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WATER DISINFECTION

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PREFACE

The World Health Organization (WHO) and the United States Environmental Protection Agency (USEPA) have been working together for several decades in the area of environmental health. A product of this longstanding and fruitful relationship has been the series of *Guidelines for drinking water quality* put out by WHO.

The joint efforts of USEPA and the Pan American Health Organization (PAHO), the WHO Regional Office for the Americas, have also yielded productive results in the regional sphere. In the aftermath of Hurricane Mitch, in Central America, agreements were signed to upgrade, set up and accredit laboratories; evaluate water treatment plants and improve sources; and offer training in sanitary inspection, source protection and the promotion of plans to improve the quality of water for human consumption.

In 2001, the project "Improvement of the quality of drinking water in Central America" was launched with USEPA support under the direct execution of the Pan American Center for Sanitary Engineering and Environmental Sciences, PAHO/CEPIS. This project is broken down into six components that are being implemented in El Salvador, Honduras and Nicaragua: 1) Water quality surveillance and control programs; 2) Epidemiological studies linking health risks and waterborne diseases; 3) Water quality legislation and standards; 4) Analysis of the sanitary behavior of school children with regard to water quality; 5) Establishment of an electronic library and 6) Transfer of disinfection technologies and their implementation in the rural area.

The final component called for the preparation of a suitable tool to contribute to the desired transfer: a comprehensive manual that, while scientific, would also be realistic and attractive. What was sought was a document that would summarize the vast store of data available in similar works and present it didactically for the use of both engineers and technicians who seek concrete data and suggestions for implementing, operating and maintaining water disinfection systems in the treatment plants of medium-sized and small towns.

The efforts of sanitary engineers Felipe Solsona, PAHO/CEPIS regional advisor on water quality, and Juan Pablo Méndez, sanitation consultant in Peru, have produced the desired document. The scope, initially confined to the subregion, has been broadened to allow for its implementation under different local conditions. It is with great satisfaction that we make this work available to experts and organizations that are dedicated to producing drinking water, in the assurance that it will help to improve the quality of life and health of rural dwellers in developing countries.

Eng. Sergio A. Caporali
Director of CEPIS

Chapter 1

DISINFECTION

Introduction

The development of humanity has been tied in, to a large degree, with the state of health of the various groups that have inhabited the planet. On occasion, entire countries or regions have been decimated by pests and plagues that are often random, temporary and unique. Even so, there are diseases that appear to be as old as mankind itself, whose force and importance are a part of everyday life: the diarrheal diseases.

The edition for 2000 of the *"World Health Report"* published by the World Health Organization (WHO) ranks diarrhea as the seventh cause of death in the world following heart disease, cerebrovascular accidents (brain strokes), acute respiratory infections, HIV/AIDS, chronic pulmonary obstructions and adverse perinatal conditions. While this ranking gives an idea of the relative importance of these causes of death, the finding of the Organization that diarrhea is by far the foremost cause of morbidity in human beings, being responsible for four billion cases a year, is much more significant. It is estimated that at any given time, almost one-half of the developing world's population is suffering from bouts of diarrhea.

Unfortunately, because of their longstanding presence in the lives of human beings, the scope and impact of diarrheal diseases on the health and quality of life of individuals and the economy of mankind as a whole tend to be overlooked. Diarrhea can be traced to the existence of deficient nutrition, inappropriate excreta disposal, inadequate hygiene and poor drinking water quality. While the former three causes can be linked to poverty and the inappropriate cultural practices of large groups of the population, the latter —poor quality drinking water— appears to be the responsibility of sanitary engineering and related sciences.

Proper treatment and delivery of safe water under favorable conditions, as practiced in developed countries, is one of the best ways to heavily reduce the rates published by WHO. Within this context, disinfection of drinking water is of key importance for resolving the problem. Not only does it constitute a suitable mechanism for doing so, but it is also a vital element of what is known as "good practice" in the modern approach to water treatment and of the analysis of the risk and critical control points (HACCP). Both proposals for action call for evaluating each water treatment stage individually and determining the critical or risk points for controlling those stages and thereby eliminating or decreasing the inherent dangers. Disinfection is the final treatment stage in this context. When speaking of "multiple barriers," disinfection is the last control stage used by public health to produce and distribute drinking water. In developed countries, this treatment stage has always centered on the microbiological quality of the water that is delivered and the results have been telling. The rates recorded in these countries are lower in several ranges than those of the developing countries. By way of example, a comparison of deaths from diarrheal diseases can be made between Europe (3 per thousand) and Africa (12.4 percent).

These results reflect the existence of two elements and give rise to two observations. In the first place, disinfection in developed countries is obviously an unavoidable, fixed and established process. It is a normal routine that is carried out using all available knowledge and with a firm conviction of what it stands for. As a result, in these countries, sanitary engineering, chemistry, biochemistry and toxicology all, technically and in depth, study the best capacities, greatest efficiencies and lowest costs. And from the sanitary and toxicological viewpoints, they probe the characteristics and the relationships between disinfectants and disinfection products and health.

The second observation to be made is that the situation is precisely the opposite in developing countries. Water treatment, above all in rural areas, is imprecise and deficient operation and the lack of maintenance are widespread. As a result, the disinfection processes are poor and their role in protecting public health fails to be respected. A survey made in 1995 by the Pan American Health Organization revealed that only 41% of the water delivered to the people in Latin America through production and distribution systems had been properly disinfected.

In light of this situation, the priorities are obviously not the same. For developing countries, the existence of simple, appropriate and reliable technologies that are acceptable to the users, low in cost and easy and inexpensive to operate and maintain is far more important than the investigation or control of the disinfected products.

While in the area of public health, the ideal situation is perfection or as close to it as possible, in developing countries, common sense would tend to indicate that such perfection could be utopian, a situation almost impossible to achieve. For that reason, a term has been incorporated, which, although it may come in for criticism, is both realistic and indicative of the needed flexibility in the face of the existing technical, economic and sociocultural conditions. This term, “quality improvement,” tacitly accepts the fact that if the ideal, the perfect situation, is not attainable, then at least a step in the right direction is better than nothing.

The perfect situation in a developed country consists of impeccable facilities, trained and certified operators, assured and continuous technical backing, sustainable management and a prescribed, reliable and cutting-edge technology. This perfection is utopian in rural areas of developing countries where the smallness of communities makes it unlikely that suitable technical personnel will be available, possible geographic isolation places essential technical backing out of reach, limited know-how allows for only confusing management and resources are in short supply. A timid and yet incomplete step, but still an “improvement of the situation,” would be the use of operational practices that are appropriate to the cultural level of the site and technology that is truly suitable.

As compared with equipment controlled by printed circuits with colored leds that operates placing dosing errors to the right of the comma, the use of a wooden box with a flush toilet valve; a bottle containing a plastic glass; a pair of electrodes that use table salt to produce hypochlorite; a bottle placed in the sun; or a simple sand filter could appear to be naive or be seen as techniques that are just too simple. Actually, these and others that are presented on the following pages are well-known examples taken from the great melting pot of the appropriate technology, which —as already stated— is a step in the right direction. Their humbleness and simplicity should not be mistaken for low performance or inappropriateness.

All of the equipment that is presented in this manual enjoys a common denominator: it has been put to the test, has a long history of use in different places and situations and is sufficiently precise to raise disinfection (and water quality) to an acceptable level of excellence.

This book is not limited to covering appropriate or alternative water disinfection systems. As a document for both the transfer of know-how and provision of information, it also discusses technologies that are in use in other places and that constitute part of the store of disinfection technology with which all experts should be familiar, even if it is not immediately applicable in the Third World.

Considerations regarding disinfection

As already stated, disinfection is a key process of any water treatment system. For that reason, it is important to emphasize a number of special considerations to be taken into account before undertaking disinfection to produce safe drinking water. Some of these are discussed in the text below.

In designing a water treatment system, particularly in the rural area, disinfection must not be approached as just one of several elements, but as a component vital to the system. Frequently, those who design water provision systems in small communities not only fail to take disinfection seriously, but even go so far as to give more importance to the amount of water produced than to is safety (quality).

No valid option offered by the appropriate technology can afford to the overlooked, nor should it be rejected out of hand, as already indicated. What is important when selecting that technology, however, is to take into account determining factors, such as available resources and the possibility of technical support with regard to community social, economic and cultural aspects.

A disinfection system cannot be designed to be separate from or incongruent with the plant or system of which it is to be a part. A microfiltration plant, for example, with automated systems, electric power and personnel trained in its operation and maintenance, could be equipped with a microprocessor-operated diaphragm or piston pump. It would not be “congruent” in this case to design a system consisting of a float and a perforated plastic tube inserted in an asbestos cement tank. At the same time, it would make no sense to think of incorporating a chlorine dioxide generator as a disinfection system for a simple rural environment that does not even have electric power.

The failure of these systems is often due to their dependence on chemical products “imported” from other countries or localities. When these products are not forthcoming, operations are temporarily delayed or discontinued, in a situation that may become permanent if the needed chemicals fail to materialize.

When choosing the disinfection technique and system to be used, it is important to keep their characteristics in mind and to compare them with those of the plant, site and community. A good recipe is to complement the best conditions of the disinfection technique and system with those of the source, place, system and population and their cultural characteristics. This is very important, for the fact is that no site, system or community is perfect.

It must also be recognized that there is no ideal or perfect disinfectant or disinfection technique. All of the techniques discussed in this manual, which have been developed and are being used throughout the world, are excellent, but they are not perfect. Objections can be raised to each and every one of them: they do not kill all of the microorganisms, they fail to eliminate cysts or parasites, they do not leave any residual in the water systems, that they depend upon chemical products the community does not produce, they produce disinfection by-products that are fairly complicated, expensive or difficult to deal with.

Among these considerations is the fact that in rural areas drinking water does not necessarily go straight from the tap to the consumer's mouth. Sometimes it is left in containers (buckets and tanks) and other times people have to travel far (public taps and water sources) to find and carry it back. As a result, this water is frequently contaminated, making it necessary to implement safety measures following the disinfection process to keep this from happening. The residual disinfectant then becomes a further barrier (and definitely the last) against the contamination of drinking water that is almost certain to occur within the dwelling. The conclusion to be drawn from this observation is that the disinfection process should leave a residual disinfectant in the water system; if this is not possible, then two different disinfectants should be used, a primary one for disinfection and a secondary one to provide the residual effect.

There are other important considerations. Good disinfection should never replace other precautions or measures to improve water quality in its course from source to users. Sometimes a well-chosen source will yield clearer and less contaminated water, thereby facilitating its treatment.

Not only must the water quality of the liquid reaching the treatment plant be considered; it is also necessary to note the quality of the liquid before the disinfectant is added. In a full treatment plant, the water undergoes rapid filtration before it is disinfected. Filtered water should be at its best, for low turbidity will result in more efficient disinfection.

Water treatment must be approached as a whole, of course, but it is also necessary to consider it as a summatory of stages, each of which must be individually evaluated, operated and supervised. This is the operating method advocated by the cited HACCP.

Operationally-speaking, the designer frequently overlooks requirements that are essential to ensure good disinfection. In order for any disinfectant to operate efficiently, it must fulfill the requirements of the C x T equation, which means that the disinfectant must be present in a given concentration (C) and must be in contact with the water to be disinfected for a minimum period of time (T). A common mistake is to design chambers that do not allow a long enough contact period, thereby disallowing the simple equation that links water volume to the disinfectant flow and required contact time:

$$V = Q \times T$$

It is important to stress the need, within the operational framework, for a good mix and dispersion throughout the water mass, irrespective of the chosen disinfectant or method used.

It is also necessary to keep in mind once the system has been installed and is operational that rural areas of developing countries almost never have enough resources of a good enough quality for its maintenance. For that reason, the most frequent mistake made by engineers or institutions responsible for building a system is to inaugurate it and leave disinfection equipment in operation after having given the operator one or two hours of training, only to return six months later to find that the disinfection system no longer works.

Disinfection equipment interacts more closely than any other part of the system with the water board, the operator and even the users themselves. For that reason, the task is twofold: first, to heighten the awareness of the entire social spectrum (operator, water board or administration and users) of the need for disinfection, its merits and the risks posed by inadequate disinfection.

In this context, the implications of disinfection must be seriously and carefully considered. The disinfectants that are added to the water, particularly the widely used chlorine, produce odors and tastes that may not be acceptable to the community. This cannot be overlooked; nor should it be considered unimportant. There are countless experiences throughout the developing world in which communities have rejected the disinfection process because of disagreeable organoleptic properties and even went so far as to demand that the measure be suppressed. It is extremely important for those responsible for installing drinking water systems and implementing disinfection processes, to communicate, report and discuss these aspects with the community over and over until they are certain that they have “heightened the people’s awareness” and that the disinfection will not be rejected despite any drawbacks. Users must be made to understand that there is a very clear relationship between the water they drink and their health (or between that water and disease) and that disinfection, despite its slight drawbacks, is the essential barrier that holds back the risk of disease.

This is the moment when one of these drawbacks, the disinfection by-products (or DBPs) must be mentioned. Almost all disinfectants produce DBPs. Chlorine generates a long list, the most obvious of which are trihalomethanes (THM), haloacetic acids (HAAs), haloacetonitriles and chlorophenols; chlorine dioxide produces over forty DBPs, including chlorates, chlorites and chlorophenols. Ozone, for its part generates aldehydes, carboxilic acids, bromates, bromoethanes, bromoacetonitriles and ketones. The problem is that many of these DBPs are carcinogenic.

At times, this real and specific fact (of the carcinogenic potential of DBPs) has resulted in the unwillingness of the engineers or persons responsible for implementing the disinfection system ("it is better to be cautious and not to disinfect too much, because disinfection causes cancer") or misinformation of the population, whose response has been a justifiable rejection ("How am I going to drink water that will produce cancer?"). It is therefore essential for all persons who work on water treatment to be absolutely clear in their minds about the risks of disinfecting and of not disinfecting.

The risk of coming down with cancer is associated with having drunk disinfected water over a long period of time (frequently a lifetime) and is a potentially low risk. On the other hand, the risk of getting ill or dying from other diseases caused by pathogens that are present in water that has not been disinfected is much greater.

In the particular case of chlorine, the risk of dying from cancer produced by having drunk disinfected water as compared with the risk of dying from a waterborne disease (diarrhea, infectious hepatitis, typhoid fever, cholera, etc.) has been estimated at 1 in a 1,000. In other words, a person who drinks water that has not been disinfected runs a risk a 1,000 times greater of dying from a diarrheal disease than of dying from cancer produced by drinking chlorinated water.

If these data on deaths from diarrhea and cancer are impressive, then the statistics on cases of people falling ill from those diseases (morbidity) are even more so. The risk of coming down with diarrhea is 1,000,000 times greater than of falling ill with cancer. The corollary is irrefutable: unchlorinated water means a much higher risk of getting sick or dying. This statistical fact led the World Health Organization (WHO) and the United States Environmental Protection Agency (USEPA) to stress that "under no condition should drinking water disinfection be jeopardized."

The second task to be undertaken is the thorough training of the operator, substitutes and members of the water boards in the requirements, in the operational means of disinfection in general and in the disinfection processes connected with the specific devices or system being used by the community. As a result of this training, people should respond almost automatically to matters of disinfection. This means preparing instructions that are clear, easy to understand, and acceptable to the board and the operators. Needless to say, technical backing is absolutely vital. Frequent supervisory, reinforcement and support visits to the community by trained personnel are essential to keep the disinfection process from being temporarily stopped or permanently discontinued.

Between 1982 and 1995, PAHO/WHO carried out a series of evaluations to determine the major causes of failure to disinfect water systems in Latin America and the Caribbean. Their findings were:

- Insufficient motivation and political commitment on the part of the community to support continuous, dependable disinfection.
- Inadequate knowledge and information about the risks of inefficient disinfection and the importance of the relationship between water and health.
- Low priority attributed to funding and economic support for disinfection.
- Unavailability of disinfectants in the local market due, on occasion, to a lack of funding, poor planning and absence of infrastructure.
- Unavailability of spare parts for equipment.
- Personnel untrained for correct operation, maintenance and repairs.
- Absence of training programs for operators and water board or administration members.
- Poorly designed and constructed disinfection systems.
- Poor quality of equipment.
- Inadequate selection of the most appropriate technology for use at the site.
- Lack of surveillance and monitoring.
- User complaints of disagreeable taste and odors.
- Overriding and widespread fear of DBPs.
- Overly complex and demanding operational and maintenance requirements.
- Electrical power failures.
- Deficient water treatment prior to disinfection (water condition adverse to disinfection).
- Intermittent operation of the water distribution system.

In order to implement a successful disinfection system, it is important to identify and deal with these causes.

Characteristics of the Manual

The organization of this manual is simple. Each of the technologies in widest use has been addressed in a separate chapter.

The following methods and technologies are presented successively:

- Solar disinfection
- Chlorination
- Ultraviolet radiation
- Slow filtration
- Ozone
- Chlorine dioxide
- Minifiltration
- Alternative methods and
- Special disinfection and disinfection in emergency situations

In a review of its pages, too much space may appear to have been devoted to chlorination. The fact is that it has been necessary to include, because of its importance, varied disinfection devices and the many forms it has taken, and the most widespread and interesting chlorination techniques, which are not piddling. Despite the criticism leveled against them and their drawbacks, chlorine and chlorine-based substances have been responsible for a veritable revolution in health. It has been estimated that a large part of the fifty-year increase in the average life expectancy in the Western world during the twentieth century can be attributed to the introduction of chlorine as a water disinfectant. A survey conducted in 1998 reveals the following distribution of disinfection technology use in the United States:

Percentage of water treatment systems using different disinfection techniques for U.S. municipal services (1998)

Disinfection process	% of systems for more than 10,000 inhabitants	% of systems for less than 10,000 inhabitants
Chlorine gas	87	70
Sodium hypochlorite	7	17
On-site sodium hypochlorite generation	0	2
Calcium hypochlorite (in powdered form)	1	9
Chlorine dioxide	3	2
Ozone	1	0
Ultraviolet radiation	1	0

Chlorine and chlorine compounds are in even greater use in developing countries, thereby justifying the emphasis given to chlorine disinfection. A description covering the following elements has been prepared for each of the methods presented:

- properties of the disinfectant and description of the method
- disinfection mechanism
- disinfection by-products
- equipment
- installation and installation requirements
- operation and maintenance
- monitoring
- advantages and disadvantages of the method
- equipment, operating and maintenance costs (stated in 2002 United States dollars)
- information sources.

In concluding, a section has been prepared comparing the various methods, cost aspects, ease of operation, adjustment to different situations, and a final section covers disinfection of pipes and tankers and disinfection in emergency situations.

Information sources

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Chapter 2

SOLAR DISINFECTION

Introduction

Solar disinfection, or SODIS as it is known, is one of the simplest and least expensive methods for providing acceptable quality drinking water. It is an ideal method for use when economic and sociocultural conditions in the community are not amenable to other treatment or disinfection alternatives, such as filtration or chlorination, even though these are also acknowledged to be simple and inexpensive.

This chapter looks into several low-cost solar disinfection alternatives, particularly ones that can be used in rural communities. These can be broken down into batch and continuous disinfection processes, according to the mechanism used.

It should be pointed out that solar disinfection is a more appropriate water treatment method for households or a small number of houses than for use in conventional or more complex systems. Furthermore, it is obviously possible only where convenient solar radiation exists.

Properties of solar disinfection and description of the method

Solar disinfection is a thermal process consisting of raising water temperature for a long enough period of time in containers that have been prepared to absorb the heat generated by solar radiation. These containers are made of a heat-conducting material and should preferably be black, for this color absorbs heat better than light colors, which, because of their reflective properties hold less heat. Use of a dark color permits the water temperature to rise rapidly and to remain hot for a longer period of time.

SODIS has never become very popular, although the method is interesting and its requirements are few. Too many variables affect its efficiency and the eventual safety of the treated water. Parameters that could interfere with perfect disinfection include geographic latitude and altitude, season, number of hours of exposure, time of the day, clouds, and temperature; volume and material of vessels containing the water; and water turbidity and color.

The World Health Organization considers SODIS to be a valid option, but only as a “lesser and experimental method.” Even so, in areas where no other means are available to disinfect water, this method can improve the bacteriological quality of water considerably. It constitutes a further example bearing out the assertion made in the first chapter that if perfection is not attainable, then a step toward “improvement” is better than nothing. It should be noted that in communities where this disinfection method has been promoted, the best results have been obtained when the measure was promoted and monitored by health officials or trained and dedicated personnel (e.g. volunteers from a community-based NGO).

SODIS technology uses equipment like solar heaters (for continuous production) and for batch systems, solar stoves, solar concentrators and a range of stills that are described in detail below. The Swiss proposal for disinfecting water in bottles and small containers is also referred to.

All of this equipment is simple, inexpensive and easy to operate. The acceptance of SODIS in several regions of the world confirms that it constitutes an attractive and appropriate solution.

Solar disinfection mechanisms

A couple of studies maintain that SODIS owes a large part of its disinfection power to photochemical action. Since ultraviolet radiation has the power to destroy microorganisms, as we will see in a later chapter, it has been claimed that the ultraviolet segment accompanying the visible portion when water is exposed to sunlight is responsible for the germicidal action. The truth is that only a very minor truly germicidal portion of the ultraviolet component, in the range of UV-C (100-280 nm), is present in solar radiation. Assuming that the germicidal portion were large enough to offer some disinfection power, most materials, including those that are transparent in sunlight, like glass and plastic, have been scientifically proven to be completely opaque in the case of ultraviolet radiation. That is why, as the pertinent chapter explains, the ultraviolet pipes that are used for disinfection are cased in protective sleeves made of quartz, the only material that is truly transparent to this type of radiation (teflon, used in some equipment, is the only partially transparent plastic). The conclusion to be reached in this simple analysis is that if water is exposed to poor radiation and a filter that is almost opaque to that UV is inserted between the two, the disinfecting capacity of that radiation will be practically nil or, in the best of cases, negligible. Obviously, then, SODIS does not operate on the basis of photochemistry, but of a thermal process, pasteurization.

High temperatures strongly affect all microorganisms; vegetative cells perish as proteins are denatured and other components undergo hydrolysis. Although some bacteria in the water are capable of forming spores, making them particularly heat-resistant, most are generally killed off at between 40 and 100 ºC, while algae, protozoa and fungi perish at between 40 and 60 ºC.

Disinfection by boiling consists of raising the water temperature to 100 °C and keeping it at that level from one to five minutes. Most, if not all, of the microorganisms present are eliminated as a result. Pasteurization, on the other hand, is defined as exposing a substance (generally a food, including water) “for a long enough period to a temperature high enough to destroy the microorganisms that can cause illness or spoil food.” Although heat tolerance is affected by factors such as water turbidity, cell concentration, physiological state and other parameters, pasteurization destroys coliforms and other non heat-tolerant bacteria; this is fortunate, because most pathogens are not heat-tolerant.

In the case of water, an effort has been made to determine the optimum relationship between length of time and temperature needed to destroy pathogenic germs. As a rule of thumb, although not an exact one, either of the following ratios will ensure a reasonable level of safe disinfection of clear water (with a turbidity of less than 5 NTU):

65 °C for 30 minutes or 75 °C for 15 minutes.

From a highly practical and operational viewpoint, these conditions are ensured in sunny zones with four to five hours of exposure during the period of maximum radiation (from 11:00 to 16:00 hours).

Disinfection by-products

The present knowledge of SODIS and the studies that have been made to date reveal that no DBPs are present.

Equipment

A number of devices have been developed that vary as to volume of water produced and cost.

Solar heaters

Commercial solar heaters used to disinfect water are no different from the heaters on the roofs of many homes that are used to heat water for use in the

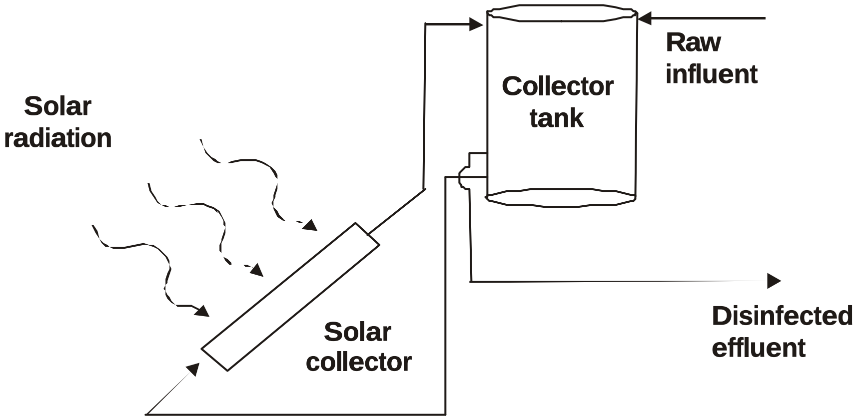


Diagram of a thermosiphon for water heating

kitchen or shower. The device consists of a collector, which is a box with an aluminum frame and a glass cover. The collector contains copper pipes painted black that are welded to two header pipes and that store the water during the heating process. The collector is connected by means of pipes of the same material to a plastic and fiberglass thermo-tank insulated with polyurethane foam to store the treated effluent. Some of these tanks are divided to allow for a heat exchange between the cold water flowing in and the hot flowing out.

These systems operate on the principle of a convector circuit or passive solar heating, in which solar radiation heat is absorbed by black pipes, raising the temperature of the water inside the collector and consequently reducing its density. Under these conditions, the lower-density hot water column no longer balances the cold-water column in the return pipe to the collector; by gravity, the former falls and displaces the latter toward the tank above. This natural circulation known as “thermosiphon” continues so long as there is enough heat to raise the water temperature and the resulting push force can overcome the pressure drop in the system.

Solar heater

When a solar heater is used for disinfection, its efficiency depends directly on the temperature that can be reached for pasteurization. Inasmuch as the water reaches its highest temperature between 14:30 and 15:30 hours, the tank should not be drained before this time in order to increase the residence time of the water in the collector.

Conventional family solar heaters are able to produce about 15 liters and larger devices yield up to 1 m^3 of water after three to four hours of operation at midday. More sophisticated solar heaters can be found in the market today with double glass covered collectors containing finned copper pipes offering selective surfaces that are able to absorb a larger amount of solar energy and convert it to useful heat. Some are able to reach water temperatures of over 90 ºC and even to vaporize it. Nonetheless, the climatic conditions must be studied to determine whether the investment is justified; otherwise, less efficient —but also less expensive— devices can be used.

Solar stoves

In many developing countries, particularly those where deforestation is a serious problem, solar stoves and concentrators are the only option available to the population for cooking their food. "Solar stoves" can also be used to disinfect water through pasteurization.

A solar stove consists of a pair of boxes of wood or cardboard, one inside the other, that are used to trap the heat of the sun and use it, in this case, to heat water. The principle consists of using the heat generated by the sun through radiation by trapping it inside the small box and preventing it from escaping by covering the box with a transparent pane, generally of glass. This heat is transferred by conduction through metal pots to the water they contain. It is desirable to use a reflector to direct the sun's rays toward the inside of the box in order to maintain the heat. The use of reflectors cuts down the process time by approximately 35%.

Solar stove

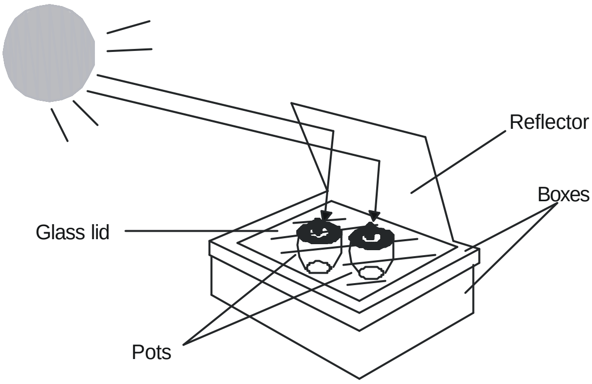


Diagram of a solar stove

The free space between the two boxes is padded with an insulating material that may be wadded newspaper, rubber foam, etc. The inside of the small box is lined with a reflecting material like aluminum foil. A black-colored sheet is placed at the bottom of this box. It is also advisable to paint the metal pots black or smoke them so that they can absorb more heat. Metal pots are preferable because clay pots act as an insulant. Nor is it advisable to use plastic because it melts at high temperatures.

Solar concentrators

Solar concentrator

Solar concentrators are a type of solar heater. They look something like a mirrored parabolic antenna or an open umbrella with a mirrored interior. These devices operate like a concave lens that receives the sun’s rays and concentrates them on a point (the focus). In the case of the solar concentrator, the pot or vessel to be heated is placed on a small platform at the focal point. Solar concentrators normally have a diameter of at least 0.80 m and can be made of aluminum covered cardboard or other materials.

Few commercial models exist, but books and brochures can be found containing instructions to build them. The concentration of solar rays that is possible with this type of stove, unlike those described earlier, can produce temperatures of up to 350 °C, making it possible to heat water very rapidly. Disinfection can thus be accomplished by pasteurization or direct boiling.

Solar stills

The solar still offers another application of thermal energy that can be handled with very simple to highly sophisticated technology. It is used to produce drinking water from seawater or contaminated fresh water and can also operate as a water disinfection system.

The principle of water disinfection using solar energy is the same as the natural hydrobiological cycle: Water in a reservoir containing salts is evaporated and condensed elsewhere (clouds and then rain), thereby producing purified water.

The solar still requires an element that will convert solar energy into a rise in water temperature so that it can be evaporated. Visible and infrared radiation is absorbed by any dark surface, particularly one that is dull black. A dull finish is used for better absorption and to prevent losses of a fraction of light through reflection. In the simplest solar stills, the solar collector consists of a black horizontal tray containing the water to be distilled, which is known as “distillant.” To prevent undesirable losses of heat, the bottom of the tray must be thermally insulated. Heating of the distillant causes the water to evaporate, leaving the mineral salts trapped in the tray. To facilitate evaporation, the evaporator should have a large area compared with the volume of distillant it can contain. The water that is evaporated in that way is collected by placing a cover of glass or some other transparent material over the evaporator at the right distance and slant.

a) Glass cover

c) Inflated plastic cover

b) Reflector glass cover

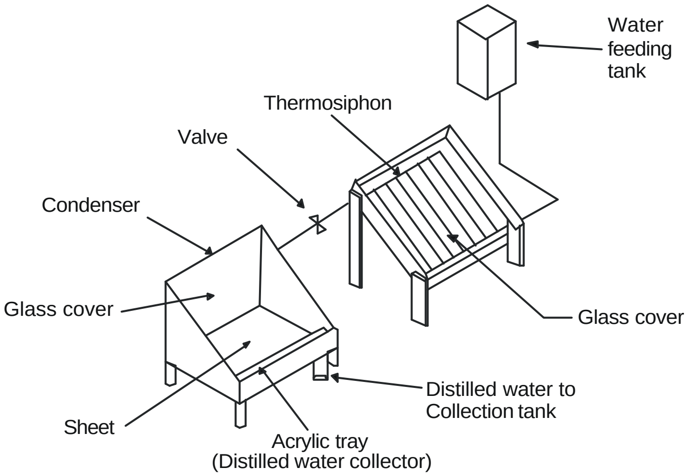
d) V-shape plastic cover

Diagrams of simple solar stills

There are several condenser designs. The simplest consists of a glass gable box with a 20° slant from the horizontal, allowing the drops of condensed water to run down into small collector channels.

Combined process of solar preheating and distillation

The Mexican Health Secretary proposed a device consisting of a water feeding tank, a thermosiphon and a condenser. It is useful in temperate areas where the temperature does not rise high enough for condensation to occur; in such cases, the thermosiphon heats the water before it runs into the condenser.



Combined themosiphon and solar stills

Disinfection in bottles and small containers

The Swiss Federal Institute for the Environment, Science and Technology (EAWAG), through its Water and Sanitation in Developing Countries Section (SANDEC), is promoting the use by households that disinfect only small amounts of water, of special black bottles and containers. Although this method has been widely accepted wherever it was implemented, information, user awareness heightening and monitoring and follow-up programs have always been necessary.

The technique consists of exposing the water to be disinfected in plastic bottles like those used for soft drinks, which may or may not be painted black, completely or only on the bottom. The Swiss have tested a series of containers, ranging from plastic bags to large narrow mouth cans (to keep hands from entering

Soft drink bottle with a temperature monitor

into contact with the disinfected water). Although the results have been excellent from both a practical and an economic viewpoint, the popular soft drink bottles have been found to be especially attractive because they are so widely available. The required exposure time and temperature are exactly the same as for any of the other techniques. In some cases, a thermometer can be added to measure the temperature reached (see monitoring).

Installation requirements

Equipment	*Installation and installation requirements*
Solar heaters	Solar heaters are fairly easy to install or to adapt to any other installation. All that is needed is to raise the hot water collector tank about 60 cm above the highest point of the collector. No special pressure is required for their operation. It is enough for the water feeding tank to be placed next to the collector, which should be on a slant approximately equivalent to the latitude of the site (between 15° and 35º, for example) and face the sun.
Solar stoves and concentrators	These devices can be easily installed anywhere. Before adopting this method, however, it is important to perform some tests by taking the water temperature after four or five hours (in the case of the stoves). The water is drinkable only if the average temperature is always above 60 °C. If solar concentrators are well built, they should disinfect water more by boiling than by pasteurizing.
Solar stills	No special requirements need to be met in the case of solar stills, which are very simple devices with no movable parts. It is important to keep animals away from the equipment, however.
Bottles and containers	Solar disinfection requires clean water with very little turbidity. Otherwise, it must be filtered beforehand using a household sand filter or very fine fabric. The bottles can be placed on any reflecting surface, such as aluminum foil. The use of colored soft drink bottles is not recommended.

Operation and maintenance

Equipment	*Operation and maintenance*
Solar heaters	Operation of this equipment is simple; all that needs to be done is to open the line valve during the day and close it at night. Its maintenance consists of keeping the collector cover clean; dirt reduces the amount of radiation that can reach the collector. The frequency of cleaning will depend on the degree of atmospheric pollution. The use of acrylic covers is not recommended because they are easily scratched and deformed.
Solar stoves	To operate this device, place the pot inside the solar stove and direct the sun's rays to the inside of the box using the reflector. It is very easy to maintain. All that needs to be done is to keep the inside, glass and reflectors clean. To keep the water clean, it is advisable to leave it in the covered container until it is to be used.
Solar stills	This system requires feeding the still with the water for treatment, either continuously or discretely –in other words– in batches. Rural families tend to use the latter method. Otherwise, the system can be used by combining it with preheating using a solar heater. Common household stills on sunny days produce between three and five liters a day per square meter. This is equivalent to a reduction in the depth of the distillant of from 0.3 to 0.5 cm/day, which means that the feeding process can be done once a day. The water should be either drunk or thrown out within the following 24 hours.
Bottles and containers	The plastic container must be very clean before the water it contains can be purified. In this case, as in all of those described above, the disinfected water must be kept in the same or another closed container in a cool place.

Monitoring

At effluent temperatures of over 55 ºC, total coliform inactivation has been demonstrated in 99% of the cases. For safety reasons, however, the golden rule is to have a margin of safety and to set 65 ºC as the minimum temperature for disinfection. Monitoring of these systems should confirm that the water at the outlet of any of these systems or following treatment reached 65 ºC.

