DISINFECTION FOR SMALL WATER SUPPLIES

Water Technology

CSIR

A TECHNICAL GUIDE

by
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1. INTRODUCTION

Numerous diseases can be transmitted through poor sanitation and unsafe drinking water. Among these typhoid, cholera and gastro-enteritis are widely spread in rural areas and are responsible for millions of deaths annually in the third world countries.

However, if water is disinfected (that means if the micro-organisms which produce the illnesses are destroyed) it can become safe for human consumption. The provision of a safe supply of drinking water, together with improved sanitation and education on domestic health and hygiene, can result in a substantial reduction in the occurrence of these water-borne diseases and infant mortality.

When analysing the practice of water disinfection in different countries of the third world it has been found that one of the reasons for the failure to adequately disinfect domestic water supplies is the lack of information and knowledge on what disinfection is and on how it can be applied in practical terms. This guide aims to provide information needed to overcome this problem.

The most important factors resulting in inadequate disinfection of domestic water supplies for small communities are:

- lack of knowledge of appropriate technology solutions;
- unavailability of disinfection units for small community water supply systems;
- discontinuity of the supply of chemicals for the disinfection units which have been installed. This is mainly due to:
  - problems and failures in chemical feeders
  - lack of disinfection chemicals (no local supplier, poor stock control)
  - poor supervision (operation and maintenance);
- lack of a policy or lack of provision to implement a policy for developing disinfection programmes;
- lack of financial means for buying, installing and operating disinfection systems;
- highly sophisticated or very complicated systems installed which are inappropriate and often remain inoperable after a breakdown;
- Lack of effective drinking water quality control programmes.

For these reasons, there is a need for disinfection systems that are:

- affordable
- simple yet as precise as possible
- easily maintained and easy to operate even in rural areas
- such that the chemicals required are readily available.

This guide will present some disinfection systems which adress these requisites (or at least most of them), and which will be useful in supporting disinfection programmes.

The description of the different systems will provide a guideline for the selection of equipment based on a balancing of the simplicity of producing/installing/operating/maintaining the equipment versus the efficiency and cost of each individual system.

Thus, not only the technical features of various disinfection equipment, but the potential of each, and what can be expected from them, is described.

2. DISINFECTION METHODS

The general treatment processes for water, like coagulation, sedimentation and rapid filtration, can reduce the microbial populations in water by up to 90%. Nevertheless, to achieve a complete elimination of disease causing micro-organisms, it is necessary to disinfect.
It is important to state that it is not easy to achieve a 100% efficiency in water disinfection, nor is it usually required. A number of variables influence the elimination of bacteria (the most harmful of organisms). These variables are:

- type and quantity of micro-organisms;
- the type and concentration of the disinfectant used;
- the water temperature, pH, and turbidity (clarity); and
- the contact time of the disinfectant with the water.

Disinfection as it is carried out in actual conditions, and with the systems described in this manual, are usually adequate to provide a barrier against most of the more common water-related diseases. However, any disinfection programme should be supported by a sound policy on supervision and on quality control. These aspects are not covered in this document, but their importance should be considered as equal to the correct technology choice.
Disinfection methods can be divided into two main categories: physical and chemical methods.

2.1 PHYSICAL METHODS OF DISINFECTION

There is a wide range of physical methods. These include sonic waves, radioactivity, ultraviolet (UV) rays, heat, storage and solar radiation.
Only three of them (heat, solar radiation and UV) will be described due to their application for small water supplies.

Disinfection by heat
This is perhaps the oldest and most reliable method for disinfecting water. The boiling of water kills virtually all micro-organisms in the water, but it has an important limiting factor: it cannot be used for large volumes of water due to the high fuel requirements. Therefore this method is not applicable for community water supply systems. On the other hand, this method could be used as an emergency measure to disinfect small quantities of water for drinking when contamination problems are detected, or when outbreaks of epidemics of water related diseases develop in a community (e.g. cholera, typhoid, gastro-enteritis). In these cases, the boiling of water to be used for domestic purposes, combined with appropriate domestic hygiene practices, will help to curtail the spread of a disease. The recommendation is to boil the drinking water for 10 minutes. After treatment the water is left to cool and stored in appropriate containers (clean and with cover) until its use.

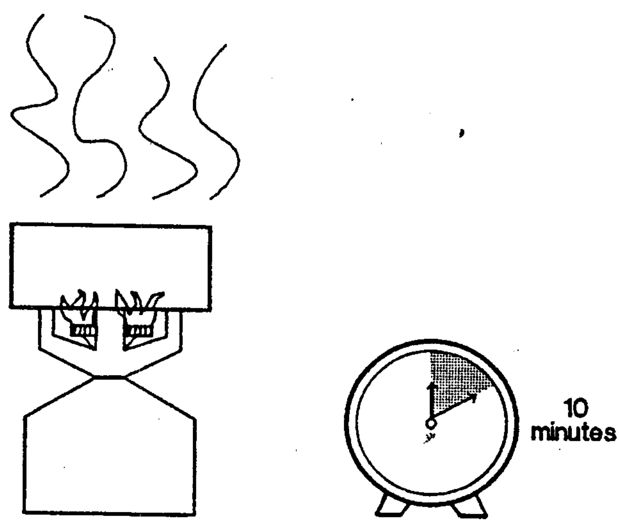


Fig 1 : Disinfection by heat

Solar disinfection

Solar disinfection is only practicable at household level. Care should be taken in the use of this method as no absolute guarantee can be given that the water will be completely safe after such treatment. Even so, for areas where there are no other means available to disinfect water, the method to be described can substantially improve the bacteriological quality of water to be used for drinking and domestic hygiene.

Sunshine, beamed onto transparent water containers, rids the water of bacteria within a few hours. If this is to be used on a continuous basis, the best situation is for areas between latitudes 35°N and 35°S and which have 300 or more sunny days per year. South Africa falls within these latitudes, and many areas of the country do experience 300 or more sunny days per year.

It has been found that when water is kept in darkness the coliform bacteria content will decrease naturally, while the total bacteria population will increase. But if exposed to the sun, both the coliform and total bacteria population will decrease, and what is more important, at a far greater speed. The presence of small concentrations of both inorganic and organic impurities has not been found to hinder the disinfection of water by sunlight. However, turbid water must be clarified before it is exposed to sunlight to ensure adequate disinfection.

Sunlight is made up of various bands of electro-magnetic waves, ranging from the invisible ultra-violet rays, through the visible range, to the infra-red range. It has been found that the portion of sunlight with wavelengths in the ultra-violet range (315-400 nm), is the most effective in terms of disinfection, accounting for about 70% of the bacterial destruction potential. Visible light, with wavelengths ranging from 400 nm to 750 nm accounts for about 30% of the destructive capacity, with the visible band of violet and blue light (400-490 nm) being the most effective.

This consideration is important when a container is being selected. Colourless plastic or glass containers are the best choice because they transmit light in the near-ultraviolet region as well as in the visible range of the spectrum. Violet and blue tinted containers come next in the order of priority. Since the lethal action continues to decrease thereafter in the descending order of green>yellow>orange>red, containers with these colours should be avoided. Stated differently, containers made of plastic or glass with green, yellow, orange or red colours obstruct the transmission of the most lethal rays of sun light, unlike those that are colourless or blue.

Round-shaped, thin walled containers have proved to be the best in that they yield faster results. The clear plastic, two litre cooldrink bottles which are widely available have been found to work well. All labels, etc. should be removed to allow maximum penetration of the solar radiation. The exposure time for common sunny days should be no less than 4 hours, preferably between the hours of 10:00 am to 2:00 pm when the intensity of solar radiation is the greatest.

Clouds tend to reduce the intensity of direct sunlight. Under such conditions, however, the scattered rays of sunlight producing diffuse daylight would still exhibit germicidal action, but at a slower rate. During cloudy days, therefore, all that is necessary is to prolong the exposure period by several hours.

Disinfection by ultra-violet radiation

Although well known for many decades, it is only recently that the technique of water disinfection by ultra-violet radiation (or "UV light" as it is commonly described) has been widely acknowledged. The reason for this is that reliable UV lamps have only been available for the past few years. The method of disinfection consists of water passing in close contact (not more than 100 mm) to a UV light source for a certain period of time (minimum 15 seconds).

The UV rays employed are usually light rays of around 254 nanometres generated by low pressure mercury lamps. The lamps can be either in direct contact with the water or cased in protective shields made of quartz or plastic from the PVDF series. Ultraviolet radiation is measured in micro-watt seconds per square centimetre (mws/cm2). The dosage of UV light required to destroy most common micro-organisms (coliform, pseudomonas, etc.) is 6 000 - 10 000 mws/cm2. All commercially available UV disinfection systems are designed for a dosage of at least 30 000 mws/cm2.

The commercially available systems are simple to install and to operate. The only maintenance needed is to routinely inspect the lamps and to change them every 7 000 - 8 000 hours of operation. Most units are designed to treat flows in the range of 1-10 m3/hr. Larger flows can be treated by connecting a number of units in parallel.

Disadvantages of disinfection by UV radiation are :

a. that the water does not retain a residual in order to prevent contamination after treatment ; and
b. there is a need for an electrical power supply.

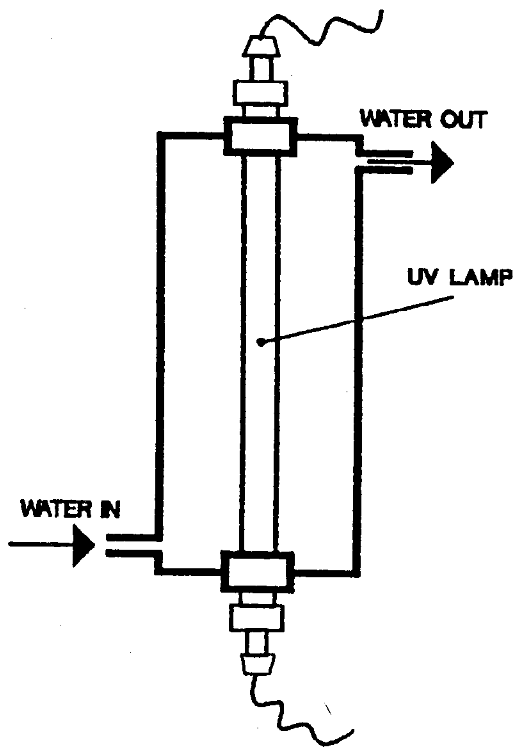


Fig 2 : UV disinfection equipment

2.2 CHEMICAL METHODS OF DISINFECTION

Several chemicals, acting as strong oxidants or as "poisons", can destroy micro-organisms. Hydrogen peroxide and other metallic peroxides, lime, potassium and calcium permanganate, iodine, bromine derivates, clean metals like copper, silver or zinc, ozone and chlorine derivates fall into this category.

From this list only chlorine and its derivates are widely used for disinfection. Ozone, iodine, potassium permanganate and bromine derivatives are also used for disinfection, but their cost is generally much higher than the cost of an equivalent amount of chlorine. Ozone generating equipment is very capital intensive and is therefore not recommended for developing countries. In the future however, it is expected that technological developments will result in simple mixed oxidant/ozone systems which require only minimal maintenance. This development will mean that ozone treatment may be incorporated in a variety of water treatment situations which may otherwise not have been feasible. Ozone is a powerful disinfectant which is also environmentally friendly since no harmful by-products are formed as a result of its use. The ozone residuals are not long lasting and are therefore unlikely to significantly affect river ecosystems. This may also be a limitation on the application of ozone where a longer lasting residual is required. Its use in water treatment presently is primarily for oxidation of unwanted compounds and not for disinfection.

Chlorination

Chemistry

The chlorination of drinking water is carried out in practice through the bubbling of chlorine gas, or through the dissolution of hypochlorites or organic-chlorine compounds, in the water.

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

$$Cl_2 + H_2O = H^+ + Cl^- + HOCl \quad (1)$$

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

$$NaOCl + H_2O = Na^+ + OH^- + HOCl \quad (2)$$

or, in the case of calcium hypochlorite,

$$Ca(OCl)_2 + 2H_2O = Ca^{2+} + 2OH^- + 2HOCl \quad (3)$$

The hydrochloric acid (HCl) and the sodium/calcium hydroxide ($NaOH/Ca(OH)_2$) dissociate and do not take part in the disinfection reaction. The hypochlorous acid (HOCl), the disinfectant, dissociates in water as follows:

$$HOCl = H^+ + OCl^- \quad (4)$$

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 pH range for natural and drinking water). When the pH value of the chlorinated water is 7.5, 50 percent of the chlorine concentration present will be undissociated hypochlorous acid and 50 percent will be the hypochlorite ion.

The different percentages of HOCl and OCl^- at different pH values can be seen in Figure 3 below.

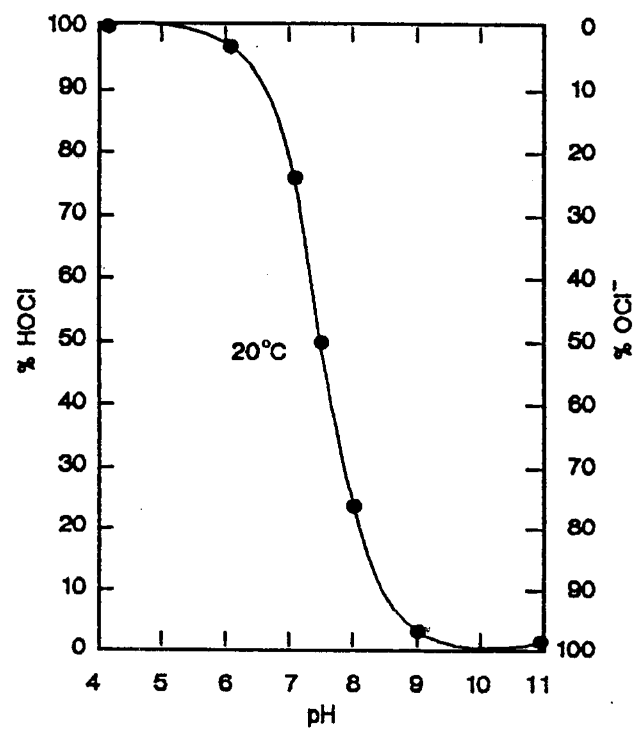


Fig 3 : Dissociation of hypochlorous acid versus pH

The different concentrations of the two species make a considerable difference to the bactericidal property of the chlorine, as these two compounds display different bactericidal properties.

