19 Disinfection

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19.1 Introduction

The single most important requirement of drinking water is that it should be free from any micro-organisms that could transmit disease or illness to the consumer. Processes such as storage, sedimentation, coagulation and flocculation, and filtration reduce the bacterial content of water to varying degrees. However, these processes cannot assure that the water they produce is bacteriologically safe. Final disinfection will be needed. Disinfection means the destruction, or at least the complete inactivation, of harmful micro-organisms present in the water. It is considered the last barrier in water treatment and in cases where no other methods of treatment are available, disinfection may be resorted to as a single treatment against bacterial contamination of drinking water.

The following factors influence the disinfection of water:

- The nature and number of the micro-organisms to be destroyed. Certain organisms like parasites and viruses may not be destroyed or completely inactivated by disinfection.
- The type and concentration of the disinfectant used. Higher concentrations are co-related to higher efficiencies.
- The temperature of the water to be disinfected. The higher the temperature the more rapid the disinfection will be.
- The time of contact. The disinfection effect becomes more complete when the disinfectant remains in contact with the water longer.
- The nature of water to be disinfected. If the water contains particulate matter, especially of a colloidal and organic nature (turbidity), the disinfection process generally is hampered due to the "protection" of the micro-organisms by the turbidity particles.
- The pH of the water. Chlorine, for example, will have better disinfection power if working at pH below 7, as the chlorine compound that will prevail is HClO. At higher pH the chlorine compound present is ClO-, which has a lesser bactericidal power.
- Mixing. Good mixing ensures proper dispersal of the disinfectant throughout the water, and so promotes the disinfection process.

In small communities there are two possible ways of disinfecting water for human consumption. If the population is scattered, disinfection can be applied at household level. In communities with a higher population density, a "central" water disinfection system is more efficient.

As a classification of different disinfection methods, physical and chemical disinfection are discussed below.

19.2 Physical disinfection

At family level the two principal physical disinfection methods used are boiling of the water and solar disinfection. Ultraviolet radiation has been gaining rising acceptance for small community systems in developed countries, because of the reliability of the components and the declining costs.

Boiling

In some areas of the world this method may be expensive for the user (too much fuel consumption and work for women). Consumers usually do not like the taste of boiled water and it also takes a long time for the water to cool. Nevertheless, it is highly effective as a household treatment, as it destroys pathogenic micro-organisms such as viruses, bacteria, cercariae, cysts and ova. Boiling is normally carried out after education campaigns. In emergency situations, boiling of water may be used as a temporary measure. To enhance feasibility, promotion may focus on boiling water only for groups with the highest risks, such as infants and young children.

Solar disinfection

Solar disinfection (SODIS[1]) works on a different principle to that of boiling. SODIS uses pasteurisation, which is based on the time/temperature relationship, to destroy pathogenic germs that may be present in the water. It has been observed that heating water above 62.8°C for 30 minutes or 71.7°C for 15 seconds is sufficient to remove waterborne bacteria, rotaviruses and enteroviruses from contaminated water. In addition, cysts of Giardia lambia are inactivated during 10 minutes at 56°C.

Popular SODIS is performed by beaming sunshine onto transparent water containers with exposure times of several hours. This technique is very appealing, as it does not depend on conventional energy, is very simple, and uses either bottles or low-cost equipment. It is environmentally friendly and people accept it without difficulty.

Nevertheless, SODIS has never reached peak popularity, as there are too many variables that influence the efficiency and eventual safety of the treated water. Parameters that may interfere with a perfect disinfection include geographical latitude and altitude; season; number of hours of exposure; time of the day; clouds; temperature; type, volume and material of vessels containing the water; water turbidity and colour.

1 www.sodis.ch

The World Health Organization considers SODIS a valid option, but as a "lesser and experimental method". Even so, for areas where there are no other means available to disinfect water, the method can substantially improve the bacteriological quality of water. The best results will be obtained when the measure is promoted and monitored by health officials or trained personnel (from a community-based or non-governmental organization – CBO or NGO).

Figure 19.1 shows both the batch and continuous solar disinfection systems. The continuous one comprises an exposure vessel or *reactor* and a tank where treated water exchanges heat with raw water (obviously without mixing).

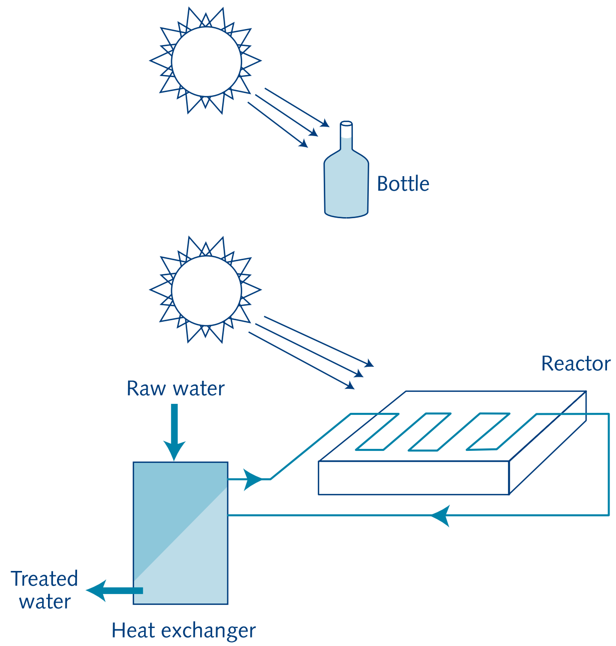

Fig. 19.1. Batch and continuous solar disinfection

Ultraviolet radiation

Even though it is not popular in the Third World, the most practical physical method that can be used for water disinfection in a "central" water treatment facility at small community level is ultraviolet radiation.

In ultraviolet disinfection, short wave radiation strikes water flows at close distance. The UV radiation (or *UV light*) is produced by low-pressure mercury vapour lamps that resemble the popular fluorescent lamps. In fact, large companies that make standard fluorescent lamps also manufacture the UV lamps; consequently, lamps, ballasts and starters for the UV systems can be bought "off the shelf".

Although it has been well known for decades, it is only recently that the technique of UV radiation has been widely acknowledged. The reasons are that the industry has achieved a great level of quality, durability and reliability in the production of lamps and that the equipment and operation costs have been drastically reduced.

The disinfection mechanism is the disrupting effect the short waves have on the genetic material (DNA) of micro-organisms and viruses, killing them in a very short time.

The most important parameters determining the efficiency of disinfection are:

- Wavelength
- Condition of the water
- Intensity of radiation
- Type of micro-organism
- Exposure time

The UV wavelengths range from 100-400 nm, but they are differentiated and called

- UV-A: 315 – 400 nm
- UV-B: 280 – 315 nm
- UV-C: 100 – 280 nm

The germicidal portion is the UV-C. The commercially available low pressure mercury vapour lamps emit at 254 nm, a wavelength that is strongly active for disinfection.
A typical UV equipment setup is shown in figure 19.2. The lamps can be either in direct contact with the water or cased in protective shields made of quartz.