Inasmuch as solar heaters were not designed for water disinfection, but merely to heat it, there is no way to check whether the temperature reached the pasteurization point. Therefore, it would be advisable to install a thermostat connected to a valve that would allow the water passage only at a temperature of over 65 ºC. A thermometer can be attached to the cover of solar stoves or bottles; in other cases, bottles can be fitted with small ampoules containing a substance that will melt at a temperature of above 65 °C, ensuring that the required pasteurization temperature has been attained.

Advantages and disadvantages of solar disinfection

Equipment	*Advantages*	*Disadvantages*
Solar heaters	Not dependent on conventional energy, whose cost rises with the growing demand. Avoid the use of toxic chemicals. Require relatively simple and low-cost equipment that is easily recovered and provides drinking water for many years. Not environmentally damaging.	Cannot be used on cloudy or rainy days. Offer no residual protection.
Solar stoves	Do not consume firewood and thus help to avoid deforestation and erosion in rural areas. It has been calculated that approximately one kilogram of firewood is needed to raise one liter of water to a boiling point. Nor do they use fossil fuels. This is particularly useful in the rural area, where it is difficult to obtain gas. Do not smoke like open fires that can cause respiratory diseases. Not expensive and easy to build.	Twice as slow as conventional stoves. Cannot be used on cloudy or rainy days. Provide no residual protection.
Bottles and containers	Extremely simple and inexpensive. Easily accepted by the communities.	Offer no residual protection. Require clean water. Cannot be used to disinfect large volumes of water.

Equipment, operating and maintenance costs

Equipment	*Total costs*
Solar heaters	The price of the commercial equipment is between $ 250 and $ 500.
Solar concentrators	There are none on the market. They must be custom-built at a cost of from $ 100 to $ 200
Solar stoves	These do not exist in all countries. They must be locally made. Their cost varies according to the material used. Normally they cost between $ 25 and $ 80, depending on access to local materials.
Solar stills	The same considerations discussed above apply. They cost from $ 75 to $ 250, depending on the availability of local materials and size of the device.
Bottles	They do not cost anything.

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Chapter 3

CHLORINE

Introduction

Water disinfection by chlorination, massively introduced worldwide in the early twentieth century, set off a technological revolution in water treatment, complementing the known and used process of filtration. As already stated in a previous chapter, it was responsible for increasing life expectancy by 50% in the developed countries.

The keys to its success are its easy accessibility in almost all of the world's countries, reasonable cost, capacity for oxidation —the mechanism for destroying organic matter—, and residual effect. All of this allows it in a fairly simple way to ensure the harmlessness of drinking water from the moment of its production to its use, thereby benefiting not only small systems, but also large cities with extensive distribution networks.

Although chlorine and chlorine-related substances are not perfect disinfectants, they have a number of characteristics that make them highly valuable:

- They have broad-spectrum germicidal potency.
- They show a good degree of persistence in water distribution systems. Their easily measurable residual properties can be monitored in water networks after treatment and/or delivery to users.
- The feeding equipment is simple, reliable and inexpensive. At the small community level, there are also a number of "appropriate technology" devices that local operators are able to handle easily.
- Chlorine and chlorine-based compounds are easily found, even in remote areas of developing countries.
- This method is economic and cost-effective.

The following chlorine-related compounds for water disinfection can be found in the market:

- Gaseous chlorine
- Chlorinated lime
- Sodium hypochlorite
- Calcium hypochlorite.

The choice of these products will depend on the answer that is given to these questions:

- How much disinfectant is needed?
- How easily is the product obtained?
- Does the necessary technical capacity exist for using, operating and maintaining the equipment?
- Are the necessary resources available to keep workers from being exposed to health risks during the storage and handling of the substance?
- Does the economic and financial capacity exist to assume the investment, operating and maintenance costs?

To answer these questions, the technical, economic and social conditions at the target site will need to be studied.

The *amount* of disinfectant that will be needed will depend upon the water flow to be treated, the required dosage according to the water quality and the country's drinking water standards. There is an unwritten rule, however, that limits the amount of chlorine gas that can be used as compared with other chlorine compounds. That ceiling stands at a volume of 500 m^3/day. Chlorine gas is not recommendable for flows of less than 500 m^3/day. This means that considering a supply of 100 liters a day per inhabitant, typical of the rural environment, the use of chlorine gas is recommendable only for populations of over 5,000 people.

The *supply* of the product definitely affects the choice that is made. Inasmuch as the rural areas are generally far from the cities and difficult to reach, it may be necessary to decide on another disinfectant or to prepare sodium hypochlorite on site.

In making a selection, available *technical capacity* must also be considered. The operation of chlorine gas facilities requires trained and competent personnel. These are hard to find and difficult to pay in rural areas. Furthermore, continuous and stable electric power is needed to operate the pumps for this system.

The extreme danger posed by gaseous chlorine means that it is important to have the technical means and trained personnel to minimize and control the *risks* inherent to installations of this kind. An undiscovered leak that is not controlled in time could cause serious accidents that could endanger human lives.

To conclude, in the case of the disinfection *costs*, it will be necessary to consider the circumstances. A more expensive solution could be advisable, for example, if it were more reliable, durable and simple to operate and its spare parts and supplies were more easily obtained. It is usually worth paying a little more if the additional investment ensures the success of the operation; in the long run, it may even turn out to be cheaper. Inasmuch as the concentrations of active chlorine in the different products vary, the needed volume of that active chlorine will also vary, meaning that the transportation costs to be considered will also differ according to the volumes needed. In any case, health must be the main consideration when choosing the most appropriate alternative.

Properties of the chlorine products and description of the method

Commercial chlorine products are obtained by different methods, which determine their concentration of active chlorine, presentation and stability. The comparative table below lists the major properties of each.

The concept of "active chlorine" that is used throughout this chapter should be explained here. "Active chlorine" is the percentage by weight of molecular chlorine rendered by a molecule of the compound. If, for example, a certain solution contains 10% active chlorine, this is equivalent to 10 g of chlorine gas being bubbled (and totally absorbed) in 100 ml (100 g) of water without any loss, hence the "10%." The word "active" means that this chlorine is ready to enter into action; it is prepared and "waiting" to attack the organic matter or any other substance that it is capable of oxidizing.

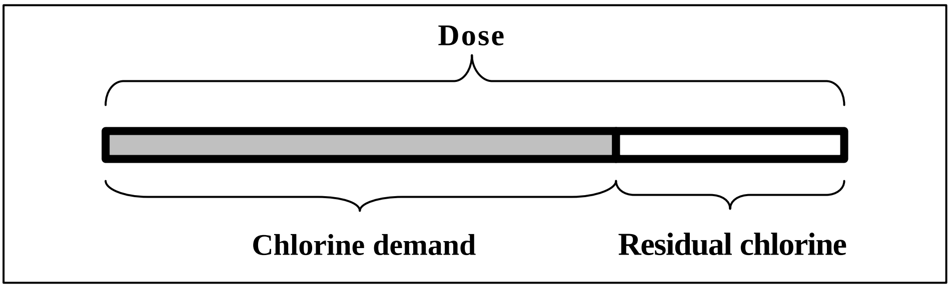
Disinfection using chlorine and chlorine-based compounds should be carried out in three successive steps that will vary to some degree according to the product that is used:

Step 1: Determination of the chlorine dose to be added to the water system
Step 2: Preparation of non-gas solutions
Step 3: Feeder calibration.

Step 1: <u>Determination of the chlorine dose to be added to the water</u>

The chlorine dose is equivalent to the total demand for chlorine (which is closely linked to the chemical and microbiological quality of the water) plus the amount of residual chlorine expected at the end of the water system. Before starting the disinfection process, it is advisable to conduct an instant chlorine consumption test known as a *"chlorine demand test."*

Name and formula	Commercial or common name	Characteristics	% Active chlorine	Stability over time	Safety	Usual container
Chlorine gas Cl_2	Liquid chlorine Chlorine gas	Gas liquified under pressure	99.5%	Very good.	Highly toxic gas	40 to 70 kg cylinders 1 to 5 ton containers
Chlorinated lime $CaO.2CaCl_2O.3H_2O$	Chlorinated lime, bleaching powder, lime hypochlorite, lime chloride	Dry white powder	15 to 35%	Fair. Deteriorates rapidly when exposed to high temperature, moisture and/or sunlight. 1% loss monthly.	Corrosive	1.5 kg cans 45 - 135 kg drums 25 – 40 kg plastic or paper bags, others.
Sodium hypochlorite NaClO	Sodium hypochlorite, liquid bleach	Yellowish liquid solution	A maximum of 1 to 15%. Concentrations of over 10% are unstable.	Poor. Loss of 2-4% a month; more if the temperature rises above 30 °C	Corrosive	Plastic and glass bottles of different sizes and demijohns
	On-site production of Sodium hypochlorite by electrolysis	Yellowish liquid solution	0.1 – 0.6 %	Low	Oxidizer	Any volume
Calcium hypochlorite $Ca(ClO)_2.4H_2O$	HTH	Powder, granules and tablets. Solid white	Powder: 20 – 35% Granulated: 65 - 70% Tablets: 65 –70%	Good. Loss of 2 to 2.5% a year	Corrosive. Imflammable in the presence of certain acid substances	1.5 kg cans, 45 - 135 kg drums, Plastic pails



Dose-demand-residual ratio

If the demand test is not performed and if the disinfection is not urgently needed (preventive chlorination), the amount of chlorine compound to be introduced can be regulated by directly adding growing amounts of chlorine until the residual concentration needed at the end of the water system is obtained. It may take several days until the dose reaches the ideal value. An interval is needed between one dose and the next to take account of the length of time needed for the water to travel from the point where the chlorine is administered to the farthest point of the system.

In emergency situations, a "rapid" demand test can be made to calculate the estimated amount of chlorine needed. This method consists of adding growing amounts of chlorine (i.e., between 1 and 10 mg/l) to water samples to be treated. The amount of residual chlorine is measured in each sample after a 30-minute period. The dose is determined by the concentration of residual chlorine closest to that sought. Even so, when the disinfection process is started and the water is sent to the distribution system, a subsequent adjustment must be made in the concentrations because of the ever-present possibility of contamination caused by seepage into the system or other factors.

Step 2: Preparation of non-gas solutions

When gaseous chlorine is used, it is applied directly with the feeder. That is not the case with other chlorine products marketed as solids or in concentrations that are not adjustable to those needed, which must be dissolved in accordance with the dosing mechanism of the equipment to be used.

The following formulas determine the amount of dissolution water needed to obtain a hypochlorite solution with an active chlorine concentration the feeder can easily handle and control:

Starting with:	**sodium hypochlorite**	**calcium hypochlorite**
Description	Marketed as a liquid with varying concentrations of active chlorine, the most common of which is 10%.	Marketed as a solid with varying concentrations of active chlorine by presentation, one of the most common being 60%.
Dissolution water required	Once the final concentration of the chlorine solution (Fc) to be used by the feeder has been defined, the following equation is used to obtain the volume of dissolution water (Vd) to be added to the stock solution: **Vd = (Co.Vo/ Fc) – Vo** Where: Co = Initial concentration of stock solution (g/L) Vo = Volume of stock solution (L) Fc = Expected concentration in dissolved solution (g/L)	Once the final concentration of the chlorine solution (Fc) to be used by the feeder has been defined, the following equation is used to obtain the volume of dissolution water (Vd) in liters to be added to the solid mass of calcium hypochlorite: **Vd = % x W/ Fc** Where: % = Percentage of active chlorine in the product W = Weight of the solid calcium hypochlorite (Kg) Fc = Expected concentration in dissolved solution (g/L)
Example	How much water must be added to 40 liters of a 10% (0.1) sodium hypochlorite solution to prepare a solution with a 2% (0.02) concentration? $Vd = \frac{0.1 \times 40}{0.02} - 40 = 160$ L	How much water must be added to 1.2 kg of calcium hypochlorite with a 60% (0.6) concentration to prepare a 2% (0.02) solution for feeding? $Vd = \frac{0.6 \times 1.2}{0.02} = 36$ L

To facilitate the operation, the dissolution tanks (at least two) should have a 24-hour capacity. The product must also be completely dissolved in the water, helped by an electric mixer, if necessary. Particles or impurities are usually found; therefore, feeders should be equipped with a filter to trap them. Furthermore, the alkalinity of concentrated sodium hypochlorite precipitates the hardness of the dissolution water, which can cause scaling on feeders and pipes. The solution should therefore be prepared 24 hours beforehand, to give the precipitates time to settle.

Step 3: Feeder calibration

Calibration of feeders to apply the optimum amount of the product depends on three elements, to wit:

- The physical characteristics of the product to be used: gas, liquid or solid.

- The necessary dose of chlorine to obtain the expected residual chlorine concentration at the end of the system.
- The water flow to be disinfected. If variations in the flow cannot be controlled, as in the case of springs, the maximum source flow should be used.

The size of the chlorine dose will be obtained by studying the chlorine demand (Step 1) and the expected concentration of residual chlorine, as usually defined by each country’s water quality standards. In this connection and as a reference figure, the WHO considers that a concentration of 0.5 mg/l of free residual chlorine in the water after a 30-minute contact period is a guarantee of satisfactory disinfection.

The water flow to be treated, for its part, not only affects the size of the chlorine dose, but also the type of equipment that is most suitable. A chlorine gas injection feeder to disinfect 10 /s is not the same as a constant charge sodium hypochlorite feeding tank to disinfect 1l/s. The calibration procedure varies according to the feeder and the latter depends on the water flow to be disinfected.

Feeder	Chlorinators for chlorine gas	Mechanical feeders and feeding pumps for liquid solutions
Description	Gas chlorinators have rotameters or measurement devices that make it possible to calibrate the equipment. Even so, the best way to determine the real feeding rate of the chlorine gas is through changes in the weight of the cylinders. Proper scales must be used that will make it possible to determine this expenditure over time.	The same equation used to determine the amount of dissolution water is used to find out the amount of hypochlorite solution to be employed. It is important to have two dissolution tanks of the proper sizes to allow for the continuous feed of the chlorine solution to the mechanical feeder or regulating tank equipped with feeding pump.
The dose is calculated using the following formula	$M = D \times Q$ Where: M (gCl/h) = Amount of chlorine to be fed D (gCl/ m^3) = Chlorine dose Q (m^3/h) = Water flow to be treated	$M = (D \times Q)/C$ Where: M (L/h) = Amount of chlorine to be fed D (mg/L) = Chlorine dose Q (L/h) = Water flow to be treated C(mg/L) = Solution concentration
Example	A 4 gCl/m^3 chlorine solution in a water source with a flow of 1,000m^3/h will require an expenditure of 4 KgCl/h or 96 Kg of chlorine a day. This will make it possible for a one-ton cylinder to supply 10 days of chlorine.	2 L/h are needed for a chlorine dose equivalent to 4 mg/L in a water source with a flow of 10,000 L/h and a 2% concentration of hypochlorite solution.

In light of those elements, the dosers that are commercially available can be *broken down into gas chlorinators* and mechanical *feeders* and *feeding pumps* for liquid solutions. These devices can be calibrated either by hand or automatically in the most sophisticated systems. The former are employed more for medium-sized cities and small communities.

Chlorine disinfection mechanisms

Drinking water is chlorinated by the bubbling of chlorine gas or the dissolving of chlorine compounds and their subsequent dosing. Chlorine in any of its forms hydrolyzes in the presence of water and forms hypochlorous acid (HOCl) in the following way:

- The reaction in the case of *gaseous chlorine* is as follows:

$$Cl_2 + H_2O = H^+ + Cl^- + HOCl \text{ (hypochlorous acid)}$$

- For *sodium hypochlorite*, the reaction that takes place is:

$$NaOCl \text{ (sodium hypochlorite)} + H_2O = Na^+ + OH^- + HOCl$$

- With *calcium hypochlorite* and the active portion of *chlorinated lime*, the reaction is as follows:

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

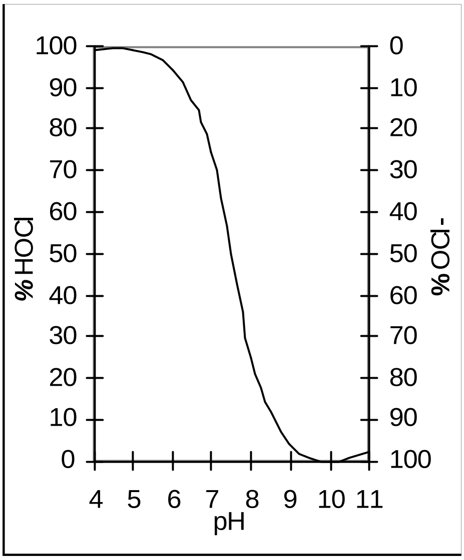
When ammonia is present in the water, chemical disinfection produces compounds such as chloramines, dichloramines and trichloramines. The chloramines serve as disinfectants also, but they react very slowly. Although chlorhydric acid (HCl) and calcium and sodium hydroxide are formed, as well, they play no part in the disinfection process.

The disinfecting agent is hypochlorous acid (HOCl), which splits into hydrogenous ions (H+) and hypochlorite (OCl-) and takes on its oxidizing properties:

$$HOCl = H^+ + OCl^-$$

Both segments of the agent are microbicides and operate by inhibiting enzymatic activity and inactivating bacteria and viruses.

Hypochlorous acid (HOCl) and hypochlorite ions (OCl^-) are both present to some degree when the pH of the water is between 6 and 9 (the normal range for natural drinking water). When the pH value of the chlorinated water is 7.5, 50% of the chlorine concentration present will consist of undissolved hypochlorous acid and the other 50% will be hypochlorite ions. The figure shows the different percentages of HOCl and OCl^- at varying pH levels.



Performance of hypochlorous acid fractions at varying pH levels

The different concentrations of the two species make a considerable difference in the bactericidal property of the chlorine, inasmuch as these two compounds have different germicidal properties. As a matter of fact, HOCl efficiency is at least 80 greater than that of OCl^-.

That is the reason why, when monitoring chlorine in water, it is advisable to monitor the pH level as well, for this will give an idea of the real bactericidal potential of the disinfectants that are present. It is important to mention that the WHO recommends a pH < 8 for appropriate disinfection.

Turbidity is another significant element in disinfection. Excessive turbidity will reduce the effectiveness of chlorine absorption and at the same time will protect bacteria and viruses from its oxidizing effects. For that reason, the WHO recommends a turbidity of less than 5 NTU, with under 1 NTU as the ideal.

Chlorine disinfection by-products

In a water supply system, chlorination is normally performed at the end of the treatment, after filtration. This is sometimes called *post-chlorination.* Occasionally a *pre-chlorination* is carried out prior to any other treatment to control algae that can clog the filters and to eliminate the smell and taste of the water. In this case and when the raw water contains some organic materials known as “precursors,” (organic matter, humic acids, etc.) disinfection by-products (DBPs) may be produced. The most characteristic constituents of chlorination DBPs are the trihalomethanes (THM).

This subject was addressed in the previous chapter. For further information, see the bibliography at the end of the chapter, which includes the PAHO/ILSI publication that covers almost all aspects of DBPs, technical, toxicological and epidemiological.

Equipment

The choice of the chlorine doser or feeder depends on three elements:

- The characteristics of the chlorine product to be used.
- The chlorine dose to be added to the water.
- The water flow to be disinfected.

With this information, some of the most widely used equipment can be classified as follows:

Classification	Feeding device	Product	Service range (inhabitants)
Chlorine gas	Pressurized (direct) Vacuum (venturi or ejector)	Chlorine gas Chlorine gas	from 5,000 inhabitants to large cities
Solution	**Under atmospheric pressure, constant head**		
	Float valve in a box Floating tube with a hole Glass/bottle system	Na or Ca hypochlorite Na or Ca hypochlorite Na or Ca hypochlorite	< 20.000
	Under positive or negative pressure		
	Diaphragm pump (positive) Suction feeder (negative)	Na or Ca hypochlorite Na or Ca hypochlorite	2.000 – 300.000
	On-site sodium hypochlorite		
	Typical generator	Na hypochlorite	< 5.000 inhab.
Solid	Erosion feeder Other feeding devices	Calcium hypochlorite Chlorinated lime	2.000 – 50.000 < 2.000

One ton cylinders and rolling tank containing chlorine

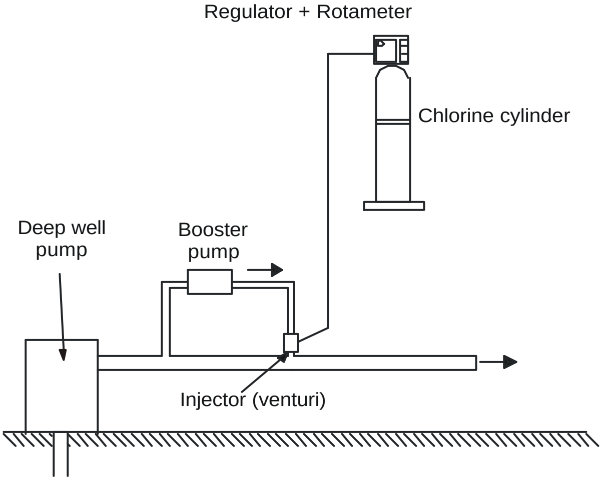
Chlorine gas feeders

Disinfection by gaseous chlorine is inexpensive and the most widely used technology in the world. More than 90% of the world population drinks water disinfected by chlorine gas. The gas is commercially available in 75 kg and one ton steel cylinders and in especially designed trucks or containers.

Chlorine gas feeders work under two principles: by vacuum through pipe injection and under pressure by means of diffusion in open channels or pipes. The most commonly used is the vacuum system.

Vacuum gas chlorinators

This system consists of a gas cylinder, a regulator with a rotameter (feed rate indicator) and an injector. It operates through the vacuum produced by the water flow-activated venturi injector that ejects a mixture of water and gas at the application point, where the gas diffuses and dissolves. The system should be equipped with anti-return



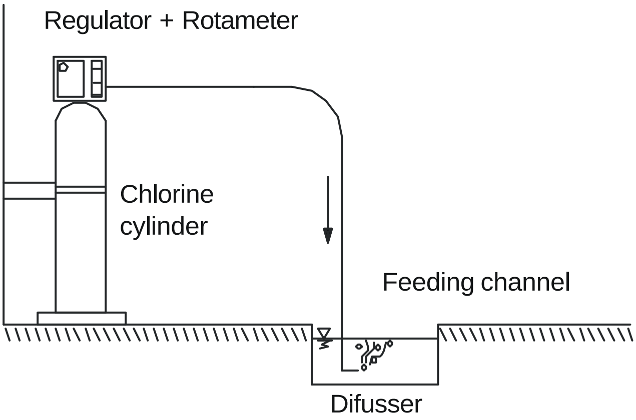
Chlorine gas vacuum equipment

valves to keep water from entering the chlorine pipes and corroding the equipment if the operation is interrupted for any reason.

Multiple 75 kg cylinders (“manifold”) and a one metric ton tank to the injector

Pressurized gas chlorinators

Use of this type of chlorinator is usually recommended when there is no possibility of employing a pressure differential or when there is no electric power to operate a booster pump that would produce the necessary pressure differential for the operation of vacuum chlorinators.



Pressurized chlorine gas feeding equipment

The system consists of a diaphragm activated by a pressurized regulator while a rotameter indicates the chlorine feed rate. A regulator controls the progression of the chlorine gas toward the diffuser.

ı *Gas chlorinator installation and installation requirements*

To install a gas chlorination system, it is first necessary to determine the most suitable type of chlorinator. The factors that determine the gas chlorinator to be installed are the capacity to supply the necessary amount of chlorine per unit of time (kg/h) and the operational flexibility. The equation for making this calculation was explained above with reference to chlorinator calibration. Converted appropriately, the equation stands as follows:

$$M = 3.6 D \times Q$$

Where:

M (gCl/h) = Amount of chlorine to be injected
D (mgCl/l) = Chlorine dose
Q (l/s) = Maximum water flow to be treated.

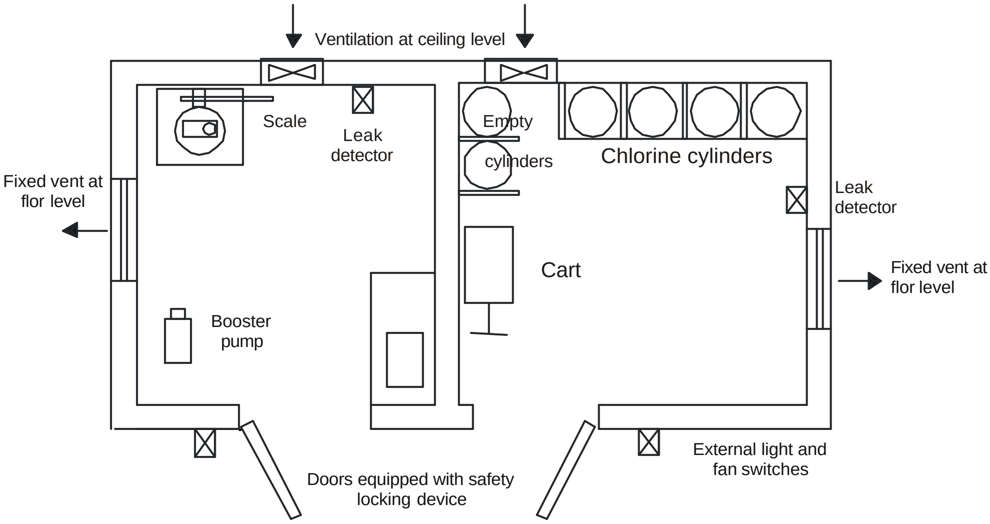
The typical feeding rates for the smallest *vacuum chlorinators* range from approximately 10 to 100 g/h. The most common devices have maximum operating capacities of 2 kg/h, 5 kg/h and 10 kg/h, making it possible to serve medium-sized to large cities.

The smallest *pressurized chlorinators* have a capacity of between 10 y 150 g/h. A simple calculation reveals that if 1 mgCl/liter is added to the water for disinfection purposes and if the population's daily water use is 100 liters/inhabitant x day, a dose of 100 g chlorine/h could disinfect the drinking water for a population of 24,000 inhabitants and 1 kg chlorine/h, for a population of 240,000 people.

The maximum continuous feeding rate must be calculated according to the lowest environmental temperature forecast because the pressure of the chlorine gas in the cylinder varies according to that temperature. The environmental temperature must be above –5 °C for a continuous chlorine gas feeding rate of 120 g/h.

As for the installation requirements and precautions, since the most precise way to determine the effective chlorine gas feeding rate being dosed is by measuring the weight of the chlorine consumed, appropriate scales must be used. Correct weighing will make it possible to calculate the exact amount of chlorine being dosed over a given period of time and also when and how soon the cylinders should be replaced. The scales for small water supply systems are designed for use with 45 or 70 kg cylinders in an upright position. All chlorine gas installations must be equipped with chains or other anchoring devices well attached to a wall to keep the chlorine cylinders from being accidentally tipped over.

Since chlorine is a dangerous gas, it must be handled carefully. For utmost safety and economy, gas chlorination systems must be designed and installed by experienced personnel and located far away from laboratories, storage areas, offices, operating areas, etc., to avoid contamination from possible leakage. The figure below shows a typical floor plan for a small gas chlorination facility. The chlorine cylinders must be stored in a separate room designed specifically for that purpose and kept away from direct sunlight to avoid their heating. Installations



Typical floor plan for a small gas chlorination facility

must be properly ventilated, always at the floor level because chlorine is heavier than air. Since one-ton cylinders are placed in a horizontal position, cranes must be available to replace them and an anchoring system to keep them from rolling.

In the case of *pressurized chlorination systems*, it is important for the contact chamber, whether channel or tank, to be designed to carry a minimum water head of 0.5 meters over the diffuser to ensure that all of the chlorine gas is dissolved and avoid its loss in the air. Since the pressure of the chlorine gas in the cylinder itself activates this type of chlorinator, there is no need for external electric power. This is an advantage when there is no source of hydraulic or electric power to produce the pressure differential required by a vacuum chlorinator.

Relatively little electric power is needed to operate *vacuum chlorinators*, only enough to introduce the water flow through the ejector (venturi). The needed water flow and differential pressure can be produced by electric or hydraulic means with the aid of a small 1 to 1.5 HP auxiliary (booster) pump. In choosing electrically-operated equipment, the reliability and stability of the power source is an important consideration.

In both systems, as a safety measure, a manual pressure relief valve is inserted between the chlorinator and the diffuser to discharge (outside the building) any remaining chlorine gas when cylinders are replaced. In this connection, all large treatment plants must always have a leak detection system and a stock of chlorine neutralizing products on hand.

Care must be taken with the materials used in chlorination equipment because they react differently to oxidation. The following table shows the resistance of some of the most common materials.

Resistance of some materials to different forms of chlorine

	Solid steel	**Stainless steel**	**Copper**	**PVC**	**Teflon (PTFE)**
Dry gaseous chlorine	Good up to 120 °C	Good up to 150 °C	Good up to 200 °C	Good up to 40 °C	Good up to 200 °C
Moist gaseous chlorine	Nil	Nil	Nil	Good up to 40 °C	Good up to 200 °C
Liquid chlorine	Good	Good	Good	Nil	Acceptable

ı Operation and maintenance of gas chlorinators

Vacuum chlorinators need to be regularly inspected and maintained by trained operators. The manufacturer's instructions must be followed to ensure that they operate properly and to avoid costly repairs and accidents. This type of system is generally long-lasting and relatively free from problems. Extreme care must be taken to keep moisture out of the gaseous chlorine in the feeding system, for moist chlorine gas will rapidly corrode or destroy the equipment: the plastic parts, metal fittings, valves, flexible connections, etc. The materials used in the chlorination system, including spare parts and accessories, must be appropriate for the handling of moist and dry gaseous chlorine. Ferric chloride scaling on the pipes, generally due to impurities in the chlorine, must be removed regularly. An appropriate quantity of spare parts must be available at all times. Flexible connections must be replaced as recommended by the manufacturer. Lead gaskets between the cylinder and the chlorinator should be used only once. When the joints between cylinder and chlorinator must be opened to replace cylinders, or for any other reason, the gaskets must be replaced by new ones recommended by the manufacturer. The reuse of used gaskets is probably the most common cause of chlorine gas leakage.

The same care must *be taken with pressurized* chlorination equipment. It is also necessary to keep in mind that a counter pressure of more than 10 m of water column will cause problems in the diffusion of the chlorine in the pipes; in that case, vacuum-type chlorinators should be chosen.

Personal safety equipment

It is common practice for an operator to check and, if necessary, adjust the chlorine gas dose three or four times during an eight-hour shift. Care should be taken not to extract more than 18 kg of chlorine gas a day from a single cylinder; more will result in the freezing of the cylinder due to a rapid fall in pressure, known as the "Joule-Thompson effect."

An experienced operator should take less than 15 minutes to routinely replace an empty cylinder with a full one. For safety reasons, at least two operators should be present for this operation.

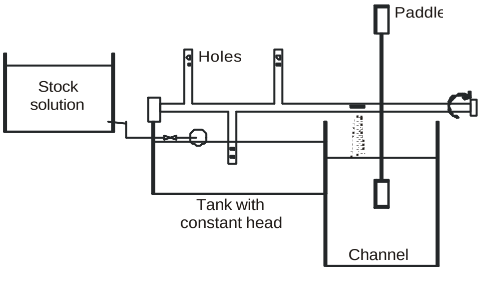
Because of its extreme toxicity and corrosiveness, strict safety regulations govern the use of gaseous chlorine. In the case of fire, the tanks or cylinders should be removed first because their fire resistance is guaranteed only up to 88 °C (with a 30-bar internal pressure). Because steel will burn in the presence of chlorine, care must be taken not to crack the containers (by not using a hammer to unblock or unfreeze valves). Moist chlorine is highly corrosive: a chlorine leak will cause external corrosion and the entry of water into pipes carrying chlorine will cause them to corrode inside.

Gas masks must be used when handling the containers in any of the areas where chlorine is stored and it should be recalled that masks with carbon filters have a limited service life.

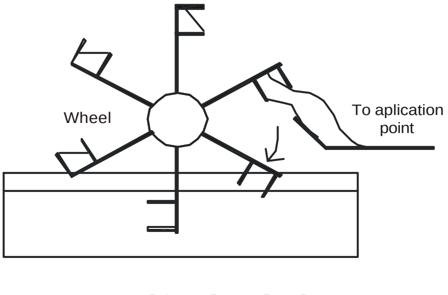
Hypochlorite feeders operated under atmospheric pressure

All chorine-based products, except for chlorine gas, are liquid or, if solid, can be dissolved and used as a solution. Hypochlorite disinfection is the most popular method used in rural areas. It is simple, easy and inexpensive and there are many available devices using the appropriate technology.

There are several ways to feed a solution and dosers can be classified according to their driving force, which can be of two kinds: atmospheric pressure and positive or negative pressure.



Paddle wheel feeder



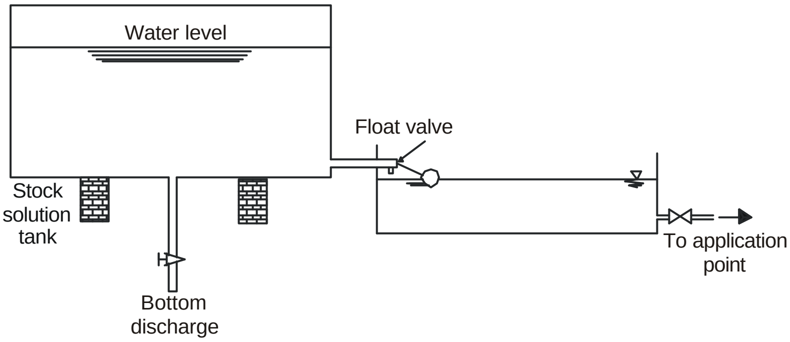
Archimedes wheel

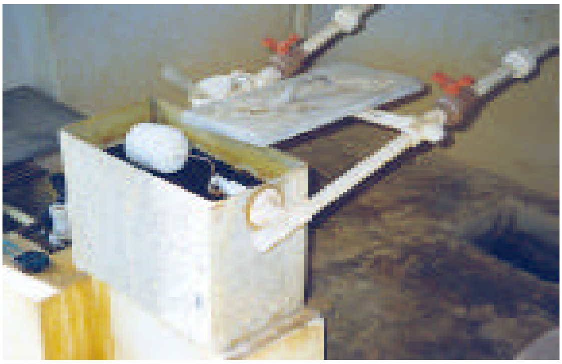
Some of the devices that work under atmospheric pressure have been *designed with a varying head, such as the paddle wheel feeder* or the *Archimedes* wheel (previous page).

The most popular devices, however, are those that operate under the "constant head" principle, which are more precise and reliable. A constant head system is composed of two elements: a constant head tank of a stock solution to be fed and a regulating mechanism. Three of the most recommended systems are shown, perhaps the most popular of which is the floating tube with a hole that is used in many countries. All three systems can be built from materials that are easily obtained locally.

Float valve in a box system

The heart of this system is a float valve similar to those 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 quite simple and cheap, is fairly accurate.