It has been proposed that the reason for this is based on the configuration of each chemical species. Hypochlorous acid (HOCl) is similar in structure to water and so it is relatively easy for it to penetrate the cell walls of the bacteria . This penetration is similar to that of water, and can be attributed to both its modest size and to its electrical neutrality (absence of an electrical charge). The OCl- ion, because of its electrical charge, is unable to diffuse as well as HOCl through the cell walls of micro-organisms. This diffusion is important because only once inside the cell can these compounds oxidise the enzymes of the cell, killing the micro-organism.

In fact the relative disinfection power of these species differs considerably.

For destroying *Entamoeba histolytica* (a protozoa parasite or cyst which causes amoebic dysentery) the relative effective ratio of OCl- to HOCl is approximately 250:1, while for destroying *E. coli* (an indicator bacterium for faecal pollution) it is 80:1. This means that the germicidal efficiency of HOCl is at least 80 times greater than that of the OCl-. This may be interpreted in one of two ways : either 80 times more OCL- than HOCl is required, or the contact time for OCL- must be 80 times longer than that for HOCL, to obtain the same effect.

This is displayed in the figure below:

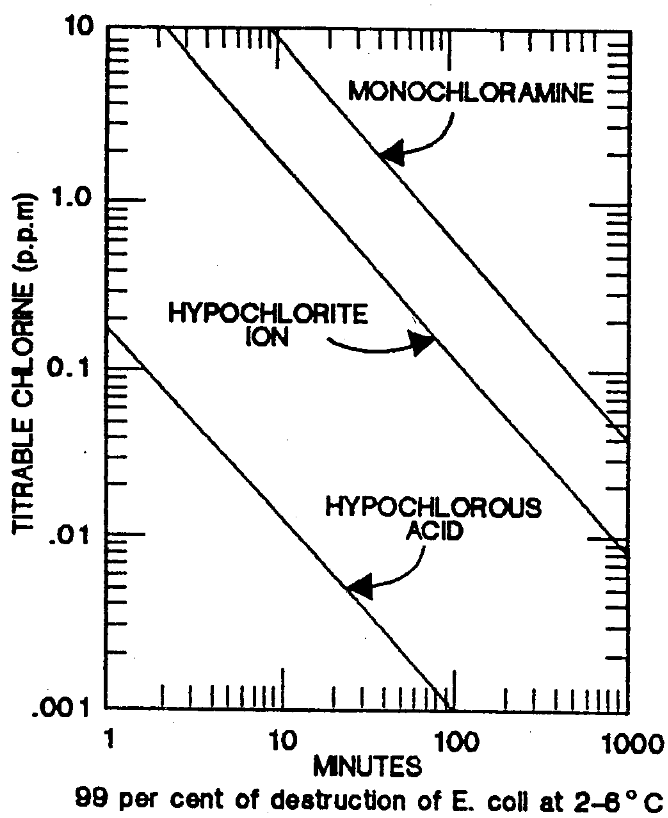


Fig 4 : Comparison of germicidal efficiency of hypochlorous acid, hypochlorite ion and mono-chloramine

In the figure the mono-chloramine compound is indicated as also having bactericidal properties, although of lesser strength than the already discussed HOCl and OCl-. A chloramine is formed when ammonia in the water reacts with chlorine to produce a predominantly mono-chloramine residual (the ratio of chlorine to ammonia-nitrogen must be 4:1 or less).

Although mono-chloramine is a poor disinfectant when compared with HOCl or OCl^-, and although it usually requires a contact time of two hours or more, it has the advantage of decaying less quickly than the other two chlorine species. Hence when there is a need to maintain a chlorine residual in an extensive reticulation system, or when there is a long period of time between the treatment of the water and its consumption, the use of chloramines should be considered. This is accomplished in practise by adding a low dose of ammonia (say 0.25 mg/l) prior to the addition of chlorine.

Compounds

Several compounds are used for the chlorination of water supplies. Each of these result in different concentrations of "active chlorine". 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. Commercially available chlorine-derivates used in water treatment and their characteristics are presented in Table I.

COMPOUND	FORMULA	PRESENTATION	FEED AS	% ACTIVE CHLORINE
Sodium hypochlorite	NaOCl	liquid	solution	10 - 15
Chlorinated lime	CaClOCl	solid	solution	30 - 35
Calcium hypochlorite	$Ca(ClO)_2$	solid	solution	30 - 70
Chloro-organics	eg $NaOOCC_6H_2$-SO_2NCl_2	solid	powder-solution	60 - 90
Chlorine	Cl_2	gas	gas	100

TABLE I - Chlorine compounds

Dose/demand/residual

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 amount of chlorine added is referred to as the "dose", and is usually measured as the number of milligrams added to each litre of water (mg/l). The chlorine dose which remains after a certain contact time is known as the "residual chlorine". The amount of chlorine used in the reaction with the substances in the water is called the "demand", and is often quoted with reference to the contact time, e.g. "a 30 minute demand".

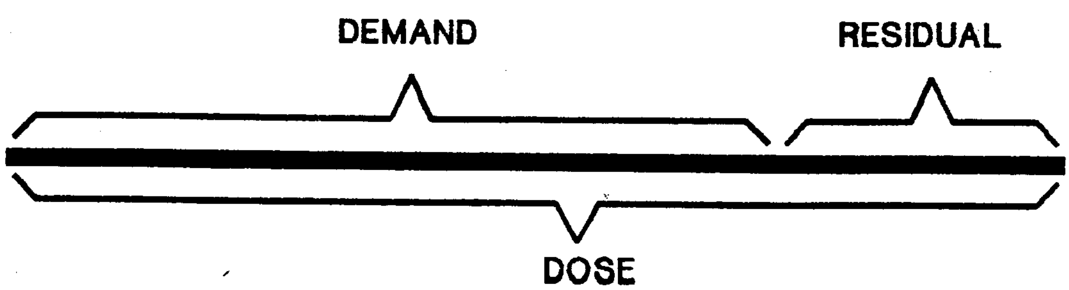


Fig 5 : Relation between dose/residual/demand

It is important to note that there should always be a certain residual remaining in the water to cope with possible future contamination (e.g. in the water reticulation). For this reason, the demand should be established through adequate analysis and a dose of slightly more than the demand should be added.

The procedure for the analysis of the demand is described in the following paragraph:

Chlorine Demand Test

1. Put 100 ml samples of water in 6 different vessels (or beakers).
2. Add to the different vessels 0.5 - 1.0 - 1.5 - 2.0 - 2.5 and 3.0 ml of a 100 ppm chlorine solution. The different doses in the different vessels would then be: 0.5 - 1.0 - 1.5 - 2.0 - 2.5 and 3.0 mg/*l*.
3. Mix thoroughly.
4. Allow 30 minutes contact in a cool place out of direct sunlight.

   Alternatively the same period of time which the treated water would have in the treatment plant, may be used as contact time.
5. Test the residual free chlorine remaining in each vessel.
6. Detect which is the first vessel to show a presence of residual chlorine.
7. The value of the nearest vessel not presenting residual chlorine will be the demand. (e.g. if the first vessel to show chlorine positive is the 2.5 ppm vessel, then it means that the demand is 2.0 ppm).

   If this analysis cannot be done, an alternative procedure is to add an approximate chlorine dose, and later to determine the residual chlorine of the final water at the treatment plant. After a few successive approximations, varying the dose by addition or subtraction, the optimal chlorine dose to achieve the desired residual can be reached.

Calculations

To determine the dosing rates and chemical stocks required, the following should be known:

– volume (or flow) of water to be treated;

– required chlorine dose; and

– active chlorine in the disinfecting chemical.

Simple mass-balance calculations will then enable the dosing rates and chemical stock needs to be determined.

Example 1

If 50 litres of water is to be disinfected each day with a dose of 2 mg/l chlorine, (i.e. a dose of 2 ppm (mg/l) of active chlorine is required), and the chemical available is NaOCl at 3% concentration, how much NaOCl will be needed?

If 1 litre requires 2 mg active chlorine, then 50 litres will require 2x50 = 100 mg active chlorine.

The stock solution contains 3% chlorine i.e. 30 g chlorine per 1 litre, or 30 mg chlorine per 1 ml solution.

Hence if 100 mg active chlorine is required, we must add 100/30 ml = 3.3 ml of stock solution.

A litre of stock solution will last approximately 1000/3.3 = 300 days.

Example 2

The flow of water in a pipe is 5 l/s. To this, a dose of 3 mg/l of active chlorine is to be added using a chloro-organic with 70% of active chlorine.

What quantity of such compound should be added per hour?

Water flow = 5 l/s = 18000 l/hr = 18 m3/hr

Chlorine dose = 3 mg/l = 3 g/m3

Hence hourly chlorine dose = 3 g/m3 x 18 m3/hr = 54 g/hr

The chlorine compound contains 70% chlorine, i.e. 70 g chlorine per 100 g compound.

Since 54 g chlorine is required, this means that 54/70 x 100 = 77 g of compound is required per hour.

For continuous dosing: A stock of 100 kg will last 54 days.

Selection of the most appropriate compound

On the basis of the previous calculations, it is possible to determine how much active chlorine will be needed. But it is not always easy to determine which chemical compound to use, as many factors may influence the selection: e.g. kind of chlorine feeder, control mechanism, the type of personnel available for the operation and maintenance, population to serve, compound costs, etc.

As a very general rule, the guide presented in Table II can be used.

POPULATION (inhabitants)	**DAILY WATER CONSUMPTION** (m3/day)	**ACTIVE CHLORINE** (kg Cl/day)	**SUGGESTED COMPOUND**
< 1000	<200	<0.5	Sodium hypochlorite Calcium hypochlorite
1000-5000	200 - 1500	0.5 - 7.5	Chlorinated lime Calcium hypochlorite Chloro-organics
> 5000	>1500	>7.5	Chloro-organics Chlorine gas

TABLE II - Compound selection

Monitoring of chlorine residuals

Three procedures commonly used to determine chlorine residuals are:

The N.N.-diethylparaphenylene diamine (DPD), the orto-tolidine (OT) and the starch-potassium iodide methods.

The DPD method is highly recommended for its accuracy and simplicity. The second method is used widely in third world countries and is perhaps the most popular. However it has a disadvantage in that OT is a carcinogen, and must be handled with caution avoiding inhalation and contact with the skin. Its use is therefore to be discouraged, and alternative methods should be used in preference. The starch-potassium iodide procedure is not specific for free residual chlorine and may therefore give false positive results. Despite this limitation, it has been included because of its widespread use in many countries

Although commercially available comparators can be found in the market, the most simple technique using common test tubes will be described. The methods are based on visual comparison between the colour developed in a tube with water to which the reagent has been added, and the colour of pre-prepared standard solutions contained in sealed tubes.

DPD Method

Since most drinking water is chlorinated to give a final residual chlorine concentration of less than 1 ppm, the permanent colour standards are prepared only for the range 0.0 - 1.0 ppm.

It is important that the test be carried out as rapidly as possible (less than 20 seconds). This will help to prevent the reagent acting on any combined chlorine present and thus reduce the risk of giving false free chlorine values.

Application of the test-tube technique requires that a local or regional laboratory prepare the colour standards and reagents. Methods for the preparation of the standards and reagents are given in "Standard Methods for the Examination of Water and Waste Water" American Public Health Association, Washington, DC. Reagents in powder or pill form can be purchased from analytical chemical suppliers, and from swimming pool dealers.

The technique for performing the test is simple and quick. A sample of water is placed in one test tube. Then the reagent (DPD) is added and is mixed by shaking the tube. The colour developed is matched against the colour standards.

OT Method

This method is similar to the DPD method. The technique for the preparation of the standards is given in the 13th and earlier editions of the "Standard methods".

Starch - Potassium Iodide Method

A more detailed description of the starch-potassium iodide technique is given as this technique, despite its limitations, is very simple to use even in rural conditions.

The reagent is prepared by dissolving 2 g of soluble starch in 100 ml of distilled water. The solution is boiled and allowed to cool to room temperature. To this solution 8 g of potassium iodide are added and dissolved. The solution should be stored in a brown glass bottle. If 2 or 3 drops of chloroform (or formaldehyde), or 0.4 g zinc chloride are added, the solution will remain stable for 2 -3 weeks.

For the determination of residual chlorine the procedure is to add 5 - 6 drops of the reagent to a 100 ml water sample contained in a measuring cylinder or in a glass container. After mixing a colour will develop and the approximate chlorine concentration will be as indicated below in Table III.

COLOUR	RESIDUAL CHLORINE (mg/l)
No colour	0.0
Light blue	0.1 - 0.3
Dark blue	>0.3

TABLE III - Potassium iodide-starch indicator

3. CHLORINE COMPOUND FEEDERS

Different methods are employed for adding chlorine to the water, depending on the type of compound used and on the volume or flow rate of the water.
An initial classification may be as follows:

Fed as
- Gas
- Powder/Tablets
- Solution

3.1 GAS CHLORINATION

Gas chlorination systems

Chlorine gas is often used at water treatment works because it is a cheap source of chlorine for disinfection.

