CHAPTER 9

9.Disinfection

CHAPTER 9: DISINFECTION

9.1 Disinfection

For the utmost safety of water for drinking purposes, disinfection of water has to be done in order to kill disease-causing microorganisms. Bacteria, viruses, and protozoa constitute the three main types of human enteric pathogens. Accordingly, effective disinfection with adequate detention time is aimed at the destruction or inactivation of pathogens. The need for disinfection in ensuring protection against transmission of water-borne diseases cannot be overemphasised and its inclusion as one of the water treatment processes is considered necessary.

Historically, boiling of water or the use of copper and silver vessels for storing water, which affects some measure of disinfection, has been employed at small scale in this country and elsewhere. Broadly, modern disinfection processes include the use of:

(i) Physical methods such as thermal treatment and ultrasonic waves.
(ii) Chemicals including oxidising agents such as chlorine and its compounds, bromine, iodine, potassium permanganate, ozone, and metals like silver.
(iii) UV radiation.

9.1.1 Mechanisms of Disinfection

The mechanism of killing pathogens depends largely on the nature of the disinfectant and the type of microorganisms. In general, four mechanisms are proposed to explain the destruction or inactivation of organisms:

(i) Damage to the cell wall.
(ii) Alteration of cell permeability.
(iii) Changing the colloidal nature of the cell protoplasm.
(iv) Inactivation of critical enzyme systems responsible for metabolic activities.

Damage to the cell wall leads to cell lysis (disintegration of cell by rupture of cell wall or membrane) and death. Alteration of cell permeability refers to the destruction of selective permeability of the cytoplasmic membrane and causes outflow from the cells of such vital nutrients, like nitrogen and phosphorus. Denaturation of cell proteins by acids and bases leads to the destruction of cells. Inactivation of critical enzyme activity vital for cell growth and survival is normally brought about by oxidising chemicals. Figure 9.1 shows the mechanism of disinfection.

Chemical disinfection normally proceeds in at least two steps:

(i) Penetration of the disinfectant through the cell wall; and
(ii) Reaction with enzymes within the cell.

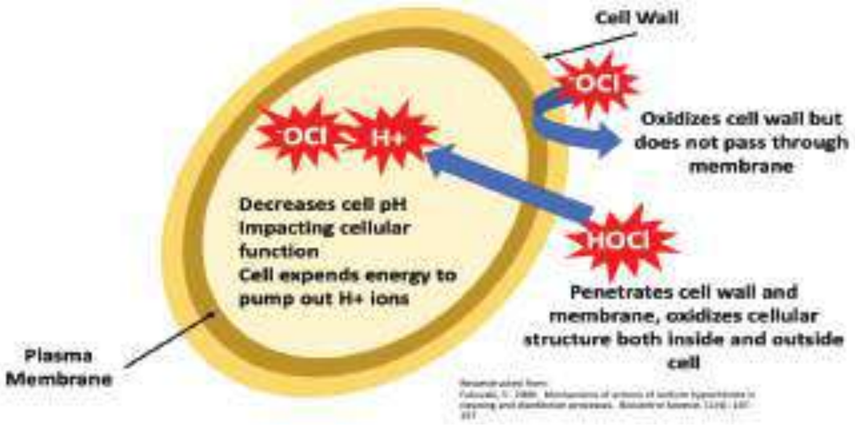

Figure 9.1: Disinfection Mechanism (source: Fukuzaki, S. 2006)

9.2 Criteria for a Good Disinfectant

For a chemical or an agent to be potentially useful as a disinfectant in water supplies, it has to satisfy the following criteria:

(i) It must be capable of destroying the pathogenic organisms present, within the contact time available and not unduly influenced by the range of physical and chemical properties of water encountered particularly temperature, pH, and mineral constituents.

(ii) It should not leave by-products of reaction which render the water toxic or impart colour otherwise will make it unpotable.

(iii) It should possess the property of leaving measurable residual concentrations to deal with possible recontamination.

(iv) It must be amenable to detection by practical, rapid, and simple analytical techniques in the small concentration ranges to permit the control of the disinfection process.

The efficiency of chemical disinfection is influenced by the following factors:

(i) Type, condition, concentration, and distribution of organisms to be destroyed.

(ii) Type and concentration of disinfectant.

(iii) Chemical and physical characteristics of water to be treated.

(iv) Contact time available for disinfection.

(v) Temperature.

9.3 Type, Condition, and Concentration of Microorganisms to be Destroyed

A chemical disinfectant has to diffuse through the cell wall before it can react with the enzyme systems. Since the different types of organisms have different cell structures and enzyme systems, the action of the disinfectant varies accordingly. Among intestinal organisms, pathogens are less resistant than the coliform group and hence, the latter can serve as a convenient index of the efficiency of disinfection.

Viruses appear to be more resistant than bacteria and require longer periods of contact as well as a higher concentration of disinfectant. The condition in which the organisms occur may also affect the efficiency of disinfection. Thus, when the bacteria are clumped together, the cell inside the clump may be protected against the action of disinfectant. The density of the organisms affects efficiency when the number is so high that there is a deficiency of available disinfectant. Such a condition may occur in the disinfection of sewage but is not usual in water works practice.

9.3.1 Type and Concentration of Disinfectant

The efficiency of disinfection will obviously depend on the nature of the disinfectant. The added chemical undergoes several transformations so that the disinfecting action is exerted by the end products of the reaction. The course of these reactions is largely influenced by the character of the water and its constituents. These reactions that may occur under different conditions will determine the type and proportion of the active disinfectants. The higher the concentration of a chemical disinfectant, the higher the destruction of organisms.

9.3.2 Chemical and Physical Characteristics of Water to be Treated

Chemical and physical characteristics of water affect the reach of the disinfectant and thus its efficacy. For example, organic matter and certain oxidising constituents in water reduce the availability of active products for disinfection. Embedded organisms in suspended materials in water may be sheltered from the action of disinfectant.

9.3.3 Time of Contact available for Disinfection

The destruction of organisms increases with the contact time available for disinfection. In practice, the contact period is limited by the design of the water treatment plant.

9.3.4 Temperature of the water

Rates of chemical reactions are speeded up as the temperature of the reaction is increased. The higher the temperature, the more rapid is the destruction of organisms.

9.4 Mathematical Relationships Governing Disinfection Variables

The kinetics of disinfection are affected by several variables. The effect of some of these disinfection variables can be quantified by empirical mathematical relationships. Under ideal conditions, three main variables alter the rates of disinfection, namely (i) the time of contact, (ii) the concentration of the disinfectant, and (iii) the temperature of water.

9.4.1 Contact Time

Contact time is an important variable affecting the rate of destruction of organisms, generally speaking, under ideal conditions and at a constant temperature. The number of organisms (N_t) surviving after a period of time t is related to the initial number (N_o) by

Chick's law,

$$log\frac{No}{Nt} = k.t \tag{9.1}$$

Where k is constant with dimension (T^{-1})

Departures from Chick's law are not uncommon; rates of kill have been experimentally observed to increase with time in some cases and decrease with time in other cases. To account for these departures from Chick's law, the following modified equation is suggested:

$$log\frac{No}{Nt} = k.t^{m} \tag{9.2}$$

Where m is a constant. If m is less than 1, the rate of kill decreases with time and if m is greater than 1, the rate of kill increases with time. Laboratory analysis and subsequent interpretation of data may provide useful information for design purposes.

9.4.2 Concentration of Disinfectant

The rate of disinfection is affected, within limits, by changes in the concentration of disinfectant. The relationship between disinfectant concentration and the time required for killing a desired percentage of organisms is generally expressed by the following equation:

$$C^n \text{ x } t_p = \text{Constant} \qquad (9.3)$$

Where C is the concentration of disinfectant, n is a coefficient of dilution and t is the time required for a constant percentage kill of the organisms.

9.4.3 Temperature of Water

At a lower temperature of water (e.g., in the winter season) the time required for achieving the same percentage of kill for the same concentration of disinfectant would be higher than those for a higher temperature (e.g., in summer months). If the time of contact cannot be changed due to design constraints, doses of disinfectants will have to be changed to account for changes in temperature to achieve the same percentage of kills.

9.5 Chlorination

Chlorination is the most widely used method for disinfecting water supplies across the world. The near universal adoption of this method can be attributed to its convenience and to its highly satisfactory performance as a disinfectant, which has been established by decades of use.

9.5.1 Chlorine Demand

Chlorine and chlorine compounds, by virtue of their oxidising power, can be consumed by a variety of inorganic and organic materials present in the water before any disinfection is achieved. It is, therefore, essential to provide sufficient time and dose of chlorine to satisfy the various chemical reactions, and leave some amount of unreacted chlorine as residual, either in the form of free or combined chlorine, adequate for killing the pathogenic organisms.

The difference between the amount of chlorine added to water and the amount of residual chlorine after a specified contact period is defined as the chlorine demand. The chlorine demand of any given water varies with the amount of chlorine applied, the time of contact, pH, temperature, and form of residual desired.

9.5.2 Chlorination Practices

The type of available chlorine residual required, and the characteristics of the water being treated, determine the process of disinfection to be employed. All chlorination practices, irrespective of the point of application, may be classified as free available residual chlorination (i.e., break point or super-chlorination) or combined residual chlorination, depending on the nature of the chlorine residual formed.

9.6 Free available residual Chlorination

9.6.1 Plain or simple chlorination

This involves the application of chlorine to water as the only type of treatment to offer the necessary public health protection. Plain chlorination can be carried out in a situation where:

(i) Turbidity and colour of the raw water are low, turbidity should not be exceeding 5 NTU;

(ii) Raw water is drawn from relatively unpolluted sources;

(iii) Water contains little organic matter, and iron and manganese do not exceed 0.3 mg/L; and

(iv) A contact period of a minimum of 30 minutes between the point of chlorination and the consumer end is available.

9.6.2 Super-Chlorination

This is adopted in case of an emergency situation such as a breakdown or in case of waters that are heavily polluted or fluctuate rapidly in quality. It can give excellent results in waters where:

(i) Plain chlorination produces taste and odour;

(ii) The water is coloured; or

(iii) Iron and manganese have to be oxidised.

It may be resorted to on special occasions when available contact time is limited at the pre-chlorination stage. Super-chlorination can effectively destroy relatively resistant organisms such as viruses and amoebic cysts. The dose of chlorine may be as high as 10 to 15 mg/L with contact periods of 10 to 30 minutes. Subsequently, the undesirable excess chlorine will have to be dechlorinated.

9.6.3 Breakpoint Chlorination

The addition of chlorine to ammonia in water produces chloramines which do not have the same efficiency as free chlorine. If the chlorine dose in this water is increased, a reduction in the residual chlorine occurs, due to the destruction of chlorine by the added chlorine. A few possible chemical reactions are as below:

$$2NH_2Cl + HOCl \rightleftharpoons N_2 + 3HCl + H_2O$$

$$2NH_2Cl + 2NHCl_2 + HOCl \rightleftharpoons N_2O + N_2 + 7HCl$$

The end products do not represent any residual chlorine. This fall in residual chlorine will continue with a further increase in chlorine dose and after a stage, the residual chlorine begins to increase in proportion to the added dose of chlorine. This point at which the free residual chlorine appears after the entire combined chlorine residual has been completely destroyed is referred to as breakpoint and the corresponding dosage is the breakpoint dosage. Breakpoint chlorination achieves the same results as super-chlorination in a rational manner and can therefore be construed as controlled super-chlorination in the case of polluted raw water. Figure 9.2 shows the breakpoint chlorination curve.

