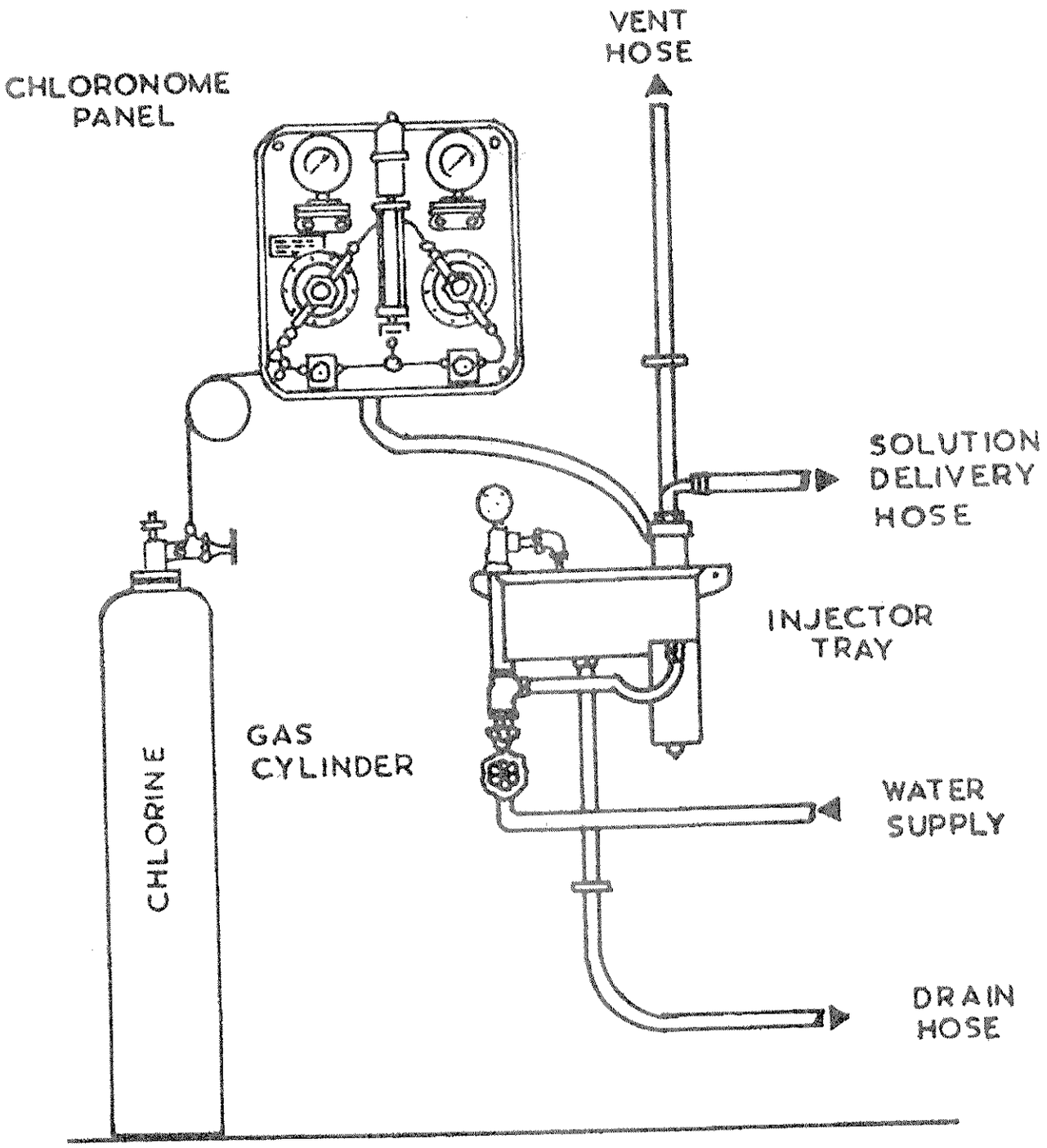

FIG. 8.3 CHLORINATOR WITH INJECTOR

temperature-pressure equilibrium indicated on the chlorine vapour pressure curve. It can be prevented by supplying properly controlled heat or by reducing the pressure. The temperature of chlorine containers and gas pipelines should be lower than the temperature of the chlorinator to prevent condensation; if chlorine gas condenses, the chlorine will be reliquified and result in erratic chlorinator operation. Chlorine pipelines removed from service for even very brief periods should be closed in a suitable manner to preclude the entrance of moisture, which will cause serious corrosion problems.