Nevertheless, some disadvantages should be pointed out when using this technique in remote rural areas. Chlorine gas is produced in very few cities in the country. This means high transportation costs and in many cases delays in delivery times. The storage and handling of the cylinders containing the gas should be done by skilled personnel who should also operate and maintain the equipment. Special safety features must be included in the design of the chlorination building housing the gas cylinders. Safety equipment such as gas masks, goggles and gloves should also be provided.

Chlorine gas is commercially available in 68 kg and 915 kg cylinders (the latter called 'one ton cylinders').

A scale to measure the weight of the cylinder in order to determine the quantity of gas fed and the quantity still available, and a vacuum injector mechanism, are part of the equipment required.

A typical installation is presented in Figure 6:

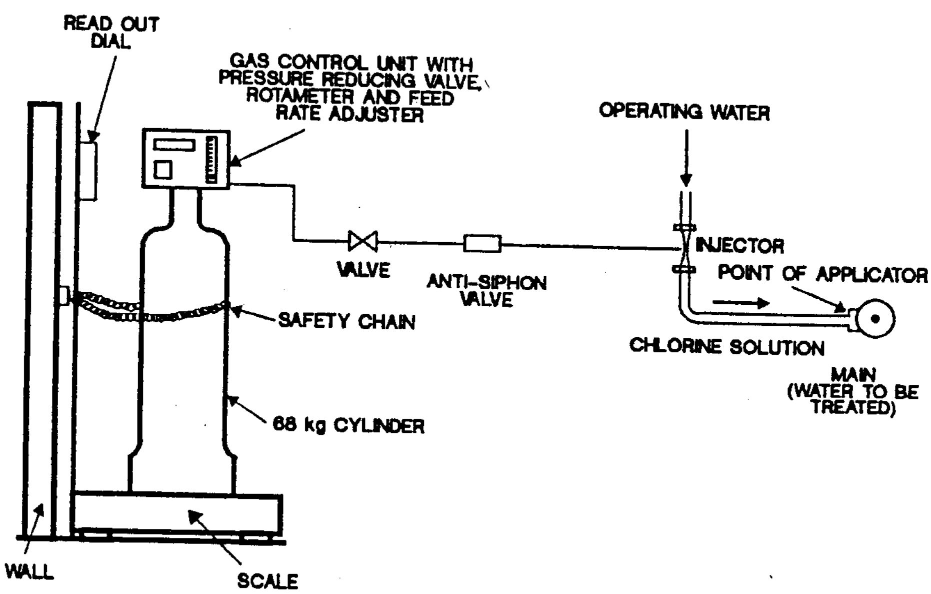


Fig 6 : Gas chlorination system

The injector is the heart of the chlorinator system. The vacuum developed by the injector allows the chlorine to flow from the storage cylinder through the chlorinator, which is the metering system, through the injector and into the water pipeline. At the injector the chlorine dissolves in the water supply to form hypochlorous acid. This is referred to as the chlorine solution. This solution flows through the distribution system to the point of use.

Injectors are designed to produce about 625 mm Hg vacuum and to limit the chlorine solution strength to a maximum of 3500 mg/l.

The water, passing through the injector, is called the operating water and may come from the same main carrying the water to be treated or, if there is not enough pressure, from a booster pump.

3.2 POWDER FEEDERS

The use of either gravimetric or volumetric feeders is only useful in big treatment plants. For small water supplies, the chloro-compounds in powder form are used by firstly dissolving them in water and then feeding as a solution, placing them directly into tanks, reservoirs, or even in hand-dug wells, or alternatively placing them inside diffusion feeders. The best diffusion feeders are the following:

- closed pots with holes
- plastic bags
- porous pots
- concentric tubes
- continuous flow diffusor
- borehole chlorinator

A special case is the use of chlor-floc.

Diffusion Feeders

Closed pot with holes

This is a pot or vessel, usually round in shape and built of any corrosion resistant material. The most common vessel used in developing countries is made out of baked clay with a capacity of 10 - 15 litres. It should have two or more 50 - 60 mm diameter holes placed around its circumference. It should also have a lid or cover.

Inside the pot, the following mixture is placed:

$^1/_2$ volume of chlorinated lime (or $^1/_4$volume calcium hypochlorite)

1 volume of coarse sand

The total quantity should be such that the mixture, once inside the pot, remains under the level of the holes. When in use, the pot is submerged approximately 1 metre below the water level. Chlorine diffuses from the pot into the water at a slow rate. Turbulence in the water enhances the rate of diffusion. Additional chlorine should be added when approximately 75% of the chlorine has been used (e.g. if 1 kg active chlorine were added, this should be replenished after extracting 250 m3 water having an average chlorine dose of 3 mg/l). This system allows for the treatment of hand-dug wells with a capacity of 10 - 15 m3 and with an average extraction of 1000 - 1500 litres/day. The system must be used with certain precautions and control, as records have shown that in some places it has worked successfully while in others there have been inadequate doses.

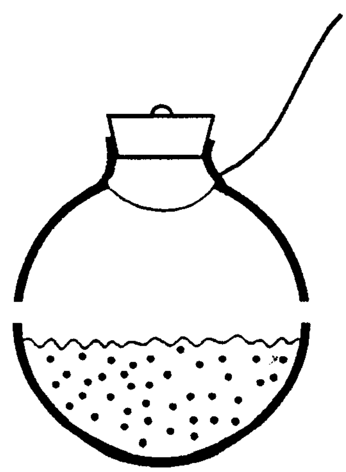


Fig 7 : Pot with holes

Plastic bags

This is a very well-known method in China. It is basically the same as the pot diffusion feeder, but in this case the container is a simple polyethylene bag with two series of 10 mm diameter holes. The first series or row is placed above the level of the disinfecting compound (sand and chlorinated lime), the second just below the compound; and the number of holes depends on the volume of water to be disinfected inside the well or reservoir.

1 - 2 m3 of water - 12 holes

3 - 5 m3 of water - 13 to 18 holes

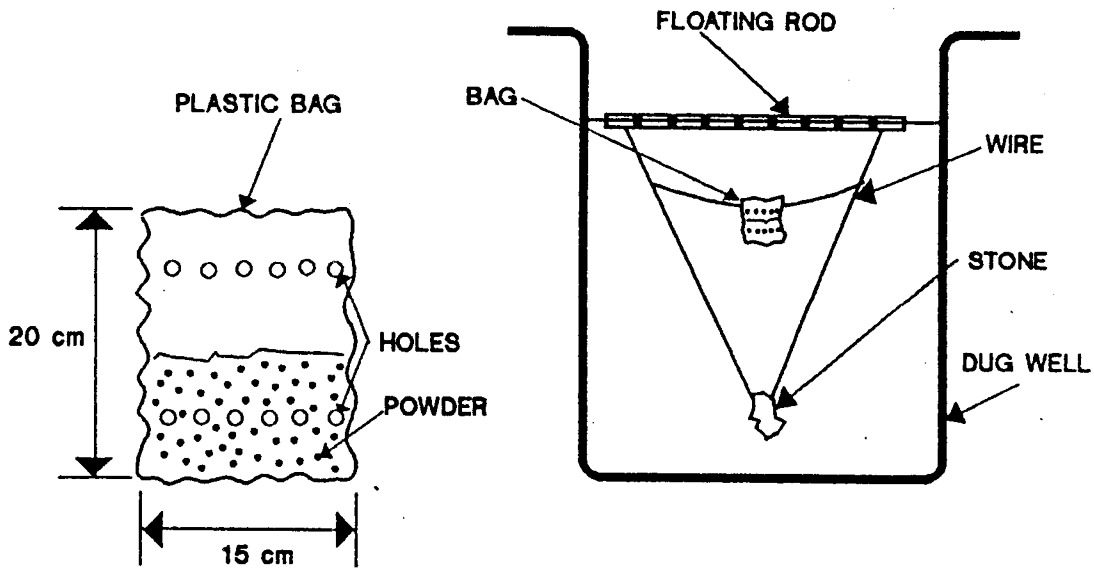


Fig 8 : Plastic bag

Porous pot

Quiet water or water with little movement can be disinfected using this method. Nevertheless it should be made clear that this is not a precise method and should only be used if a better one can not be implemented. The heart of the system is a pot of any shape, with a capacity of about 5-15 litres. This pot is made out of a mixture of clay, sand and (here is the secret): 10-15% of saw-dust. When baked, the saw-dust is burned and the pot retains an ideal porosity that allows the chlorine to diffuse in the water. When in use it is filled with chlorinated lime or calcium hypochlorite. It is covered and is submerged in the water requiring disinfection. It is very important to control its rate of diffusion, which may vary, depending on the wall porosity, the water movement and the time the system has been operating. From time to time as the porous walls become clogged, it should be thoroughly rinsed with clear water.

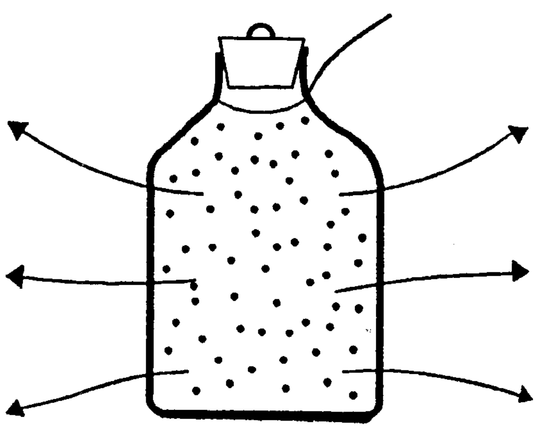


Fig 9 : Porous pot

Concentric tubes

This is a similar system to the one previously described. The difference is that it is constructed out of two PVC concentric tubes. The inner tube should be able to fit tightly inside the outer one. The inner tube has a slot 12 - 20 mm wide. The more exposed this slot, the larger the quantity of chlorine which will be diffused. To prevent the chloro-compound from escaping from the slot, it is advisable to place a plastic netting on the inside of the slot.

When in use the chloro-compound (chlorinated lime, calcium hypochlorite, etc.) should be mixed with sand in the already described proportions. This mixture is placed inside the inner tube and the concentric tubes, with a fixed proportion of the slot exposed, are submerged in the water to be treated. The bigger the slot, the larger the chlorine dose. If installed in a channel, the flowing water will cause turbulence and enhance the diffusion process.

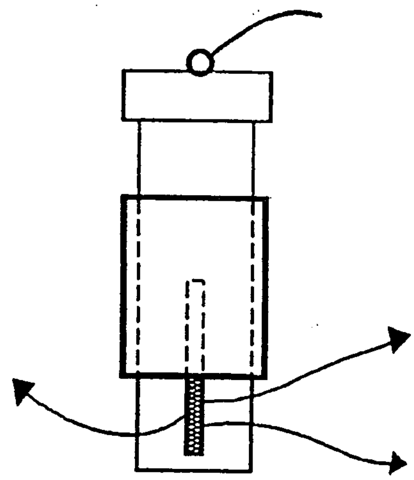


Fig 10 : Concentric tubes

Continuous flow diffuser

Many models of this system are available - e.g. in South Africa (Klorman and Thomas Chlorinator), in Latin America and the Caribbean (the 'J A feeder'), in the USA (the SANI KING and the Water Sure chlorinators) and in Europe (Aquaward).

It is very useful for disinfecting water entering a tank or reservoir, as the feeder is connected in the pipeline at the inlet of the tank. This is highly recommended because the reservoir will provide considerable retention time. The feeder has two chambers. The first (upper) holds preformed chlorine tablets and the second (lower) acts as a diffusion area. The disinfection dose can be varied by tightening the cylinder holding the tablets to a greater or lesser degree. The tablets are usually made of HTH, or any other commercial chloro-organic powder.