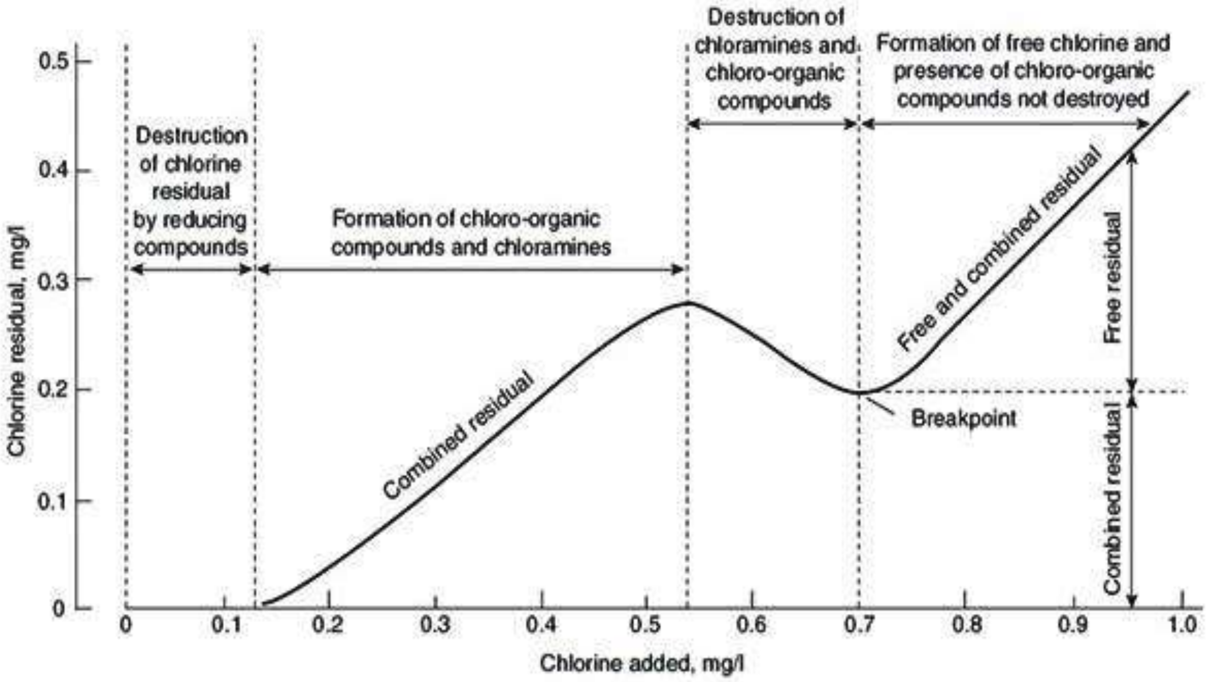

Figure 9.2: Break Point Chlorination Curve

9.6.4 Combined Available Residual Chlorination

This method involves the application of chlorine to the water to react with natural and added ammonia, to form a predominantly combined monochloramine chlorine residual. Doing this will produce the most reliable way to maintain the residual through part or all of a water treatment plant or distribution system. Chloramines are less effective disinfectants and oxidants than free available chlorine forms but the residual will persist much longer than free available chlorine which has a tendency to diffuse and be lost. A minimum of 30 to 60 minutes of contact time must be provided before delivery to the consumer and in long transmission mains and non-looped distribution systems, monochloramine residual should be maintained to the furthest point in the system 24/7. Depending upon the characteristics of water, this can be accomplished as follows:

- (i) Application of chlorine only, if sufficient ammonia is present in the water;
- (ii) Addition of both chlorine and ammonia, if it contains little ammonia; or
- (iii) Addition of ammonia, if free available residual chlorine is already present in water.

In order to control chlorine-ammonia treatment effectively, the optimum ratio of chlorine to ammonia has been found to be between 3:1 and 4:1 to optimise any remaining level of free ammonia in the system. Free ammonia in the system can cause nitrification in the distribution system and that should be avoided.

This practice is useful after filtration for controlling algae and bacterial growths, for reducing ‘red water’ troubles in distribution systems at dead ends, and for providing and maintaining a stable residual throughout the distribution system.

9.7 Real-Time Chlorine Concentration

Modern software available to the water sector pertaining to distribution system has the ability to predict real-time chlorine concentration using the sensor data from distribution pipe network for 24×7 water supply system. The data generated by SCADA or the IoT sensors is pushed to the cloud service of digital twin technology, where this data is saved, and predictive analysis is made.

The data is then sent back to human machine interface (screen) of SCADA of ULB where the real-time graphs of chlorine concentration are delineated. Sensors have been discussed in Part B, Chapter 10: Automation of Water Supply of this manual.

9.8 Points of Chlorination

The use of chlorine at various stages of the water supply system right from raw water collection to the distribution network is a common practice and terms like pre-chlorination, post- chlorination and re-chlorination have come into common usage depending upon the points at which chlorine is applied.

9.8.1 Pre-chlorination

Pre-chlorination is the dosing of chlorine to raw water prior to any unit treatment process and is generally upstream of Parshall flume. The point of application, as well as dosage, will be determined by the objectives viz., control of biological growths in raw water conduits, promotion of improved coagulation, prevention of mud ball and slime formation in filters, reduction of taste, odour, and colour, and minimising the post-chlorination dosage when dealing with heavily polluted water. Pre-chlorination is also required to control and prevent the growth of algae. However, in order to reduce the formation of disinfection by-products (DBPs), the practice of dosing chlorine dioxide with chlorine is increasing. For the same reason, ozone application is increasingly used in pre-oxidation.

Satisfactory disinfection is obtained by Pre-chlorinating to maintain 0.10 to 0.20 mg/L free residual chlorine in the outlet of filter at normal pH values.

9.8.2 Post-chlorination

Post-chlorination is the application of chlorine to water before it enters the distribution system to maintain the required amount of free residual chlorine. Post-chlorination dose is applied with 30 minutes of contact time in chlorine contact tank before the water enters the clear water sump. Many times, a booster chlorine dose is required at the service reservoirs in the distribution system to maintain the residual chlorine level.

9.8.3 Re-chlorination

When the distribution system is long and complex, it may be difficult to maintain the minimum chlorine residual of 0.2 mg/L at the farthest end. To achieve this, if a very high dosage is applied at the post-chlorination stage, it would, apart from being costly, make the water unpalatable at the reaches close to the point of chlorination. The maintenance of the required residual, in such cases, can be accomplished by a stage-wise application of chlorine in the distribution system which is called re-chlorination. Re-chlorination is carried out in service reservoirs, booster pumping stations, or at points where the delivery mains supply to distribution zones. Real-time measurement for critical locations needs to be incorporated into the system.

9.8.4 Chlorine Residual

In the post-monsoon period, the minimum residual chlorine shall be maintained as 0.20 mg/L at the end of the distribution system, and during monsoon or in epidemics, 0.50 mg/L at the end of the distribution system. Practically, the chlorine concentration at entry point of distribution system or service reservoir and furthest point in the distribution is measured. This exercise is repeated for four to five readings and then a graph of initial chlorine concentration versus residual chlorine at end is plotted. From this graph, the required initial chlorine dose is determined.

Generally, groundwater sources are naturally pure because water percolates through various layers of soil. A required chlorine dose needs to be added in the service reservoir or the outlet of the tube well for direct pumping to maintain residual chlorine of 0.20 mg/L at end of the operation zone/DMA of distribution system.

Total chlorine and free residual chlorine can be determined using BIS Standard IS 3025 (Part 26): 2004, Methods of sampling and test (physical and chemical) for water and wastewater.

9.9 Application of Chlorine

Chlorine can be applied to water by three methods:

(i) By the addition of a weak solution prepared from bleaching powder, HTH (high-test hypochlorite), etc., for disinfecting small quantities of water.

(ii) By the addition of a weak solution of chlorine prepared by electrolysing a solution of brine.

(iii) By the addition of chlorine, either in gaseous form or in the form of a solution made by dissolving gaseous chlorine in a small auxiliary flow of water, the chlorine gas is obtained from pressurised chlorine cylinders.

The first method of chlorine application has the merits of simplicity, non-requirement of electrical energy, and relative safety in operation and handling as available chlorine is either in powder or solution form. However, the demerits include instability of bleaching powder, its hygroscopic nature, and a relatively low percentage of available chlorine (25%-33%). To overcome these disadvantages, some variants with the basic chemical compound of calcium hypochlorite are recommended. These compounds possess a high chlorine content of about 65%-70% and are stable, easily soluble, and non-hygroscopic. However, these are expensive and require safety in handling.

The second method of chlorine application requires the deployment of electro-chlorinators to prepare a chlorine solution from the electrolysis of water containing sodium chloride. An electro-chlorinator essentially comprises of a direct current (DC) source for providing energy for electrolysis, an electrode pair installed in a container, and a hypochlorite solution storage and dispensation device. During electrolysis, chlorine is not created as a gas but is available in solution form as a sodium hypochlorite solution. This is the major advantage of this technique as transportation, storage, and application of chlorine gas involve major safety considerations to avoid hazards and fatal accidents.

The third method of chlorine application is presently the common practice for medium to large public water supplies. However, it requires elaborate safety practices and the use of chlorinators or chlorine evaporators and auxiliary equipment.

9.10 Chlorinators

A chlorinator is a device designed for feeding chlorine to a water supply. Its functions are:

(a) To regulate the flow of gas from the chlorine container at the desired rate of flow.
(b) To indicate the flow rate of gas feeding.
(c) To provide means of properly mixing the gas either with an auxiliary supply of water or with the main body of the liquid to be disinfected.

The main components are summarised in Table 9.1.

Table 9.1: Chlorinator system components

Part	Purpose
Vacuum Regulator	Reduces the gas pressure from the container (minimum one bar) to the sub-atmospheric pressure of the chlorinator and

Part	Purpose
	adjusts the gas flow rate to correspond to the vacuum set by the adjustment of the V-notch plug within its orifice.
Pressure Relief System	Discharges chlorine gas to the outside through the pressure relief vent or valve, if excessive gas pressure in the chlorinator should occur.
Positioner	Controls the rate of gas flow through the chlorinator by adjusting the position of the V-notch plug within its orifice, generally by automatic control with a manual override.
Flowmeter	Indicates chlorinator feed rate. (Read the widest part or top of the float or centre of the ball for rate marked on tube).
Differential Regulating Valve	Ensures that the vacuum differential across the gas control V-notch plug is consistent.
Pressure Check Valve	Prevents water back feeding into the chlorinator from the injector.
Vacuum Relief System	Admits air into the chlorinator system through the vacuum relief vent or valve, if excessive vacuum should occur.
Pressure Gauges	Indicate gas pressure at the containers and water pressure at the injector.
Vacuum Gauges	Indicate vacuum in the chlorination system.
Injector	Creates the vacuum for the system and sucks the chlorine gas into the operating water supply to form the chlorine solution for injection into the water supply to be disinfected.
Vacuum Switch	A local or remote mounted vacuum switch provides an alarm in the event of a high or low vacuum condition signifying a loss of gas feed
Gas Warning Light, Audible Alarm and Air Blower Switch	Give warning that a predetermined level of chlorine gas has been detected in the air of the chlorine store and enables air blower to be switched on to displace gas from store via the low-level inlet and air duct to the outside.

9.10.1 Types of Feeders

Chlorinators are used for the control and measurement of chlorine in the gaseous state and to supply chlorine as a gas or an aqueous chlorine solution. The principle of operation of this equipment depends on the regulation of flow by establishing a pressure relationship between the upstream and downstream sides of either a constant, or a variable orifice in the chlorine flow gas line. Control of the feed rate is affected either by varying the pressure differential across a fixed orifice (variable differential unit) or by varying the size of the orifice (constant differential unit). The requirement for chlorination equipment should adhere to IS 10553 (Part 1) (1983, reaffirmed 2022).

These feeders are of two types, viz., (a) Pressure type and (b) Vacuum type.

(a) Pressure Type Gravity Feed Chlorinator (IS 10553-4, 1983, Reaffirmed 2021)

(b) Vacuum Type Chlorinator (IS 10553-2, 1983, Reaffirmed 2021)

9.10.2 Number of Chlorine Cylinders or Containers

The normal chlorine dosage required to disinfect water in public water supply systems, not subject to significant pollution, would not exceed 2 mg/L. The actual chlorine dosage has to be determined on the basis of chlorine demand tests. The chlorine feed rate is then computed by dividing the expected maximum dosage of chlorine by the maximum flow rate.

Total daily chlorine requirements can be estimated from the daily average consumption in a maximum day. The peak and the minimum rate requirements should be taken into consideration when designing a chlorine supply and feeder system and not merely the total daily requirements of chlorine.

When chlorine gas is withdrawn from a cylinder containing the liquefied gas, the pressure drops, and the liquid 'boils' liberating more gas till the pressure is restored. This boiling absorbs heat continuously, then produces a cooling effect in the liquid region. If the withdrawal is continued, the liquid may freeze, and no more gas will be evolved. It is, therefore, essential to keep the atmosphere, around the containers in service, warm and to ensure that there is no abnormal rate of withdrawal from a single container with heavy demand for gas.

The recommended discharge rates are approximately 6.5 to 7.5 kg/hr. from a one-tonne container and 0.8 kg/hr. from cylinders. Equipment should have sufficient capacity to exceed the highest expected demand at any time and to provide continuous effective discharge under all prevailing hydraulic conditions. It is a good practice to arrange for duplicate/standby equipment since the disinfection process cannot be stopped at any time.