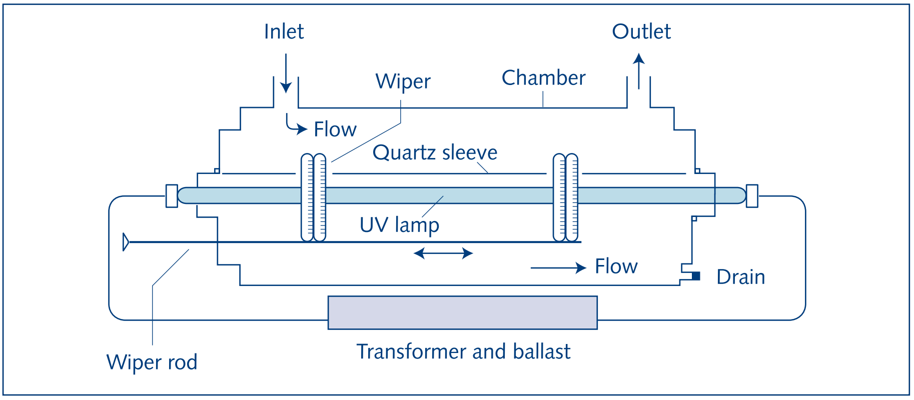

Fig. 19.2. A typical UV disinfection system

Deposits of calcium carbonates, silt, organic material or iron onto the bulbs or the sleeves can reduce the output and the germicidal power. Now, almost all systems have sleeve wipers that reduce the problem.

A modern UV disinfection system may include the following:

- A non-corrosive chamber that hosts the system
- UV lamps
- Mechanical wipers, ultrasonic cleaners or any other self-cleaning mechanism
- Sensors connected to alarm systems for monitoring UV intensity
- Safety shut-off in case of high or low flow rates, low lamp intensity or elevated temperatures of the lamp or system components
- Lamp-out monitors
- Electronic ballasts or current stabiliser

The condition of the water is linked with the effective intensity of radiation. If the water is clear, the intensity will be higher. If there are too many UV-absorbing elements like turbidity, organic matter, iron and/or manganese, these will shield the micro-organisms from the lethal rays. A clear (or as clear as possible) water is thus important to ensure a powerful effect. To have an effective disinfection process whereby the entire water body is properly reached by the rays, the water depth should not be more than 75 mm.

Ultraviolet radiation is measured in milli-Watt seconds per square centimetre (mWs/cm^2) or micro-Watt seconds per square centimetre ($\mu Ws/cm^2$).
Obviously, different micro-organisms will have different resistance against the radiation. The dosage of UV light required to destroy most common micro-organisms (coliform, pseudomonas, etc.) is between 6000–10,000 $\mu Ws/cm^2$. Standards for UV dosage in different countries range between 16,000 and 38,000 $\mu Ws/cm^2$. As with any other disinfectant, the time of exposure is vital to ensure a good performance. It is not easy to determine the right contact time with accuracy (as this depends on the type of flow), but the period of time should be related to the needed dosage. Normal exposures are in the order of 10-20 seconds.

An advantage of the method is its simplicity of operation and maintenance. There is no need to buy and store any chemicals. It leaves no bad taste or odour in the water and carries no risk of overdose. It effectively destroys bacteria and viruses.
There are also limitations. The efficacy of UV light for the inactivation of *Giardia lambia* or *Cryptosporidium cysts* has long been doubted by microbiologists. It is unsuitable for water with high levels of suspended solids, turbidity, colour or soluble organic matter. In those cases, pre-treatment of the water is needed. Also, unlike chlorination, UV radiation does not produce any residual that would protect the water against new contamination and that could also serve for control and monitoring purposes.

Ultraviolet light for disinfection is used in small communities in several developed countries but is rarely applied in developing ones. This may change in the coming years.

In brief:

Pros
- Simple process
- Efficient process
- No chemicals involved
- Does not modify aesthetic characteristics of water
- Can be managed by unskilled personnel

Cons
- Intermediate to high cost of equipment when compared with chlorine solution feeders
- Water should be very clear. Needs electric power
- There is no residual

O & M tips
- Checking should be done to ensure that there is no scaling on protective sleeves

19.3 Chemical disinfectants

Several chemicals, acting as strong oxidants, can destroy micro-organisms. Hydrogen peroxide and other metallic peroxides, lime, potassium and calcium permanganate, iodine, bromine, ozone and chlorine and its related compounds all fall into this category. Clean metals like copper, silver, mercury and zinc also disinfect, basing their action on a mechanism that is probably related to the absorption of the metallic ions by the organism, which in some way affects the chemistry of its cell structure.

It is not only important to have the potential to destroy germs. A good chemical disinfectant for use in developing countries should also possess the following important characteristics:

- Quick and effective in killing pathogenic micro-organisms present in the water
- Readily soluble in water in concentrations required for the disinfection
- Capable of providing a residual
- Not imparting bad taste, odour or colour to the water
- Not toxic to human and animal life
- Easy to detect and measure in water
- Not producing disinfection by-products (DBPs)
- Easy to handle, transport, apply and control
- Simple or "appropriate technology" devices for dosing
- Readily available in far away locations
- Low cost

Unfortunately there is not one disinfectant that complies with all of those conditions. Almost all of them fall into a category that could be called "far from complying". Only a few may be called "almost complying".

A brief description is given here for the most popular included in the first group: ozone, iodine, bromine, potassium permanganate and metallic ions. More detail is provided for the ones in the second group: chlorine and its compounds.

Ozone

Ozone, being a very strong oxidant, is effective in destroying organic matter and in eliminating compounds that give objectionable taste or colour to water. Nowadays it is used in several important water facilities in the industrialised countries. Like ultraviolet rays, ozone normally leaves no measurable residual, which could serve for monitoring the process or that may protect against new contamination of the water after its disinfection.

Disinfection by ozone, like chlorine, leads to the formation of both inorganic and organic DBP. The most frequently found are bromates, bromoform, bromoacetic acid, aldehides, ketones and carboxilic acids, which are carcinogenic.

The high installation and operation costs, the need for continuous supply of power and the need for a proper operation and maintenance, do not make the use of ozone a recommended practice for small systems in developing countries.

Iodine

Iodine has attractive properties as a disinfectant. It has an effective bactericide and virucide power over a wide range of pH. In fact, iodine, unlike other halogens, becomes a more effective virucide as the pH increases. Iodine has been widely used for individual water supplies and for small batches of water. From farmers to hikers the use of iodine is popular either in solution, drops or tablets.

In spite of its attractive properties as a disinfectant, iodine has not gained widespread use in water treatment. One reason is that it is more costly (about ten times more expensive) than chlorine. Another may be that the use of iodine for water disinfection over extended periods of time has been seriously debated, as it may have physiological effects on iodine-sensitive people. The high volatility of iodine in aqueous solution is also a factor against its use except in emergency situations.

Bromine

Compared with chlorine and iodine, bromine is a more effective amoebic cysticide throughout the pH range. Its residual is more persistent than that of chlorine and, once in solution, it can be dosed easily with a diaphragm pump. On the other hand, bromine is not easily found everywhere it is a bit dangerous to manipulate, and it is more costly than chlorine. Little experience exists for its use as disinfectant for drinking water. For these reasons, bromine is not recommended for small water supplies.

Potassium permanganate

This is a powerful oxidising agent, and has been found to be effective against cholera vibrios but not for other pathogens. It leaves stains in the container and hence it is not a very satisfactory disinfectant for community water supplies.

