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GUIDELINES FOR THE SELECTION AND APPLICATION OF DISENFECTION TECHNOLOGIES FOR SMALL TOWNS AND RURAL COMMUNITIES IN LATIN AMERICA AND THE CARIBBEAN

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PREFACE

The provision of safe drinking water has long been recognized as a most effective public health intervention. It has been said that the number of water taps is a better indicator of peoples' health than the number of hospital beds. However, to accrue the health benefits it is absolutely mandatory that water for human consumption be of adequate chemical and biological quality and this entails water source protection, water treatment and precluding recontamination. Within this endeavor, water disinfection is of fundamental importance for the improvement and maintenance of the desired microbiological quality.

Disinfection of water supplies in Latin America and the Caribbean is not a new process. It has been recommended and carried out since early in the century. However, for various reasons this practice is far from universal and large numbers of people in the Region are being exposed to water related health risks due to deficiencies in disinfection or its absence altogether. The difficulty of selecting an appropriate water disinfection technology, particularly for small communities, is certainly one of the leading reasons. The consequences are evident in the high incidence of waterborne diseases in the Region brought in to the limelight by the recent outbreak of cholera in almost all of the countries of Latin America.

The Pan American Health Organization, in developing these guidelines for the selection and application of appropriate disinfection technologies, aims at supporting professionals and governments in the Region in their tasks of making water disinfection a standard and universal practice. In these guidelines, the pros and cons and the strengths and weaknesses of the various present and potential methods of disinfection are evaluated and summarized in light of the restrictions and conditions typical of Latin America and the Caribbean. In addition, guidance is provided to assure selection of the most suitable disinfection system under prevailing conditions. The application of these guidelines should aid in the careful assessment of the existing situations and conditions, help identify the reasons and limitations that have precluded effective disinfection and provide a logical and practical framework for the planning and implementation of viable disinfection programs.

It is hoped that making this information available to those responsible for providing drinking water in the countries will contribute to more reliable, safe and effective disinfection of this vital resource and result in a sustainable improvement in health.

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CONTENTS

Page

1. DISINFECTION FUNDAMENTALS FOR DRINKING WATER 1
  1.1. Introduction 1
  1.2. Importance of drinking water disinfection 2
  1.3. Desirable characteristics for a water disinfectant 3
  1.4. Effectiveness of a disinfectant 4

2. TYPES OF DISINFECTANTS AND DISINFECTION METHODS 15
  2.1. Chlorination 17
  2.2. Ozonation 31
  2.3. Mixed oxidants 38
  2.4. Ultraviolet radiation 45
  2.5. Iodination 50
  2.6. Minor and experimental disinfection processes 61
    Bromine
    Metallic ions
    Heat
    Gamma radiation and X-rays
    Natural sunlight

3. UNDESIRABLE BY-PRODUCTS OF CHLORINATION 69
  3.1. Tastes and odors 71
  3.2. Trihalomethanes 74

4. DISINFECTANT DOSING DEVICES 77
  4.1. Chlorination and chlorinators 79
  4.2. Ozone disinfection systems 106
  4.3. MOGOD Systems 114
  4.4. Ultraviolet disinfection systems 124
  4.5. Iodination systems 128

5. SELECTION OF DISINFECTION SYSTEMS 135

CONCLUSIONS 147

ANNEXES 149
  ANNEX I. Transitional and emergency disinfection 151
  ANNEX II. Diseases related to water supply and sanitation 159

LIST OF FIGURES

Page

Figure 1. Effect of cyst concentration on the time requirements for 100% destruction of *E. histolytica* at 45°C. 5

Figure 2. Effect of n value on C· t values at different disinfectant concentration (C· t values in parentheses) 7

Figure 3. Length of time necessary for inactivation of various microorganisms by free available chlorine at 20°C.- 29°C 7

Figure 4. Effect of pH on inactivation of *G. muris* cysts with ozone at 25°C 8

Figure 5. Effect of temperature on inactivation of *G. muris* cysts with ozone at 25°C 8

Figure 6. Effect of pH on the proportion of HOCl and OCl- species in distilled water 19

Figure 7. Residual chlorine concentrations and exposure times for destruction of poliovirus 1 and coxsackie virus A2 & A9 at temperatures above 4°C. and pH values below 8.0 23

Figure 8. Cyclic chain mechanisms for decomposition of ozone in pure water with initiation by hydroxyl ion 33

Figure 9. The influence of electrical voltage and current upon oxidant species composition 39

Figure 10. Survival of atypical bacteria for different contact times/ different concentrations: Santa María Aztahuacán well 41

Figure 11. Survival of atypical bacteria for different concentrations and contact times: Agrícola Oriental Well 42

Figure 12. Solubility of chlorine and iodine as a function of temperature 50

Figure 13. Halogen demand of water after addition of ammonia at 24°C. and pH 7.5 53

Figure 14. Percentage of titratable iodine as I^2 and HOI in water at 18°C 55

Figure 15. Destruction of bacteria, cysts and viruses by $I^2$and HOI at 18°C 58

Page

Figure 16. Theoretical breakpoint curve 72

Figure 17. Relationship between ammonia nitrogen, organic nitrogen and chlorine 73

Figure 18. Vacuum type solution feed chlorination system 81

Figure 19. Tank top vacuum type chlorinator and booster pump 83

Figure 20. Typical plan for a small gas chlorination facility 84

Figure 21. Schematic of the installation of a pressure feed gas chlorinator 86

Figure 22. Schematic of the operation of a diaphragm pump 88

Figure 23. Schematic of a typical motor driven diaphragm metering pump 89

Figure 24. Positive displacement diaphragm type hypochlorinator feeding into a pressure line 90

Figure 25. Typical plan of a hypochlorination and hypochlorite storage facility 92

Figure 26a. Schematic of a venturi type hypochlorinator installation 93

Figure 26b. Schematic of a venturi type chlorinator installation 94

Figure 27. Typical chlorine tablet erosion feeder 95

Figure 28. Typical dry pellet feeder installation 96

Figure 29. Typical tablet erosion feed chlorinator installation in a water storage tank 97

Figure 30. Submerged orifice solution feed hypochlorinator 99

Figure 31. Common designs for locally fabricated diffusion type chlorinators which do not provide a sufficiently constant release of chlorine to be satisfactory 103

Figure 32. DIFFU-MAX 104

Figure 33. The basic components of the ozonation process 106

Page

Figure 34. Typical configuration of a corona discharge cell for generation ozone 108

Figure 35. Two common plate type of ozone generators 108

Figure 36. Tube type of ozone generators 109

Figure 37. Schematics of typical ozone contactors used in small water system 111

Figure 38. Schematic of typical MOGOD electrolysis cell 115

Figure 39. TIR-2000 lifetime vs. current density 116

Figure 40. Typical stand-alone protective enclosure for MOGOD disinfection equipment 118

Figure 41. Typical characteristic curve for a venturi 119

Figure 42. Typical venturi installation with booster pump 119

Figure 43. Typical plumbing for MOGOD venturi feeding directly into a well 120

Figure 44. Typical plumbing requirements for MOGOD venturi 120

Figure 45. Typical MOGOD venturi installation to feed into a gravity flow storage tank 121

Figure 46. Contact chamber with flow in clear teflon tubes 124

Figure 47. Contact chamber with flow parallel to the ultraviolet lamps using baffles to create turbulence 125

Figure 48. Iodine saturator-pressure differential feed type 128

Figure 49. Iodine saturator and diaphragm pump dosing device 129

Figure 50. Typical iodinated resin disinfection system 129

Figure 51. Algorithm for disinfection system selection 144

LIST OF TABLES

Page

Table 1. Oxidation potential and relative oxidation potential of strong oxidant species based on reference of chlorine = 1 16

Table 2. Summary of C· t value ranges for 99% inactivation of various microorganisms by disinfection at 5°C 25

Table 3. Recommended microbiological and biological quality of drinking water 27

Table 4. Comparison of testing methods for residual chlorine in drinking water 29

Table 5. Comparison of resistance of different microorganisms to ozone inactivation 35

Table 6. C· t values of MOGOD for various microorganisms for pH 6 to 7.5 43

Table 7. Range of reported UV (254 nm) energy (microwatt seconds/cm^2) necessary for one lethe 47

Table 8. Effect of pH on hydrolysis of iodine and chlorine 54

Table 9. Concentrations of iodine and contact times necessary for 99% inactivation of polio and f^2 viruses 57

Table 10. Comparative values from confirmed experiments on disinfecting water with iodine at 23°C to 30°C at pH 7.0 57

Table 11. Microbial quality of potable water in a "boil water order" 64

Table 12. Dosages of irradiation necessary for 99% inactivation of various microorganisms in distilled water 66

Table 13. Forms of chlorine frequently used for disinfection of small drinking water supplies in Latin America and the Caribbean 79

Table 14A-B. Characteristics of disinfectants and disinfection systems 142-143

Page

ANNEX I:

Table I-1. Preparation of 1 liter of a 1% stock solution of hypochlorite from various compounds of calcium hypochlorite 153

Table I-2. Disinfection of water in household container of various capacities with different concentrations of hypochlorite solutions to deliver doses of 2 and 5 mg/liter 154

Table I-3. Common commercial disinfectants for individual and household use 156

1. DISINFECTION FUNDAMENTALS FOR DRINKING WATER

1. DISINFECTION FUNDAMENTALS FOR DRINKING WATER

1.1. INTRODUCTION

The basic reason for disinfecting drinking water is to insure the destruction of waterborne human pathogens. Disinfection of community water supplies is a primary public health measure which dates back to the early 1900s, and its importance has been proven in both theory and practice. Adequate treatment and dependable disinfection of water supplies were able to dramatically reduce the incidence of typhoid and cholera long before the development of antibiotics and immunizations. Wherever it has been carried out adequately, disinfection has assured health benefits for the users.

Numerous studies over the past 50 years have demonstrated the benefits of disinfection. Two recent works are particularly noteworthy: 1) In "Studies of Diarrhea in Quindio, Colombia: Problems Related to Water Treatment(1985)", doctors David Bersh and Margarita Osorio(1) disclosed an inverse relationship between the level of residual chlorine and the rates of diarrhea among children under 5 years of age, over a five year period; and 2) in a pilot project financed by UNICEF and conducted by the Institute of Child Health in Calcutta, West Bengal, India, 1982, 300 families received disinfection of drinking water and another 300 families did not(2). All other factors were determined to be essentially the same. Over a nine month period there was an 80% reduction in the incidence of diarrheal disease among the children receiving the disinfected water and only a 5% reduction in the children who did not receive disinfected water.

In situations where water is the predominant vehicle for the transmission of disease, adequate levels of disinfectant and sufficient contact time will reduce the incidence. It can assure that drinking water will not be a vehicle for such diseases as cholera, infectious hepatitis, polio, typhoid and paratyphoid fevers, amoebiasis, balantidiasis and enteritis caused by *Rotavirus, Campylobacter* and pathogenic *E. coli.* These diseases are debilitating and sometimes deadly; they impose a terrible economic and physical handicap on everyone involved, especially the poor who can least afford it. Although good chemical coagulation, sedimentation and filtration commonly reduce the number of microorganisms in water by 99 per cent, adequate levels of disinfection are still required to produce microbiologically safe water. Disinfection is important in all systems but it is particularly critical in small communities and rural areas, where it may be the only form of treatment provided.

Disinfection of water supplies is not only one of the simplest water treatment technologies but it is also very cost effective, with an estimated range of cost from US$0.50 to $1.50 per person per year, which is approximately the cost of one or two bottles of soft drink or mineral water. The expense of insuring the safety of drinking water is so low and the benefits are so great that it is hard to conceive of a good reason for the preponderant failure to adequately disinfect small drinking water supplies all over the world.

Surveys by the Pan American Health Organization and others have indicated that disinfection is inadequate or unreliable, in spite of the proven health benefits, even where facilities have been provided. In the PAHO-sponsored workshop in May,1984, for the introduction of the new WHO Guidelines for Drinking Water Quality, a participant survey indicated that more than 75% of the water systems in Latin America and the Caribbean were either inadequately disinfected or not disinfected at all. Subsequent national studies and investigations indicated a somewhat higher percentage of failure. Concomitantly the incidence of waterborne disease remains high in most countries. It is no surprise that the 1991 cholera epidemic in Latin America has, to a great extent, been linked to failure to disinfect water supplies.

In recent decades, the number of communities provided with water supply systems has grown significantly in the Region of the Americas, and most national plans aim at further increases in coverage; however, the need to make water safe does not seem to have been given adequate attention. Deficient drinking water supply disinfection constitutes one of the most serious problems affecting the health of the residents of small towns, rural areas and marginal urban areas, and is one that can be resolved with relatively small investments. Effective and reliable disinfection would allow the users to reap the major health benefits of a safe water supply.

1.2. IMPORTANCE OF DRINKING WATER DISINFECTION

In the mid 1800s, even before the germ theory was demonstrated, polluted water had been associated with the transmission of enteric diseases, particularly cholera and typhoid, and this had prompted public health authorities, based on experience and intuition, to set regulations such as the law passed in London in 1852 requiring that all drinking water should be filtered. With mounting evidence of the transmission of diseases by microorganisms, the treatment of drinking water gained momentum, and water filtration and disinfection became standard public health practice.

Disinfection of water has been traditionally understood as the destruction of pathogenic intestinal bacteria. Fortunately this process also kills or inactivates most other disease-causing organisms, but not necessarily all of them. Today, disinfection for drinking water can be defined as a process for the destruction or inactivation of pathogens and other undesirable microorganisms. Sterilization is the process of complete destruction of all living matter, including cysts, spores and viruses. It is used where total absence of living matter is required, for example in some medical and laboratory procedures. Pasteurization like disinfection, does not inactivate all living microorganisms, but kills most of the pathogens, like in the pasteurization of milk. The objective of present-day disinfection of drinking water is to ensure that essentially safe water reaches the consumer, by destroying most, if not all, of the pathogens; by maintaining a protective barrier against pathogens entering the distribution system; and by suppressing subsequent bacterial growth in the system.

In the broader context of water quality, safe drinking water intended for human consumption should not contain any harmful organisms and should also have low concentrations of chemicals or other substances which present hazards to health. In addition, it should also be without turbidity, color, disagreeable taste or odor. Biologically, the above requirements imply the removal or destruction of enteric bacteria, viruses, protozoa cysts and bacterial spores that may cause infection or disease.

Although direct health benefits experienced by the improvement of drinking water are well recognized, the fact that these go beyond the reduction of the incidence or the lowering of the death rate of a specific disease is frequently overlooked, particularly when comparing the effectiveness of safe drinking water supply and sanitation with other health interventions designed to control very specific diseases or situations. Already in 1904 Allen Hazen(3) presented data relating a commensurate decrease in death rates from other diseases to the reduction in typhoid fever: "As it was expressed at the time, when one death from typhoid fever is avoided by the use of better water, two or three deaths from other causes are also avoided". In other words, for each life saved from death by typhoid two or three others would be saved from death by other causes. "At Hamburg, Germany, for example, for each decrease in death from typhoid fever after installation of filtration, there were 15.8 fewer deaths from other causes" (3). Undoubtedly the proportion will vary depending on the conditions existing in each particular case, but the fact should not be ignored in any evaluation of the benefits of the provision of safe drinking water supply. The above considerations are of particular importance in developing regions of the world with poor sanitation and the resultant heavy contamination of water sources with pathogenic bacteria, viruses and protozoa.

The benefits to health and well-being of safe drinking water supply systems, particularly when accompanied by sanitation and health education, are in reality very broad, as these prevent the transmission of water and excreta-borne diseases; contribute to improved nutrition; relieve women of the chores of carrying water; promote cottage industries; and in general improve the well-being of people. In addition, safe water supplies play a crucial role in economic development.

Sometimes it is suggested that water quantity be given priority over water quality; however, it must be reemphasized that drinking water for human consumption must be free from organisms that represent hazards to health. Even large quantities of unsafe water will not satisfy this requirement. On the other hand, safe water can comply with this requisite and also attend to domestic and personal hygiene needs (washing, bathing, the preparation of food, etc.) and other uses.

1.3. DESIRABLE CHARACTERISTICS FOR A WATER DISINFECTANT

To be suitable for disinfection of water for human consumption a disinfectant should meet certain general criteria:

1. The disinfectant must be able to destroy or inactivate, within specific time limits, the kinds and numbers of pathogenic organisms likely to be present in the water to be treated.