When the gas discharge rate from a single container will not meet the requirements, two or more can be connected to a manifold and discharge simultaneously. It is advisable not to couple more than four containers to a manifold. When discharging through a manifold, care must be taken that all the containers are at the same temperature, particularly when connecting a new cylinder to the manifold. Where more than three or four cylinders are used, the connections would be arranged in groups so that one complete group can be changed at a time. Storage of chlorine lasting a month or two should be provided. It is advisable to keep the full cylinders in the same room as the cylinders in service.

The chlorine tonner/cylinder are available according to their weights in 45, 67, 100 and 900 kg. For using this type of tonners, the rule of thumb is 1 MLD capacity plant requires 1 kg of chlorine to generate 1 mg/L of residual chlorine. The tonner/cylinder replacement period is normally considered as 45 days.

9.10.3 Chlorine Cylinder/Tonner Store and Chlorination Room

The chlorine cylinders and feeders should be housed in an isolated room, easily accessible, close to the point of application, and convenient for truck loading and safe container handling. The floor should be at least 15 cm above the surrounding ground and drainage, should have at least two exit doors or the building should have at least two exit doors for cross ventilation that allows an approximate air change in 10 minutes. For small installations, the provision of a ventilator opening at the bottom, one opposite the other is adequate.

Separate and reasonably gas-tight enclosures, opening to the outdoors, should be provided for housing the chlorine feeding equipment in large installations and buildings occupied by waterworks personnel. These enclosures should be vented to the upper atmosphere and equipped with positive means of exhaust (near the floor level, at the centre of the room or opposite to the entrance) capable of a complete air change within 2 to 4 minutes in an emergency. A satisfactory ventilation scheme involves a combination of fresh air and an exhaust system, consisting of fans that force the fresh air into the enclosure through openings near the ceiling with exhaust fans to clear away any chlorine contaminated air near floor level. The design of the exhaust system should not include the natural ventilation that may be available.

Additionally, a gas scrubber system should also be provided along with an absorption tower for safety.

9.10.4 Chlorine Evaporators

Chlorine vaporisers, better known as evaporators, are needed whenever conditions require the withdrawal of liquid chlorine from the containers. Typically, this action is necessary when the daily chlorine requirements exceed 100 to 1000 kg and would require the manifold provisioning for the excessive number of containers. Evaporators provide the heat necessary to vaporise or change the liquid chlorine to the gaseous state so that it may be handled in the normal fashion by the other components of the chlorination system.

An evaporator consists of a chlorine pressure vessel to which heat can be applied under controlled conditions, the source of heat may be electricity, steam, or hot water with several different models and versions available from different manufacturers. The most commonly used models are electrically heated and have maximum rated capacities of 150 kg/hr. In all cases, the source of heat is thermostatically controlled to maintain a constant temperature and ensure a superheated chlorine gas output.

The liquid absorbs heat from the water chamber through the wall of the pressure vessel until it reaches the vaporisation temperature and boils, releasing chlorine gas. With the chlorination system in operation, gas is withdrawn from the pressure vessel, allowing more liquid to enter the system and continue the process. The gas leaving the vessel contacts the hot upper wall and causes the gas to be heated to a higher or superheated temperature. Baffles may be used to assist heat transfer.

As heat is absorbed by the chlorine, the water is cooled until it drops below the control thermostat setting and causes the electric immersion heater to be actuated. The heater remains on until the water reaches the upper limit of the thermostat. At this point, the heater is shut off and this cycle is continued as long as the evaporator is in use. As chlorine is vapourised, any impurities contained in the liquid are left behind, coating the inside surface of the pressure vessel. This coating acts as an insulator that inhibits heat transfer from the water to the chlorine and necessitates higher and higher water bath temperature settings. Eventually, the pressure vessel will require cleaning as the evaporator will be unable to vaporise the desired amount of chlorine gas at the desired degree of superheat. The frequency of cleaning will vary from installation to installation and is a function of chlorine purity and the chlorine feed rate. The evaporator manufacturer's cleaning instructions should be followed closely for best results.

Typically, evaporators are supplied with various gauges and controls, in addition to the control thermostat, to permit simple, safe operation. Taken individually, they include the following components.

- Control thermostat senses the water temperature and turns the heater on and off to control water bath temperature.
- Water-level gauge is a sight glass that permits the operator to observe the water bath level.
- A chlorine bath-pressure gauge indicates chlorine gas pressure within the pressure vessel.
- The chlorine gas temperature gauge indicates the temperature of the superheated chlorine gas leaving the pressure vessel.

- Water temperature gauge indicates the temperature of the water bath.
- Low water temperature switch actuates a persistent lower water bath temperature, which normally indicates loss of the heater system. The switch may be used to actuate an alarm and automatically close the chlorine gas ‘shut off’ valve to avoid the pulling of liquid chlorine into the gas system.
- High water temperature switch actuates a persistent high water bath temperature. Excessive temperature may be caused by i) by failure of the heater controls, which allows the heater to remain on; or ii) by loss of water from the water bath. The switch may be used to actuate an alarm and turn off power to the electric heater.
- Low water level switch actuates a persistent low water bath level, caused by a failure of the water supply system. Switches may be used to actuate an alarm and automatically open a water valve.
- Magnetic heater contactor acts in response to the control thermostat to energise or de-energise the electric immersion heater.
- Cathodic protection protects from corrosion to all metal surfaces of the evaporator in contact with water.
- The vent alarm switch actuates whenever gas flow occurs in the vent line and indicates that the gas pressure relief valve is opened.
- A liquid chlorine expansion tank protects the liquid chlorine piping system from damage due to overpressure by offering a chamber into which the liquid can expand. This tank is strongly recommended for installation in any section of liquid piping which may be purposely or accidentally isolated by closing valves.

Some, or all, of the aforementioned controls, gauges, and accessories may be supplied with an evaporator.

9.11 Electrolytic Chlorinators or On-site Chlorine Generators

Rather than storing traditional chlorine gas chemicals such as sodium or calcium hypochlorite, one can use electricity, salt, and water to generate sodium hypochlorite, safely, and on demand. This technology is commonly referred to as electro-chlorination (EC), chlorine electrolysis, or in-situ chlorine generation.

EC system works on a simple principle of electrolysis of brine solution (sodium chloride salt solution). There are two electrodes - anode and cathode, placed at a specific distance, between which the brine solution is passed. A low voltage is applied. The potential difference is responsible to create a current through the brine, which is a good conductor of electricity. In this process, dissociated salt (NaCl) breaks down into Na+ and Cl- ions. A small amount of hydrogen gas is also evolved. Following reactions take place:

$$NaCl + H_2O + 2e^- = NaClO + H_2$$

NaClO (or NaOCl) is sodium hypochlorite, which is then injected for disinfection at a suitable point.

Hydrogen gas, being in very small amounts, does not impose any operational hazard. It is suitably vented off.

A representative diagram of EC system is given in Figure 9.3:

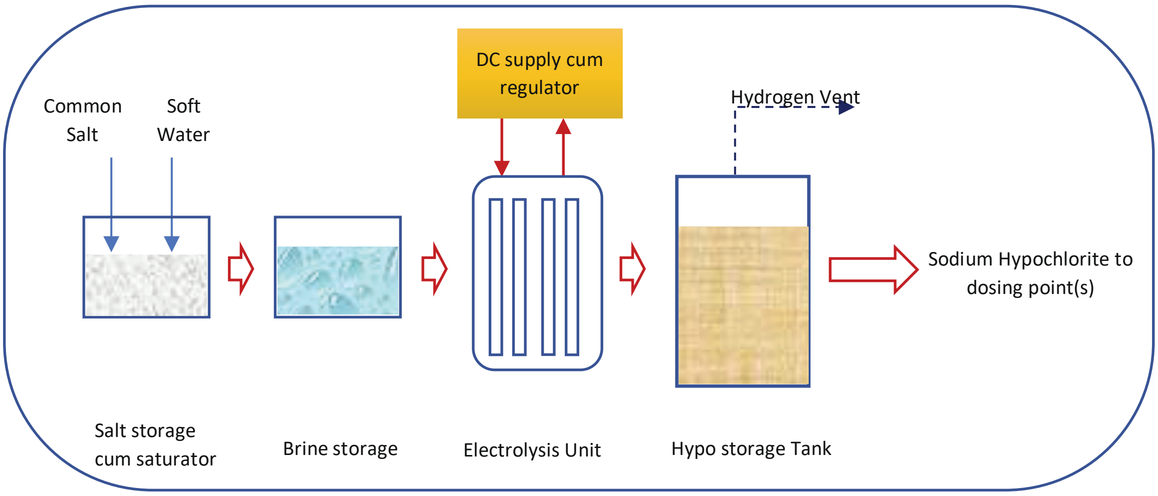

Figure 9.3: Electro-chlorination (EC) system

The hydrogen by-product is diluted with a large volume of air in an enclosed ventilation system and is discharged safely into the atmosphere. The supersaturated salt solution is diluted to a 3% concentration. Chlorine is generated at the anode and caustic soda is generated at the cathode. They react with each other to form dilute (0.5% to 1%) sodium hypochlorite solution. Electro-chlorinators are commercially available in India in capacities ranging up to 1000 g/hr. of chlorine using the salt solution and up to 100 kg/hr. of available chlorine using seawater. It is reported that power consumption may be less than 5 kWh/kg of available chlorine for units with capacities greater than 500 g/hr. and common salt requirements are of the order of 4-4.5 kg/hr. of available chlorine. However, no IS specifications are presently available for these electro-chlorinators, and these electro-chlorinators are based on emerging technology.

Though power consumption is low, and cost of common salt is negligible, it is experienced that the capital cost of these units is huge and require skilled supervision. Also, annual maintenance charges are on the higher side.

9.12 Ancillary Equipment

9.12.1 Weighing Machines

Weighing scales are necessary to record the weight of chlorine used in 24 hours which would serve as a check of the daily consumption and also enable the cylinders to be changed when they get empty.

9.12.2 Personnel Protection Equipment

Severe exposure and potential health hazards exist wherever toxic compressed gas and other respiratory irritants are handled or used. An approved gas mask should be provided for every employee involved with handling them. Additionally, suitable protective equipment for emergency use should be available outside rooms where hazardous materials are located near the entrance, away from areas of likely contamination. Such equipment might be provided in several locations at larger installations.

Canister type gas masks with a full-face piece and specific or all-purpose commodity canister should be used only for relatively short exposure periods and only if it has been clearly established that sufficient oxygen is present (not less than 16% in air) and that contamination does not exceed the allowable level (1% of chlorine). Canister masks might not be useful in emergencies since these criteria might not be readily ascertained, especially if suitable forced ventilation schemes are not provided. Regular replacement of overage canisters, even though unused, is recommended.

Self-contained breathing apparatus, with a full-face piece and a cylinder of air or oxygen carried on the body or with a canister that produces oxygen chemically, is suitable for high contaminant concentrations and is the preferred means of respiratory protection. Protection is provided for a period that varies with the amount of air, oxygen, or oxygen-producing chemicals carried.

Respiratory protective equipment should be carefully maintained, inspected, and cleaned after each use and at regular intervals. Defective or inoperable equipment is worse than none at all. All such equipment should be used and maintained in strict accord with the manufacturer's instructions, no person should enter contaminated areas unless attended by an observer who can rescue him in the event of a respiratory problem or other emergencies.

It is a good practice to provide eye protection devices (or masks with full-face pieces) and other protective clothing for workers exposed to hazardous materials. Emergency showers, eye baths, or other suitable water-flush systems should be provided in convenient locations for use by accidentally exposed personnel. Installation of an automatic chlorine leak detector with or without visible or audible alarms should be considered. The typical arrangement of PPE at the time of installation is shown in Figure 9.4.

Figure 9.4: Typical arrangement of PPE at time of Installation

9.12.3 Chlorine Detectors

Continuous monitoring of the atmosphere in areas where chlorine is stored and fed is an important aspect of any safety programme. Instruments for this purpose are called chlorine detectors, which are not to be confused with the detectors used for measuring residual chlorine in the water.

Concentrations are expressed as ppm by volume in air, not as parts per million parts by weight, as the expression is used to denote concentrations in water. For comparison, 1 ppm of chlorine by volume in air is equivalent to 3 mg/m^3 of air. The threshold of odour perception is about 3 ppm.

Two types of detectors are available. In type one, the air to be sampled is directed to a rotating drum covered with a strip of sensitised paper. The paper is white and light is reflected from it to a photoelectric cell. The current from the cell is amplified and used to keep an electric relay open in an alarm circuit. If the air sample contains chlorine, the paper darkens, the light is absorbed, the current from the photoelectric cell drops below that required to keep the relay open and thus the alarm circuit is energised.