Equipment cleaning and repair should be performed under the direction of thoroughly trained personnel who are fully familiar with all the hazards and the safeguard necessary for the safe performance of the work. All precautions pertaining to education, protective equipment and health and fire hazards should be reviewed and understood. Repair to chlorine systems should not be undertaken while the system is in operation and while piping systems are in service. Chlorine pipelines and equipment should be first purged with dry air as a safeguard to health; this is especially important where cutting or welding operations are undertaken because iron and steel will ignite in presence of chlorine at about 235 ^{0}C. Immediate drying of a chlorine pipeline into which water or moisture has been introduced or which has been opened for repairs, is essential if corrosion is to be prevented.

8.7.3.1 Piping Systems

Moist chlorine unlike dry gas or liquid chlorine is highly corrosive.; Pipelines, valves and other fittings through which dry chlorine passes should be tightly closed when not in use to prevent absorption of the moisture from the air. Dry chlorine gas or liquid chlorine under pressure should be conveyed through extra heavy wrought iron or steel pipe or flexible annealed copper tubing tested for 35kg/cm^2 working pressure. The discharge line from the chlorine container should be flexible and slopping upwards, especially when chlorine is discharging in the liquid state. Long pipelines should be avoided. Hard rubber, silver or Platinum tubing is necessary for conveyance of moist chlorine gas or aqueous chlorine solutions at low pressure.

To prevent condensation of gas, piping systems and control equipment should be at the same or a higher temperature than the chlorine container. Chlorine gas lines are preferably located overhead rather than along with floor, to take advantage of the warmer ambient temperature. For liquid chlorine piping systems, conditions, which contribute to vaporization, could be avoided.

For pipes 35 mm diameter and smaller, connections may be either screwed, welded or flanged. If flanged, facing should be small tongue or grove. Gaskets should be made of antimony lead (with 2 to 3% antimony) or asbestos sheet. Rubber gaskets are not suitable. Screwed fittings should be of forged steel construction.

Pressure indicators in the system have Teflon diaphragms or silver foil protectors. Pressure reducing valves may be of bronze or silver plated body with silver diaphragm or of monel metal with a Teflon diaphragm.

