TECHNICAL NOTE

INFORMATION FOR ACTION FROM THE WATER AND SANITATION FOR HEALTH PROJECT

Disinfection for Rural Community Water Supply Systems in Developing Countries

1. Introduction

Disinfection of water supplies is an important step in reducing the risk of waterborne diseases. In the United States and most developed countries disinfection is considered necessary and is routine in public water systems. The record is mixed in developing countries with reliable disinfection the exception rather than the rule. The reasons for this dubious record include cost, failure to understand the importance of disinfection, and the lack of social and institutional frameworks that facilitate the daily operation and maintenance tasks of even simple systems.

In many countries the record in rural areas is so poor and the prospects for success so limited that it is not even considered practical to attempt to disinfect water supplies. In 1991 cholera surfaced in several Latin American countries and health specialists predict that the disease will become endemic in the region for the foreseeable future. Cholera is also endemic in parts of Africa and Asia. The presence of this life-threatening disease makes water system disinfection both more necessary and more feasible. People are highly interested in cholera prevention.

The rural water supply systems supported by the U.S. Agency for International Development (USAID) serve communities ranging in size from 250 to 1000. These water systems provide different levels of service but all the technologies are simple. They include wells with hand pumps and motor driven pumps and surface water sources which are rarely filtered. Water is typically transmitted through plastic or metallic pipes which go either to households or to neighborhood standpipes. Meters are not usually installed either at the source or at the household or neighborhood connection.

The purpose of this technical note is to give information about disinfection in rural community water supply systems in developing countries. It places an emphasis on the health and technical aspects of disinfection and does not attempt to explain whether disinfection should be undertaken in a particular project or community. Decisions on specific cases must take into account a knowledge of local conditions and the nature of the project in question, in addition to technical information.

Water can also be disinfected by individual households. However, household disinfection is not addressed in this Technical Note. The topic is addressed in a separate Technical Note entitled "Household Water Disinfection" also available from the WASH Project.

2. What is Disinfection?

Disinfection of water is the process of destroying or inactivating disease-causing (pathogenic) organisms in water supplies. Although it is not as thorough as sterilization, which completely destroys all living organisms, disinfection makes the water safe for drinking and cooking. The most common method of disinfecting community water supplies is chlorination.

Health authorities worldwide accept the effectiveness and importance of chlorination and history records its effectiveness. After the widespread introduction of chlorination in the United States in 1920, the number of waterborne disease outbreaks dropped steadily between 1920 and 1960.

Pathogenic organisms found in water supply sources include a variety of bacteria of intestinal origin, intestinal parasites, viruses, and some larger organisms. The most common waterborne diseases prevented by disinfection are shown in Table 1.

Table 1. Diseases Prevented by Disinfection

Bacterial	Viral	Parasitic
Typhoid fever	Hepatitis	Amebiasis
Paratyphoid	Rotavirus diarrhea	Giardiasis
Childhood bacterial diarrheas		Crypotsporidium
Cholera		

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Childhood diarrhea—caused by a variety of bacterial, viral, and parasitic organisms—is the most important group of waterborne diseases. The number one cause of death in children under five, diarrheal disease causes 4.6 million deaths annually in this age group alone. Cholera is a severe, life-threatening diarrheal illness in children and adults which spreads in epidemics through Asia, Africa, and, more recently, Latin America.

3. Effectiveness of Disinfection

Each of the organisms responsible for waterborne diseases has a different resistance to chlorine and the other disinfectants used in water supply practice. In the past, the normal practice was to provide a chlorine contact time of 20 minutes. It is now clear that certain resistant organisms, particularly those of parasitic origin, require a longer contact time for effective disinfection. Another determinant of the success of disinfection is the strength or concentration of disinfectant used. Other important factors influencing the success of disinfection are water temperature and pH, and the presence of interfering substances.

For optimum effectiveness, disinfection of contaminated water supplies should be constant. Because waterborne diseases can be caused by a single dose, such as drinking a glass of water, instead of cumulative or chronic exposure, disinfection which allows intermittent exposure to contaminated water will be less effective in preventing disease.