In the second type, air from the point or points of sampling is drawn to the detector by an air pump through a filter and flowmeter that indicates the sample flow rate. The air sample is directed to an electrochemical sensing cell, the electric output of which increases with the presence of chlorine. A meter movement is incorporated to indicate visually the strength of the chlorine in the air and an adjustable switch is included to provide a contact closure for remote audible/visual alarms and, or remotely operate an exhaust fan.

9.12.4 Automatic Changeover System

Increased emphasis on the need for uninterrupted chlorination has led to the use of automatic changeover systems, particularly at unmanned stations. The basic concept of these systems is to switch from a depleted source of chlorine to a standby source automatically without the presence of an operator. Several methods have been used to accomplish this. One system consists of electrically operated chlorine shut-off valves, actuated by a chlorine pressure switch that senses the loss of chlorine pressure due to empty cylinders. Another system uses two pressure-reducing valves, each attached to its own source of chlorine and manifold on the downstream sides. The pressure settings of the two valves are adjusted so that the valves control at a pressure approximately 3.52 m H_2O apart. Since a pressure-reducing valve will not open until the downstream pressure is lower than its setting, the valve with the higher setting opens first, allowing gas to flow through the valve from its source. This process continues until the first source is depleted and the downstream pressure drops to the setting of the second valve, at which point it opens and chlorine flows from the standby source.

The recent development of small cylinder-mounted chlorinators has added more types of automatic changeover systems to the marketplace. It is not necessary to detail the operation of each, but merely to state that they meet the basic need of permitting continuous chlorine feed in a simple inexpensive manner for even the smallest gas chlorination facilities.

9.13 Safety Considerations

(i) Only trained personnel should be permitted to handle chlorine cylinders and chlorinating equipment. They should be made aware of the hazards involved, the precautions to be observed and first aid to be rendered in emergencies. Rubber gloves, aprons, and suitable gas masks should be provided. These should be housed in an easily accessible (unlocked) cupboard placed outside the chlorinator room. It is very important that the operating personnel are trained in the proper use of gas masks. A faulty gas mask is worse than none at all. Hence, it is very important that these are tested frequently, and the containers are changed at proper intervals.

(ii) When a chlorine leak occurs, the mechanical ventilation system should be opened immediately before any person enters the chlorine room. It must be made a point that chlorine container valves are closed first before any investigation is started.

(iii) Cylinders containing chlorine should be handled gently. They should not be bumped, dropped, or rolled on the ground and no object should be allowed to strike them with force. The protective hoods over the valve should always be kept in place except when the cylinders are in use. Flames should never be applied to chlorine cylinders or their valves.

(iv) Cylinders should not be stored in the open or damp places. Empty cylinders should be stored away from full cylinders so that they do not get mixed up. It would be desirable to tag the empties as an additional precaution. Incidentally, this will ensure the prompt return of used cylinders.

(v) In case the valve is found to be stuck, the cylinder should be immediately returned to the supplier. No attempt should be made to ease a stuck valve by hammer, as this is very dangerous.

(vi) Only the spanners prescribed for use should be used as it is important not to put too much leverage on the valves.

(vii) Cylinders, as well as the chlorinators, must be tested at the start and end of every shift period, for leaks, first by trying to detect the sharp irritating smell of chlorine, then by passing over each cylinder and around each valve and pipe connections, a rod with a small cotton wool swab tied on the end, dipped in an aqueous solution of ammonia. Any leakage noticed anywhere must be attended immediately otherwise same is going to lead major trouble in the plant. If chlorine is present in the air, the swab will appear to 'smoke' due to the formation of white clouds of ammonium chloride. If the leak appears to be heavy, all persons not directly concerned should leave the area and the operator should put on his mask and make a thorough search for the leak. In tracing a leak, always work ‘downstream’, i.e., start at the cylinder and work down along the line of flow until the leak is found. It will save many valuable minutes over the practice of starting in the middle of the chlorinator and searching vaguely back and forth over the whole equipment.

(viii) Water should never be applied to a chlorine leak to stop it as it will only make the release of ‘free chlorine’. If the leak is in the chlorinator, the cylinder should be immediately shut off until the pressure has reduced. The joint or gasket should be repaired, and replaced with new packing, if necessary.

(ix) Solvents such as petroleum, hydrocarbons, or alcohols should not be used for cleaning parts that come in contact with chlorine. The safe solvents are chloroform and carbon tetrachloride. Grease should never be used where it can come in contact with chlorine as it forms a voluminous frothy substance on reaction with chlorine. The only special type of cement, recommended by manufacturers, should be used.

(x) No direct flame should be applied to a chlorine cylinder, when heating becomes necessary, as this is hazardous. A water bath, with a controlled temperature not to exceed 27 °C, should be used.

(xi) Before disconnecting the flexible lids from containers to gas headers, the cylinder valves should be closed first and then the gas under pressure should be drawn from the header and flexible lids before the header valve is closed. The exhaust system should be turned on and operated on while the cylinders are being disconnected or repairs are being made.

The arrangement inside of chlorinator room and tonner room at the site is shown in Figure 9.5. The new development in safety for chlorine tonner as tonner safety container shells is shown in Figure 9.6. The arrangement at the site from outside of a tonner room is shown in Figures 9.7 and Figure 9.8.

Figure 9.5: Chlorinators (Vacuum Type), booster pumps, Tonner handling in Maharashtra

Figure 9.6: New Development as tonner safety container shells have been developed

Figure 9.7: Installation of chlorine cylinders (100 kg) and chlorinators At Packaged water treatment plant, Rajapur, Dist. Ahemadnagar, Maharashtra

Figure 9.8: Chlorination Room and tonner yard at Ghulewadi (10 MLD) WTP, Dist. Ahemadnagar, Maharashtra

Other safety factors (IS 4263, 1967: Code of Safety for Chlorine, Reaffirmed 2018)

1. Initial lead pipe (armoured plastic or copper) shall be replaced after six months which is normally practised for all types of chlorinators.
2. The gas valve can be opened and closed as per requirement, but the water flow system shall be continuous in operation. It will ensure the remaining gas gets into the solution. This safety

is not seen in any other chlorinators. Hence, there is no O&M to the system. Flowing water is not wasted, it is let in the sump.

3. The tonner/cylinder valve joint and the initial pipe joint with the unit shall be carefully tested with ammonium chloride for checking the leakage of gas.
4. Green plants shall be kept in the vicinity of tonner/cylinders to identify the change of colour of leaves. This practice is for using any type of chlorinators.
5. For safety against tonner/cylinder leakage arrangement to move it to CaO solution tanks shall be provided. This is also common care to be taken for all types of chlorinators.

9.13.1 Handling Emergencies

As soon as there is an indication of a chlorine leak or other abnormal condition, corrective steps should be taken. Leaks never get better by themselves; they always get worse if not promptly and suitably repaired. Authorised trained personnel with suitable gas masks should investigate and all other persons should be kept away from the affected area. The ventilation system should be placed in operation immediately. Unconfined chlorine, being heavier than air, tends to lie close to ground levels (the characteristic must be kept in mind in designing a chemical storage and use areas and an appropriate natural or mechanical ventilation system). If leaks cannot be handled promptly, the chemical supplier or nearest office or plant of the producer should be called immediately for emergency assistance.

In case of fire, containers should be removed from the fire zone immediately. Portable tanks, tank cars, trucks, and barges should be disconnected and if possible, should be removed from the fire zone. Even if there are no visible leaks, water should never be applied to a chlorine container. Chlorine is only slightly soluble in water and the corrosive character of its reaction with water always will intensify the leak. In addition, the heat supplied by even cold water will increase the vaporisation rate. Similarly, leaking chlorine containers should not be thrown into a body of water because the leak will be aggravated and the container might float when still partially full, allowing an uncontrolled gas evolution at the surface.

If a leak occurs in equipment or piping, the supply should be discontinued and the material under pressure at the leak should be disposed of. Leaks around the container valve stem usually can be stopped by tightening the pack out or gland. If this action does not stop the leak, the container valve should be closed and material under pressure in the outlet piping should be disposed of. If the valve does not shut off tight, the outlet plug, or cap should be applied. In the case of a leaking valve of a tonne container, the container should be positioned so that the valves are in a vertical plane with the leaky valve on the top. Additionally, the following actions can be taken if a tonner is found to be leaking:

- Position the cylinders or tonne containers so that gas instead of liquid escapes. The containers may be insulated with sacks, earth, etc., to decrease the absorption of heat and discharge rate.
- Apply appropriate emergency capping devices, if available.
- Call the supplier or nearest producer for emergency assistance.
- If practical, reduce pressure in the container by removing the gas to process or suitable disposal system. Caustic soda, soda ash, or other suitable alkali absorption system should be provided for disposing of chlorine from leaking cylinders and tonne containers.
- In some cases, it might be desirable and possible to move the container to an isolated spot where it will do the least harm.

Safety in handling hazardous materials depends to a great extent upon the effectiveness of employee education, proper safety instructions, intelligent supervision, and the use of safe equipment. Training for both new and old employees should be conducted periodically to maintain a high degree of safety in handling procedures. Employees should be thoroughly informed of the hazards that may result from improper handling. They should be cautioned to prevent leaks and thoroughly instructed regarding proper action to take in case leaks do occur. Each employee should know what to do in an emergency and should be fully informed about first aid measures. In addition, employee training should encompass the following:

- Instruction and periodic drills or quizzes regarding the locations, purpose, and use of emergency fire-fighting equipment, alarms, and emergency crash shutdown equipment such as valves and switches.
- Instruction and periodic drills or quizzes regarding the locations, purpose, and use of personnel protective equipment.
- Instruction and periodic drills or quizzes regarding the locations, purpose, and use of safety showers, eye baths, bubblier drinking fountains, and the closest source of water for use in emergencies.
- Instruction and periodic drills or quizzes of selected employees regarding the locations, purpose, and use of respiratory first-aid equipment.
- Instruction to avoid inhalation of toxic vapours and all direct contact with corrosive liquids.
- Instruction to report to the proper authority all leaks and equipment failures.

Gas Scrubber and/or neutralisation tank shall also be provisioned in the chlorine storage room. These are discussed in the following sections.

9.13.2 Gas Scrubber

This system consists of a blower, an alkali (NaOH) tank, an absorption tower packed with Raschig rings, an alkali circulation pump, piping valves, lightweight FRP, and PVC duct. In the event of a leak that is uncontrollable with the emergency kit, this system would allow the person to breathe easily rather than panic. In this system, the leak is confined by a hood covering the leaking container, sucking the chlorine by blower and delivering it to the absorption tower (Figure 9.9). The chlorine leak absorption capacity of the system is kept 100 kg/hr. and 200 kg/hr. for 100 kg. cylinder and 900 kg. tonner respectively. If one is confronted with other container leaks, one or more of the following procedures should be considered:

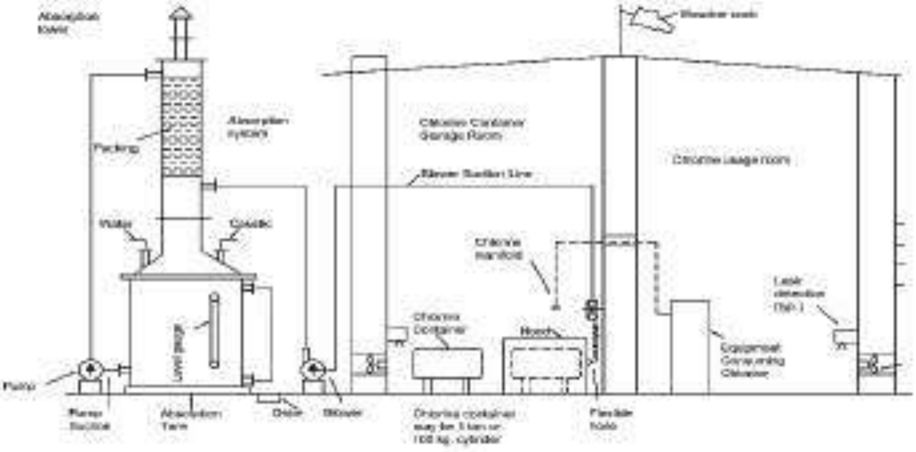

Figure 9.9: Typical Chlorine Leak Absorption System

9.13.3 Neutralisation tank

As a regular part of chlorine storage and use, provisions shall be made for emergency disposal of chlorine from leaking cylinders or ton-containers. Chlorine may be absorbed in solutions of caustic soda or soda ash or agitated hydrated lime slurries. Caustic soda is recommended as it absorbs chlorine more readily. The proportions of alkali and water recommended for this purpose are given below in Table 9.2:

Table 9.2: Quantities of Lime and Soda Ash for emergency disposal of chlorine

Chlorine Container Capacity	**Soda Ash and Water**		**Hydrated Lime and Water**	
kg	Weight (kg)	Volume (l)	Weight (kg)	Volume (l)
45	136	450	58	566
68	220	680	82	815
900	2,720	9,050	1,160	11,350

Source: Section 8.2 in IS 4263

9.14 Chlorine Compounds

Chlorine may also be applied in the form of compounds such as bleaching powder or calcium or sodium hypochlorite which make the chlorine available when they come into contact with water. These are used for disinfection of small water supplies having capacities up to 1 MLD as a primary disinfectant and as an emergency disinfectant for large plants.