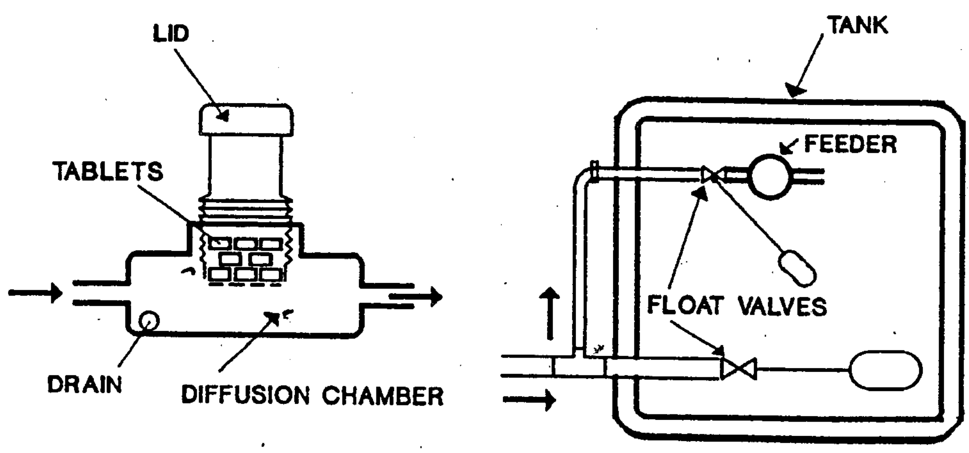
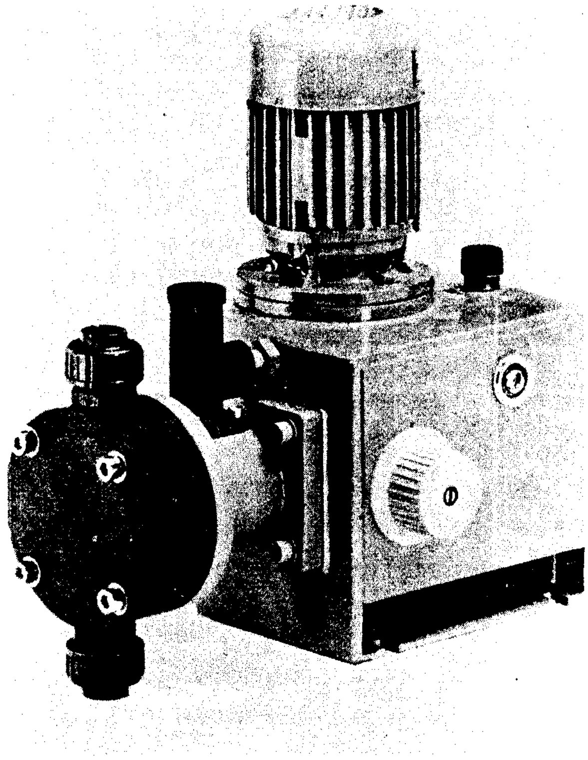
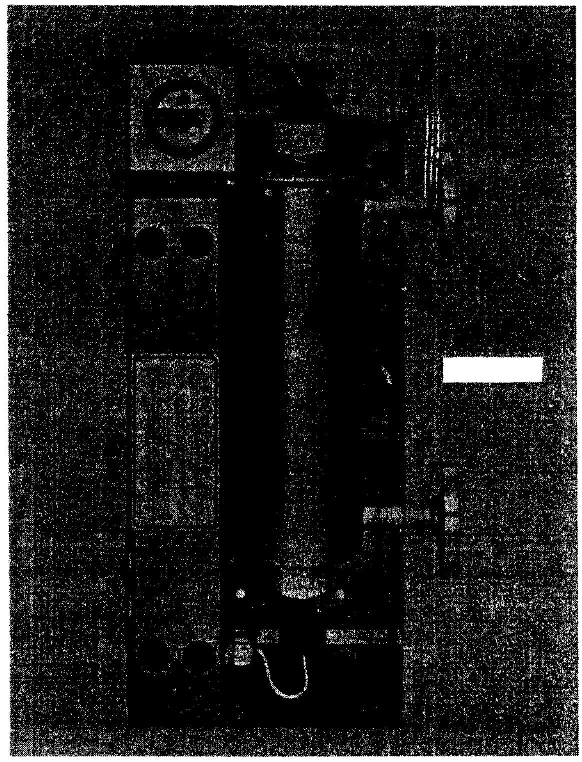


Fig 11 : Continuous diffusor

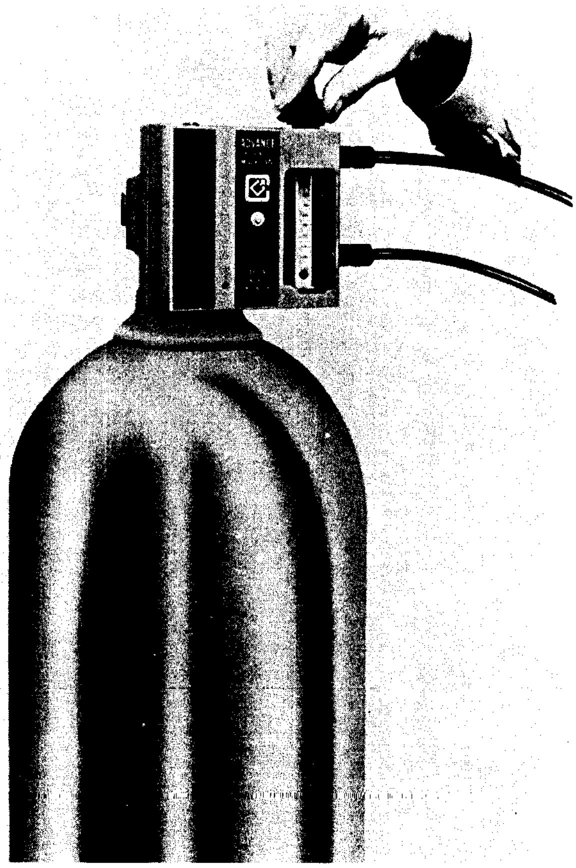
The problem: contaminated water



Diaphragm pump

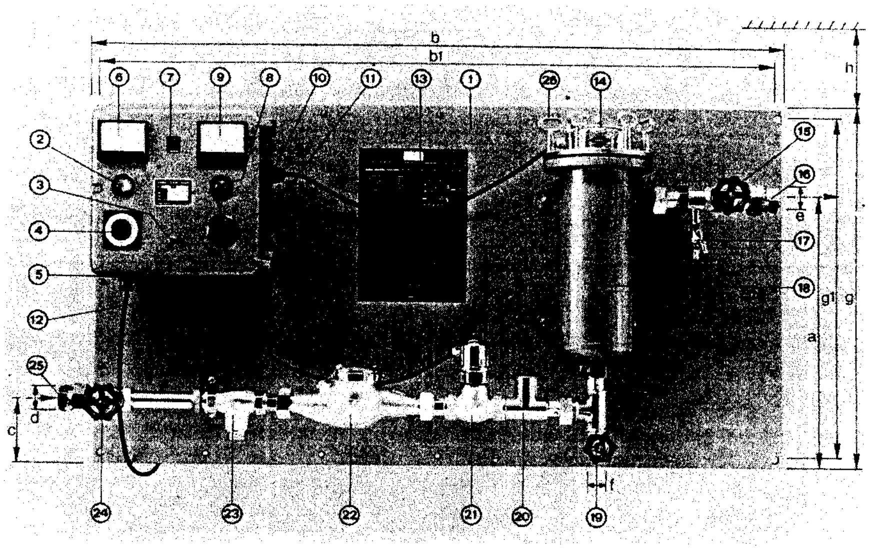


UV disinfection system



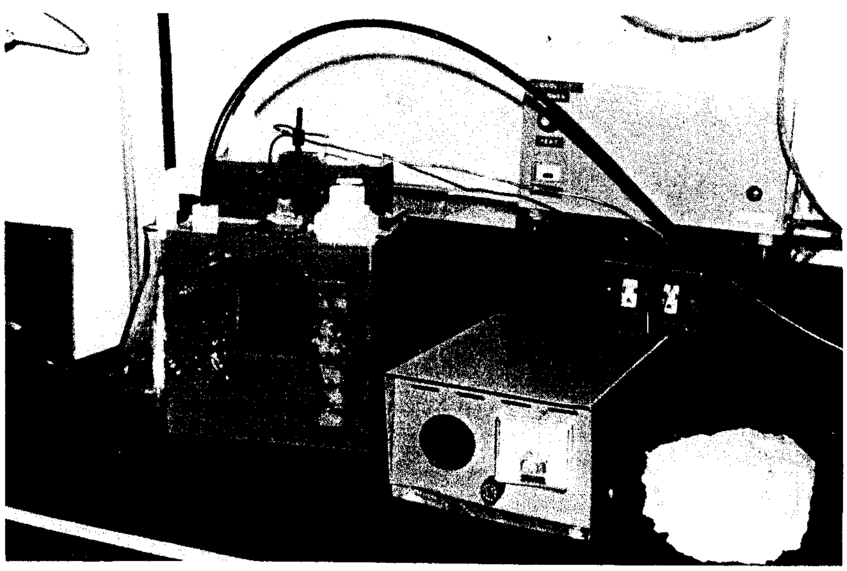
Gas chlorinator

Continuous flow diffuser

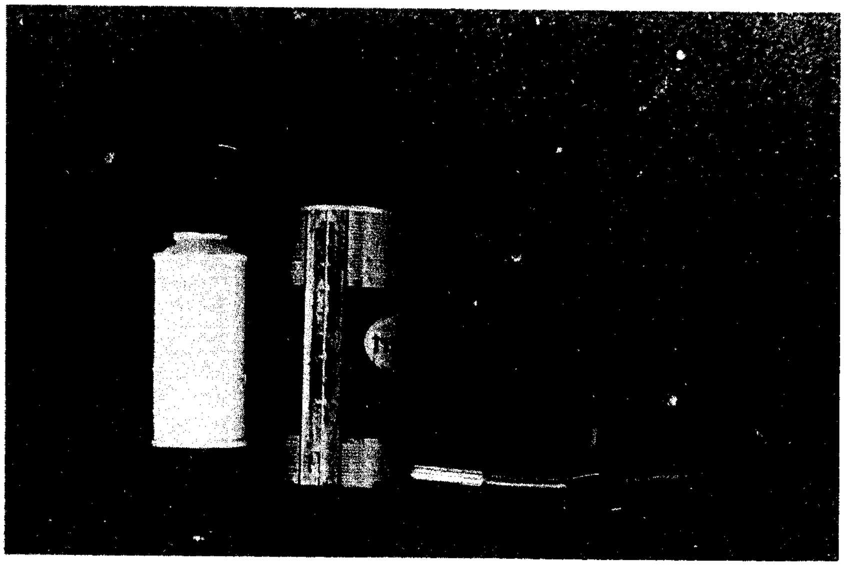


Electrolytic silver equipment

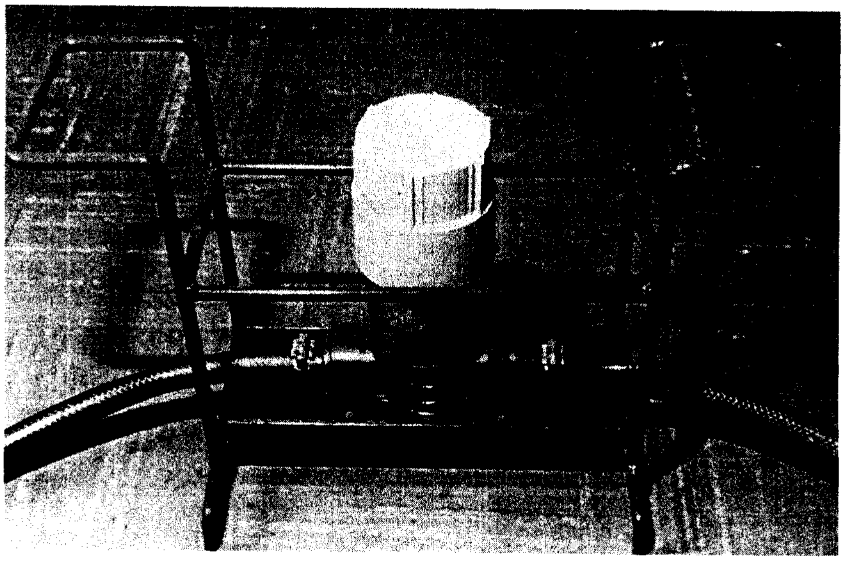
Borehole chlorinator



Ozone-chlorine generator



Beer and spray cans disinfection system



Continuous flow diffuser (Klorman)

Chlor-floc

Borehole chlorinator

Similar to the continuous flow diffuser, the borehole chlorinator is installed directly in the pipeline. It has been designed for use with boreholes equipped with handpumps or small motorised pumps (10 - 40 l/min).

The chlorinator consists of a bowl holding calcium hypochlorite tablets. The water runs past the tablets in the same way that it runs through an on-line filter.

The bowl is placed in a by-pass, and to provide a running flow along this branch, a restriction is applied in the main pipe between the inlet and return pipes of the by-pass. This is done by installing either a valve or an orifice plate in the pipeline.

For a 40 mm main pipe, and a flow of between 1 and 2.5 m3/hour, the diameter of the hole in an orifice plate should be between 20 and 24 mm.

This can be a disadvantage in some situations as the hole introduces a considerable pressure loss.

In South Africa this chlorinator is sold under the name of 'FLOWRITE BOREHOLE CHLORINATOR'.

It is extremely important when using this chlorinator, or any other device that utilizes tablets, to always use approved tablets, for example HTH. Some swimming pool chlorine tablets release cyanuric acid which may be harmful if consumed over a period of time.

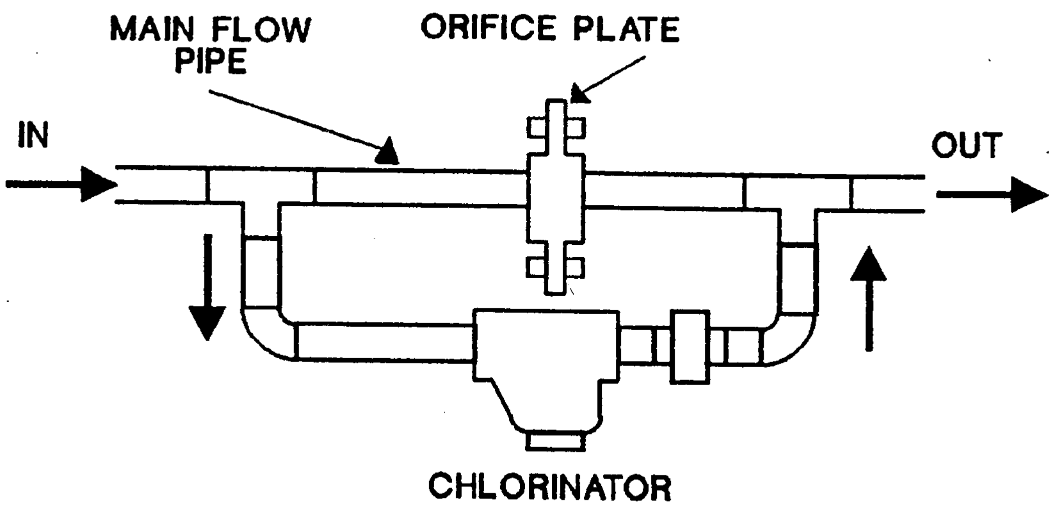


Fig 12 : Borehole chlorinator

Chlor-floc

As in the case of disinfection by heat or sunlight, this method is only suitable for treating small amounts of water on an individual household level, or it can be extended to treat batch quantities of water up to 3 000 l at a time.