19.4 Metallic ions

Several metallic ions (gold, silver, copper, mercury, etc) have germicidal properties called oligodynamia. Most of them, though, have drawbacks: gold is expensive; copper is good as an algicide but not so good as a bactericide; mercury is toxic. Silver seems to be the only one to have relatively good characteristics for water disinfection. It is not very toxic to human beings and the doses used in water treatment are very low, in the range of 20 - 75 micrograms/litre. Silver is added to treated water by dosing it from solutions or by direct electrolysis of silver or silver coated electrodes in the running water. Residual silver is not likely to decay easily, and it does not produce taste, odours, colour or DBPs.

Even though the bactericidal power of silver is important, it is not so quick as that of other disinfectants. It has also been found to be not a very good virucide. Besides, organic matter or other salts present in the water may hinder its activity.
Finally, silver disinfection treatment costs can be tens or even hundreds of times more expensive than low-cost disinfectants.

19.5 Chlorine and its compounds

Water disinfection by chlorination, massively introduced worldwide in the early 20th century, was perhaps the most important technological development in the history of water treatment. Filtration and chlorine disinfection of drinking water have contributed significantly to the increase in life expectancy in developed countries during the 20th century. In the USA, at the beginning of the new millennium, over 98% of water systems disinfected their waters with chlorine or chlorine-based compounds.

Even though chlorine and chlorine related substances are not perfect disinfectants, they have a number of characteristics that are highly valuable:

- They have a broad-spectrum germicidal potency and show a good persistence in water distribution systems. This means that they present residual properties that can be easily measured and monitored in networks or after the water has been treated and/or delivered to the users.
- Equipment needed for dosage is simple, reliable and low-cost. At village level, a number of “appropriate technology” feeders have proved to be easy to use, functional and accepted by local operators.

- Chlorine or chlorine-based products are easily found even in remote locations in developing countries.
- It is very economic and cost effective.

The most popular substances in the chlorine family are chlorine; chlorinated lime; high-concentration hypochlorites and sodium hypochlorite. They present different chlorine concentrations or *active chlorine*; which is a measure of their strength.

Active chlorine is the percentage by weight of molecular chlorine that would be rendered by a molecule of the compound. If, for example, a certain solution contains 10% of active chlorine, this is equivalent to 10 g of chlorine gas being bubbled (and totally absorbed) in 100 ml (100 g) of water.

Chlorine

Chlorine is a greenish yellow toxic gas found in nature only in the combined state, chiefly with sodium as common salt. It has a characteristic penetrating and irritating odour, is heavier than air and can be compressed to form a clear amber-coloured liquid. Liquid chlorine is heavier than water. It vaporises under normal atmospheric temperature and pressure. Commercially, chlorine is manufactured by the electrolysis of brine, with caustic soda and hydrogen as by-products. As a dry gas, chlorine is non-corrosive but in the presence of moisture it becomes highly corrosive to all metals except silver, titanium, gold and lead. Chlorine is slightly soluble in water, approximately 1 percent by weight at 10°C.

Chlorinated lime (Bleaching powder)

Before the advent of liquid chlorine, chlorination was mostly accomplished by the use of chlorinated lime. It is a loose combination of slaked lime and chlorine gas, with the approximate composition $CaCl_2.Ca(OH)_2.H_2O + Ca(OCl)_2.2Ca(OH)_2$. When added to water, it decomposes to give hypochlorous acid, HOCl. When fresh, chlorinated lime has active chlorine content of 33-37%. Chlorinated lime is unstable. Exposure to air, light and moisture makes the chlorine content fall rapidly. The compound should be stored in a dark, cool and dry place; in closed, corrosion-resistant containers.

High-concentration hypochlorites

These are not only twice as strong as chlorinated lime (60-70% available active chlorine content) but retain their original strength for more than a year under normal storage conditions. They may be obtained in small volume packages or in bulk. They are available in granular or tablet form.

Sodium hypochlorite

As a solution, sodium hypochlorite (NaOCl) usually contains 10-15% active chlorine in the commercial product. Household bleach solutions of sodium hypochlorite usually contain only 3-5% available chlorine. It is the characteristics of chlorine and its compounds that have dictated the methods of handling and application in water disinfection practice.

19.6 Pre- and post-chlorination and disinfection by-products

In a water facility, chlorination is normally performed at the end of the treatment, after the filtration stage. This is sometimes called post-chlorination.

Pre-chlorination is sometimes applied prior to any other treatment. This is done for the purpose of controlling algae, taste and odour. In this case and when the raw water carries some organic materials (called *precursors*) it may give place to the production of disinfection by-products (DBPs). The most characteristic constituents of the DBPs are the trihalomethanes (THMs).

There has been some concern about THMs as some of them are carcinogenic. Though this is true, the risk of having widespread outbreaks of diarrhoeas and other water-related diseases due to the lack of disinfection largely outweighs the risk of having some cases of cancer. The WHO and the USEPA strongly recommend not jeopardising the microbiological safety of water in order to prevent eventual cases of cancer. Volume 1 of the *WHO Guidelines for Drinking Water Quality* states: "An efficient disinfection should never be compromised". Furthermore, the International Agency for Research on Cancer (IARC) in 1991 evaluated every available major scientific analysis of the potential health effects of chlorinated water, and concluded "chlorinated water is not a classifiable human carcinogen".

19.7 Chlorination in practice

Chemistry

Chlorination of drinking water is carried out in practice through the bubbling of chlorine gas or through the dissolving of chlorine compounds.

In the case of chlorine gas, the reaction that takes place is:

$Cl_2 + H_2O \rightleftharpoons H^+ + Cl^- + HOCl \rightleftharpoons$

In the case of hypochlorites, the reaction that takes place is:

$NaOCl + H_2O \rightleftharpoons Na^+ + OH^- + HOCl$

Or in the case of chlorinated lime (the portion that takes part in the reaction is $Ca(OCl)_2$):

$Ca(OCl)_2 + 2H_2O \rightleftharpoons Ca^{++} + 2\ OH^- + 2HOCl$

The hydrochloric acid (HCl) and the sodium and calcium hydroxides formed in the different reactions do not take part in the disinfection process.

The disinfectant species, the hypochlorous acid (HOCl); dissociates in water as follows:
$HOCl \rightleftharpoons H^+ + OCl^-$

The pH of the water will govern the relative quantities of HOCl and OCl^-.

Both hypochlorous acid (HOCl) and hypochlorite ion (OCl^-) are present to some degree when the pH of the water is between 6 and 9 (the usual range for natural and drinking water). When the pH value of the chlorinated water is 7.5, 50% of the chlorine concentration present will be undissociated hypochlorous acid and 50% will be the hypochlorite ion. The different percentages of HOCl and OCl^- at different pH values can be seen in figure 19.3.

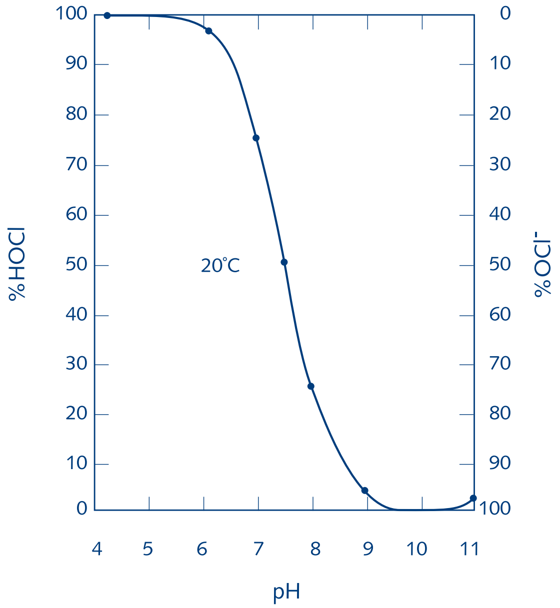

Fig. 19.3. Dissociation of hypochlorous acid versus pH

The different concentrations of the two species make a considerable difference to the bactericidal property of the chlorine, as these two compounds display different germicidal properties. In fact, the HOCl efficiency is at least 80 times greater than that of the OCl^-.

