

wash pipe. A syphon breaker ends the washcycle. The filter washes itself automatically, at the proper time at a given loss of head, without any mechanical instrument or operating tables. There is no maintenance from a mechanical standpoint of view. These filters are useful for low turbidity waters and for small installations.

7.7 DISPOSAL OF WASTES FROM WATER TREATMENT PROCESSES

Disposal of wastes from the water treatment plants has become increasingly important with the availability of technology and the need for protection of the environment. Treatment of waste solids adds to the cost of construction and operation of treatment plants.

Wastes from water treatment plants comprise of :

- (a) sludge from sedimentation of particulate matter in raw water, flocculated and precipitated material resulting from chemical coagulation, or residuals of excess chemical dosage, plankton etc.;
- (b) wastes from rinsing and backwashing of filter media containing debris, chemical precipitates, strainings of organic debris and plankton and residuals of excess chemical dosage etc.; and
- (c) wastes from regeneration processes of ion exchange softening treatment plant containing cations of calcium, magnesium and unused sodium and anions of chlorides and sulphates originally present in the regenerant.

7.7.1 DISPOSAL METHODS

In continuous sludge removal, the feasibility of discharging of water treatment plant sludge to existing sewers nearby should be considered. For lime softening plant sludge, the reclamation by calcining and reuse can be explored [8.4.2.1 (a) (3)]. Sludge from clarification units using iron and aluminium coagulants can be dewatered by vacuum filtration using lime as the conditioner, to a cake that can conveniently be trucked for landfill. The material will be still greasy and sticky. Recovery of alum from sludge by treatment with sulphuric acid offers possibilities of reducing the quantity of sludge to be handled. Sand drying beds are an acceptable method for dewatering certain types of sludge from settling tanks or clarifiers for further disposal by landfill. Simple lagooning of sludge does bring about a reduction in the bulk of the sludge to be handled and further disposal as landfill is necessary. Backwash water from filters can sometimes be recycled back to the plant inlet which can possibly improve settling and filtration. Reclamation of backwash water from filters can be adopted in areas of water scarcity. Simultaneously this reduces the disposal problem of the waste.

7.8 PERFORMANCE CAPABILITIES

7.8.1 SLOW SAND FILTERS

The following standards of performance for slow sand filters are recommended:

- (a) The filtrate should be clear with a turbidity of 1NTU or less.
- (b) The filtrate should be free from color (3 or less on the cobalt scale).

- (c) When the raw water turbidity does not exceed 30 NTU, the filter runs should normally be not less than 6 to 8 weeks, with the filter head not exceeding 0.6 m.
- (d) The initial loss of head should not normally exceed 5 cm. A higher head will indicate that the entire sand bed needs overhauling.

7.8.2 RAPID SAND FILTERS

For rapid sand filters performance standards may be based on the following criteria:

- (a) The filtrate should be clear with the turbidity of 1NTU or less.
- (b) The filtrate should be free from colour (with 3 or less on the cobalt scale).
- (c) The filter runs should normally be not less than 24 hours with a loss of head not exceeding 2 m.
- (d) For an efficient filter, the wash water consumption should not exceed 2 per cent of the quantity filtered in between washing.

CHAPTER 8

DISINFECTION

8.1 INTRODUCTION

Water Treatment processes such as storage, coagulation, flocculation, sedimentation, filtration, aeration and water softening are specifically designed to produce waters that are aesthetically acceptable and economical to use. Though these physico-chemical processes assist in removal or killing of microorganisms to varying degree, these cannot be relied upon to provide safe water. For utmost safety of water for drinking purposes, disinfection of water has to be done for killing of disease producing organisms. Bacteria, viruses and amoebic cysts constitute the three main types of human enteric pathogens and effective disinfection is aimed at destruction or inactivation of these and other pathogens such as helminths responsible for water-borne diseases. The need for disinfection in ensuring protection against transmission of water-borne diseases cannot be overemphasized and its inclusion as one of the water treatment processes is considered necessary.

Historically, boiling of water or use of copper and silver vessels for storing water which effect some measure of disinfection have been employed in this country and elsewhere. Broadly, modern disinfection processes include use of :

- (i) Physical methods such as thermal treatment and ultrasonic waves.
- (ii) Chemicals including oxidizing chemicals such as Chlorine and its compounds, Bromine, Iodine, Potassium Permanganate, Ozone and metals like Silver.
- (iii) Radiation.