Waterborne diseases are a major public health problem due to a number of interrelated problems: poor sanitation, high levels of environmental contamination, shortage of water for household use, poor water quality, and inadequate hygienic practices. Improving water quality through disinfection is necessary to reduce waterborne diseases. Several studies show, however, that disinfection is most effective when implemented in combination with increased access to water, increased water quantity, improved sanitation, and education in hygiene.

The relative importance of disinfection will also depend on local disease patterns. For example, disinfection will not reduce diseases such as schistosomiasis that are spread by skin contact with infected water sources. In contrast, water quality interventions, including disinfection, are especially important in areas facing problems with cholera, since assured water quality is the primary means of controlling this classic waterborne disease. Fortunately, cholera vibrios are very susceptible to chlorine.

Positive Effects of Disinfection

In addition to their ability to kill or inactivate pathogenic organisms, disinfectants produce other positive effects.

Most disinfectants are also oxidizing agents and serve useful purposes such as removal of iron and manganese and the control of some tastes and odors. They also prevent, or at least reduce, algal growths. Maintenance of pipeline capacity, filter media and water quality in the distribution system are additional positive effects of disinfection.

Negative Effects of Disinfection

Disinfection may be costly and handling disinfectants hazardous. Additional negative results of disinfection are disagreeable tastes and odors; these usually relate to an excessive dosage or the presence of certain organic compounds in the water.

The creation of disinfection by-products has only been recognized since the early 1970s. The results of studies on laboratory animals indicate that certain compounds resulting from chlorination are carcinogenic or have long-term toxic effects. Recent legislation in the United States calls for increasing control and monitoring of chlorine by-products such as Trihalomethanes (THM). Health authorities in developed countries now regulate THM at levels between 50 and 300 parts per billion (ppb). The World Health Organization has adopted a guideline limit for chloroform of 30 ppb.

The degree of long-term risk from these carcinogens cannot be accurately determined. However, at the regulated value for THM (100 ppb), the U.S. Environmental Protection Agency believes the risk to be on the order of one additional case of cancer in a population of 100,000 in a lifetime. The related risks of chlorine by-products are, therefore, generally considered low compared to the risks of inadequate disinfection.

4. Types of Disinfection Applicable for Small Community Systems

Many disinfection processes exist. Table 2 shows which have been used with success in small systems in developing countries.

Chlorine is the most commonly practiced disinfection method for municipal water supplies. A major advantage of chlorine is that it forms stable residues which are easy to measure. These residues also protect the distribution system from biological regrowth and provide a limited protection against contamination from cross-connections in the distribution system.

Iodine, along with bromine and chlorine, belong to a group of chemicals known as halogens. Although iodine has excellent germicidal qualities and low reactivity with organic compounds and poses no objectionable taste and odor problems, it is not used for large-scale disinfection in developing countries because it is more costly than chlorine compounds.

Table 2. Disinfection Processes for Small Systems

Types of Disinfection	Applicable to Small Systems
Chlorine (gas)	
Chlorine dioxide	
Chloramine	
Hypochlorite	x
Iodine	x
Bromine	x
Ozone	
Mixed oxidant gases	x
Ultraviolet light	
Ultrasonics	
Irradiation	

Hypochlorite Compounds

Of the various chlorine compounds, chlorine, in the form of a liquid/gas mixture, is most commonly used for medium and large systems.

Hypochlorite, which is available in solid or powder forms, is more commonly used in small systems. The active ingredient in this group of compounds is the hypochlorite ion (OCl). This ion hydrolyses to form hypochlorous acid (HOCl) which is the most effective disinfectant of the various compounds formed during chlorination. An important distinction between hypochlorites and chlorine gas is that the reaction of hypochlorites and water increases the alkalinity, or pH, balance, while the reaction of water and chlorine gas decreases the pH, making the water more acidic. This is why hypochlorites are most often used for small water systems in which the water is normally corrosive to metal pipes and fittings.