Therefore, in monitoring chlorine in water, the pH also needs to be monitored, as this will give an idea of the real bactericidal potential of the present disinfectant species.

Dose/Demand/Residual

The amount of chlorine added to the water is referred to as the *dose*, and is usually measured as the number of milligrams added to each litre of water (mg/l). The amount of chlorine destroyed in the reaction with the substances in the water is called the *demand*. The amount of chlorine (either free or combined) that remains after a certain contact time is known as the *residual chlorine*.

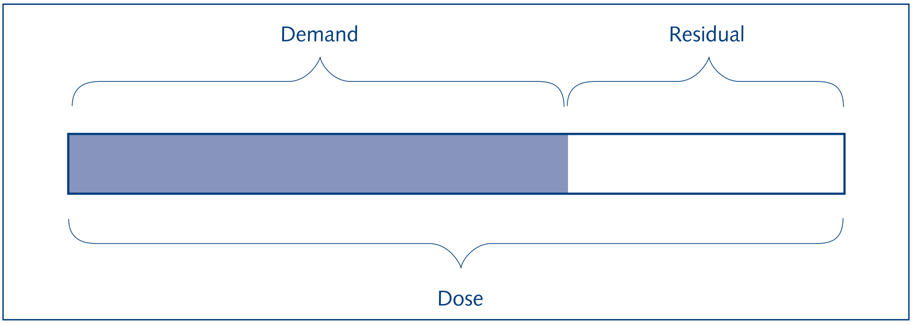

Fig. 19.4. Relation between dose/demand/residual

The graphic (figure 19.4) illustrates that, if the dose is correctly applied, the water will take up the demand in order to achieve full disinfection, and there will still be a residual left that will cope with any post-contamination (for example in the distribution network). The residual is also important as a check on the effectiveness of the dosing, as monitoring the residual will test whether the disinfection treatment has been complete or not.

When chlorine in the form of one of these compounds is added to water, a certain period of time is required for the chlorine to react with the micro-organisms and compounds in the water. This time is called the *contact time*, and a minimum of 30 minutes is usually recommended. The presence of the residual chlorine should be determined only after the specified retention time. If a 30 minutes retention time was set, then the monitoring should be done after that time has elapsed. This is what is called the C x T concept (concentration after a certain contact time).

WHO recommends the following conditions for a proper disinfection:

- Residual chlorine: ≥0.5 mg/l
- Contact time ≥ 30 minutes
- pH: < 8
- Turbidity: < 5 NTU; but ideally < 1 NTU

Several countries do not have, in their drinking water standards, an upper limit for residual chlorine in a distribution system. The WHO gives a guideline value of 5 mg/l. It is important that this value is not exceeded, as sometimes may happen in the first connections in the distribution network.

Determination of residual chlorine

Several methods are available to measure residual chlorine in water. Two of the simpler methods are presented here.

a) Diethyl-para-phenylenediamine method (DPD)

Free available chlorine reacts instantly with N-diethyl-para-phenylene-diamine producing a red coloration provided iodine is absent. Standard solutions of DPD-potassium permanganate are used to produce colours of various intensities. In this way, DPD can be used as a colorimetric method to indicate the concentration of residual chlorine. The colour produced by this method is more stable than that in the orthotolidine method.

b) Orthotolidine method

Orthotolidine, an aromatic compound, is oxidised in an acid solution by chlorine, chlorazines and other oxidants to produce a yellow coloured complex, the intensity of which is directly proportional to the amount of oxidants present. The method is suitable for the routine determination of chlorine residuals not exceeding 10 mg/l. The presence of natural colour, turbidity and nitrate interferes with the colour development. Due to the fact that orthotolidine has been demonstrated to be carcinogenic it is advised to handle the chemical with caution.

Application of chlorination

Household level

The most convenient chlorine compound for chlorination use in the home is sodium hypochlorite. Households may collect the disinfectant in liquid form from central distribution points and are taught to use it to disinfect the water in their own containers. Hypochlorite distribution projects have shown a good level of acceptability and success. The chemical can be brought from outside the area or it can be produced locally, for example in a clinic or school with on-site NaOCl generators.

These generators are electrolytic cells that produce a weak NaOCl solution from NaCl brine. The electric power can be obtained either from a normal source or from photovoltaic cells. The production and power consumption for these cells are between 1 and 2 g of chlorine per amp-hour. The concentration of the solution is between 5 and 7 g chlorine/litre (0.5-0.7%). They work on a batch system and some maintenance is needed to prevent electrode scaling.

This type of project can be very successful provided there is good information/education support. Also continuous monitoring from health officials or a community-based NGO is extremely important to ensure success.

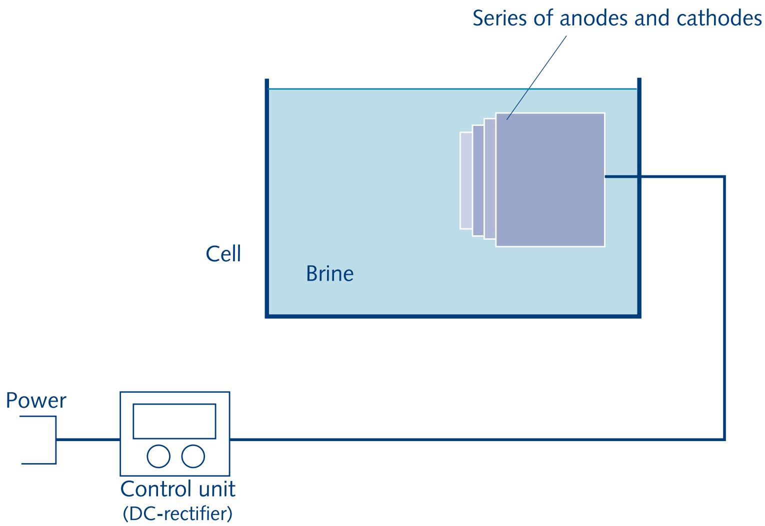

Fig. 19.5. On-site sodium hypochlorite generator

Pros
- Simple process
- Good for spread rural population and also for small rural systems
- Can be managed by unskilled personnel
- Photovoltaic cells can provide the electric power

Cons
- Produces low concentration hypochlorite solution
- Intermediate cost of equipment
- Need for electric power
- There is need for community education when used at household level
- It should be monitored

O & M tips
- Care and proper maintenance should be in place to control the electrode scaling

Disinfection of small water bodies (dug wells, small reservoirs, etc.)

Dug wells are used either as individual or communal sources of drinking water. There are a number of devices that have been used for on-site disinfection (pot chlorinators, porous pot chlorinators, double pot systems, the Chinese plastic bag chlorinator, etc). However, proper disinfection of these sources is not easy because it is very difficult to have a constant disinfectant feeding rate.