Disinfection and sterilization are different processes. While disinfection aims at selective destruction of disease producing organisms, sterilization is employed to completely destroy or inactivate all micro-organisms including bacteria, amoebic cysts, viruses, algae and spores.

8.2 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:

- (a) 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;
- (b) Should not leave products of reaction which render the water toxic or impart colour or otherwise make it unpotable;

- (c) Possess the property of leaving residual concentrations to deal with possible recontamination;
- (d) Be amenable to detection by practical, rapid and simple analytical techniques in the small concentration ranges to permit the control of disinfection process.

8.3 MECHANISMS OF DISINFECTION

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

- (i) Damage to 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 cell wall leads to cell lysis and death. Alteration of cell permeability refers to the destruction of selective permeability of cytoplasmic membrane and causes outflow from the cells of such vital nutrients, as nitrogen and phosphorus. Denaturation of cell proteins by acids and bases leads to destruction of cells. Inactivation of critical enzyme activity vital for cell growth and survival is normally brought about by oxidizing chemicals.

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.

8.4 FACTORS AFFECTING EFFICIENCY OF DISINFECTION

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

- (a) Type, condition, concentration and distribution of organisms to be destroyed.
- (b) Type and concentration of disinfectant.
- (c) Chemical and physical characteristics of water to be treated.
- (d) Contact time available for disinfection.
- (e) Temperature of water.

8.4.1 TYPE, CONDITION AND CONCENTRATION OF ORGANISMS TO BE DESTROYED

The 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 different enzyme systems, the action of the disinfectant must necessarily vary. 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 higher concentration of disinfectant. Spores are relatively resistant but fortunately are not of such significance as pathogens. Cysts are extremely resistant. 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 the efficiency only when the number is so high that there is a deficiency of available disinfectant. Such a condition may occur in disinfection of sewage but is not usual in water works practice.

8.4.2 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 really exerted by the end products of 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. Higher the concentration of a chemical disinfectant, the higher is the destruction of organisms.

8.4.3 CHEMICAL AND PHYSICAL CHARACTERISTICS OF WATER TO BE TREATED

Organic matter and certain oxidising constituents in water reduce the availability of the active products for disinfection. Embedded organisms in suspended materials in water may be sheltered from the action of disinfectant.

8.4.4 TIME OF CONTACT AVAILABLE FOR DISINFECTION

The destruction of organisms increases with contact time available for disinfection. In practice, the contact period is limited by the design of the plant and is usually not less than 30 minutes.

Adequate period of contact is available in most plants because the chlorinated water has a considerable detention in the clear water reservoirs before it is supplied. However, in small plants where such storage is not provided, the contact period is determined by the time taken for the water to flow from the point of application of chlorine to the point of drawal of water by the first consumer. If the minimum contact time is not available the dose of disinfectant should be suitably increased.

8.4.5 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.

8.5 MATHEMATICAL RELATIONSHIPS GOVERNING DISINFECTION VARIABLES

The kinetics of disinfection is affected by several variables as enunciated in section 8.4. 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.

8.5.1 CONTACT TIME

Contact time is an important variable affecting the rate of destruction of organisms. Generally speaking, under ideal conditions and at constant temperature. The number of organisms (N_t) surviving after a period of time t is related to the initial number (N_0) by Chick's law

$$\log \frac{N_0}{N_t} = k.t \quad (8.1)$$

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 has been suggested:

$$\log \frac{N_0}{N_t} = k.t^m \quad (8.2)$$

Where m is a constant. If m is less than 1, 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.

8.5.2. CONCENTRATION OF DISINFECTANT

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

$$C^n \times t_p = \text{Constant} \quad (8.3)$$

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. Values of n greater than one indicate rapid decrease in the efficiency of disinfectant as its concentration is reduced, if n is less than 1, contact time is more important than concentration and for n equal to 1, both affect the efficiency of disinfection to the same extent. Concentration-time relationship for HOCl at 0 – 6 °C resulting in 99% kill for E.Coli and several different viruses are:

$$\begin{aligned} C^{0.86} \times t_{99} &= 0.098 \text{ for adenovirus 3;} \\ &= 0.24 \text{ for E-Coli} \\ &= 1.2 \text{ for poliomyelitis virus} \\ &= 6.3 \text{ for coxsackie virus A}_2 \end{aligned}$$

Since value of n is less than 1, changes in contact time have more effect on killing of organisms than corresponding changes in concentration of HOCl. Further these equations

also indicate that some viruses (e.g. Coxsackie Virus A₂ are more resistant to killing by HOCl than commonly used indicator organisms, E-Coli.