2. The testing for the concentration of the disinfectant in water should be accurate, simple, rapid and suitable for conduct in the field setting as well as in the laboratory.

3. The disinfectant must be reliable for use within the range of conditions likely to be encountered in the water supply.

4. The disinfectant should be capable of maintaining a residual concentration in the water supply distribution system to safeguard against recontamination or regrowth of microorganisms.

5. It should not introduce nor produce toxic substances, nor otherwise change the characteristics of the water so as to make it unsuitable for human consumption or aesthetically unacceptable to the consumer.

6. The disinfectant itself must be reasonably safe and convenient to handle and apply.
7. The cost of the equipment, its installation, operation and repair as well as the purchasing and handling of materials required for sustained effective dosing should be reasonable.

1.4. EFFECTIVENESS OF A DISINFECTANT

Several factors influence the efficiency of a water disinfectant. A good understanding of the effect of such factors is necessary in order to estimate their impact on disinfection and, if possible, to control them in order to increase the efficiency of the process. The following are some of the most important.

The nature and concentration of the target organisms

Different kinds of organisms react in different ways to various disinfectants. In general, bacterial spores are more resistant than protozoa cysts. Cysts are more resistant than viruses, and viruses are more resistant than vegetative bacteria. The number of bacteria, if very high(4), or in clumps which protect them, may affect the results expected. Since the time required to kill the organisms is proportional to the number originally present as shown in Figure 1 this consideration should normally not be a problem in water supplies where high quality raw water is used and other provisions are taken to insure the safety of the water supply system, as recommended by good public health practice; however, where polluted water has to be utilized for a raw water source it should be a primary concern.

The importance of water source quality and the need for careful operation and maintenance to preserve the integrity of a piped water supply system is exemplified by a study conducted in Qidong County, China (4a). The conclusion of the five-month study was that the incidence in enteric infectious disease in six villages which had received a better quality of water through deep well tap water (DWTW) piped into the houses was 38.6% lower than in six villages where surface water was used as the source. There was no disinfection in either system. The average total bacterial count of the surface water samples from the control villages was 3551 per ml and the average coliform count was 772 per liter. In contrast, samples from the DWTW systems averaged 5.4 total bacteria per ml and 2.3 coliforms per liter. During the summer months power cuts disrupted the well pumps and all the people had to drink surface water at times. A regression analysis of the percentage of time that the power was cut demonstrated that if they were able to eliminate the power cuts altogether, the five month incidence of diarrhea in the summer and autumn could decline by 90%.

The nature of the water to be disinfected

Suspended matter and turbidity can shelter the pathogenic organisms. The WHO Guidelines for Drinking Water(5) recommend a turbidity of less than 1 Nephelometric Turbidity Unit (NTU) when chlorination is practiced. Substances present in the water may react with the disinfectant, usually decreasing the effectiveness.

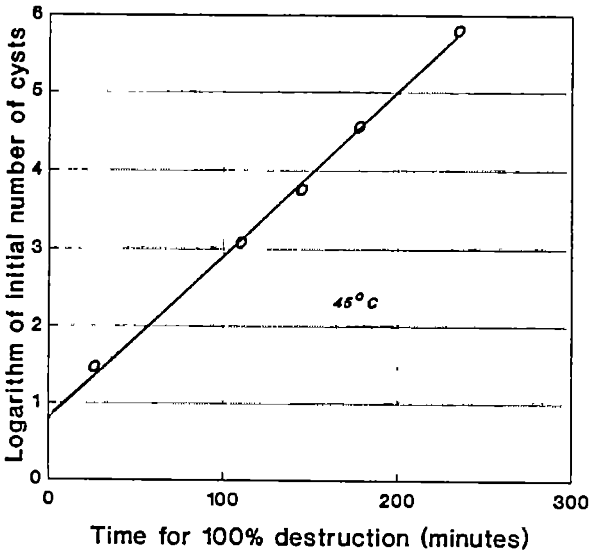

Figure 1. Effect of cyst concentration on the time requirements for 100% destruction of *E. histolytica* at 45° C. (C·t values)

Organic matter and reducing agents such as iron, manganese and hydrogen sulfide react with the oxidizing agents, making it necessary to increase the dosage to maintain a residual. The temperature and pH also can affect the survival of the organisms as well as the form and effectiveness of the disinfectant.

C·t values

It is extremely difficult to compare the effectiveness and efficiency of different disinfectants even under carefully controlled laboratory conditions because of the number of variables which affect the disinfection process. Physical and chemical conditions, in addition to widely varying disinfection resistance between different isolates of the same species as well as between different species within the three major groups of microorganisms (bacteria, virus and protozoa), make the comparison a very complex task. In the far more complex world of practical water treatment and distribution, judicious application of laboratory studies tempered by operational experience and perspicacious observation are necessary to assure reliable and effective disinfection.

In general, the higher the concentration of active disinfectant the shorter the time required to inactivate the organisms.

The higher the temperature the greater the effectiveness (the higher the kill) of the disinfectant, and vice versa. In general, chemical disinfectants work poorly as freezing temperature is approached. Temperature has little influence on the effectiveness of ultraviolet light and ionizing radiation.

The longer the time that organisms are exposed to a disinfectant, the greater the opportunity for action. The thoroughness of the kill or inactivation is proportional to the contact time.

Laboratory derived C·t values are presently the most widely accepted parameters for comparing the efficiency of disinfectants for drinking water. The "C·t" concept was derived from the work of Watson and is expressed by the empirical equation:

$$\mathbf{k = C^n \cdot t}$$

where:

k = constant for the specific microorganism exposed under specific conditions (mg·min/liter)

C = concentration of disinfectant (mg/liter)
n = coefficient of dilution
t = contact time necessary for a fixed percent inactivation (min.)

If $n > 1$ the disinfectant concentration influences the inactivation to a greater extent than the time of exposure and for $n < 1$ the opposite is true. For $n = 1$ both are of equal influence. Figure 2 illustrates the effect of the n value on C·t values at different disinfectant concentrations(6).

The effectiveness/efficiency of a disinfectant is commonly illustrated on a log-log graph with one axis representing time in minutes and the other axis representing concentration of the disinfectant in milligrams per liter (mg/liter). When the pH and temperature are held constant this log-log plot of the contact times and concentrations necessary to achieve a predetermined reduction (normally 99%) of organisms usually approximates a straight line. Figure 3 shows the inactivation of various organisms by free available chlorine for different pH values(7). Different **n** values for different organisms are reflected in the different slopes of the lines.

A change in pH or temperature usually has a significant effect on the efficiency of a disinfectant.

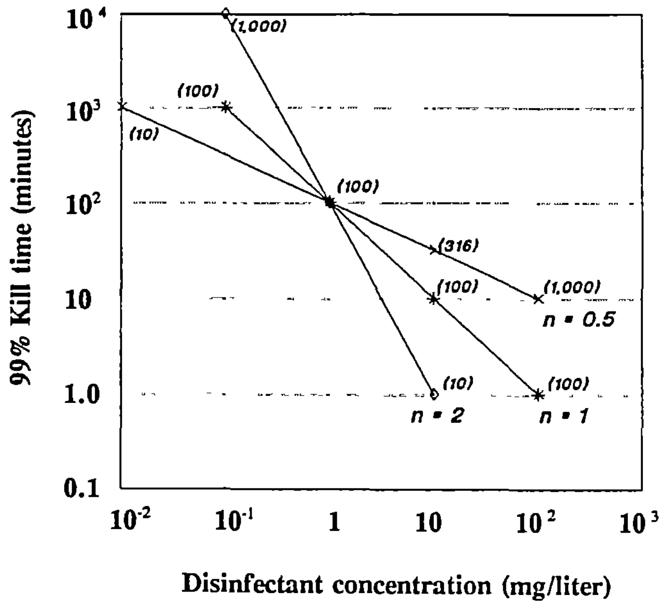

Figure 2. Effect of n value on C • t values at different disinfectant concentration. (C·t values in parentheses)

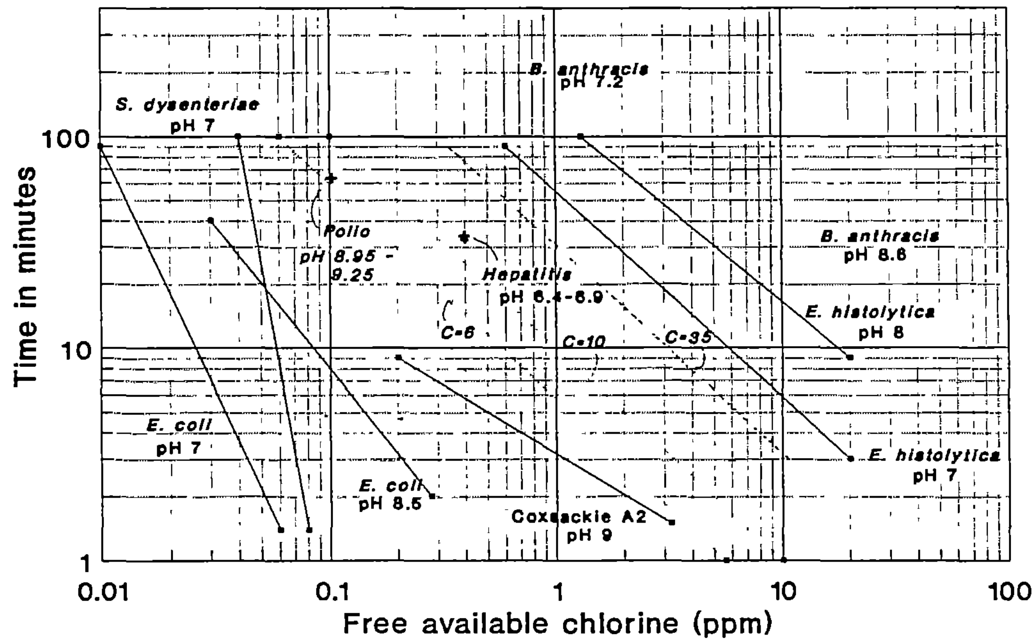

Figure 3. Length of time necessary for inactivation of various microorganisms by free available chlorine at 20°C. - 29°C.

Figure 4 presents the effect of temperature on the inactivation of *G. muris* cysts with ozone(8). The very large difference between the effect of the first drop of 10°C from 25°C to 15°C and the second drop of 10°C from 15°C to 5°C should be noted; however, even at 5°C ozone is an effective disinfectant.

Figure 5 illustrates the effect that a pH change has on the inactivation of *G.muris* with ozone at a constant temperature of 25°C (8).

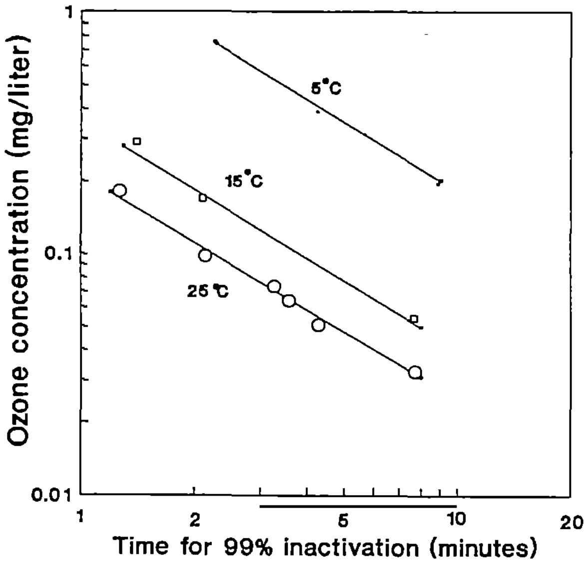

Figure 4. Effect of ~~pH~~ on inactivation of *G.muris* cysts with ozone at 25°C. Temperature

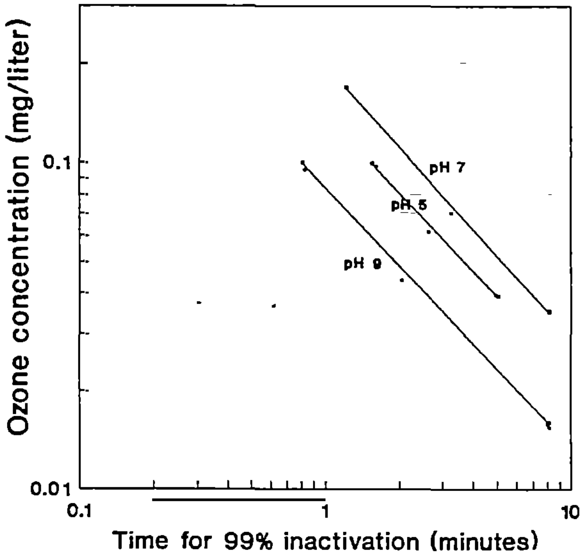

Figure 5. Effect of ~~temperature~~ on inactivation of *G. muris* cysts with ozone at 25°C. pH

Common waterborne pathogenic microorganisms in Latin America

Information on the principal pathogens carried by water sources in Latin America and the Caribbean is limited primarily because of the difficulty in isolating individual species when low concentrations of pathogenic organisms are examined. A recent study on the microbiology and parasitology of water destined for human consumption, conducted in Colombia(9) on raw and treated water addresses this subject. Although specific pathogens were not isolated from the water samples, it was confirmed that acute diarrheal diseases decreased significantly after six months of application of chlorine.

In studies of diarrhea in children and infants it has been estimated that rotavirus is the main culprit all over the world(10) and especially in developing countries. It is also believed that bacterial agents are responsible for up to 45% of the cases of diarrhea for all age groups in the latter countries and that traveller's diarrhea is caused primarily by enterotoxigenic *E. coli*(11).

In Latin America and the Caribbean, gastrointestinal disorders related to water are particularly prevalent among infants and children. Many studies have been conducted to determine the agents responsible for diarrhea in small children and infants. For example, *Urrestarazu et al.*(12) found that in children under two years of age, with acute diarrhea, the agents most frequently isolated were: in 41.8% of the cases enterotoxigenic *E. coli*; in 14.1%, rotavirus; in 12.2%, enteropathogenic *E. coli*, and in 11.2%, *Klebsiela pneumoniae*. *C. jejuni* was present in 9.2% of the cases. Among the parasites, *Giardia lamblia* was found in 3.5% of the cases and *Entamoeba histolytica*, in 3.5%. *Mata et al.*(13), in a 5.5-year surveillance study in Costa Rica of children with diarrhea admitted to a hospital and examined after 4 days of the onset of the disease, found that rotavirus was associated with more than 40% of the cases. Enterotoxigenic *E.Coli* ranked second with 13.4%, *Shigella* 18.1%, *Salmonella* 7.3% and *Campylobacter fetus and jejuni* 8% were implicated in the cases studied. In 63.2% of the cases more than one agent was detected. *Trujillo et al.*(14) reported that in a study in Medellin, Colombia of 25 children with acute diarrhea and 25 ambulatory cases with mild diarrhea, 45% of the acute cases and 36% of the mild cases showed rotavirus as the agent. Also, in the mild cases 8% showed *Salmonella* and 4% *Giardia lamblia*. In the acute cases *E. histolytica* was isolated in 4%, *Trichuris trichura* in 4% and *Strongyloides stercoralis* in 4%, of the cases. *Guderian et al.*(15) studied diarrhea in 100 children two years of age or less, admitted to hospitals in Quito, Ecuador. Enteropathogenic agents identified were: *Campylobacter* (23%), rotavirus (21%), *Shigella* (12%), *Salmonella enteritidis* (3%), *Giardia lamblia* (5%) and *Entamoeba histolytica* (1%). A single agent was found in 38% of the cases; two agents, in 18%; and three agents, in 6%. In 1985 *Simhon et al.* (16) reviewed the virology of rotavirus and the epidemiology of diarrhea caused by this virus concluding that in children and infants it is one of the principal causes of diarrhea particularly in developing countries. The maximum incidence is produced in the coldest months in temperate as well as in tropical climates.

The studies mentioned above on etiological agents suggest that the majority of diarrhea cases in children in Latin America, like in other developing countries, are produced primarily by bacteria and rotaviruses, and that protozoa may be a less significant pathogen than it is in industrialized countries; however, the latter should not be ignored. Furthermore, in endemic zones where basic sanitation is lacking, it is to be anticipated that there will be proportionately higher concentrations of bacteria, protozoa, viruses and parasites than those in well sanitized zones.