9.14.1 Bleaching Powder (IS 1065: Part 2, 2019)

Bleaching powder ($CaOCl_2$) is a variable mixture of calcium hydroxide, calcium chloride, and calcium hypochlorite. When it is mixed with water, the calcium hypochlorite decomposes into calcium chloride and chlorine. The action exerted by bleaching powder, is, therefore, similar to that of gaseous chlorine in the water. Bleaching powder is characterised by its content of available chlorine, i.e., chlorine which can be liberated by complete reaction with water. Commercial brands have available chlorine of 20% to 30%, i.e., 20 to 30 parts by weight of chlorine per 100 parts by weight of bleaching powder. Since fresh bleaching powder contains only 20%-30% available chlorine, its use involves the extra expense of transporting and storing the inert material. Furthermore, bleaching powder is an unstable compound and loses its available chlorine on storage. Bleaching powder is hygroscopic in nature, it loses its chlorine strength rapidly due to storage and, hence, should not be stored for more than three months. Hence, a proper storage arrangement to keep the bleaching powder/bags dry is important. The chlorine content should be periodically measured and recorded to decide the required dosage for disinfection.

Bleaching powder is generally made into a thin slurry with water, and the supernatant, which contains the chlorine in the solution, is applied to the water by a suitable feeding mechanism such as a float-operated gravity box. In every installation, the solution may be applied through a drip feed mechanism. Devices that can give constant feed can be easily fabricated. An injector may be fitted on a bleed line on the pump discharge to suck the solution of the powder in proportion to the flow of water.

All these considerations make its use uneconomical except in very small installations or for special cases such as disinfection of mains. Figure 9.10 show an arrangement at the site for dosing of bleaching powder.

Figure 9.10: Bleaching Powder dosing tanks at 10 MLD Vaijapur WTP, Maharashtra

9.14.2 Hypochlorites

Chemicals used are sodium hypochlorite and calcium hypochlorite. Specially fortified brands of calcium hypochlorite, such as perchloron and HTH, can have 60-70 per cent available chlorine. Calcium hypochlorite can be fed either in the dry or solution form, while sodium hypochlorite is fed as a solution. The solution form is usually preferred. Corrosion-resistant materials such as ceramics, glass, plastic, or special rubber should be used while handling hypochlorite solutions. Generally, 1% to 2% chlorine solutions are prepared and fed directly through solution feeders. Usually, constant head gravity devices with adjustable orifices are used to dose chlorine solution in the tanks. These can be fed through chemical proportioning pumps and can be injected under pressure into pressure pipelines by venturi or orifice feeders.

Sodium Hypochlorite

Sodium hypochlorite (NaOCl) is a solution made from reacting chlorine with a sodium hydroxide solution. These two reactants are the major co-products from most chlor-alkali cells. Sodium hypochlorite, commonly referred to as bleach, has a variety of uses and is an excellent disinfectant/antimicrobial agent. It is a broad-spectrum disinfectant that is effective for the disinfection of viruses and bacteria. Sodium hypochlorite is most often encountered as a pale greenish-yellow dilute solution referred to as liquid bleach, which is a household chemical widely used (since the 18th century) as a disinfectant or a bleaching agent. In solution, the compound is unstable and easily decomposes, liberating chlorine which is the active principal component of such products. The pH of hypochlorite solutions should be raised to over 11 in order to extend the shelf life before it is used.

Sodium hypochlorite can be produced in two ways. One is by dissolving salt in softened water, resulting in a concentrated brine. This brine is then electrolysed to form a sodium hypochlorite solution containing 150 grams of active chlorine per litre. During this reaction, hydrogen gas is also formed. The chemical also can be produced by adding chlorine gas to caustic soda, producing sodium hypochlorite, water and salt as described earlier as electro-chlorinator.

In drinking water facilities, 12 per cent sodium hypochlorite is a disinfectant. In the time that it takes to ship the chemical, it typically degrades to 11 per cent. In the calculations of dosages or concentrations, 10 per cent should be used as the starting point. The decline is predictable if environmental factors are controlled.

Sodium hypochlorite is a strong oxidiser. Oxidation reactions are corrosive, and solutions can burn skin on contact. The strength of commercially available sodium hypochlorite is 10%-15%. Available chlorine is 12%-15%. The shelf life of the solution is six months. Both calcium and sodium hypochlorite are non-hazardous in nature but requires safe handling procedures such as protective gear and eye protection.

Calcium hypochlorite

Calcium hypochlorite [$Ca(OCl_2)$] is an inorganic compound. It has a high alkaline pH level of around 11-12 and contains 25%-30% free available chlorine. It is the main active ingredient of commercial products called bleaching powder, chlorine powder, or chlorinated lime, used for water treatment and as a bleaching agent. This is described in earlier section as bleaching powder.

9.14.3 ClO_2

Chlorine dioxide is an unstable gas, a free radical, and exists as a greenish-yellow to orange gas at room temperature with a characteristic pungent chlorine-like odour. Figure 9.11 show a schematic process diagram and typical arrangement for ClO_2. It is formed by reacting a strong solution of chlorine (7,500 mg/L of Cl_2 at pH 3.5) with sodium chlorite.

$$Cl_2 + 2NaClO_2 \rightleftharpoons 2ClO_2 + 2NaCl$$

The theoretical ratio of chlorine to sodium chlorite is 1:2.6. In practice, however, a large excess of chlorine is generally applied in order to avoid unreacted chlorite in the treated water. Chlorine dioxide is unstable and subject to explosion in gaseous form and easily be detonated by sunlight or heat, but aqueous solutions of the gas are stable and safe. Its solubility in water is 3 g/L at 20 °C.

Chlorine dioxide has many different types of uses, particularly in water treatment. Among these are disinfection, bleaching, and chemical oxidation. It has been reported to be a good bactericide and algaecide, and its bactericidal efficiency are relatively unaffected by pH between 6 and 10. It does not combine with ammonia and most organic impurities before oxidising them. The common dosages of chlorine dioxide range from 0.2 to 0.3 mg/L. Although chlorine dioxide is itself a disinfectant, the excess chlorine used in its generation, apart from ClO_2 is generally counted upon to achieve disinfection. It can be effectively used for the destruction of tastes and odours, particularly those which are caused by phenolic substances. ClO_2 does not produce trihalomethane or HAAS, which are the precursor to the formation of DPBs. There is a growing worldwide practice to use a combination of chlorine dioxide along with chlorine in the pre-chlorination units.

Gas phase chlorine dioxide concentrations in excess of 10% can decompose rapidly. This is the reason that chlorine dioxide must be generated at its point of use. For on-site generators, three feed chemical combinations are available: 1) chlorine-sodium chlorite, 2) acid-sodium hypochlorite-sodium chlorite, and 3) acid-sodium chlorite. In India, in some plants in the public water sector, ClO2 and combination with NaClO have shown promising results to treat algal laden water and vegetation imparted colour.

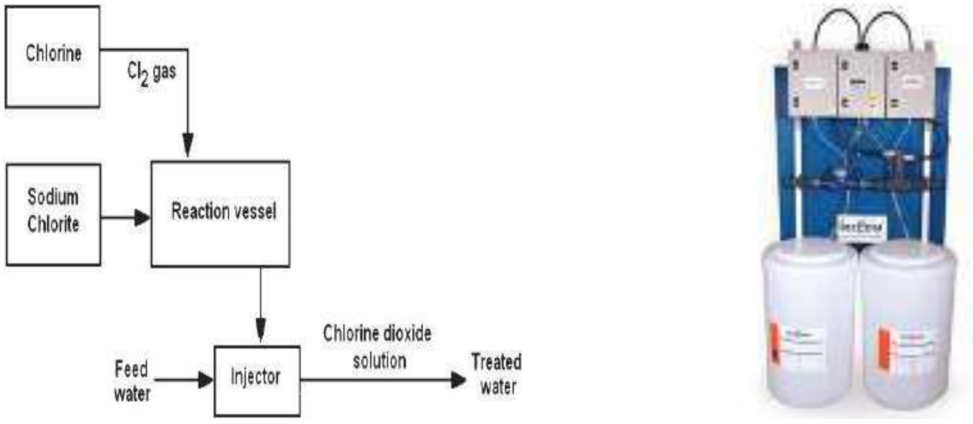

Figure 9.11: Schematic process Diagram and typical arrangement

9.14.4 Sodium dichloroisocyanurate

Sodium dichloroisocyanurate is the sodium salt of a chlorinated hydroxytriazine and is used as a source of free available chlorine, in the form of hypochlorous acid, for the disinfection of water. It is widely used as a stable source of chlorine for the disinfection of swimming pools and in the food industry. It is also used as a means of disinfecting drinking water, primarily in emergencies, when it provides an easy-to-use source of free chlorine, and, more recently, as the form of chlorine for household point-of-use water treatment. The BIS Standard sodium dichloroisocyanurate, IS 15733:2008, Reaffirmed 2019, should be followed when using it for disinfection purposes.

9.15 Chlorine Contact Tanks (For Post-Chlorination)

The effectiveness of chlorination depends on the bacteriological and virus load, chlorine concentration, contact time, and temperature. It is commonly seen that chlorine or its compound are normally dosed in a treated water channel of a filter house or treated water sump or treated water reservoir. It is not possible to dose chlorine uniformly using such methods. Hence, it is recommended to provide a dedicated chlorine contact tank/chamber in the treated water sump/clear water reservoir. In existing plants, they can be accommodated in between the treated water channel of the filter house and the treated water sump. As a practice, the detention time of the chlorine contact tank is recommended as 30 min. It shall be constructed in RCC with a roof slab in square, rectangular, or circular shape. The tank shall have baffles so that the water flows horizontally. At the inlet to the tank, a feeder pipe (perforated) shall be provided to distribute the chlorine solution up to the entire depth of the tank. The outlet to the tank shall be at the top (Figure 9.12 and Figure 9.13). The construction of the tank should be in RCC M30 or above and the plaster (CM 1:2) should be at least 0.40 m in thickness. Other commercially developed products like FRP or paints which resist chlorine corrosion should preferably be applied. The inlet of chlorine contact tank (CCT) should be at the bottom, and outlet at the top. CCT should be in two compartments for plant of capacity more than 100 MLD with separate inlet and outlet for each compartment.

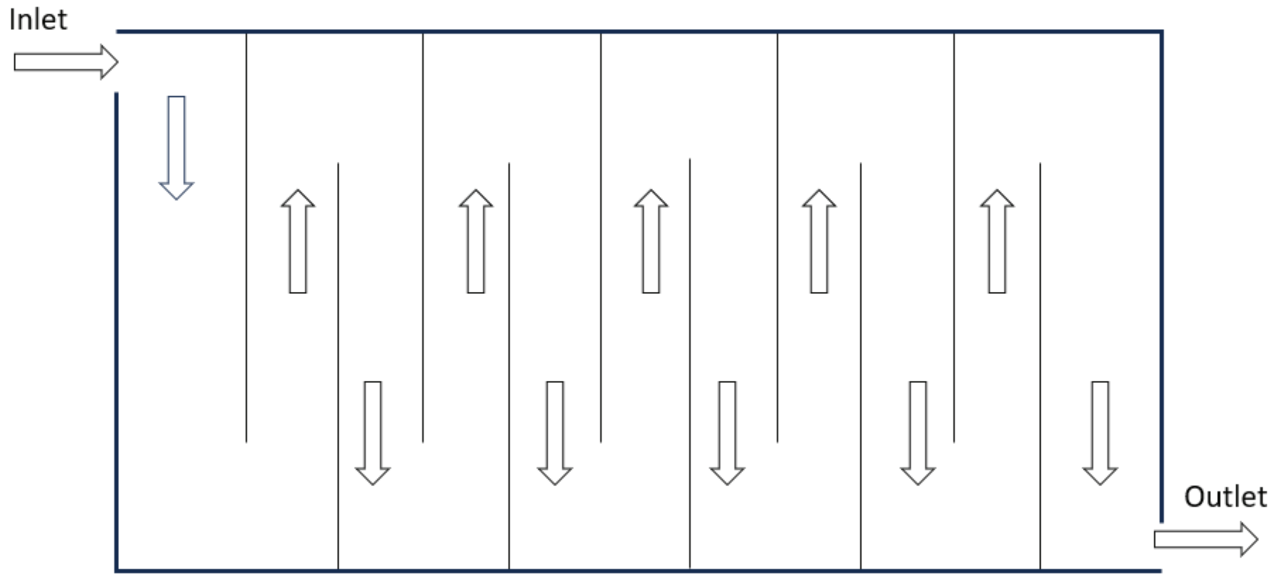

Figure 9.12: Schematic (Plan) Rectangular basin with baffle walls

Figure 9.13: Circular contact tank under construction

9.16 Disinfection Methods other than Chlorination

Chlorine and its compounds are most widely used for disinfection. However, possible formation of carcinogenic by-products, by reaction of chlorine with some organics and change in tastes and odours due to the reactions of chlorine with some water constituents, have been reported.