Water collected from a river, pond or dam is not only polluted with germs but may also look dirty (turbid).

Chlor-floc is available as a powder or in tablet form and is a mixture of a coagulant and a chlorine disinfectant. It can be obtained from most pharmacies and in some supermarkets. The powder is obtainable from Control Chemicals (Pty) Ltd in Johannesburg.

To disinfect and clarify 20 litres of water, add one tablet or a teaspoon of powder to the twenty litre container and stir briefly. After a few minutes standing, the dirt will settle to the bottom of the container. Clean water which is also disinfected can then be obtained by straining the water through a piece of cloth. Alternatively the clear supernatant water can be carefully drawn off.

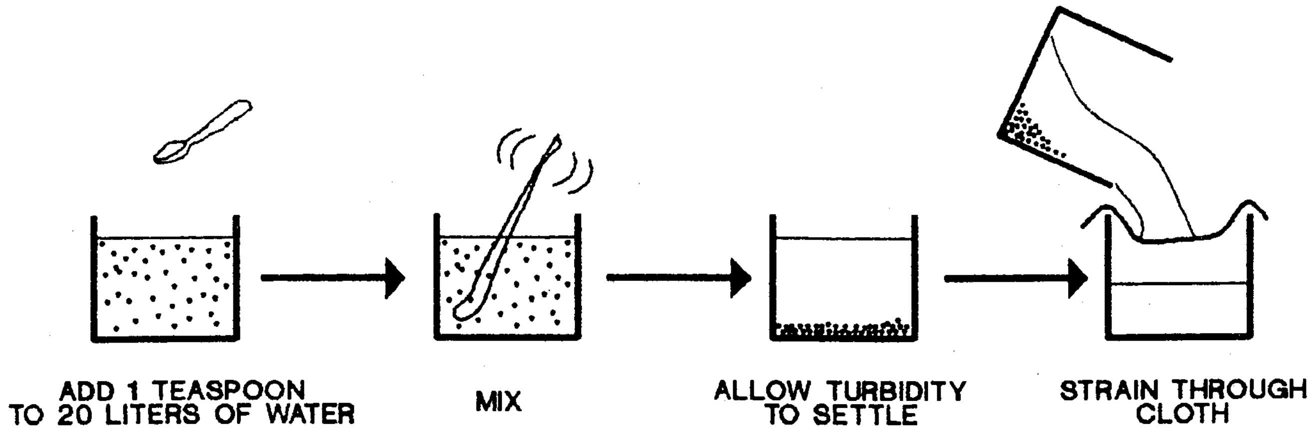


Fig 13 : Treatment with chlor-floc

3.3 SOLUTION FEEDERS

Two possible driving forces for feeding chlorine solutions, are:

– atmospheric pressure, and
– positive pressure.

Atmospheric pressure feeders

The atmospheric pressure feeders can be divided into:

– fed by hand (bleach method)
– constant head feeders
– wheel feeders
– suction feeders

Dosing by hand (Bleach method)

Dosing by hand, although not a feeder as such, utilises a chlorine solution and allows this technique to be placed in this section. Because household bleach may be used as the chlorine solution, this method is often referred to as the bleach method.

This method has the same restriction as boiling water, sunlight, and chlor-floc, in that it cannot be used in community water treatment plants.

The reason for their inclusion in this Technical Guide is that they represent important individual solutions in cases where there is no possibility of treating water in a centralized service, or when an epidemic necessitates urgent measures to curtail the outbreak.

The method is well known in third world countries and in many areas its use is a common practice.

It makes use of Jik, Javel or any other kind of bleach which is normally used for the whitening of washing (in fact, a bleach is a solution of sodium hypochlorite with a 'strength' ranging from 2% to 10% but usually 3.5%). The use of perfumed bleaches however, should be avoided for the disinfection of water. To destroy germs, one drop of the bleach in one litre of water will be sufficient, or alternatively 1 teaspoon in 20 litres of water. The water should be stirred in order for the bleach to be properly mixed and then it should be left to stand for at least one hour.

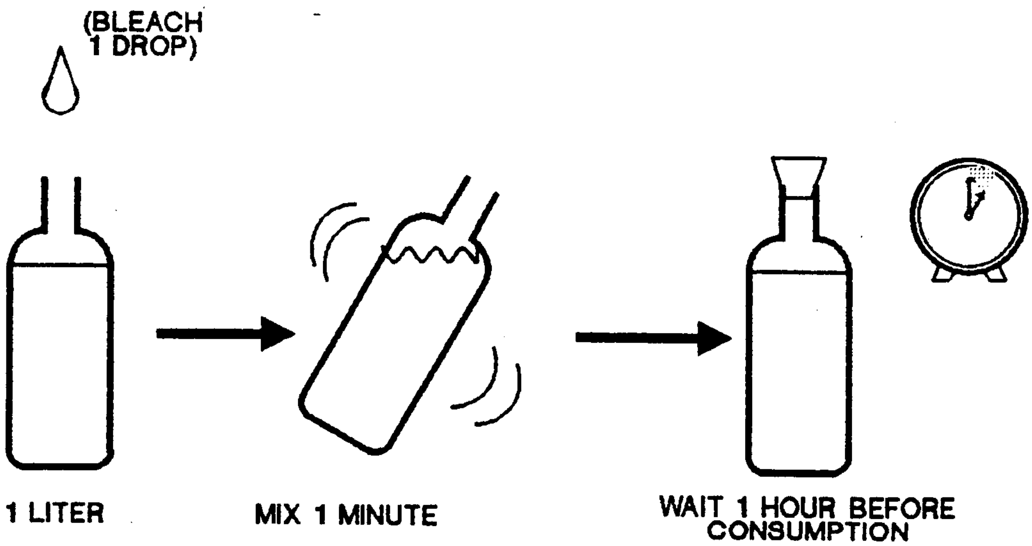


Fig 14 : Purification of water using bleach

Constant head feeding

These systems are composed of two elements: a constant head and a regulating orifice. The constant head feeders are used to dose chlorine in channels or in tanks.

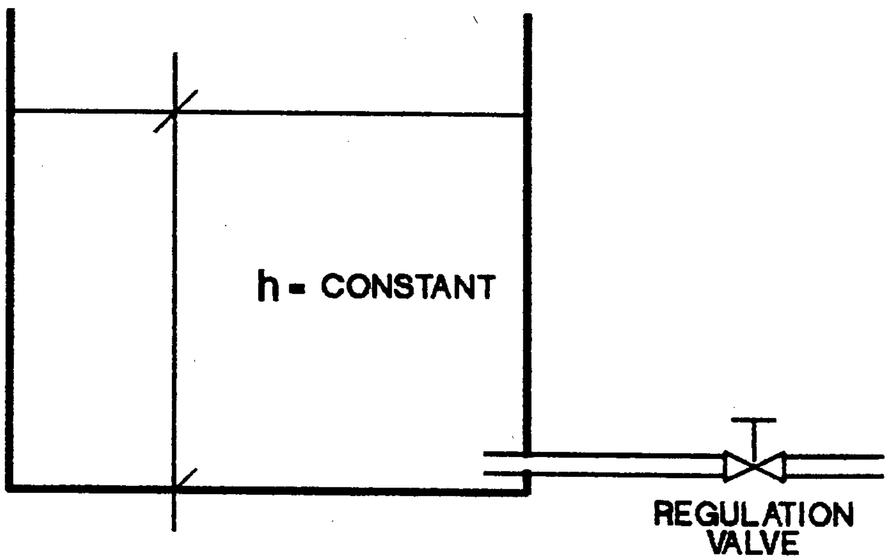


Fig 15 : Constant head system

Inverted bottle

A big inverted bottle (10 - 15 litres), holding a solution of a chloro-compound is placed head down in a piece of tube (with bottom) or in a proper container. The tube or the container should have an outlet with a regulatory valve. This is one of the simplest methods for feeding and has been widely used in many rural areas. However, the feeding rate can vary considerably. On the other hand it is very cheap and it constitutes a good system to start a disinfection programme.

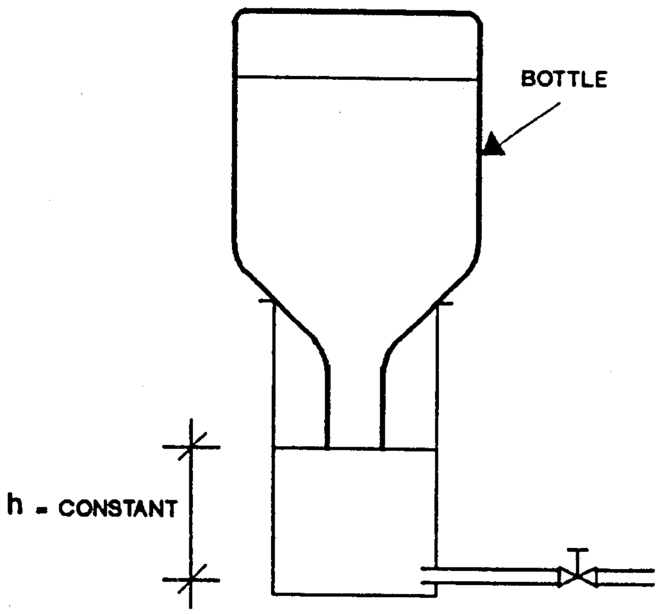


Fig 16 : Inverted bottle

Float valve

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

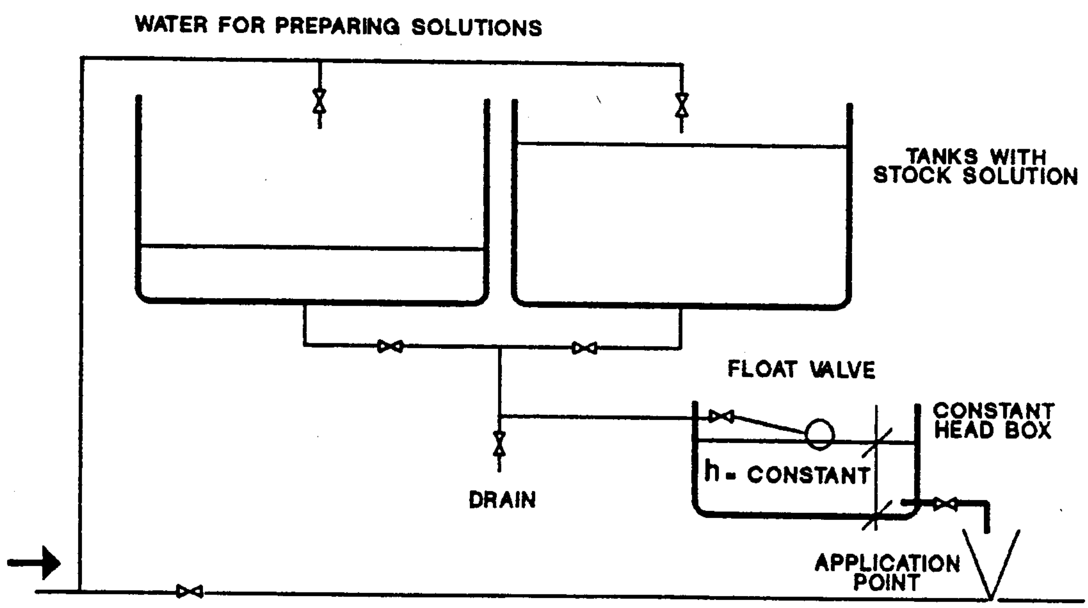


Fig 17 : System with float valve in box

Floating tube with hole

This system has been widely used in several different arrays. The basic element is a PVC tube (a cane can also be used instead of the 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 solution enters through the hole and it flows away from the tank through a flexible plastic hose with a small diameter.

In the preparation of the chlorinate solution, the presence of certain insoluble matter may lead to blockages of the small holes. There is, however, a design (see drawing A) which avoids this problem. The tank is divided by a perforated screen. In one chamber the solution is prepared while in the other the feeder is placed. The feed flow rate can be regulated by:

a. lowering or raising the tube (and consequently the hole/s) or

b. opening or closing a small regulatory valve placed on the exterior of the tank.

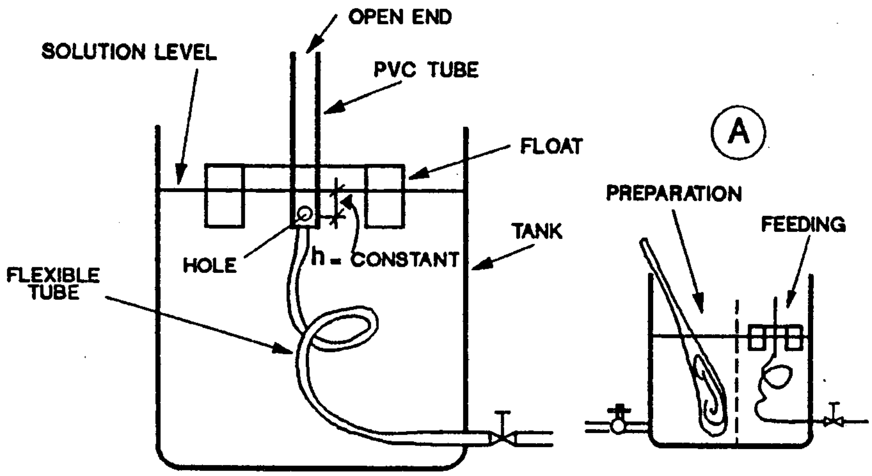


Fig 18 : Floating tube with hole

Constant head aspirator

The aspirator is fitted with a right-angled capillary outlet and a centre tube air inlet. When it is filled and the solution drops from the outlet, air is drawn down the centre tub and bubbles up into air space. The centre tube is full of air and atmospheric pressure exists at its foot. Thus the heed across the capillary is independent of the level in the aspirator, and can be altered (thus altering the drip rate) by rotating the capillary between horizontal and vertical positions. If a connection is taken from the air inlet into the reservoir terminating at the top water level, then when the reservoir is full, the air inlet will be stifled and the solution flow will cease. This on/off control is not instantaneous as sharpness of cut-off will depend on the characteristics of the float valve and on the volume of air in the aspirator.