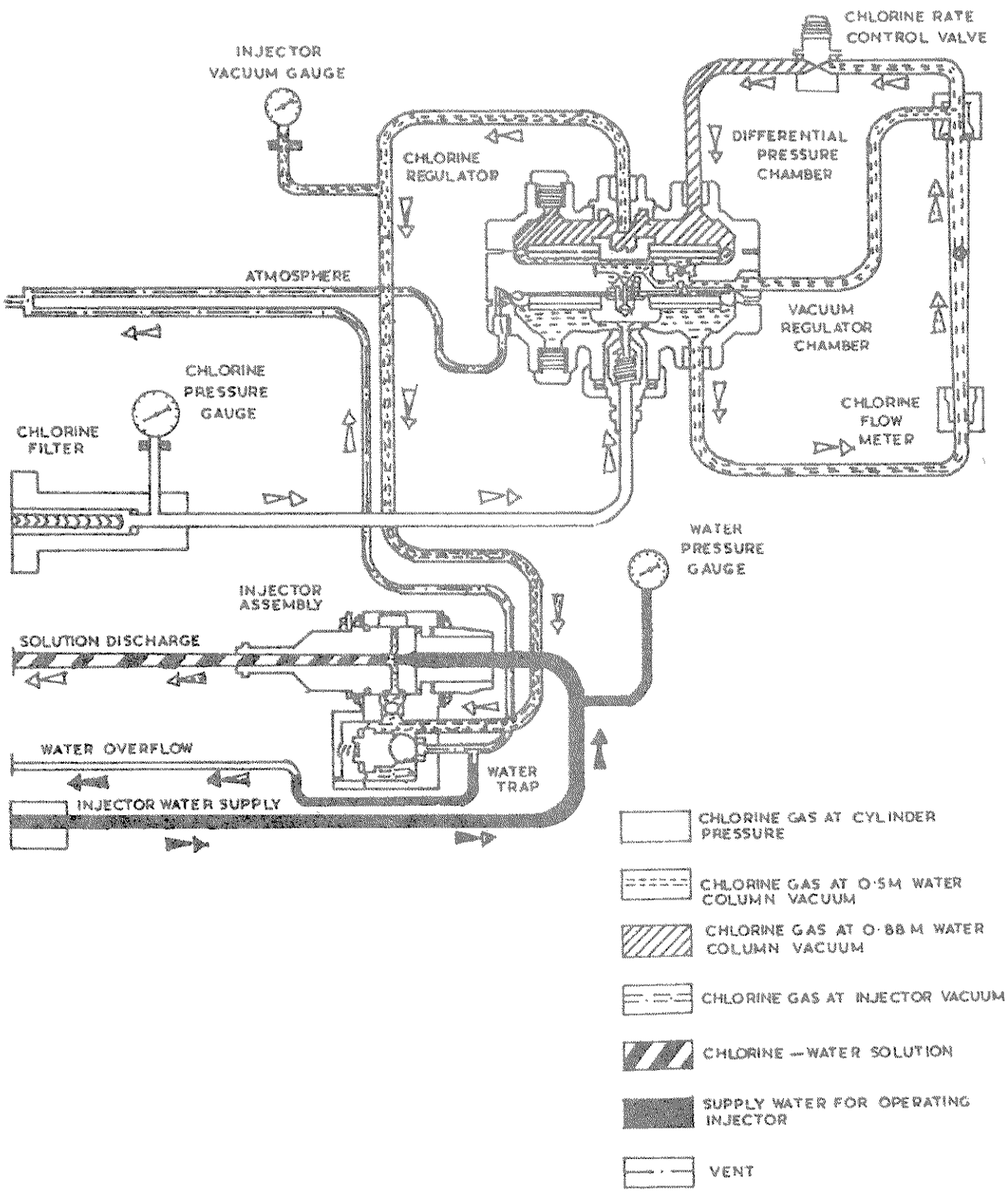

FIG. 8.4 MANUALLY OPERATED VACUUM TYPE CHLORINATOR

8.7.3.2 Number Of Cylinders Or Containers

Normal chlorine dosage required to disinfect water supplies not subject to significant pollution would not exceed 2mg/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 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 producing 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, round the containers in service warm and to ensure that there is not an abnormal rate of withdrawal from a single container with heavy demand of gas.

The recommended discharge rates are approximately 6.5 to 7.5 kg/hr, from a one ton container and 0.8 kg/hr from cylinders. Equipment should have sufficient capacity to exceed highest expected demand at any time and to provide continuous effective discharge under all prevailing hydraulic conditions. It is good practice to provide for duplicate equipment since 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 3 or 4 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.

8.7.3.3 Maintenance

Every chlorinator is supplied with an instruction book that will include specific steps to follow in servicing. However, following are four areas most often associated with maintenance requirement and cause of trouble.

(a) Moisture

Moisture in chlorine is corrosive to ferrous and most nonferrous metals. Most chlorinators use plastic materials in the sections where gas is handled under vacuum. Metal parts or fittings, which are generally external to the chlorinator, are header valves, header lines and flexible connections. When any connection is broken, even for a short time, the openings should be plugged immediately to exclude moisture. Corrosion is internal and not

evident upon external inspection until failure occurs. A good rule to follow is to exclude moisture from any part of the equipment that is normally exposed to dry chlorine only.