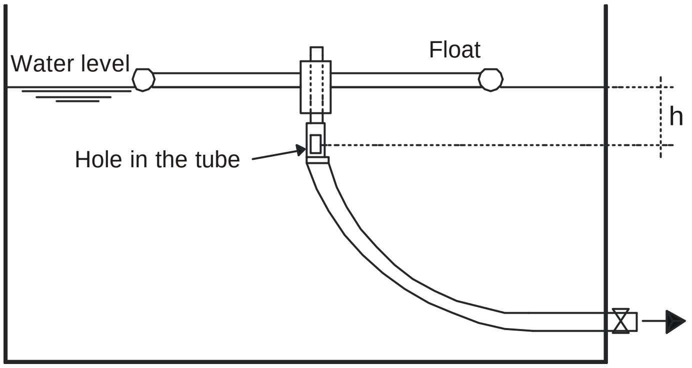




Float valve in a box system

Floating tube with hole system

This system has been widely used in several different arrays. The basic element is a PVC tube with one or more holes. The tube is attached to any kind of floating device and the hole should be situated some centimeters below the solution level so that the solution enters the delivery tube and flows at the desired feeding rate toward the application point. One advantage of this kind of hypochlorinator is that it does not corrode because it is made of plastic piping. Furthermore, there are no valves to break down and the obstructions produced by calcium or magnesium scaling is easily removed. The feeding rate can be easily adjusted merely by changing the depth of the holes. When properly designed, installed and maintained, this kind of chlorinator has proven to be exact and reliable.



Floating tube with a hole feeder

Installation and installation requirements

These systems should be built of materials that are resistant to the corrosion caused by a strong hypochlorite solution. The solution tank can be made of high-density polyethylene (PEHD), fiberglass or asbestos-cement. The floater can be PVC or wood. No aluminum, steel, copper or stainless steel should be used because they are rapidly destroyed.

This device, like all constant head systems, is easy to install. Its application is limited to cases where the hypochlorite solution can flow by gravity toward the mixing site, whether channel or chlorine contact chamber, or directly toward a storage tank. The installation should include an airspace in the discharge pipe to avoid possible siphoning. The system should also be designed in such a way that there is no chance of having the contents of the solution tank discharge all at once accidentally into the mixture channel or the contact chamber if an accessory or pipe is broken or any other type of spill occurs. The installation design should facilitate handling of the chlorine compounds and solution mixtures and adjustment of the dosing. A water faucet should be located conveniently for use in preparing stock solutions and for general hygiene.

Operation and maintenance

These devices are easy to operate, maintain and repair and do not require the care of specialized operators. The latter can be easily trained over a short period of time. Continuous oversight is needed, however, to make sure that the equipment, particularly the submerged hole, is kept clean, that the size of the dose is appropriate, that the tank solution has not run out or its concentration been weakened, that there is no change in the water flow, etc. For that reason, it must be cleaned periodically and a filter must be used to trap all particulate material.

Great care must be taken when preparing the hypochlorite solution by hand, as explained earlier. When using calcium hypochlorite, the concentration of the solution must be between 1% and 3% available chlorine to impede the excessive formation of calcium scaling and sediments. Sodium hypochlorite solutions can have a 10% concentration. Higher concentrations are not advisable because they lose their strength rapidly and if too high they can crystallize.

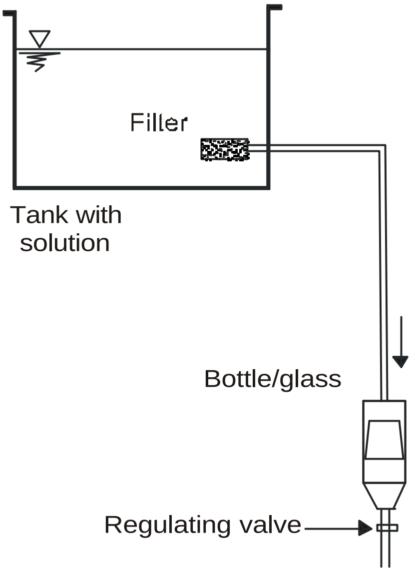
Bottle/glass system

One of the authors of this manual developed this system for rural water disinfection in Argentina in the 1970s at PAHO’s request. It consists of a tank containing the stock solution, a dosing element, connections and a regulating valve.

The system is precise, inexpensive and easy to build and operate. The dosing range is from 2 to 10 l/h, making it applicable to small communities of up to 20,000 inhabitants. Parallel installation of two or more dosers will make it possible for larger feeds.

Installation and requirements

The tank should be installed 1 m (or more) above the level where the dosing element is placed. The latter is a simple system composed of a container with a floating device, the container being a cylindrical glass or plastic bottle with smooth walls and a 1.0 to 1.5 liter capacity. The base of the bottle should be removed and the container inverted (the neck pointing downward).



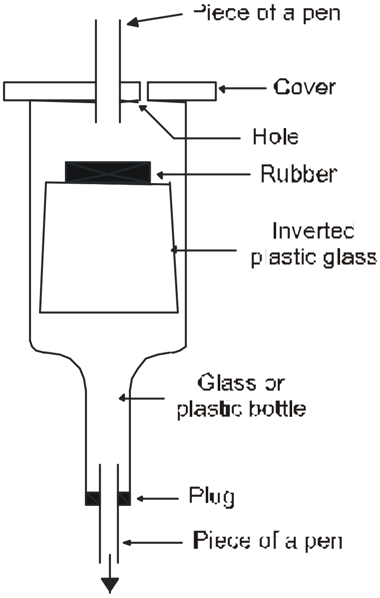
Bottle/glass dosing device

A small cover made of wood or plastic is glued to the upper part (area of the removed base) of the device using epoxy glue. This cover has two holes: a central hole, where another ¼” plastic tube or a piece of pen is introduced (without any ink cartridge) and left protruding approximately 1 cm. This tube should be firmly welded or glued to the cover and its borders should be leveled and smoothed. The second hole allows the air to flow freely.

The floating device is a plastic glass or jar, with or without a top, placed upside down (with the mouth facing downward) inside the bottle. A piece of soft rubber is glued to the outside of the base. With the air trapped inside, the jar or the plastic glass will operate as a floating device. The flow is regulated using a simple locally manufactured valve.

Operation and maintenance

The operation of this equipment is simple. Once the connections have been made, the hypochlorite solution should be let to flow and the conduits checked so see that there is no trapped air. Then the dose applied is regulated using the valve. If the stock solution runs out and the feeder “dries,” the floating device will drop;



Bottle/glass dosing element

Bottle with plastic jar

on being refilled, it could fail to return to its proper position. It is therefore suggested that the container with the stock solution should not be allowed to dry. Care should also de taken with the insoluble particles. Because the conduits are relatively narrow, liquid hypochlorite should preferably be used and a filter should be inserted to trap particles.

Hypochlorite feeders under positive or negative pressure

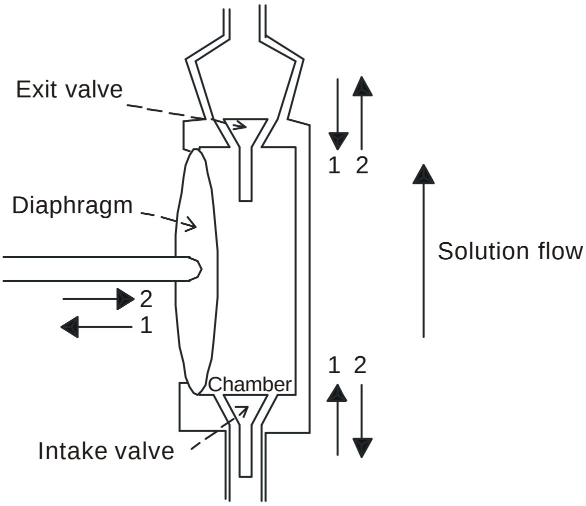
Positive pressure feeders work by raising the chlorine solution above atmospheric pressure and subsequently injecting it into a water pipe. The most important positive pressure system is the highly popular diaphragm feeding pump.

Negative pressure feeding or suction pumps, for their part, operate on the principle that the chlorine solution is suctioned out by the vacuum created by a venturi or by connecting the feeder to an adduction pipe. The venturi is the most used negative pressure system. It is installed in the pressurized water supply pipe itself or in an alternate line, as can be seen later.

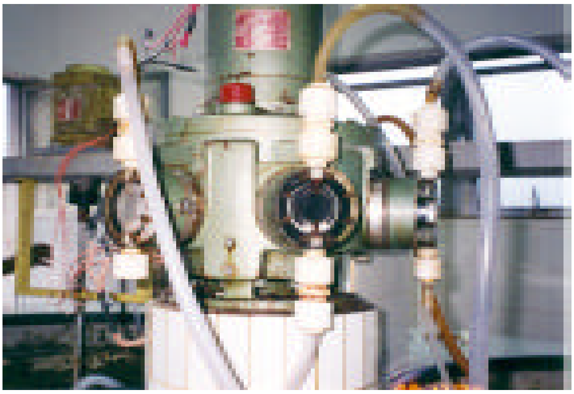
Diaphragm pump feeding system

These pumps are equipped with a chamber housing two one-way valves, one at the point of entry and the other at the exit. The solution is added to the chamber through the intake valve as the diaphragm, powered by an electric motor expands, and is expelled outside the chamber by the exit valve as the diaphragm contracts. The flexible diaphragm is made of material resistant to the corrosive effects of hypochlorite solutions.

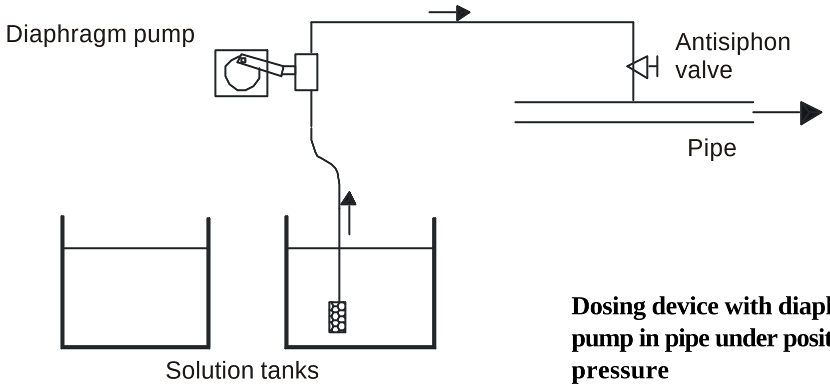
The task of the pump is to raise the level of the solution by means of a series of strokes. The application point can be a channel or a reservoir (atmospheric pressure) or a water pipe under positive pressure.



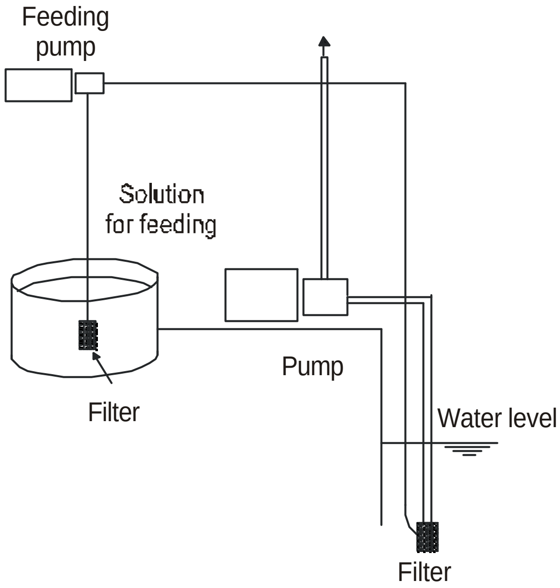
Operation of the chamber with its diaphragm pump



Multiple head pump



Dosing device with diaphragm pump in pipe under positive pressure



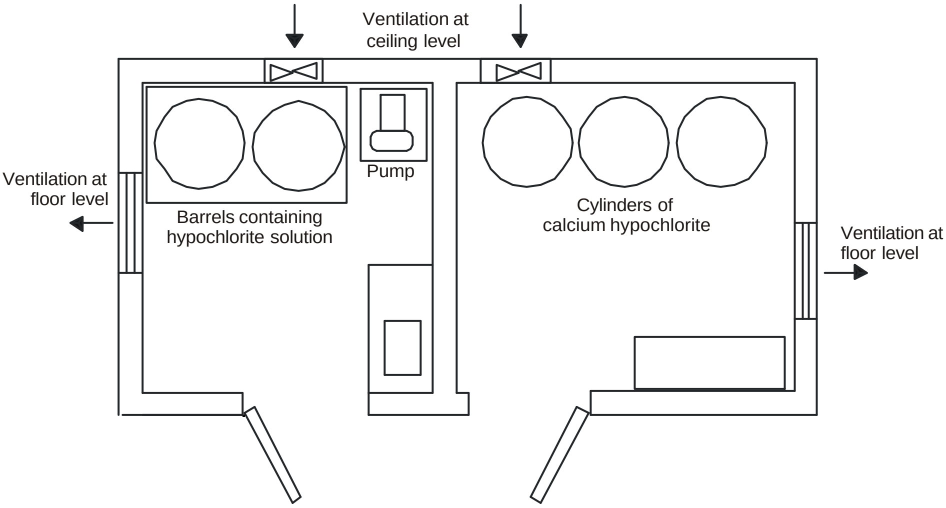
Dosing device with diaphragm pump in pipe under negative pressure

This type of hypochlorinator has a large capacity; the smallest device supplies nearly one liter of hypochlorite/hour and the largest almost 200 liters/hour. A widely varying water flow can be disinfected, depending upon the concentration of the solution and the desired dose of chlorine.

Installation and installation requirements

Diaphragm pumps are usually powered by electric motors; hydraulically-powered pumps are less common. The latter can be used when there is no reliable source of electric power. An advantage of this system is that the hypochlorite feeding speed can be calibrated to the water flow speed by using a special device. A disadvantage of using hydraulic power is its mechanical complexity, which often causes operating and maintenance problems. Relatively little power, generally from ¼ to ¾ HP, is needed to operate the hypochlorinator. In choosing this type of chlorinator, it is important to consider the reliability and quality of the power source to be used.

A well-designed installation should protect the chemical products against the effects of sunlight and provide the necessary conditions for easy management and mixing of chemical solutions. It should also be well-ventilated and very high temperatures and moisture should be avoided. The installation should be designed to facilitate its operation and maintenance and reduce potential chlorine risks. A separate room is recommended for storing the hypochlorite because of its corrosive and reactive nature. The figure below shows the diagram of a typical calcium hypochlorite chlorination installation.



Typical calcium hypochlorite installation

ı Operation and maintenance

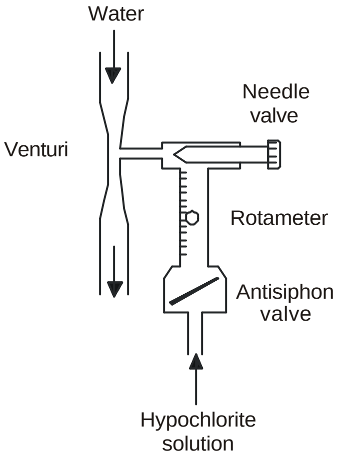
The capacity of diaphragm pumps can be regulated to adjust the hypochlorite solution feed by adjusting either the frequency or length of the pump stroke. Most hypochlorinators use variable speed motors to regulate the frequency or length of the pump stroke. Some employ mechanical means to adjust its length and a few make use of both methods. Control of the pump stroke frequency appears to be the method of choice of most small water supply systems because of its simplicity. Starting and stopping, as well as the feed rate, tend to be controlled manually, although starting and stopping can also be controlled automatically using a magnetic switch connected directly to the water pump regulator. Complicated control systems that adjust the feed rate automatically are not generally recommended for use by small communities.

Chlorinators of this kind are simple to operate and maintain, but do require continuous and appropriate maintenance. The feed can be exact and uniform if the equipment valves are kept free from precipitates and scaling. A concentration of 1 to 3% is recommended for calcium hypochlorite solutions in order to reach an economic balance between the costs of pumping and of preventing calcium precipitation in the check valves and diaphragm chamber. Special care must be taken when the water is hard, containing high contents of dissolved solids, or when using dissolved chlorinated lime. The use of sodium hypochlorite solutions with a concentration of less than 10% is recommended in order to avoid precipitates and maintain the stability of the chlorine.

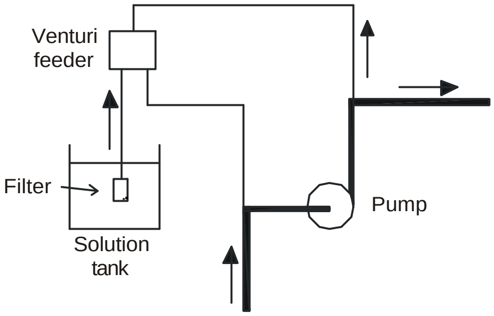
Because the diaphragm pump is made up of metal pieces, these can corrode and reduce its service life. For that reason, the pump must be replaced periodically. The check valves are exposed to calcium scaling and so must be cleaned with an acid solution to avoid their deficient operation or having to replace them more frequently due to a loss of elasticity as a result of oxidation. Hypochlorite solutions must also be handled with care. Inasmuch as they are highly corrosive, the tools and containers used to prepare them must be made of plastic or ceramic or other corrosion-resistant materials. Personnel must be trained to handle spills and in the correct equipment operation and maintenance procedures.

Suction feeders (venturi-type)

The suction feeder in widest use employs a venturi device that makes it possible to feed chlorinated solutions through pressurized pipes. This type of



Venturi and rotameter



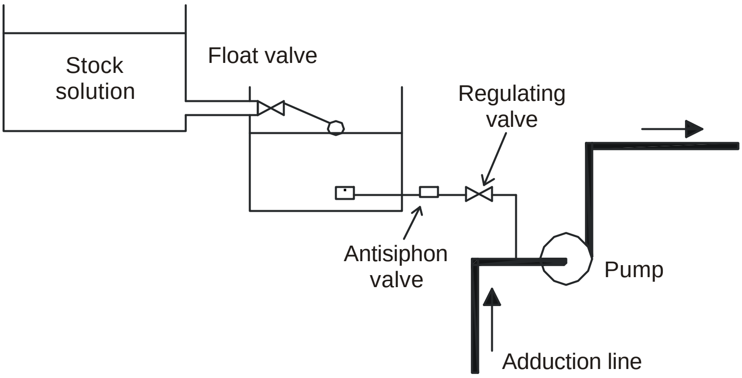
Typical installation of the system

chlorinator is based on the same principle as that of the ejector used in gas chlorinators. The vacuum created by the water flow through the venturi pipe suctions the hypochlorite solution and discharges it directly into the main water stream or a secondary one. The feed is regulated by adjusting a needle valve installed between the venturi device and the rotameter, as shown in the figure.

Venturi hypochlorinators made by several manufacturers are available in the market. They are relatively inexpensive and easy to install, operate and maintain. Their feeding capacity ranges from 1 to 25 liters/hour. An important advantage of this type of feeder is that if no water flows through the device, the chlorine solution will not be released, thereby avoiding the possibility of overdosing. However, if a high concentration of stock solution is injected, it can harm the pump rotor. Another way of creating the necessary suction to feed the hypochlorite solution is by connecting the feeder to an adduction pipe, as shown in the figure. An antisiphon valve must be used in this configuration to avoid the return of the solution if the pump stops operating.

Installation and requirements

The venturi device functions efficiently within a relatively narrow range of operation. For that reason, care must be taken in its selection to ensure that the hydraulic requirements of the device match the characteristics of the water supply



Feeder in adduction pipe

system (maximum and minimum flow). Venturi devices should not be used for wide fluctuations in flow and pressure outside their range of operation. They should also be resistant to strong hypochlorite solutions, whose oxidizing potential could attack and rapidly deteriorate the device.

Venturi devices can be installed in the wall or directly on the pipes, depending on their design. Their installation is so simple that specialists are not needed. All of the flexible plastic pipes should be appropriately installed to facilitate the operation and maintenance of the devices. Beforehand, a filter should be installed in the device and it should be arranged in such a way that the venturi can be easily removed to clean any precipitates or scaling that could obstruct it. As in the case of all hypochlorinators, special precautions must be taken in designing the chlorination and storage installations because of the reactive nature of chlorine solutions.

The venturi device does not require a great deal of water pressure to perform. In some cases, however, a reliable source of electric power will be needed to flush a small amount of water through the venturi to create the necessary vacuum.

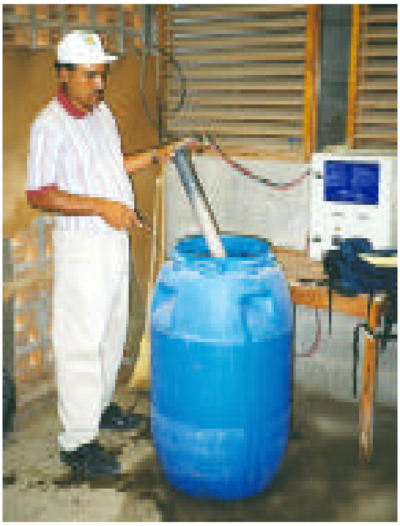
ı *Operation and maintenance*

Venturi hypochlorinators are not very precise, particularly when the flow varies widely, making it necessary to frequently adjust the feed. Acrylic venturi devices are better because they permit the operator to visually determine when they need cleaning and are also resistant to hypochlorite. All venturi devices are liable to calcium scaling due to the hypochlorite solution or the presence of hard water. They should be cleaned on a routine basis and, if necessary, use acid to remove the hardest scaling and other precipitates or sediments. Most joint gaskets, retaining valves, springs and joints deteriorate over time because of being in contact with hypochlorite; they should, therefore, be replaced periodically. These spare parts should be made of proper materials and be on hand at all times.

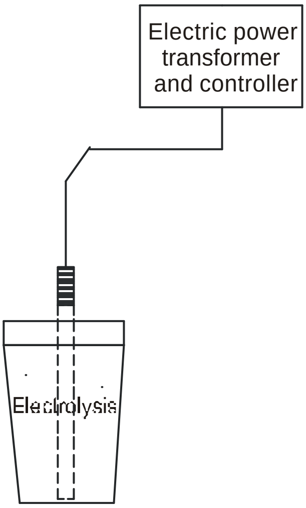
On-site sodium chloride electrolysis

Disinfection, because of its importance, cannot be a sporadic process. Availability of the disinfectant at all times is a basic requirement that should be considered when choosing the disinfection system to be used. In small isolated or hard-to-reach rural towns or communities where a continuous supply of hypochlorite cannot be ensured because of the lack of transportation or of the means for its purchase at the proper moment, an alternative should be studied. This is the on-site generation of sodium hypochlorite.

On-site hypochlorite generation consists of the electrolysis of a solution of approximately 30 grams of sodium chloride/liter, a 3% concentration, to produce 400 liters a day of a stable solution containing 5 to 7 g of active chlorine/liter (0.5 – 0.7%). Using this mechanism, suitable quality drinking water can be supplied to a population of up to 5,000 people by means of conventional feeding systems for



On-site production of NaClO



community water systems or for direct household use. On-site hypochlorite generators need electric power to operate, meaning that a stable source of energy must be available. An alternative in the absence of such power would be equip the generator with solar panels and batteries.

Up until a few years ago, these devices were not an alternative for developing countries because of their complex technology and high cost. They are now becoming more popular, however, because new materials, such as titanium, are being used to produce dimensionally stable anodes (DSA) and improvements have been made in the power sources.


NaClO on-site production system for a 5,000 people community

In order for sodium hypochlorite generators to be effective and appropriate for use in rural areas and small towns, they must:

- be inexpensive;
- be easy to operate and maintain;
- be reliable and durable, offering uniform production;
- be able to use locally available table salt (sodium chloride), and
- have a production capacity of between 0.5 and 2.0 kg of chlorine every 24 hours.

Commercial devices have been developed in several countries and PAHO/CEPIS has made technical evaluations of the most widely used. The characteristics and requirements of the water supply system in question should govern the application of these systems.

- ***Installation and requirements***

The system includes dissolution tanks. A reserve of salt must also be stored, requiring additional space. Although the devices for producing NaOCl are easily installed, precautions must be taken to separate them from the components that are susceptible to corrosion, such as the electrical controls, motors, pumps, regulators and other metal equipment, because the area adjacent to the production units tends to be highly corrosive. The installations must be designed in such a way that they facilitate the handling of the salt and the transfer of the hypochlorite solution from one tank to another and to the application site. The premises should be well-ventilated.

The efficiency of sodium hypochlorite production varies slightly according to the different types of device. Experience has shown that 6 to 10 kilowatts/hour of electric power are needed to produce one kilogram of available chlorine. This small amount of power can be obtained from a variety of sources, such as solar cells, windmill or hydraulic energy-powered electric generators, etc. Irrespective of the choice made, the source of energy must be reliable. An advantage of the on-site sodium hypochlorite production system is that it can operate during the hours when there is electricity and store the hypochlorite for use when there is none.

These devices are very safe because they produce sodium hypochlorite solutions with a low concentration in relatively small amounts and most of these solutions are used immediately or within a very short period of time. Even though the procedure is low-risk, care must be taken, especially when opening the electrolytic cell, because of the possibility of a gaseous chlorine build-up. The precautions cited for the use of sodium hypochlorite should be followed in general.

Operation and maintenance

This type of device is reliable if it is made from materials that are resistant to the highly corrosive properties of the chemical products that are to be used and produced. Maintenance should be carried out at regular intervals in accordance with the specifications. A problem that can arise with certain types of devices is electrode scaling due to the presence of calcium and magnesium in the salt. The scaling can be reduced by using refined salt and good quality dissolution water. The use of water softeners helps. Titanium anodes with a coating of iridium or ruthenium oxide are generally more lasting (between four and six years) than graphite anodes (used by some devices instead of titanium anodes), which last about a year. The titanium anodes can be cleaned using a chlorhydric acid solution.

Solid calcium hypochlorite feeders

Calcium hypochlorite feeders are manufactured for large and small flows. The former are volumetric or gravimetric feeders that drop a measured amount (in volume or weight) into a small dissolution tank (always accompanied by mixing),

Dissolution feeders and tanks

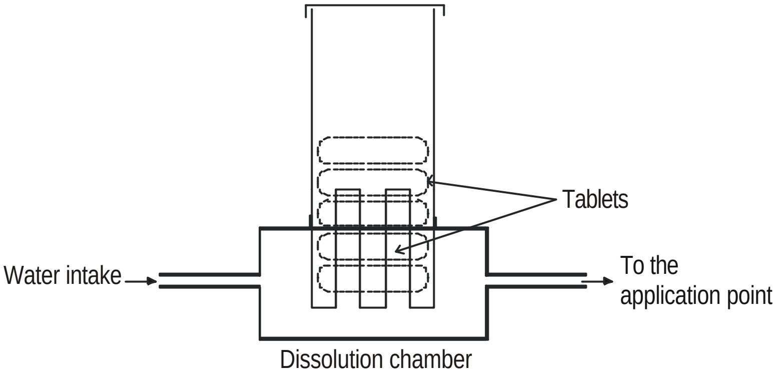
where it dissolves and is later fed at the application point. The use of these devices is not popular, for when large flows are to be treated chlorine gas is the choice. To disinfect small flows (typical in medium-sized and small communities), devices operating through tablet erosion or the direct feeding of solid calcium hypochlorite pills are preferred.

The concentration of active chlorine in these presentations is between 65 and 70%, unlike the 33% concentration of powdered calcium hypochlorite, marketed under different brands. Care must be taken, however, to ensure that they are appropriate for disinfecting drinking water and that they do not contain substances like cyanurates. Sodium cyanurates, which also release chlorine on being dissolved in water, should only be used in emergency situations, because not enough evidence exists about their harmlessness when used over long periods of time.

Tablet and pill erosion feeder

Erosion feeders use high concentration calcium hypochlorite tablets (HTH) that can be obtained from distributors or prepared locally by mechanically compressing powdered calcium hypochlorite. This system has found an important niche in the disinfection of water supply systems for small communities and households. The devices are easy to handle and maintain and are cheap and durable, as well. The tablets are safer than the hypochlorite solutions and the gaseous chlorine and are easier to handle and store.

Erosion feeders gradually dissolve hypochlorite tablets at a preset rate while a water current flows around them. This mechanism provides the necessary chlorine dose to disinfect the water. As the tablets dissolve, they are replaced by new ones that fall into the chamber by gravity. The concentrated chlorine solution feeds a tank, an open channel or a reservoir, as the case may be.

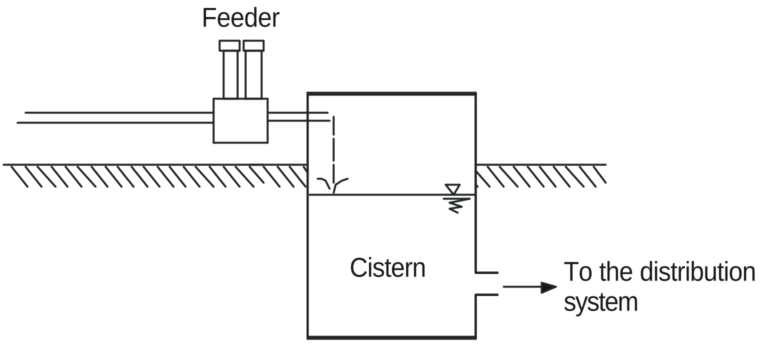


Erosion feeder

Deep well (or storage tank) pill feeders that supply the pills at a regulatable constant speed can be found in the market. On being submerged, the pills dissolve slowly and release a reasonably constant supply of residual chlorine. The use of these feeders is recommended only when the operation is continuous.

Installation and requirements

Only minimum specialized training is needed to install these feeders. In most cases, it is enough to train a operator in a basic knowledge of plumbing and piping. However, although the feeding devices are made of non-corrosive materials and have no movable parts, the manufacturer’s instructions must be followed to ensure their durability and adequate operation in accordance with the specifications. Attention must also be paid to the water temperature, on which the tablets’ solubility depends.

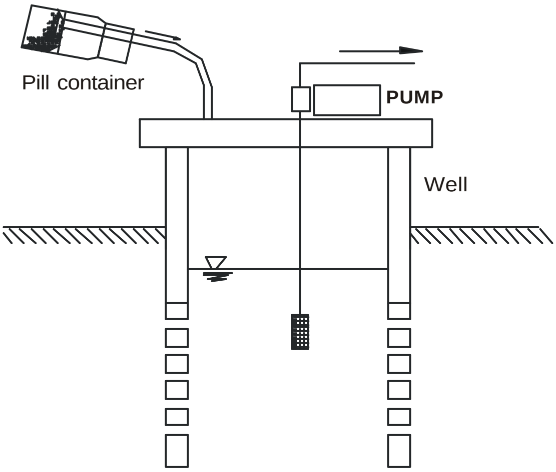


Typical installation of a calcium hypochlorite tablet erosion chlorinator

The figures illustrate the typical installation of tablet erosion chlorinators and a pill feeder.

The tablet erosion feeder requires only the necessary hydraulic power to ensure that water flows through it. This type of chlorine feeder is very flexible, both as to amount of chlorine used and the location of application points. Several feeders can be used for larger systems.

Operation and maintenance



Typical installation of a calcium hypochlorite pill chlorine feeder

Tablet and pill erosion feeders are simple to operate. The equipment can be calibrated easily, but not very precisely by adjusting the immersion depth of the column of tablets or the speed or flow of the water that is flushed through the dissolution chamber. Once the feeder has been calibrated and if there are no major variations in the flow, it will normally require little attention, except to check to see that the container is filled with tablets to ensure continuous dosing. The tablet feeder mechanism should be inspected on a regular basis to check for obstructions. It must be well cleaned, returned to its proper position and then calibrated. Inspection and replenishment of tablets will depend on the specific installation, the chlorine feed and the volume of water treated. Operators can be trained rapidly because the device is easy to operate.

Safety wise, hypochlorite tablets are usually easier and safer to handle and store than other chlorine compounds; even so, it is necessary to take some minimum precautions. It is important not to use tablets that are designed for swimming pools, because these tend to contain isocyanurate, a chemical compound that is not recommended for human consumption over a long period of time.

Advantages and disadvantages of the methods

The table in the following page has been prepared to facilitate the comparison of the chlorine feeders described.

Monitoring of chlorine compounds and chlorine-based products

Regular measurement of the amount of residual chlorine will make it possible to control the operation of the feeder and the absence of contamination in the water distribution system. For that reason, such measurement is essential.

There are several methods for measuring residual chlorine in the water. Two of the simplest are the following:

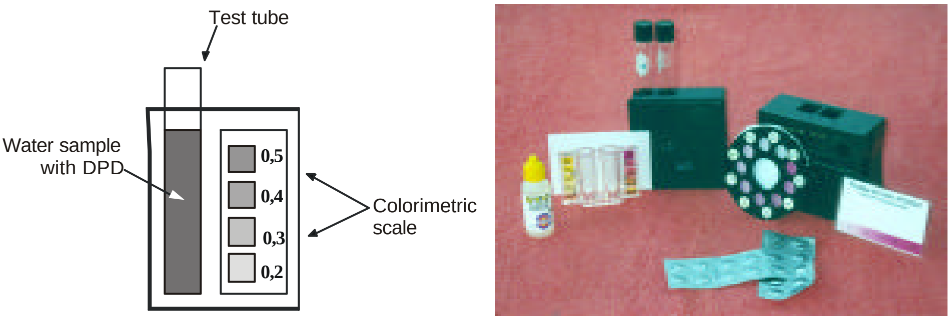
- ***Diethyl-para-phenylenediamine method (DPD)***

Available free chlorine reacts instantly with N-diethyl-para-phenylenediamine to produce a reddish tint providing that no iodine is present. Standard DPD-potassium permanganate solutions are used to produce colors of various intensities. In this way, DPD can be used as a colorimetric method to measure the concentration of residual chlorine. The color produced by this method is more stable than that of the Orthotolidine method.

This simple method uses DPD tablets that are dissolved in a chlorinated water sample to produce the reddish coloration, which by comparison makes it possible to determine the concentration of residual chlorine in mg/l. The device used for this purpose is known as a “chlorine comparator.”

Comparative table of advantages and disadvantages of chlorine and chlorine compound feeders

Classification	Feeder	Advantages	Disadvantages
Chlorine gas	- Vacuum - Pressurized	Widespread technology. Chlorine gas production in almost every country. Cheap chemical product. Pressurized chlorination does not need electric power.	Costly system for very small towns. Needs auxiliary equipment. Operators require training. If not properly operated, the system can be dangerous because the gas is poisonous. Not recommended for systems treating less than 500 /m^3 day. Vacuum chlorination needs electric power.
Chlorine solutions	**Under atmospheric pressure with a constant head**		
	Float valve in a box	Extremely easy to operate and maintain. Very cheap. Can be built locally. Reliable. Does not need electric power. Permits feeds for minimum flows. Can be used in any situation, except in closed drilled wells.	Feeds not very precise. Error around 10%. Feed variations require constant control. Material may corrode.
	Floating tube with a hole	Constant head. Extremely simple. Very cheap. Can be built locally. Reliable. Does not need electric power.	Depending on the way the system was built, the dosing error may be up to 20%.
	Bottle/glass system	Extremely simple. Very cheap. Can be built locally. Ideal for small communities. Dosing error less than 10%. Does not need electric power.	Should be kept clean.
	Under positive or negative pressure		
	Diaphragm pump (positive)	Highly reliable. Very popular. Easy to operate. One of the few systems that works under pressure. Can introduce up to 6.0 kg/cm^2 of solution directly into pressurized water pipes.	Personnel should be trained in its operation and maintenance. Intermediate to high cost for a rural system. Needs electric power. Should be monitored. The chlorine can produce corrosion of the pump motor.
	Suction feeder (negative)	Extremely simple. The cheapest solution for feed in pressurized pipes.	Surveillance and maintenance are needed to avoid obstruction of venturi device.
	On-site sodium hypochlorite generator	Does not require transport of chlorinated products. Produced on-site. Simple and easy to operate.	Requires soft water to avoid electrode scaling. Constant surveillance and trained personnel are needed to take safety precautions because of the formation of chlorine gas. Production limited to the capacity of the device.
Solid chlorine	Erosion feeder	Extremely simple. Ideal for small communities. One of the best solutions for dosing at the entrance to a tank. Does not need electric power.	Intermediate cost. Dosing errors around 10% . Needs tablets. In some feeders, the tablets (if locally produced) tend to get stuck or to form caverns and do not fall into the dissolution chamber.