Acute viral hepatitis is considered to be of Regional concern (17, 17a), with incidences in developing countries usually much higher than in the industrialized states. In Latin America the incidence varies from 24 to 93 per 100,000 of population, with the majority of cases (50-85%) affecting children under the age of 15.

Amebiasis is a disease of international importance, estimated to affect about 10% of the world population. In Latin America and the Caribbean some countries register incidences as high as 56%, although rates above 30% are relatively rare(18).

Typhoid fever is endemic in many countries of Latin America and has been implicated with drinking water as well as food.

In January 1991 cholera, a classic waterborne disease, was introduced in Perú and by July 1992 it had resulted in epidemics in 18 countries with a total of more than 600,000 cases and more than 5,000 deaths.

Where water is the main means of transmission of these diseases, its disinfection significantly contributes to their control. Safe water supply and sanitation practices, accompanied by health education, are an important component of the strategies recommended for reducing the incidence of waterborne diseases and these constitute the only permanent means of controlling the incidence.

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2. TYPES OF DISINFECTANTS AND DISINFECTION METHODS

2. TYPES OF DISINFECTANTS AND DISINFECTION METHODS

This section deals primarily with the disinfectants which are most commonly utilized or have a good potential for use in Latin America and the Caribbean but it also covers a number of less common methods and minor processes to address frequently asked questions regarding their efficiency and use. In this way it is hoped to facilitate the task of selecting the most appropriate disinfection systems for small towns and rural communities.

There is no perfect disinfectant—one that will work optimally under all circumstances. Every disinfectant has its advantages and disadvantages, and its strong and weak points, as well as a specific set of conditions for optimum effectiveness. Problems arise when a disinfectant doesn't fit the particular situation, because its advantages are not really important under the prevailing conditions or its weaknesses are overriding. For example, it is important that the logistics requirements of a disinfection method not exceed the capacity of the supporting infrastructure, and the operation and maintenance not be too complex for sustained operation. Disinfectants and disinfection equipment should be selected to meet the specific requirements of the particular application as closely as possible and all factors that influence reliability, continuity and effectiveness should be taken into account.

Most disinfectants used in drinking water supplies can be grouped under the following headings:

a) Oxidizing agents
b) Radiation
c) Metallic ions
d) Heat

In drinking-water disinfection technology, the expression "oxidizing agents" covers a number of substances. Table 1 presents the oxidation potential and the relative oxidation power of various strong oxidant species, with the relative oxidation power based on a reference of chlorine = 1.0. It needs to be pointed out that a strong oxidant is not necessarily a good disinfectant, as is the case with hydrogen peroxide. A relatively weak oxidant, such as iodine, can be a very effective disinfectant.

Since most forms of chlorine are such effective disinfectants and are so widely used in Latin America and the Caribbean, these are discussed first, in section 2.1. Ozone, one of the most powerful oxidants, is also an excellent water disinfectant. Although discovered many years ago, it has been used to a lesser extent than chlorine in the Americas. Renewed interest has been raised in this Region, primarily because of concern for the possible development of trihalomethanes in the disinfection of water with free chlorine and because of disclosure of the presence of difficult-to-kill organisms, such as *Giardia* cysts and *Cryptosporidia*. Ozone is reviewed under section 2.2.

Recent studies and experiences with mixed oxidants (generated on-site) have demonstrated equal or greater disinfecting capability, than that of chlorine. For this reason, on site generated mixed oxidants offer considerable potential for use in small communities. The disinfection aspects of mixed oxidants are discussed in section 2.3.

TABLE 1. Oxidation potential and relative oxidation potential of strong oxidant species based on reference of Chlorine = 1

Oxidant Species	Oxidation Potential (Volts)	Relative Oxidation Power
Fluorine	**2.87**	**2.25**
Hydroxyl radical	**2.80**	**2.05**
Atomic oxygen	**2.42**	**1.78**
Ozone	**2.07**	**1.52**
Hydrogen peroxide	**1.77**	**1.30**
Perhydroxyl radical	**1.70**	**1.25**
Permanganate	**1.68**	**1.23**
Chlorine dioxide	**1.50**	**1.10**
Hypochlorous acid	**1.49**	**1.10**
Chlorine	**1.36**	**1.00**
Bromine	**1.07**	**0.79**
Hypoiodous acid	**0.99**	**0.73**
Hypochlorite ion	**0.94**	**0.69**
Iodine	**0.54**	**0.40**

Ultraviolet radiation, which is regaining attention because of its ability to disinfect without producing significant physical or chemical changes in the treated water, is reviewed in section 2.4. Iodine is widely used as an emergency disinfectant for short periods of time and as a supplementary disinfectant for microbiologically difficult situations. It is discussed in section 2.5. Bromine and metallic ions are being used under special conditions but are still considered as experimental disinfectants of drinking water supplies. These, together with other minor disinfectants, are presented in section 2.6. Hydrogen peroxide and potassium permanganate, although strong oxidants, are weak disinfectants and, therefore, are not considered in detail.

2.1. CHLORINATION

Chlorination principles

Chlorine, the most common water disinfectant, has a long history in water treatment. Its early use was to control foul odors in water, but by the late 1800s it was being accepted as a water disinfectant and by the early 1900s it was used for this purpose on a regular basis in water treatment plants of the United States.

Characteristics of chlorine

Chlorine is available commercially in various forms, which are relatively simple to apply. It is generally the most economical as well as the most widely available disinfectant. Chlorine is an effective bactericide and viricide under most conditions, and provides a residual that can be easily measured. From the health point of view this is its primary use. The residual also helps safeguard the distribution system against recontamination, prevents bacterial growth, and retards microbiological fouling of pipes and other system components. In addition, because of the strong oxidation power of some of its species, under special circumstances it also finds use in the control of tastes and odors, as well as in the removal of iron, hydrogen sulfide, ammonia and color.

At room temperature (20°C) and atmospheric pressure, chlorine is a greenish yellow gas, soluble in water up to 7.29 g/liter and at 0°C up to 14.6 g/liter; however, gas chlorinators usually operate under a recommended partial vacuum which produces a maximum operational solubility of about 3.5 g/liter. At atmospheric pressure, chlorine gas compresses easily and liquefies at -34.5°C, as it also does at 21°C and 7.0 kg/cm^2 of pressure. As a gas, its density is 2.5 times greater than that of air and as a liquid it is 1.5 times as heavy as water. Below 9.6°C and at atmospheric pressure, chlorine gas forms into ice upon contact with moisture (chlorine ice). Liquid chlorine vaporizes readily at atmospheric pressure and room temperature. One volume of liquid chlorine at 0°C converts into 457.6 volumes of gas at standard temperature and pressure.

Although chlorine gas is itself not explosive or flammable in air, it can support combustion of readily oxidizable materials such as carbon. Dry chlorine gas will not attack ferrous metals, ferrous alloys or copper. It is important that chlorine gas does not contain water vapor; moist chlorine gas is extremely corrosive and will destroy ferrous metals including stainless steel. Only gold, platinum, tantalum and titanium do not react with moist chlorine. Silver forms a layer of silver chloride, which is inert. Special materials (usually plastics) have been developed to handle aqueous solutions of chlorine or moist chlorine gas. Liquid chlorine destroys regular PVC and both soft and hard rubber.

Aside from chlorine gas, several chlorine compounds are used for water disinfection, such as hypochlorites, chlorine dioxide and chloramines. The latter are usually formed in the water itself in the presence of ammonia but can alternatively be added as a preformed chemical.

Health effects

For humans and animals, chlorine gas is highly toxic when inhaled. At low concentrations, the effects of chlorine are a pungent odor and some irritation of the eyes and upper respiratory track.

The odor-irritant threshold varies from 0.06 to 5.8 mg/m^3 (0.02 to 2.0 ppm), depending on the sensitivity of the individuals and other factors. The maximum allowable concentration in the working environment varies in different countries, from 1 to 3 mg/m^3 (0.344 to 1.032 ppm) in air. For the general population it is estimated that if irritation is the critical effect, levels should be below 0.1 mg/m^3 (0.034 ppm). At concentrations of 2.9 to 5.8 mg/m^3 (1.0 to 2.0 ppm), chlorine gas turns into a problem and at 11.6 mg/m^3 (4.0 ppm) it becomes almost intolerable (19). The latter is the maximum concentration that can be breathed for one hour without serious effects. Concentrations of 60 to 90 mg/m^3 (40 to 60 ppm) are dangerous if breathed for 30 to 60 minutes, and concentrations of and over 1,500 mg/m^3 (1,000 ppm) are likely to be fatal after a few deep breaths. In strong solutions chlorine is irritating when it comes in contact with the skin. Liquified chlorine can cause severe burns.

In drinking water chlorine itself does not appear to be carcinogenic, mutagenic or teratogenic to animals. In the concentrations used in the disinfection, it is harmless; however, chlorine in the presence of some organic compounds can form trihalomethanes(THMs) with possible adverse health effects. Chlorine taste and odor may start to develop at about 1.0 mg/liter in distilled water but some compounds of chlorine, like chlorophenols, have a much lower taste and odor threshold. Both THMs and chlorophenols are discussed in section 3.

Chemistry of chlorination

Chlorine gas

Chlorine gas and water react to form hypochlorous acid (HOCl) and hydrochloric acid (HCl). In turn the HOCl dissociates into the hypochlorite ion (OCl^-) and the hydrogen ion (H^+), according to the following reactions:

$$Cl_2 + H_2O <===> HOCl + HCl$$

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

The reactions are reversible and the relative concentrations of the reactants and the products depend on the pH value of the solution. Between pH 3.5 and 5.5, HOCl is the predominant species. From about pH of 5.5 to 9.5, both HOCl and OCl^- species exist in varying proportions, while above pH 9.5, OCl^- predominates entirely. Figure 6 shows the changes in the concentrations of these components with varying pH values(20). In aqueous solution molecular chlorine exists only at very low pH values. The HOCl and OCl^- species are commonly referred to as free chlorine.

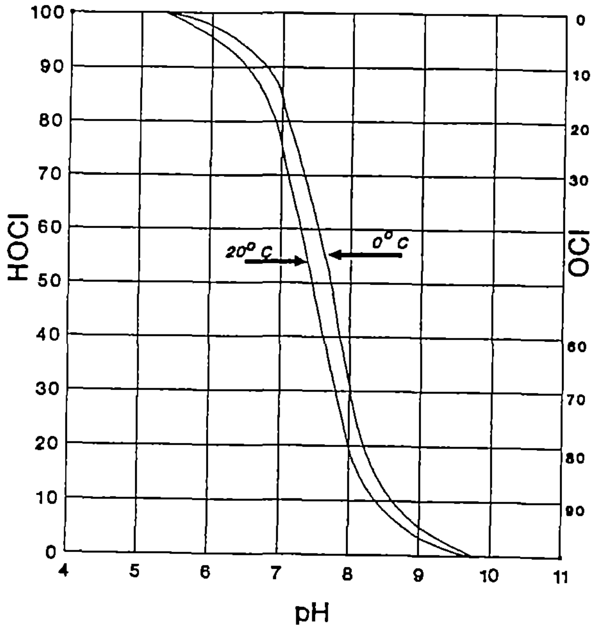

Figure 6. Effect of pH on the proportion of HOCl and OCl- species in distilled water.

Hypochlorites

Other forms of chlorine commonly used in disinfection are the hypochlorites of calcium and sodium. When these highly soluble salts of hypochlorous acid are added to water, the following reactions may take place:

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

$$NaOCl + H_2O <====> HOCl + Na^+ + OH^-$$

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

The pH of the solution will determine the proportions of HOCl and OCl^- , as indicated in Figure 6. Chlorine gas tends to decrease the pH of water while hypochlorites tend to increase it.

High test calcium hypochlorite (HTH) can contain up to 70% available chlorine but for safety reasons it is usually 65%. Calcium hypochlorite is also produced with a 35% available chlorine concentration in many countries. Both are marketed under a variety of names. The most common form is a highly corrosive, white granular powder with a strong chlorine odor. It can also be obtained in tablets or pellets. The usual packaging of HTH is drums of 25 to 50 kg, or in cans for smaller amounts. The drum material should be corrosion resistant. Calcium hypochlorite may be easier to handle than chlorine gas for small communities; however, the proper storage of calcium hypochlorite is also of primary importance to avoid the danger of fires and explosion.

Sodium hypochlorite is usually available as a solution, in strength varying from 2.5% to 15% available chlorine (the most common strength is 10%), packaged in plastic or glass bottles of various sizes and with different commercial names. At the higher concentrations it loses strength rapidly. In some cases it can be fed into a water supply at commercial strength but usually it is diluted. Crystalline sodium hypochlorite is rarely used in water disinfection.

Chlorinated lime is often manufactured locally in Latin America and can have a chlorine content as high as 35% but it usually has less. It may vary considerably in strength from one country to another. Also, it frequently contains excessive foreign matter, causing operational problems in dosing devices. Chlorinated lime is usually supplied in 45 kg. or larger drums. If furnished in plastic bags, extreme care needs to be exercised in handling and storage to avoid breaking them and producing unsafe situations.

Awareness of these characteristics as well as of the fact that all the hypochlorite compounds loose strength with storage, especially if exposed to air and sunlight, are important considerations when preparing dosing solutions. Both calcium and sodium hypochlorite are considerably more expensive than chlorine gas.

Chloramines

If ammonia is present in the water, or if it is added intentionally, chlorine can react to form monochloramines, dichloramines or trichloramines :

$$\mathrm{HOCl} + \mathrm{NH_3} <===> \mathrm{NH_2Cl}(\text{monochloramine}) + \mathrm{H_2O}$$
$$\mathrm{HOCl} + \mathrm{NH_2Cl} <===> \mathrm{NHCl_2}(\text{dichloramine}) + \mathrm{H_2O}$$
$$\mathrm{HOCl} + \mathrm{NHCl_2} <===> \mathrm{NCl_3}(\text{trichloramine}) + \mathrm{H_2O}$$

The relative proportion of monochloramines and dichloramines depends on the reaction rate, which is a function of the pH and the ratio Cl_2:NH_3. Chlorine also reacts with other substances forming various compounds. Some of these merely use up chlorine while others have some disinfecting ability and still others may be objectionable.

Chloramines are much less effective disinfectants than free chlorine. Free chlorine may in fact be two orders of magnitude more effective. The dosing of ammonia to form chloramines is an additional operation that may increase the cost of disinfection and add to the handling process.

The use of chloramines has regained interest in the light of concern for the formation of trihalomethanes that might result from free residual chlorine; however, chloramines are such weak disinfectants that they require very long contact time or increased dosages. They also require the addition of ammonia to the water when not present, which further complicates the operation and makes this process inappropriate for small water supplies. Thus, chloramines are more suitable as a secondary rather than primary disinfectant.

Chlorine Dioxide

The reaction of sodium chlorite with chlorine is important in water disinfection because it produces chlorine dioxide, a powerful oxidant with strong bactericidal characteristics:

$$2NaClO_2 + Cl_2 <===> 2ClO_2 + 2NaCl$$

Under acidic conditions the reaction is as follows:

$$2NaClO_2 + HOCl + HCl <===> 2ClO_2 + 2NaCl + H_2O$$

Chlorine dioxide is a good disinfectant but since it is much more expensive than chlorine, it is seldom used for disinfection only. Because of its oxidizing qualities, it is usually applied where improvement of water quality, in addition to disinfection, is required. For example, it may also be used to control taste and odor, and to destroy organic matters. Because chlorine dioxide is generated on site, and because of the complexity and risks involved in its production and handling, it is generally not recommended for use in small communities.

Effectiveness of chlorine as a water disinfectant

The exact mechanism through which chlorine disinfects, even after many years of study, is still not completely understood. A commonly accepted theory is that the hypochlorous acid can penetrate the bacterial cell wall, disrupting its integrity and permeability, and by reacting with sulfhydryl groups, inactivate enzymes essential for the metabolic process; thus killing the organism. This helps explain why HOCl, a small neutral molecule, is a considerably better disinfectant than the negatively charged OCl^- ion, which does not easily penetrate the cell wall because of its charge.