8.5.3 TEMPERATURE OF WATER

The effect of temperature on rate of kill is usually expressed by the Vant Hoff-Arrhenius relationship assuming that the rate of disinfection is controlled either by the rate of diffusion of disinfectant through the cell wall or by rate of chemical reaction with cellular enzymes:

$$\text{Log} \frac{t_1}{t_2} = \frac{E(T_2 - T_1)}{2.303RT_1T_2} \quad (8.4)$$

Where t_1, t_2 are time for given percentage of kill at temperatures T_1 and T_2 in °K, E is the activation energy (in J/mol or cal/mol) and R is the gas constant equal to 8.314 J/mol.°K or 1.99 cal/mol.°K. Typical values of E at pH 7.0 for aqueous chlorine and chloramines are 34,332 and 50,242 J/mol respectively. As the pH increases, value of E also increases. This type of relationship indicates that at lower temperature of water (e.g. in winter season) the time required for achieving the same percentage of kill for the same concentration of disinfectant would be higher than those for higher temperature (e.g. in summer months). If 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 same percentage of kill.

8.6 CHLORINATION

8.6.1 CHLORINE AND ITS PROPERTIES

Chlorine is an element, having the symbol Cl with an atomic weight of 35.45, melting point -101.5 °C and boiling point 34.5°C. Gaseous chlorine is greenish yellow in colour and is approximately 2.5 times heavier than air. Under pressure, it is a liquid with an amber colour, oily nature and approximately 15 times as heavy as water. Liquefaction of chlorine gas is accomplished by drying, cleaning and compressing the gas to 35 kg/cm². During this process, the resultant liquid chlorine is separated from noncondensable gases. The temperature of the liquid chlorine in the container influences the internal pressure of the chlorine gas and hence its flow from the container. Liquid chlorine must be vaporised in order to be withdrawn as gas and this tends to reduce its temperature and thereby its vapour pressure. At too high discharge rates, the liquid will be cooled excessively resulting in the formation of frost on the outside of the container. While dry chlorine is non-corrosive, moist chlorine is highly corrosive. Chlorine gas is harmful to human beings since it is a powerful irritant to lungs and eyes. Fatal concentrations are generally avoided as its irritant nature is recognisable at much lower concentrations, the odour threshold being 3.5 ppm by volume. The safety limit for a working environment permits the maximum allowable concentration of chlorine in air of 1 ppm by volume for an exposure period of 8 hours.

8.6.2. CHLORINE-WATER-REACTIONS

8.6.2.1 Free Available Chlorine

Chlorine reacts with water to form hypochlorous acid (HOCl) and Hydrochloric acid (HCl) according to the equation:



This hydrolysis reaction is reversible. The hypochlorous acid dissociates into hydrogen ions (H^+) and hypochlorite ions (OCl^-) according to the equation:

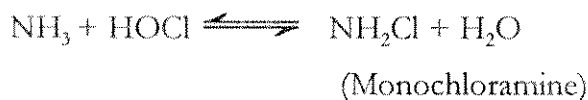


This reaction is also reversible. Free available chlorine may be defined as the chlorine existing in water as hypochlorous acid and hypochlorite ions. The undissociated HOCl is about 80 to 100 times more potent as a disinfectant than the OCl^- ion.

Both the above reactions are dependent upon the pH of the water. When the pH value of the chlorinated water is above 3, which is normally the case, the hydrolysis reaction is almost complete and the chlorine exists entirely in the form of HOCl. The influence of pH on the disinfectant action, therefore is governed by the second reaction as waters with pH value below 3 are very rare. From a consideration of the second equation, it is evident that as the pH increases, more and more HOCl dissociates to form OCl^- ion. At pH values of 5.5 and below it is practically 100% unionised HOCl while above pH 9.5, it is all OCl^- ions. Between pH 6.0 to 8.0, there occurs a very sharp change from undissociated to completely dissociated hypochlorous acid with 96% to 10% of HOCl, with equal amounts of HOCl and OCl^- being present at pH 7.5 (Fig. 8.1). The addition of chlorine does not produce any significant change in the pH of the natural waters because of their buffering capacity.