A 20-litre aspirator is a useful size for many situations. Coarse adjustment of drip rate is made by altering the height of the centre tube.

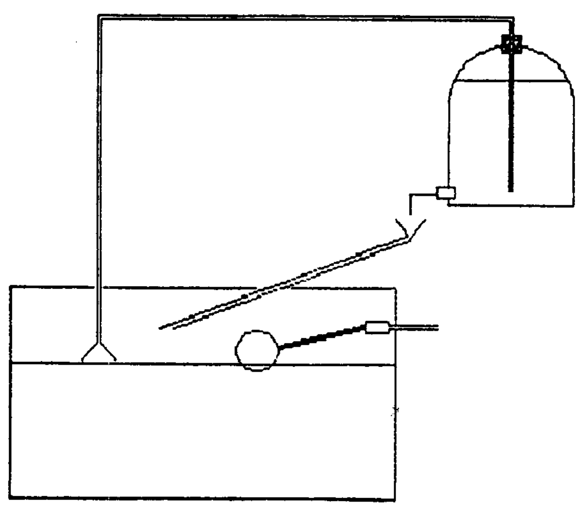


Fig. 19 : Constant head aspirator

Plastic bottle with inverted cup

This feeder was designed by the author of this paper, in Argentina, and is made from an inverted plastic bottle with the bottom removed. A plastic or wooden cover with a small hole is glued onto the bottom. A tube of 8-10 mm diameter (a piece of empty ball point pen) is inserted through this cover. A similar tube is placed through a rubber stopper in the bottle neck and this, when the system is installed, faces downwards.

A very light plastic cup is also placed in an inverted position inside the bottle. On its bottom (outside) a piece of soft rubber of 2 - 3 cm2 with a thickness of about 1 cm should be glued. This cup acts as a float, regulating the solution flow into the bottle and maintaining a constant head inside it. Regulation of the flow out of the bottle is by means of a hinge valve as shown in Figure 20 below.

The hypochlorite solution tank should be placed 1 metre above the feeder (the bottle) in order to maintain sufficient head to supply solution to the inverted bottle. To prevent the clogging of the feeder tubes (this usually happens because the hypochlorite powders always have some insolubles), a small filter should be added to the system. The filter can be made from a small plastic pill container with a piece of cotton wool inside. Another possibility is to use a petrol filter.

A similar device can be made from a beer can with a spray can (with the valve removed) as float. A rubber is attached to the top of the spray can. An additional requirement for this equipment is the need of a good zinc oxide paint to prevent corrosion of the metallic cans. This last system has also been used in Latin America for adding fluorides to drinking water. The proper use of this feeder allows solution dosing of between 0.1 and 10 litres/hour with errors of less than 10%.

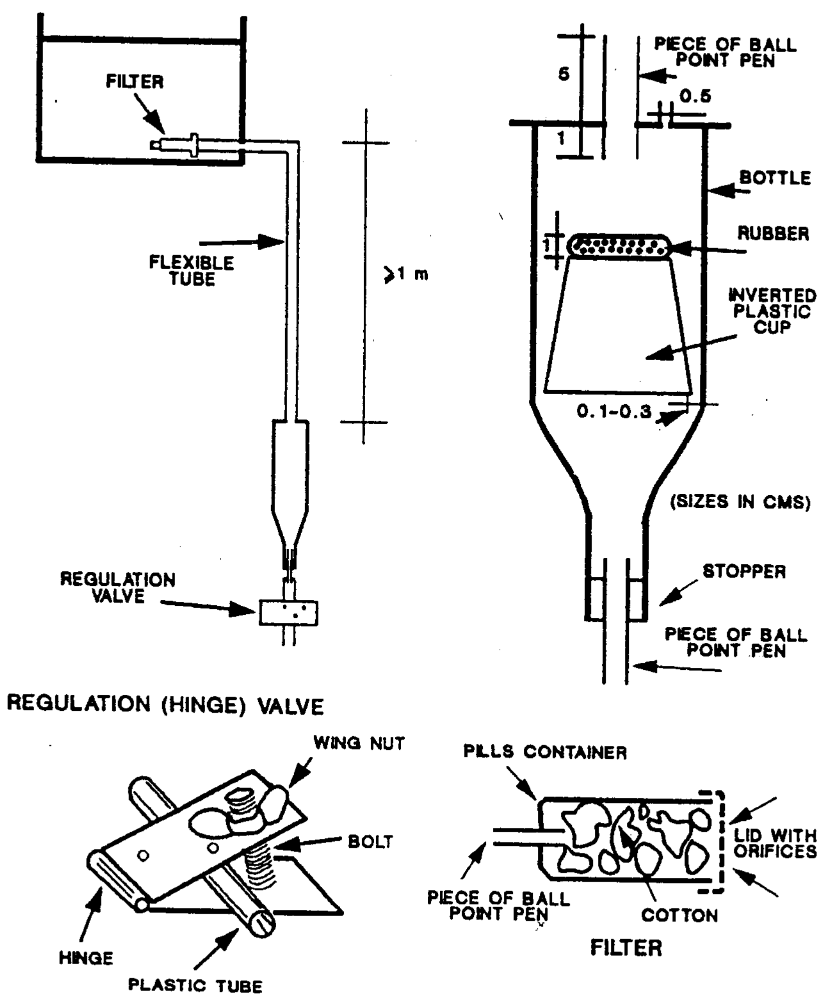


Fig 20 : Plastic bottle feeder system

Vandos feeder

This chemical feeder has the unique feature of not being affected by particulate matter present in the chlorine solution. Developed in South Africa, the system consists of 3 drums, 2 of which are fixed and one which floats inside the lower drum. The chlorine solution is placed in the lower fixed drum which is larger than the other two drums. The upper fixed drum is filled with water, and the floating drum is positioned empty in the lower drum. Water from the upper drum flows through an orifice plate into the floating drum. As the floating drum fills, it displaces chlorine solution from the lower drum through the overflow. Because the water level in the upper drum drops at the same rate as the rate that the floating drum sinks into the lower drum, the head difference between these drums, and hence the water flow rate, remains constant. The rate of flow is governed by the height of the upper fixed drum, and by the size of the orifice.

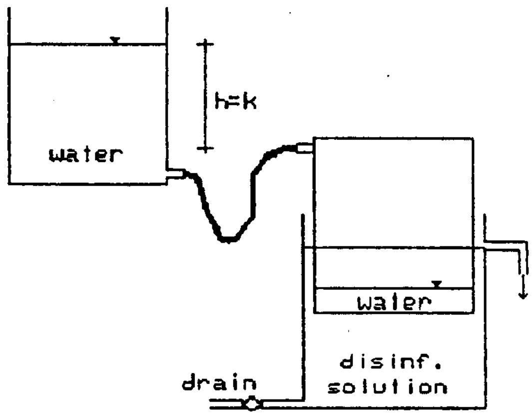


Fig 21: Vandos Chemical Feeder

Other atmospheric pressure feeders not described in detail here, are the following:
- BWK tipping dosimeter
- Wallace and Tiernan self powered chemical doser

Wheel feeders

Archimedes wheel

This is a wheel which rotates by means of mechanical, electrical or hydraulic power. The wheel has arms with buckets or small pots (plastic for corrosion prevention) fixed on the ends. These small containers lift the chlorine solution. The feeding dose can be regulated by changing the capacity of the containers or by varying the speed of rotation.

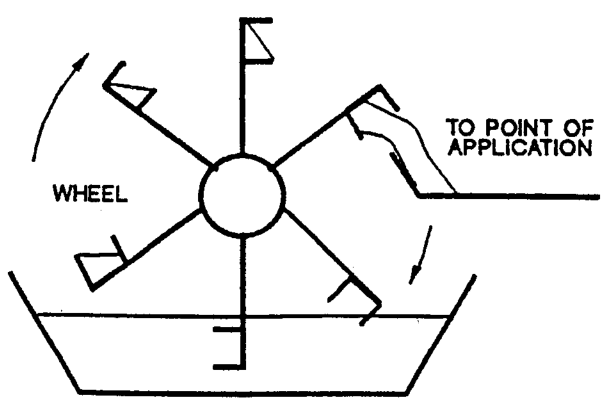


Fig 22: Archimedes wheel

Paddles in a channel

This is a very interesting system developed in Colombia.

If the water to be chlorinated flows in an open channel, the power of the flow can be used to move paddles connected to a hollow axis. Attached to the axis are also two or three hollow rods with holes in the ends. As the axis turns, these rods scoop up a small quantity of chlorine solution held in a container adjacent to the channel. The solution flows through the rods into the hollow axis, and as the axis has a slope (3-5%), it flows through the axis and is discharged into the channel. A constant level is maintained in the tank containing the chlorine solution by means of a float valve.

This system is very interesting as not only it is very simple, but the dose is also proportional to the water flow rate (the faster the flow of water, the quicker the paddles rotate resulting in increased solution feed).

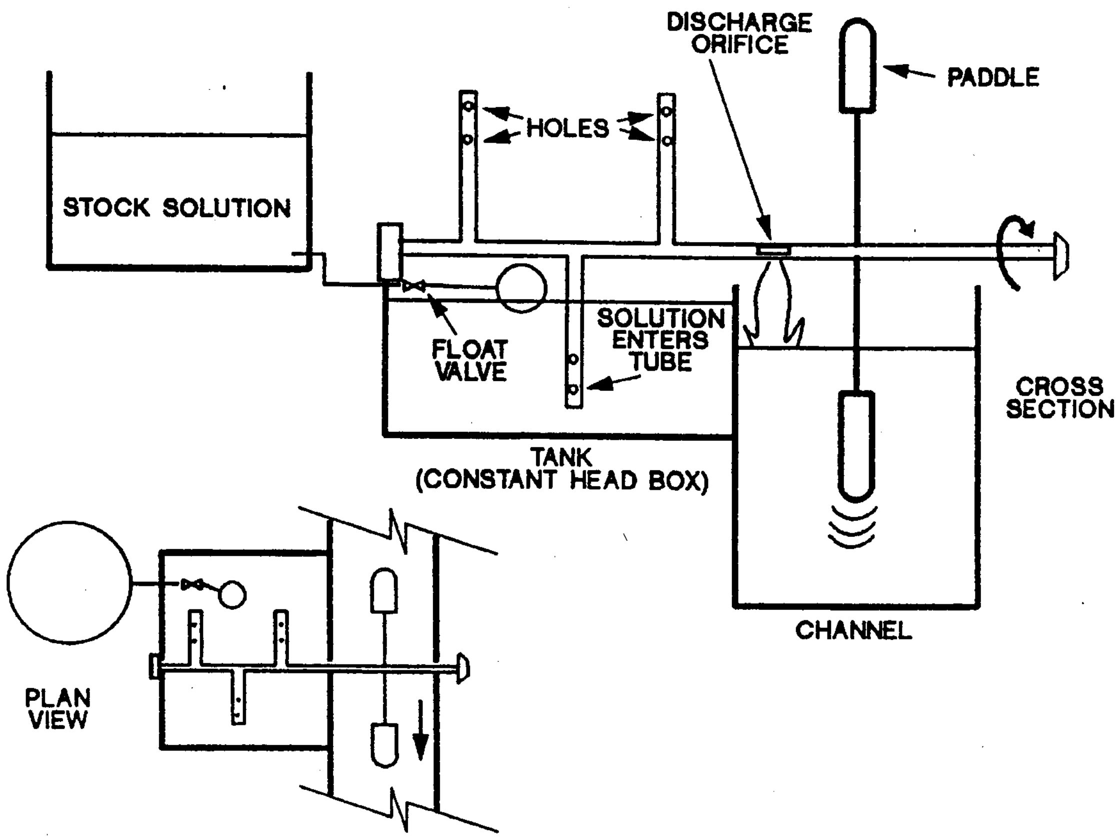


Fig 23 : Paddles in channel

Suction feeders

These chlorine feeders work on the principle that the water pressure in the pipeline is reduced, and hence the chlorine solution which is at atmospheric pressure, is driven into the pipeline at that point.

System through narrowing tube

The narrowing of a pipeline through a Venturi tube, a nozzle, or through an orifice plate, produces a partial vacuum that allows the sucking of a chlorine solution from a tank. If this tank has a constant pressure (achieved with a float valve for example), the flow feed will also be constant, provided that the water flow in the pipeline remains the same.