Whatever the mechanism involved in the process, from the practical point of view, there are two chlorination practices: combined residual chlorination—when the residual chlorine, remaining in the water after a specified period of time, is in the form of chloramines or of organic compounds; and free residual chlorination—when the residual chlorine is either in the HOCl or OCl^- form. These two forms of residual chlorine exercise different responses in the organisms being disinfected.

Whether the free-available-chlorine residual or the combined-available-chlorine residual is opted for will depend on several factors; however, the main consideration should always be the effectiveness in respect to the inactivation of the pathogenic microorganisms that may be encountered in the water to be disinfected. In this context, consideration of effect of the pH value and temperature of the water; concentration of the chlorine compound; presence of ammonia and other substances in the water, which react with chlorine; contact time of the chlorine and the water; and method of chlorine application are essential to determine the effectiveness.

The effectiveness of chlorine against the principal pathogenic microorganisms in water is summarized briefly in the following paragraphs:

Bacteria

The effectiveness of chlorine against bacteria has been studied extensively. There is general agreement that the Salmonellas, Shigellas, Vibrios and most intestinal bacteria are more susceptible to chlorination than the indicator organism *E. coli*. *E. coli*. is therefore considered a good indicator of bacterial pollution. There is also general agreement on the fact that free chlorine residuals are about a 100 fold more effective than combined chlorine residuals. Free chlorine residuals of 0.2 to 0.5 mg/liter are considered adequate for bacterial disinfection under most conditions.

In conclusion, bacterial pathogenic agents in water can be controlled effectively by dependable chlorination and by maintaining appropriate residual levels in the distribution system, i.e. of the order of 0.2-0.5 mg/liter, provided fairly clean water sources are used(5) (that is, with turbidity of less than 1 NTU.)

The above conclusion is important because bacterial agents are responsible for up to 45% of the cases of diarrhea in children of developing countries and traveller's diarrhea, of common occurrence in most countries, is caused primarily by enterotoxigenic *E. coli*. Diarrhea in children and infants has been given great deal of attention. However, the causes of diarrhea in older population groups have not been given the same attention.

Virus sp.

The viruses usually associated with drinking water are rotavirus, hepatitis, polio viruses 1 and 2, coxsackie and the echoviruses. In general viruses are considered to be more resistant to higher temperatures and low pH. They also show large variations in resistance to different disinfectants. Rotavirus is thought to be the main cause of diarrhea in children all over the world. The infectious hepatitis virus is of special epidemiological importance because it is endemic in most of the countries of the Region. If is usually transmitted by the oral/fecal route and is frequently water-borne. It is also somewhat resistant to chlorine in normal doses, and, because of its small size, it may pass through conventional water filtration media.

Although significant progress has been made recently in isolation and cultivation techniques of hepatitis A virus, there are few new studies regarding the resistance to various disinfectants and the question of actual resistance to chlorine does not seem to be completely clarified. Wilson and Sobsey(21) report experimental work leading to the conclusion that two strains of hepatitis A were less resistant to chlorine than Polio 1 and echovirus 1, a four log reduction having been obtained with free-chlorine residuals of 5.0 mg/liter and 1.0 mg/liter at temperature of 5°C and temperature between 5-25 C, respectively. Within the pH range of 4.5 to 9.5, pH had little influence on disinfection effectiveness. More information is needed to narrow the range of the recommended dosage levels.

Presently it is accepted that well operated conventional flocculation, sedimentation and filtration remove a substantial percentage of the viruses that may be present in water. *Robeck et al.* (22) report 99.7% removals of poliovirus 1 through these processes. It has been known for a long time that different viruses present different resistances to free chlorine. For example, adenovirus 3 is less resistant than *E. coli*, while poliovirus 1 and coxsackie virus A2 and A9 appear to be more resistant than other enteroviruses studied(23). Bauman and Ludwig(7) suggested that chlorine dosages required to inactivate coxsackie viruses, which are more resistant to chlorine than other enteroviruses, be used as a guide for disinfection of small nonpublic water supplies.

The relation between concentration of residual chlorine in water and the duration of exposure of water to the disinfectant depends on the percentage of virus destruction desired and on the pH and temperature of the water(24). Figure 7 shows the residual chlorine concentrations and exposure times for the destruction of poliovirus 1 and coxsackie virus A2 and A9 at temperatures above 4°C and pH values below 8.0. At 0.1 mg/liter the destruction rate would be 99% to 99.9% with a 30 min. exposure, and at 0.4 mg/liter, 99.99% to 99.999% after 30 min. exposure.

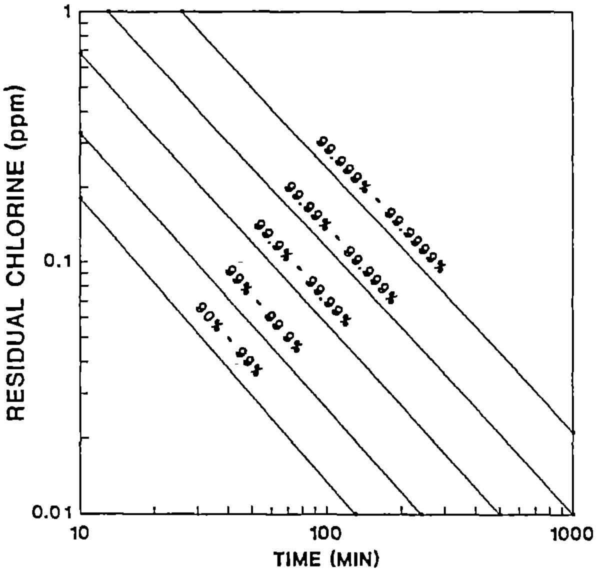

Figure 7. Residual chlorine concentrations and exposure times for destruction of poliovirus 1 and coxsackie virus A2 & A9 at temperatures above 4°C. and pH values below 8.0.

The WHO Scientific Group on Human Viruses in Water, Wastewater and Soil, 1979 (25), was of the opinion that water supplies derived from virus-contaminated sources should always be disinfected, since other processes alone are not adequate under all conditions to produce safe water. It also stated that well-operated disinfection processes can destroy viruses efficiently, for example with free available chlorine residuals of 0.5 mg/liter with a contact time of 30-60 minutes or with an ozone residual of 0.2-0.4 mg/liter for 4 minutes. The studies carried out by Bersh and Osorio(1) have considerable practical value and have demonstrated under field conditions the effectiveness of chlorine in relation to the reduction of diarrhea incidence; when free chlorine residuals are maintained continuously above 0.5 mg/liter and preferably 0.7 mg/liter in the water supply.

According to Chang(24), flocculation and filtration are needed to purify the water to a degree suitable for chlorination; the water also must have low concentrations of ammonium ion, organic matter and virus.

In the WHO Guidelines for Drinking-water quality, WHO recommends the following:

"It is recommended that, to be acceptable, drinking-water should be free from any viruses infectious for man. This objective may be achieved (a) by the use of a water supply from a source which is free from wastewater and is protected from faecal contamination; or (b) by adequate treatment of a water source that is subject to faecal pollution. Adequacy of treatment cannot be assessed in an absolute sense because neither the available monitoring techniques nor the epidemiological evaluation is sufficiently sensitive to ensure the absence of viruses. However, it is considered at present that contaminated source water may be regarded as adequately treated when the following conditions are met:

- a turbidity of 1 NTU or less is achieved;
- disinfection of the water with at least 0.5 mg/litre of free residual chlorine after a contact period of at least 30 minutes at a pH below 8.0.

The turbidity condition must be fulfilled prior to disinfection if adequate treatment is to be achieved. Disinfection other than by chlorination may be applied provided the efficacy is at least equal to that of chlorination as described above. Ozone has been shown to be an effective viral disinfectant, preferably for clean water, if residuals of 0.2-0.4 mg/litre are maintained for 4 minutes. Ozone has advantages over chlorine for treating water containing ammonia but, unfortunately, it is not possible to maintain an ozone residual in the distribution system. Where virological facilities can be provided, it is desirable to examine the raw water sources and the finished drinking-water for the presence of viruses. This will provide baseline data to evaluate the health risk faced by the population. A reference method should be used for the concentration and detection of viruses in large volumes of drinking-water (e.g., 100-1000 litres)" (25).

The above considerations are most important, since for a large range of viruses of human origin, including the enteroviruses, it is estimated that one single infectious viral unit can produce infection in man (26).

Protozoa

The presence of protozoa in diarrhea and gastroenteritis seems to be proportionately less frequent than from bacteria but it is still significant and should not be ignored. In this group of microorganisms *Entamoeba histolytica* is of special concern because there is a high prevalence of amebiasis in Latin American and the Caribbean countries. Amebiasis is endemic in all the countries of the Region, but in some it has been reported to affect as much as 56% of the population; however, rates higher than 30% are relatively rare, but where these exist they usually are a good indication of insanitary conditions and lack of health education. Amebiasis epidemics, where traced, have been caused by contamination of the drinking water with sewage(18). The potential for dissemination of the disease is very high, as an infected person produces some 14,000,000 cysts per day, with each cysts being a potential source of infection(27).

The disinfecting ability of chlorine on *Entamoeba* cysts has been investigated for some time. Chang(28) reported amoeba cysts being 160 times more resistant to HOCl than *E. coli* is and 9 times more resistant than the hardiest viruses. HOCl destroyed the cysts in 10 minutes at 25°C, with a residual of 3.5 ppm. At pH 4.0, 30°C and 10 minutes exposure, 2.0 mg/liter of free residual chlorine were required to produce a 99.9% reduction in cysts; at pH 10, 12.0 mg/liter of chlorine were required for the same 3-log reduction.

Giardia has triggered a great deal of interest in recent years because of its appearance in water supplies which were chlorinated but unfiltered. *Giardia* cysts are considered to be among the most resistant pathogens. There may also be a problem with *Cryptosporidium* and *Balantidium*; these and other protozoa require further investigation.

In his studies on "Inactivation of Microbial Agents by Chemical Disinfectants" Hoff(6) summarizes C • t values for 99% inactivation of various microorganisms by disinfectants, at 5°C (Table 2). The table illustrates the bactericidal and viricidal effectiveness of free chlorine and chlorine dioxide. It can be seen that chloramines are relatively weak disinfectants. Also, the table shows that *Giardia* cysts are highly resistant to both free chlorine and chlorine dioxide. Attempts to use the table to estimate C • t values for higher levels of inactivation are not advised.

TABLE 2. Summary of C • t value ranges for 99% inactivation of various microorganisms by disinfection at 5°C (6)

MICROORGANISMS	C • t VALUES OF DISINFECTANT		
	FREE CHLORINE pH 6 TO 7	PREFORMED CHLORAMINE pH 8 TO 9	CHLORINE DIOXIDE pH 6 TO 7
E. coli	0.034 - 0.05	95 - 180	0.4 - 0.75
Polio I	1.1 - 2.5	768 - 3740	0.2 - 6.7
Rotavirus	0.01 - 0.05	3806 - 6476	0.2 - 2.1
Phage 2	0.08 - 0.18	-	-
G. lamblia cysts	47 - 150	-	-
G. muris cysts	30 - 630	-	7.2 - 18.5

Schistosomiasis

This parasitic disease is estimated to affect over 10 millon people in the Region of the Americas and the incidence may be increasing(17a). Although schistosomiasis is not usually associated with drinking water, it should be noted that chlorination can eliminate this organism. Free chlorine has been found to be effective against the Schistosomiasis cercariae under specific conditions. Frick and Hillyer(29) showed that at 20°C and 30 minutes of contact, residuals of 0.3 mg/liter at pH 5.0, 0.6

mg/liter at pH 7.5, and 5.0 mg/liter at pH 10, effectively inactivated *S. mansoni* cercariae. Although the major method of schistosomiasis control is through limiting man-water contact, the provision of safe water supplies has contributed to the control in several countries.

For a large number of communities in the size range under consideration in this document, the only line of defense against waterborne diseases is the disinfection facility. Even in small water supplies where coagulation, sedimentation and filtration are practiced, disinfection plays a most important role. In effect, water quality in small water supplies is of great concern because these are the public water supplies that experience most outbreaks of waterborne disease. This is usually due to poor quality raw water sources and treatment deficiencies, especially in filtration an disinfection.

From the practical point of view, it is important to have some guidance as to the general levels of chlorine residuals that should be maintained in the distribution system.

Based on the recommendations by the U.S. Public Health Service and the modifications by the National Research Council in 1956, a minimum contact time of 30 minutes for a free chlorine residual of 2 mg/liter has been recommended in the Americas. Since these recommendations were developed for the control of bacteria and *Entamoeba histolytica* in tropical and semitropical climates, such residuals although effective against bacteria and viruses may not be effective against *Giardia, Cryptosporidium* and other highly resistant protozoa particularly in low temperature water.

The WHO criteria listed earlier are not sufficient in themselves to insure the absence of cysts of *Giardia lamblia* and other intestinal pathogenic protozoa that may be present in the water supply. In recent years special attention has been given to the removal of *Giardia* cysts by filtration. Several studies are available on the subject. In general there is consensus that well operated coagulation settling and filtration effectively removes *Giardia* cysts. Becker and Lee(30) have obtained experimental results with >99.999% removal of *Giardia* cysts in slow sand filters, with near 100% removal in direct filtration in a mixed-bed media following chemical addition and mixing. On the average, the turbidity of raw water was 0.33 NTU and that of treated water was 0.15 or less.

As far as protozoa are concerned, coagulation and/or filtration are required in addition to chlorination in cases where water sources may be expected to contain this kind of pathogens. This process should remove the cysts, and carefully controlled free residual chlorination would assure that water has a minimum number of pathogenic microorganisms.

For raw water supply to be acceptable for treatment solely by disinfection, the finished water has to meet the same criteria as a water subjected to complete treatment. The raw water should be free of protozoa, should have no chlorine demand, have less than 1 NTU turbidity. The water in the distribution system should be monitored every day, if possible, for chlorine residuals. Bacteriological tests for total and fecal coliforms should be routinely conducted at least once a month (26). Table 3 summarizes the recommendations of the WHO(26) regarding microbiological and biological quality of drinking water.

TABLE 3. Recommended microbiological and biological quality of drinking water(26)

ORGANISM	UNIT	GUIDELINE VALUE	REMARKS
I. MICROBIOLOGICAL QUALITY:			
A. Piped water supplies			
A.1 Treated water entering the distribution system.			
Faecal coliforms	number/100 ml	0	Turbidity <1 NTU; for disinfection with chlorine, pH preferably <8.0, free chlorine residual 0.2-0.5 mg/liter following 30 minutes (minimum) contact.
Coliform organisms	number/100 ml	0	
A.2 Untreated water entering the distribution system.			
Faecal coliforms	number/100 ml	0	In 98% of samples examined throughout the year--in the case of large supplies when sufficient samples are examined.
Coliform organisms	number/100 ml	0	
Coliform organisms	number/100 ml	3	In an occasional sample, but not in consecutive samples.
A.3 Water in the distribution system.			
Faecal coliforms	number/100 ml	0	In 95% of samples examined throughout the year--in the case of large supplies when sufficient samples are examined.
Coliform organisms	number/100 ml	0	
Coliform organisms	number/100 ml	3	In an occasional sample, but not in consecutive samples.
B. Unpiped water supplies			
Faecal coliforms	number/100 ml	0	Should not occur repeatedly; if occurrence is frequent and if sanitary protection cannot be improved, an alternative source must be found if possible.
Coliform organisms	number/100 ml	10	
C. Bottled drinking water			
Faecal coliforms	number/100 ml	0	Source should be free from faecal contamination.
Coliform organisms	number/100 ml	0	
D. Emergency water supplies			
Faecal coliforms	number/100 ml	0	Advise public to boil water in case of failure to meet guideline values.
Coliform organisms	number/100 ml	0	
Enteroviruses	-	no guideline value set	
II. BIOLOGICAL QUALITY:			
Protozoa (pathogenic)	-	no guideline value set	
Helminths (pathogenic)	-	no guideline value set	
Free-living organisms (algae, others)	-	no guideline value set	

It is important to reemphasize that when dealing with any of the water treatment processes, including disinfection, removal or inactivation of microorganisms is a function of the number of organisms originally present. If the water is heavily contaminated, a large number of microorganisms could still remain viable in the treated water. Further, there also has to be assurance that adequate contact time and proper mixing is provided to insure sufficient contact of the microorganisms with the disinfectant.