8.6.2.2 Combined Available Chlorine

The free chlorine can react with compounds such as ammonia, proteins, amino acids and phenol that may be present in water to form chloramines and chloro-derivatives which constitute the combined chlorine. This combined available chlorine possesses some disinfecting properties though to a much lower degree than the free available chlorine. Theoretically some free available chlorine can exist along with combined available chlorine since these reactions do not go to 100% completion. The reactions with ammonia are:





(Trichloramine or Nitrogen chloride)

The monochloramine (NH_2Cl) and the dichloramine (NHCl_2) have disinfectant properties, though twenty five times less than that of free chlorine, while the trichloramine has no disinfectant properties at all. The pH of the water generally determines the ratio between the amount of mono and dichloramines formed which have nearly equal bactericidal powers. Below pH 4.4, trichloramine is found. Between pH 4.4 to 5.5, only dichloramine exists and in the range of 5.5 - 8.4, both mono- and dichloramines prevail in a ratio fixed by the pH. At pH 7.0, equal quantities of mono and di-compounds and above pH 8.4 only mono-chloramines are noticed.

8.6.2.3 Chlorine Demand

Chlorine and chlorine compounds by virtue of their oxidizing power can be consumed by a variety of inorganic and organic materials present in 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 type and quantity of residual desired.

8.6.2.4 Estimation Of Chlorine

The usual tests practised for estimating the residual chlorine in water are the orthotoulidine test (OT) and orthotoulidine arsenite test (OTA), the former used for total residual chlorine concentration and the latter for free available chlorine. When orthotoulidine reagent is added to water containing chlorine; a greenish yellow colour develops, the intensity of which is proportional to the amount of residual chlorine present. Soluble tablets of DPD (diethylphenylene-diamine) have also been used satisfactorily in place of orthotoulidine reagent.

O.T AND O.T.A. METHODS

The orthotoulidine test procedure does not overcome errors caused by the presence of nitrates, iron and manganese, all of which produce a yellow colour with orthotoulidine nor is it able to discriminate between "Free Chlorine" and "Combined Chlorine". The O.T.A. method permits these differentiations. The principle of the method is that chlorine either free or combined is destroyed on addition of sodium arsenite whereas the colour produced by the reaction of chlorine with orthotoulidine as well as the interfering agents is unaffected. The reaction of orthotoulidine with free chlorine is instantaneous while with combined chlorine it is very slow and does not begin until about 10 seconds. This property is used for distinguishing free from combined chlorine. The test is carried out as follows:

- a) Take three tubes marked to hold 10 ml and label them 'A', 'B' and 'C'
- b) To tube 'A' add 0.5 ml. of orthotoulidine solution. Then add 10 ml. of water sample and mix. Add 0.5 ml or 0.5% sodium arsenite (NaAsO_2) immediately. Mix and compare with standards as rapidly as possible. Record the result (A).