Corrosion products, primarily ferric chloride, are a major cause of chlorinator malfunctioning.

(b) Impurities in Chlorine

Even trace amount of impurities can cause problems if they accumulate. Two compounds are frequently found in chlorinators after continuous use. One, ferric chloride, may be present in the chlorine containers or may result when careless operation allows moisture to enter the system. This compound is recognizable as a dark brown, syrupy liquid and is soluble in water. After chlorinator parts are washed to remove impurity, they must be dried thoroughly before reassembly.

The other material, hexachloroethane or a similar compound, is classed as a volatile solid. It tends to deposit in gas lines at points of pressure-temperature drop. This material is not soluble in water, but can be dissolved in trichloroethane, a common industrial solvent.

(c) Flexible Connections

Flexible connection (comprising small diameter metal tubing), used to connect two cylinders or ton containers, need special attention. Because they are flexed every time a cylinder is changed, they are subject to metal fatigue. These connections should be changed once a year.

Each time a connection is made either to a chlorine container or to the chlorinator, a new gasket must be used.

(d) Gaskets

Elastomeric (flexible) materials used for gasket and O-rings generally become brittle in time. If a gasketed joint is not broken, the gasket may last for years. A regular programme of replacement is desirable but guidelines are difficult. Every recommended spare-parts list includes spare gaskets. If swelling or hardening of a gasket is noted, it should be replaced. Distorted or hardened gaskets cannot be properly seated.

8.7.4 Chlorine Housing

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 building should have at least two exit doors for cross ventilation that allows an approximate air change in 10 minutes. For small installations, provision of 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 in buildings occupied by persons. These enclosures should be vented to the upper atmosphere and equipped with positive means of exhaust (near the floor level, at the center 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 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 availed.

8.7.5 Chlorine Evaporators

Chlorine vaporizers, 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/24 hr and would require the manifolding of an excessive number of containers. Evaporators provide the heat necessary to vaporize 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.

As 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 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 vaporization 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 vaporized, 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 waterbath temperature settings. Eventually, the pressure vessel will require cleaning as the evaporator will be unable to vaporize 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 :

- Control thermostat senses water temperature and turns 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.
- Chlorine bath-pressure gauge indicates chlorine gas pressure within the pressure vessel.
- Chlorine-gas-temperature gauge indicates 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 persist 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 persist high-water bath temperature. Excessive temperature may be caused by failure of the heater controls, which allows the heater to remain on or 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 persist 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 energize or deenergize the electric immersion heater.
- Cathodic protection protects from corrosion all metal surface of the evaporator in contact with water.
- Vent alarm switch actuates whenever gas flow occurs in the vent line and indicates that the gas-pressure-relief valve has opened.
- Liquid chlorine expansion tank protects the liquid chlorine piping system from damage due to over pressure 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.

8.7.6 Ancillary Equipments

8.7.6.1 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.

8.7.6.2 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 respirator failure or other emergencies.

It is 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 alarm, should be considered.

8.7.6.3 Chlorine Detectors

Continuous monitoring of 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 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 1, the air to be sampled is directed to a rotating drum covered with a strip of sensitized 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 to that required to keep the relay open and thus the alarm circuit is energized.

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 flow meter 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 air and an adjustable switch is included to provide a contact closure for remote audible/visual alarms or an exhaust fan.

8.7.6.4 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 stand by 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 pressure approximately 5 psig 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 market place. 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.

8.7.7 Safety Considerations

(a) 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.

(b) 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.

(c) 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.

(d) Cylinders should not be stored in the open or in 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 prompt return of used cylinders.

(e) 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.

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

(g) 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 'down stream' 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.

(h) Water should never be applied to a chlorine leak to stop it as it will only make it. 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 replacing with new packing, if necessary.

(i) Solvents such as petroleum, hydrocarbons or alcohols should not be used for cleaning parts which 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. Only special cements recommended by manufacturers should be used.