Other reasons for using hypochlorite compounds for small systems in developing countries are their availability and the relative ease and safety in handling. Capital costs

Table 3. Hypochlorite Chemicals

	Chlorinated Lime	Sodium Hypochlorite	Calcium Hypochlorite
Other names	Bleaching powder	Chlorine bleach	HTH, Perchloron high test hypochlorite
Formula	$CaO*CaOCl_2*3H_2O$	$NaOCl$	$Ca(OCl)_2*4H_2O$
Form	Powder	Solution	Powder, tablets, granules
Appearance/properties	White, Unstable, Deteriorates, Alkaline, Precipitates in hard waters	Yellow, Deteriorates, Hygroscopic, Corrosive, Gives off chlorine gas	White, Strong chlorine odor, Hygroscopic, Corrosive
Unit weight *(commercial strenths)*	45-50 lb./cu.ft. (675-750 kg./cu.m.)	10.0-10.2 lb./gal.[1] (1.18-1.21 kg./l.)	Granules 68-80 lb./cu.ft (1020-1200 kg./cu.m.) Powder 32-50 lb./cu.ft. (480-750 kg./cu.m.)
Commercial strength *(available chlorine)*	25-37%	10.4-12.2%[2]	60-70%
Feeding form *(percent available chlorine)*	up to 2% solution	up to 15% solution	up to 3% solution
Comments:	Store in dry well-ventilated area.	Store in cool dark area.	Store in dry well-ventilated area.

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[1] 12 percent sodium hypochlorite = 10.0 lb./gal. (1.18 kg./l.); 15 percent sodium hypochlorite = 10.2 lb./gal. (1.21 kg./l.)

[2] 12 percent sodium hypochlorite = 10.4% available chlorine; 15 percent sodium hypochlorite = 12.2% available chlorine.

Fig. 1

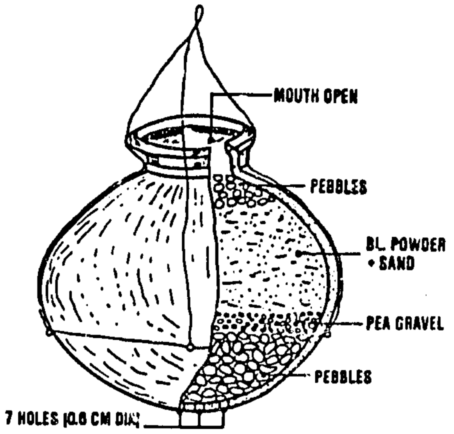


Fig. 2

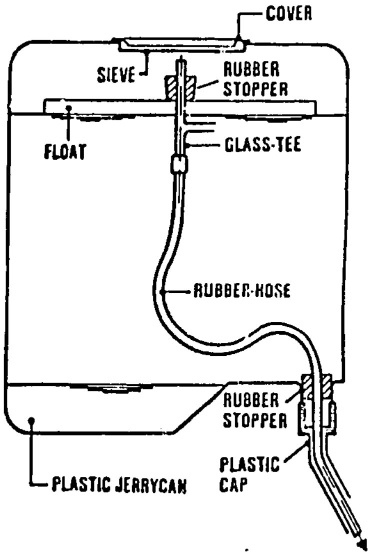
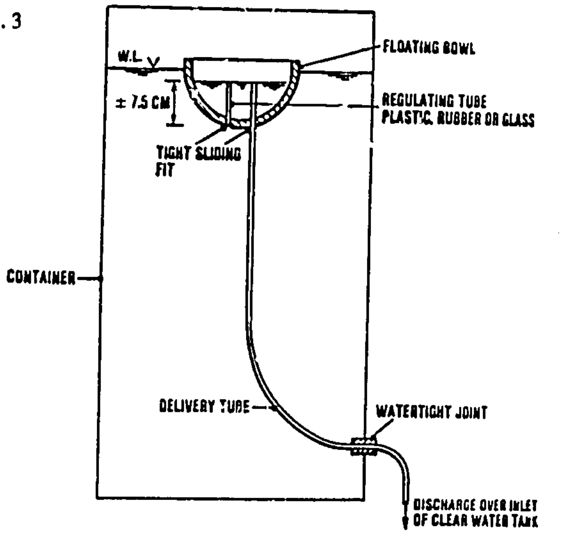


Fig. 3



of the equipment to feed hypochlorites into water systems are relatively low and the equipment itself is simpler than that used for gas chlorination.