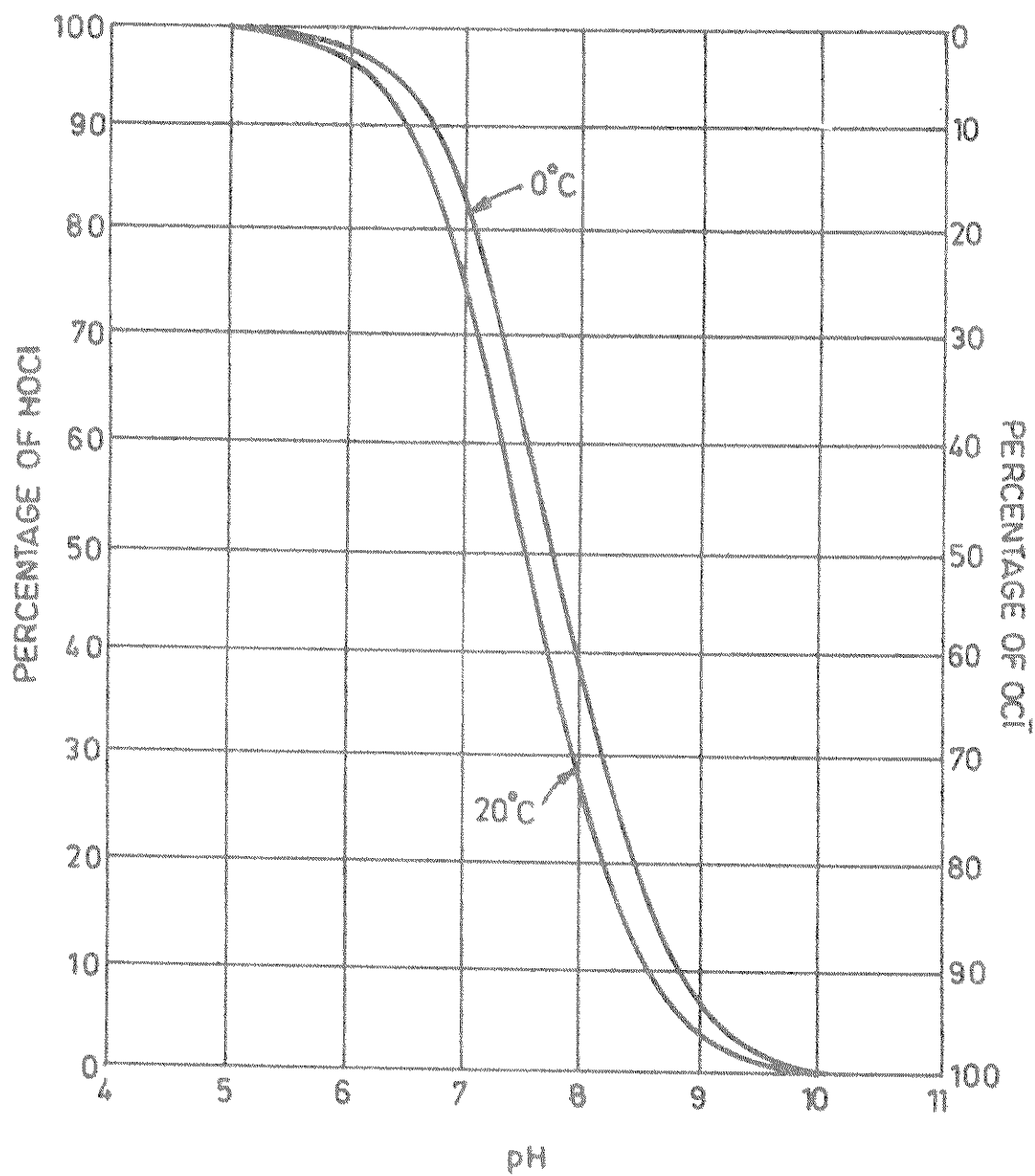


FIG. 8.1 RELATIVE DISTRIBUTIONS OF HOCl AND OCl⁻ AT DIFFERENT pH VALUES

- c) To tube 'B' containing 0.5 ml of arsenite solution, add 10 ml of water sample. Mix quickly and immediately add 0.5 ml of orthotoulidine reagent. Mix and compare with colour standards as quickly as possible. Record the reading (B1). Compare with colour standards again in exactly 5 minutes and record result (B2). B1 and B2 are due to interfering substances.
- d) To tube 'C' add 0.5 ml of orthotoulidine reagent and then add 10 ml of the sample. Mix and allow to stand for exactly 5 minutes. Compare the colour with standards. Record reading (C).
- e) Compute different values as follows:
 - ◆ Total residual chlorine = $(C - B2)$
 - ◆ Free residual chlorine = $(A - B1)$
 - ◆ Combined residual chlorine = $(C - B2) - (A - B1)$

8.6.3 CHLORINATION PRACTICES

8.6.3.1 Free Residual And Combined Residual Chlorination

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 practice, irrespective of the point of application may be classified as free available residual chlorination (i.e. break point or superchlorination) or combined residual chlorination, depending on the nature of the chlorine residual formed. From practical viewpoint, both are not equally applicable to all water sources for disinfection or to improve the quality.

(a) Free available residual Chlorination

(1) Plain or simple chlorination:

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

- (i) Turbidity and colour of the raw water is low, turbidity not exceeding 5 to 100 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; or
- (iv) Sufficient contact period between the point of chlorination and the consumer end is available.

(2) Super-Chlorination:

This is adopted in case of an emergency like a break down or in case of waters which 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 oxidized

It may be resorted to on special occasions when available contact time is limited at the pre-chlorination stage. Super chlorination can effectively destroy the 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. Excess chlorine will have to be dechlorinated.

(3) Dechlorination:

When superchlorination is employed, the water usually contains excess of free available chlorine which must be removed before it becomes acceptable to consumers. Dechlorination is the partial or complete reduction of undesirable excess chlorine in water by any chemical or physical treatment.