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

(k) 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 while the cylinders are being disconnected or repairs being made.

8.7.8 Handling Emergencies

As soon as there is 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 chemical storage and use areas and 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, truck and barges should be disconnected and if possible, should be removed from the fire zone. If there are no leaks, water should be applied to a leaking 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 vaporization rate. Leaking chlorine containers similarly 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 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 off. Leaks around container valve stems 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 off. 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 ton container, the container should be positioned so that the valves are in a vertical plane with the leaky valve on the top.

If one is confronted with other container leaks, one or more of the following procedures should be considered:

(i) Position cylinders or ton containers so that gas instead of liquid escapes. The containers may be insulated with sacks, earth etc to decrease absorption of heat and the discharge rate.

(ii) Apply appropriate emergency capping devices, if available.

(iii) Call the supplier or nearest producer for emergency assistance.

(iv) 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 ton containers (100 kg of Cl_2 can be neutralized with 125 kg of caustic soda).

(v) In some cases it might be desirable and possible to move the container to an isolated spot where it will do the least harm.

8.7.9 Personnel Training

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:

(i) Instruction and periodic drill or quiz regarding the locations, purpose and use of emergency fire-fighting equipment, alarms and emergency crash shut-down equipment such as valves and switches.

(ii) Instruction and periodic drill or quiz regarding the locations, purpose and use of personnel protective equipment.

(iii) Instruction and periodic drill or quiz regarding the locations, purpose and use of safety showers, eye baths, bubblier drinking fountains and the closest source of water for use in emergencies.

(iv) Instruction and periodic drill or quiz of selected employees regarding the locations, purpose and use of respiratory first aid equipment.

(v) Instruction to avoid inhalation of toxic vapours and all direct contacts with corrosive liquids.

(vi) Instruction to report to the proper authority all leaks and equipment failures.

8.8 CHLORINE COMPOUNDS

Chlorine may also be applied in the form of compounds such as bleaching powder or as 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 upto 0.5 mld.

(a) Bleaching Powder

Bleaching powder 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 water. Bleaching powder is characterized by its content of available chlorine i.e. the chlorine which can be liberated by complete reaction with water. Commercial brands have an available chlorine of 20 to 30% i.e. 20 to 30 parts by weight of chlorine per 100 parts by weight of bleaching powder.

Bleaching powder is generally made into a thin slurry with the water and the supernatent, which contains the chlorine in solution, is applied to the water by a suitable feeding mechanism such as a float operated gravity box. In every installations, the solution may be applied through a dripfeed mechanism. Devices which can give constant feed can be easily fabricated. In the case of well supplies, bleaching powder solution may also be introduced at the suction side of the pump. 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. A very simple method involving the use of porous earthenware cylinders which can be suspended in wells has been developed in the country. This method offers promise in the chlorination of rural water supplies where cost and technical skill have to be kept at a minimum.

Since bleaching powder contains only around 30% available chlorine, its use involves the extra expense of transporting and storing the inert material. The cost is further increased because the material is sold in nonreturnable drums which have no salvage value. Furthermore, bleaching powder is an unstable compound and loses its available chlorine on storage. All these considerations make its use uneconomical except in very small installations or for special cases such as disinfection of mains.

(b) Hypochlorites

The chemicals used are Sodium Hypochlorite and Calcium Hypochlorite. Specially fortified brands of Calcium Hypochlorite such as Perchloron and High Test Hypo (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 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 pipe lines by venturi or orifice feeders.

(c) Chlorine Dioxide

Chlorine dioxide is an unstable gas. It is formed by reacting a strong solution of chlorine (7500 mg/l of Cl_2 at pH 3.5) with Sodium Chlorite.

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

Theoretically 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 but aqueous solutions of the gas are stable and safe. It has been reported to be a good bactericide and its bactericidal efficiency is relatively unaffected by pH between 6 and 10. It is a good sporicide and a strong oxidant. It does not combine with ammonia and most organic impurities before oxidizing 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 of chlorine used in its generation, rather than ClO_2 is generally counted upon to achieve disinfection. It can be effectively used for destruction of tastes and odours, particularly those which are caused by phenolic substances.