The most common forms of hypochlorite are sodium hypochlorite, calcium hypochlorite, and chlorinated lime. The major factors to consider in selecting the hypochlorite compound for use are the quantities purchased, transportation costs, and the stability of the different compounds.

Bulk purchases lower the unit costs of these compounds. However, the cost of storage and loss of strength over time, especially for sodium hypochlorite, reduce the advantage of bulk purchases. For example, unopened high-test hypochlorite loses about 10% of its available chlorine in one year, while a 12% sodium hypochlorite solution loses about 10% of its available chlorine in 10 days.

Chlorinated lime has a very short life, especially in warm climates. Combining quicklime and chlorinated lime, to make the compound known as "tropical bleach," is more stable at warm temperatures and contains 25-30% available chlorine.

Because calcium hypochlorite comes in a much more concentrated form than the other hypochlorite compounds it is preferred for long-distance shipment.

Calcium hypochlorite and chlorinated lime are solid forms of hypochlorite. Solutions made from these two must be fed in more dilute forms, especially in hard waters, to avoid buildup of calcium salts which may clog equipment and small-diameter piping.

Materials which are suitable for containing hypochlorite solutions include glass, rubber, plastic, asbestos-cement, and fiberglass. Table 3 gives the properties of these three forms of hypochlorite.

5. Methods of Feeding Hypochlorites

Methods used for feeding hypochlorites in water systems typically supported by USAID vary from simple batch systems to electrically driven chemical feed pumps. Ten types are described in the literature. An in-depth determination of the effectiveness or relative merits of each of these types is difficult to obtain. However, a brief discussion of each follows. The first two types are used in wells, the remainder in piped systems.

1. Hand or batch feed

Used for special situations such as disinfecting wells, hand or batch types are suitable for treating small quantities of clear, slightly contaminated water. One method uses a container with small diameter tubing connected to an outlet near the bottom with the flow of solution regulated by a clamping device on the tubing. Frequent manual adjustment and cleaning are required for these types to be effective, and they are usually abandoned after a short time.

2. Pot type

One of the simplest, and least expensive, hypochlorination methods is the pot type. An earthen, plastic, or other locally available container is filled with a mixture of gravel, sand, and hypochlorite powder (usually bleaching powder). After several 6-8 mm holes are drilled in the bottom of the container it is suspended in the well with its mouth uncovered. (See Figure 1.)

In these type chlorinators the concentration of chlorine is reduced with time and, as with most simple disinfection systems, the chlorine dosage is highest when usage is low and low when usage is high. Thus, the first users in the morning might experience a high chlorine dosage with the resulting disagreeable taste and odor.

Some variations of the "pot" types include: a) a vessel made of coconut shells, b) one made from plastic pipe, and c) a double pot variation which consists of one pot filled with bleaching powder and sand inside another pot.

The following types of hypochlorinators, normally used in piped systems, should be located upstream of a distribution storage tank where the flow is relatively constant, the storage volume reduces the effects of short-term high or low dosages, and chlorine contact time is provided.

3. Drip feed

Normally used in small gravity or pumped systems where the flow is relatively constant, one drip feed type hypochlorinator uses a float in the chlorine solution to support a glass tee or tube with a small orifice just below the float and a constant head on the orifice. (See Figure 2.)

4. Floating bowl

A variation of the drip feed method, the floating bowl has a small tube inserted in the bottom that produces a constant flow of hypochlorite solution. Another small tube in the bowl conducts the hypochlorite solution to the feed point. (See Figure 3.)

Both of these drip feed types require frequent attention and plug up if used with solutions exceeding those recommended in Table 3. When used in pumped systems, these types sometimes feed into a tank connected to the suction side of the pump. When the pump stops, this hypochlorinator must be stopped manually. (See Figure 4.)