Various other agents of disinfection are available and some of them such as ozone and ultraviolet rays, are finding increasing usage in water treatment practice. Broadly, the three main types of disinfectants are (1) physical agents including heat, (2) chemical agents, and (3) radiations of various types such as ultraviolet rays, gamma rays, and x-rays. Some of these disinfectants are discussed in subsequent sections.

9.16.1 Heat

The boiling of water will disinfect it. This practice, however, cannot be used to disinfect municipal supplies for economic reasons. Boiling of water is applicable for disinfecting an individual's drinking water in emergencies like accidental contamination of public water supply or during an epidemic breakout. The thermal resistance of different microorganisms and viruses varies significantly with spores being up to 3,000,000 times more resistant than *E. coli*, viruses, and bacteriophages. As no important water-borne disease is caused by spore-forming bacteria or other heat-resistant organisms, boiling of water can render the water safe for drinking purposes against diseases. A continuous flow water pasteurises with flow rates of 1000 lph, and is available for use.

9.16.2 Chemical Disinfectants

Chemical disinfectants are commonly grouped under the following categories:

(i) Oxidising chemicals include halogens, ozone, and other oxidants such as potassium permanganate and hydrogen peroxide.

(ii) Metal ions.

(iii) Alkalis and acids.

(iv) Surface active chemicals.

9.16.3 Halogens other than Chlorine

Halogens are oxidising agents and include fluorine being the strongest and iodine the weakest oxidising agent. However, disinfecting efficiency does not correlate directly with an oxidising capacity of a disinfectant. As fluorine can oxidise water, it cannot be used for disinfecting water.

Bromine is a heavy dark reddish-brown liquid that upon addition to water forms hypobromous acid (HOBr), the dissociation of the acid resulting in the formation of hypobromite ion (BrO^-). Bromine also reacts with ammonia in water to form monobromamine and dibromamine. No stable tribromamine is formed. Monobromanine is a strong bactericide, almost as strong as free bromine, in contrast to monochloramines. Bromine has been used for the disinfection of swimming pool waters on a limited scale. However, because of its higher cost and less effectiveness, its use for public water supply has not found acceptance.

Iodine is a bluish black solid and its addition to water yields hypoiodous acid (HOI) and hypoiodite (IO). Iodine reacts less with organic matter compared to chlorine and is relatively stable in water. At pH 7, the percentage of iodine, hypoiodous acid, and hypoiodite ion have been reported to be 52, 48, and 0, for a total iodine residual of 0.5 mg/L. Both iodine and hypoiodous acids are equally good disinfectants. Iodine does not react with ammonia to form iodamines, but oxidises ammonia. It also oxidises phenols. Because of these reasons, less iodine is required to obtain free iodine residuals. Iodine has been used for the disinfection of swimming pool waters and small quantities of water in the field. Iodine tablets (e.g., tetraglycine hydroperiodide tablets) have been used by the defence personnel. However, iodine is more costly than chlorine and imparts a typical colour and odour to water, hence it is not used for disinfection in water treatment plants.

9.16.4 Metal Ions

Several metals including silver, copper, mercury, cobalt, and nickel possess significant bactericidal properties. However, except silver, none has been found suitable for disinfecting drinking water supplies. Silver is relatively ineffective against viruses and cysts in acceptable concentrations. Long detention periods are required but very low concentrations of the order of 15 bg/L of silver ions are sufficient to destroy most organisms. Silver can be introduced into the water either in the form of silver salt or by immersing silver or silver-coated electrodes in the water and applying an electrical potential. Successful applications at 100 V have been reported. As the solubility of most silver salts is adequate, enough silver ions may dissolve which is considered sufficient for most disinfection purposes. However, these disinfection methods are restricted to households or very small water supply schemes (1-10 KLD).

9.16.5 Ozone

Ozone is a faintly blue gas of pungent odour. Being unstable, it breaks down to normal oxygen and nascent oxygen. This nascent oxygen is a powerful oxidising and germicidal agent. Ozone is produced by the corona discharge of high-voltage electricity into dry air. Ozone, being unstable, has to be produced on-site.

Ozone is a disinfectant and is also highly effective in the removal of tastes, odours, colour, iron, and manganese. Ozone acts similarly to chlorine and disinfects by oxidising and destroying the cell wall of microorganisms, resulting in a leak of cellular components outside the cell. This leads to protoplasmic damage of the cell, adversely affecting constituents of the nucleic acids ultimately resulting in depolymerisation. Ozone, being a bioactive oxidising disinfectant, splits into O_2 and O_1 molecules, and O_1 being highly reactive, results in the breakdown of bacterial cell walls by altering the function of carbohydrates and proteins. As ozone reacts with chemical contaminants before attacking the microorganisms, it produces essentially no disinfection residual unless the ozone demand of water has been satisfied. Ozone achieves rapid kills once free ozone residuals are available. Ozone is effective in killing some chlorine-resistant pathogens like *Giardia, Cryptosporidium,* and certain viruses. Ozone does not impart offensive tastes and odours to water, nor does it usually produce toxic substances such as chlorinated hydrocarbons or trihalomethanes (THMs). Further, the efficiency of disinfection by ozone is unaffected by the pH or temperature of the water over a wide range.

Ozone can be added at any of the locations such as pre-oxidation, intermediate oxidation and/or post-ozonation (disinfection) in the water treatment plant. Ozone should be used for pre-oxidation prior to sand filter. Ozonation has many benefits:

i. Removal of iron and manganese
ii. Removal of micro-pollutants, e.g., pesticides, pharmaceutical and personal care products (PPCPs)
iii. Improvement in the performance of coagulation, flocculation, and sedimentation process resulting in lower water turbidity and reduced coagulant dosages
iv. Improved disinfection and reduction in DBPs
v. Elimination of odour and taste causing compounds

Among the disadvantages of ozone treatment are:

(i) Its high cost of production
(ii) Inability to provide residual protection against recontamination
(iii) Its generation is on-site due to instability

However, despite these disadvantages, ozone has been extensively used in developed countries for the disinfection of municipal water supplies as their systems are 24x7 and entry of contaminants is ruled out.

a) CT values for ozonation

Ozone-based disinfection also works in the similar principle that of chlorine disinfection. Hence, C (residual concentration of the disinfectant, mg/L) and T (exposure time, minute) are important factor in designing ozonation system for disinfection in a water treatment plant. There are complex methods to determine CT values in case of disinfection using ozone and few of the methods are as follows (USEPA, 2010):

- T10 Method
- Continuous Stirred Tank Reactor (CSTR) Method
- Extended T10 Method
- Extended CSTR Method

Considering the complexity of these methods, the following approach can be considered to determine CT values for ozonation.

Cryptosporidium is one of the most resistant pathogens to disinfection, hence it can be safely presumed that if *Cryptosporidium* is removed/killed/inactivated, other pathogens can also be inactivated. CT values for *Cryptosporidium* are presented below for various log removal at various temperatures. Table 9.3 shows CT Values for Inactivation of Cryptosporidium by Ozone.

Table 9.3: CT Values for Inactivation *of Cryptosporidium* by Ozone

S.No.	Log removal	Water temperature			
		15°	20°	25°	≥30°
1	0.5	3.1	2.0	1.2	0.78
2	1.0	6.2	3.9	2.5	1.6
3	1.5	9.3	5.9	3.7	2.4
4	2.0	12	7.8	4.9	3.1
5	2.5	16	9.8	6.2	3.9
6	3.0	19	12	7.4	4.7

Source: USEPA, 2010, Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual

There are limited studies available in India about presence of *Cryptosporidium oocysts* in drinking water. Presence of average count of *Cryptosporidium oocysts* varied from 0.17/100 L in Chennai (2015) to 160/100 L in Amritsar (2019) (Utaaker et al, 2019, Daniels et al, 2015, Anbazhagi et al, 2007). However, a maximum count of 1800/100 L *Cryptosporidium oocysts* in Chennai. Considering log credit of 2 (average) for sedimentation, coagulation and flocculation and filtration (WHO, 2022 and USEPA, 2010), additional 0.5-1.0 log removal (credit) due to ozone is recommended. This credit should be used for design purposes for ozone treatment system.

However, there is a need to estimate ozone dose prior to disinfection as ozone will be consumed by organic matter, ammonia, etc. It is recommended that following doses of ozone should be considered:

Optimal concentration to remove organic matter by ozone is at an ozone dose of: O_3/DOC = 1 mg/mg (Source: https://www.lenntech.com/library/ozone/drinking/ozone-applications-drinking-water.htm)

b) Components of ozonation system

There are following four main components of an ozone disinfection system:

i. Oxygen (feed gas) unit
ii. Ozone generator
iii. Ozone contactor
iv. Off-gas ozone destruction unit

However, configuration of these units can vary based on various factors, viz., capacity of water treatment plants, raw water quality, performance of preceding water treatment units, etc.

Ozone in produced by ozone generators normally fed by oxygen concentrators through a high-voltage electric field. This ozone is then monitored in water by an ozone in water analyser. The ozone-enriched gas is directly dosed into the water by using porous diffusers at the bottom of baffled contactor tanks. The contactor tanks, normally about 5 m deep, can provide contact time in the range of 10-20 minutes. Minimum 80% of the applied ozone is possibly dissolved in water, whereas the remainder ozone contained in the off-gas is circulated through an ozone destructor and ultimately vented to the atmosphere (WHO, 2022). Ambient ozone is controlled by ozone sensors; these check if the ozone destructor works sufficiently. Ozone generators are shown in Figure 9.14.

Figure 9.14: Ozone Generator

c) Ozone Injection techniques

Ozone gas can be injected in water in different ways. The two most used techniques are:

- I. Venturi
- II. Diffuser

A venturi injects the ozone gas in the water via a vacuum. The advantages of a venturi are the compact installation, possible high yield (up to 90%). In the picture below, an example of a venturi system can be found. A side stream injection with pump is used.

A diffuser works under pressure. A diffuser creates a bubble column. The advantages are high yield, simple construction, and advantageous for high flow rates (i.e., drinking water systems). Disadvantages are the required surface area and the need of tall buildings to increase the efficiency.

Ozonation should be followed by chlorination to have free residual chlorine in the range of 0.2-0.5 mg/L while transporting water to households.

d) Slime and biofilm formation

Ozonation processes increases biodegradable part of natural organic matter (NOM) in water as several large organic molecules are broken into smaller biodegradable organic molecules. These smaller biodegradable organic molecules result in increased biodegradable dissolved organic carbon (BDOC) or assailable organic carbon (AOC). Higher BDOC or AOC normally leads to enhanced bacterial growth in water distribution system. It is reported that AOC levels should be less than 100 ppb to prevent/control excessive bacterial growth in water distribution system (LeChevallier et al., 1992) Similarly, by having an ozonation unit upstream of filtration, microbial activity and consequently slime formation, particularly in underdrain system, increases in the filter (provided environmental conditions such as pH, dissolved oxygen, and temperature are favourable). Hence, appropriate underdrain systems should be designed so as to prevent clogging while operations of filtration systems.