Testing of disinfectant concentrations

An important consideration in selecting a disinfectant is that it should be possible to rapidly and easily test its concentration in water in the field. Chlorination usually can provide a residual that can be readily measured enabling the result to be fed back into the process for adjustment of the dosage, when necessary. The residual can also be used as a measure of the chlorination process performance.

Chlorine levels can be determined by a number of methods. Most are described in the book, Standard Methods(31). The amperimetric titration method is one that is used in many instances in Latin America and the Caribbean, particularly in laboratories of larger water supply systems. This method measures free and total residual chlorine and can differentiate between mono-and dichloramines. The method is sensitive and accurate to the low microgram range; however, it requires laboratory conditions and considerable skill and experience. The use of this method in small communities would not be recommended.

The most widely used methods in Latin America and the Caribbean are the DPD (N,N-diethyl-p-phenylenediamine) colorimetric and the orthotolidine. The DPD with a comparator is easy to use under field conditions. A spectrophotometer would detect 10 micrograms/liter. Both the colorimetric and the titration methods are described in the "Procedimientos Simplificados para el Examen de Aguas"(32). Precautions need to be taken on account of interfering substances and deterioration of reagents. The cost of the comparators and reagents probably is one tenth that of the amperometric titrators.

The FACTS (syringaldazine) test is a colorimetric or spectrophotometric test which directly measures free chlorine (Cl_2 + $HOCl/Cl^-$) species. Operator skills are similar to those required for the DPD test. The expected accuracy is slightly less. The stability of the products is about the same (30 minutes) but the shelf life of the reagents is shorter. FACTS has the disadvantage of difficulty dissolving the syringaldazine in isopropanol and its use is generally confined to the laboratory. It is not used for total or combined chlorine measurements.

The orthotolidine method is still in use in Latin America and the Caribbean, but is being phased out because of concern due to the carcinogenicity of the reagent and also its short shelf-life. There are a number of low-cost color comparators that are available on the commercial market or that are manufactured locally, ranging in price from US$ 5.00 to about $ 12.00 (33). They are not precision-instruments but usually are calibrated with increments of 0.2 mg/liter (residual chlorine). Some of them use a liquid form of DPD, which is not recommended because it has been shown to be quite unstable due to its sensitivity to oxidation by oxygen. Dry powder or tablet form of DPD is recommended. There are a number of more precise, color comparators which have increments of 0.05 mg/liter (residual chlorine). These should be used where more accurate measurements are desired.

The WHO Guidelines for Drinking-Water Quality(34) describe in Vol. 3, Annex 7, three methods for the testing of chlorine: the comparator technique, the test tube technique and the starch-potassium iodide-method. Table 4 compares the various methods for testing chlorine residual in drinking water.

TABLE 4. COMPARISON OF TESTING METHODS FOR RESIDUAL CHLORINE IN DRINKING WATER[1]

METHOD	SUITABILITY			
	Location	Total	Combined	Free
Iodometric[2]	Lab	Yes	No	No
Amperometric	Lab	Yes	Yes	Yes
DPD				
titration	Lab	Yes	Yes	Yes
colorimetric (photometer)[2]	Lab	Yes	Yes	Yes
color comparator[2]	Field	Yes	Yes	Yes
FACTS (Syringaldazine)	Lab	No	No	Yes
Orthotolidine[2] [3]	Field	Yes	Yes	Yes

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(21) Wilson, L.K. and M.D. Sobsey, "Inactivation of Hepatitis A virus by Chlorine in Water." AWWA 1987 Annual Conference Proceedings, Kansas City, MO. June 14-18. pp.447-462.

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[1] Most strong oxidants (ozone, hydrogen peroxide, chlorine dioxide, bromine and iodine) interfere with measurements in all of these tests.

[2] Organic contaminants may produce a false free chlorine reading in colorimetric methods.

[3] All orthotolidine methods were deleted from "standard methods" after 14th edition because of poor accuracy and the toxic nature of orthotolidine.

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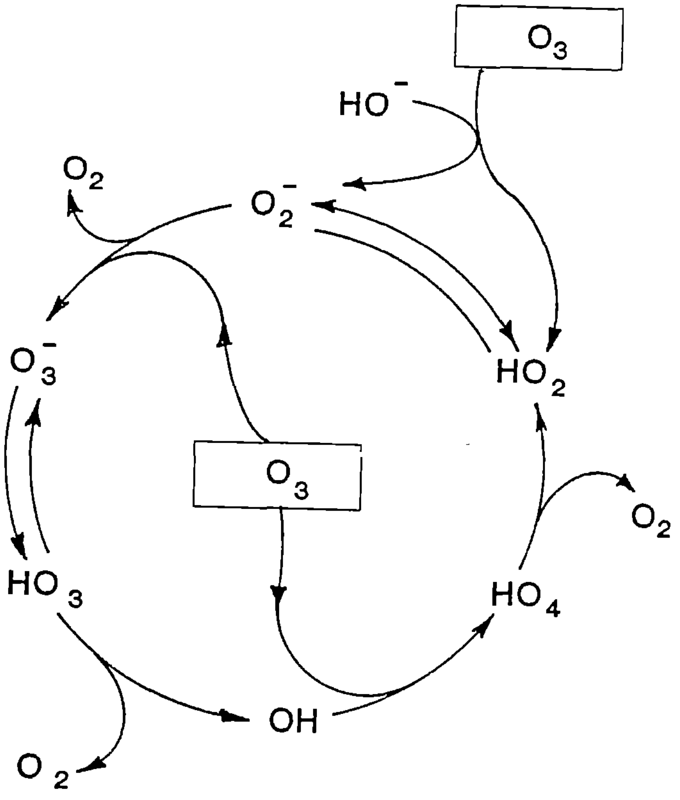

Figure 8. Cyclic chain mechanisms for decomposition of ozone in pure water with initiation by hydroxyl ion.

Since the kinetics of the reactions of ozone with many compounds will be too slow to be practical in water treatment and the ultimate demand for ozone almost always exceeds the supply, the aforementioned reactions will cease long before the organic substances have become totally oxidized. For treatment of organics, ozone's main uses have been for the cleavage of multiple bonds, for pretreatment prior to filtration, and as a coagulant aid.

It has recently been found that when ozone is combined with hydrogen peroxide and/or ultraviolet light, it is possible to oxidize many organics and inorganics more effectively than with ozone alone. The success of these processes is believed to be due to the intermediacy of the hydroxyl radical(38). These processes, along with others which generate the hydroxyl radical (such as ozone at high pH values and hydrogen peroxide with metal hydroxyl radical initiators), are commonly referred to as "advanced oxidation processes". The chemistry of these processes is rather complex and still not completely understood, and in any case is beyond the scope of this paper because it is not directly pertinent to the disinfection of water with ozone.

The main importance of this to disinfection is that much of the ozone will usually be consumed by other substances commonly present in the water supplies and this demand will have to be satisfied before disinfection can be assured. It also means that ozone will not provide a stable residual even though it is an excellent primary disinfectant which achieves initial destruction of microorganisms. A secondary disinfectant will still have to be added to provide that residual to protect the water in the distribution system against recontamination or regrowth of microorganisms. Because of these reasons (and because of its relatively high cost), ozone is rarely used for disinfection alone but also to simultaneously enhance other treatment processes through its oxidative power.

Effectiveness

From a standpoint of biocidal efficiency, ozone is the most potent disinfectant used for water supplies, with the $C \cdot t_{99}$ product for most organisms being less than 1/10 that of HOCl or chlorine dioxide. The concentration-contact times to inactivate or kill all waterborne pathogens are much lower than for free chlorine or for any other disinfectants used in water supplies. The $C \cdot t_{99}$ value for *E. coli* ranges from 0.006 to 0.02 for temperature of 1°C and pH of 7.2. For poliovirus I, at 5°C and pH of 7.2, the $C \cdot t_{99}$ value ranges from 0.1 to 0.2; at 20°C the mean $C \cdot t_{99}$ value is 0.05. For rotavirus, the $C \cdot t$ value at a temperature of 4°C ranges from 0.006 to 0.024, with the lower value reflecting a pH of 6 and the higher, a pH of 9. For *G. muris* cysts at 5°C, the value is determined to be 1.94. The disinfection capability of ozone does not change significantly over the normal range of the pH of water supplies(39). Table 5 compares the resistance of different microorganisms to ozone(8). Even the *Naegleria gruberi* cyst, one of the most resistant organisms to disinfection, has a $C \cdot t_{99}$ of only 4.23 at 5°C.

Ozone has two major limitations as a sole disinfectant: its half-life in water is usually shorter than 1/2 an hour and it reacts with organic substances to produce lower molecular weight by-products that are more biodegradable than their precursors. Sontheimer(40) found that application of 1 mg/liter of O_3 to water with 1.0 mg/liter of dissolved organic carbon resulted in 75% conversion of the dissolved organic carbon (DOC) into biodegradable compounds and 2.0 mg/liter of O_3 resulted in a 90% conversion; therefore, ozone might give rise to biological regrowth in the distribution system because it biodegrades organics into forms which can be used as nutrients by microorganisms commonly found in distribution systems. Because of these two limitations, ozone is usually used in combination with other disinfectants (secondary disinfectants) with weaker but more durable residuals, to prevent regrowth in the distribution system. Through subsequent filtration, the ability of ozone to react with organics can be used to advantage to remove the converted compounds that have become biodegradable.

Another consideration is that, as with other disinfectants, ozone must come in contact with the organisms to be effective; clumping might protect some of the organisms and inadequate mixing might fail to bring the organisms into contact with the ozone before it is dissipated.

Economically, ozone appears more favorable when, in addition to disinfection, it is simultaneously used for other purposes in water treatment; such as the break-down of synthetic organics, removal of phenols, avoidance of formation of trihalomethanes, flocculation enhancement and the like. As pointed out earlier, ozone is such a strong oxidant that it is almost always utilized for multiple purposes in the treatment of water supplies, rather than for disinfection alone.

TABLE 5. Comparison of resistance of different microorganisms to ozone inactivation

Test organisms	pH	Temp. °C	C mg/L	t min.	C • t mg • min./L	References
Escherichia coli	7.2 7.2	1 1	0.07 0.065	0.083 0.33	0.006 0.022	Katzenelson et al.
Mycobacterium fortuitum	7.0	24	0.8-1.08	0.58	0.53	Farooq et al.
Coxsackie A9	7.2	20	0.15	0.12	0.018	Roy et al.
Poliovirus 1	7.2 7.2	20 5	0.15 0.15	0.5 1.47	0.075 0.22	Roy et al.
Poliovirus 2	7.2	20	0.15	4.83	0.725	Roy et al.
Giardia muris	7.0 7.0	25 5	0.03-0.15 0.15-0.7	9.0-1.8 12.9-2.8	0.27 1.94	Wakramanayake
Naeglaria grubei	7.0 7.0	25 5	0.3-1.2 0.55-2.0	4.3-1.1 7.8-2.1	1.29 4.23	Wakramanayake
Entamoeba histolytica	7.5-8.0	19	0.7-1.1	<5	-	Newton et al.

Testing for Ozone

Monitoring and testing for ozone involves more than simply monitoring a residual in the water distribution system. It is also necessary to monitor the off-gas from the contact chamber(s) to assure that ozone is not being wasted and to assure that a sufficient amount of ozone has been applied to obtain the oxidation/disinfection desired. It is also necessary to monitor the ozone in the treated water, so that the ozone production rate can be adjusted to accommodate changes in influent water quality. This is especially important if the water has not received adequate treatment prior to ozonation to sufficiently stabilize the ozone demand: continuous monitoring is necessary to provide reliable treatment by the ozone.

A number of tests have been used. The simplest but outdated test for monitoring ozone that was used in smaller, older, European plants was the "sniff" test which was based on the fact that the nasal threshold detection level for ozone in air was approximately 0.01 ppm. It was used to assure that the off-gas from the contactors still contained ozone. This, is neither reliable nor accurate, and is also potentially dangerous; so it is not advised even for small communities.

The potassium iodide method described in Standard Methods(31) involves the oxidation of iodide ion(I^-) in water to iodine(I_2), according to the equation:

$$O_3 + 2I^- + H_2O ===> I_2 + O_2 + 2OH^-$$

The resultant solution is then titrated with sodium thiosulfate using starch as an indicator. Unfortunately other oxidants, such as chlorine, chlorine dioxide, hydrogen peroxide and potassium permanganate, that are capable of oxidizing the iodide ion, interfere in the test. Because of this and because the test is tedious and time consuming, it is more useful as a standard method for the calibration of ozone-sensing devices rather than for a routine test.

The indigo trisulfonate method(41) has advantages in that it is based on measurement of discoloration that is rapid and stoichiometric. Its primary attributes are its sensitivity, selectivity, accuracy and simplicity. Adding malonic acid to the sample will mask the interference of chlorine. The gas-diffusion-flow-injection analysis (GD-FIA) procedure, it is especially reliable but it is a laboratory procedure not suitable for field testing.

Another satisfactory method of measuring aqueous ozone is with amperometric- type instruments which use a flow-through measurement cell of two dissimilar metal electrodes (often gold and copper) to generate a current proportional to the ozone present. These are presently utilized by automated monitoring and control systems for ozonation in water treatment plants. Their major shortcoming is the need for frequent calibration and cleaning of the electrodes which are subject to fouling.

Absorption of ultraviolet light radiation of wave lengths between 240 to 300 nm can be utilized to determine the content of ozone in both air and water. Lamps with a wave length of 254.7 nm are generally utilized for these purposes. Devices which utilize this method, along with double-beam spectrophotometric instruments, are available for continuous monitoring of the ozone in both the water product and the off-gas from the contact chamber. Such equipment is commonly utilized in automated, computerized control systems which adjust the production of ozone to match or accommodate changes in water quality as they occur, so as to assure sufficient oxidation/disinfection and to minimize excess ozone in the off-gas. Unfortunately, although the UV molar absorptivity for gaseous ozone is agreed upon, the accuracy of the absorptivity measurement is still somewhat uncertain for aqueous ozone, with values ranging from about 2900 to 3600 Langleys per centimeter of penetration per mole of aqueous ozone.

Although it is possible to monitor ozone residuals and make dosing adjustments manually, this is rarely done, except in case of extremely stable water conditions such as can be found in some well supplies. Under these circumstances, it is possible to make a manual adjustment at sufficiently spaced intervals to be practical. Today, complete automation of monitoring and adjustment is the most common practice followed, even on the smallest systems; however, this is only feasible where excellent customer support by the supplier/manufacturer is readily available. In Europe, the United States and Canada, contracts for follow-up inspection and routine maintenance, as well as for replacement and repair, are available. This arrangement has been enabled by the dependability and long life of the equipment, and may be appropriate for small communities which lack the necessary technical skills to maintain and repair such equipment; however, such a service arrangement is not yet known to be widely available in Latin America.

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2.3. MIXED OXIDANTS

PAHO coined a term MOGGOD as an acronym to generically describe the process of "mixed oxidant gases generated on-site for disinfection". This section will be limited to those methods in which electrolysis of a sodium chloride solution produces a mixture of active oxygen and chlorine species which, together, act as a powerful oxidant and disinfectant. Even though it is also possible to produce other types of mixed oxidants, such as interhalogens by electrochemical processes and various oxygen species by photolytical processes, these methods will not be covered herein, because the use of electrolysis-type of MOGGOD devices in small communities and towns of Latin America has achieved considerable success; whereas for the others, there is very limited experience in their use in community water systems. More recently, devices which produce a mixed oxidant solution instead of a gas have been developed. The oxidant species produced and the effectiveness as an oxidant and a disinfectant appear to be comparable to the mixed oxidant gas when injected into water. Thus, the term herein is change to MOGOD to be inclusive of both devices.

Characteristics of mixed oxidants

The electrolytic, simultaneous production of more than one oxidant is not really new but is generally viewed by the chemical industry as undesirable, because the industry's goal is usually to produce a pure oxidant for specific purposes; thus, the effort has usually been to suppress the production of mixed oxidants. In the water treatment industry, however, mixed oxidants can be desirable, since the superior disinfection properties of electrolytically on-site generated solutions, in comparison to the properties of sodium hypochlorite applied to the same water, has been noted by a number of investigators(42).

