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 tanks and disinfection in emergency situations.

Information sources

Galal-Gorchev, H. *Guías de la OMS para la calidad del agua potable y evaluación de los riesgos para la salud vinculados con los desinfectantes y los SPD*. Study presented in the PAHO/ILSI Publication “La calidad del agua potable en América Latina” (1996).

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