8.9 DISINFECTION METHODS OTHER THAN CHLORINATION

Chlorine and its compounds are most widely used for disinfection because they meet the requirements of a good disinfectant more fully than any other disinfectant. However, possible formation of carcinogenic byproducts by reaction of chlorine with some organics and enhancement of 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, 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.

8.9.1 HEAT

Boiling of water will disinfect it. This practice, however, cannot be used to disinfect municipal supplies for economical reasons. Boiling of water is applicable for disinfecting individual's drinking water in emergencies like accidental contamination of public water supply or during epidemic breakout. The thermal resistance of different microorganisms and viruses varies significantly with spores being upto 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. Continuous-flow-water-pasteurises with flow rates of 1000 lph are also available.

8.9.2 CHEMICAL DISINFECTANTS

Chemical disinfectants are commonly grouped under following categories:

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

(ii) Metal ions.

(iii) Alkalies and Acids.

(iv) Surface active chemicals.

8.9.2.1 Halogens Other Than Chlorine

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

Bromine is a heavy dark reddish-brown liquid which upon addition to water forms Hypobromous acid (HOBr), the dissociation of the acid resulting in formation of hypobromite ion (OBr). Bromine also reacts with ammonia in water to form monobromanine and dibromanine. No stable tribromanine is formed. Monobromanine is a strong bactericide almost as strong as free bromine in contrast to monochloramines. Bromine has been used for 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 oxidizes ammonia. It also oxidizes phenols. Because of these reasons, less iodine is required to obtain free iodine residual.

Iodine has been used for disinfection of swimming pool waters and small quantities of water in field. Iodine tablets (e.g. of tetraglycine hydroperiodide) have been used by the Army. Iodine is less dependent on pH, temperature, time of contact and nitrogenous impurities than chlorine and can also kill amoebic cysts which chlorine does not. It has the same disinfecting power as chlorine. Because of certain advantages over chlorine, iodine is better for post disinfection than chlorine providing longer lasting protection against pathogens and reduced offensive tastes and odours. However, it is more costly than chlorine.

8.9.2.2 Ozone

It 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 oxidizing and germicidal agent. Ozone is produced by the corona discharge of high voltage electricity into dry air. Ozone, being unstable, has to be produced onsite.

Ozone possesses more superior bactericidal properties than chlorine and is highly effective in removal of tastes, odours, colour, iron and manganese. As ozone reacts with chemical impurities prior to attacking the microorganisms, it produces essentially no disinfection unless ozone demand of water has been satisfied but much more rapid kills are achieved, once free ozone residuals are available. Studies have reported 99.99% kill of E.Coli

2962 UA&E/97—22A

within less than 100 seconds in the presence of only 10 bg/1 of free available ozone. Ozone is effective in killing some chlorine resistant pathogens like cysts and certain virus forms. Ozone, unlike chlorine, does not impart offensive tastes and odours to water, nor does it usually produce toxic substances such as chlorinated hydrocarbons. Further the efficiency of disinfection by Ozone is unaffected by pH or temperature of the water over a wide range.

Among the disadvantages of ozone treatment are:

(i) Its high cost of production.

(ii) Inability to provide residual protection against recontamination.

(iii) Its generation onsite due to unstability.

However, despite these disadvantages, ozone has been extensively used in Europe for disinfection of municipal water supplies.

8.9.2.3 Potassium Permanganate

Potassium permanganate is effective in removal of taste and odour and inorganic impurities such as iron, manganese and hydrogen sulphide besides possessing noticeable disinfecting properties. It is more expensive disinfectant than chlorine but has the advantages of not producing offensive taste, odour and/ or potential toxicity.

8.9.2.4 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 15bg/l are sufficient to destroy most organisms. Silver can be introduced in water either in the form of a 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 ion may dissolve which is considered sufficient for most disinfection purposes.