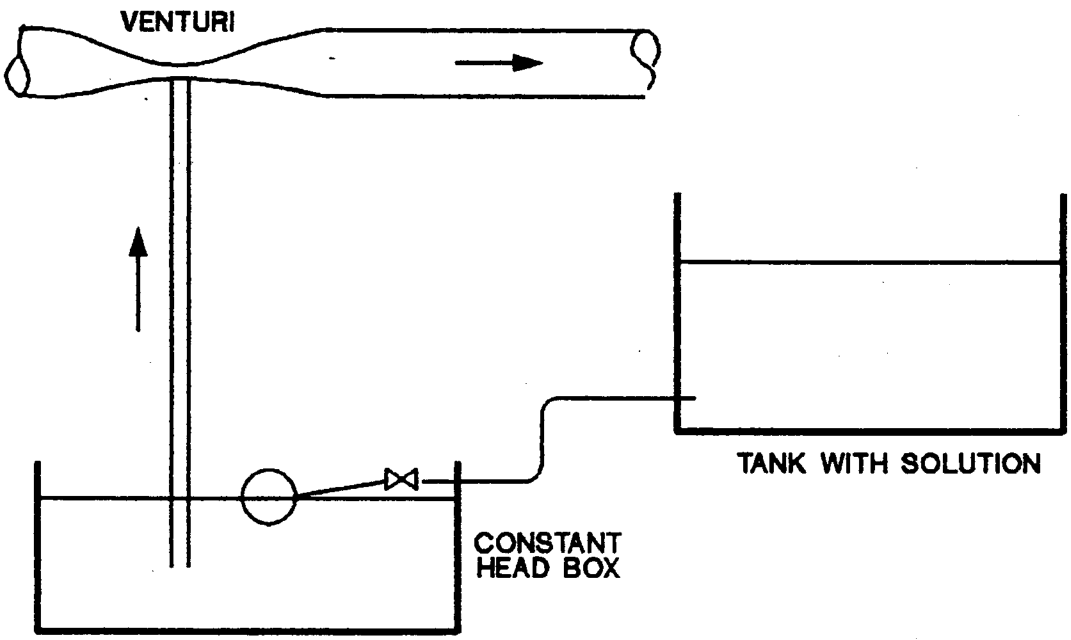


Fig 24 : Venturi

Venturi with rotameter

A loop around a pump allows the water to run through a small venturi connected to a rotameter. The venturi sucks the hypochlorite solution contained in a tank at atmospheric pressure. The array: venturi-rotameter can be made out of acrylic or polypropylene. The rotameter has a regulating valve that allows for variation in the dose.

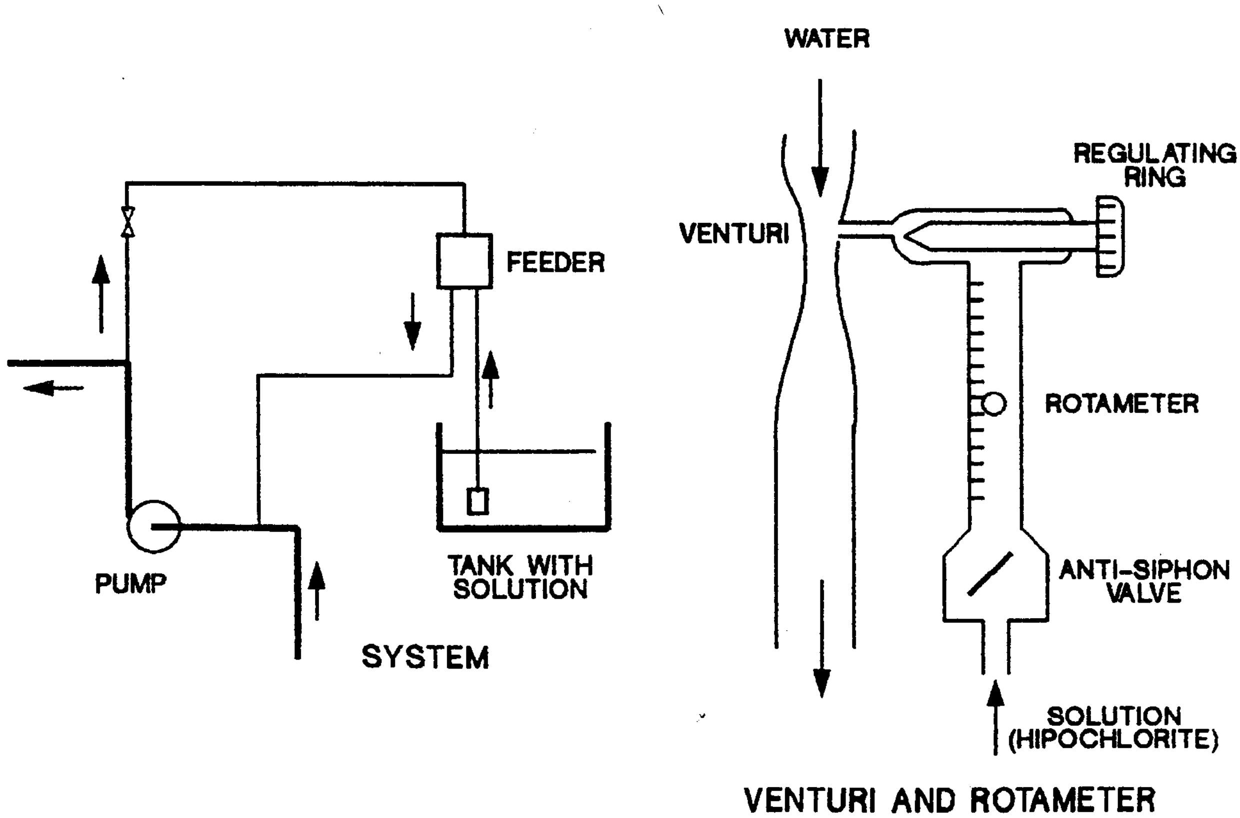


Fig 25 : Venturi with rotameter

Feeding into a pump suction

If there is a system with a pump, a small tube can be connected to the pump's suction. The tube can be as small as 6 mm in diameter. The feeding system is a series of elements connected one after the other as follows: a shut-off valve, a regulatory valve, an anti-siphon valve, a box with constant pressure (float valve) and the tank with the feeding solution.

The anti-siphon valve can be made from a piece of thin rubber (e.g. from a bicycle tube).

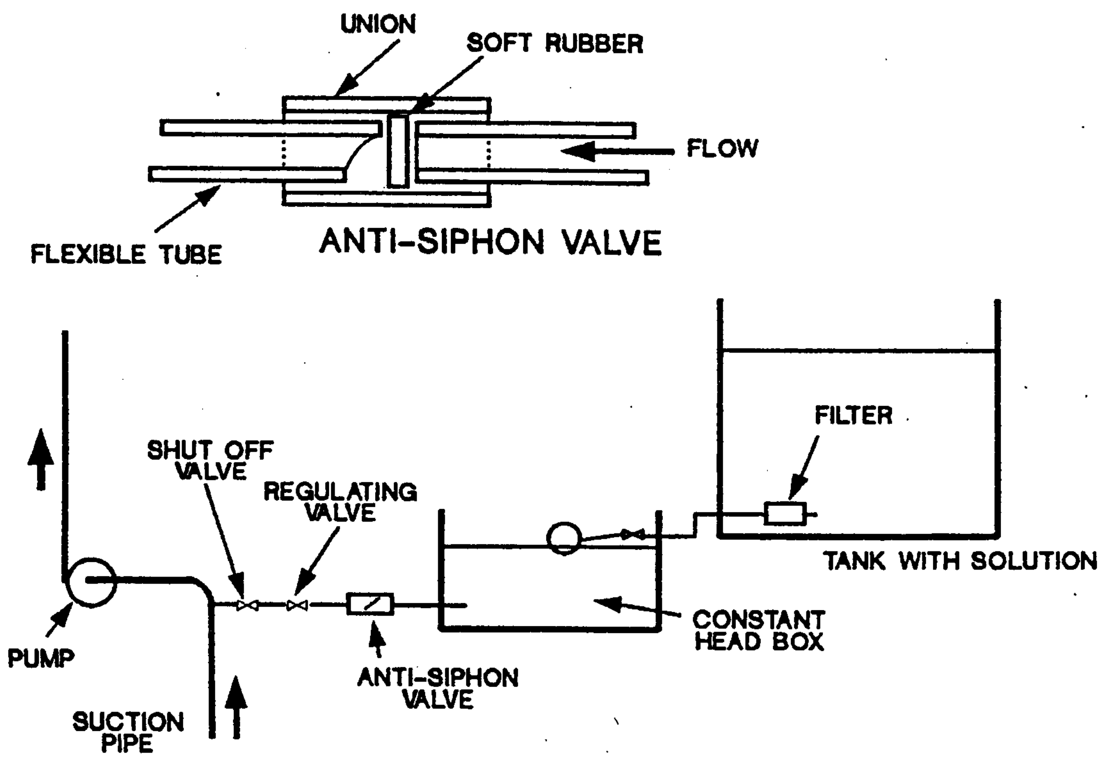


Fig 26 : Feeding into a pump suction

Positive Pressure Feeders

These feeders work on the principle that the chlorine solution is pressurised above atmospheric pressure and subsequently injected into the water pipeline.

Liquid dispenser

An interesting device that doses liquid hypochlorite has been produced in South Africa under the name of Dosotron. This is a dosing pump that injects solution into the water line.

A constant volumetric dosage is obtained through a drive piston equipped with two valves driven in an upward-downward movement by the water flowing through it, drawing the disinfecting solution from an open tank, and injecting it into the line.

The dispenser is connected to the pipe carrying the water to be treated either directly or by means of a by-pass. The flows which can be treated range from 30 to 1 500 litres/hr.

The system cannot operate with a positive back pressure, and requires a free outlet.

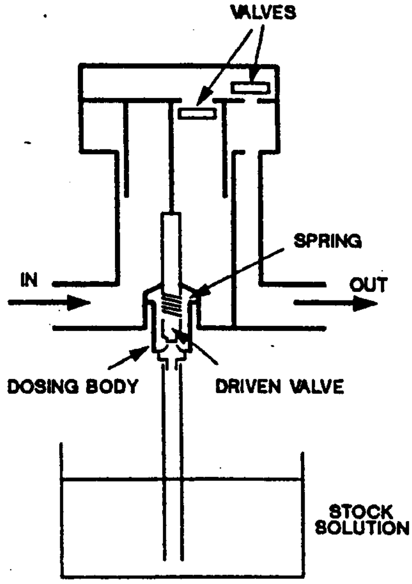


Fig 27: Dosotron liquid dispenser

Diaphragm metering pumps

The diaphragm metering pumps are equipped with a chamber of a chemical resistant material (acrylic, Teflon, etc.). There are a one-way valve at the inlet and at the outlet of the chamber. 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 solution is pumped from a stock tank below the chamber level (to prevent accidental siphoning). A small filter is located in the inside of the tank to avoid clogging of the valves.

The application point may be a channel, or reservoir (atmospheric pressure), or a pipeline (positive pressure). Depending on the pump type, back-pressures of up to 10 kg/cm2 can be tolerated. An anti-siphon valve placed on the dosing line at the application point will prevent siphoning of the chlorine solution when the pipeline becomes empty and a negative pressure is developed. In local and international markets, there is a great variety of pump models, with the most common pumping rates being in the range 0 to 250 litres/hour.

Models are also available where the diaphragm is driven by hydraulic action.

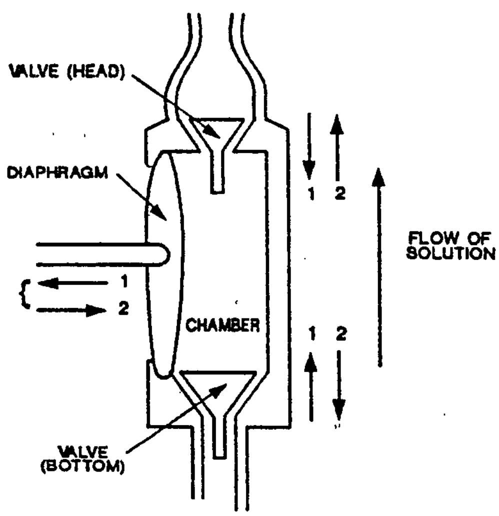


Fig 28 : Diaphragm chamber

A typical installation using a diaphragm metering pump is shown in Figure 29 below:

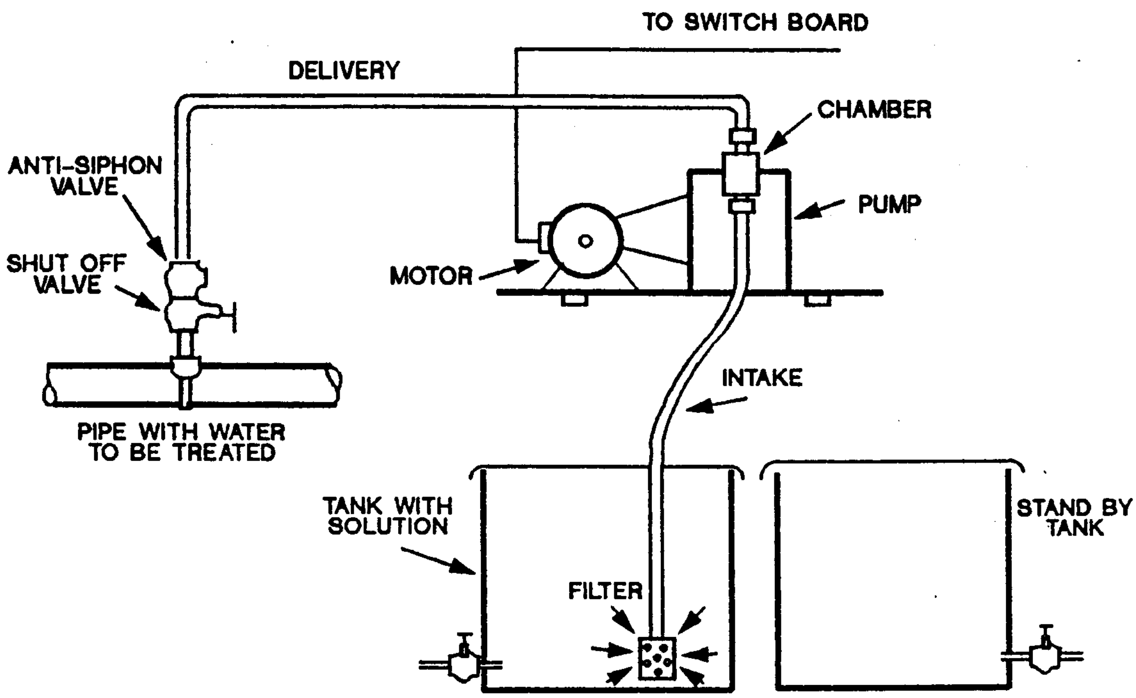


Fig 29 : Feeding system with a diaphragm pump

Other pressure dosing systems not described in detail here, include the following:
- Baldoser
- Dosmatic liquid dispenser (similar to Dosotron)
- Water-sure 150 series chlorinators
- Peristaltic dosing pumps

4. ON-SITE CHLORINE GENERATION/OZONE-CHLORINE GENERATION

The production of chlorine or other disinfecting chemicals on-site considerably reduces the logistical problems of buying, transporting, handling and storing hazardous chemicals.