Chlorine comparators by the O-T and DPD methods

Orthotolidine method

Orthotolidine, an aromatic compound, is oxidized in an acid solution by chlorine, chlorazines and other oxidants to produce a yellow-colored complex, the intensity of which is directly proportional to the amount of oxidants present. The method is suitable for the routine determination of residual chlorine not exceeding 10 mg/l. The presence of natural color, turbidity and nitrates interferes with the color development. Orthotolidine has been shown to be carcinogenic and should be handled with care.

Measurement of the chlorine concentration

Chlorine measurements should be taken at the following points of water supply systems:

- After chlorination, at the exit of the treatment plant, to check whether the amounts of disinfectant are correct.

  It is important to bear in mind that if there is no storage reservoir for water and disinfectant mixing at the treatment plant, the contact time between the chlorine and the water may be so short that the chlorine demand is not met. In this case, the value that is obtained can signal the presence of "active chlorine," but in the following minutes this chlorine will be consumed by organic matter. It is advisable, then, to wait at least 30 minutes after injecting the chlorine in the water to measure the residual concentration of the disinfectant.

- At the tap of the consumer farthest from the treatment plant. This measurement will make it possible to determine the presence of any contamination in the water distribution system. These measurements should be taken several times a day every day of the year.

Feeder and operation and maintenance costs

The costs of the feeders will vary according to the amount and type of chemical product to be used, the type of control exercised (if needed) and the installation needs. The estimated costs of the devices can be found in the table below.

The operating and maintenance costs vary according to the type of chemical product used and the size and complexity of the device. Feeder manufacturers provide a list of recommended spare parts, which should be kept on hand as a minimum. Most manufacturers train treatment plant personnel in the maintenance and servicing of their equipment. Some even run exchange programs under which that equipment is given maintenance in their facilities. This allows operating personnel to send such devices to be repaired while a replacement unit operates.

Chlorination costs are generally very low; even so, there are differences when the cost of chlorine gas is compared with that of hypochlorination. In many parts of the world, the cost of the gas is one-quarter or one-half that of an equivalent hypochlorite solution. However, the initial investment and installation and operational costs for a gas chlorination system are usually higher than those of hypochlorination installations, some of which cost practically nothing. This often places gaseous chlorine at an economic disadvantage in the case of very small water supply systems.

Experience suggests the breakeven point between the costs of gas and of hypochlorination to be a dosing rate of roughly 500 to 1,000 mg of chlorine a day. The selection of gas or hypochlorites will have to be carefully studied in the case of medium-sized communities because the advantages and disadvantages can overlap and the choice may have to be based on additional elements. The operator’s required skill and the community’s capacity to cover its cost are important considerations when making a choice. A detailed analysis of all important elements and the predominating circumstances is needed in each case.

Relative costs of different chlorination systems

Classification	Feeder	Description of the device	Capital costs in U.S. dollars
Chlorine gas	Vacuum	• Vacuum chlorine feeder, installed in cylinder with injector-diffuser	$900 – 1,200
		• Manual gas feeder, installed in container	$2,000
		• Automatic gas feeder, installed in the wall	$4,000
		• Automatic gas feeder, installed in a cabinet	$6,000
		• Hand feed pump for chemical compound feeding	$1,000
		• Automatic feed pump for chemical compound feeding	$3,000
		• Installed wall gas detector	$2,000
		• Type A emergency kit	$1,500
		• Type B emergency kit	$2,500
		• 70kg chorine gas cylinder with valve	$350 – 400
		• Scale	$220
		• Booster pump and pipes	$250
Chlorine solutions	**Under atmospheric pressure, constant head**		
	Float valve in a box	• Hypochlorinator with float valve, solution tank and pipes • Sodium hypochlorite per kilogram of available chlorine	$50 – 80
	Floating tube with hole	• Hypochlorinator with submerged constant head hole, solution tank and pipes • Sodium hypochlorite per kilogram of available chlorine	$20 – 60
	Bottle/glass system	• Solution tank, pipes and bottle/glass device • Sodium hypochlorite per kilogram of available chlorine	$10 – 50
	Under positive or negative pressure		
	Diaphragm pump (positive)	• Diaphragm pump with electrical controls, plastic solution tank and pipes • Sodium hypochlorite per kilogram of available chlorine	$700 - 1,000
	Suction feeder (negative)	• Solution tank, pipes and venturi • Sodium hypochlorite per kilogram of available chlorine	$200 – 350
	On-site sodium hypochlorite generator	• Electrically regulated cells	$500 -10,000
Solid chlorine	Erosion feeder	• Erosion dosing devices	$150 – 400

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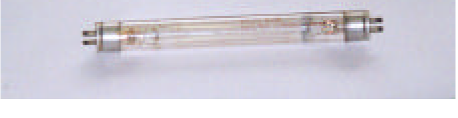
Chapter 4

ULTRAVIOLET RADIATION



Introduction

Even though ultraviolet radiation (or “UV light”) is not popular in the Third World, it is the only practical physical method for water disinfection at the small community level (with a centralized water system). The practical applications of ultraviolet radiation started in 1901, when this light was first produced artificially. The technique was considered for use in drinking water disinfection when quartz was found to be one of the few materials that are almost totally transparent to ultraviolet radiation, allowing it to be used as protective casing for the lamps. The first experiments were carried out in Marseilles, France, in 1910. Between 1916 and 1926, UV was used in the USA for the disinfection of drinking water and on ships to provide potable water. The popularity of chlorine and chlorine compounds, together with their low cost, slowed the production of UV equipment until the 1950s and, in fact, even until 1970, when the lamps became reliable and long-lasting.

The concern aroused by the identification of disinfection by-products (DBP), particularly those associated with chlorine disinfection, led many water systems to shift to the use of UV. Today, at the opening of the twenty-first century, there are over 2,000 installations in Europe that use UV light to disinfect drinking water, and a single plant in Germany (Wahnbachtalsperrenverband) treats a flow of no less than 329,000 m^3/day.

The glaring disadvantage of UV radiation cancels out its major advantage with regard to DBPs: it does not leave treated water with any disinfectant residual to cope with future contamination of the distribution or household water systems.

Nevertheless, ultraviolet disinfection is being widely used in the water supply systems of small establishments, such as hospitals, food and beverage industries and hotels. Its use has been stepped up recently for effluent disinfection in sewage treatment plants. Its capacity for disinfection without producing major physical or chemical changes in the treated water has once again brought it to the fore as a disinfectant for small water systems. The market is filled with devices for large water treatment plants, even a small gadget that hikers can carry in one hand to disinfect lake and river water.

Properties of ultraviolet radiation

UV wavelengths are very similar to those of sunlight. The most important parameters of UV radiation relating to water disinfection are:

- *Wavelength:* The germicidal portion is between 240 and 280 nm (nanometers) with maximum disinfecting efficiency existing at close to 260 nm. These limits fall within what is known as the *ultraviolet - C* range (100-280 nm), *which is different from the ultraviolet - A* (315-400 nm) and *ultraviolet - B* (280-315 nm) ranges.

- *Condition of the water:* While water temperature has little or no influence over the effectiveness of ultraviolet disinfection, it does affect the operative yield of an ultraviolet lamp when submerged in the water. Although the water itself absorbs ultraviolet energy, suspended or dissolved solids, turbidity and color absorb even more. The concentration of solids in suspension in drinking water is generally less than 10 ppm, the level at which the water starts to experience problems of ultraviolet light absorption. Water turbidity should be as low as possible and turbidities of over 5 NTU should be avoided at all costs.

- *Intensity of radiation:* The closer the emission point is to the water, the more intense the radiation will be and, accordingly, the more efficient the disinfection. A rule of thumb states that the water depth should be no more than 75 mm to ensure that the UV rays reach every part of it properly.

- *Type of microorganisms:* Ultraviolet radiation is measured in microwatts per square centimeter ($\mu W/cm^2$) and the dose in microwatt seconds per square centimeter ($\mu Ws/cm^2$) (radiation x time). Resistance to the effects of radiation will depend upon the type of microorganism involved. Nevertheless, the dosage of UV light required to destroy the most common microorganisms (coliform, pseudomona, etc.) is between 6,000 and 10,000 $\mu Ws/cm^2$. Standards for UV dosage in different countries range between 16,000 and 38,000 $\mu Ws/cm^2$.

- *Exposure time:* As in the case of any other disinfectant, the exposure time is vital to ensure a good performance. It is not easy to determine the exact contact time (as this depends on the type of flow and the characteristics of the equipment used), but the period of time should be related to the needed dosage (remember the concept of C x T and the explanation given). In any case, the normal exposure time is from 10 to 20 seconds.

The needed length of exposure time of the water to UV radiation, for a given degree of microorganism inactivation, is inversely proportional to the intensity of the light that penetrates the water, bearing in mind the water's absorption capacity and the light dispersion due to the distance.

The disinfection method is simple. It consists of bringing a UV lamp into contact with a water flow in such a way that the UV radiations acts on the microorganisms in the water under the conditions described above, with the consequent disinfection effect.

UV radiation disinfection mechanisms

The disinfection mechanism is based on a physical phenomenon whereby short wave UV radiation acts on the genetic material (ADN) of the microorganisms and the viruses, destroying them rapidly without producing any major physical or chemical changes in the treated water.

UV inactivation is thought to occur as a result of the direct absorption by the microorganism of the UV radiation, bringing about an intracellular photochemical reaction that changes the biochemical structure of the molecules (probably of the nucleic acids) that are essential to the microorganism's survival. It has been shown that irrespective of the duration and intensity of the dosage, the expending of the same total energy will result in the same degree of disinfection.

The following table contains the values reported by different sources of UV radiation dosages for the elimination of some microorganisms that give an idea of the range and order of the exposure magnitude.

Most UV disinfection equipment uses a minimum exposure (in the water) of 30,000 µWs/cm^2. This is enough to inactivate pathogenic bacteria and viruses, but perhaps not enough for certain pathogenic protozoa, protozoan cysts and nematode eggs that can require up to 100,000 µWs/cm^2 for total inactivation.

UV radiation disinfection by-products

As already stated, UV light has the capacity to treat water without producing major physical or chemical changes in the treated water. Drinking water disinfected by UV light is not known to have negative effects on the health of its consumers. This disinfection process does not add any new substances to the water, therefore eliminating the risk of the formation of DBPs. Nor does UV light alter the taste or smell of the treated water. The dosage and frequency used for the disinfection are

UV radiation needed for up to 99.99% destruction of waterborne pathogens

Bacteria	**Power** μW/cm^2	**Other organisms**	**Power μW/cm^2**
Bacillus anthracis	8.700		
S. enteritidis	7.600		
B. Megatherium sp.(veg)	2.500	**Yeasts**	
B. Megatherium sp.(spores)	5.200		
B. peratyphosus	6.100	*Saccharomyces ellipsoideus*	13.200
B. subtilis	11.000	*Saccharomyces* sp.	*1.600*
B. subtilis spores	*22.000*	*Saccharomyces cerevisiae*	13.200
Clostridium tetani	22.000	Brewers' yeast	660
Corynebacterium diphtheriae	6.500	Bakers' yeast	800
Eberthella typosa	4.100	Pastry yeast	13.200
Escherichia coli	6.600		
Micrococcus candidus	12.300	**Spores**	
Mycobacterium tuberculosis	10.000		
Neisseria catarrhalis	8.500	*Penicillium roqueforti*	26.400
Phytomonas tumefaciens	500	*Penicillium expansum*	22.000
Proteus vulgaris	6.600	*Mucor racemosus A*	35.200
Pseudomonas aeruginosa	10.500	*Mucor racemosus B*	5.200
Pseudomonas fluorescens	6.600	*Oospora lactis*	1.100
S. typhimurium	15.200		
Salmonella	10.000	**Viruses**	
Sarcina lutea	26.400		
Serratia marcescens	6.160	*Bacteriophage (E. coli)*	6.600
Dysentry bacilli	4.200	Influenza (Flu) virus	6.600
Shigella paradysenteriae	3.400	Hepatitis virus	8.000
Spirillum rubrum	6.160	Poliovirus (Poliomyelitis)	1.000
Staphylococcus alous	5.720	Rotavirus	24.000
Staphylococcus aureus	6.600		
Streptoccus hemolyticus	5.500	**Algae**	
Streptoccus lactis	8.800		
Streptoccus viridans	3.800	*Chlorella vulgaris*	2.000
Vibrio cholerae	6.500		

not known to produce any related substances. Nor does overdosing UV light produce any harmful effect. Even so, the operator of UV disinfection equipment must use protective goggles and clothing to avoid exposure to the high power radiation characteristic of ultraviolet light.

Equipment

Ultraviolet light is produced by high- and low-pressure mercury-vapor lamps, with the latter being the more popular. They resemble the well-known florescent lamps. As a matter of fact, the UV lamps are manufactured by the same large companies that make standard florescent lamps. Consequently, the lamps, the ballasts and the starters for the UV system can be bought "off the shelf," except when special sizes are needed.

Although the lamps rarely burn out, they are generally replaced when they have lost from 25% to 30% of the UV light they produced when new. These lamps have a duration of 10,000 hours, which, in practical terms and considering the need for their replacement when they have reached 70-75 % of their normal intensity, means that their service life is from nine months to one year of uninterrupted operation.

UV light water disinfection, as already mentioned, is produced at wavelengths of between 240 and 280 nm, with maximum germicidal efficiency being attained at 260 nm. The low-pressure mercury arc lamps to be found in the market produce a UV light wavelength of roughly 254 nm.

The UV lamp uses a simple mechanism. Inside the lamp —a quartz or silica tube—, an electric arc strikes a mixture of mercury and inert argon vapor. When that happens, the argon does not participate; its function is to help start up the lamp, extend the life of the electrode and reduce losses. The mercury molecules, on the other hand, are excited by the electric current; when the electrodes in the outer orbits descend to orbits at a lower energy level, they release the surplus energy in the form of ultraviolet radiation.

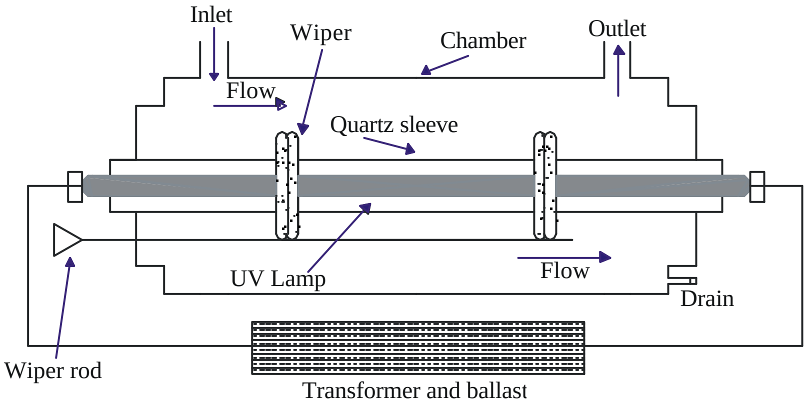
The mission of the starter is to produce a strong discharge that will touch off the gas's first ionization. They create a short-circuit over the lamp, which preheats the electrodes, and then interrupt the current suddenly. This produces a high voltage peak in the ballast's inductive reactance that starts up the arc. The ballasts establish the lamp's operating current (and consequently its voltage), produce a high impedance toward the electric network at the moment of start-up and a low resistance, minimizing energy losses (heat generated). In other words, the ballast is an element that regulates the flow of electrons in the tube, like a traffic policeman.

There are two basic types of chambers for exposing the water to UV radiation: those in which the lamps are submerged in the water and those that remain outside the water. The UV light units of submerged lamps must provide for an insulated area where the lamp can be placed. This is accomplished by encasing it in a protective shield of quartz, which is transparent to the UV rays. Quartz is the only material with this characteristic; of the plastics, only PTDF (Teflon) is partially translucent.

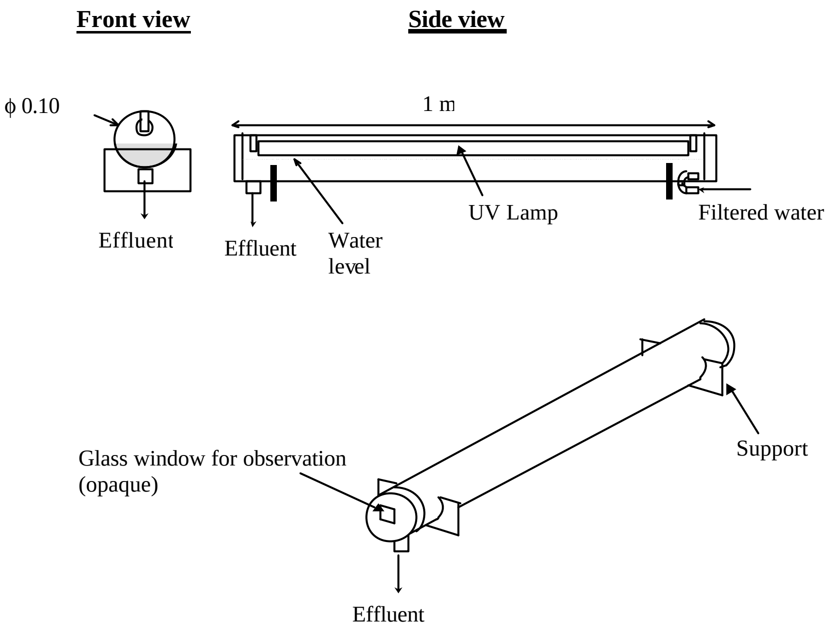
In the second type, the lamps are suspended over the water being treated, almost grazing it.

A modern UV disinfection system may include the following elements:

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



Typical UV radiation system with submerged lamp



Typical UV disinfection system with lamp outside the water

Duct on which the UV water disinfection lamps will be placed.
The design of the baffles inside the duct will ensure that the water flow to be disinfected will glide with a homogeneous front and that all of it will be equally irradiated.

An important consideration when designing disinfection equipment is to ensure that each microorganism receives the biocide radiation dosage in the contact chamber. This is attained by determining the correct space between the lamps and the reflecting surfaces inside the chamber and stirring the water properly when it flows through the chamber. The submerged lamp UV disinfection equipment can have two basic water flow configurations: either parallel or perpendicular to the length of the lamps. If the flow is perpendicular, the lamps themselves and their protective shields can produce the necessary turbulence to ensure that all of the water is exposed to the biocide dosage. If the flow runs parallel to the length of the lamps, however, static agitators (baffles) will have to be used to produce the necessary turbulence.

Installation and requirements

The installation of the typical UV disinfection system is shown in the corresponding figure. The lamp is cased in a protective quartz sleeve. With the old systems, it was difficult to keep the lamp or the sleeves clean because of calcium carbonate scaling, sediments, organic materials or iron that limited its penetration and germicidal power. Today, almost all of the systems have sleeve wipers to reduce that problem.

Electric power is an essential requirement. Consumption varies according to the condition of the water to be treated; 22 watts/hour per cubic meter of water treated is considered optimum. Inasmuch as UV light does not leave any residual, the electric power source must be extremely reliable for the entire time it takes for the water to flow through the disinfection unit. Communities that have no reliable electric power source should install an independent emergency power source to ensure that disinfection is not interrupted at any time.

System using pipes parallel to the water flow in a drinking water treatment plant

The system may be installed either in or outside a shelter that protects it from adverse climatic conditions and vandalism. In the former case, a shelter helps to protect the equipment from temperature extremes or other conditions that could damage it or affect its operation.

UV disinfection equipment does not need much space because the necessary contact/exposure time is very short. Although it is one of the disinfection systems that occupies the least space, sufficient space should be left to replace the lamps and to store enough lamps to cover two years of operation.

Operation and maintenance

The operational and maintenance requirements of UV disinfection systems are minimum, but crucial to an adequate yield. The quartz sleeves or Teflon pipes must be kept free from sediments or other deposits that would reduce the radiation, thus contributing to scaling. In small systems that are generally cleaned by hand, the quartz sleeve should be wiped at least once a month and, in special circumstances, two or three times a week.

The lamps should be replaced at regular intervals to guarantee at least 30,000 microwatts-second/cm^2 in the area of exposure at all times. These will vary from lamp to lamp, but generally are programmed for the average interval when their intensity drops to less than 70% of its nominal potential. Lamps may need to be replaced more frequently in cold water.

Inasmuch as UV light leaves no residual disinfectant whatsoever, the entire system must be thoroughly disinfected with an appropriate chemical disinfectant before activating the unit for the first time. Any external contamination of the distribution system due to return siphoning or a crossed connection must also be remedied and the system disinfected before starting it up again.

Monitoring

The only reliable way to determine the biocide efficiency of UV disinfection is by taking samples of the treated water and conducting microbiological tests to determine the content of indicator microorganisms. The intensity of exposure at one or two strategic points in the exposure chamber can be measured using a photoelectric cell, but this does not necessarily mean that all of the microorganisms have received a large enough dosage of UV light to inactivate or kill them. In any case, the intensity of the UV light should be monitored on a continuous basis and the dosage should be large enough to guarantee sufficient exposure at all times under the expected water quality and flow conditions.

A certain degree of automation and complexity are needed in the monitoring system from a practical point of view. Monitors for the UV censors that visually show if the UV light levels are high enough to ensure disinfection should be included. The control system should allow UV lamps to heat up for at least five minutes before starting the water treatment. For systems that treat variable water flows, the control system should be able to turn lamps on and off to be able to attain the necessary dosage in accordance with the particular flow. It is also recommended to have a sensor that is able to automatically cut off the water flow at any time that the UV system is unable to produce a sufficient dosage for disinfection.

Advantages and disadvantages

Simple operation and maintenance are the first of the advantages. Another important one is that no chemicals are needed for UV disinfection. Furthermore, the exposure time is very short in comparison with the necessary contact time for conventional disinfectants, meaning that no contact tanks are needed. The effectiveness of UV disinfection in killing off a wide range of microorganisms is another advantage. All of these elements are especially important for water disinfection. Furthermore, the equipment has no movable parts that will wear out. The water does not require prior treatment, except for the filtering of turbid water. The system is inexpensive to operate. A wide range of equipment is available, from large water treatment plants to family water disinfection systems. This should be kept in mind because not only on-site hypochlorite generation, but also ultraviolet radiation can be used in family water disinfection programs.

The disadvantages, on the other hand, include a major reduction in efficiency when water turbidity or color increases, allowing microorganisms to take shelter from the effects of UV light in suspended particles. Another disadvantage is the difficulty in measuring the effectiveness of disinfection, except through microbiological analysis to determine the presence of indicator organisms after UV light treatment, which is very hard to do in distant rural areas.

The greatest disadvantage of the method, however and as already stated, is that UV light does not leave any residual. This makes it necessary, after disinfecting with this system, to apply a chemical compound to guarantee the water's microbiological safety through the entire distribution system and even when it is stored in households.

The threat of new contamination or renewed bacterial activity in a water distribution system are impelling reasons for questioning the widespread use of UV light disinfection without the addition of a secondary disinfectant to provide a residual effect. The doubtful effectiveness of ultraviolet rays against some pathogenic protozoan cysts and nematode eggs means that the surface water must first the filtered or undergo another treatment for their removal before ultraviolet disinfection. UV disinfection tends to be more costly than conventional disinfection methods. The use of this disinfection method alone, without a secondary disinfectant, is recommended only for preventive disinfection; when the water supply is reliable, has a turbidity of less than 1 NTU, and when there is little likelihood that the water will become contaminated in the system after UV treatment. In all other cases, a secondary disinfectant should be added.

To sum up:

Advantages	Simple. Efficient. No chemicals involved. Does not modify aesthetic characteristics of the water. Can be managed by unskilled personnel.
Disadvantages	Higher cost of equipment when compared with chlorine solution feeders. The water should be very clear. Needs electric power. There is no residual effect.
Operating and maintenance tips	Checking should be done to ensure that there is no scaling on protective sleeves. Such scaling should be removed consistently.

Costs

The characteristics and complexity of UV systems vary. Although the system centers on the lamp (or lamps), this is the least expensive element of a complete UV disinfection apparatus.

Asked for a budget for the disinfection of raw water with a flow of 6,000 m^3/day for human consumption, one company prepared budgets ranging from a reasonable price of $ 50,000 to half a million dollars. Ten times more! This glaring difference in price stems from the disparity between the modesty of a basic simple system and the paraphernalia of auxiliary elements accompanying the sophisticated equipment.

Care must be taken when participating in the preparation of the terms of reference for the purchase of UV disinfection equipment to properly separate the capacity of the equipment and the provision of safety elements for all aspects of its operation, from elements that are not so necessary, that are supplementary and even a luxury.

Aside from the cost data explained in the previous paragraph, smaller systems, for treating 100 m^3/day (1,000 people), for example, can cost \$ 300; this means a per capita cost of \$ 0.3/person. The operating cost of this system is calculated at \$ 0.02/m^3. At the household level, the yearly operating and amortized capital costs can range between \$ 10 and \$ 100 per family.

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Chapter 5

SLOW FILTRATION

Introduction

Slow sand filtration (SSF) is the world's oldest known water treatment system. It emulates nature's purification process when rainwater seeps through the layers of the earth's crust and forms aquifers or underground rivers. Slow filtration is used mainly to eliminate water turbidity, but can be considered a water disinfection system if it is properly designed and operated.

Unlike rapid sand filtration, in which the microorganisms are stored in the filter interstices until they are returned to the source water through backwashing, SSF consists of a group of physical and biological processes that destroy waterborne pathogens. It is a clean technology that purifies water without creating any additional source of environmental contamination.

A slow filter is basically a box or tank containing a floating layer of the water to be disinfected, a sand filter bed, drains and a set of regulating and control devices.

Rural slow sand filter

Properties and description of slow filtration disinfection

Slow filtration is a simple, clean, yet efficient water treatment system. It needs larger areas than a rapid filtration system to treat the same water flow. Therefore, its initial cost is higher. Its simplicity and low operating and maintenance costs, however, make it an ideal system for rural areas and small communities, considering also that the land in those areas is relatively less expensive.

Slow filtration, as mentioned, is a naturally developing process without the application of any chemical substance. It does, however, require a good design, proper operation and careful maintenance to keep the filter's biological mechanism operating properly and ensure that microbiological elements are efficiently removed.

In 1974, Huisman & Wood described the method of disinfection via slow filtration as the slow circulation of raw water through a porous layer of sand. During the process, impurities come into contact with the surface of the particles in the filtering medium and are trapped. A series of chemical and biological degradation processes reduce the trapped material to simple forms that are kept in solution or as inert material until their subsequent removal or cleaning.

The raw water flowing into the unit remains over the filtration media from three to twelve hours, depending on the filtration velocity that is chosen. During this period, the heaviest particles in suspension settle and the lightest particles are able to agglutinate, facilitating their subsequent removal. During the day, influenced by the sunlight, the algae grow as they absorb carbon dioxide, nitrates, phosphates and other nutrients from the water, to produce cellular material and oxygen. The oxygen so formed dissolves in the water and reacts chemically with the organic impurities, making them easier to assimilate by the microorganisms.

A biological layer, known as “schmutzdecke” or “filter skin,” forms on the surface of the filtration medium. Organic in origin, it is made up primarily of algae and numerous other forms of life, such as plankton, diatoms, protozoa, rotifers and bacteria. The water to be disinfected must first pass through this layer before reaching the filtration medium per se. The intensive action of the microorganisms in the schmutzdecke traps, digests and degrades the water’s organic content. The dead algae, together with the live bacteria in the raw water are also consumed in this process. As the nitrogen compounds are degraded, the nitrogen is oxygenated. Some of the water color fades and sieving traps a large percentage of the inert particles in suspension.

Once the water passes through the schmutzdecke, it enters the filter bed and is forced through it in a process that normally takes several hours. It is at this point that the physical and biological processes that constitute the final purification take place.

Slow filtration disinfection mechanisms

Several physical phenomena or mechanisms similar to those of rapid filtration prior to biological water disinfection —a few of which we mentioned earlier—, are at work in the slow filtration process. These mechanisms are very important, for they allow the organic particles to concentrate on and adhere to the biological bed for subsequent degrading.

The function of each of the physical or removal mechanisms that are produced in slow filtration are described briefly below, together with the biological mechanism that is responsible for the disinfection.

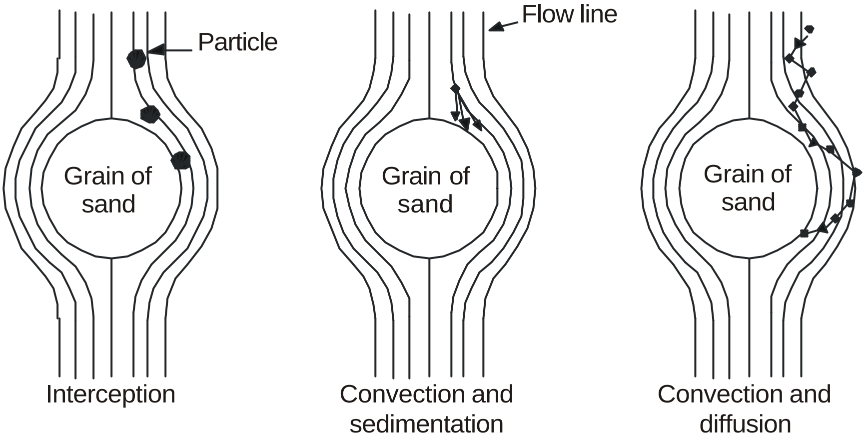
1. Transport mechanisms

This basically hydraulic stage of removal illustrates the mechanisms that bring about the collision of particles and grains of sand; these mechanisms are: sieving, interception, sedimentation, diffusion and interstitial flow.

- **Sieving:** Through this mechanism, particles that are larger than the filter material interstices are trapped and held on the surface of the filtration medium.

- **Interception:** This mechanism allows particles to collide with the grains of sand.

- **Sedimentation:** Through this mechanism, particles are attracted by the force of gravity to the grains of sand, bringing about their collision. The action of electrostatic forces and those involved in the attraction of masses add considerably to this phenomenon.



Transport mechanisms

- **Diffusion:** This occurs when microvariations in the thermal energy of the water and the gases dissolved in it modify the particle's path, causing it to collide with the grain of sand.

- **Interstitial flow:** This mechanism refers to collisions among particles caused by the uniting and separation of flow lines due to the tortuousness of the filtration medium interstices. These continuous changes in the flow's direction create more opportunities for collision.

2. Adherence mechanism

This mechanism makes it possible to remove the particles that have collided with the grains of sand as a result of the mechanisms described above. The action of electrical forces, chemical actions and the forces exerted by the attraction of masses, as well as by the biological film that grows above them and where larger organisms, such as protozoa and rotifers, wreak havoc on pathogens, give the grains of sand their property of adherence.

3. Biological disinfection mechanism

The total removal of particles in this process, as indicated earlier, is due to the combined effect of the mechanism of adherence and the biological mechanism. Vigorous schmutzdecke must be produced in sufficient amounts to allow the filter to operate as a true "disinfection system." Only at that point will the SSF be able to operate properly. This is what is meant by the expression, the filter (or layer) "is ripe."

At the beginning of the process, the harmful or beneficial waterborne bacteria feed on the organic matter and multiply selectively, helping to produce the filter's biofilm. These bacteria oxidize the organic matter to obtain the necessary energy for their metabolism (disassimilation) and convert part of it into the material they need for their growth (assimilation). In this way, dead substances and organic matter are turned into live matter. The water carries the products of disassimilation down deeper, where they are used by other organisms.

The bacteriological content is limited by the amount of organic material present in the raw water and is accompanied by a concomitant mortality phenomenon, during which organic matter is freed for use by bacteria living at lower levels and so on, successively. In this way, the degradable organic matter that is present in the raw water is gradually decomposed into water, carbon dioxide and relatively innocuous salts, such as sulphates, nitrates and phosphates (mineralization), which are discharged in the filter effluents.

The bacteriological activity described is stronger in the upper part of the filter bed and decreases gradually with greater depth and the availability of food. When the upper layers of the filter are cleaned, the bacteria is removed. Another filter maturing period is then needed until the necessary bacteriological activity is developed. Bacteriological activity declines or stops at a depth of from 0.30 to 0.50 m (depending on the filtration velocity); on the other hand, biochemical reactions are produced that convert the products of microbiological degradation (such as amino acids) into ammonia and the nitrites into nitrates (nitrification).

Rural slow sand filter

Since the yield of the slow filter depends mainly on the biological process, while the biological layer is developing, the efficiency is low and SSF should not be considered an eliminator of organic matter, but only an improver of water quality, particularly of its turbidity.

A SSF may take from two to four weeks to mature.

Slow filtration disinfection by-products

The by-products of slow filtration disinfection are natural substances produced by biological degradation that hold no risk for human health, because the process does not require the addition of chemicals to react with the matter dissolved in the water. The by-products of slow filtration, in that sense, are carbon dioxide and relatively innocuous salts, such as sulphates, nitrates and phosphates, together with a low content of dissolved oxygen. Aeration can reverse these conditions.

Equipment and infrastructure

Given the simplicity of slow filtration, all that is needed is a pumping device when the hydraulic head must be raised so that the water can reach the filter. The quality of the crude water determines whether other installations are needed, in addition to the slow filter, to adjust the condition of the raw water to the filter's operating requirements.

The following table summarizes the pre-treatment alternatives for the installation of a slow sand filter, in accordance with variations in the quality of the source.

Process selection criteria, according to the quality of the source

Alternatives	Acceptable raw water quality limits		
	90% of the time	**80% of the time**	**Sporadically**
Slow sand filter (SSF) only	To ≤ 50 NTU Co ≤ 50 CU Fc. ≤ $(10)^4$/100 ml	To ≤ 20 NTU Co ≤ 40 CU	To max ≤ 100 NTU
SSF + gravel prefilter (GP)	To ≤ 100 NTU To ≤ 60 NTU Fc ≤ $(10)^4$/100 ml	Co ≤ 60 CU Co ≤ 40 CU	To max ≤ 150 NTU
SSF + GP + settling basin (SB)	To ≤ 300 NTU Co ≤ 60 CU Fc ≤ $(10)^4$/100 ml	To ≤ 200 NTU Co ≤ 40 CU	To max ≤ 500 NTU
SSF + GP + SB + presettling basing	To ≤ 500 NTU Co ≤ 60 CU Fc ≤ $(10)^4$/100 ml	To ≤ 200 NTU Co ≤ 40 CU	To max ≤ 1,000 NTU

Co = **Raw water color**
Fc = **Fecal coliforms**
To = **Turbidity of crude water**
CU = **Units of platinum cobalt color**
NTU = **Nephelometric turbidity units**

The most important design parameter in SSF is the filtration velocity (V_f), which must have a value in the range of:

$$0.1\ m^3/m^2\ \text{hour} - 0.3\ m^3/m^2\ \text{hour}$$

It should be noted that [m^3/m^2 hour] = [m/hour]

Other important design parameters in relation to the filtering material are:

Supporting bed:

Layer	Type	Particle diameter (mm)	Layer thickness (mm)
Upper	Coarse sand	1 – 2	50
Second	Fine gravel	2 – 5	50
Third	Gravel	5 – 10	50
Lower	Gravel	10 – 25	150

Filtration medium:

Effective size, d_{10}	0.15 – 0.45 mm
Uniformity coefficient UC	1.5 – 4.0
Filter media depth	0.5 – 0.7 m

When slow filtration is the only treatment, the velocity will be 0.10 m/h. Higher velocities may be considered for special cases in which other preliminary processes are involved, as shown in the following table:

Filtration velocity in accordance with
the number of preliminary processes

Processes	V_f (m/h)
SSF	0.10 – 0.20
Sedimentation (S) + SSF	0.15 – 0.30
Prefiltration (PF) + SSF	0.15 – 0.30
S + PF + SSF	0.30 – 0.50

The design velocity is also important for determining the number of units the filter will operate with. At least three units should be used for velocities of over 0.2 m/h.