The methods mentioned give users the false expectation of drinking safe water. When dealing with open dug wells it is better to adopt a disinfection program at household level, like the hypochlorite system described previously.

Disinfection of drinking water at community level

It is very important that a small community water system is designed for operation and management by the local people. This means that technology choice should be adapted to the local reality and to the cultural acceptability of the users.

There are a number of options available for disinfecting rural water supplies. Each has its pros and cons and issues that need to be discussed with the community members before a final choice is made.

Chlorine gas. Disinfection by gaseous chlorine is very economical and is the universally used technology around the world. More than 90% of the world population drinks water disinfected by chlorine gas.

The most commonly used gas system consists of a cylinder with the gas, a regulator with a rotameter (feed rate indicator) and an injector. The system operates under the vacuum created by water flowing past a venturi. A mixture of water and gas is injected at the application point, where the gas diffuses and dissolves.

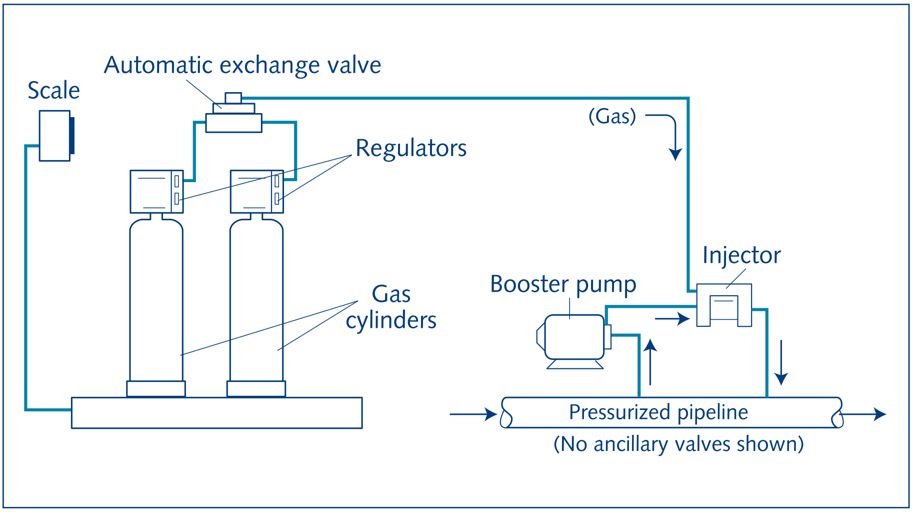

Fig. 19.6. A chlorine gas system

Even though the system is relatively simple, to ensure that the operation is safe and precise the personnel need proper training and several environmental safety precautions need to be in place (such as well-ventilated operating rooms, leak detectors, alarms, self-contained breathing apparatus, scales for gas cylinders, anchoring for the cylinders and safe gas transport systems).

In general the costs of any chlorination method are quite low. However, in many countries the operating costs of chlorination using chlorine gas are about 25-50% of the

cost of the equivalent solution of hypochlorite. But the capital investment costs required for gas chlorination, together with the precautions and training needs, make chlorine gas unfeasible for very small water supplies. As a rule of thumb it is considered that the gas should be used for communities with flows of water exceeding 500 m^3/day.
Today chlorine gas systems are reliable, but for conditions prevailing in small communities, hypochlorite disinfection may be more reliable and simpler.

Pros
- Widespread technology
- Chlorine gas is produced in almost every country
- Cheapest chemical
- Most widely used in the world

Cons
- Costly system for very small villages
- Needs ancillary equipment
- Personnel need training
- Can be dangerous if not properly operated
- Not recommended for systems treating less than 500 m^3/day

O & M tips
- Care should be taken on leaks
- Personnel should be strict on safety regulations and always use protective equipment

Chlorine solutions. All the other chlorine-based chemicals are liquid or can be dissolved and used as a solution. This is the most popular way to disinfect in the rural environment and small communities. It is simple, easy, and low-cost appropriate technology devices can be used.

In the feeding of the chlorine solution, different dosing systems can be applied. These dosing systems can be subdivided into atmospheric pressure and positive pressure systems.

Under the heading of atmospheric pressure, the most popular methods are the ones using the *constant* head principle and the *erosion system*. Devices used include wheel feeders, suction feeders, or just feeding by hand (batch method usually used when a community tank is filled and then open for consumption).

A *constant head system* retains a stock solution at a fixed depth in a tank from which it is fed through a regulating valve to the water to be disinfected. An important precaution to be taken is to ensure that the stock chlorine solution does not have precipitates that may clog the valves. It is suggested always to install a small filter (comparable to the gasoline/diesel filters) upstream of the regulating valves.

These systems are used to dose chlorine solutions in channels or in tanks.

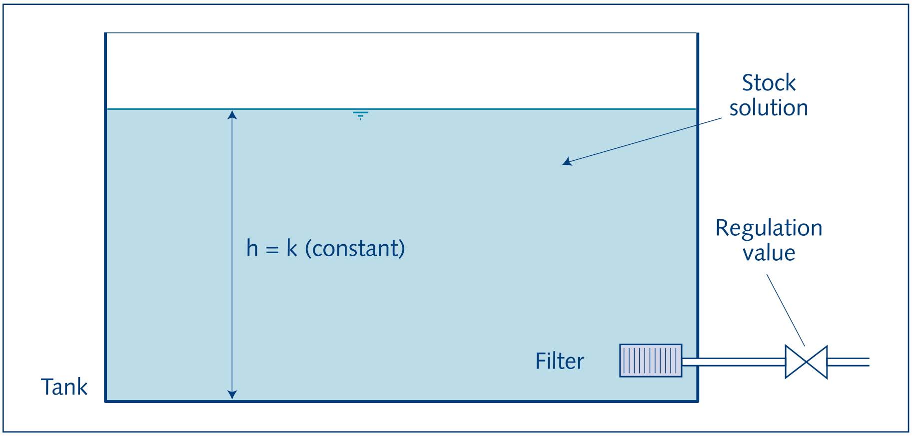

Fig. 19.7. Constant head system

There are a many such devices. Three of the most popular are shown here.

1. Float valve in box system

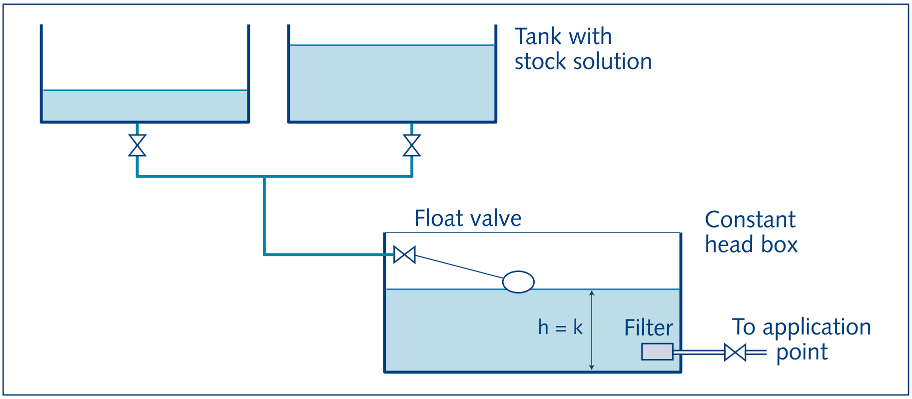

Fig. 19.8. Float valve in box

The heart of this system is a float valve, the same kind as used in toilet cisterns. One or two tanks hold the stock solution to be fed, and the float valve is placed in a small box. The system, although very simple, is cheap and accurate.