8.9.2.5 Acids And Bases

Addition of acids or bases resulting in pH values below approximately 3 and above approximately 11 creates toxicity and pathogens do not survive long in such waters. Increased acidity and basicity increases ionic strength and osmotic pressure which are suggested to be responsible for the destruction of cells.

Disinfection of water is achieved during Lime-soda softening process due to increased pH. However, explicit use of acids and alkalies for the sole purpose of disinfecting water is not commonly practiced. Changes in pH may have marked effect on the efficiency of disinfection by certain chemical disinfectants such as chlorine.

2962 UA&E/97—22B

8.9.3 RADIATION

Several types of radiations including ultraviolet, gamma and X-rays and microwaves are cited in literature, for destruction of microorganisms. While high energy gamma rays of 1.10 and 1.30 million electron volts (Mev) are emitted by cobalt-60, X-rays are produced by electron bombardment of a heavy metal target in an evacuated X-ray tube. The wavelength of gamma rays corresponding to 1.10 Mev is 0.03366 A^0 compared to the wavelengths of 2537 A^0 of ultraviolet rays, making gamma rays one million times as powerful and giving them great penetrating properties. Gamma rays are highly effective even against spores and viruses. Death of cells results from ionization reactions within cell molecules and secondary radiation effects and chemical reactions due to production of unstable atoms, free radicals and other chemical species formed by the interactions of gamma rays with organic molecules present in water. A dosage of 100,000 to 150,000 rads (1 rad = 100 ergs per gm.) to the organisms is sufficient with the exception of Bacillus subtilis which is difficult to kill. X-rays also have been found to be suitable for killing bacteria. However, because of the high costs involved and other unfavourable properties of leaving no residual protection against recontamination, these have yet to find large scale practical applications in water treatment practice.

8.9.3.1 Ultraviolet Radiation

It was observed that exposure of water to sunlight and artificial light leads to destruction of organisms. These bactericidal effects of intense sunlight or artificial light are primarily due to ultraviolet rays. Ultraviolet radiation may kill a cell, retard its growth, change its heredity by genemutation. 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 region from 2500-2650 A^0 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 2537 A^0 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 is 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 30mm, including surface reflection of 2%. Presence of iron even at low concentration of 1mg/l may drastically increase absorption by over 80%. Water depths of about 120 mm are recommended for efficient disinfection.

Intensity of ultraviolet rays is expressed in terms of germicidal unit which is an intensity of 100 mw per sq. cm. at wave length of 2537 A^0. It has been reported that Fscherichia Coli kills of 99.99,99, and 90% can be achieved by ultraviolet rays of 3000, 1500 and 750 mW-sec per sq.cm. Typically a 30 watt lamp could achieve 99.9% kill for water flows of approximately 2.5 to 17.0 m^3/hr hr for water depths ranging from 125 to 880 mm approximately assuming 90% absorption of ultraviolet rays.

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

CHAPTER 9
SPECIFIC TREATMENT PROCESSES

9.1 INTRODUCTION

Water treatment involves physical, chemical and biological changes that transform raw water into potable water. The treatment process used in any specific instance must depend on the quality and nature of the raw water. Quality requirements for industrial uses are frequently more stringent than for domestic supplies. Additional treatment may be required by the industry like demineralization of boiler feed water to prevent scale deposit.

Water treatment processes may be simple like sedimentation or may involve complex physico-chemical changes, as with coagulation. The specific treatment processes include control of algae, control of taste and odour in water, removal of colour, softening, removal of iron and manganese, defluoridation of water, demineralization of water and corrosion.

9.2 CONTROL OF ALGAE

9.2.1 GENERAL

Algae give rise to a variety of troubles in water supplies. They impart odours and tastes to the water. Synura causes a perceptible odour. Asterionella, Meridion and Tabellaria produce aromatic odour. Algae like Dinobryon, Peridinium, Uroglenopsis, Asterionella and Tabellaria produce fishy odour. Grassy odour is caused by Aphanizomenon,Anabaena, Gomphosphaeria, Cylindro-spermum and Rivularia. Septic odour is caused by Cladophora, Hydrodictyon, Ceratium, Aphanizomenon, Anabaena and Cylindrospermum. When algae like Microcystis, Anabaena and Aphanizomenon die en mass and decay, they produce foul odours.