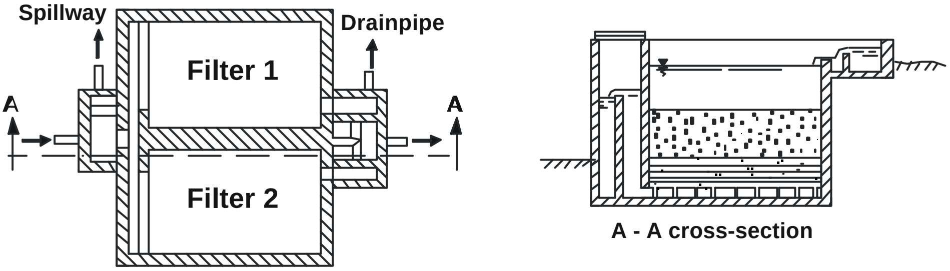
The area of each unit (As) is a function of the filtration velocity (Vf), the flow (Q), the number of operating shifts (C) and the number of units (N).

$$As = (Q \times C) / (N \times Vf)$$

With continuous operation, the unit area (in m^2) will be equal to:

$$As = Q / (N \times Vf)$$

Slow sand filters can be rectangular or round, depending on the material they are made of: concrete, reinforced cement or brick. The figure shows a modified rectangular concrete slow filter.



A - A cross-section

Modified rectangular concrete slow filter

Installation requirements

The following aspects should be considered when installing a slow filtration plant:

a. Location

- The area should be accessible and be equipped with a means of communication that will facilitate the filter's subsequent construction, operation and maintenance.
- Groundwater should not be present or should be located at a great depth.
- The area should be safe and not be exposed to natural or human risks.
- The topography of the chosen area should offer the necessary differences in elevation that would allow the system to operate entirely by gravity.

b. Community-related aspects

- Sociological studies should be made to determine the customs and beliefs that could affect the system's acceptance.

- The available demographic information should be checked.
- The human and material resources available to adjust the system design should be determined.
- The incidence of waterborne diseases and the presence of vectors should be studied.

c. Conception of the system

- To keep the system's operation reliable, avoid the use of devices to raise the water level (pumps). In that way, the system will not depend on electric power or sophisticated spare parts that are usually not available locally and that increase the system's maintenance costs.
- If the water level must be raised for topographical reasons, a single pumping stage should be implemented to raise the raw water to a level from which it can be distributed to the water reservoir and the system by the force of gravity.
- Continuous slow filtration is preferable, to allow for the operation of the smallest units possible and the continuous supply of the nutrients and oxygen needed to maintain the biofilm. To guarantee this situation when a pumping stage is used, a raw water storage tank should be built to supply the filtration plant by gravity over the 24-hour day.

d. Raw water conditions

The raw water conditions that affect filtration efficiency most strongly are temperature, concentration of nutrients and of toxic substances and affluents that are heavily turbid and colored. These are briefly described below:

- **Temperature:** The biological process that takes place in the filter is affected by temperature variations; it can lose 50% of its efficiency if it operates at less than 5 °C.
- **Concentration of nutrients:** The development velocity of the biological formation in the filter depends on the concentration of nutrients in the water, on which the microorganisms feed.
- **Concentration of algae:** Algae are important for the formation of the schmutzdecke. Excessive algae growth, however, due to the overabundant supply of sunlight and nutrients, and the presence of phosphates and nitrates in the water, can cause serious operational problems or problems with the quality of the treated water. While the growth of algae is difficult to control,

the problem can be resolved by controlling the nutrients in the water and the effect of the light on the reservoirs of raw water.

- **High concentrations of turbidity:** Slow filters have a very limited capacity for reducing water turbidity when it is very high. High turbidity causes the filter surface to become muddied, thus decreasing the capacity for biolayer formation and drastically reducing the run of the filter. This, in addition to affecting the quality of the water produced, also increases the operation and maintenance costs.

e. Filtering material

- Setting up a platform next to the filters for the washing and drying of the sand is a matter to be considered. A roofed storage area is also needed to store the bagged sand and the tools, and the installations should be fenced to keep out children and animals.

Operation and maintenance

The routine operating tasks include adjusting and measuring the water flow; monitoring the quality of the water produced; cleaning the surface of the sand by “scraping off” the upper portion of the filter (approximately 5 cm of sand); washing and storing the sand, and subsequently rebuilding the filter bed. The period between cleaning operations, known as the “run,” varies. Sometimes the cleaning must be done every three or four weeks and, in special circumstances, every several months.

Proper operation and maintenance are reflected in the filter’s efficiency, especially during the start-up stage or when a new filter is put into operation. During normal operations, the maturing of the biofilm, the frequency of the scraping operation, the duration of each cleaning operation and the way filter sand is replenished, are all important.

Insofar as the start-up is concerned, it should be borne in mind that new sand does not reduce bacteriological contamination. The initial effluent must be discarded time after time until an acceptable degree of efficiency is confirmed. This process can be accelerated, however, by sowing the filter with mature sand taken from other filters in operation.

The scraping of the filter bed should be started when the water in the filter box reaches its maximum height and begins to overflow through the spillway.

To reduce its impact on the efficiency of the treatment, the filter scraping operation should be carried out over a single day to avoid killing off beneficial microorganisms in the sand layer that will be kept in the filter to shorten the ripening period. It is important to use the ditching method for the resanding operation – when the bed has reached its minimum acceptable level (0.30 m) and the sand must be replenished to its design thickness. To do this, the sand at the bottom, which is semi-clogged, is placed on the filter surface, on top of the new sand, to speed up the ripening of the sand bed.

The filter must be thoroughly washed at least once every five years in the following way: all of the sand and the gravel are removed very carefully to keep them separate; the sand is washed; the sides of the filter box are scrubbed; the drainage of the box is readjusted, and then the sand and gravel bed is rebuilt. Any lost sand or gravel must be replaced. If any cracks are found on the sides or bottom of the box, these must be mended before the filter bed is added.

When the systems are well-designed, operated and maintained, the effluent from the slow filtration plants will require only very low doses of chlorine as a final barrier —just to make sure that the water keeps its bacteriological quality until it is consumed. This water has a very low health risk.

Monitoring and evaluation criteria

Water turbidity and bacteriological contamination are the main parameters for characterizing surface water in rural areas. When the treatment is combined with prefiltering or sedimentation, the specific purpose of these units is to reduce turbidity, while that of slow filtration is to reduce contamination. When only slow filtration is available, it must accomplish both purposes.

A minimum monitoring program for a slow filtration plant should include taking samples of raw and treated water to check the quality of the raw material that is entering the system and that of the final product obtained.

Turbidity measurement is simple and can easily be made by a trained operator. Daily measurements during the rainy season will make it possible to:

a) Evaluate the quality of the raw water.
b) Establish and supervise the plant yield.

c) Develop criteria for adjusting the plant operation.
d) Upgrade the characteristics of the units.

Advantages and disadvantages of slow filtration

Advantages	Disadvantages
ı The greatest advantage of this unit is its simplicity. A slow filter without a velocity controller and whose levels are controlled only by means of spillways is very reliable and simple to operate, using the means available in the rural areas of the developing countries. ı No organoleptic changes take place in the water quality. ı Communities accept the water treated by SSF.	ı Water with a turbidity of over 20 or 30 NTU should not undergo slow filtration without pretreatment, though occasionally peaks of 50 to 100 NTU are acceptable. ı Low temperatures impair the efficiency of this unit. ı The presence of biocides or pesticides in the affluent can modify or destroy the microbiological process on which slow filtration is based.

Equipment and operation and maintenance costs

The costs of slow filtration systems depend, for the most part, on the cost of the necessary cement, gravel, reinforcement steel, filter sand, pipes, valves and other elements. The prices of these materials vary according to different regional and local circumstances. Therefore, the following table contains only material cost estimates per production unit for four typical designs. It should be borne in mind that the information given in this table is based on data collected from a slow filtration project; it does not include labor costs or contractors' fees.

Description	Capital costs in $ per production unit (m^3/h)	Yearly operating and maintenance cost
ı Filter with protected slopes	$ 1,000 – $ 4,000	10% of the total capital costs
ı Circular reinforced cement filter	$ 1,500 – $ 3,000	
ı Circular stonework filter	$ 1,500 – $ 6,000	
ı Concrete filter	$ 3,000 – $ 12,000	

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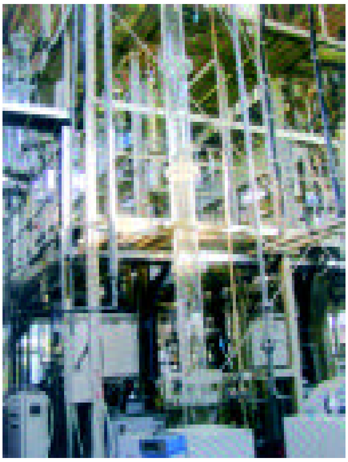
Chapter 6

OZONE



Introduction

Ozone has been known for more than one hundred years. In 1840 it was given its present name of "ozein," which means to stink, to reek. In 1857, an ozone generator was designed and in 1906 it was used for the first time in a water treatment plant in Nice, France.

Less than 10 plants were in operation in the United States before 1980, but the number has been growing heavily and, as we will explain, the demand for ozone plants will rise, as water treatment methods become more demanding.

Properties of ozone as a disinfectant and description of the method

Ozone (O_3) is a gas allotrope of oxygen. At normal temperature and pressure, it is an unstable gas that rapidly decomposes to return to its oxygen molecule (O_2). Due to this characteristic, it cannot be stored or packed in a container, but must be generated on-site and used immediately. Ozonation is generally chosen when its most important property is needed: its large oxidizing potential that enables it to eliminate organic compounds that give water a disagreeable color, taste or smell and, at the same time, to inactivate waterborne pathogens. An important characteristic of ozonation is the absence of a residual effect, which in this case is beneficial because the continued presence of ozone in the water would give it an unpleasant taste; at the same time, it is also a disadvantage because, as has already been stated, a disinfectant residual is needed to ensure water quality until it reaches the consumer.

Despite its excellent properties, its use is restricted to large cities with highly contaminated water sources; small and medium-sized communities use it very little. Ozonation's main drawbacks for them are its high initial and operating costs, as well as problems in its operation and maintenance. Even so, when the most accessible water sources are highly contaminated (biologically and chemically), ozonation may be the most recommendable method for oxidizing the organic substances and primary disinfection, provided that a secondary chlorination is always added to maintain the residual effect during water distribution.

While ozonation has been tested extensively, for communities with less than 10,000 people, it would probably be best to start off with a demonstration project insofar as its operation, management, and infrastructure are concerned. The future application of ozonation in small communities is becoming more feasible, as smaller capacity ozonation equipment is appearing on the market and prices are becoming more reasonable.

Ozone disinfection consists of the addition to the water source of sufficient quantities of ozone as rapidly as possible, in order to satisfy the demand and maintain an ozone residual during a long enough period of time to ensure microorganism inactivation or destruction. Most water supply systems require a larger amount of ozone than of chlorine, because of its high oxidation potential. Ozone disinfection is generally aimed at maintaining a minimum residual of 0.4 to 0.5 ppm after 10 to 20 minutes of contact with the water.

Ozone disinfection mechanisms

Ozone disinfection is based on the high power of ozone as a general cell oxidizer, making it an efficient bacteria destroyer. Evidence suggests that it is just as effective against viruses, spores and resistant bacteria and mold cysts.

The disinfecting capacity of ozone, unlike that of chlorine, does not depend so much on the length of time it is kept in the water (although this does have an effect), as on the dosage administered (in the C x T formula, the value of “C” predominates). The reason for this is that its high oxidizing potential makes ozone extremely unstable, even in distilled water; this means that only when the material with a high oxidizing capacity has been oxidized will some ozone remain and that for a short time only. Otherwise, it is quite possible that the demand for ozone may not have been completely satisfied. The importance of properly determining the ozone demand and the difficulty in determining the residual that will ensure complete disinfection are understandable, given ozone’s short permanence in the water.

When organic material is present, the chemistry is even more complex and ozone decomposition accelerates. With an oxidizing potential of 2.07 volts, ozone theoretically can oxidize most organic compounds and turn them into carbon dioxide and water. However, because it is selective as to the substances that it will rapidly oxidize, the kinetics of ozone’s reactions with many compounds will be too slow to convert them into carbon dioxide during the water treatment process. Inasmuch as the total demand for ozone is almost always larger than its supply, these reactions will cease long before all of the organic substances have been totally oxidized. In treating organic substances, ozone has been used mainly to rupture the multiple links as a preliminary treatment prior to filtration and as an aid to coagulation.

Another consideration to be kept in mind is that the effectiveness of ozone, like that of other disinfectants, depends on its contact with the microorganisms; therefore, an effort should be made to keep them from clumping and protecting themselves (if the water is turbid). A system should also be used to enhance the contact with the ozone before the gas dissipates.

Ozone disinfection by-products

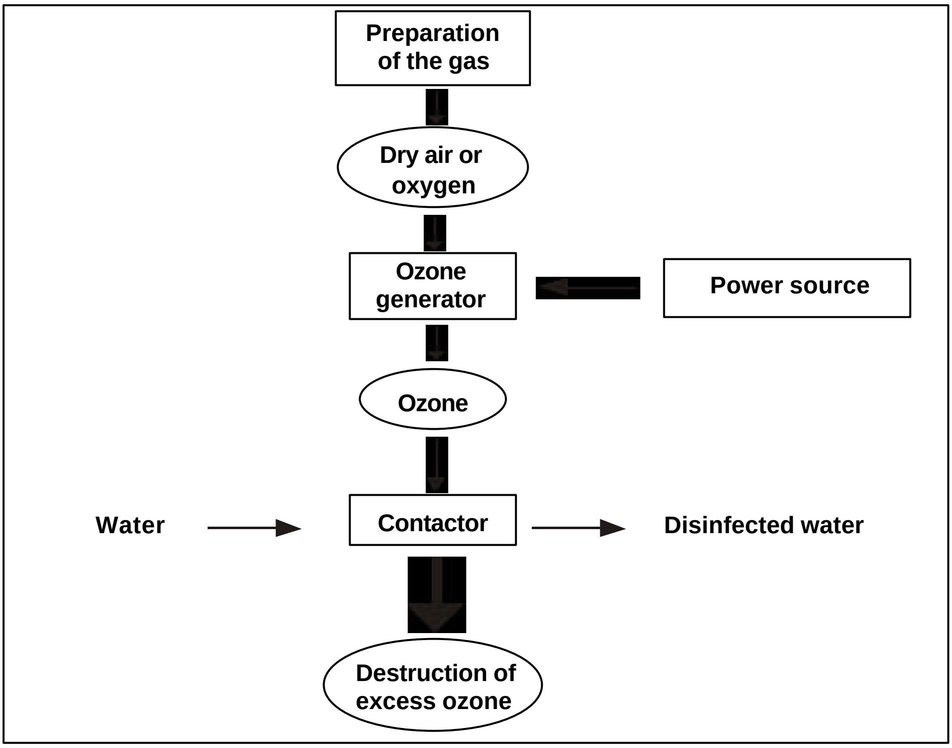
The ozone concentration needed to disinfect drinking water is not known to have any adverse effect on health. However, like chlorine, ozone can produce by-products, such as bromates, bromoform, bromacetic acid, aldehydes, ketones and carboxylic acids. Of these, the aldeydes are probably the most troubling for human health, but not enough information is available as of yet to evaluate the risk of exposure to these compounds in drinking water.

As in the case of chlorine, the health risks of no disinfection must be weighed against the presence of disinfection by-products. While much remains to be investigated with regard to the DBPs of natural or treated water ozonation, the existing tests indicate that the process can be considered safe for human health.

Chlorination immediately following ozonation is recommended for secondary disinfection, in order to cut down heavily on trihalomethane (THM) formation. It is also recommended that ozonation be followed by activated carbon or biofilm absorption because certain compounds are more biodegradable than usual after the process and it is necessary to avoid the risk of a biological resurgence in the water distribution systems.

Equipment

Ozonation systems have five basic components: the gas (air or pure oxygen) preparation unit; the ozone generator; the electric power source; the contactor and the surplus gas elimination unit. In most cases, as already stated, a secondary disinfectant is added to the ozone to ensure the presence of a lasting disinfectant residual in the distribution system.



Basic diagram of the ozonation process

The sections shown in the figure are described in more detail below.

a) Preparation of the gas

The purpose of the gas preparation device is to dry and cool the gas containing the oxygen. Crown-discharge type generators use dry air or pure oxygen as the oxygen source for conversion into ozone.

When air is used, it is vital to dry it to a point of condensation of –65 °C to maximize the effect of the ozone and reduce to a minimum the formation of nitrogen oxides that accelerate electrode corrosion. The air should also be cooled because the ozone rapidly decomposes into oxygen at temperatures of over 30 °C.

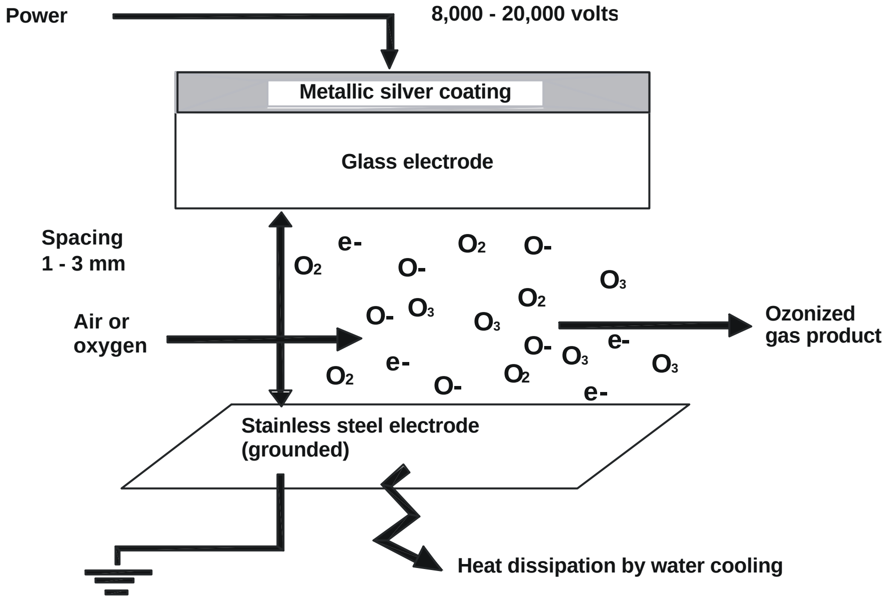
Chemical driers can also be used instead of refrigeration to dry the air. The cost is a little higher and varies considerably from place to place. But in the case of small systems, the simplicity of their operation and maintenance can offset that cost. Zeolite towers that act like a molecular screen have been used successfully to produce pure oxygen by eliminating the nitrogen in the air. Continuous improvements are being made to increase the ozone yield.

b) Ozone generators (ozonizers)

The ozonation systems used for water treatment generate ozone at the application site and almost all of them do so by means of a crown discharge produced by the passage of oxygen or dry air between two dielectrics.

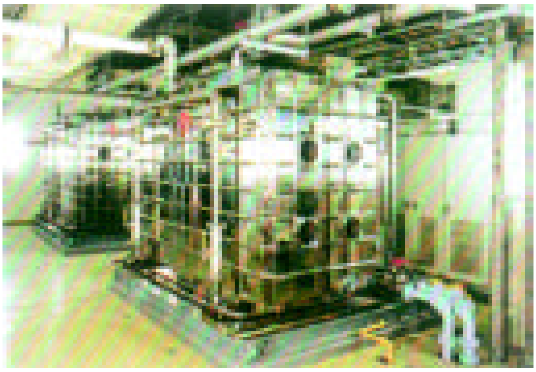
The patented ozone generators to be found on the market are the Tube, Otto plate and Lowther plate varieties. The Otto plate design, which is the oldest, operates by atmospheric or negative pressure and has the advantage of being able to operate at condensation points of up to – 30 °C without suffering any major damage; this design is ceasing to be used, however, because it is the least effective.

The Lowther plate device, which is air-cooled and can use atmospheric air or pure oxygen, requires the least power of all and has been used in small water supply systems. Little is known about its long-term operation, however.



Dielectric ozone generator

The horizontal tube, a water-cooled device, is used more for industrial purposes and for large water treatment plants, but several smaller versions have been developed for smaller capacity water treatment plants.



Generator in a DW treatment plant, Tokyo

A patented unit using small diameter dielectric tubes is able to generate up to 14% of ozone from oxygen, this being one of the values that has been reported thus far.

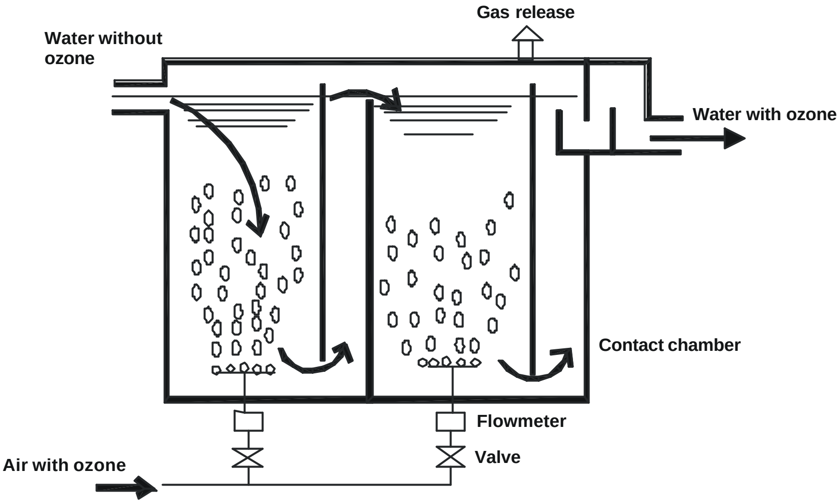
c) Electric power source

The most commonly used electric power sources are low frequency (50 to 60 Hz) and high voltage (> 20,000 volts). Technological advances have produced devices that operate at high frequency (1,000 to 2,000 Hz) and 10,000 V, which are used for large water systems. The higher frequency power sources tend to be more effective, but have not yet been introduced massively in small community water supply systems.

d) Contactors

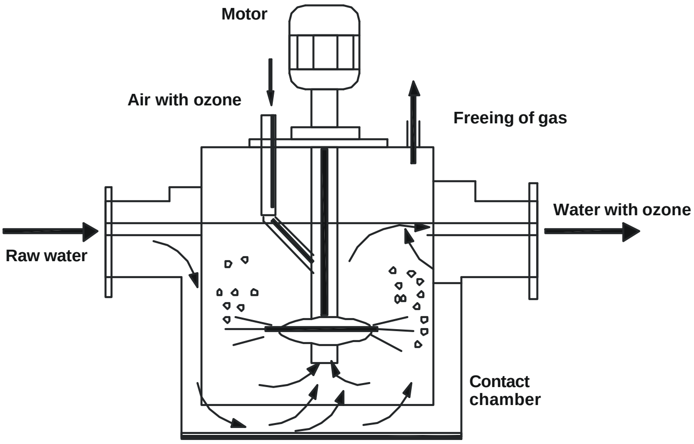
Ozonation systems use contactors to transfer the ozone that has been generated to the water for disinfection. The type of contactor chosen depends on the specific objective of the ozonation. These can be broken down into rapid reaction objectives: such as microorganism inactivation, iron, magnesium and sulfur oxidation, and flocculation improvement; and slow reaction objectives: the oxidizing of more difficult substances, such as pesticides, volatile organic substances and other complex organic substances that for kinetic reasons tend to require longer reaction times. In this latter case of longer reaction times, ozonation is usually completed by using ultraviolet light or hydrogen peroxide in a combined effect that is generally known as an “advanced oxidation process.”

Failures of ozone disinfection systems can generally be traced to injector failures and defects in the contactor design and construction. There are two basic contactor designs: one with bubble diffuser chambers and the other containing a turbine-agitated reactor. In the former, there can be a series of chambers separated by deflectors or baffles or the chambers can be arrayed in parallel, in which case



Separate chamber contactor with baffles and diffusers

the device is called a “multicolumn” contactor. Studies have revealed that the multicolumn bubble diffuser produces the most efficient transfer. In water supply systems, ozone is frequently generated with a pressure of 1 kg/cm^2 and disperses in very fine bubbles that discharge in a 5-meter high water column in which the oxidation and disinfection take place. Contact columns or chambers (usually filled with irregular pieces of plastic material to lengthen the exchange period and disperse the bubbles), static agitators and propeller or turbine diffusers can be used to accelerate the ozone gas solution and help to ensure mixing and contact.



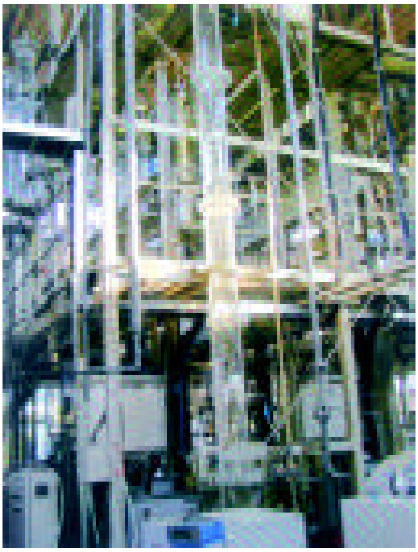
Turbine diffuser

All type of contacts use the counterflow, in which the water flows downward and the air bubbles rise to maximize the contact time.

e) Destruction of the surplus ozone

The dissolved ozone will reach a concentration directly proportional to the partial pressure exerted by the ozone on the water. As a result, even with a transfer efficiency of 90% (one of the highest attained), the escaping gas can contain from 500 to 1,000 ppm of ozone. The surplus ozone gas is frequently recirculated to a prior unit process to improve the oxidation or flocculation so that it can be used to the fullest.

Despite the recirculation, (surplus) ozone is generally present in the escaping gas and should be destroyed or sufficiently diluted for safety reasons. In small water treatment plants, ozone can be diluted with air, but large treatment plants use one of the three following methods to destroy surplus ozone: 1) thermal decomposition by raising the water temperature to over 300 °C; 2) catalytic decomposition by making it flow through metal or metal oxides, and 3) absorption in moist granular activated carbon.



Ozone system
Tamagawa plant (Japan)

Installation and requirements

- **Power requirements:** While the installation of the ozone system does not require much power, the air drying does. The combined power consumption is 25 and 30 kilowatts-hour of electricity per kilogram of ozone generated in the oxygen and air-fed systems, respectively.

  Since it is important to maintain the disinfection process while the water flows, it may be necessary to have reserve power generators on hand at sites where the electric power supply is not reliable, in order to guarantee the continuity of the disinfection. This could be an important consideration in small towns where the electric power supply is not continuous.

- **Installation requirements:** In order to produce the amount of ozone needed by medium-sized and small towns, all elements, except the contactor, may be put together in a unit and mounted on a trolley to convey it to the site of use. This is usually the least expensive way to install small ozonation systems. Since the contactors for small ozonation plants can be made of concrete, reinforced fiberglass or PVC, they are often built at the site.

  A minimum of 20 square meters of space are needed for a small ozonation system. The building should be well aired using a fan and the doors should open outward. All of the ozone gas pipes should be made of 304-L and 316-L stainless steel for dry and damp service, respectively. The equipment lay-out plan should include enough space for removing and replacing the ozone generator components. Tube-type generators will require additional space. The enclosure should be made of corrosion-resistant material, such as brick or concrete blocks.

Operation and maintenance

The everyday operation of small ozonation systems involves very few requirements. Daily maintenance tasks have been estimated to take about half an hour a day. The reason why these figures are so low is that most of the operation is automated. Even so, a highly skilled technician is needed to repair or service the air preparation equipment, ozone generator, and automated monitoring or control system.

Usually, the monitoring and dosage adjustment functions are fully automated, even in the smallest systems. This can be done only in places where the supplier or manufacturer offers safe and reliable customer service, however. Many failures of ozone generators are due merely to burned out fuses undetected by the operator. Repair of the electronic equipment would probably be beyond the ability of the operator of a treatment plant in a town or small city of a developing country. Furthermore, the system instruments must be continuously adjusted and calibrated and the air drier must be kept in good operating condition to avoid the premature failure of the dielectric as a result of humidity.

Monitoring

Monitoring and testing to detect ozone involve more than just watching over the residual in the water distribution system. It is also necessary to keep an eye on the gas that escapes from the contact chamber or chambers to make sure that ozone is not being wasted and that a sufficient dose has been administered to produce the desired oxidation and disinfection. In addition, the ozone in the treated water must be monitored so that the production rate can be adjusted to changes in the quality of the affluent water. This is particularly important if the water has not undergone appropriate treatment before ozonation. In any case, continuous vigilance is necessary for reliable ozone treatment.

Among the tests for detecting the gas is the potassium iodine method described in the “Standard Methods” of the American Water Works Association of the United States of America, which, because it is slow and tedious to perform, is more practical as a standard method for calibrating ozone detection devices than for routine tests.

Another one is the indigo colorimetric method, based on the measurement of the potassium indigo trisulfonate discoloration. Its main virtues are that it is sensitive, selective, exact and simple. Its disadvantage, however, is that this method must be carried out in a laboratory and cannot be used for field tests.

Another satisfactory method for measuring the amount of ozone in the water is to use amperometric instruments that utilize a continuous flow measurement cell with two different metallic electrodes to generate a current proportional to the amount of ozone that is present. These electrodes are being used today in water treatment plant automated ozonation surveillance and control systems. Their major drawback is that the electrodes need frequent calibration and cleaning because they are contaminated fairly easily.

Lastly, there are some devices that use the absorption of radiation from UV rays, together with double beam spectrophotometric instruments for continuous ozone surveillance, both in the treated water and in the gas escaping from the contact chamber. This equipment is usually used in the automated control systems that adjust ozone production to bring it into line with changes in water quality as these occur, in order to ensure appropriate oxidation and disinfection and reduce to a minimum excess ozone in the escaping gas.

Although manual adjustments can be made in the dosage, based on the monitoring of the ozone residual, this is not practical, except when the water quality is extremely stable, as can be found in some wells. In such cases, it is possible to make manual adjustments at sufficiently long intervals for the method to be practical.

Full automation of the surveillance and adjustment functions is the normal practice today, even in the smallest systems. This is only possible, however, when the supplier or manufacturer provides customers with immediate technical assistance. In small communities that do not have the necessary technical expertise to maintain and repair equipment of this kind, this is not possible.

Advantages and disadvantages

The important point of disinfection via oxidation is that a large part of the ozone will generally be consumed by other substances that are usually present in the water and that this demand must be satisfied before disinfection can be assured.

From the viewpoint of biocide effectiveness, ozone is the strongest disinfectant used in water supply systems. The contact times and concentrations for inactivating or killing waterborne pathogens are much lower than those of free chlorine or any other disinfectant. Ozone disinfection capacity does not vary much within the normal pH interval of water supply systems.

Its main disadvantage is that ozone does not provide a stable residual, although it is an excellent primary disinfectant that accomplishes the destruction of microorganisms. Therefore, it will be necessary to add a secondary disinfectant to provide the disinfectant residual and protect the water against possible contamination in the distribution system. For these reasons and because its cost is relatively high, *ozone is rarely used for disinfection purposes alone*; rather, it is used when other aspects of water treatment must be improved simultaneously with disinfection, through ozone's power of oxidation.

Ozone has two other important limitations as a single disinfectant: its average life in the water is generally less than 30 minutes and it also reacts with organic substances to produce derivative substances with a lower molecular weight that are more biodegradable than their precursors.

This could generate new microbial growth in the distribution system because the ozone decomposes the organic substances and converts them into forms that microorganisms usually to be found in distribution systems can use as nutrients. Because of these limitations, ozone tends to be combined with other disinfectants (secondary disinfectants) that have weaker but more lasting residuals, in order to impede the resurgence of microorganisms in the distribution system.

The capacity of ozone to react with organic substances can be put to use to eliminate the converted compounds that filtration following ozonation have made biodegradable.

Economically-speaking, ozone can be used most beneficially when it is employed for other water treatment purposes, at the same time as the disinfection, such as to decompose synthetic organic substances, eliminate phenols, avoid the formation of trihalomethanes, improve flocculation and for other similar purposes. As indicated earlier, ozone is such a strong oxidant that it is almost always used for multiple purposes in treating water supplies, instead of merely as a disinfectant.

Costs

Insofar as the cost of ozone equipment is concerned, a typical generator for a small population of 10,000 people (with a daily water consumption of 100 liters/ person x day), costs approximately $ 20,000. This cost can be misleading, however, because a generator must be accompanied by a series of auxiliary devices with an additional cost, which is usually high. By way of example, the cost of a system to treat 1,500 m^3/day (15,000 inhabitants) is shown below, broken down into components:

Component	**Cost ($)**
Generator	25,000
Exchange tank	15,000
Dissolved O_3 analyzer	7,000
Auxiliary and spare parts and extras	5,000
Total cost of the system	**52,000**

It is necessary to add the installation costs, which companies charge separately, and the cost of the technicians that the companies supply, costs that range from $ 500 to $ 750 a day plus travel fares and living expenses for the installation and start-up periods.

The maintenance costs, above all if the systems depend on technicians that must travel from distant sites, can also be large. The operating expenses, for their part, are not large of themselves, with the average cost being estimated in the range of $ 0.03 to $ 0.06 per m^3 of treated water.

For rural use, a small simple system with no extras or analyzers to treat up to 200 m^3 of water a day can cost between $ 5,000 and $ 10,000.

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Additional reference

International Ozone Association: www.int-ozone-assoc.org

Chapter 7

CHLORINE DIOXIDE

Introduction

Chlorine dioxide (ClO_2) is a disinfectant with a stronger biocidal capacity than that of chlorine and chlorine compounds. Its selective oxidating qualities make its application an alternative to be considered for cases where not only must the water be disinfected, but its organoleptic qualities must also be improved. It has a major effect on controlling the taste and odor of water, as well as destroying organic substances that color the water or are trihalomethane (THM) precursors. For that reason, it is applied particularly when the raw water contains large concentrations of precursors and the use of traditional chlorination would act on these precursors to bring about the formation of disinfection by-products (DBP). Even so, its use as a disinfectant in water treatment plants is limited by the complexity and sensitivity of its production and its relatively high cost.

Chlorine dioxide is not sold off the shelf, but must be generated on-site. Furthermore, it is used only as a primary disinfectant and its generating and management are complex and risky. For those reasons, its use is not recommended for small communities with little technical expertise. That is why it is not very popular in developing countries and is used only very occasionally for medium-sized to large systems in developed countries. Those are quite possibly the reasons why the use of chlorine dioxide will be given little priority in rural areas of developing countries as compared with other, more “friendly” disinfectants like chlorine, UV radiation and SSF and its popularity will be comparable only to the excellent, but sensitive and demanding, ozonation process.