Pros
- Extremely simple principle
- Very cheap
- Can be manufactured locally
- Reliable
- Does not need electric power

Cons
- Error around 10%
- Material may corrode

O & M tips
- Keep small orifices clean
- Use filter to eliminate particulate matter or sediments

2. Floating tube with hole system

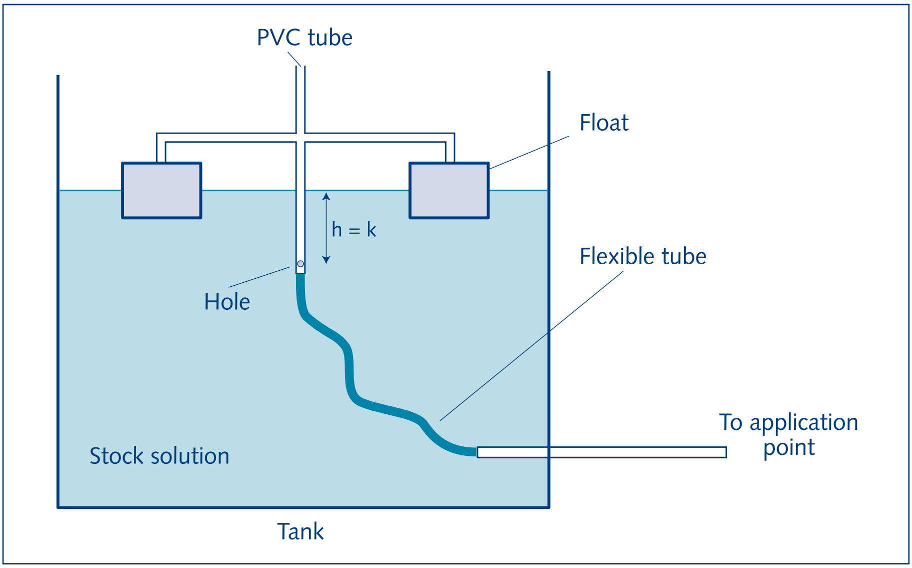

Fig. 19.9. Floating tube with hole

This, too, has been widely used in several different arrays. The basic element is a PVC tube with one or more holes. The tube is fixed to any kind of floating device and the hole/s should be placed some centimetres below the solution level. The tube is adjusted to such a level that the exact volume per second enters into the delivery tube and flows down to the application point.

Pros
- Extremely simple.
- Very cheap.
- Can be manufactured locally.
- Popular.
- Does not need electric power

Cons
- Depending on the way the system was built the dosing error may be up to 20%

O & M tips
- Keep small orifices clean. Use filter to eliminate particulate matter or sediments

3. Bottle/glass system (developed in Argentina)

This system consists of a tank with the stock solution, a dosing element and a regulating valve.

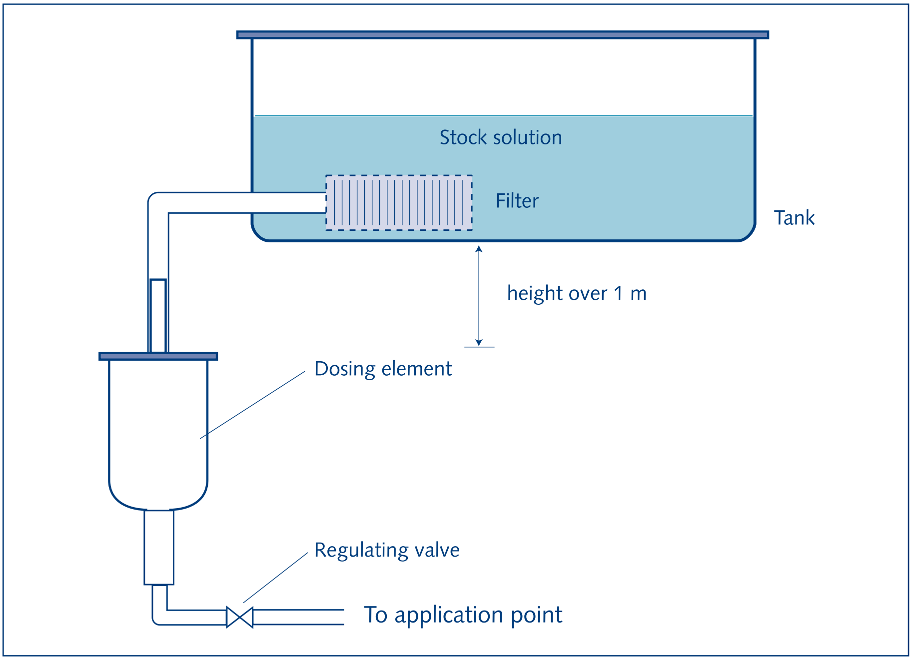

Fig. 19.10. Bottle/glass dosing element

The tank should be installed a metre (or more) above the level where the dosing element is placed. The dosing element is a simple system composed of a container with a floating device. It is made of a cylindrical plastic or glass bottle with smooth walls and with any volume between 0.5 and 1 litre. The bottle's base should be removed and the bottle inverted (the neck facing down).

On the upper part (area of the removed base) a small cover made of wood or plastic is glued with epoxy putty. This cover has two holes. In the central one, a $^1/_4$" plastic tube or a piece of a discarded pen is introduced, protruding about 1 cm. This tube should be firmly welded or glued to the cover and its upper and lower edges should be levelled and smoothed. The second hole allows the air to flow freely.

An inverted plastic beaker is placed inside the bottle. On the external part of the base, a piece of soft rubber is glued. Because air is trapped in the beaker, it operates as a floating device to regulate the flow to the bottle and the liquid level in the bottle. The flow to the water tank is regulated with a simple valve.

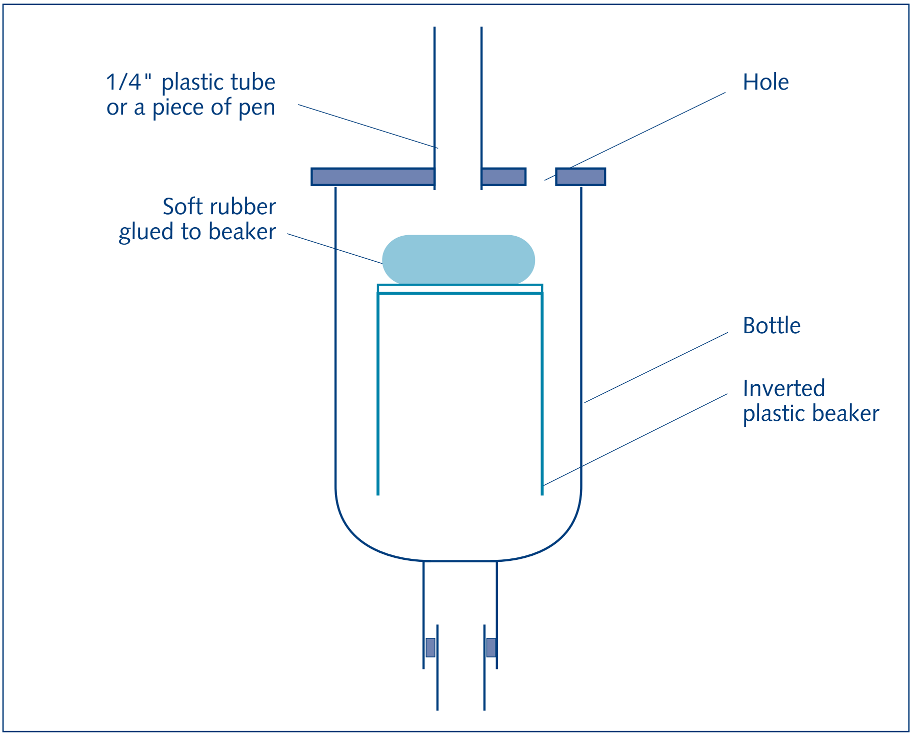

Fig. 19.11. Bottle/beaker dosing element (detail)

Pros
- Extremely simple
- Very cheap
- Can be manufactured locally
- Ideal for small communities
- Dosing error less than 10%
- Does not need electric power

Cons
- Should be kept clean.