Prolonged storage and absorption on charcoal, granulated carbon and activated carbon are effective. Also reducing compounds like sulphur dioxide, sodium thiosulphate and sodium bisulphate are frequently used as dechlorinating agents. Dechlorination by sulphur dioxide and its derivatives is feasible, rapid and precise. About one part of SO_2 (by weight) is required for each part of chlorine to be removed, the exact amount to be determined by the Stoichiometric relationship:



(4) Breakpoint Chlorination:

As already explained in section 8.6.2.2., 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 schemes are as below:



The end products do not represent any residual chlorine. This fall in residual chlorine will continue with further increase of 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 corresponding dosage is the breakpoint dosage. Breakpoint chlorination achieves the same results as superchlorination in a rational manner and can therefore be construed as controlled superchlorination.

(b) Combined Available Residual Chlorination

This method involves the application of chlorine to water to produce with natural or added ammonia, a combined available chlorine residual and to maintain the residual through part or all of a water treatment plant or distribution system. They are less effective

disinfectants and oxidants than free available chlorine forms. The residual, however, will persist much longer than free available chlorine which has a tendency to diffuse and be lost. A minimum of 30 to 60 minutes contact time must be provided before delivery to the consumer. 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 3:1 or more to ensure the presence of an excess of ammonia.

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.

(c) Points of Chlorination

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

(i) Prechlorination

Prechlorination is the application of chlorine to water prior to any unit treatment process. 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 minimizing the post chlorination dosage when dealing with heavily polluted water.

(ii) Postchlorination

Postchlorination is the application of chlorine to water before it enters the distribution system to maintain the required amount of free chlorine specified in 2.2.9 (c).

(iii) Rechlorination

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 postchlorination 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 stagewise application of chlorine in the distribution system which is called rechlorination. Rechlorination is carried out in service reservoirs, booster pumping stations or at points where the mains supply to distribution zones.

8.6.4 CHLORINE RESIDUAL

Satisfactory disinfection is obtained by prechlorination to maintain 0.3 to 0.4 mg/l free available residual throughout treatment or 0.2 to 0.3 mg/l free available residual in the plant effluent at normal pH values. At higher pH of 8 to 9, at least 0.4 mg/l is required for complete bacterial kill with 10 minutes contact time. For 30 minutes contact time the dosage reduces to 0.2 to 0.3 mg/l.

The normal concentration of chlorine employed in the water works practice destroys causating organisms associated with typhoid fever, dysenteries and various gastrointestinal disorders. Cysts of *E. histolytica*, the causative organisms of amoebic dysentery are not destroyed but are inactivated at higher doses of 0.5 mg/l of the free residual chlorine.

Complete data are unavailable upon which to base recommendations of residual chlorine requirements to ensure destruction of water borne viruses. However, in practice 0.5 mg/l of free chlorine for one hour is sufficient to inactivate virus, even in water that was originally polluted and hence this may be adopted to make the water safe.

Where water supply is infested with nematodes, the supply should be prechlorinated for 6 hours to maintain a free available residual of 0.4 to 0.5 mg/l. This treatment attenuates most nematodes and renders them immobile which can be removed by settling processes.

8.7 APPLICATION OF CHLORINE

Chlorine can be applied to water by three methods:

- (a) By the addition of a weak solution prepared from bleaching powder, HTH etc. for disinfecting small quantities of water.
- (b) By the addition of a weak solution of chlorine prepared by electrolysis of a solution of brine.
- (c) 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 being obtained from pressurized 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 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 electrochlorinators to prepare a chlorine solution from electrolysis of water containing Sodium Chloride. An electrochlorinator essentially comprises of a direct current (DC) source for providing energy for electrolysis, an electrode pair installed in a container and hypochlorite solution storage and dispensation device. During electrolysis, chlorine is not

evolved as a gas but is available in solution form as hypochlorite solution. This is the major advantage of this technique as transportation, storage and application of chlorine gas involves major safety considerations to avoid hazards and fatal accidents.

Electrochlorinators are now commercially available in India in capacities ranging up to 1000 g/hr of chlorine using 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 electrochlorinators, and these electrochlorinators are based on emerging technology.

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 use of chlorinators or chlorine evaporators and auxiliary equipments.

8.7.1 SAFE HANDLING PRACTICES

8.7.1.1 Storing Shipping Containers

Chlorine cylinders preferably should be stored upright and secured, and in such a manner as to permit ready access and removal. Ton containers should be stored horizontally, slightly elevated from ground or floor level and blocked to prevent rolling; a storage rack of I-beams is convenient. Ton containers should not be stacked or racked more than one high unless special provision is made for easy access and removal. Full and empty cylinders and ton containers should be segregated.