5. Canister type

The canister type of hypochlorinator, also referred to as the dissolving or diffusion type, is sometimes located on a bypass line with a small portion of the pipeline flow diverted through it. Calcium hypochlorite, usually in tablet form, is dissolved as the flow passes the tablets. (See

Fig. 4

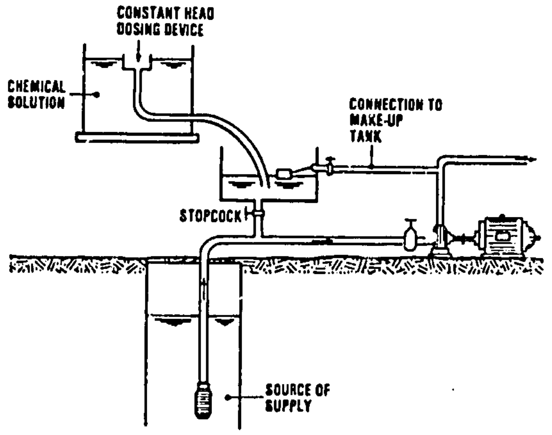


Fig. 5

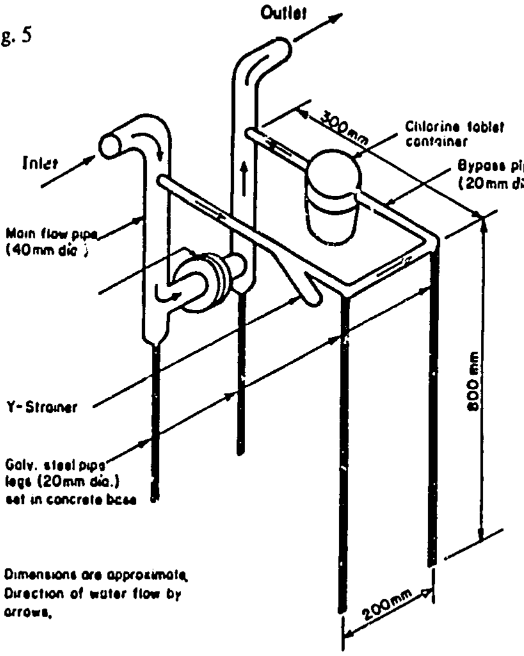


Fig. 6

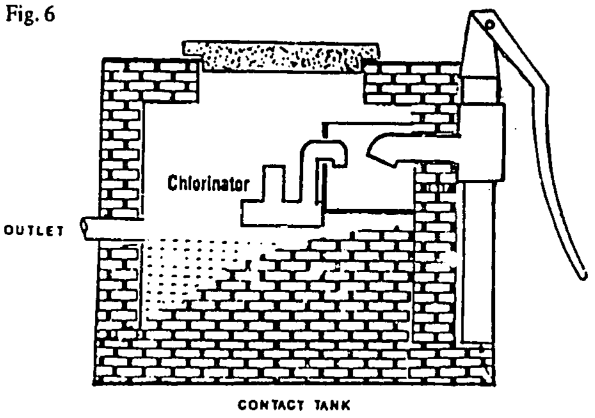


Fig. 7

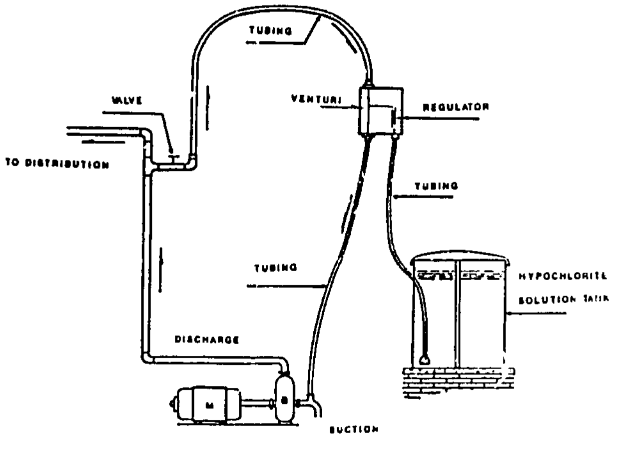


Fig. 8

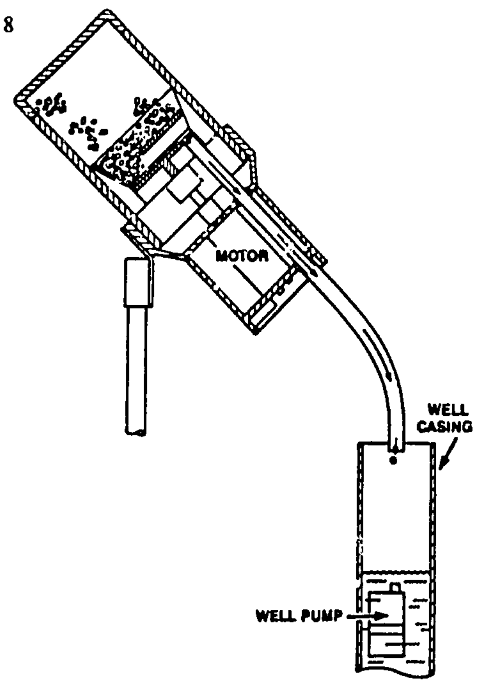


Fig. 9

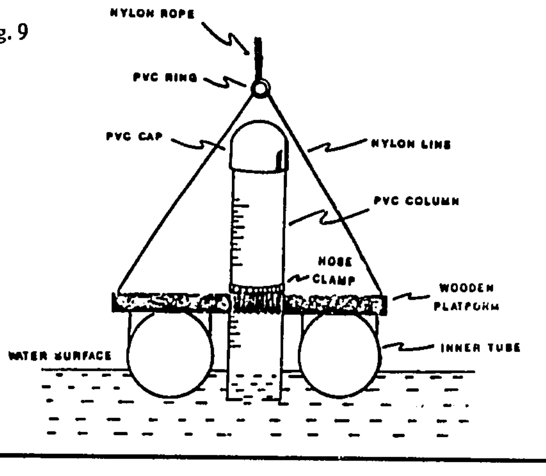


Figure 5.) This means that dosage is related to flow: increased velocities speed up the rate of dissolution. High chlorine concentrations can occur if the flow stops or decreases to a low level. To avoid this problem, some canister-type hypochlorinators are designed to be located near the point of discharge of the pipeline above the main line. They then drain completely when the flow stops.

6. Syphon type

A variation of the canister type is located in an inlet box of a distribution tank in such a manner that a syphon effect creates an intermittent flow through the device. (See Figure 6.)

7. Venturi type

In this type hypochlorinator, a venturi tube produces suction which draws hypochlorite solution into the line. The flow of hypochlorite is regulated by a rotometer in the suction line. (See Figure 7.)

8. Electric feed pump (solution)

Where electric power is reliable, electrically operated solution feed pumps can be successful for small pumped groundwater supply systems. The feed pump normally used is a metering type positive displacement diaphragm which provides a constant feed rate. The dosage is varied by adjusting the length of the diaphragm's movement. Operation of this chemical feed pump is normally initiated by the closure of the well pump circuit. For this type it is important to maintain an adequate stock of standby parts and a spare feed pump to put into operation until repairs can be made.