O & M tips
- Use filter to eliminate particulate matter or sediments

Erosion systems use tablets of high concentration hypochlorites. The system is commercially available and is inexpensive and durable. The systems are very easy to operate and maintain. The tablets can be bought from distributors or made locally. The tablets are safer and easier to handle and store than liquid or gas chlorine compounds.

Tablet erosion feeders take advantage of the rate of solubility of the hypochlorite tablets in running water. Tablets gradually dissolve at a predetermined rate as water flows around them, to provide the required chlorine dosage. As tablets are dissolved, they are replaced with new tablets fed by gravity into the chamber. The discharge from the feeder is a concentrated chlorine solution that is fed into a tank, an open channel or reservoir.

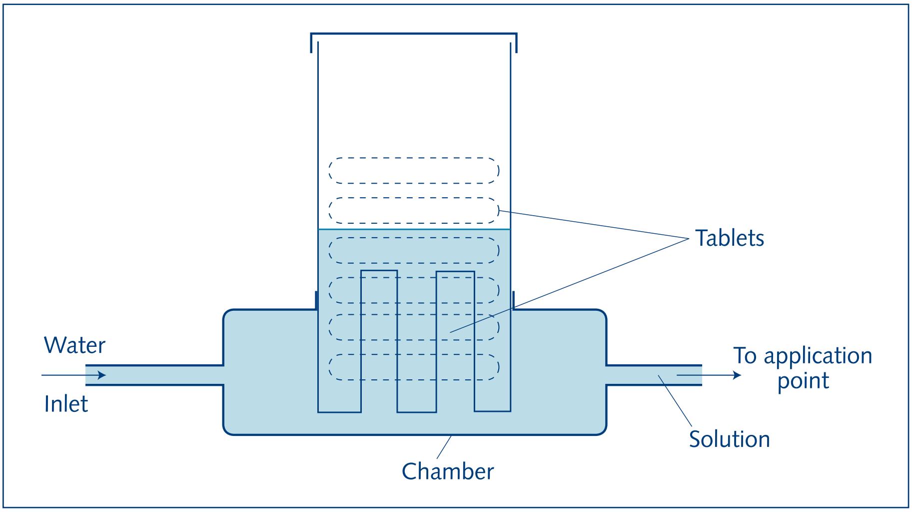

Fig. 19.12. Erosion feeder

Pros	• Extremely simple. Ideal for small communities
	• One of the best solutions for dosing at the entrance of a tank
	• Does not need electric power
Cons	• Intermediate cost
	• Dosing errors around 10%
	• Needs tablets
	• In some feeders the tablets (if locally produced) tend to get stuck or form caverns and do not fall in the dissolution chamber
O & M tips	• Make sure to use the proper tablets

Positive pressure feeders work on the principle that the chlorine solution is pressurised above atmospheric pressure and subsequently injected into a water pipeline. The most important positive pressure system is the highly popular diaphragm metering pump. These pumps are equipped with a chamber that has two one-way valves, one at the inlet and one at the outlet. The solution is drawn into the chamber through the inlet valve as the diaphragm opens, and is forced out of the chamber through the outlet valve as the diaphragm closes. An electric motor drives the diaphragm.

The task of the pump is to elevate the solution by means of a series of strokes. The application point may be a channel or reservoir (atmospheric pressure), but also a pipeline with running water (positive pressure).

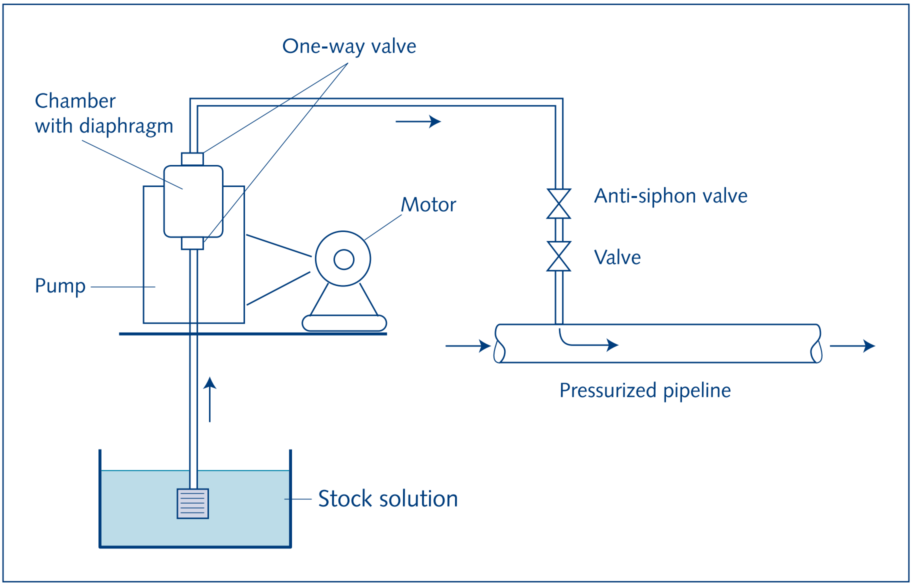

Fig. 19.13. Diaphragm pump system

Pros
- Highly reliable
- Very popular
- Simple to operate
- One of the few systems to work under pressure

Cons
- Personnel should be trained in its operation and maintenance
- Intermediate to high cost for a rural system
- Needs electric power

O & M tips
- Give continuous and proper maintenance
- Check the anti-siphon valves

A second way to inject a chlorine solution in a pressurised pipeline is shown in figure 19.14.

This system is very simple and economical, but if the mixing of the injected stock solution in the pipeline is not good, it may cause damage to the pump turbines.