Among the different MOGOD devices, there is considerable variation in the reported ratio of oxygen to chlorine species generated. This is thought to be due to the differences in electrolysis cell design, electrode material and configuration, and concentration of the salt in the electrolyte. Figure 9 depicts the relative proportion of species reported by *Pendergrass et al.*(43) for the device developed by the Los Alamos Technical Associates (LATA). The proportion fluctuates with the voltage, having an anomaly commencing at about 18 volts for an electrolyte concentration of 30g/liter. The proportion reported for the cell manufactured by Oxidizers Inc. ranges from 50% to 60% chlorine and 40% to 50% oxygen species. The GIDOX unit, which was made by FENAR, of Argentina, produced about 75% oxygen species and 25% chlorine species. The device fabricated by CEDAT, in Mexico, is reported to produce roughly 50% of each species. One prototype was reported to produce up to 90% oxygen species and 10% chlorine species. Depending on the characteristics of the water to be treated, actual experiences in the field indicate that there may be advantages to using different proportions but this remains to be investigated under controlled conditions.

The oxygen species of MOGOD have been shown to include hydrogen peroxide, ozone, and short-lived oxidants not precisely identified. The chlorine species include the hypochlorite ion, hypochlorous acid, and traces of chlorine dioxide. The presence of the chlorine species is to be expected in the electrolysis of a sodium chloride solution. The presence of hydrogen peroxide can be explained by the fact that nascent oxygen in the presence of nascent hydrogen ion generally combines to form hydrogen peroxide(44). The presence of ozone and free radicals have been explained by the reactions on the catalytic surface of the anodes(45).

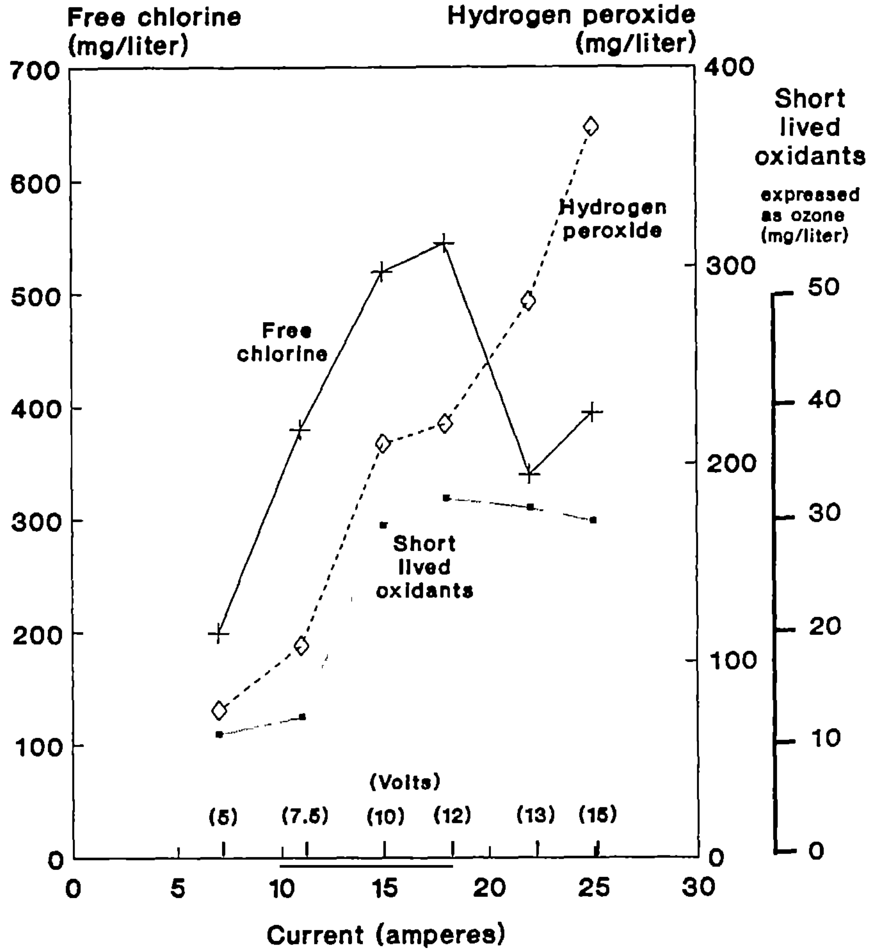

Figure 9. The influence of electrical voltage and current upon oxidant species composition.

Because of the mutual interference of strong oxidants in the standard tests and because of the complexity of the potential reaction of the different oxidant species, a precise determination of the spectrum of oxidants produced by the various MOGOD devices remains to be done. However the oxidant mixture has a higher oxidation potential than hydrogen peroxide. From a practical standpoint, such data is not of overriding importance; because it has been demonstrated, in both the laboratory and the field, that this combination of mixed oxidants generated on-site is a powerful oxidant and disinfectant which, in several ways, is safer and more effective than chlorine(43). Comparative testing of disinfection in community water systems with MOGOD and with chlorine indicate that MOGOD results in a more stable residual in the distribution system as measured by DPD and Orthotolodine tests. Why this occurs is not well understood but seems to be related to the synergistic effect of multiple oxidants and the destruction of microbiological flora on the walls of the pipes.

Health effects

Because the mixture of oxidants contains some of the strongest oxidant species of both oxygen and chlorine (refer to Table 1, section 2), investigations are being carried out to determine if the same undesirable by-products which are formed by chlorine and ozone are also formed by MOGOD. Initial results from PAHO's demonstration project indicate that for the same water treated, MOGOD will form 50% to 80% less trihalomethanes than chlorine gas (45). *Duguet et al.*(46) found that the addition of hydrogen peroxide to water during ozonation increased the rate of ozone transfer and of oxidation of organic compounds and significantly reduced the amount of precursors of trihalomethanes. This may also help explain the reduction in the level of THMs in water, after exposure to MOGOD treatment(47). In any case, for small, remote community water systems, the risk of contracting disease from microorganisms is many orders of magnitude greater than the risk of getting cancer from undesirable by-products(29).

MOGOD has not been found to form chlorophenols. In actual disinfection of small water systems, it has consistently improved taste and odor problems that chlorine exacerbated. Preliminary studies indicate that there may be cleavage of double bonds of unsaturated aliphatics to form aldehydes and possibly ketones, but in amounts lower than broken by ozone. Neither chlorates nor chlorites have been detected in the treated water, under either laboratory or field conditions(45).

Experience to date indicates that the health risk of undesirable by-products of MOGOD is less than that from chlorine. All evidence indicates that the health benefits of disinfection with MOGOD far outweigh any health risk it may pose(45).

Chemistry

Although the proportions of the different oxidant species generated by MOGOD devices are still not precisely determined, each species is a strong oxidant. The hydroxyl radical, atomic oxygen, perhydroxyl radical, ozone, hydrogen peroxide, hypochlorous acid and chlorine are among the oxidants reported to be produced by various MOGOD devices. The first four, which have a very short life, altogether comprise only a small but effective portion of the oxidants, and should be considered together as "short- lived oxidants," such as was done by LATA (43) because, for all practical purposes, they can't be differentiated. Hydrogen peroxide and the perhydroxyl radical are not effective disinfectants in water, but they preferentially react with many substances in water that would otherwise reduce the availability of the more effective disinfectants.

The chemistry of multiple strong oxidants in an aqueous environment is very complex and probably will not be completely understood for years. of the oxidants.

Effectiveness

Mixed oxidants have proven effective against a broad spectrum of microorganisms (some of which are among the more resistant to inactivation by chemical disinfection) over a wide range of pH and temperature conditions. Testing to date indicates that the effectiveness of MOGOD as a water disinfectant appears to equal or exceed that of chlorine.

Pendergrass et al. tested mixed-oxidant solutions generated in the LATA's electrolysis cell, against *Legionella pneumophila, Escherichia coli, Giardia muris* cysts, *Pseudomonas aeruginosa* and *Bacillus subtilis* (43). With an initial concentration of 0.40 mg/liter of short-lived oxidants and 0.44 mg/liter of free chlorine, they achieved a 100% kill of *Giardia* cysts in 3°C water, after 30 minutes of contact time. These results are comparable to those of Hibler(48).

A group of tests (47) reported in 1987 were carried out by Mexico City's General Water Works Administration (Dirección General de Construcción y Operación Hidráulica DGCOH), using a MOGOD device produced by Oxidizers Inc. (Virginia Beach, Va.,USA). The device was tested on water from two contaminated wells (located in "colonias" Santa Maria Aztahuacán and Agrícola Oriental), that contained atypical, hard to kill, microbes. Water from the Santa María Aztahuacán well (pH of 8.0, temperature of 21°C) was treated with sodium hypochlorite at 10 mg/liter free chlorine residual and with mixed oxidants that were generated at 2 amps (equivalent free chlorine residual = 1.3 mg/liter) or at 10 amps (equivalent free chlorine residual = 4.9 mg/liter). The results are presented in Figure 10.

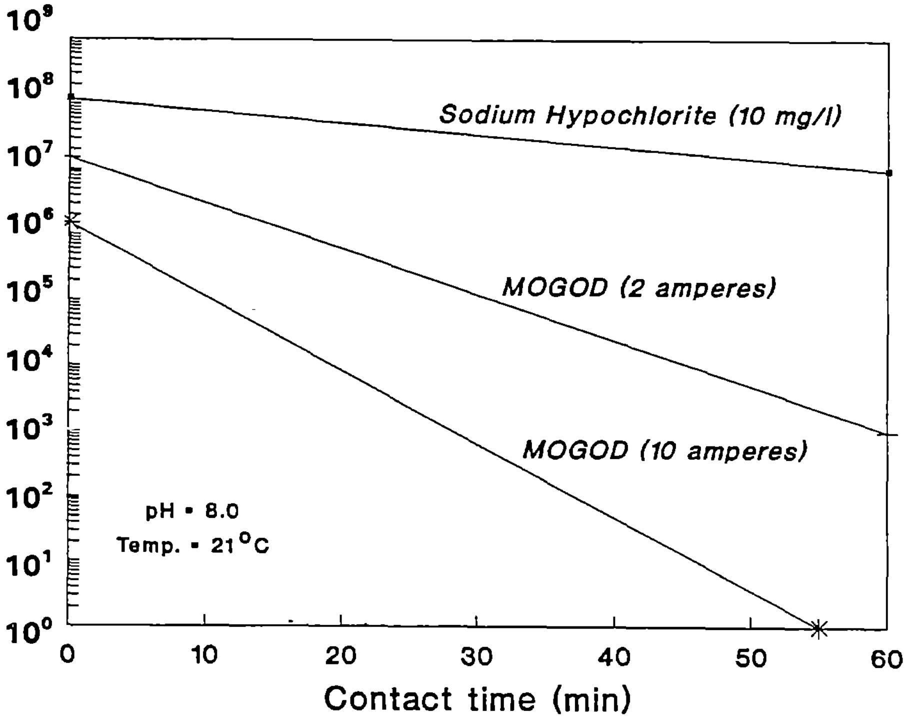

Figure 10. Survival of atypical bacteria for different contact times/ different concentrations: Santa María Aztahuacán well.

The tests from the more contaminated Agrícola Oriental well (pH of 8.35, temperature of 22.8°C) unfortunately did not include a sodium hypochlorite baseline but included additional dose of MOGOD (at 20 amps and equivalent to a free chlorine residual of 10.4 mg/liter). The results are shown in Figure 11.

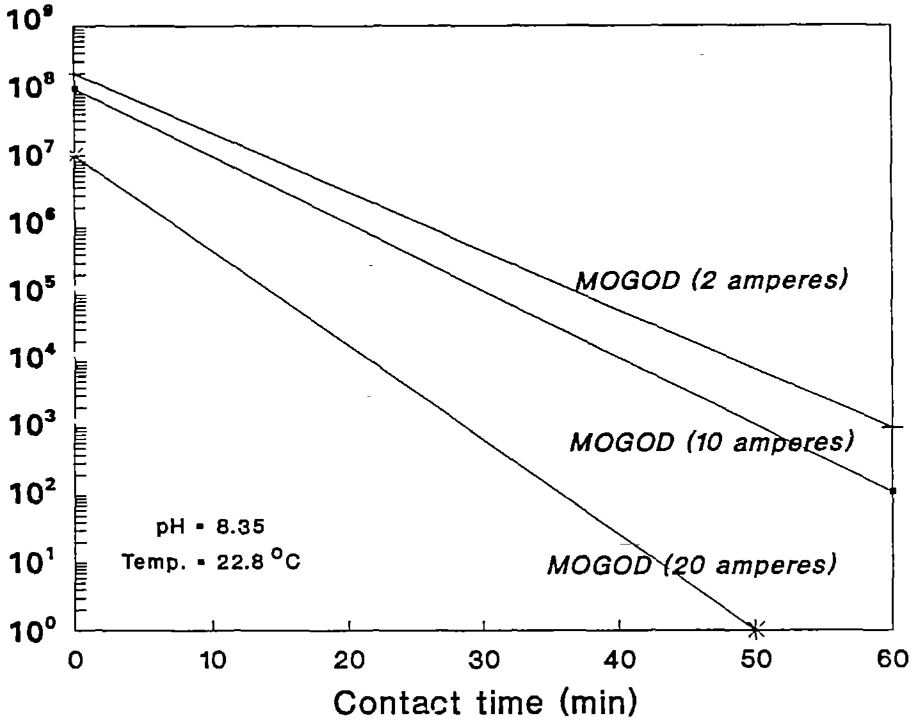

Figure 11. Survival of atypical bacteria for different concentrations and contact times: Agrícola Oriental Well.

Olivieri and Ramirez(49) compared bactericidal and viricidal activity of MOGOD to that of chlorine. Using solutions prepared from the mixed oxidant gas diluted with air and from chlorine gas, they concluded that the gas produced by the particular MOGOD device tested, inactivated *E. coli*, *P. aeruginosa*, and f2 virus with a disinfectant activity equivalent to chlorine solutions at an equal, total oxidant residual under the same chemical and physical conditions. Using available data, from all sources PAHO has calculated the C•t values for MOGOD summarized in Table 6.

Testing

For MOGOD, it is necessary to differentiate between testing for field monitoring and for scientific investigation. For countries without experience, it is preferable that both be done prior to mass purchasing of equipment.

TABLE 6. C • t_{99} values of MOGOD for various microorganisms for pH 6 to 7.5.

Organism	C•t_{99} (mg•min/liter)
Giardia Lamblia	
@ 3 - 5 °C	6 - 10
@ 20 °C	3
Legionella pneumophilia	<3
Staphylococcus aureus	60
Escherichia coli	<2
Pseudomona Aeruginosa	<3
Bacillus subtilis spores	2000
f_2 bacteriophage virus	<3

The DPD (N,N-diethyl-p-phenylenediamine) test for chlorine is recommended for MOGOD; it is gradually replacing the orthotolodine arsenite (OTA) method which is still used in some Latin American countries, in spite of the fact that OTA is a suspected carcinogen. Testing for MOGOD residual in the water treatment plant as well as in the distribution system can be accomplished satisfactorily by either one of the methods. Both of these methods yield the total oxidants present and do not distinguish between free residual chlorine, hydrogen peroxide, ozone and other strong, short-lived oxidants which may be present. From a practical standpoint, this is not important for determining the initial dose of disinfectant or monitoring the residual remaining in the system, because both the OTA and the DPD methods can be thought of as yielding a "chlorine equivalent" of oxidants. In the field the OTA indicates a 10% higher equivalent residual than DPD. PAHO recommends the use of DPD for field testing.

The results of field monitoring of more than fifty small water systems in Mexico, Colombia, Costa Rica, Cuba, Honduras, Perú, Argentina, Venezuela and the United States indicate that maintaining a minimum free residual of 0.1 mg/liter, as measured by either of these two methods, will assure systems free of both total and fecal coliform bacteria. Where investigated, it was found that most of the reactive, short-lived oxidants were consumed in the initial few minutes following the dosing of MOGOD gases into the water, satisfying to a great extent the initial chlorine demand (45,47). The multiple oxidants seem to act synergistically in this respect. The residual present in the distribution system has been determined to be primarily of free residual chlorine, although there is variation depending upon the chemical content of the water; additional studies will be necessary to precisely ascertain which oxidants remain active under a wide range of conditions.