9. Electric dry pellet type

This electric feeder injects calcium hypochlorite pellets directly into a well casing when the well pump is running. (See Figure 8.) This feeder is normally activated by a flow signal or closure of the pump circuit.

10. Floating dispenser

A floating type of hypochlorinator used in the Caribbean islands consists of a plastic column supported by a small rubber inner tube which is designed to be located in a storage tank. It uses large hypochlorite tablets, and the chlorine residual is controlled by adjusting the height of the column which regulates the number of tablets exposed to the water. The unit is suspended by a rope which is also used to retrieve it. (See Figure 9.)

On-Site Generation of Hypochlorites by Electrolysis

Generating sodium hypochlorite on-site by electrolysis is becoming more economical and is reportedly cheaper than purchasing hypochlorite. Now used for rural water supplies in the former Soviet republics, Asia, Africa, and Latin America, on-site generation is used for large treatment plants where, due to safety or handling considerations, gas chlorination is undesirable. In some cases sodium hypochlorite is generated at a central location and then delivered to nearby water systems.

On-Site Generation of Mixed Oxidants

In 1982 the Pan American Health Organization (PAHO) began promoting a disinfection technology with the acronym "MOGGOD" (Mixed Oxidant Gases Generated On-site for Disinfection). PAHO began a demonstration project in 1986 to introduce Latin American and Caribbean countries to the MOGGOD concept, which depends on the electrolysis of a salt solution.