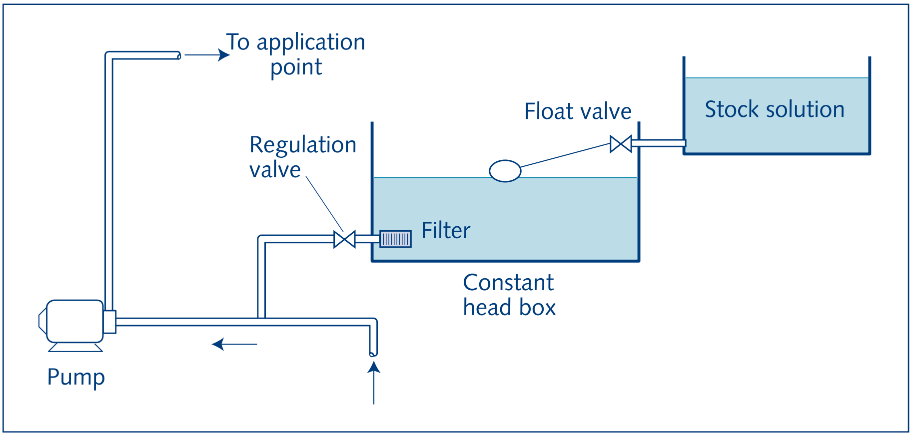

Fig. 19.14. Chlorination for pumped supplies

Pros
- Very simple
- The cheapest solution for a feed under pressure

Cons
- It should be monitored
- Sometimes there is corrosion in the pump rotor due to the chlorine

O & M tips
- Use filter to eliminate particulate matter or sediments

Disinfection of new tanks, pipes and wells

New tanks. All new tanks and reservoirs should be disinfected before they are brought into service. Similarly, tanks that have been out of service for repair or cleaning should also be disinfected before they are put back in service. Prior to disinfection, walls and bottom of tanks should be cleaned by sweeping and scrubbing to remove all dirt and loose material.

One of the disinfection methods used for a new tank is to fill it to the overflow level with clean water to which enough chlorine is added to produce a concentration of 50-100 mg/l. The chlorine solution is introduced into the water as early as possible during the filling operation in order to ensure thorough mixing and contact with all surfaces to be disinfected. After the tank is filled, it is allowed to stand, preferably for 24 hours but not for less than 6 hours. The water should then be drained out and the tank refilled for regular supply.

A second method, which is quite satisfactory and practical under rural conditions, is the direct application of a strong solution (200 mg/l) to the inner surfaces of the tank. The surface should remain in contact with the strong solution for at least 30 minutes before the tank is filled with water.

New mains and pipes. Whatever precautions are taken, distribution mains and pipelines are likely to be contaminated during laying. Therefore, they must be disinfected before they are brought into use. Distribution systems also need to be disinfected from time to time when they are contaminated by main fractures or floods.

Every pipeline should be cleaned by swabbing and flushing in order to remove all foreign matter. Immediately before use, the packing and jointing material should be cleaned and disinfected by immersion in a 50 mg/l chlorine solution for at least 30 minutes.

A practical means of applying chlorine solution for disinfection of rural water supply systems is to flush out each section to be disinfected. The intake valve is shut off and the section is allowed to drain. Then the discharge hydrant or valve is shut off and the section is isolated from the rest of the system. The disinfecting solution is fed through a funnel or a hose into a hydrant or opening made especially for this purpose at the highest part of the pipeline. Since air valves are usually placed at these high points, removing an air valve is often a convenient way to provide a point of entry.

Wells. New, rehabilitated or redeveloped wells should be disinfected before they are used for drinking water supply. Also wells that are suspected of being contaminated (e.g. in case of continuing poor well water quality or cholera outbreak, etc.) need to be disinfected. Better than regular disinfection is to find and correct the source and cause of the well contamination.

Before disinfecting the well water body, the walls of the lined well are cleaned by jetting chlorinated water (concentration 20 mg/l) and brushing to remove all dirt. Protect skin and eyes as chlorinated water is aggressive, and provide good ventilation or work short periods as chlorine gases are harmful.

Disinfection is done by estimating the volume of the well water body, and then adding sufficient chlorine to get a concentration of 50 mg/l. A contact time of 12-24 hours is needed. The chlorinated water should then be pumped out. Then the well is ready again for drinking water use.

19.8 Disinfection of water supply in emergency situations

A more detailed overview of water supply and disinfection in emergency situations is given in chapter 24. Long-term measures for the provision of safe water supply, aided by personal hygiene and health education, will greatly help to protect and promote public health. However, natural disasters like cyclones, earthquakes and floods do occur and sometimes result in complete disruption of water supplies.

While efforts are being conducted to put the systems back into operation, top priority also has to be given to providing the affected population with safe drinking water. While there is no single measure that is the panacea for all situations, the following may be useful to ensure a safe water supply depending upon local conditions and available resources.

Simultaneous action to tide over the situation should include a thorough search for all possible sources of water within a reasonable distance of the affected area. Water from private water supply systems and other sources may be transported by tankers to the points of consumption. In an emergency situation, if quantity is important, quality is mandatory. To achieve bacteriological safety, proper disinfection should be ensured.

Health officers are often confronted with a peculiar situation. It is not lack of disinfectants, but an excess that brings the problem. After a disaster strikes an area, it is usually flooded with a great variety of disinfectants. Normally these are chlorine-based compounds, but of different compositions and concentrations. It is then essential to have the knowledge to handle them properly.

Two suggestions

Firstly, it is important that the population never prepare their own stock solutions from high concentration hypochlorites. The user should be given a disinfectant solution ready to be used in a batch system (for disinfection of a family tank or container). Secondly, an ideal stock solution to be used in emergency situations is the one holding a concentration of 5000 mg of active chlorine/litre.

Health officers can prepare the stock solutions from any chlorine-based product using the following formula.

$$\frac{V_{water} \times C_{stock}}{C_{product} \times 10} = W_{product}$$

Where:

V_{water} = Volume of stock solution that will be prepared, in litres

C_{stock} = Concentration of stock solution intended (if as suggested, it is intended a 5000 mg/l concentration, then the value for C stock should be = 5000)

$C_{product}$ = Chlorine concentration in the product as specified by the manufacturer (in the formula, only the number should be placed, for example 65 when the chlorine concentration in the product is 65%)

10 = Factor in order that the result be given in grams of the product

$W_{product}$ = weight (in grams) of product to dissolve

The disinfection dose that will be suggested to the population should be 5 mg/l in the moments of the extreme emergency, and then 2 mg/l under less stressing conditions. The minimum contact time should be 30 minutes.

The appropriate dilutions that people should prepare with the stock solution they are given is presented in the following table.

Table 19.1 Appropriate dilutions with stock solution

Volume of water to disinfect (litres)	Volume of stock solution (of 5000 mg/l) to add for a 5 mg/l final concentration	Volume of stock solution (of 5000 mg/l) to add for a 2 mg/l final concentration
1	20 drops = 1 ml	8 drops
5	100 drops = 5 ml	40 drops = 2 ml
10	10 ml	4 ml
20	20 ml	8 ml
100	100 ml	40 ml
200	200 ml	80 ml
1000	1 litre	400 ml

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Web sites

American Water Works Association - AWWA: http://www.awwa.org/

CEPIS-PAHO/WHO: http://www.cepis.ops-oms.org/

Disaster info (Guía latinoamericana de Tecnologías Alternativas en agua y saneamiento): http://www.disaster.info.desastres.net/

EPA-Office of water: http://www.epa.gov/

International Water and Sanitation Centre IRC: http://www.irc.nl/

Loughborough University (Water, Engineering and Development Centre – WEDC): http://www.lboro.ac.uk/

Minnesota Rural Water Association: http://www.mrwa.com/

The International Ultraviolet Association: http://www.iuva.org/

The University of New Hampshire: http://www.unh.edu/

Tripod (The World Water Project Ultraviolet Disinfection): http://www.tripod.lycos.com/

Water Health International. INC.: http://www.waterhealth.com/

Water Supply and Sanitation Collaborative Council: http://www.wsscc.org/

WHO: http://www.who.int/

SANDEC on solar disinfection: http://www.sodis.ch