An explanation is due here, however. Chlorine dioxide has been the subject of a great deal of research and in recent years new technologies and forms of production have appeared, making this technique one of the most active and innovative, together with the synergistic methods that are described later in this manual. It is quite possible that science will at any moment come out with a new method that will reduce the shortcomings of today’s methods and remain the only choice that combines all of their qualities and advantages.

Properties of chlorine dioxide as a disinfectant and description of the method

Chlorine dioxide is a yellowish-green gas that is stable and relatively soluble in water until it reaches concentrations of up to 2%. One of the more interesting properties of chlorine dioxide is its biocidal efficacy over a wide pH range from

3 to 10 (even better at from 4 to 9). In addition to its disinfecting properties, chlorine dioxide also improves the quality of the drinking water —it neutralizes odors, removes color and oxidizes iron and manganese. Chlorine dioxide is ultraviolet light sensitive.

Although new methodologies ("SCD" or "Stabilized chlorine dioxide") have appeared that could change the situation, today ClO_2 cannot be compressed or stored in cylinders like chlorine gas; nor can it be transported because of its instability. As a result, it must be produced on-site by special generators.

Two mechanisms are usually used to generate chlorine dioxide: by reacting sodium chlorite with chlorine gas (two chemical compounds system) or by reacting sodium chlorite with sodium hypochlorite and sulphuric acid (three chemical compounds system).

$$2NaClO_2 + Cl_2 \longrightarrow 2ClO_2 + 2NaCl \qquad \text{(two compounds)}$$

$$2NaClO_2 + NaOCl + H_2SO_4 \longrightarrow 2ClO_2 + NaCl + Na_2SO_4 + H_2O$$

(three compounds)

Strictly as a disinfectant, ClO_2 offers the following advantages:

- Its bactericidal potential is relatively independent of the pH at between 4 and 10.
- It works better than chlorine for treating spores.
- It needs little contact time.
- It is quite soluble.
- No corrosion is produced at high concentrations, thus reducing maintenance costs.
- It does not react to ammonia or ammonium salts.
- It improves coagulation.
- It is better than chlorine for removing iron and manganese.

Chlorine dioxide has limited residual properties; for that reason, chlorine is generally used as a secondary disinfectant to ensure additional protection of the water distribution system.

Chlorine dioxide disinfection mechanisms

Chlorine dioxide exists in the water as ClO_2 (little or no dissociation) and, therefore, is able to permeate through bacterial cell membranes and destroy those cells. Its actions on viruses include the absorption and penetration of the protein coat of the viral capsid and reacting with the viral RNA, thus damaging the genetic capacity of the virus.

Chlorine dioxide produces a smaller microbicidal effect than ozone, but it is a stronger disinfectant than chlorine. Recent research in the United States and Canada demonstrates that chlorine dioxide destroys enteroviruses, *E. coli* and amoebas and is effective against *Cryptosporidium* cysts.

The following table compares the biocidal efficacy, stability and effect of pH efficacy of chlorine dioxide and three common disinfectants.

Biocidal efficacy, stability and effect of the pH

Disinfectant	Biocidal efficacy	Stability	Effect of pH efficacy
Ozone	1	4	Little influence
Chlorine dioxide	2	3	Little influence
Chlorine	3	2	Decreases considerably as pH rises
Chloramines	4	1	Little influence

1 = More ; 4 = Less

This table shows that ozone, despite having the strongest oxidation potential, is the least stable of the four compounds. It can also be noted that chloramines may be the least effective biocide, but exhibit a longer residual effect.

Chlorine dioxide reacts with phenolic compounds, humic substances, organic substances and metal ions in the water. This oxidation potential frequently improves the taste, odor and color of the water and also eliminates the possibility of THM production when the constituent elements of chlorine dioxide are appropriately dosed in the water at the site.

By-products of disinfection with chlorine dioxide

Where chlorine disinfectants react with different substances through oxidation and electrophilic substitution, chlorine dioxide reacts only via oxidation. That is why the use of chlorine dioxide can result in reduced THM formation in treated water. Production of high levels of THM in chlorine dioxide treated water can usually be attributed to poor chlorine dioxide generator performance, generally because of excess chlorine, a substance that participates *per se* in THM formation.

Often the products of chlorine dioxide oxidation do not contain halogen atoms and more specifically, in the presence of humic substances, chlorine dioxide does not generate high levels of THM. No formation of trihalomethane containing bromine has been noted when treating humic materials with chlorine dioxide. Nor does it react with ammonia to form chloramines.

Even so, the existence of DBP cannot be denied and the products formed by the reaction of chlorine dioxide with organic material in the water include chlorophenols and maleic, fumaric and oxalic acids. A study of the by-products of chlorine dioxide in a pilot treatment project revealed the presence of more than 40 DBP, most of them of unknown toxicity.

During the oxidation of organic material, the chlorine dioxide breaks down to a chlorite ion. Chlorite and the chlorates are precisely the most important DBPs produced by the use of this disinfectant.

The WHO has not yet established a guideline value for chlorine dioxide because of its rapid breakdown into chlorite, chlorate and chloride and because the provisional WHO guideline value for chlorite of 200 mg/liter offers adequate protection against the potential toxicity of chlorine dioxide.

Equipment

There is no industrial standard for the performance of chlorine dioxide generators. Generator efficiency is defined not only in terms of the conversion of sodium chlorite into chlorine dioxide, but also of the generating of by-products such as chlorate ion, free chlorine and surplus chlorite. If the generator fails to operate properly, it can produce these by-products in excessive amounts and reduce the expected results. Poor generator performance will also result in higher operating costs than desired.

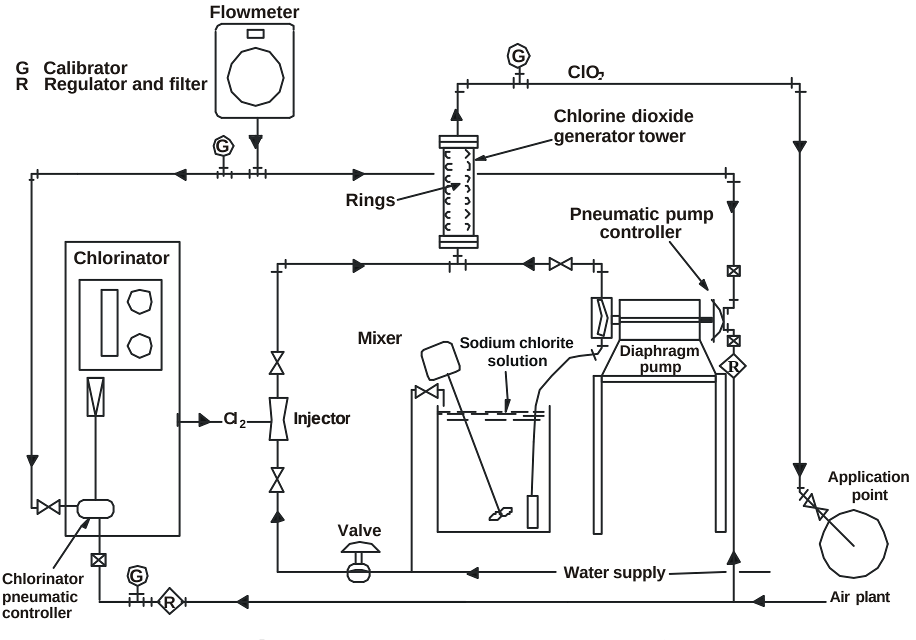
Modern chlorine dioxide generators are capable of consistently performing at the desired levels, when properly operated.

It should be borne in mind that disinfection with chlorine dioxide is recommended only for cities that have human and material resources necessary for good operation and maintenance, as well as for the follow-up of appropriate safety measures.

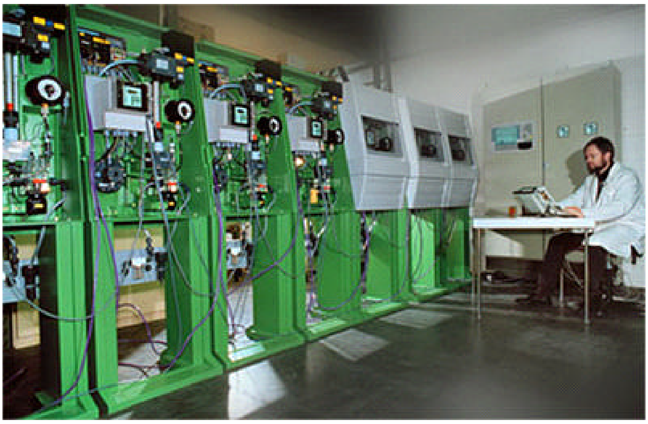
Chlorine dioxide generator with automatic proportional feeding

Although each component of a ClO_2 generating plant is relatively simple (pumps, flowmeters, mixers, injectors, etc.), together they make up a complex system requiring trained personnel for its understanding, operation, maintenance and repair.

The figure illustrates a typical chlorine dioxide installation that uses an air pressure signal to provide a proportional control over the supply of chemical substances. The same results can be obtained if some internal components of the pneumatic or electrical system are changed.



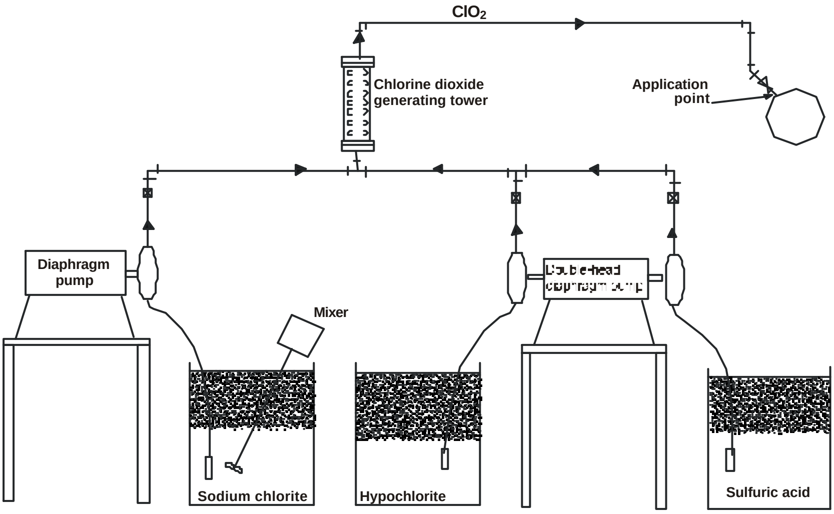
ClO_2 generator (two-component system)



Plant for producing 100 kg of ClO_2/hour (600,000 inhabitants)

The chlorination station may consist of a diaphragm pump that feeds a sodium chlorite solution to the reaction tower, installed in the chlorine dioxide discharge line. The diaphragm pump is controlled pneumatically in such a way that it is compatible with the feeder's automatic proportional control.

The water flow treated by the chlorine dioxide station is governed by the degree of concentration of the chlorine solution. The maximum concentration possible under ideal hydraulic conditions is 5,000 ppm, while the lowest limit for producing the necessary reaction is 500 ppm.



ClO_2 Generator (three-component system)

- ***Equipment adapted to generate chlorine dioxide from hypochlorite***

The figure illustrates the equipment for water works that use hypochlorite. These installations usually treat only a flow of from 30 to 45 l/s, which is equivalent to a maximum population of between 30,000 and 40,000 people. They can also be used in small well water supply systems with only one automatic start-up and stopping operation.

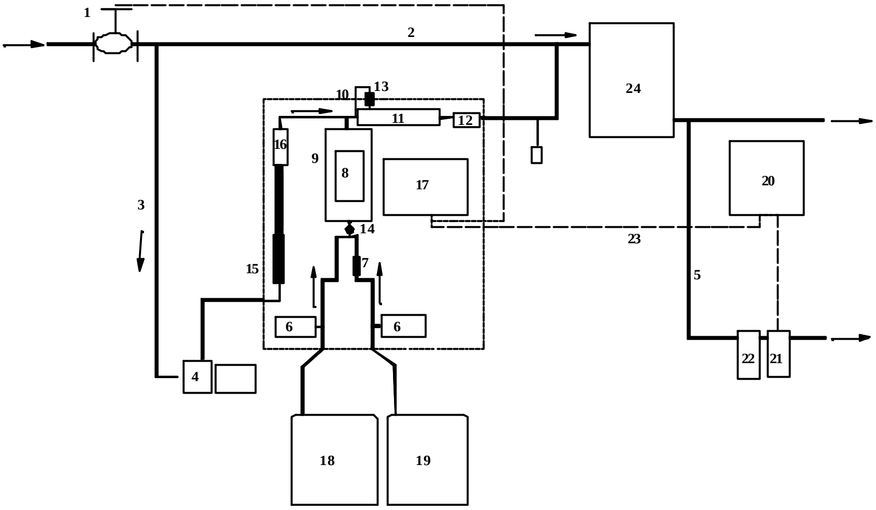
- ***Modern chlorine dioxide generating equipment***

As already stated, a ClO_2 system can be relatively complex, using modern technology to permit a dosage proportional to the water flow through digital flow controllers. The efficiency of the operation makes it possible, on the one hand, to optimize operating costs; it is more economic, because no surplus sodium chlorite or chlorhydric acid is produced. On the other hand, such careful operation makes THM formation impossible, inasmuch as trihalomethanes appear when the dosages of chlorine dioxide components are not properly proportioned. This equipment can generate 30 to 4,000 g/h of chlorine dioxide, making it possible to treat flows of from 20 l/s to as much as 2.5 m^3/s for a 0.5 mg/l dose in the water. The flexibility of this equipment allows for the supply of any size population from a small town of 20,000 to a city of two million.

Installation and requirements

Chlorine dioxide in aqueous solution is highly corrosive –even more so than chlorine in some aspects. By way of example, there are rubber hoses for chlorine concentrations of from 1,500 to 2,000 ppm that are known to have been in service for 20 years. Those same hoses could not be used in a generating tower chlorine dioxide feeder for more than 4 or 5 years. The recommended materials for chlorine dioxide feeding lines are, in order of preference: type I PVC and polyethylene. The use of rubber hoses should be avoided.

Special care should be taken in storing sodium chlorite and safety experts should be consulted about the subject. The compound should be stored in an outside structure, preferably away from the main buildings, and built, insofar as possible, of non-burning material, such as corrugated steel, prefabricated concrete or brick. In hot climates, sufficient water should be available to keep the sodium chlorite area fresh and prevent its deterioration from the heat.



Installation layout of a modern chlorine dioxide generating system

Where:

1. Water intake
2. Main pipe
3. Shunt for the disinfection system
4. Booster pump
5. Branch pipe for monitoring
6. Metering pumps
7. Flow sensor
8. Reactor
9. Reactor support
10. Proportioning valve (pressure sensitive)
11. Mixer
12. Check valve
13. Air valve
14. Suction device
15. Equipment frame
16. Check valve
17. Production level control device
18. Safety container for acid
19. Safety container for chlorite
20. Supplied chlorine dioxide meter
21. Chlorine dioxide test probe
22. Water level controller
23. Connector
24. Contact chamber (10 – 15 minutes)

Small system for a low water flow

Electric power and trained personnel are needed to install this equipment. The installation must be carried out appropriately to ensure safe management of the supplies used to generate chlorine dioxide. The necessary chemical substances must also be available, such as chlorhydric or sulphuric acid, sodium chlorite, sodium hypochlorite or chlorine gas, according to the chosen type of equipment.

Operation and maintenance

Sodium chlorite must be handled with great care to avoid its spillage during the operation. If spilled, an absorbent cloth must never be used; the surface must always be flushed with plenty of water; too little is worse than none.

Monitoring

Because chlorine dioxide reactions include the formation of chlorite ion as a by-product, a simple test kit cannot provide the analytical data required for its control. The analysis of the chlorine dioxide generator stream and treated water is required to accurately quantify the dosage and by-products. It is necessary to differentiate specifically between the chlorine dioxide, chlorite ion and free chlorine in the generator stream in order to determine both yield and efficiency. Four-step amperometric titration is the recommended method for determining the generator’s yield and efficiency. Test equipment is available for concentrations of less than 5 mg/l in the treated water, but it has its limitations and interferences.

The truth is that ClO_2 monitoring is a further disadvantage, because trained personnel are needed for routine analyses and it should be kept in mind that an average of 45 minutes are needed to determine each chemical.

Advantages and disadvantages of the method

Advantages	Disadvantages
- Effective against many microorganisms and more potent than chlorine over a short contact period. - Stronger oxidant and contributes to the removal of odor, color and bad taste. - No trihalomethane formation. - Apparently not affected by variations in pH. - Improves iron and manganese removal.	- Complex. - Costs more than chlorine. - Chlorite and chlorate by-products are formed. - Must be generated on-site. - Trained workers are required for its operation and maintenance. - Difficult to analyze in the laboratory.

Costs

The capital costs of chlorine dioxide production equipment vary according to a number of elements. The costs cannot be evaluated generically with any precision. In each case, budgets must be requested from the suppliers, which will analyze the type of process, quality of raw water involved, treatment plant characteristics, country, site, installation conditions, and so forth.

From the operational viewpoint, the United States Environmental Protection Agency study is generally the standard. In 1998, the EPA analyzed the cost of supplementing the Safe Drinking Water Act (the country's federal standard) through disinfection with ClO_2 .

Operational costs of chlorine dioxide in dollars (1998)

For a population of (inhabitants)	Cost of disinfection ($/m^3)
10,000	0.02
60,000	0.01

Information sources

ALLDOS International. *Photos*; www.alldos.de

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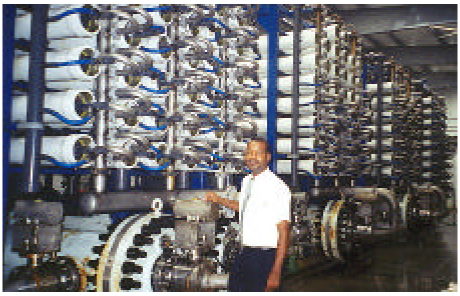
Chapter 8

MINIFILTRATION



Introduction

While conventional filtration (slow and rapid) uses particulate material, minifiltration utilizes special membranes. Disinfection by minifiltration operates on the physical principle of filtration, unlike chlorine, chlorine dioxide or ozone disinfection, which follow the principle of chemical oxidation.

Although minifiltration methods are effective for removing pathogens, they are not often used in cities in developing countries because of the high investment and operating and maintenance costs involved. The treated water produced by the few plants using these systems in Latin America is excellent and, because they are almost fully automated, the operators do not necessarily have to be trained. These plants operate like efficient robots that take in dirty water and produce an excellent quality effluent.

However, because of the microprocessing of the automated systems, any problems that could arise would have to be resolved by the manufacturers themselves. The results are high costs, delays and users who may be temporarily left without drinking water service. These systems have the additional disadvantage of requiring a secondary disinfectant to ensure the water's innocuousness until it is consumed, because the treatment does not provide any residual effect.

Properties of disinfection by minifiltration and description of the method

Minifiltration encompasses **microfiltration**, **ultrafiltration**, **nanofiltration** and **reverse osmosis**. Membrane pore size determines the difference in category. As a result, the disinfecting property of these membranes depends on their capacity to "retain" the pathogens, which are larger than the pore size. The following table shows the methods and pore diameters that retain species or microorganisms, from the viewpoint of retention with a disinfection capacity. While the ranges presented are not exact, they do give an idea of the relative range of each.

Disinfection by microfiltration is carried out using a membrane with pore diameters of up to 0.2 microns. Although this is the largest membrane used for minifiltration, its capacity is sufficient to allow a drinking water treatment plant to cover, in a single step, some of the most serious problems presented by the technologies in use today. Among them:

Minifiltration characteristics

Filter (membrane)	Pore diameter Microns (m)	Pressure (psi)	Retention (filtered substances)
Reverse osmosis	< 0.001	200 – 1,500	Salts, free radicals
Nanofiltration	0.001 – 0.01	70 – 250	Sugars, molecules
Ultrafiltration	0.01 – 0.1	15 – 200	Colloids, viruses
Microfiltration	0.1 – 0.2	10 – 50	Bacteria, cysts

From the viewpoint of the treatment:

- Simpler operation
- Reduction of chemical products needed for coagulation
- Removal of suspended solids and turbidity
- Reduction of sludge requiring disposal.

From the viewpoint of the disinfection:

- Removal of bacteria in general
- Removal of *Giardia, Cryptosporidium* and other parasitic cysts
- Virus reduction
- Less use of chemical disinfectants (with prechlorination).

This type of treatment is obtained by using any of the minifiltration methods listed above; as the pore size grows smaller, retention increases.

Disinfection by *nanofiltration,* for example, uses a membrane with pores and operating pressures whose values fall between those of ultrafiltration and reverse osmosis membranes. The typical operating pressures are between 70 and 250 psi (pounds per square inch).

Nanofiltration membranes retain a portion of the total dissolved solids (mainly diatomic ions) and remove most of the dissolved organic matter present in the natural water. This means that nanofiltration is also a highly efficient color remover.

Nanofiltration is useful in drinking water treatment plants for:

- Desalinizing brackish water
- Removing organic trihalomethane (THM) precursors from surface water.

Mechanism in disinfection by minifiltration

Disinfection by minifiltration is attained by passing the water to be treated through the membrane contact surface, where the water particles are retained or permeated, according to their physical size. That is why moderate differences in pressure are applied; transmembrane pressure can be positive when applied to the affluent and negative (vacuum) when applied to the treated effluent.

The table below lists a series of species, compounds and microorganisms that can be removed using the different techniques.

By-products of disinfection by minifiltration

Disinfection by minifiltration, which is a purely physical process, does not generate by-products because no chemical compounds are used.

Materials and equipment used

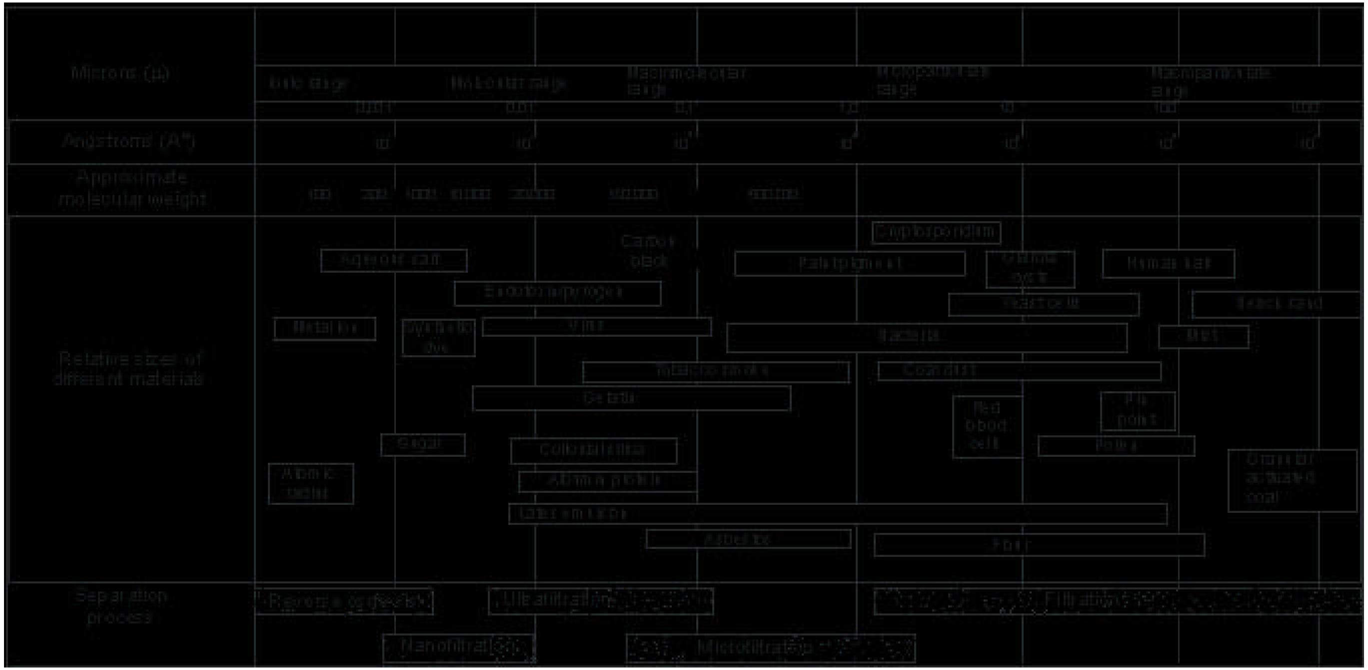
The membranes used for minifiltration consist of very thin microporous layers attached to a thicker and porous support. The membranes can be made of different materials: cellulose acetate, different ceramics, polysulfone resin and polyvinylidene resin, while the supporting structure is generally fashioned from polypropylene, polyester or even polytrifluorethylene resin.

While ceramic and metal membranes are generally used for industrial purposes, polymer membranes are coming into common use for drinking water treatment and municipal applications.

Minifiltration devices, as already stated, operate with a positive or negative (vacuum) transmembrane pressure differential. Different types of membranes are used for each device.

a) Pressure-driven membranes

These membranes were first designed as flat sheets rolled to form a spiral shape. Their low tolerance to solid matter and the high pressures needed for their operation made them very expensive to use. For that reason, they are often utilized for microfiltration. They are employed when the aim is not to retain solids, but to desalinize brackish or sea water through nanofiltration or reverse osmosis.



Minifiltration classification

Some membrane structures

Hollow fiber membranes were developed in the past decade to meet the need for microfiltration with low operating costs. These membranes rapidly became the industry standard and are used to treat drinking water.

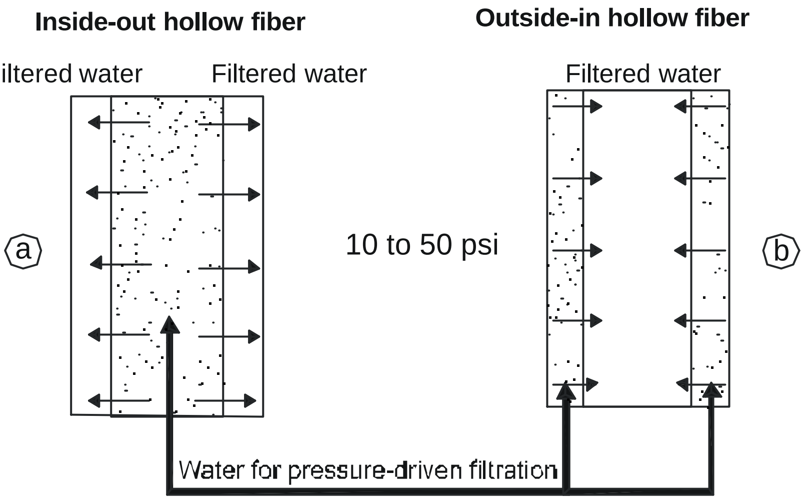
There are two kinds of pressure-driven hollow fiber membranes:

- *Inside-out membranes*, where the affluent is inside the membrane and the clean water is obtained when it passes through the membrane and emerges outside (figure a). (Next page).
- *Outside-in membranes*, where the affluent is outside the membrane and the clean water is produced when it passes through the membrane on going inside (figure b).

All pressure-driven, hollow fiber membranes are installed in pressure containers that apply the necessary pressure for proper fluid transfer. The typical operational pressure for these membranes is 10 to 50 psi.

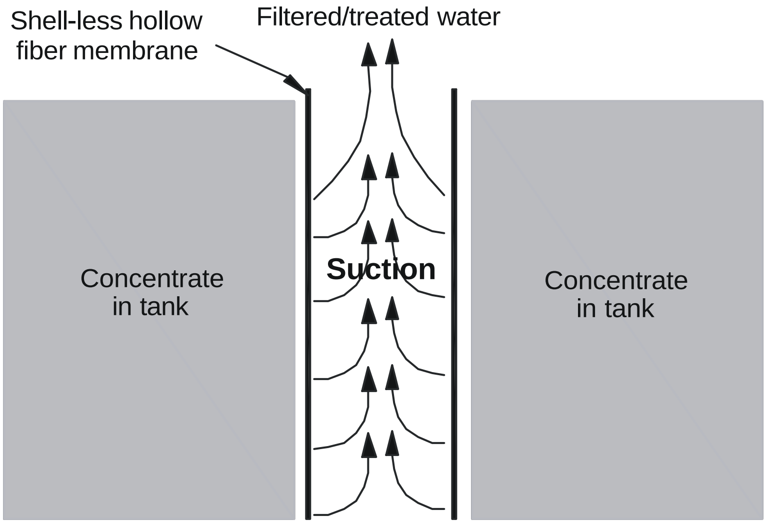
b) Vacuum-driven membranes

Vacuum-driven membranes operate under a pump-generated suction within the hollow fibers. The treated water passes through the membrane, enters the hollow fibers and is pumped out for distribution.An airflow is introduced at the



Pressure/driven microfiltration methods

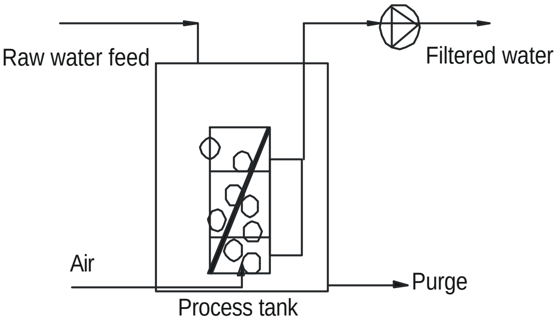
bottom of the membrane module to create a turbulence that scrubs and cleans the outside of the membrane fibers, allowing them to function at a high flux rate. This air will also oxidize iron and other organic compounds, producing better quality water than that provided by normal filtration.



Operating principle of an inmmersed outside-in membrane

When an outside-in hollow fiber membrane is used, no pretreatment is needed, even if the feed water contains clays and fine particles. In a single step, it replaces the coagulation, flocculation, clarification and sand filtration steps of conventional plants, but also eliminates the pretreatment required by spiral membranes and inside-out membranes.

In a plant of this kind, the membranes are immersed in the so-called "process tank," from which the water flows to the inside of the membranes. The filtered water, now clean, is pumped out. A fan produces the air needed to keep the membranes clean. The plant flow diagram is shown below.



Flow diagram of microfilter with an immersed membrane

Installation of a ZeeWeed membrane in the process tank

Installation and requirements

The minifiltration equipment used in a drinking water treatment plant consists of a set of filtering devices that work in parallel and comprise a single structure. Some are as simple as small packaged plants, while others, such as that shown in the figure, are highly complex. The equipment varies widely and can be installed in large or small communities.

The entire minifiltration system is mechanical and requires electric power. For that reason, it needs to be indoors and not left out in the open. The room

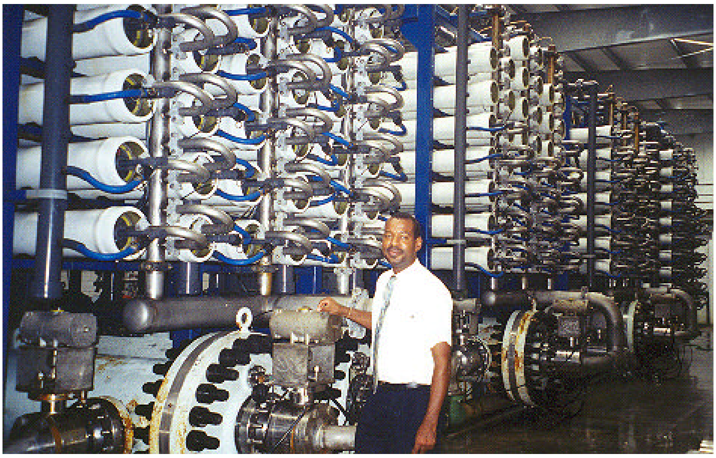
Minifiltration membranes

constructed to house it must be large enough to allow for its operation and maintenance. It should also be built of sturdy materials for safety reasons. Its design must allow for daytime operation in sufficient natural light, with good artificial lighting provided for nighttime operation. A metal, rather than a wooden, door is recommended because the room will contain equipment that is both economically and technically valuable. Since the minifiltration system must be installed by skilled workmen, the supplier must be asked to see to its installation.

While minifiltration reduces the need for pretreatment, a secondary disinfectant must be added to ensure the innocuousness of the treated water.

Raw water quality must also be considered because there is an indicated membrane material for each pH and temperature. The earliest filtration membranes were made of cellulose acetate. That material, however, does not support pH levels outside the range of 2 to 9, nor temperatures above 35 °C. Furthermore, its chemical resistance is limited.

The polymeric and ceramic membranes mentioned above were developed to overcome these limitations. As compared with cellulose acetate membranes, those made of polysulfone resin operate irrespective of the pH and can bear temperatures of up to 110 °C with good chemical resistance. Ceramic membranes are used in tubular systems, generally for applications that require resistance to extreme pHs and temperatures, both.



Typical installation of a minifiltration system (RO)

Finally, and for obvious reasons, if the raw water is overly turbid, a pretreatment system is advisable, such as prefiltering or coarse grained gravel filtration.

Operation and maintenance

The system's operation and maintenance depend upon the type of membrane used and the material it is made of. Even so, control over transmembrane pressure should be maintained in all cases, because filtration capacity diminishes at pressures of over one bar. To maintain this pressure when using a microfiltration membrane, prevention of scaling on the membrane surface or inside its support is essential. This material build-up increases resistance to the permeate flow.

Care must be taken to ensure that the air injector works at all times, thereby avoiding scaling and depositions that would clog the filter. The system is designed to avoid clogging, so long as it is operated properly.

Monitoring

Tests must be conducted and samples taken of treated and untreated water to monitor the system's efficiency. The parameters to be studied are: the quantity of solids in suspension and in solution in the treated water and also the percentage of microorganisms removed. Both of these parameters must be analyzed, because microorganisms conceal themselves in solids in solution and in suspension.

Advantages and disadvantages

- No chemical compounds are needed for the operation.
- On eliminating organic substances, turbidity, suspended solids and part of the water color are reduced.
- The presence of trihalomethane precursors that could form as a result of secondary chlorination is reduced.
- Operating and disposal costs are reduced, better controlled and more reliable measurements can be taken, less space is needed and constant and variable flows and qualities are well handled.
- Water treatment membranes can work as a continuum, are energy-saving, and can be easily scaled and combined with other processes.
- The advantages of membrane use for drinking water treatment include: absolute barrier effect against microorganisms, lower chlorine requirement for secondary disinfection, and smaller plant size. Furthermore, each type of membrane has its own specific advantages.
- Membrane systems, particularly the low flow type, are compact, easy to operate and could, in the future, become an interesting technology for small communities and remote locations. Because they are modular, membrane plants can be built to treat volumes as small as 40 l/minute (sufficient for a population of 500 people), but at present they are also being produced for treatment plants with flows of up to 1 m^3/s. The largest nanofiltration plant in Europe at the beginning of the millennium (Mery Sur Ouise, Paris) treats 1.6 m^3/sec and serves 500,000 residents.
- Another important advantage is iron and manganese removal due to the oxidation of the water-soluble forms of these elements.
- Among the disadvantages of microfiltration is the continued contamination of support materials also subject to scaling, thus reducing the process efficacy.
- The process is simple and can operate automatically, but highly trained personnel who are generally not available locally are needed if problems arise.
- Minifiltration is much more expensive than the more popular disinfection methods.