One device used produces mixed oxidant gases (including ozone, hydrogen peroxide, and chlorine), while another type produces a solution containing mixed oxidants. Sodium chloride—available almost anywhere and easily transported and stored—is the only chemical used. The technology, still in the developmental stage, appears to provide effective and reliable disinfection when correctly applied and may cost less than other methods. Results of the demonstration project have been encouraging. However, according to PAHO, further research is needed to determine the best systems and contexts for use.

6. Cost of Disinfection

It is critical to consider the cost of a disinfection system—not only the initial capital cost of installing it, but also the recurrent costs of keeping it operational. Traditionally, capital costs are covered by the government or external support agency that built the system, but often no provision is made for ongoing operational costs. The lack of funds to maintain a system is a common reason for system failure.

Capital costs vary from a few dollars for the pot type of chlorinator to several thousand for electrolysis devices. Chemical feed pumps cost about $1,000 in the United States in 1990. When standby equipment is included, capital costs almost double; these costs can be contained by placing several chemical feed pumps at a regional location to serve as standby for a large group of systems. Capital costs also increase considerably if the equipment is not locally manufactured or if import duties are added to the total cost.

For systems serving 1,000 persons or more, the capital cost of the hypochlorite feed equipment and appurtenances normally represents less than 1% of the total water system costs. For similarly-sized systems with more sophisticated feeders and installed standby equipment, the capital cost related to disinfection can be as high as 2-3% of the total. Naturally, these costs can differ substantially from country to country.

Other costs that must be considered are the cost of chemicals, operations and maintenance, and, depending on the method used, the cost of power. Cost estimates have limited applicability. Two are given here just to provide order of magnitude estimates. One recent estimate for the annual cost of chemicals for a water system serving 1,000 persons is $500 per year or $.50 per person per year based on a water demand of 100 liters per capita per day, a dosage of 2 parts per million and a cost of $3.10 per pound of available chlorine. (These are U.S. costs in 1990.) This is equivalent to $2.50 per year for a family of five, but it should be noted that the amount of water provided per capita per day is four or five times that of most A.I.D. projects. A slightly more recent report from PAHO states that the overall cost of disinfection is less than $1.00 per capita per year.

7. Lessons Learned from Experience

Most disinfection methods for small community water systems in developing countries have not worked on a sustained basis. The main reasons for these failures are:

- inadequate community education about the value of disinfection,
- inadequate operator training and motivation,
- inappropriate technology,
- an unavailable or undependable supply of chemicals,
- lack of spare parts,
- difficulty in operating and repairing equipment,
- inadequate organization for the purchase, transport, and storage of chemicals,
- limited reliability and life of equipment, and
- cost of chemicals when borne by the rural community.

For disinfection to be successful in small rural systems there must be an ongoing program to educate the population about the benefits of disinfection. The national or regional agency responsible for rural water supply systems must promote the disinfection program and convince the local agency and system operator that the benefits outweigh the costs.

In most cases the operators of local systems are poorly educated or illiterate. This makes it difficult to train them adequately. Motivation of the operator, who may have to travel long distances on foot, is also important for the success of disinfection.

Continued monitoring of local systems to ensure that they are functioning correctly is important. If, for example, chlorine is fed in high doses, there will be objectionable tastes and odors, and consumers may seek alternative, unsafe sources.

Since disinfection is often not sustained in small systems, emphasis should be placed on securing the best quality raw water supply available and on protecting water supplies from contamination. Reliance on treatment alone to insure safe drinking water is not adequate.

Groundwater, springs, or upland surface water sources remote from population centers should be sought. Hygiene education also plays an important role in teaching people correct water-handling methods so that water, clean at the source, is not contaminated during household storage or handling.

The engineer designing a small water system in a developing country should thoroughly investigate the availability and cost of the various chemicals in that country. The reasons for success or failure of disinfection facilities in other similar systems should also be investigated.

Disinfection will be most sustainable in small water systems in developing countries if the following conditions exist:

- Technology appropriate to the situation is selected.
- Disinfection system design is based on available chemicals.
- Spare parts and equipment are available and kept in stock.
- Operators are well trained and communities educated about disinfection both initially and on a continuing basis.
- A regional agency is able to provide adequate technical, financial, and motivational support.

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This Technical Note was prepared by Dennis Harris. Issued March, 1992.