice versa. Ammonia is added first where the formation of objectionable taste and odour compounds caused by the reaction of chlorine and organic matter is a concern. However, most drinking water systems add chlorine first in the treatment plant in order to achieve the required concentration and contact time (CT) to meet the disinfection requirements. Typically, the point of ammonia addition is selected to "quench" the free chlorine residual after a target period of time based on optimizing disinfection versus minimizing DBP formation. Because the germicidal effectiveness of monochloramine is a factor of 200 less than for free chlorine, extremely long contact times are required for monochloramine to meet disinfection requirements. Therefore, if ammonia is added first, a means of ensuring that CT requirements are met must be developed.

4.6.8. Impact on Other Treatment Processes

Monochloramine addition impacts other processes at the water treatment facility. These impacts include:

1. Ammonia used in the chloramination process can provide nutrient ammonia for nitrifying bacteria growth in the distribution system, which can cause increased nitrate levels in the finished water where systems do not normally test for nitrate;

2. Imbalances in chlorine and ammonia concentrations (in greater than an 8 to 1 ratio) can cause breakpoint chlorination reactions to occur when encountered in distribution system; and

3. Monochloramine addition upstream of filters will reduce biological growth on filters. This has a favourable impact on the filters by keeping them clean and reducing the backwash frequency. It also has the undesirable impact of reducing BDOC removal in the filters when the filters are run in a biological mode.

4.6.9. Environmental Effects

Temperature, pH, and organic and inorganic compounds all play a part in the effectiveness of chloramines. Below is a summary of the affect these parameters have on pathogen inactivation.

Temperature
Similar to most other disinfectants, the bactericidal and viral inactivation efficiency of chloramine increases with increasing temperature. Moreover, the efficiency dramatically decreases under conditions of high pH and low temperature. For example, the inactivation of *E.coli.* is approximately 60 times slower at a pH of 9.5 and temperatures of 2 and 6 °C than at a pH of 7 and temperatures between 20 and 25°C.

pH
The addition of ammonia gas or ammonia solution will increase the pH of the water. The effect of pH on disinfection has more to do with the organism than with the disinfectant, however, pH also impacts disinfection efficiency by controlling the chloramine species distribution. However, pH may be a compounding factor because changes in pH may alter the physiological response of the organism.

The actual pH shift may be small in well-buffered water but the effects on disinfectant power and corrosiveness of the water may require consideration. Ammonia gas forms alkaline solutions, which may cause local plugging by lime deposition. Where hard water is to be treated, a side stream of pre-softened water may be needed for ammonia dilution so as to reduce plugging problems.

Organic Nitrogen and Other Compounds
In addition to ammonia, free chlorine reacts with organic nitrogen compounds to form a variety of organic chloramines. These organic chloramines are undesirable by-products because they exhibit little or no microbiocidal activity. Several other reactions may occur which divert chlorine from the formation of chloramines. These reactions can include oxidation of iron, manganese, and other inorganics such as hydrogen sulphide.

4.6.10. DBP Formation

The effectiveness of chloramines to control DBP production depends upon a variety of factors, notably the chlorine to ammonia ratio, the point of addition of ammonia relative to that of chlorine, the extent of mixing, and pH.

Monochloramine (NH_2Cl) does not produce DBPs to any significant degree, although some dichloroacetic acid can be formed from monochloramine and cyanogen chloride formation is greater than with free chlorine. The inability to mix chlorine and ammonia instantaneously allows the free chlorine to react before the complete formation of chloramines. In addition, monochloramine slowly hydrolyzes to free chlorine in aqueous solution. Therefore, halogenation reactions occur even when monochloramine is formed prior to addition in the treatment process. The closer the chlorine to ammonia ratio is to the breakpoint, the greater the formation of DBPs. In addition to controlling the formation of DBPs, chloramination results in

lower concentrations of a number of the other specific organic halides generated from free chlorine, except for cyanogens chloride. The application of chloramines results in the formation of chlorinated organic material, although it occurs to a much lesser degree than from an equivalent dose of free chlorine.