Storage areas should be clean, cool, well ventilated and protected from corrosive vapours and continuous dampness. Cylinders and ton containers stored indoors should be in a fire resistant building, away from heat sources (such as radiators, steam pipes etc.) flammable substances and other compressed gases. Subsurface storage areas should be avoided, especially for chlorine and sulphur dioxide. If natural ventilation is inadequate, storage and use areas should be equipped with suitable mechanical ventilators. Cylinders and ton containers stored outdoors should be shielded from direct sunlight and protected from accumulations of rain, ice and snow.

All storage, handling and use areas should be of such design that personnel can quickly escape in emergencies. It is generally desirable to provide atleast two means of exit. Doors should open out and lead to outside galleries or platforms, fire escapes, or other unobstructed areas.

8.7.1.2 Emptying Containers

Chlorine cylinders deliver gas when in an upright position and liquid when in an inverted (or partially so) position. Ton containers in a horizontal position and with the two valves in a vertical line deliver gas from the upper valves and liquid from the lower valve.

To withdraw gas from a cylinder or ton container, the liquid chlorine must be vaporized. The flow rate is a function of the vaporization rate, which, in turn, is dependent on the rate of heat transfer to the liquid.

8.7.1.3 Connecting And Disconnecting Containers

The design and operation of facilities should be such as to minimize all hazards associated with connecting emptying and disconnecting chlorine containers. These operations should be performed in well-lighted places by authorised personnel equipped with gas masks or other suitable respiratory protection devices. Container valve protection goods should always be in place when the container is not in use. Valves should not be left open when operating personnel are not available to maintain proper surveillance of the operations.

Connections to valve outlets on cylinders and ton containers can be made by either a clamp and adapter or a union connector; the former is preferred. In making connections it should be ascertained that the outlet valve is closed before the outlet cap is removed. Gasket surfaces should be thoroughly inspected and cleaned and a new gasket of standard material should be used. Connections that do not fit should never be forced.

Cylinder and ton container valves should be slowly opened by using a special wrench, not more than 150 mm long, for this purpose. One complete turn of the stem in a counter-clockwise direction opens the valve sufficiently to permit maximum discharge. An auxiliary cylinder or ton container valve should be installed adjacent to the container valve between it and the chlorine feeder or gas header on manifold systems. Such a valve serves as an emergency shut off if the container valve should leak. Moreover, it prevents chlorine gas from escaping from the supply line when the container is removed from service. In the interests of safety, the ventilation system should be operating whenever containers are being placed into or removed from service and at all times in which an emergency exists or adjustments and repairs are being made.

Specifications and manufacturing of chlorine cylinders/containers, its transportation, handling, filling, possession and safety shall be governed as per Gas Cylinder Rules, 1981 of Central Government.

8.7.2 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.

8.7.2.1 Types Of Feeders

Chlorinators are used for 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 these equipments 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 orifice (constant differential unit).

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

(a) Pressure Type Gravity Feed Chlorinator

In the gravity feed chlorinator, dry gas at slight pressure is introduced into a cylindrical tower made of corrosion resistant material. Water is introduced at the top of tower (Fig. 8.2). As water flows down slowly, it gradually absorbs the chlorine. The resultant solution flows out of the tower by gravity to the point of application. Fig. 8.3 depicts a chlorinator with injector.

(b) Vacuum Type Chlorinator

Chlorine gas is maintained under vacuum throughout the metering apparatus. The opening of the chlorine inlet valve is governed directly by the vacuum induced in the system. This type of chlorination is most common because of safe operation (Fig. 8.4).

The Vacuum Type Chlorinator Consists of:

- (i) A differential vacuum regulator flow meter;
- (ii) A compensating vacuum regulating valve to maintain a constant down stream pressure;
- (iii) Flow regulating pressure valve to maintain constant downstream pressure;
- (iv) An injector or educator to create the necessary vacuum in which gas will be mixed with a small quantity of water prior to the point of application;
- (v) A vacuum pressure breaker to prevent the possibility of water being drawn into the apparatus, to prevent build up of pressure;
- (vi) Variable area flow meter to measure the amount of chlorine gas flowing.

8.7.3 ENGINEERING CONTROL OF HAZARDS

Careful consideration should be given to methods of handling chlorine shipping containers. Ceilings high enough for overhead hoists and floors of sufficient area for ease in handling mechanical equipment should be provided. Storage and use areas should be properly ventilated so as to minimize possible accidental reaction of chemicals, which is based on their previously noted characteristics. Piping systems should be as simple as possible with a minimum number of joints; they should be well supported, protected against temperature extremes and adequately sloped to allow proper drainage.