A technology based on electrolysis, results in the formation of disinfectants out of common table salt. Two possible pieces of equipment are readily available on the international market. The first is an on-site chlorine generator and the second is an ozone/chlorine generator.

The equipment is composed of an electrolytic cell divided by means of a semi-permeable membrane into two semi-cells. A stainless steel cathode will lead to the formation of sodium hydroxide (NaOH) and hydrogen as by-products. In the other semi-cell one anode (chlorine equipment) or more than one anode with patented arrays (ozone-chlorine equipment) will allow the formation of the oxidising gasses.

The latter type of generator results in the production of, besides chlorine, a mixture of oxygen species (mainly ozone and hydrogen peroxide). It is known that ozone is one of the most powerful disinfectants for drinking water. It is not only highly effective against viruses and bacteria, but also helps to eliminate organic (phenols, benzenes, etc.) and inorganic compounds (iron, manganese, cyanides, etc.).

The only substances needed for the operation of the generators are sodium chloride and water. The equipment runs on electricity, and the amount of oxidising gasses produced is controlled by the intensity of the applied current. The oxidant production capacity of this equipment ranges from 0.1 to 5 kg of oxidant gasses/day, which gives a wide operational range from family use to rural treatment plants of about 40 000 inhabitants.

The gasses are injected in the stream of water to be treated by means of a venturi or a plate with a hole.

The operation of this equipment is very easy: one should check that there is always salt in the compartment, and from time to time the sodium hydroxide solution in the cathodic semi-cell must be diluted. Maintenance consists of cleaning the cell and rinsing the membrane every 2 to 3 weeks.

There are a wide range of chlorine-from-salt generators available, both locally and internationally. The capital costs of these systems are usually high. Systems which operate without a membrane are usually less costly, but also less efficient. The chlorine/ozone generator is a newer technology (now only 5 years old) and is claimed to have a number of advantages over other disinfection systems, including:

a. It may be a potentially better system than all of the previous disinfecting techniques;

b. It is an appropriate technology system that makes disinfection simple and easy;

c. Its needs in terms of power requirements are very low;

d. The prime materials used for running the equipment (salt and water) are simple, cheap, easy to find in any rural area and their handling involves no risk at all;

e. The equipment produces only the required quantity of disinfecting substances.

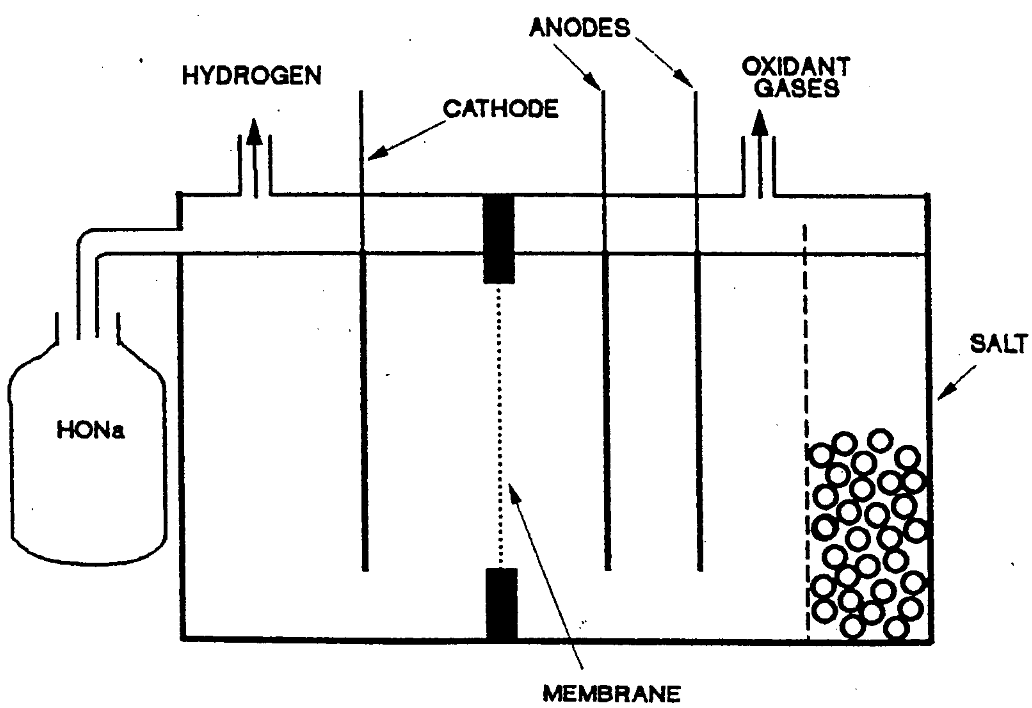


Fig 30 : Ozone-chlorinator

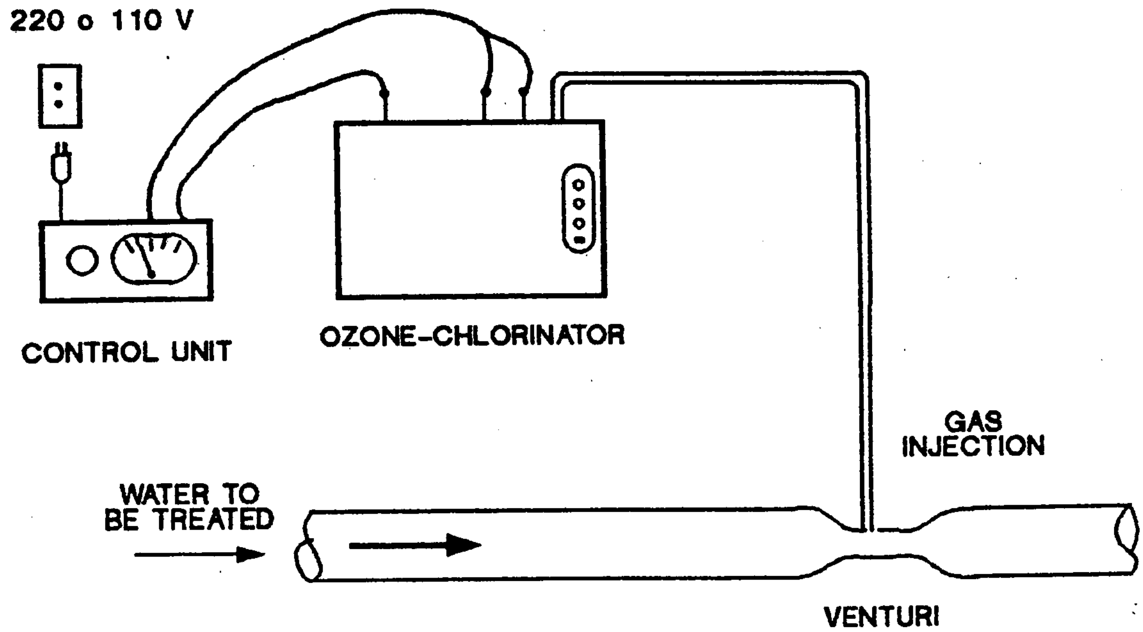


Fig 31 : Disinfection system with an ozone-chlorinator

5. SILVER

The use of silver as a germicide is described as a result of oligodynamic action of the metal on biological processes. Oligodynamics means simply 'effect or power in small amounts'. Although it is not clearly known how the silver acts in destroying micro organisms, it is probable that its action is a result of absorption of the silver ions by the organism which in some way affects the chemistry of the cell structure. Some microbiologists like to call this process the 'poisoning' of the cell.

The doses recommended for a high germicidal efficiency are in the range of 0.05 - 0.1 ppm.

The apparent virtues of silver for water treatment seem to be that it does not itself produce taste, odour, colour or form additional products that might do so. Another advantage is that the silver residual may persist for many days, thus allowing water stored for a considerable length of time to have continuing protection.

The disadvantages are that the costs are high (the electrodes that provide the silver ions wear out relatively quickly). Although the World Health Organisation has not provided upper limits for silver concentration in drinking water, the S A Department of National Health and Population Development has set a guideline maximum limit of 0.05 ppm (a safe concentration if argyria-bluish discolouration of the skin is to be avoided). There are no simple tests for measuring the silver content of water, and there is considerable doubt as to the most effective method of dosing water with controllable amounts of silver.

Two methods are used when using silver for disinfection. The first is to pass water through silver coated devices which should be constructed for easy cleaning, otherwise the surfaces may become coated and result in diminishing activity of the silver. The second method, the electrolytic one, seems to offer the most practical approach to the use of silver.

This second method makes use of a number of special silver electrodes connected to the positive pole of a weak electric power source. An inert electrode is used as the negative pole where hydrogen is produced. By electrolysis, silver ions are liberated by the electrodes into the water to be treated in proportion to the current applied.

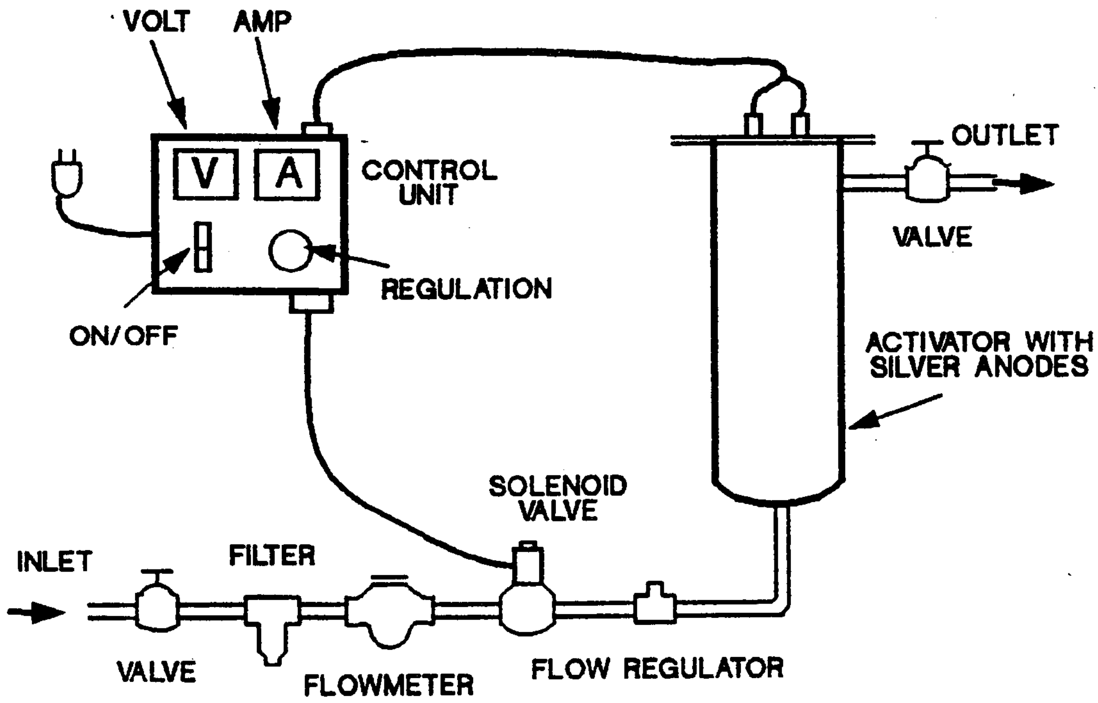


Fig 32 : Electrolytic silver equipment

The size of the equipment is such that only small water supplies can be treated by this method. Some doubt as to the effectiveness of silver for virus inactivation has also been raised.

6. SUMMARY

Table IV summarises the general characteristics of the disinfection methods already described:

Table IV : Comparison of systems / chemicals

	Equip-ment costs	Can equipment be made? on-site	Can it operate without electricity	Needs chemicals?	Availability of chemicals in rural areas	Safety (danger level)	Operation & maint-enance	Running costs	O & M personnel skills	Amounts of water to treat
UV	High	No	No	No	-	Low	Low	Medium	Low	Low
Chlorine gas	High	No	Yes	Yes	Low	High	High	Medium	High	High
Sodium hypoch.	Low	Yes	Yes	Yes	Low	Low	Medium	High	Low	Medium
Calcium hypoch.	Low	Yes	Yes	Yes	Medium	Medium	Medium	High	Low	Medium
On-site generation	High	No	No	No	Yes (salt)	Low	Low	Low	Low	Medium
Silver	High	No	No	No	-	Low	Low	High	Low	Low

7. REFERENCES

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