Laboratory testing for precise determination of the species and their proportions present in the gas produced by the various MOGOD devices have not been altogether successful because of the extreme reactivity, mutual interference and the dry condition of the gas mixture. Testing for such determinations in an aqueous solution has been difficult, because of the complex mechanism of decomposition of the ozone and free radicals; the reactivity of the stronger oxidants with other species present; the multiple potential reaction pathways; the oxidation by-products; and the mutual interference among some of the oxidants. PAHO recommends that the series of tests used by Los Alamos Technical Associates for estimating the species present (43) be adopted by developers and laboratories as the standard methods for estimating the spectrum of species in MOGOD. In this series of tests, chlorine is determined by the Phenylarsine titration; H_2O_2, by UV (290nm) absorbance; and short lived oxidants (ozone and/or free radicals), by Indigo trisulfonate dye decolorization (600 nm).

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2.4. ULTRAVIOLET RADIATION

Disinfection with ultraviolet (UV) light has been used extensively for institutional water supplies, such as those for hospitals, food and beverage industries, and ships; more recently, it has also been used for the treatment of sewage effluent. In demonstration projects for small-community water systems in the United States, Canada, Europe, and Brazil, UV light has been used for the primary disinfection which is usually followed by a secondary chemical disinfectant (usually chloramines) to provide an adequate residual to assure against regrowth of microorganisms in the distribution system.

Characteristics

Disinfection of water with UV light can be achieved with wave lengths of light between 240 and 280 nanometer (nm), the maximum germicidal efficiency being with about 260 nm. Fortuitously, low-pressure mercury arc lamps, which are commercially available, produce an ultraviolet wavelength of about 253.7 nm. Water temperature has little, if any, influence on the disinfection effectiveness of the UV light itself but it does have an effect on the operational output of the UV light by the lamp. In theory, water can be disinfected to any degree by this method; however, there are a number of factors that decrease the penetration (or absorption) of the UV rays in the water and in actual water treatment this is an important consideration because it affects the efficiency of the process.

UV energy is absorbed as it passes through the wall of the UV lamp, the quartz or teflon sleeve and the walls of the reactor. It is also absorbed by the water itself, but to a much greater extent by the types of suspended and dissolved solids, turbidity and color. In drinking water, the concentration of suspended solids is generally well below the 10 mg/liter level at which it begins to cause problems with UV-light absorption(50). The degree of color and the type and amount of dissolved organic carbons seem to be of greater importance in regards to the absorption of the light by the water than turbidity is, but turbidity can shield the organisms from exposure to the ultraviolet light. Ultraviolet light absorption can be thought of as a UV-light demand which must be determined specifically for the water to be treated thus the dose of radiation to be applied should be determined by the "worst quality conditions" which can be expected in actual operations. The radiation absorption is quantified by a spectrophotometric measurement of the intensity of UV light of a wavelength of 253.7 nm, before and after the UV light has travelled through a known distance of the water being tested.

Health effects

There are no known, direct, adverse health effects to the user of water which has been disinfected with UV light. No substances are added to the water in the disinfection process; there is no risk of forming trihalomethanes; and UV light does not alter the taste and odor of the water treated. At the dosage and frequency used for disinfection the formation of by-products has not been reported. Overdosage with UV light is not known to have any deleterious effects on the water.

The operator of the UV-light disinfection equipment must, however, use protective glasses and clothing to avoid exposure to the high-energy radiation of UV light.

Effectiveness

For a given degree of inactivation, the required time of exposure of water to ultraviolet light is inversely proportional to the calculated intensity of the light penetrating the water, where the absorptivity of the water and the dispersion of the light due to the distance are taken into account(51). It was demonstrated in 1975 that, regardless of the duration and intensity of the dosage, if the same total energy is delivered, the same degree of disinfection is achieved(52). The energy necessary for destruction or inactivation of an organism is expressed in the units of microwatt seconds per square centimeter (μw·sec/cm^2).

It is believed that inactivation with UV light is brought about by the direct absorption of the UV energy by the microorganism and a resultant intracellular photochemical reaction which changes the structure of biochemical molecules (probably in the nucleoproteins) which are essential for the organism's survival.

Escherichia coli has been found to be more resistant to disinfection by UV light than *Salmonella* and *Shigella* species(53). It has also been disclosed that *Streptococcus faecalis* is about 3 times more resistant; *Bacillus subtilis*, 4 times more resistant; and the spores of *B. subtilis*, 6 times more resistant to UV-light disinfection than *E. coli* (54). With doses of 4,000 μw·sec/cm^2, more than 4 logs of inactivations of Poliovirus, Echovirus and Coxsackie virus have been reported(55). Most manufacturers of ultraviolet disinfection equipment provide a minimal exposure (in clear water) of 30,000 μw·sec/cm^2. This is quite adequate for inactivation of pathogenic bacteria and viruses but still might not be sufficient for certain pathogenic protozoa, protozoa cysts and nematode eggs which may require up to 100,000 μw·sec/cm^2 for complete destruction.

Ultraviolet disinfection has been shown to follow Chick's law of disinfection kinetics (56), as expressed by the equation:

$$\frac{-\log N}{N_0} = \frac{I \cdot t}{Q}$$

where N_0 = the original number of organisms
N = the number of surviving organisms
I = the intensity of exposure, in microwatts per square centimeter
t = the time of exposure, in seconds and
Q = the dose for 1 log survival, in microwatts sec per square centimeter

The necessary dose for 1 log survival is commonly referred to as a lethe. Unfortunately there is considerable variation in the reported absolute magnitude of Q, primarily because of the difficulty in accurately determining the average duration and intensity of exposure in the contactors utilized.

Derived by the authors, Table 7 summarizes the reported range of UV energy necessary for the inactivation/kill of various organisms. The U.S. Public Health Service criteria for UV-light disinfection is a minimum dose of 16,000 microwatt seconds per square centimeter, with a maximum water depth of approximately 7.5 cm; however, as indicated earlier, most manufacturers recommend a standard dose of 30,000 microwatt seconds per square centimeter for drinking water applications.

TABLE 7. Range of reported UV (254 nm) energy (microwatt seconds/cm^2) necessary to inactivate various organisms

Microorganism	Energy required
Escherichia coli	**360 - 2,400**
Staphyloccus aureus	**210 - 400**
B. Paratyphi	**320**
B. subtilis	**1,000 - 2,440**
***B. subtilis* spores**	**2,160 - 12,000**
Pseudomonas aeruginosa	**2,500**
S. typhimurium	**3,200**
T 3 coliphage virus	**160**
Poliovirus	**780**
Nematode eggs	**18,400**
Paramecium	**40,000**
***Giardia muris* cyst**	**60,000 - 100,000**

Testing

The only reliable testing for the biocidal efficiency of UV disinfection is through sampling of treated water and testing for indicator organisms. With a photocell, it is also possible to measure the intensity of exposure from one or more strategic points within the exposure chamber but this doesn't necessarily mean that all of the organisms have received an adequate dose of UV light to assure inactivation or kill. Such UV-intensity monitoring should be done on a continuous basis and the dose should be considerably in excess (usually 150% to 200%) to provide an adequate safety factor to assure sufficient exposure at all times under expected conditions of water quality and flow.

Other considerations

One major advantage of disinfection with UV light is that no chemicals are required. Another distinct advantage is that the time of exposure can be quite short compared to contact durations necessary for conventional chemical disinfectants. It is also effective for a wide range of microorganisms.

A major disadvantage is that UV provides no residual. Another is a serious reduction in efficiency when there is an increase in turbidity or color of the water. There is also the difficulty of measuring the effectiveness of a specific installation other than through testing for the presence of an indicator organisms following the UV treatment; it is possible to monitor the energy produced by the lamp but not the energy impinging upon the organisms being disinfected. (One of the authors has inspected a regrowth of bacteria and slime molds on the inner wall of piping within 3 meters following diatomaceous earth filtration and UV dosage of approximately 25,000 microwatt-sec/cm^2 on a water with a turbidity less than 2 NTU).

The threat of recontamination and/or regrowth of bacteria in a water distribution system and the questionable effectiveness of ultraviolet rays against some of the pathogenic protozoa cysts and nematode eggs are compelling reasons to question broad use of UV disinfection without the addition of a secondary disinfectant to provide an effective residual. UV disinfection is usually more costly than conventional methods of disinfection. The use of this method of disinfection alone, without a secondary disinfectant, would be advised where the disinfection is precautionary; where the water supply is dependable and of very good biological quality, with turbidities less than 1 NTU, such as found in some groundwater; and where there is little chance of recontamination of the distribution system following the UV treatment. In all other cases a secondary disinfectant should be added.

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2.5. IODINATION

Characteristics of iodine

Iodine—a dark, grey, nonmetallic element with an atomic weight of 126.92—is the only halogen which is solid at normal room temperature and it is also the least soluble of this group. Because it is a solid, its solubility increases with an increase in temperature while that of chlorine (a gas) decreases. Depending on the temperature, the solubility can vary from 200 to 400 mg/liter (at 20°C it is 290 mg/liter). Figure 12 illustrates the difference in solubility of chlorine and iodine(57). Iodine has the lowest oxidation potential of the three common halogens—chlorine, bromine, and iodine (Table 1)—and hydrolyzes the least of the three. Its low solubility might create difficulties in applying this disinfectant in large water supply systems but this property could be an advantage in small water supply systems because it would tend to prevent severe overdosage.

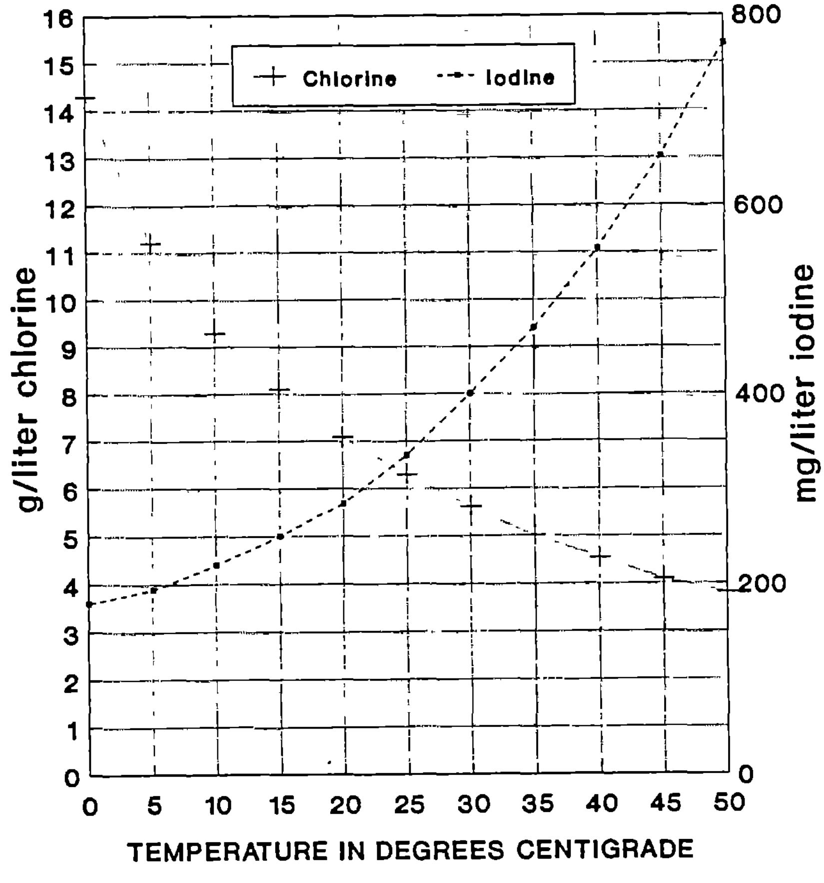

Figure 12. Solubility of chlorine and iodine as a function of temperature.

Health effects

Unlike chlorine, the health concern for iodine is more closely related to the iodine itself rather than to products of reactions of iodine with other substances commonly found in water. This is primarily due to the fact that iodine is a weak oxidant and neither the thermodynamics nor the kinetics of reactions in an aqueous environment favor its combination with other substances; for example, iodamines are not formed at the dosage required for disinfection. Iodine is a much less potent generator of trihalomethanes than chlorine or bromine. Iodoforms are produced only under conditions which rarely exist in water treatment and distribution systems.

Testing for health effects of relatively high concentrations of iodine in drinking water was conducted by the Bureau of Medicine and Surgery, Department of the US Navy(58). The purpose was to determine if prolonged ingestion of iodine caused toxic effects. Sodium iodide was added to the water supply of a naval installation. The water system consisted of a rainwater-collection source that had been disinfected with chlorine prior to storage and distribution.

For the first 16 weeks the average dose per man was estimated to be 12 mg/day and during the last 10 weeks the dosage was increased to provide an estimated per capita average of 19.2 mg/day. Clinical tests were conducted to detect any pathological effects and trends, and comparisons were made to personnel not receiving iodinated water. Symptoms, signs, and laboratory tests indicative of disease were searched for in individual subjects. Analysis of the data did not reveal evidence of weight loss, vision failure, cardiovascular damage, altered thyroid activity, anemia, bone marrow depression, nor renal irritation. The conclusion of the six-months study was that there was no unusual incidence of any form of skin diseases; no evidence of sensitization to iodine among the personnel receiving iodinated water; and no indication of impaired wound healing nor defective resolution of infections, as a consequence of the consumption of the iodinated water.

A long-term experience of disinfecting with iodine involved two piped water systems which served three prisons in the State of Florida. These systems were disinfected with iodine for a period of 5 years, during which time a residual between 0.8 and 1.0mg/liter was maintained. Prior to iodination, 125 individuals in the test group were evaluated twice. Examination of the skin and thyroid gland; counting of white and differential blood cells; measurement of concentration of serum protein-bound iodine and serum thyroxine; and measurement of 24-hour radioactive iodine uptake by the thyroid gland were done. Follow-up examinations were conducted for the subsequent 5 years to detect changes, especially of deleterious nature, in health. None of the prison inmates developed clinical evidence of hyper- or hypothyroidism throughout the study. Only 29 people in the initial test group remained in prison for the entire study period and in six of them the thyroid gland was slightly enlarged. There was no evidence of any allergic reactions nor was there any change in serum thyroxine concentration. No detrimental effects on thyroid function or general health were detected during the entire test period (59,60).

The health concerns of iodine which have been succinctly expressed by Zoeteman(57) are quoted:

> "Iodism is an allergic reaction of over-sensitive people to iodine when the therapeutic dose of iodine is much larger than the daily requirement. The allergic reaction can be either of an acute

> or of a chronic nature. Acute iodism is manifested by angioneurotic symptoms, from urticaria to hemorrhagic exudates. Chronic iodism is more common than the acute form, the main symptoms being chronic rhinitis, enlargement of the salivary glands and various acneiform exanthemas.
>
> Jod - Basedow is the development of hyperthyroidism in the course of goitre therapy when the therapeutic dose is considerably larger than the daily requirement. As a result of prolonged nutritional deficiency of iodine hyperactive nodules can develop in a goitre. It is these nodules that secrete almost all the hormone, the remaining thyroid tissue being practically inactive. Given a larger supply of iodine, the nodules can produce excess of thyroid hormone, thus inducing Jod-Basedow. Thus iodine does not cause, but conditions the development of the disease. Stanbury and his colleagues reported a case of a woman with endemic goitre who developed Jod-Basedow after the administration of 1.5 mg of iodine per day. The symptoms usually disappear several weeks after the administration of excessive iodine has been discontinued.
>
> Iodine thyroiditis appears sometimes at the beginning of iodine therapy. It is an enlargement of the goitre which may be painful. The complication can occur about the seventh day of therapy if large doses are administered. After iodine therapy has been discontinued the goitre decreases spontaneously. Iodine thyroiditis is a transitory harmless phenomenon.
>
> Enlargement of the goitre, with or without hypothyroidism occurs after the administration of massive doses of iodine (50 - 500 mg or more per day) for the treatment of bronchial asthma, arteriosclerosis e.o. This iodine induced goitre arises because in some people and some animals iodine in large doses inhibits the release of thyroid hormone into the blood-stream. The shortage of thyroid hormone in the blood leads to a compensatory increase in the secretion of thyrotropin which produces enlargement of the thyroid. This type of goitre disappears spontaneously after the administration of iodine has been discontinued and the concentration of iodine in the blood has decreased.
>
> All the above complications of iodine therapy of goitre are very infrequent. Among 1000 adults, most of them with large nodular goiters, who received large doses of iodine (5 - 15 mg/day) under careful and frequent control, only one patient developed iodine thyroiditis and one Jod-Basedow."