As ozone addsa large quantity of oxygen to the water, a favourable environment for microbial growth is created on the filter media. Hence, it is advisable to locate ozonation unit in a water treatment plant (USEPA, 1999). Ozonation units can either be at the end of treatment system if used only for disinfection purposes, or can be located as follows:

- i. Pre-ozonation
- ii. Intermediate ozonation
- iii. Main ozonation

In case ozonation is located at the end of water treatment chain, granulated activated carbon (GAC) should precede it. As explained earlier, this filter will act as biological active filtration (BAC) primarily due to microbial growth on filter media, but have several advantages as explained below:

- Prevention of excessive growth and regrowth of microorganisms (biofilm) in water distribution system
- Removal of NOM that is precursors to disinfection by-product formation due to subsequent chlorination (for having residual chlorine in distribution system)
- Reduction in BDOC/AOC concentration in treated water, thus considerably reducing possibility of regrowth of microorganisms
- Reduction in the demand of residual chlorine of the treated water. This will help in considerably lower levels of disinfection by-product
- Control or minimisation of ozonation by-products
- Removal of algae in treated water

Growth of biomass is high on GAC due to rougher surface characteristics as compared to anthracite, sand, or any other filter medium.

e) Possible layout of water treatment plants with ozonation units

As explained earlier, ozonation will considerably improve treated water quality. However, ozone has substantially low half-life in water and chlorine will be required to take care of microbial contamination in distribution systems. In addition, GAC (also terms as biologically active filtration in this case due to microbial growth on GAC) remains an inevitable unit of treatment involving ozonation. Hence, the combination of ozonation, GAC filter, and chlorination should be used wherever ozonation is proposed for optimum treatment. Figure 9.15 shows a possible treatment scheme with ozonation: source water is contaminated with organic matter, the ULBs should adopt ozonation as part of water treatment plant.

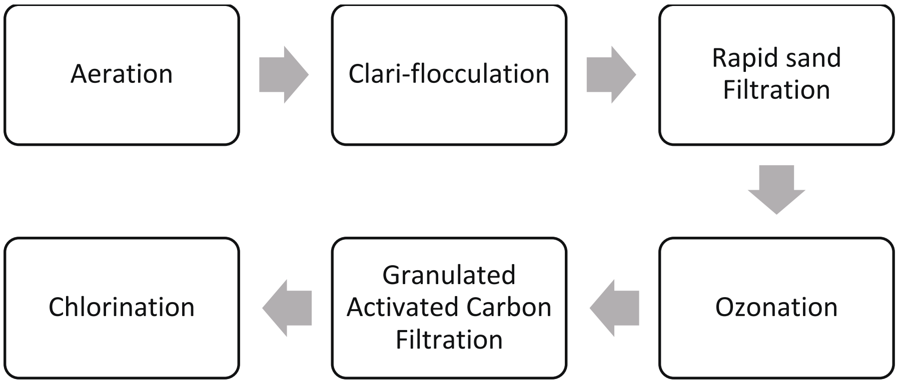

Figure 9.15: Treatment Scheme with Ozonation

Ozonation in TG Halli Water Treatment Plant, Bangalore

The Chama Raja Sagar(CRS) reservoir also known as TG Halli reservoir at TG Halli, is located downstream of the Hesaraghatta Lake near Bangalore. This reservoir has been enlarged from time to time over the years, to partially meet the increasing water supply demand of Bangalore city.

The existing water treatment plant at downstream of TG Halli reservoir is not in operation for a long time as there is no water supply from the reservoir. TG Halli reservoir also receives contaminated water due to the discharge of untreated/ partially treated sewage from the sewage treatment plants at Arkavathi and Kumudavathi, which are located in the catchment area of TG Halli reservoir. In order to revive the drinking water supply from TG Halli reservoir, 110 MLD capacity WTP based on Ozone with Granular Activated Carbon Filtration Process is taken up at TG Halli by demolishing the existing WTP with major advancements in process technology.

After conventional treatment units such as aeration, coagulation and flocculation, lamella plate settlers are provided. Clarified water from lamella plate settlers will be brought into a common inlet channel leading to the GAC filters. Dual media filters comprising of GAC and sand are provided to remove residual organics and suspended matter from the water before chlorination and water supply. In TG Halli project, GAC filter media of 1400 mm depth is used. The GAC of mesh size 8X30 with surface are of 1,000 to 1,200 m^2/g is used.

In TG Halli project, the ozone generation unit of 15 kg/hour (three units of 5 kg/hour each) is proposed for installation. Pre-ozonation with 0.60 mg/liter and post-ozonation with 5 mg/liter is proposed from the ozone generation unit. The ozone shall be diffused through the diffusers in post ozonation and through the static mixers in pre-ozonation unit. The project is being commissioned.

f) Emerging Technologies: Oxygen Enriched Ultrafine Bubbles /Nanobubbles Technology for Disinfection of Drinking Water and Ozone enriched Microbubbles for Pretreatment of Raw Water

Chlorination is commonly used for disinfection of drinking water, which is producing disinfection by-products, and these are carcinogenic in nature.

Oxygen enriched Ultrafine Bubbles /Nanobubbles or Ozone enriched ultra fine/Nanobubbles (less than 200 nm) deliver higher surface area and remain buoyant in water for days (roughly four times longer than normal diffuser) thus ensuring the residual benefits of maintaining the quality of treated water for a longer period. Therefore, oxygen enriched ultrafine bubbles/nanobubbles have been proven to be alternative disinfectant to chlorination.

In ozone bubble technology, the oxygen formed during decomposition of ozone generates OH radicals that oxidize pollutants. Though ozone ultrafine/nanobubbles are effective for pretreatment as well as disinfection, the amount of residual ozone at the point of usage may arise concerns related to public health and safety as nano bubbles have residual effect. This needs to be further evaluated before application. However, microbubble ozone (10-50 micron) may be considered for pretreatment in lieu of conventional ozonation for pre-treatment and disinfection as microbubble ozone do not have any residual effect as the application of ozone dose is less than the conventional ozone treatment.

The Ultrafine/Nanobubble technology may be considered for disinfection of drinking water as it has residual effect. The micro bubble zone technology may be considered for both pre-treatment and disinfection. The combination of both micro bubble ozone for pre-treatment and ultrafine/nano bubble ozone may also be considered for pre-treatment and disinfection.

However, it is recommended that the Ultrafine/nanobubble technology and micro bubble ozone technologies shall be tested at pilot scale in India under field operating conditions before any large-scale application. Alternatively, the reliable field data for large scale water treatment plants working elsewhere (outside India) may be studied and the technologies validated before large scale application in India.

9.16.6 Ultraviolet Radiation

It has been observed that exposure of water to sunlight and artificial light leads to the destruction of organisms. These bactericidal effects of intense sunlight or artificial light are primarily due to ultraviolet (UV) rays. UV light is shorter wavelength (higher energy) than visible. It is called ultraviolet because it is just beyond violet light. Technically, ultraviolet light is defined to be any wavelength of light - also called electromagnetic radiation - shorter than 400 nanometres. UVC (200-280 nm) light inactivates microorganisms by damaging their genetic material (DNA) and rendering them unable to replicate. Ultraviolet radiation may kill a cell, retard its growth, and change its heredity by a gene mutation. UVA (315-400 nm) and UVB (280-315) are responsible for sun tanning and sun burning.

(a) Dose (Fluence), Irradiance and Contact Time - Theory behind the UV-Tube

To inactivate a given microorganism, the water must be hit with a certain amount or dose of UV light. Dose, more properly referred to as fluence, is determined by variables associated with the design and operation of the UV disinfection device, as well as the characteristics of the water that is treated.

(b) Fluence calculation within the UV-Tube

Fluence is calculated as the product of light intensity at a given wavelength and exposure time. Intensity at any given point is determined by bulb strength and the geometry of the reactor. The greater the thickness of water that the light travels through, the lower the intensity received. The exposure time is governed by the geometry and the hydrodynamics of the reactor. The UV-tube is designed such that the lowest fluence received by any of the water is sufficient to achieve the desired reduction in microorganisms. Fluence may be reported in mW-sec/cm^2, which is equivalent to mJ/cm^2, or in the SI units, J/m^2. Standard doses delivered by a UV drinking water treatment system are between 15 and 50 mW-sec/cm^2.

(c) Intensity

Intensity decreases due to attenuation and dissipation. In other words, the further from the source, the lower the strength of the light, because it is spread over a larger area (due to dissipation) and the lower the strength of the light, because it interacts with molecules in the water (attenuation). While dissipation is predicted simply by the geometry of the UV-Tube, attenuation depends on characteristics of the water. If the water contains a high concentration of materials that absorb UV light, then less UV will be transmitted. The amount of light absorbed per centimetre is expressed as the absorption coefficient (a). As this coefficient increases, transmissivity decreases exponentially, therefore the absorption coefficient of the water plays a very important role in the effectiveness of the UV disinfection device.

(d) Absorption Coefficient

The absorption coefficient describes how much light is lost as it travels through a medium. It can be determined experimentally and is reported in inverse centimetres. The absorption coefficient of pure distilled water is close to zero. NOM, iron, nitrate, and manganese absorb UVC light and will increase the absorption coefficient of a water sample. Absorption coefficients in drinking water would be expected in the range of 0.01 to 0.2 cm^{-1}.

(e) Flow Rate

The higher the flow rate, the shorter the hydraulic detention time, therefore the smaller the dose received by the water. An appropriate flow rate must be determined based on the other characteristics of the water and on the desired dose.

(f) Suspended particles, Particle Associated Microorganisms and Turbidity

Turbidity is a measure of the quantity of particulates in a solution. It is determined by shining an infrared beam of light through a one-centimetre-thick sample and measuring light detected by sensors placed at ninety degrees to the beam. Turbidity is not necessarily correlated with the absorption coefficient. Turbidity is commonly reported in NTU.

Turbidity is often thought to be a limiting feature in ultraviolet disinfection. However, work has shown that particles, as long as they are not UV-absorbers, do not significantly reduce the overall irradiance by either shading or scattering, but only when organisms are embedded within them (Linden, 1998; Emerick, 1999). Particle suspension can increase the apparent absorption coefficient - as measured by a spectrophotometer - by scattering rather than absorbing light (Linden, 1998). This effect can lead to under prediction of design capabilities.

(g) Bulb Types

The maximum UV absorbance of DNA, 260-265 nm, coincides well with peak output of low-pressure mercury arc lamps at 253.7 nm. Two different types of lamps are typically used in water disinfection, medium pressure and low-pressure mercury vapour arc lamp. Table 9.4 displays their differences.

Table 9.4: Comparison between different types of lamps used in water disinfection

Characteristic	Low Pressure/Low Intensity	Medium Pressure/High Intensity
Typical Energy Use:	60 W	5,000 W
Percentage Output at 253.7 nm:	88%	44%
Ozone Production:	NONE	POSSIBLE (quartz can be doped to prevent formation)
Susceptibility to Cooling:	YES	NO
Susceptibility to Cooling:	GOOD	POOR
Benefits:	Efficiency (lower energy requirements)	Smaller, Less Maintenance, Use with Poor Quality Water

Current UV-tube designs use a low-pressure mercury vapour arc lamp.

(h) Bulb Strength

Fluence depends on bulb strength. A 30-watt low-pressure GE T8 bulb emits approximately 5 watts at 254 nm. As the bulb ages its strength will slowly diminish. GE recommends a replacement after 7,500 hours, assuming bulb is turned on for three-hour periods. Each start is expected to decrease the bulbs lifetime, so if the bulb is left on for periods greater than three hours, it may last longer. Conversely, if a bulb is turned on and off for periods shorter than three hours, its lifetime may be reduced to fewer than 7,500 hours. There is a need for more information on the effect of bulb on/off cycles, temperature conditions and general deterioration over time.

Depending upon the dose of radiation and the particular portion of the cell receiving radiation, one or several of the above-mentioned ‘three’ effects may occur. Wavelength ranging from 2,500 to 2,650 A° is recommended for maximum destruction of cells.

Ultraviolet rays are most commonly produced by a low-pressure mercury lamp constructed of quartz or special glass which is transparent and produces a narrow band of radiation energy at 2,537 A° emitted by the mercury-vapour arc.

Efficient disinfection can be achieved if,

(i) Water is free from suspended and colloidal substances causing turbidity,

(ii) Water does not contain light absorbing substances such as phenols, ABS, and other aromatic compounds,

(iii) Water is flowing in thin films or sheets and is well mixed,

(iv) Adequate intensity and time of exposure of UV-rays are applied.

About 2% of applied energy of ultraviolet rays may be reflected and some energy is absorbed by the impurities present leading to attenuation of radiant energy. Even distilled water will absorb about 8% of the applied energy for a water depth of 30 mm, including a surface reflection of about 2%. The presence of iron even at a low concentration of 1 mg/L may drastically increase absorption by over 80%. A water depth of about 120 mm is recommended for efficient disinfection.

(i) Intensity

The intensity of ultraviolet rays is expressed in terms of germicidal unit which is an intensity of 100 milliwatts (mW) per sq. cm. at wavelength of 2,537 A°. It has been reported that 99.99%, 99%, and 90% kills for Escherichia Coli can be achieved by ultraviolet rays of 3,000, 1,500, and 750 mW per sq. cm respectively. Typically, a 30-watt lamp could achieve 99.9% kill for water flows of approximately 2.5 to 17.0 m3/hr. for water depths ranging from 125 to 880 mm approximately assuming 90% absorption of ultraviolet rays.