Long pipelines for liquid chlorine should be avoided. Sections of pipelines that can be isolated or shut off at both ends (such as by valves) must be provided with a suitable expansion chamber to avoid possible hydrostatic rupture due to pressure and volume increase accompanying high temperatures. Condensation or reliquefaction can occur in chlorine gas lines that pass through areas where the temperature is below the

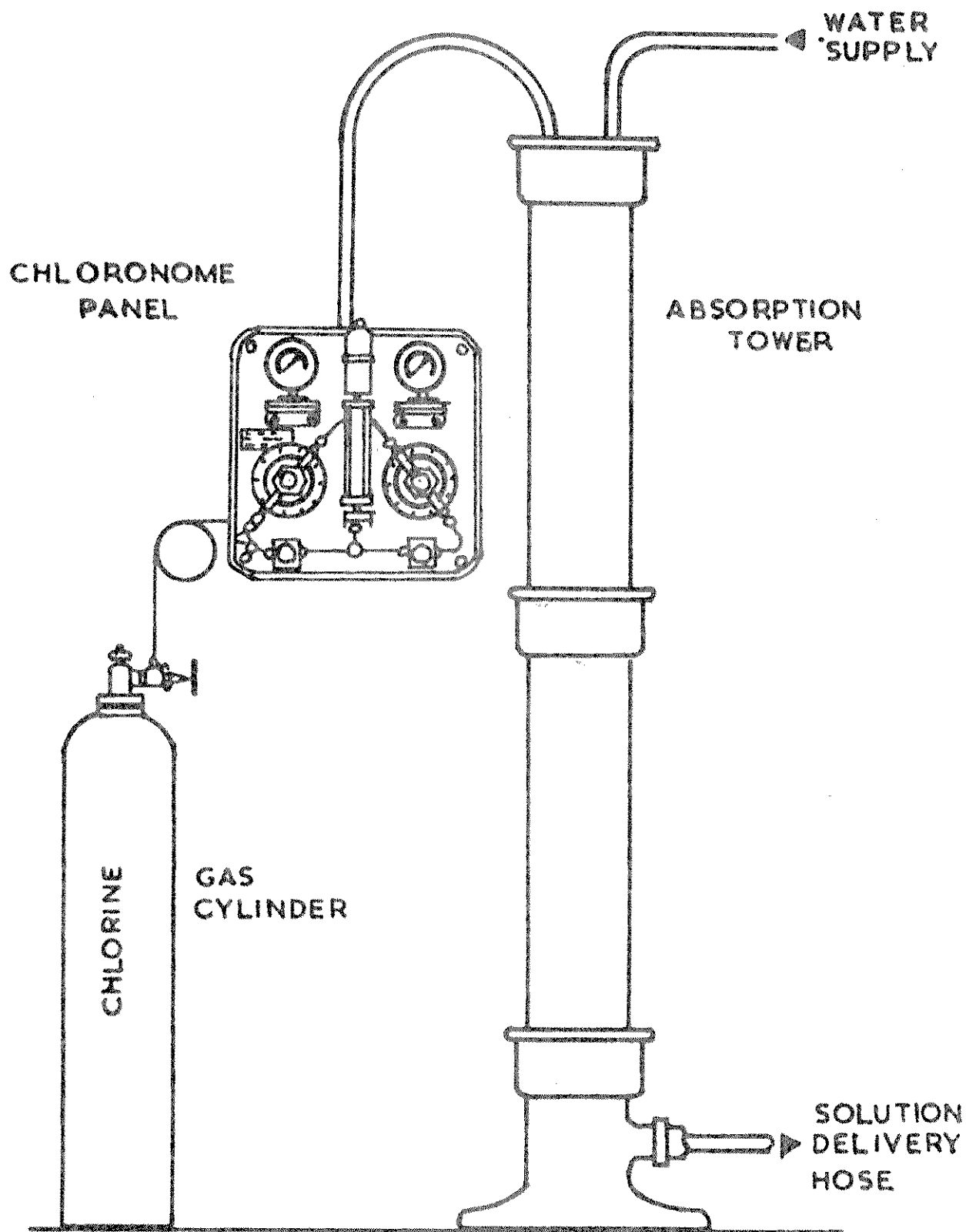


FIG. 8.2 CHLORINATOR WITH ABSORPTION TOWER