Equipment, operating and maintenance costs

Equipment costs are difficult to determine, because they depend largely on the country and the community where it is to be installed. However, these costs are considered high in all cases. As a general rule, the capital investment is calculated at between $ 200 and $ 300 per cubic meter of water to be treated a day. The capital cost of reverse osmosis can be even higher, reaching almost $ 1,000/m^3 of water to be treated.

It would be unfair, however, to compare these high costs with those of simple chlorination, which are very low. The reason is that chlorination is a disinfection treatment, while minifiltration is a much broader drinking water treatment in which disinfection could be considered a by-product of the treatment.

The same holds true for the operating and maintenance costs, for which typical figures could fall between $ 0.4 and $ 0.8 per cubic meter of treated water.

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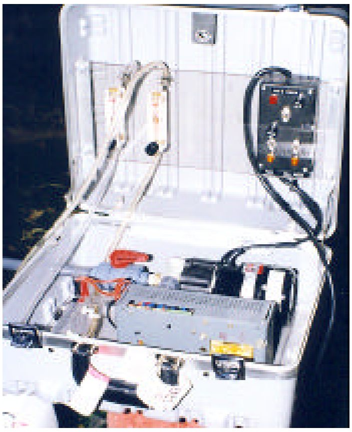
Chapter 9

ALTERNATIVE DISINFECTION METHODS



Introduction

If what is meant by disinfection is the elimination of pathogens that could harm human health, then from the viewpoint of disinfection possibilities alone, there are countless ways to kill off these small living organisms. There have been experiments over the years in which continuous and sharp changes in only the water's pH have been enough to disinfect contaminated water.

Temperature is another key element. Boiling is perhaps the oldest and best-known method of disinfection. It is not enough merely to bring water up to a temperature of 100 °C, however. An appropriate ratio between time and temperature must be reached so that disinfection is produced by "pasteurization," as we have seen in the chapter on solar disinfection. Other experiments have shown that sudden sharp changes from high to low temperature, without any need for permanence, are also effective in eliminating microorganisms.

At the end of nineteenth century, when the existence of bacteria and their relationship to disease was already known, work was done with pressures. Contaminated water was placed in hermetically sealed containers and submitted to pressure. After a few minutes' time, the pressure was suddenly brought down to normal and the result was pure, germ-free water.

Similar experiments using continuous and violent shaking over long periods of time apparently also resulted in disinfection. Certain ancient cultures placed their drinking water in silver jars. Without understanding why, they knew that after a period of contact with these containers, the water was safe to drink. The list is almost endless. Microorganisms can be eliminated in a variety of ways.

Obviously, however, only a few of these possibilities are viable. The power to annihilate is not sufficient, in itself. It must be accompanied by specific characteristics, such as simple equipment and ease of operation and maintenance. If chemicals are used, these must be easily available at the site of use. Disinfection must be accomplished rapidly and the inexpensiveness of the method is vital. The risks must not be excessive, nor must the water's characteristics be modified; it has already been discussed the problem of disinfection by-products in this connection.

These requirements limit the long list of possible disinfection methods. This manual has given a detailed description (up to this point) of only those methods that can be used for disinfection because of their special characteristics. There are others, however, that without being overly obtuse and without having been classified as the most suitable methods, fall somewhere in between. These are the methods that have been used in special situations (in emergencies and during disasters, for example) or that are under experimentation or are being developed, or that for only one or another specific reason (cost or the small size of the flow to be treated), are good, but are not among the top disinfection methods. These will be briefly described in this chapter to provide full information to the engineer or technician wanting to know all of the disinfection possibilities.

Disinfection with bromine

Description

As a member of the halogen family, bromine is very similar to chlorine and operates in the same way: once dissolved in water, it produces hypobromous acid (HOBr), a first cousin to hypochlorous acid (HOCl). The disinfecting power of HOBr is very high, although slightly less than that of hypochlorous acid.

The advantage of using bromine is that at normal temperature it is liquid, making it easier to handle and dose than chlorine. It should be stressed, however, that bromine is both corrosive and aggressive and must be handled very carefully. Furthermore, it is not easily found in just any country or city, unlike chlorine, which can be purchased off the shelf.

Effects of bromine on health and DBP production

Since bromine vaporizes very easily and its gas is highly aggressive, care must be taken to keep from inhaling it. It should be stressed that neither chlorine nor bromine appear to be carcinogenic per se or when dissolved in water. Chlorinated water and bromated water are not carcinogenic. But, like chlorine, bromine forms trihalomethanes, and if fulvic acids and ammonia are present in the raw water, it will produce bromoform. Therein lies the risk, because the latter compounds are carcinogenic and, like many other DBP, are reason for concern.

Disinfecting action of bromine

HOBr acts similarly to HOCl, as we have already mentioned —that is, by penetrating the membranes of microorganism cells. Once inside the cell, the very presence of HOBr appears to "disorganize" the cell structure; at the same time, it also attacks by reacting with sulfhydryl compounds to inactivate enzymes and stop the metabolic process, leading to the microorganism's death.

Equipment

Bromine, as a liquid, is dosed by means of a diaphragm or piston pump and both its operating requirements and safety measures are the same as those used and described for chlorine.

Monitoring

There is no specific test for bromine. The orthotolidine method used to determine the presence of chlorine is used for routine analyses of bromine, although it is subject to interference.

Costs

As already indicated, bromine acts similarly to chlorine in water and could have been as popular as the latter had it not been for the price difference. It has been estimated that, using the same dosing equipment, bromation is five times as expensive as chlorination. To that, we must add the difficulty of obtaining bromine.

Advantages and disadvantages of bromine disinfection

Disinfection with bromine offers almost all of the same advantages as chlorination. However, it has two major disadvantages that the latter method does not have: it is much more expensive and it is difficult to acquire in just any community, particularly small and remote communities in developing countries.

Disinfection with silver

Description

Most metals are "oligodynamic;" this means that "with only a small amount, they can produce an effect." Metals like silver, copper, mercury, manganese and iron, among others, are all potential water disinfectants. However, of all of these metals, only silver, for several reasons, has been used to some extent to disinfect water for human consumption, and this use dates back to ancient times.

Effects of silver on heath and DBP production

Silver is not particularly toxic to human beings and, on being ingested, the body absorbs only a very small fraction. Large doses of this metal used for certain medical treatments have been found to cause discoloration of the skin, hair and nails (argirosis), but no problem has been noted with the small concentrations needed to disinfect water. The WHO has not proposed any guideline value for silver in drinking water, precisely because of its relative safety. Treatment of drinking water with silver produces no abnormal taste, smell or color. Nor are any DBP generated.

Disinfecting action of silver

Silver has disinfecting properties only in its colloidal state —when it is in the form of extremely small particles in suspension which, because of their size, are easily charged electrically. In this state, it is also known as silver protein, silver salts, weak silver protein and strong silver protein. The salts that are used are silver chloride and silver iodide.

In its colloidal form, silver does not eliminate viruses, but is considered highly effective in destroying different types of bacteria. Silver's disinfection mechanism acts by inactivating bacteria and mold cell enzymes that need oxygen for their metabolism; its causes their cellular disruption, although over periods that vary widely according to the water temperature. Very long periods are required at temperatures of 10 °C or less, making it difficult to determine silver's precise germicidal power. Colloidal silver can remain in the water for a long period of time, but is not considered to have good residual power because of the slowness of its reactions in eliminating organic matter. The recommended dose for high germicidal efficacy is in the range of 25 to 75 micrograms of silver per liter (0.025 – 0.075 mg/l).

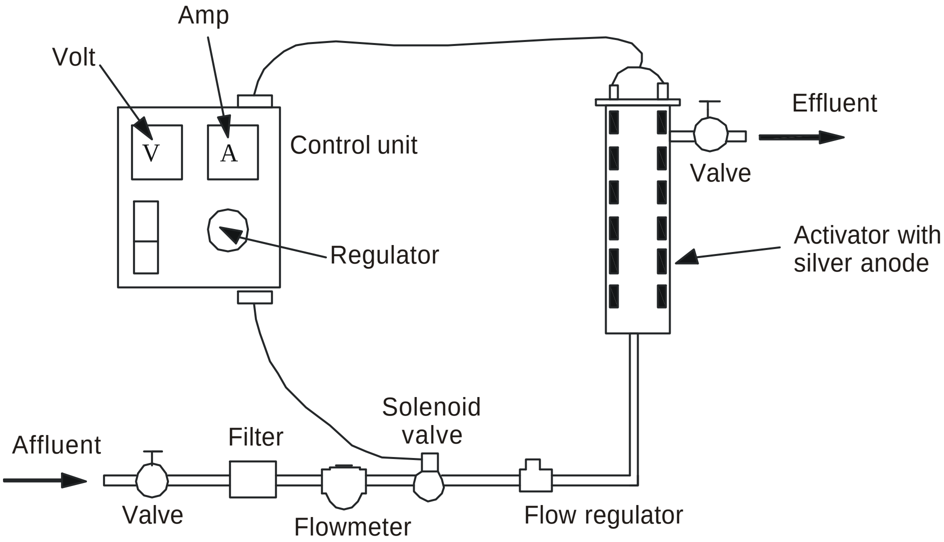
Equipment

Three methods are used for disinfection with silver. The first or "contact" method requires the passage of the water through silver saturated devices, such as tanks with walls and screens coated with special silver-containing paint. The second method consists of dosing low concentration silver solutions in the same way used for chlorine solutions, with similar equipment and feeders. The third, electrolytic, method appears to be the most practical. A number of silver electrodes are connected to the positive pole (anode) of a low power electric source. An inert electrode is used as a negative pole, where hydrogen is produced and freed. Through electrolysis, the silver ions are freed by the electrodes inside the water current to be treated in proportion to the supply current. The method is appropriate, for the dose can be varied by changing the current.

The electrolytic method is used only for small water supply systems. From a practical and safety viewpoint, a certain degree of automation and complexity are needed in the control system, which should have sensors to check the properness of the disinfection. This simply cannot be done manually. A connection should be made to a solenoid valve that can cut off the water flow automatically at any moment if the system is unable to produce the proper dose.

Monitoring

There is no simple test for measuring the silver content of the water. The measurements taken with the existing test show a considerable degree of error. The most effective method is to dose the water with controllable amounts of silver —in other words, the control is carried out basically through the dosing and not analytically following it.



Typical silver electrolyte equipment

Costs

Silver paint is not very expensive, but this is the least appropriate method. The dosing of a silver solution for a small population requires the equipment already cited in the case of chlorination; a wide range of diaphragm metering pumps can be used and their cost is not high. The solutions, on the other hand, are extremely costly, especially compared with the equivalent chlorine solutions that provide the same bactericidal capacity.

The electrolytic devices are expensive for small systems and can cost anything from $1,000 on up. The final cost depends on the size of the flow to be disinfected and the ancillary equipment needed. Insofar as the operating cost of this equipment is concerned, not only must the cost of the silver solution be considered, but also that of the electric power. In the case of its maintenance, it is necessary to consider the cost of electrodes, which must be replaced frequently because they are the only source of the silver ions and they wear out fairly rapidly.

Advantages and disadvantages of disinfection with silver

Silver's apparent advantages for water treatment are that it does not produce any taste, odor or color in the treated water and that no by-products are formed as a result of its use.

The methodology is very simple and easy to handle in rural areas of the developing world. For that reason, it is appropriate for household water disinfection.

One of its disadvantages is the difficulty in controlling dosing for lack of a simple laboratory analysis. The second disadvantage —and this has proven to be an insurmountable barrier throughout history— is the high production cost. Both the electrolytic method, in which the electrodes that are needed to produce the silver ions wear out fairly rapidly, and the dosing of colloidal silver are expensive. Disinfection with silver has been estimated to cost between 200 and 300 times more than chlorination.

Disinfection with iodine

Description

Iodine belongs to the halogen family and is solid at normal temperature. Its has low solubility in water and is the least aggressive substance in the family (chlorine + bromine).

Effects of iodine on health and DBP production

Unlike chlorine and bromine, substances that per se do not cause any problems when consumed in the normal concentrations to be found in drinking water, iodine of itself can do so. Actually, concern over iodine use does not have to do so much with the DBP, as with the action of the chemical itself.

Although iodine is essential for the synthesis of thyroid hormones, it is not certain what will happen if it is oversupplied in drinking water. There have been reports of numerous cases of "iodism," which can be defined as an allergic reaction produced in people who are hypersensitive to the consumption of iodine in doses larger than their daily need. According to the WHO, "the consumption of iodized water does not appear to have caused adverse effects on human health, although some changes have been noted in the state of the thyroid gland." Furthermore, Volume 2 of the "WHO Guidelines for drinking water quality" states that "little relevant information is available about the effects of iodine," and goes on to add that "inasmuch as iodine is not recommended for water disinfection over long periods of time, exposure to iodine from its consumption in drinking water is quite unlikely."

This substance, like other members of the family, generates DBP. However, because of its lower oxidizing potential and its lower reactivity, iodine produces less THM than the others.

Disinfecting action of iodine

Once dissolved in water, iodine, like chlorine and bromine, forms the corresponding hypo-acid (in this case, hypoiodous acid) HOI. Depending on the water's pH, however, a portion (which can be quite large) remains in the water as $I_{2.}$ The table below gives an idea of the relative concentrations of each compound, depending on the pH and these have been compared with the relative concentrations of hypochlorous acid and hypochlorite ion.

Percentage of iodine and chlorine species according to the solution’s pH

pH	I_2	HOI	OI-	Cl_2	HOCl	OCl-
5	99	1	0	0	99.5	0.5
6	90	10	0	0	96.5	3.5
7	52	48	0	0	72.5	27.5
8	12	88	0.005	0	21.5	78.5

It should be stressed that while the hypoiodite ion is not a good disinfectant, both I_2 and hypoiodous acid are; and they also possess highly desirable microbicidal characteristics. The two are good bactericides and destroy even spores, cysts and viruses.

When iodine is used as an emergency disinfectant and in small volumes, the doses employed are larger than those that would normally be used to disinfect drinking water systems. In such cases, solutions from 1 to 8 mg/l are commonly used, with contact periods of at least 30 minutes. When using iodine tincture, which is prepared with a 2% concentration, the recommended dose is two drops per liter of water to be disinfected.

Equipment

Iodine can be added to water by passing a steam current through a bed of iodine crystals and then dissolving the steam in water. The most recommendable method, however, is to prepare a saturated solution by passing a water current over the bed of iodine crystals and then dosing them with a conventional diaphragm pump.

Monitoring

There are two methods for determining the iodine content of water. The most widely used is amperometric titration, while the second is spectrophotometry, using N,N-dimethylaniline or leuco crystal violet (LCV) as a reagent. Although these methods are not complicated, the plant operators or chemists must be trained to perform the tests.

Costs

All operational parameters being equal (equipment, simplicity, ease in handling, etc.), iodine, like bromine, cannot compete with chlorine and its compounds for water disinfection purposes, because it costs 10 to 20 times as much and is difficult to find in remote areas of developing countries.

Advantages and disadvantages of disinfection with iodine

Iodine disinfection is as simple as chlorination. Its use over long periods of time for water disinfection has been questioned by many health organizations, particularly because of the physiological effects it can have on people who are sensitive to it. Although no decisive tests have been made and there is little confirmed data on the subject, when deciding whether or not to use iodization as a disinfection method, these considerations should bear more weight than its higher costs, which are also convincing reasons for deciding against it.

Its easy handling, on the other hand, makes it a good option for disinfection purposes in emergency situations.

Disinfection with sodium dichloroisocyanurate (NaDCC)

Description

Sodium dichloroisocyanurate, often called “sodium isocyanurate,” and recognized by the abbreviation “NaDCC,” is a compound that frees chlorine in very precise concentrations. It is easily handled and contains a high concentration of active chlorine (60%). Its use is highly practical and it does not leave the usual telltale odor and taste of other chlorine treatments. It is stable over long periods of time, making it appropriate for storage over much longer periods than any other chlorine compound. If conditions are optimum, it can be stored for over five years without losing its strength.

Effects of NaDCC on health and DBP generation

As it will be seen in the following section, on being dissolved in water, NaDCC produces a sodium cyanide molecule. It is not known how this compound —and in fact, how isocyanurate itself— affects human health and it is precisely this lack of information that has kept the method from being used indiscriminately despite all of its benefits.

The WHO has stated that “there is concern over the possible toxic potential of NaDCC, above all for long-term use in disinfecting water for human consumption” and goes on to add that “this concern stems from the insufficiency of health and toxicological evidence to make a final judgment on the subject.”

This means that NaDCC is not condemned because it is harmful to health, but merely that its long-term use for water disinfection is not recommended because of a lack of information about its possible harmful effects on health, as well as its innocuousness.

This situation may possibly change as the results of studies come in and the information begins to be evaluated worldwide; for the moment, however, the use of this compound is recommended in some countries only for emergency disinfection purposes, in which case it is tacitly assumed that its use would be for short periods of time only.

The situation is the same in regard to the formation of DBP. Not only is nothing known about the problems stemming from the possible generation of DBP by cyanurates, but there are also the classical DBP of hypochlorus acid to be considered, among them THM, which have been mentioned frequently throughout this manual.

Everything that has been studied about sodium isocyanurate points to the following suggestion: Use for systematic disinfection, no. For emergency disinfection, yes.

Disinfecting action of NaDCC

Sodium dichloroisocyanurate is an organic compound deriving from isocyanurate, which, when dissolved in water, frees hypochlorus acid through the following reaction:

$$\underset{\text{Sodium dichloroisocyanurate}}{NaCl_2\,C_3N_3O_3} + 2\,H_2O = \underset{\text{Sodium cyanurate}}{NaH_2C_3N_3O_3} + \underset{\text{Hypochlorous acid}}{2\,HOCl}$$

It is the hypochlorous acid, whose qualities were described in chapter 3, that is responsible for its disinfecting potential.

Equipment

Any of the dosing devices mentioned in the chapter on chlorine can be used, inasmuch as NaDCC dissolves in water to form a typical solution.

Monitoring

What is monitored is the residual chlorine, and for that reason both the DPD and the orthotolidine methods can be used.

Costs

The costs are slightly higher than those of using traditional chlorine compounds, like sodium or calcium hypochlorite.

Advantages and disadvantages of disinfection with NaDCC

Its simplicity, stability and ease in handling are among the most important advantages of this method. It does not produce the characteristic odors and tastes of other chlorine compounds. It also leaves a disinfectant residual.

Its main disadvantage is the lack of evidence of its innocuousness when consumed over long periods of time.

Disinfection using mixed oxidant gases

Description

Although Faraday laid the groundwork for electrolysis and worked extensively to produce chlorine from sodium chloride in the mid-nineteenth century, that technique has remained almost unchanged at the service of heavy industry until today. Sanitary engineering drew on its use to massively incorporate chlorine as a drinking water disinfectant.

In the 1970s, perhaps influenced by the new concepts of the appropriate technology, which emerged as a remedy for the lack of realistic technology acceptable to the rural communities of developing countries, the perception of Faraday's electrolysis underwent a change. It was no longer viewed as a technique only for operating large factories, but also as a simple method to enable small communities and even individual users to prepare their own chlorine on-site, in their own homes, using only electricity and table salt (sodium chloride).

Researchers then began to concentrate on reducing the scale of electrolysis use from the large factory to the rural workshop, to the water treatment plant of a small village, to the home. A whole series of electrolysis devices emerged, which can be broken down into two main groups: electrolysis with and without a membrane. Membrane systems reproduce the industrial chlorine production technique, while those without a membrane produce low-concentration hypochlorite solutions.

There was an interesting development in the research carried out on these systems. In an effort to escape the numerous patent restrictions placed on sodium chloride electrolysis, researchers played around with the placement of the electrodes, particularly with the dimensionally stable anodes (DS anodes) and produced equipment that generates not only chlorine, but also, as a result of the electrode arrangements, other high oxidizing species, including radicals of different types: ozone, nascent oxygen, atomic oxygen and others. PAHO generically calls this mixture of oxidant gases MOGGOD (mixed oxidant gases generated on-site for disinfection purposes). Because of their production in an electrolytic cell divided into separate and independent chambers, these gases constitute a highly concentrated and oxidant mix.

The cathode chamber produces hydrogen and the anode chamber, the oxidant gases. The two chambers, or semicells, are separated by a special membrane that is permeable only to certain ions.

This unique feature —the membrane— was responsible for the initial success and the subsequent failure of this method, for the membrane required delicate operation and a maintenance that, although simple, was also essential to keep the equipment operating at its best. Many systems of this kind were installed in small communities in the 1980s, but few were able to survive, given the operating and maintenance needs that rural areas of developing countries were unable to meet. As a result, very few of these systems continue to operate today.

The other technique, electrolysis without a membrane, is much simpler. It is merely a matter of letting chlorine production in the basic medium continue its accustomed chemical reactions to produce, without much intervention or risk, a solution that, while very weak (generally, it is a 0.6% active chlorine solution), is easy to use and handle. This is obviously not the means used to produce oxidant gases, but is included here because of its common origin. Hypochlorite is produced by the following reaction:

$$2Na^+ + 2Cl^- + H_2O = Cl_2 + H_2 + 2\ HONa$$

$$Cl_2 + 2\ HONa = 2\ NaOCl + H_2$$

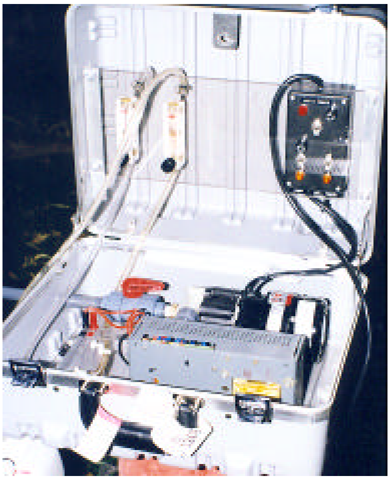
Although the MOGGOD system had a promising start, because of its operational and maintenance needs, only the systems that produce hypochlorite were successful.

Effects of the mixture of oxidant gases on health and DBP generation

Since these systems are basically chlorine producers, all of the considerations regarding the effects of chlorine on health and on production, management and DBP risks mentioned in chapter 3 are valid here.

Disinfecting action of the mixture of oxidant gases

The same considerations discussed with regard to chlorine are applicable here. However, it should be stressed that in the case of the MOGGOD, some components of the mixture cause an action that is so strong and so synergic (as can be seen further ahead in this chapter) that it was thought that no microorganism or organic compound could resist its oxidating power.

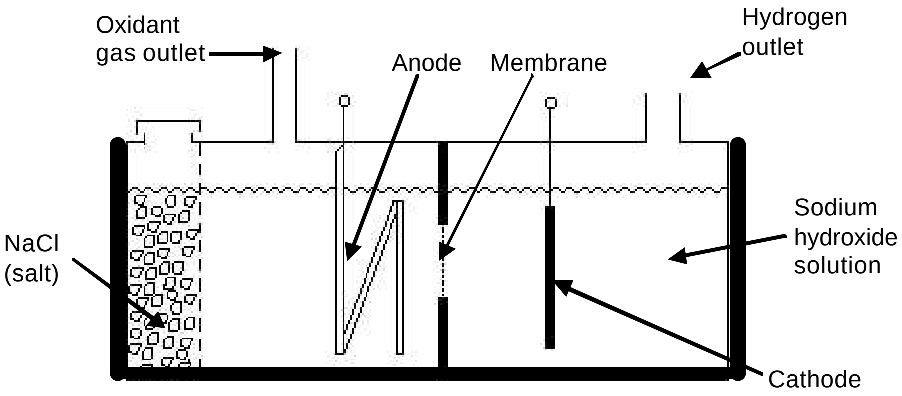


Equipment for generating hypochlorite in a water current

Equipment

The costs of on-site hypochlorite generators was reviewed in chapter 3 “Chlorine.”

A few systems were designed in the United States for on-site hypochlorite generation, but inside a water current. Some 200 of them are in operation in national parks and small communities in that country.



MOGGOD system

The figure demonstrates the components of a MOGGOD system.

The oxidant gases that emerge from the device are injected into piping equipped with a Venturi.

Monitoring

The oxidant gases are monitored in exactly the same way as residual chlorine, using the same techniques: orthotolidine and DPD.

Costs

With a very few exceptions, MOGGOD equipment are small. Their prices range from \$ 500 to \$ 4,000. The operating costs are very low because table salt (the main input) has always been and still is very inexpensive. Since the equipment uses low amperage, the cost of the electricity is not very high, either.

Advantages and disadvantages of disinfection using a mixture of oxidant gases

On-site hypochlorite generating equipment has had good results. Once the hypochlorite solution is generated, there are several possibilities: 1) dosing it in drinking water systems 2) using it to disinfect water, not at the community level, but at the single family level, and 3) conducting programs to distribute bottles of hypochlorite for household disinfection purposes. Although advances have been made in all three areas, the centralized production of hypochlorite (in a hospital, school or community center) and its distribution to a given number of families has been the most successful course of action.

Disinfection by radiation

Description

Chapter 4 addressed ultraviolet disinfection, which consists merely of placing a substance (in this case, water) where it can be radiated with a certain wavelength.

There are two other types of radiation that have only been used experimentally, but that could potentially be employed in the future with a good capacity for disinfection. These are "gamma" and "X"-rays.

Effects of radiation on health and DBP generation

As in the case of ultraviolet radiation, these create no health or DBP problems.

Disinfecting action of radiation

Any type of radiation is characterized by a particular wavelength, which is inversely proportional to the wave frequency. This means that the shorter the wavelength, the higher the frequency; and, quite obviously, a higher frequency means more force or energy. Inasmuch as gamma and X-rays have a higher frequency than ultraviolet rays, they have more energy and, therefore, a stronger bactericidal capacity.

Two mechanisms for disinfection by radiation have been recognized: one in which the radiation power damages the microorganism's DNA and the other where the collision of the radiation with some oxygen atoms that are components of the cell or cells generate ozone and other radicals that disturb it to the point of destruction.

Equipment

No specific equipment exists for water treatment with gamma or X-rays. The equipment that can be found is based on cobalt radioisotope emissions; it is quite complex and its operation, although not difficult, does require especially trained personnel.

Costs

No reliable data is available on the cost of this type of water treatment. Inasmuch as it is highly unlikely that this technique will come into wide use, no comparative studies have been made of the differences between disinfecting food products and water. If this technique were to be implemented today, it would doubtlessly cost a great deal more than the usual and widely used disinfection methods.

Synergic disinfection methods

Description

According to the dictionary, the term “synergy” means “the interaction and combined activity of two or more biological beings, substances or components to produce something that is qualitatively and quantitatively different from the sum of their individual capacities.” In other words, the formula for a synergy is: $1 + 1 \neq 2$ and the result can be, for example: 0.7 or 3.

In the specific case of the substances used as disinfectants, if, by adding together the individual capacities of each of them, we were to obtain a capacity larger than the sum of the two (in the case of the example, if by adding 1 + 1 we were to obtain 3), this would mean the discovery of a new, much more powerful substance with better qualities than either of the two individual substances and even than the combined qualities of the two. That is precisely what happens in certain special cases and what is called “disinfection synergy.”

Not many of these synergies exist, but those that are mentioned below are promising and suggestive of a new field that will be broadened and enriched by new research, experiences and discoveries.

The synergic cases that have been most studied are the following:

- Silver/hydrogen peroxide
- Silver/copper
- Silver/copper/chlorine
- Iodine/chlorine
- Ozone/hydrogen peroxide
- Ozone/UV.

Effects of synergic disinfection methods on health and DBP generation

Information can be found about each of the separate disinfectant substances, but, as already stated, if the resulting substance does not have the same qualities as the individual components, then it is to be assumed that their effects on health and DBP formation will not necessarily be as expected. There may be in store for some surprises and thorough studies will be needed before it can be certain of their innocuousness or can determine the level of risk associated with each synergic product.

Disinfecting action of synergic methods

In all of the cases, the disinfecting action is much greater than the sum of the actions of each component of the synergic product. While it is not certain about all of the mechanisms involved, most have already been mentioned (oxidation, enzyme destruction, disturbances of the cell living and reproduction mechanisms, etc.), and obviously all of them are broadened and enhanced in the case of synergic substances.

Equipment

The equipment is no different from that used for each individual technique. In the case of the iodine/chlorine method, the doses of each substance or the mixture of the two are administered by the same diaphragm dosing pumps.

Monitoring

Little information is available about this monitoring, but it is understood to involve the normal chemical detection techniques that are in use today.

Costs

The information about the costs is not very clear, but obviously the costs will be higher than those corresponding to each individual substance.

Advantages and disadvantages of synergic disinfection methods

The advantage is a large disinfecting power that in some cases eliminates the risks and dangers associated with the use of the individual substances. A typical case in point is the reduction of DBP.

Household filters

Description

While small household filters do not have the necessary capacity to treat large water volumes, we have included them in this manual because, properly handled and accompanied by community information and education programs, they represent an important means for bettering drinking water quality in rural areas.

The subject is somewhat controversial, since the market is filled with filters; there are a whole range of processes (techniques) and a variety of forms and capacities. This makes their classification and rating extremely difficult. It should be stressed here that many of these filters have been made commercially without any scientific backing. They have been manufactured to make money and are not necessarily what they claim to be.

Lastly, it is important to stress the need for the user to be scrupulous in keeping the elements of the system clean and in changing the cartridges. Otherwise, these filters can become a greater problem than the one they are intended to solve.

Household filters are used to: 1) eliminate turbidity, 2) remove odors and tastes and some organic substances, among them DBP, and 3) disinfect. Some devices cover only one of these functions, while others accomplish two or the three purposes mentioned. Obviously, in order to have safe water, it is necessary to use a filter that disinfects it.

Household filters disinfect water through filtration or a physical or chemical action. In the former case, the water passes through ceramic candles with very tiny pores with diameters of less than 0.4 microns that retain even bacteria.

In the latter case, the most common disinfecting filters use UV or silver-coated sand.

There are no special observations to be made here, for we have already commented on UV radiation and silver disinfection. These filters cannot possibly generate DBP (with one clarification to be made under the following point).

CEPIS system

Filter with candles imbedded in fine sand and a geotextile covering to reduce candle clogging. The filtered water is collected on the bottom and is kept there, protected, until it is consumed.

Disinfecting action of household filters

As in the case of their effects on health, the disinfecting action of these filters was already commented under UV radiation. In the case of ceramic candles, the effect is merely mechanical. The filter pores, because of their smaller diameter, retain the microorganism. It is precisely with regard to this point that a comment should be made.

The bacterial load of a household filter effluent has frequently been found to be heavier than that of the raw water entering it. The explanation for this is that the microorganisms that are retained are dead organic matter that slowly builds up and becomes food for the new microorganisms that appear. The passage of some microorganisms through the pores (perfectly possible in this context of enormous profusion and saturation) creates colonies “on the other side of the filter” and slowly the entire filter (on both sides of the ceramic candle) turns into a mass of microbes. In the jargon of chemistry and sanitary engineering, many of these filters are called “nesting boxes,” for they offer ideal conditions for bacteria multiplication.

This does not mean, however, that household filters are bad or risky. What is risky is the behavior of the users, for the problem of nesting boxes appears only when the filter’s capacity has been

oversaturated -when the raw waters are excessively turbid and contaminated and when the user fails to clean the filter or does not change the cartridges with the frequency recommended by the manufacturer. It is for that reason that follow-up actions and on-going motivation and educational campaigns are recommended to ensure that people operate these elements properly.

Equipment

There are a large number of household disinfection systems. A system can be put together, and can most likely be found in the market, using a paper or thick cellulose cone or cartridge to eliminate heavy turbidity, a candle filter or an element with a UV lamp to eliminate microorganisms and an activated coal cartridge to eliminate unpleasant odors and tastes.

The water flow volumes also vary, the devices range from those that treat several cubic meters a day to small ones that are attached to a faucet to filter a few liters of water a day.

Monitoring

There are no easy ways to monitor these systems. They can only be monitored through bacteriological analyses, which are not always possible in the medium where these filters are used.

Costs

The costs vary widely, ranging from fifty or sixty dollars to a thousand dollars for a highly sophisticated and complete system.

Information sources

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Chapter 10

SPECIAL AND EMERGENCY DISINFECTION

Dug wells

Dug wells have been an important water source since ancient times and many towns continue to use them. The water in these wells comes from groundwater which, particularly in villages and towns, is almost always contaminated by seepage from nearby latrines. In addition, most of the wells are not properly protected and do not have mechanisms for drawing water that keep users from touching it. The well water may already be contaminated or handling may contaminate it when the water is drawn —the truth is that rarely is a public dug well free from the risk of transmitting waterborne diseases.

National and international institutions, public health agencies and health professionals have for decades been calling for disinfection campaigns for dug wells.

The first result of such efforts is that today a large number of different dosers can be found, almost all of which use chlorinated lime. These include containers with holes, plastic bags, concentric bottles and an entire range of porous ceramic pots. The second is that all of these empirical methods are bad and fail to accomplish their desired aim.

The fact is that a dug well is not used consistently: during the night, it is not used at all and during the day, water is drawn in varying amounts and at different rates. This means that the concentrations provided by constant feeding systems will, unfortunately, also vary widely at different times of the day or night. The end result is that users detest the chlorination of these wells because at times the chlorine con-

The classical dug well with all the conditions conductive to contamination

tent is so strong that the water is undrinkable and at other times those who drink it sicken because of the lack of sufficient chlorine.

This specific situation has brought on the current trend, favored by many public health institutions, of abandoning the inefficient disinfection of dug wells. Instead, people are recommended to collect water (dirty and contaminated) from the well, take it to their own homes and there filter and disinfect it. Sodium hypochlorite generated through electrolysis at either the community or household level can be used as a disinfectant, as can any other means available in the community (silver solutions, for example).

While this course of action requires good educational and monitoring plans, the results in the long term are far more positive than the controversial disinfection of open wells.

Carrying the water

Filtration at the family household level

Disinfection using hypochlorite in the home

Disinfection of tanks, tankers and pipes

New tanks

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

One of the methods for disinfecting a new tank is to fill it to overflowing with clean water to which enough chlorine has been added to produce a concentration of 50 to 100 mg of chlorine per liter of water.

The chlorine solution is added to the water as early as possible during the filling operation to ensure thorough mixing and contact with all of the surfaces to be disinfected. Once the tank has been filled, the water should be allowed to stand, preferably for 24 hours, but never for less than six. It should then be drained out and the tank refilled for normal supply.

Elevated tank

A second method that is highly satisfactory and practical for rural use is the direct application of a strong solution (200 mg of chlorine/l) to the tank's interior surfaces. The solution should be allowed to remain in contact with the surfaces for at least 30 minutes before refilling the tank with water.

Cisterns and tankers

A tank on wheels is just like a stationary tank, except for the obvious difference that it can be moved from one place to another. Therefore, the disinfection requirements and methodology to be used should be

Two quite different services

identical. There are, however, three subtle differences: 1) the accessibility to the interior 2) the material of which the tank is made and 3) the owner.

Accessibility is important, for it would be difficult to inspect or properly disinfect a tank unless the inside can be reached. Sometimes, there is no other choice but to scrub the walls and sweep the bottom. Unless there is reasonable access to the inside of a tank, its use as a container for drinking water should not be permitted.

In many rural areas where water is transported in tankers, conditions are poor and resources lacking. Often the tanks are no more than iron containers resting on four wheels. They may not even have an internal coating to protect the material of which the tank is made from the oxidating effect of the water and even less so from an agent as aggressive as chlorine.