(j) Water Depth

For a given-sized UV-tube, determining the best water depth (or weir height) involves a trade-off between residence time and water thickness. The higher the water height, the greater the volume of water in the tube at any given flow rate, and therefore, the greater the average residence time. However, the higher the water height, the greater the attenuation of light and the lower the dose reaching the water at the very bottom of the tube. Since attenuation is proportional to the absorption coefficient, the optimal water height will depend on the absorption coefficient. The optimal weir height (or water depth) is inversely related to the absorption coefficient.

The advantages of ultraviolet radiation are that exposure is for short periods, no foreign matter is actually introduced and no taste and odour is produced. Overexposure does not result in any harmful effects. The disadvantages are that no residual effect is available and there is a lack of a rapid field test for assessing the treatment efficiency. Moreover, the apparatus needed is expensive.

9.17 Disinfection By-Products

Disinfection by-products (DBPs) pose a threat to human and animal health. These are chemical, organic, and inorganic substances that can form during a reaction of a disinfectant with naturally present organic matter in the water. Table 9.5 provide details of DBPs of various disinfectants.

Disinfection processes can result in the formation of both organic and inorganic DBPs. The most well-known of these are the organochlorine by-products, such as trihalomethane (THM) compounds and haloacetic acids (HAAs), related to chlorination. The concentrations of these organochlorine by-products are a function of the nature and concentration of oxidisable organic material in the water, the pH of the water, the water temperature, the free chlorine concentration, its contact time with the organic material.

The types of DBPs that are formed depend on several influential factors listed below.

- The type of disinfectant
- The level of disinfection dose
- The disinfection residue

Effect of reaction time, temperature, and pH is given as follows:

- When the reaction time is shorter, higher concentrations of trihalomethanes (THM), and halogenic acetic acids (HAA) may be formed. When the reaction time is longer, some temporary forms of DBPs may become disinfection end products, such as tribromoacetic acid ($C_2HBr_3O_2$) or bromoform. Haloacetonitriles (HAN) and haloketones (HK) are decomposed.
- When temperatures increase, reactions take place faster, causing a higher chlorine concentration to be required for proper disinfection. This causes more halogenic DBPs to form. An increase in temperature also enhances the decomposition of tribromoacetic acids, HAN, and HK.
- When pH values are high, more hypochlorite ions are formed, causing the effectivity of chlorine disinfection to decrease. At higher pH values, more THM is formed, whereas more HAA is formed when pH values are lower. At high pH values, HAN, and HK are decomposed by hydrolysis, because of an increase in hydrolysis reactions at higher pH values.
- Surface water sources are more susceptible to organochlorine by-product formation than ground water because they receive organic matter in runoff from lake and river catchments. This organic matter comprises mostly humic substances from decaying vegetation, much of which can be in dissolved form as well as in colloid form. The concentration of this organic matter in surface water catchments can vary significantly after rainfall events.

Table 9.5: DBPs of Various Disinfectants

Disinfectant	Organo-halogenic DBPs	Inorganic DBPs	Non-Halogenic DBPs
Chlorine (Cl_2)/ Hypochlorous acid (HOCl)	Trihalomethanes, Halogenic acetic acids, Haloacetonitriles, Chlorine hydrates, Chloropicrin, Chlorophenols, N-chloramines, Halofuranones, Bromohydrins	Chlorate (particularly the application of Hypochlorite)	Aldehydes, Alkanic acids, Benzene, Carboxylic acids
Chlorine dioxide (ClO_2)		Chlorite, Chlorate	unknown
Chloramines (NH_3Cl, etc.)	Haloacetonitriles, Cyano chlorine, Organic chloramines, Chloramino acids, Chlorohydrates, Haloketones,	Nitrite, Nitrate, Chlorate, Hydrazine	Aldehydes, Ketones
Ozone (O_3)	Bromoform, Monobromine acetic acid, Dibromine acetic acid, Dibromine aceton, Cyano bromine	Chlorate, Iodate, Bromate, Hydrogen peroxide, Underbromic acid, Epoxy, Ozonates	Aldehydes, Ketones, Ketoacid, Carboxylic acids

9.17.1 Total Organic Carbon (TOC) measurement

Drinking water specifications including bacteriological requirements, virological requirements, biological requirements, and pesticide residue limits shall comply with the requirements given in the Bureau of Indian Standards IS 10500: 2012 (Reaffirmed Year: 2018). To monitor this, sampling and analysis of various parameters shall be conducted according to Bureau of Indian Standards BIS 3025 (Part 1 to Part 79) and IS 1622 (1981, reaffirmed 2019). However, parameter like total organic carbon (TOC) are not included in that standard.

Various sources of water are ‘Rivers, Lakes, Canals, Ground, Rain and Sea, etc.’ which are contaminated due to discharge of untreated municipal and industrial water. Consequently, the organic carbon is present in fresh water as constituent of many waste materials and effluents. The organic carbon also arises from living organic matter in fresh water. Total organic compound (TOC) is emerging as an alternate parameter to measure organic load in both raw and treated water and is widely being recognised as an index of organic substance in water.

Furthermore, the raw water containing TOC, when treated in water treatment plant (WTP) with chlorine as disinfectant, DBPs like trihalomethanes (THMs) and haloacetic acids (HAAs) may be formed, which are carcinogenic. The lower the TOC, the better the quality of water and vice versa. Few of the developed countries have notified TOC limits 4-5 mg/L in source water and 2-3 mg/L in drinking water. TOC removal shall be required mainly in WTPs that uses a conventional treatment to treat surface water. TOC is used as a surrogate parameter to DBPs therefore a detailed study for the same is needed.

Anna University, Chennai, has been entrusted by the MoHUA (CPHEEO) to carry out a study namely ‘Formation, Fate and Treatment methods for DBPs in Water and Wastewater’, which will focus on monitoring and removal methods of TOC as well as the application of ozonation as a disinfectant for different concentrations of TOC and other micro-pollutants in raw water sources. The outcome of the study shall be available at the Ministry’s website.

9.18 Advantages and limitations of various disinfection methods

Advantages and limitations of various disinfection methods are given in Table 9.6.

Chemical disinfection methods are generally more effective against bacteria and viruses, with little or no effect in the case of chlorination for the inactivation of protozoan pathogens. On the other hand, UV light is very effective against protozoan pathogens with additional effectiveness against bacteria and, to a lesser extent, viruses in water.

9.18.1 Combinations of disinfectants

Combination of disinfectants is known to lead to greater inactivation when the disinfectants are added in series rather than individually. There are also benefits from two or more disinfectants in dealing with a range of different types of pathogens of different sensitivities to disinfectants, e.g., UV is effective for *Cryptosporidium*, but much less effective for many viruses, whereas chlorine is effective for viruses but not so much for *Cryptosporidium*. Further, another benefit from using ozonation and UV treatment in sequence is that ozone can degrade natural organics which cause UV absorption and, hence, allowing the UV dose to be a more effective. A graphical representation of UV and chlorination dosage necessary to inactivate a range of common pathogens is shown in Figure 9.16. It can be seen that there is a benefit in the multi-barrier use of both disinfection methods in the provision of full-spectrum pathogen control.

The Advantages and Limitations of various disinfection methods are given in Table 9.6

Table 9.6: Advantages and Limitations of various disinfection methods

Process	Advantages	Limitations
Chlorination	• Capability and design aspects are well understood.	• Chlorination by-products and taste and odour issues.
	• Established dosing technology.	• Ineffective against *Cryptosporidium*.
Chloramination	• No significant by-product issues.	• Considerably less effective as compared with chlorine.
	• Generally, less taste and odour issues than chlorine.	• Not usually practical as a primary disinfectant.
Ozone	• Strong oxidant and highly effective disinfectant.	• No residual for distribution, possible regrowth in the water distribution system.
	• Additional advantage of destruction of organic micro-pollutants (pesticides, taste, and odour compounds).	• Energy intensive and expensive equipment.
Chlorine dioxide	• Can be more effective than chlorine at higher pH, and less taste and odour and by-product issues.	• Weaker oxidant than ozone or chlorine.
		• Dose limited by consideration of inorganic by-products (chlorate and chlorite).
UV	• Generally, highly effective for protozoa, bacteria, and most viruses and particularly for *Cryptosporidium.*	• Less effective for viruses than chlorine.
	• No significant by-product.	• No residual for distribution, possible re-growth in the water distribution system.

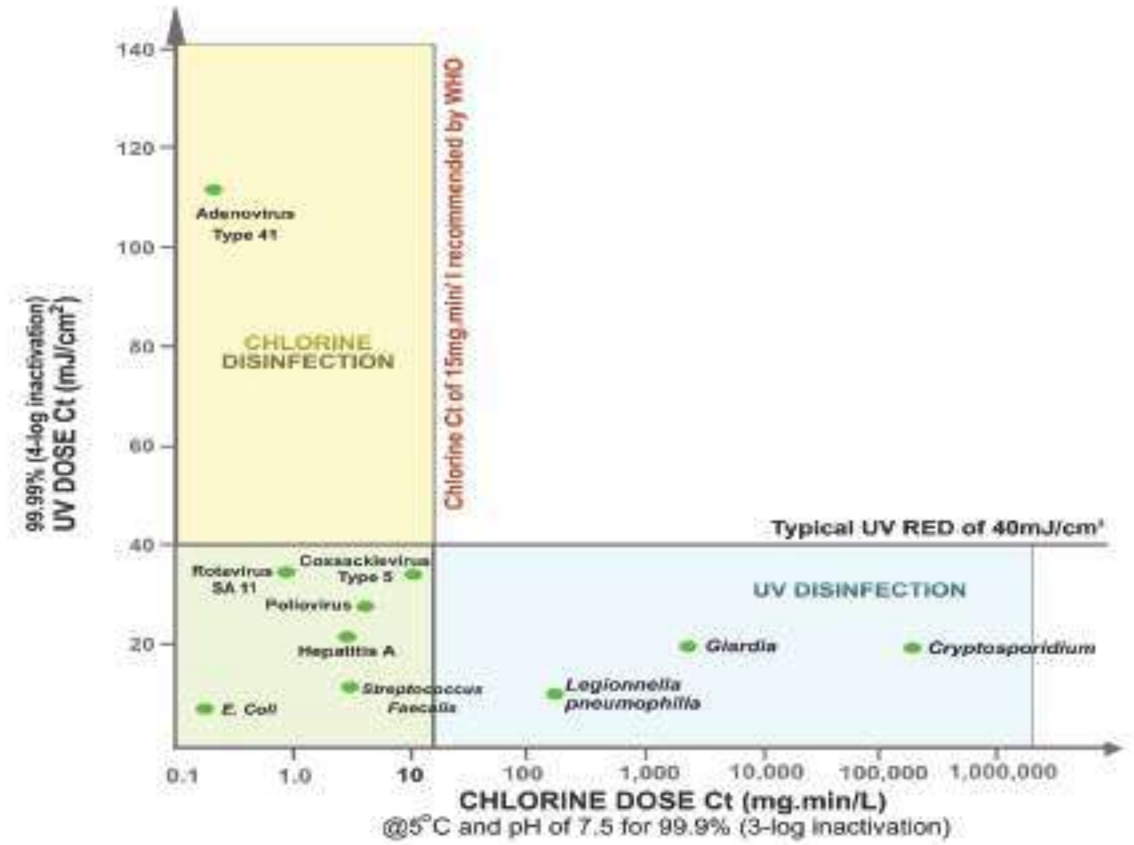

Figure 9.16: Synergistic uses of UV and chlorination disinfection systems

It is to be noted that, while working on combination of disinfectants, care needs to be taken to consider interactions between them, if any. Chlorine is reduced by UV treatment. Although the extent of chlorine reduction is small (e.g., 0.1 to 0.2 mg/L at a dose 40 mJ/cm^2) it is best if chlorine is dosed after UV. Chlorine reacts with ozone to produce chlorate. However, it is unlikely that sufficiently large ozone residual would reach a final chlorination process, for such chlorate formation to become an issue.

UV disinfection can be particularly attractive where there is insufficient space at site for a chlorine disinfection contact tank. Chlorine should not be dosed upstream of a Granular Activated Carbon (GAC) process as the GAC will reduce the chlorine, leaving little or no chlorine residual downstream. Chlorinated water is sometimes used for filter backwashing. There may be some potential for formation of THM with organic material present within the filter. On the other hand, there may be benefits to using chlorinated water to control excessive biological growth in the filter media.