Some algae impart sweet or bitter or sour tastes to water. Algae like Nitella, Geratium and Synura give rise to bitter taste, while algae such as Chara, Euglena, Aphanizomenon, Microcystis, Cryptomonas and Gomphosphaeria impart sweet taste to water.

Algae interfere in the process of flocculation and sedimentation. Algae like Asterionella and Synedra prevent floc formation. Water containing Gomphosphaeria and Anabaena need to be agitated for proper floc formation. They buoy up the flocs and carry into the filters. They choke the filters and as a result reduce the filter runs. Algae associated with filter clogging are Asterionella, Fragilaria, Navicula, Synedra, Cymbella, Diatom, Oscilatoria, Rivularia, Trachelomonas and Closterium. Algae like Synedra and Oscillatoria can pass through rapid sand filter. Algae such as Euglena, Phacus, Navicula, Nitzschia and Trachelomonas get through slow sand filter. These algae in distribution system cause biological corrosion.

Lyngbya, Anabaena, Cylindrospermum, Nodularia and Microcystis are some of the common toxic algae associated with fish and cattle mortality. Hay fever is caused by Anacystis and Lyngbya Contorta. The gastrointestinal disturbances are also said to be due to algal toxicity.

Algae may be killed by treating the water with suitable chemicals. However, the procedure of allowing the algae to establish themselves and then adopting algicidal measures has a number of disadvantages, viz. (i) the dose of chemical required is greater than that needed, if the treatment is adopted at the incipient stages of growth (ii) the dead algae decay and produce acute odour problems (iii) the dead algae provide a pabulum for a second crop which are generally more prolific than the first and also more resistant to the action of algicides. It is therefore, preferable to take all possible measures to discourage the growth of algae and to reserve the use of algicides as a final treatment.

9.2.2 Causative Factors for Growth

Algal growth is influenced by a number of factors such as nutrients in the water, the availability of sunlight, the character of the reservoir and temperature.

9.2.2.1 Nutrients in Water

Nutrients like nitrogen and phosphorus favour the growth of algae. Swamp water or water in contact with decaying vegetation as well as water polluted by sewage contain large amount of organic matters favouring certain types of algal growth. Among the various mineral compounds, those of nitrogen and phosphorus are particularly favourable and are generally brought in by agricultural return waters and some industrial wastes. Algicidal treatments have limited value when the water is rich in such nutrients because the conditions are favourable for the growth of succeeding crops of algae.

9.2.2.2 Eutrophication

Eutrophication is the process whereby lakes become enriched with nutrients that make the water undesirable for human use, both for water supplies and recreation. Limnologists categorize lakes according to their biological productivity. Oligotrophic lakes are nutrient poor. Typical examples are a cold-water mountain lake and a sand bottomed, spring-fed lake characterised by transparent water, very limited plant growth, and low fish production. A slight increase in fertility results in a mesotrophic lake with some aquatic plant growth, greenish water and moderate production of game fish. Eutrophic lakes are nutrient rich. Plant growth in the form of microscopic algae and rooted aquatic weeds produces a water quality undesirable for body-contact and non-body contact recreation.

9.2.2.3 Effects of Eutrophication

The process of eutrophication is directly related to the aquatic food chain. Algae use carbon dioxide, inorganic nitrogen, orthophosphate and trace nutrients for growth and reproduction. These plants serve as food for microscopic animals (Zooplankton). Small fishes feed on Zooplankton and large fishes consume small ones. Abundant nutrients unbalance the normal succession and promote blooms of blue-green algae that are not easily utilized as food by Zooplankton. Thus, the water becomes turbid. Floating masses of algae