This leads to another condition that must be fulfilled unconditionally: all tanks should be made of material that is suitable for holding water or should be duly given an internal coating that is approved for contact with drinking water.

This point has to do with the owner of the tanker. It so happens that it is usually difficult to convince or force these people to make necessary improvements in their vehicles. Education, information, and consciousness-raising must be used to persuade them. But it will also be necessary to call on health or even police authorities to force them to fulfill pertinent sanitary conditions. In some situations, tankers have been found to spread diseases, when it is their social task is to improve the quality of life of many people.

New mains and pipes

Distribution mains and pipelines are likely to be contaminated during their operation and laying, irrespective of the precautions taken. Therefore, they must be disinfected before they are put into use. Distribution systems need to be disinfected when contaminated in the event of main breaks or floods.

Every pipeline should be cleaned by swabbing with any of the modern instruments designed for that purpose and then flushed in order to remove all loose foreign matter. Immediately before use, the packing and jointing material should be cleaned and disinfected, if possible. This should be followed by the internal disinfection of the pipeline.

A practical means of applying chlorine solution (with a concentration of 50 mg of chlorine/liter) for the disinfection of pipes is to flush each section to be disinfected. The intake valve is shut off and the section is allowed to drain dry through the discharge hydrant or valve. 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 hose into a hydrant or opening made especially for this purpose at the highest point on the pipeline. Since air valves are usually placed at the high points, removing an air valve is often a convenient way to provide a point of entry for the disinfecting solution. The solution should be left in the section for a period ranging from 12 to 24 hours and never less than six.

Household tanks

Most national water quality monitoring programs or public utility control programs focus specifically on water production and distribution until it enters the individual household connections. Furthermore, in many developing countries, for reasons of economy, drinking water projects are built to supply household tanks that serve as “lungs.” At times, the choice is made to distribute the storage capacity in a summatory of small tanks in each home supplied, instead of by building large tanks and cisterns.

Water of excellent quality that has been produced and distributed has been found time and again and in many countries, as well, to have spoiled precisely before being consumed. The reason for this is the poor condition of household tanks. One of the authors of this manual participated in a research project on the state of the water in the tanks of an important city in a developing country. It was

found that in 75% of the cases the tanks contaminated the water that flowed into them.

The same author found, at the conclusion of another tank disinfection program in a small rural town of another developing country, that the list of dead animals encountered in the household tanks that were cleaned and disinfected ranged from cockroaches to birds and from rats to ferrets, without counting an impressive series of such varied objects as small pieces of furniture, branches, cans, toys and even a bicycle.

The lack of legislation requiring home owners to take care of, clean and disinfect household water tanks and the absence of tank protection programs carried out by public health institutions is responsible for this situation, which is common in countries where water is stored in household tanks. It can also be attributed to a notorious lack of health education among users, for the apathy of those who are responsible for keeping the tanks clean (the home owners) is almost always due to their ignorance of the risks that can be avoided by keeping those tanks in excellent sanitary condition.

The cleaning and disinfection of household tanks should be popularized, either at the initiative of public health institutions, the local water company or the homeowner, through standards and rules that are simple and instructions that are easy to follow.

A household tank can be cleaned and disinfected in ways that are no different from those discussed in the section on new tanks and reservoirs. Even so, it is necessary to bear in mind two different details, for these elements are almost always smaller in household tanks than in the tanks or reservoirs of a water system or service. Household tanks can hold any volume, but the most common in single-family dwellings have a capacity of between 400 and 1,000 liters. These volumes sometimes make appropriate cleaning of the tank interior difficult. The second special characteristic is the cover. Many of the problems with household tanks can be traced to covers that fail to close tightly or the absence of such covers.

Below are a series of simple and precise instructions to be given to the people, together with explanations about the need to keep household tanks clean and disinfected:

1. Prepare a reasonable supply of water in closed and covered containers because no water will be available during the cleaning and disinfection process.
2. Start by removing the tank cover and shut off the floatation valve so that water stops flowing from the main. At that point, the water in the home can no longer be used until the process has been completed.
3. Open the tank's drain valve ("discharge or drain") and drain the water until only 10 cm remain on the bottom.
4. Using that water and a hard bristled brush, scrub the inside walls of the tank until they are as clean as possible. A hand brush, together with clean cloths can also be used to help. A flashlight can be useful in this case.
5. Drain out all dirty water through the tank's drain valve (not through the household installations and water taps).
6. Repeat the operation as often as necessary until the inside walls are clean.
7. Open the flotation valve and let water run into the main and fill the tank ¼ full. Add enough sodium or calcium hypochlorite to produce a final concentration (when the tank is full) of 100 mg of chlorine per liter of water. (In countries where a single product is available, i.e. sodium hypochlorite with a fixed concentration throughout the country —for example, 8%— , the authorities who prepare the instructions could calculate the amount to be added. In that case, the instructions should merely state: "add such and such a volume of bleach for every one thousand liters of tank capacity." In areas where various chlorine compounds are sold freely, the necessary amount should be calculated using the following formulas).

On the basis of:	Sodium hypochlorite	Calcium hypochlorite
Description	This compound is sold as a liquid under several different names (bleach, etc.), with varying chlorine contents, the most commonly found being from 7% to 10%.	This compound is marketed in solid state with varying chlorine contents, the most common being from 60% to 70%.
Formula to be used	$V = \frac{Vt \text{ x } 10}{\%}$ Where: V = Volume in milliliters of sodium hypochlorite to be added to the water tank Vt = Tank volume = Volume of water to be added to the tank to prepare the disinfecting solution 10 = Multiplier to be used to state the result in milliliters of the product % = Chlorine concentration in the product, as specified by the manufacturer (place only the number in the formula, for example "7" when the chlorine concentration in the product is 7%)	$W = \frac{Vt \text{ x } 10}{\%}$ Where: W = Product (calcium hypochlorite) weight in grams to be dissolved in the tank Vt = Tank volume = Volume of water to be added to the tank to prepare the disinfecting solution 10 = Multiplier to be used to state the result in grams of the product % = Chlorine concentration in the product, as specified by the manufacturer (place only the number in the formula, for example "65" when the chlorine concentration in the product is 65%)
Example	For a 500-liter tank using sodium hypochlorite with an 8% concentration, the amount of the product to be added to the tank will be: $V = \frac{500 \text{ x } 10}{8} = 625 \text{ ml}$	For an 800-liter tank using calcium hypochlorite with a 70% concentration, the amount of the product to be dissolved in the tank will be: $W = \frac{800 \text{ x } 10}{70} = 114 \text{ g}$

8. Once the disinfectant has been added, fill the tank to the top level.
9. When the tank is full of the disinfecting solution, open each of the household water taps and let the water run until a strong chlorine smell is noticeable. Then turn off the water. This operation is important for disinfecting not only **the tank, but also all of the household pipes and taps. This water must not be drunk or used for any other purpose whatsoever.**
10. Leave the household water system untouched for 12 hours so that the chlorine can act (the period can be shortened, but to no less than six hours). If possible, leave it undisturbed overnight.
11. Following the disinfection, drain off all of the water in the tank and open all of the household taps to eliminate all of the chlorine still remaining in the pipes.

12. Let fresh water from the distribution system enter the tank. It can now be used for drinking and other purposes, because the installations have been disinfected.
13. Make sure that the tank is well covered and that no animals or birds can get inside. The ideal situation would be to padlock the tank cover.
14. Repeat the tank cleaning and disinfection process every six months and never let more than a year pass between operations.

Disinfection of the water supply in emergency situations

Long-term measures for the provision of a 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 the water supply. While efforts should be made to put the systems back into operation, top priority should also be given to providing the affected population with safe drinking water.

While no single universal measure is applicable to 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 water sources 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. Failure to do so could result in the outbreak and spread of the dreaded pandemics that sicken people already in a state of psychological shock over the disaster itself, not only physically, but also spiritually.

There are two important moments following a disaster. One is “absolutely immediate” and the other, “relatively immediate,” on the second or third day after the event. In the former case, with the impact of the disaster (whether an earthquake, a cyclone, or other event) still too fresh in their minds, disorder reigns and means of all kinds are in short supply. In those cases, the boiling of water is all that can be recommended. Vigorous boiling for a minute kills off any microorganism that may be present in the contaminated water.

During the second moment —two or three days after the occurrence of the disaster— a peculiar situation arises that health officers in particular must cope with. It is not the lack of disinfectants but, rather, their excess supply that creates the problem. After disaster strikes an area, it is flooded with a wide variety of donated disinfectants. These are normally chlorine-based compounds, but of different compositions and concentrations. It is useful to know how to handle them properly.

Two suggestions are to be made in this situation:

- First, it is important for the population never to prepare or handle stock solutions with a high hypochlorite concentration. People should be given a disinfecting solution ready for use in a batch system (for disinfection of a household tank or container).

- Second, an ideal stock for use in emergency situations is one that has a concentration of 5,000 mg of chlorine/liter.

Health officials should prepare stock solutions from any chlorine-based product using the following formula.

$$\boxed{\frac{V_{water} \ \mathrm{x} \ C_{stock}}{C_{product} \ \mathrm{x} \ 10} = W_{product}}$$

Where:

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

C_{stock} = Concentration of stock solution (if, as suggested, a 5,000 mg of chlorine/L of water is intended, the value for C_{stock} should be = 5,000)

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

10 = Multiplier to be used to state the result in grams of the product

$W_{product}$ = Grams of the product to be dissolved in V_{water}

While there is no hard and fast standard, the following is considered to be a good dose:

The disinfection dose that will be suggested to the population is 5 mg/l during extreme emergencies and then 2 mg/l under less stressful conditions.

It should be recommended at all time that the chlorine be “allowed to work” at least 30 minutes.

The following table presents the appropriate dilutions that people should prepare from the stock solution they are given.

Volume of water to be disinfected (liters)	**Volume of stock solution (of 5,000 mg/l) to be added to obtain a final concentration of 5 mg/l**	**Volume of stock solution (of 5,000 mg/l) to be added to obtain a final concentration of 2 mg/l**
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
1,000	1 liter	400 ml

If iodine tincture (which is a solution with a 2% concentration) is available, the recommendation is to add five drops per liter of water and allow it to act for a 30-minute period.

Chapter 11

COMPARATIVE DATA ON DISINFECTION TECHNIQUES

Introduction

The foregoing pages of this manual describe the water disinfection techniques used throughout almost the entire world. This chapter presents tables that summarize the characteristics, advantages and disadvantages of each of the methods, together with the most appropriate sites for their application. The organization of the information in that way will make it easier to choose the technology that is most appropriate for local conditions. This is a process that will have to be undertaken by the engineers, government officials, water companies, community organizations and their leaders, and families that must select one of them to disinfect the water for human consumption in a given community. The criteria to be used in choosing the most appropriate technique must be based on a series of evaluations, and not merely measurements.

Summary of the disinfection techniques

The series of lists and tables given below will contribute not only elements for reaching decisions, but will also serve as summaries of the information that has been covered in this manual.

	SODIS
Method	Continuous
Applicability	Households and small villages
Form of action	Pasteurization
Equipment	Typical solar water heaters. Can be made locally and even by the users themselves
Complexity	Very low
Advantages	Extremely simple. Acceptable to the users. Causes no changes in water properties (except for the temperature). No DBP generated
Disadvantages	Disinfection depends on a large number of varied parameters. Difficult to standardize and ensure thoroughness of disinfection. There is no residual
Equipment cost	Moderate
O&m cost	Almost nothing
Availability	Intermediate. Can be made locally
Maintenance	Simple but continuous
Controls	Simple but continuous

Analytical test	Difficult because there is no residual to be measured. Only bacteriological analysis can confirm disinfection efficacy
Recommendations	Very good option for scattered rural populations and small villages
SODIS	
Method	Batch (stoves, bottles and containers)
Applicability	Households
Form of action	Pasteurization
Equipment	Soft drink bottles. Pans and simple solar stoves
Complexity	None
Advantages	Extremely simple. Acceptable to users. Causes no changes in water properties (except for the temperature). No DBP generated.
Disadvantages	Disinfection depends on a large number of varied parameters. Difficult to standardize and ensure thoroughness of disinfection. There is no residual
Equipment cost	None
O&m cost	None
Availability	High. The method using soft drink bottles is universal
Maintenance	Simple
Controls	Few
Analytical test	Difficult because there is no residual to be measured. Only bacteriological analysis can confirm disinfection efficacy
Recommendations	Very good option for scattered rural populations and small villages
CHLORINE	
Method	Gas
Applicability	Very broad. Medium-sized and large towns (5,000 to 10,000 inhabitants and over)
Form of action	Oxidation of organic matter
Equipment	Feeders mounted in cylinders and tanks, operating under pressure and by vacuum. Need pumps to recirculate water and other ancillary equipment. Appropriately conditioned areas and personal protection equipment are required
Complexity	Intermediate
Advantages	Simplicity. The most widely used method in the world. Chlorine gas is produced in almost every country. Inexpensive. There is an easily measured residual in the treated water

Disadvantages	A gas supply must be ensured in some distant communities. Operators need some training. Can cause changes in water taste and odor. Generates DBP
Equipment cost	Intermediate
O&m cost	Very low (gas chlorination is the least expensive of the most widely used methods)
Availability	Intermediate. The equipment and spare parts can only be obtained in large cities
Maintenance	Intermediate. Operators must be trained
Controls	Very frequent or almost constant. Automatic alarm systems are advisable.
Analytical test	Very simple. A large range of simple and inexpensive residual chlorine comparators are available
Recommendations	Despite some disadvantages, this is still the most popular method for intermediate and large cities and will continue to be for quite some time. It is one of the best options
CHLORINE	
Method	Solution dosing under normal pressure
Applicability	Small communities and even some intermediate ones
Form of action	Oxidation of organic matter
Equipment	A large variety of extremely simple devices. Some of them, stemming from the appropriate technology, are excellent and very popular. This is the most widely used technology in rural areas of developing countries
Complexity	Very low
Advantages	Simplicity. This is the most popular chlorine disinfection method, together with the use of chlorine gas. Hypochlorites are produced in almost every country. Dosers can be made locally. Inexpensive. There is an easily measured residual in the treated water
Disadvantages	Although this method is more popular than the use of chlorine gas, the supply of hypochlorite must be assured in some distant communities. Can cause changes in water taste and odor. Generates DBP
Equipment cost	Minimum. Some dosers cost almost nothing
O&m cost	Very low
Availability	High to intermediate
Maintenance	While extremely simple, it still requires maintenance and supervision

Controls	Although rapid and simple, they must be conducted frequently
Analytical test	Extremely simple. A large range of simple and inexpensive residual chlorine comparators are available
Recommendations	The best method for rural areas of developing countries
	CHLORINE
Method	Pressurized solution feeding
Applicability	Almost the full range of populations, but better for medium-sized towns
Form of action	Oxidation of organic matter
Equipment	Diaphragm or piston pumps
Complexity	Intermediate to low
Advantages	Extremely simple and almost automatic system. Hypochlorites are produced in almost every country. Pumps can be repaired locally. Economic. There is an easily measured residual in the treated water
Disadvantages	Although this method is more popular than the use of chlorine gas, the supply of hypochlorite must be ensured in some distant communities. Can cause changes in water taste and odor. Generates DBP
Equipment cost	Moderate to low
O&m cost	Low
Availability	Wide, but only in medium-sized to large cities
Maintenance	Simple
Controls	Although rapid and simple, they must be performed frequently
Analytical test	Extremely simple. A large range of simple and inexpensive residual chlorine comparators are available
Recommendations	Excellent option for small communities and pumping systems
	CHLORINE
Method	On-site electrolysis
Applicability	Households. Scattered rural populations. Small communities
Form of action	Oxidation of organic matter
Equipment	There are two kinds of systems that differ as to production capacity. The small ones for household use or scattered rural populations are small and simple. The industrial systems for use in drinking water treatment plants are larger and complex

Complexity	Low for the small and household systems and intermediate to high for the industrial ones
Advantages	Simple. Can be used by scattered populations. Generate low concentration, easily handled hypochlorite. There is an easily measured residual in the treated water
Disadvantages	While the low-concentration hypochlorite that is produced is better for drip feeders, it is inconvenient for disinfecting large flows. Needs electric power. Can cause changes in water taste and odor. Generates DBP
Equipment cost	Low to intermediate for small systems. High for industrial ones
O&m cost	Moderate
Availability	The equipment and spare parts can be found only in certain countries; in developing countries, they must almost always be imported. The basic input -table salt- is available everywhere
Maintenance	Moderate to low (anode carbonate scaling must be monitored)
Controls	Although rapid, they must be performed frequently
Analytical test	Extremely simple. A large range of simple and inexpensive residual chlorine comparators are available
Recommendations	The best method for any disinfectant distribution plan among scattered rural populations
CHLORINE	
Method	Tablet erosion
Applicability	Small communities
Form of action	Oxidation of organic matter
Equipment	Although all the equipment operates exactly the same way, a wide range is available for disinfecting different flows
Complexity	Low
Advantages	Extremely simple. Although they are of modern manufacture, the dosers appear to have been the result of the appropriate technology. Economic. The equipment can be operated under normal pressure or in pressurized pipes. There is an easily measured residual in the treated water
Disadvantages	While this method is ideal for rural areas, it depends on an input (the tablets) that must be imported or brought in from other places. Can cause changes in water odor and taste. Generates DBP
Equipment cost	Low
O&m cost	Low

Availability	Not very good. The tablets are not always available
Maintenance	Moderate to low (the tablet container must be monitored to keep caverns from forming)
Controls	Although rapid and simple, they must be performed frequently
Analytical test	Extremely simple. A large range of simple and inexpensive residual chlorine comparators are available
Recommendations	Where the tablet supply is assured, the method has come into wide use
	ULTRAVIOLET RADIATION
Method	Lamp in or outside the water
Applicability	The entire range of towns, from very small to very large
Form of action	Destruction of microorganism DNA
Equipment	Wide range, with lamps both in and outside the water
Complexity	The basic equipment per se (the UV lamp) is not complex. The necessary ancillary equipment has a varying range of complexities, depending on the degree of safety sought
Advantages	Simple. No chemicals needed. Short exposure period. Does not modify organoleptic characteristics of the water. No DBP generated
Disadvantages	Several types of testing devices are needed to ensure proper dosing. There is no simple and rapid way to measure disinfection efficacy. Needs electric power. There is no residual
Equipment cost	Low for simple systems without much protection. High for well-protected systems. Intermediate for systems that have only the essential elements for good operation
O&m cost	Low to moderate
Availability	Dependence of distant or rural areas on external suppliers
Maintenance	Simple but careful. Sleeves must be kept clean when lamps are submerged
Controls	Only the “controls must be controlled” (equipment monitoring radiation emissions and lamp life, etc.)
Analytical test	Only bacteriological analysis can confirm disinfection efficacy
Recommendations	Interesting method because of its simplicity. Applicable and in demand not only in large cities, but also a good option for rural areas

	SLOW FILTRATION
Method	Slow sand filtration (SSF)
Applicability	Small towns. To a lesser extent, medium-sized towns.
Form of action	Microorganism elimination by action of the biolayer (“fagocytosis”) covering the sand grains
Equipment	Slow sand filters, almost always built on site, using concrete, steel and other materials
Complexity	Low
Advantages	Extremely simple. Operates almost by itself. Eliminates raw water turbidity, as it disinfects. Does not modify organoleptic properties of water. Does not need electric power. No DBP generated
Disadvantages	To work effectively as a disinfection system, it must be well-built; contain the proper well-classified and washed sand; and operate under appropriate temperature, flow, filtration velocity and other conditions. There is no simple and rapid way to measure disinfection efficacy. There is no residual
Equipment cost	Moderate to intermediate. Although SSF is generally built to eliminate turbidity, the cost of the disinfection device is hidden in the total filter cost
O&m cost	Almost nothing
Availability	High. The building materials and the sand -heart of the system- are found almost everywhere
Maintenance	Low
Control	Extremely simple
Analytical test	Only bacteriological analysis can confirm disinfection efficacy
Recommendations	Oldest water treatment method, revitalized as a disinfection system. Always a valid option for rural populations
	OZONE
Method	Dry air or oxygen-driven
Applicability	Wide range, though more used for medium-sized and large systems because of its intrinsic characteristics (specialization, cost, operational requirements, etc)
Form of action	Oxidation of organic matter
Equipment	Basically two types: dry air or oxygen-driven. Smaller devices sold as package (mounted in fixed framework or container and transported by truck, vessel or train)

Complexity	High
Advantages	Excellent disinfectant. At times, improves organoleptic properties of treated water
Disadvantages	Overly complex for many communities in developing countries, even large ones. Trained personnel needed for operation and control. Generates DBP, but less than chlorine. There is no residual. Needs assured electric power
Equipment cost	High
O&m cost	Among the most expensive of the disinfectants
Availability	Very low. Equipment must be purchased in developed countries.
Maintenance	High and careful
Control	Most equipment is sold with control systems. System control alarms must be heeded
Analytical test	Laboratory detection methods exist, but are complex. No field detection methods. Distribution system water cannot be analyzed due to very short average life span of O_3
Recommendations	At present, only for countries with the capacity to use the technique
CHLORINE DIOXIDE	
Method	Two and three component systems
Applicability	Wide-range, though more used for medium-sized and large systems because of its intrinsic characteristics (specialization, cost, operational requirements, etc)
Form of action	Oxidation of organic matter
Equipment	Each system (2 or 3 component) is a summatory of different devices. Most systems sold as a package
Complexity	Although each device is relatively simple (pump, contactor, tank, etc), the full system is quite complex
Advantages	Excellent disinfectant. Improves iron and manganese removal. Not affected by changes in water pH. Improves organoleptic properties of treated water at times
Disadvantages	Overly complex for many communities in developing countries, even large ones. Trained personnel needed for operation and control. Generates DBP, but less than chlorine. There is no residual. Needs plentiful chemical inputs and assured electric power
Equipment cost	High
O&m cost	High

Availability	Very low. Equipment must be purchased in developed countries.
Maintenance	High and careful
Controls	Most equipment is sold with control systems. System control alarms must be heeded
Analytical test	Four-step amperometric titration requiring specific instruments and trained operators
Recommendations	At present, only for countries with the capacity to use the technique
	MINIFILTRATION
Method	Microfiltration, ultrafiltration, nanofiltration and reverse osmosis
Applicability	Varied range of possibilities. Generally used for small and medium-sized communities
Form of action	Microorganism retention through mechanical filtration
Equipment	Pore diameter of filtering membrane determines use of micro, ultra, or nanofiltration or R.O. Equipment varies according to pretreatment, form of filtration (inside-out or outside-in), transmembrane pressure exerted to permit filtration and advisable care of membranes. Almost always sold as a package
Complexity	High. Although simple in principle, the equipment is highly complex in practice
Advantages	Provides excellent quality water. Disinfection is a by-product of water quality improvement treatment. Does not modify organoleptic properties of water. No DBP generated
Disadvantages	Complexity. Well-trained operators and maintenance personnel are needed. Local technicians hard put to resolve problems. There is no residual. Needs electric power
Equipment cost	Very high
O&m cost	Intermediate to high
Availability	Very low. Equipment must be purchased in developed countries
Maintenance	High and careful
Controls	Most equipment is sold with control systems. System control alarms must be heeded
Analytical test	Only microbiological analysis can confirm disinfection efficacy
Recommendations	Interesting technique with a future. At present, like ozone and chlorine dioxide, only recommendable for developed countries because of its complexity and much higher cost than methods in widespread use

	BROMINE
Method	Solution
Applicability	Small and medium-sized towns
Form of action	Oxidation of organic matter
Equipment	Same as that used for hypochlorite solutions. A large variety of extremely simple devices are available. Some of them from the appropriate technology are excellent and widely used
Complexity	Very low
Advantages	Same simplicity as that of sodium hypochlorite solutions that have attracted many supporters. Dosers can be produced locally. There is an easily measured residual like that of chlorine in the treated water
Disadvantages	Not nearly as popular as chlorine and its compounds because it doesn’t have the same uses. Difficult to obtain bromine in developing countries. Much more expensive than chlorine. Generates DBP
Equipment cost	Low. Some dosers cost almost nothing
O&m cost	Very low
Availability	Of dosers, high to intermediate. Of chemical input -bromine-, very low
Maintenance	Although extremely simple, requires more supervision and maintenance than chlorine-based systems
Controls	The same as those to be used for chlorine technology
Analytical test	Like that of chlorine. The same comparators are used
Recommendations	Good technique. Not recommendable for developing countries because of difficulty in obtaining bromine
	SILVER
Method	Solution dosing
Applicability	Household level. Small communities
Form of action	Oligodynamics
Equipment	Same as that used to dose sodium hypochlorite solutions (dosing pumps, pressurized dosing equipment and equipment for dosing under normal pressure, etc.)
Complexity	Very low
Advantages	Simplicity. Efficacy. Does not modify organoleptic properties of treated water. No DBP generated

Disadvantages	Ag solutions are not widely used or easy to obtain. Difficult to control Ag concentration in water. No simple methods for measuring residual concentration. Much more expensive than hypochlorite
Equipment cost	Moderate to low
O&m cost	Low to intermediate (depending on location of available solutions)
Availability	Generally low
Maintenance	Simple
Controls	While rapid and simple, must be frequently performed
Analytical test	No practical method for rural use
Recommendations	Good option for household water disinfection
	SILVER
Method	Electrolysis
Applicability	Small communities
Form of action	Oligodynamics
Equipment	Electrolytic cells placed inside containers closed under pressure
Complexity	Low
Advantages	Simplicity. Efficacy. Does not modify organoleptic properties of treated water. No DBP generated
Disadvantages	Difficult to control Ag concentration in water. No simple methods for measuring residual concentration. Much more expensive than hypochlorite. Needs a good electric power supply
Equipment cost	Moderate to intermediate
O&m cost	Intermediate (depending on location of available spare parts, electrodes, etc.)
Availability	Generally low
Maintenance	Simple
Controls	While rapid and simple, must be frequently performed. Need for automatic control system in case of power outages
Analytical test	No practical method for rural use
Recommendations	Recommended at the rural level only when chlorine and chlorine compounds cannot be used
	IODINE
Method	Solution dosing
Applicability	Households. Small communities

Form of action	Oxidation of organic matter
Equipment	That used for chlorination, but dosing pumps are preferred
Complexity	Low, but care must be taken in preparing the iodine solution when crystalline iodine is used
Advantages	Extremely simple and less aggressive than chlorine. No problem with DBP generation. There is a residual
Disadvantages	Its use is questioned because of reactions it produces in sensitive persons. Considerably more expensive and harder to obtain than chlorine
Equipment cost	Moderate
O&m cost	Low
Availability	Of equipment (pumps), good, but only in medium-sized and large cities. Of the iodine, low
Maintenance	Simple
Controls	Simple, but must be frequently performed
Analytical test	The iodine content in water can be determined by amperometric titration or spectrophotometry. These require appropriate instruments and personnel with some training. There are no rapid field methods.
Recommendations	Not a recommendable method. Little used for routine disinfection. Its ease of handling makes it a good option for emergency situations
	DICHLOROISOCYANURATE
Method	Solution dosing under normal pressure
Applicability	Small communities and even some medium-sized ones. Population in emergency shelters
Form of action	Oxidation of organic matter
Equipment	Diaphragm or piston pumps
Complexity	Intermediate to low
Advantages	Extremely simple and almost automatic system. Economic, but less than so than other chlorine compounds. Does not modify water taste and odor like other chlorine compounds. There is an easily measured residual in the treated water
Disadvantages	Not enough evidence of its total innocuousness for health. Generates DBP
Equipment cost	Intermediate for small systems and always higher than the cost of systems using other chlorine compounds

O&m cost	Low
Availability	Good, but only in medium-sized to large cities
Maintenance	Simple
Controls	While rapid and simple, must be frequently performed
Analytical test	Extremely simple. A large range of simple and inexpensive residual chlorine comparators are available
Recommendations	Good method for use in emergency situations and in temporary shelters. Not recommendable for long-term use in systematic disinfection
DICHLOROISOCYANURATE	
Method	Powder or tablet to be dissolved in small containers
Applicability	People in emergency shelters
Form of action	Oxidation of organic matter
Equipment	Buckets and containers
Complexity	Low or none
Advantages	Extremely simple system. Economic, but less so than other chlorine compounds. Does not modify water taste and odor like other chlorine compounds. Highly stable and easy to handle in the difficult conditions in the shelters. There is an easily measured residual in the treated water
Disadvantages	Not enough evidence of its total innocuousness for health. Generates DBP
Equipment cost	Only the product cost, which is not very high, but always more than that of traditional chlorine compounds
O&m cost	None
Availability	Good, but only in medium-sized to large cities
Maintenance	None
Controls	While rapid and simple, must be frequently performed
Analytical test	Extremely simple. A large range of simple and inexpensive residual chlorine comparators are available
Recommendations	Good method for use in emergency situations and in temporary shelters. Not recommendable for long-term use in systematic disinfection

	MIXED OXIDANT GASES
Method	Moggod
Applicability	Small communities
Form of action	Oxidation of organic matter
Equipment	Dosing pumps and venturis, by model
Complexity	Of the equipment, intermediate to high. Of the method, very low
Advantages	Excellent disinfectant, apparently more effective than even chlorine.
	Very easily operated equipment. Table salt, the main input, can be found anywhere, no matter how remote. There is a measurable residual
Disadvantages	Moggod equipment (not that used for on-site electrolysis) is somewhat complex. Problems can arise if equipment is not properly maintained. Generates DBP. Needs electric power
Equipment cost	Intermediate
O&m cost	Low
Availability	Of the equipment, low. Of the basic input –table salt-, extremely high
Maintenance	Need good maintenance. Reported failures are due to deficient maintenance, above all the cleaning of membranes and electrodes
Controls	Frequent
Analytical test	Extremely simple. A large range of simple and inexpensive residual chlorine comparators are available
Recommendations	Despite its relative complexity, a good option for very remote sites that have electric power, but cannot obtain chemical substances, such as hypochlorites, etc. locally. Operators must have simple training and also be aware of the importance of good maintenance
	SYNERGIES
Method	Several
Applicability	Depends on the method
Form of action	Depends on the individual methods that constitute the synergic method. These can be oxidation, radiation, etc.
Equipment	No different from the equipment used for each individual technique
Complexity	Obviously more complex than the use of individual techniques
Advantages	Synergy provides disinfection actions not obtained through other methods, both as to microorganism destruction and DBP generation. Greater complexity leads to disinfection excellence

Disadvantages	Complexity, difficulty in knowing exactly what mechanisms occur in the disinfection process. Higher costs. Need for more controls and trained personnel. Possible difficulty in measuring residual.
Equipment cost	Depends on each particular case. Costs are obviously higher than those of using each of the synergic techniques individually
O&m cost	Variable
Availability	Low at present, for these are not in widespread use
Maintenance	Depends on the particular method
Controls	Depends on the particular method
Analytical test	Responds to the analytical needs of each individual method. Possibly some difficulty or need for delicate or complex equipment and instruments
Recommendations	Today, these are more within the area of research and development than in wide use. Not recommended at the moment for rural areas of developing countries
	HOUSEHOLD FILTERS
Method	Several
Applicability	Households. Small population groups, such as villages
Form of action	Microorganism elimination via oligodynamics or filtration
Equipment	Individual or modular filters (several filters with different functions arrayed in a series). Some units need no replacement (those using ceramic candles), while others do (those using silver coated sand)
Complexity	Very low
Advantages	Simplicity, disinfection efficacy and elimination of tastes, odors and other organic matter. Ease of household use at tap for direct consumption minimizes lack of residual
Disadvantages	Market flooded with too many brands and models. Many do not provide what they claim to and so do not truly “disinfect.” Must be given very thorough maintenance
Equipment cost	Low to intermediate
O&m cost	Depends on the type of filter used. Ceramic candles are cleaned and reused. Other filters must be replaced. Costs vary according to the type of product
Availability	Good
Maintenance	Extremely simple. Highly important to take the necessary care when washing or replacing modules, as instructed by the manufacturer

Controls	Not necessary
Analytical test	No simple and rapid analytical tests can be performed because there is no residual. Microbiological tests are needed to confirm disinfection efficacy
Recommendations	Highly recommendable, particularly for household use. Care must be taken to ensure that units are reliable (certifiably well-made of appropriate materials) and are given thorough maintenance.

Comparative tables of disinfection techniques

Below are two comparative tables, the first covering different disinfectants and their applicability and the second, the characteristics of dosing devices.

Information sources

Skinner, B.; *Chlorinating small water supplies*, a WELL study available at WEDC, Loughborough University, UK (2001).

Comparative table of the different disinfectants and their applicability

	SODIS	■$_2$	UV	S.S.F.	■$_3$	ClO_2	MINI	■$_2$	Ag	▮$_2$
Efficacy										
- Bacteria	H	H	H	H	H	H	H	H	H	H
- Viruses	H	H	H	I	H	H	H	H	I	H
- Protozoa	L	L	L	H	I	I	H	L	L	I
- Helminths	L	L	L	H	H	I	H	L	L	L
Raw water influence on										
- pH	L	H	L	L	L	L	H	I	L	L
- Turbidity	H	I	H	L	H	I	H	I	I	H
- Organic matter	I	L	L	L	L	L	I	L	L	L
Generated DBP	NO	YES	NO	NO	L	L	NO	YES	NO	NO
Maintains protective residual	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES
Possible changes in water waste and odor	NO	YES	NO	NO	NO	NO	NO	YES	NO	NO
Range of use flows	L	L-I-H	L-I-H	L-I	L-I-H	I-H	I-H	L-I	L	L-I
Equipment cost	L	L	L-I	I	I-H	I-H	H	L	L-I	L
Operating cost	L	L	L-I	L	H	H	H	I	I	I-H
Operator cost	L	L-I	L-I	L	H	H	H	L-I	L-I	L-I
Need for chemicals	NO	YES	NO	NO	NO	YES	NO	YES	YES	YES
Need for electric power	NO	L	I	NO	H	H	H	L	L	L

H = High I = Intermediate L = Low

Characteristics of different devices and feeders

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Can be used in water currents (channels, unpressurized piping)	YES	NO	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
Can be used for pressurized dosing (pressurized piping)	NO	NO	YES	NO	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES
Can be used for intermittent flows	NO	SI	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	YES
Can be used for flows: Low, Intermediate or High (L.I.H.)	L	L	I-H	L-I	I-H	L-I	L-I	L-I-H	L-I	L-I-H	I-H	I-H	L-I	L-I	L
Can be made locally by local craftsmen	YES	YES	NO	YES	NO	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO
Spare parts available on-site or in nearby communities	YES	YES	NO	YES	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO
Need for operator maintenance and repair skills: Low, Intermediate or High (L.I.H.)	L	L	I	L	I	L	L	L/I	L	H	H	H	I	I	L

1. Continuous heaters (SODIS)
2. Batch heaters (SODIS)
3. Gas feeders (Chlorine)
4. Solution feeders (floating box; glass/bottle; tube with a hole) (Sodium hypochlorite, Br_2, Ag, and other solutions)
5. Dosing pumps (Sodium hypochlorite, Br_2, Ag, and other solutions)
6. Venturis (Sodium hypochlorite, Br_2, Ag, and other solutions)
7. Erosion feeders (Calcium hypochlorite)
8. UV radiation equipment
9. Slow sand filter
10. Ozonation equipment
11. Chlorine dioxide equipment
12. Minifiltration
13. Electrolytic devices (Ag)
14. MOGGOD
15. Household filters

H = High
I = Intermediate
L = Low