The subject of using iodine over extended periods of time for water disinfection has been debated by many health agencies, mainly because of the physiological effects which iodine can have on iodine-sensitive people.

Although there has been no convincing medical evidence of adverse health effects or of altered thyroid function on healthy individuals at levels of iodine which would normally be maintained for disinfection of water supplies (0.5 to 1.0 mg/liter), the range of the safety factor is sufficiently narrow that most health agencies limit this form of disinfection to emergencies or short periods of use. A total, body intake of 2 mg/liter (2000 micrograms/liter) of iodine per day approaches the threshold for toxic level of intake(61). If 1.0 mg/liter of iodine were the residual in drinking water and the average person drank 2 liters/day, there would be no margin of safety for additional intake of iodine from other sources such as food. It is estimated that the average dietary intake of iodine per person is about 400 micrograms/day(62); however, in areas where iodized salt is used, the intake may be higher, as the usual concentration of iodine in salt is between 1:10,000 and 1:20,000 (by weight) and the average daily consumption of salt is about 10 grams per person, making the iodine-intake from salt to be about 1.0 mg/day/person.

Chemistry

Since iodine has the lowest oxidation potential (0.54 volts) of the common halogens (Table 1), it reacts least readily with organic compounds and substances. It does not form iodamines when exposed to nitrogenous substances in water. The characteristic of reacting very slowly or not at all with most substances commonly found in water systems is a distinct advantage in maintaining an effective residual in a distribution system. Figure 13 depicts the difference between the persistence of chlorine and iodine residuals in the presence of ammonia(57).

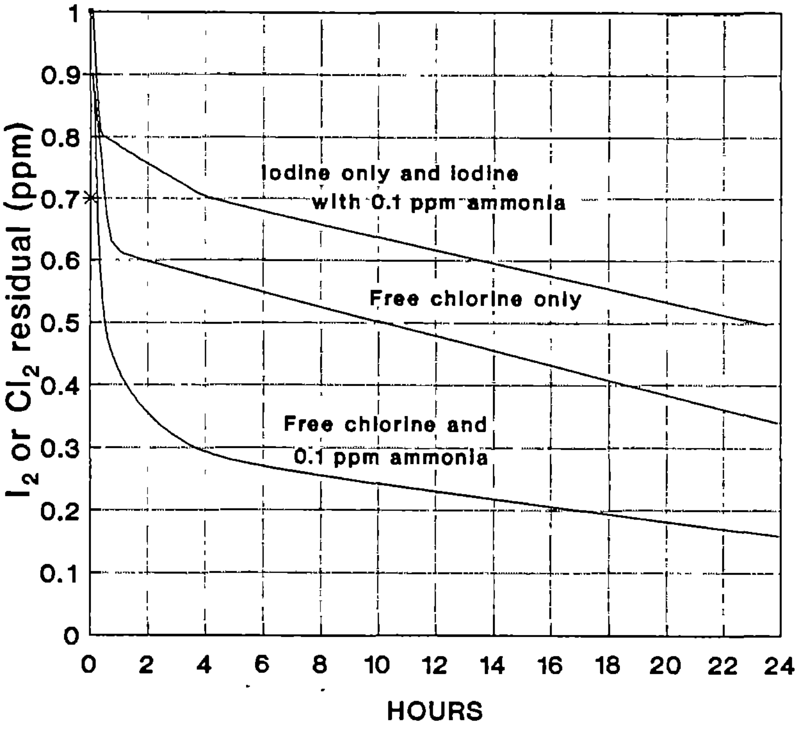

Figure 13. Halogen demand of water after addition of ammonia at 24°C and pH 7.5.

I_2 reacts with water to form hypoiodous acid (HOI) and iodide ion (I^-). The hypoiodous acid subsequently dissociates into the hydrogen ion (H^+) and hypoiodite ion (OI^-). This is illustrated in the following equations.

$$I_2 + H_2O <===> HOI + H^+ + I^-$$

$$HOI <===> H^+ + OI^-$$

TABLE 8. Effect of pH on hydrolysis of iodine and chlorine

pH	Percent of species in residual					
	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

Table 8 compares the effect of pH on the species distribution. Above pH values of 9, the autoxidation of hypoiodous acid (HOI) begins to form hypoiodate (HIO_3) which has little disinfection capacity. Fortunately the predominant species continue to be HOI up to pH 10, thereby assuring potency as a disinfectant in the higher range of pH encountered in water supplies.

Figure 14, illustrates the percentages of titratable iodine (I_2) and HOI in water at 18°C and different pH values (24). This allows estimation of the available disinfectant species under specific conditions.

Effectiveness as a disinfectant

Iodine has been recognized as a drinking water disinfectant since early in this century and has been widely used for small volumes of water, such as for individual water supplies under field and emergency conditions. Currently the most common form is a tablet which was specially developed for the US armed forces and which contains tetraglycine hydroperiodide, sodium acid phosphate and inert filler(63). These tablets are used throughout the world for emergency disinfection of drinking water and by campers hikers and hunters. Iodine has also had limited but successful use in disinfecting small semipublic, institutional and farm water supplies; however, it has never gained widespread use in public water supplies, in great part due to its high cost, which is about 10 times that of chlorine, and due to the narrow margin of safety between the necessary dosages to achieve adequate disinfection and the threshold level to protect iodine-sensitive persons (a small percentage of the general population) from suffering adverse health effects. Iodine has also been found to be effective in swimming pool sanitation.

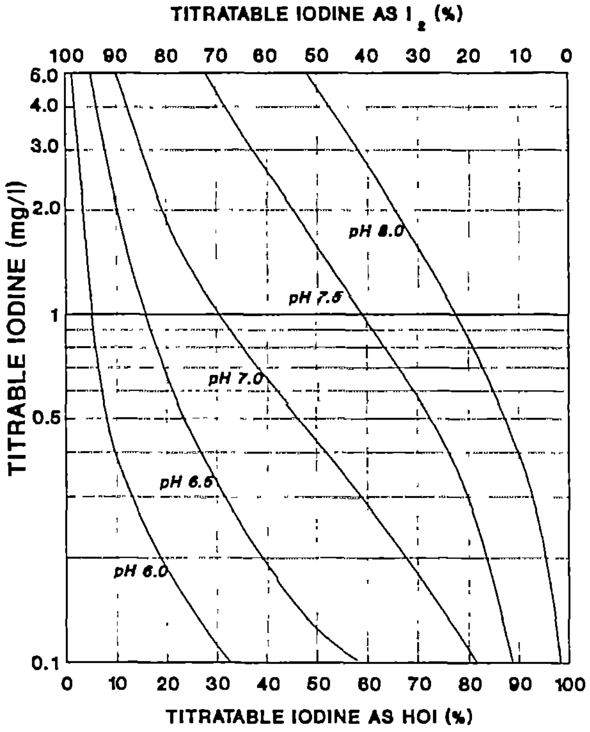

Figure 14. Percentage of titratable iodine as I_2 and HOI in water at 18°C.

In general iodine fulfills the criteria for a disinfectant listed in section 1.3 of this manual and for some of the criteria it is outstanding. Iodine has many characteristics of disinfection that are comparable to chlorine and bromine.

Free iodine (I_2) is an effective bactericide over a wide range of pH. The effect of free iodine concentration and of exposure time, pH and temperature of water on enteric bacteria was investigated by Chambers et al.(64). They were able to inactivate all of the organisms tested in less than 5 minutes of contact time. At 2° to 5°C, they found that 3 to 4 times as much iodine was required for a pH value of 9.0 as was required for a pH of 7.5, but even for >99.9% inactivation in high pH water at >20°C, the required dosage was always less than 1 mg/liter. Chang(27) felt that molecular iodine (I_2), due to the absence of electrical charge, was a better cysticide and sporicide than chlorine because it was more diffusible through the cell wall. On an atom-to-atom basis, the bactericidal effectiveness of iodine is about twice that of chlorine.

The practical, six-year field study/demonstration project conducted by *Black et al.*(59,60) maintained an iodine dosage of 1.0 mg/liter during almost all of the study. Toward the end of the study, the feed level was reduced to 0.8 mg/liter, 0.6 mg/liter and 0.4 mg/liter, each for a subsequent period of 4 weeks, to determine the effect of reduced dosage. There was no significant difference noted in the bacteriological data. The pH of the water was 7.4 but for a 3 month period it was artificially raised to 8.5. There was no change in the bacteriological quality of the treated water for this entire period, except for a weekend when the iodine feed pump failed to dose the system with iodine. With the multiple-tube technique and the membrane-filter technique of examination for bacteria, 0.6% and 3.6% of the 2,539 distribution-system samples, respectively, were unsatisfactory, the examination period including the weekend the feed pump was inoperative and the time when there were lower dosages of iodine.

Although there are a large number of studies on cyst inactivation by iodine, there seems to be considerable discrepancy concerning dose, pH, temperature, numbers of cysts tested, source of cysts and methods of determining viability; however, the investigators generally agree that iodine is an excellent cysticide in low pH waters. This suggests that molecular iodine, I_2, rather than hypoiodous acid (HOI), is the effective form. Chang(27) found that both diatomic iodine (I_2) and hypochlorous acid (HOCl), each with a residual concentration of 3.5 mg/liter, destroyed amoebic cysts in 10 minutes at 25°C. At a pH of 7 and temperature of 30°C, iodine has a $C \cdot t_{99}$ value of 80 for cysts of *E. histolytica*(26). This favorable $C \cdot t$ value is due to the fact that the predominant iodine species at pH 7 is I_2, which has good cysticidal properties. Chang(65) calculated a cysticidal efficiency of hypoiodous acid to be 1/3 and 1/2 that of I_2 at 6°C and 25°C, respectively. In systems which operate at a pH of 8 or above, the predominant species is HOI, which is not a very strong cysticide; this could present a problem, especially in cold water, if either *E. histolytica, G. lamblia or G. muris* cysts are present.

Iodine is not only an effective bactericide but it is also an effective viricide. This is illustrated in Table 9 (66). Chang(24) reported virucidal effects in 10 minutes with iodine concentration of 14.6 ppm. Poliovirus 1 (one of the viruses most resistant to disinfection) is more susceptible to inactivation from HOI than from I_2. Iodine, unlike other halogens, becomes a more effective virucide as the pH increases. At pH of 6.0, iodine has slightly less virucidal activity than hypochlorous acid but at a pH of 8, iodine is far more effective than chlorine because the predominant chlorine species is OCl^-, which is not an effective virucide. Viral inactivation by iodine is thought to be attributable to its reaction with vital amino acids and proteins(67). Considering the range of microorganisms (bacteria, viruses, protozoa cysts and spores) that need to be destroyed in most water systems, Chang concluded that HOI was more effective than I_2.

Table 10 presents comparative $C \cdot t_{99}$ values for coliform bacteria, Poliovirus I, f_2 virus and Simian cysts(66).

TABLE 9. Concentrations of Iodine and Contact Times Necessary for 99% Inactivation of Polio and f_2 Viruses

Test Microorganism	Iodine mg/liter	Contact Time,min	C•t	pH	Temp. •C	References
f_2 Virus	12	10	120	5.0	5	Kruse, 1969
f_2 Virus	7.5	10	75	6.0	5	Kruse, 1969
f_2 Virus	5	10	50	7.0	5	Kruse, 1969
f_2 Virus	3.3	10	33	8.0	5	Kruse, 1969
f_2 Virus	3.0	10	30	7.0	25 - 27	Kruse 1969
Poliovirus 1	30	3	90	4.0	25 - 27	Kruse, 1969
Poliovirus 1	1.25	39	49	6.0	25 - 27	Berg et al, 1974
Poliovirus 1	6.35	9	57	6.0	25 - 27	Berg et al, 1964
Poliovirus 1	20	1.5	30	7.0	25 - 27	Kruse, 1969
Poliovirus 1	30	0.5	15	10.0	25 - 27	Cramer et al, 1976

TABLE 10. Comparative Values from Confirmed Experiments on Disinfecting Water with Iodine at 23°C to 30°C at pH 7.0

Organism	Total Iodine mg/liter	Minutes for 99% Inactivation	C•t value
Coliform bacteria	0.4	1	0.4
Poliovirus I	20	1.5	30
f_2 virus	10	3.0	30
Simian cysts	15	10.0	150

Figure 15 presents the Ct curves for I_2 and HOI at 18°C (57). This data indicate that iodine compares very favorably with chlorine as a water disinfectant. Like other halogens the effectiveness of iodine against bacteria and protozoa cysts is reduced by high pH, but, unlike bromine and chlorine, the effectiveness is increased against viruses at high pH.

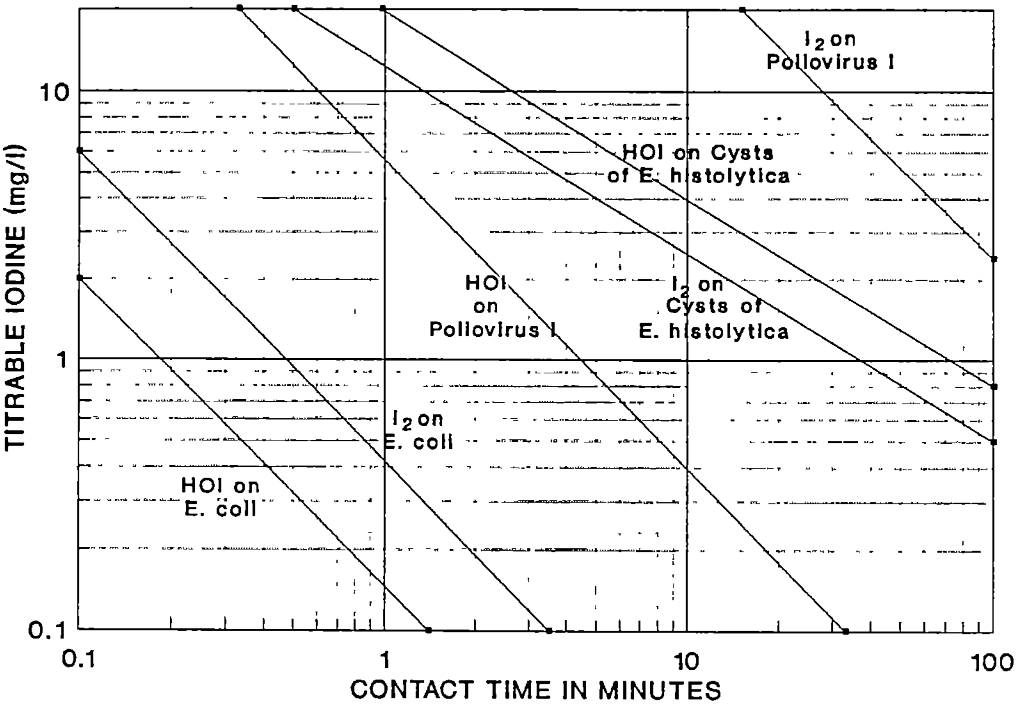

Figure 15. Destruction of bacteria, cysts and viruses by I_2 and HOI at 18°C.

Recently, iodine has been used in combination with chlorine to remove persistent bacterial contamination from water distribution systems(68). Apparently there is a synergistic effect when used in combination with chlorine and together, even at low concentrations, these two halogens are able to break through the protective coatings which the bacteria form on the walls of the pipe. This has considerable potential for disinfecting and cleaning small systems infested with chlorine resistant microorganisms.

Iodine can also be loaded onto available sites on strong-based quaternary ammonium anion exchange resins, forming resin-iodide complexes known as polyhalide resins which go by the trade names of Triocide, Pentacide and Polyhalex. The polyhalide resins are very small beads which when placed in a bed or column form a porous media. The water to be treated is passed through this bed or column. Various papers (69)(70)(71)(72)(73) have been published describing the biocidal action of these resins as a "demand disinfectant" which kills microorganisms by the release of iodine at the resin surface as the microorganisms come in contact with the iodine-loaded resin. This is a mechanism which differs from that of the microorganism coming in contact with a disinfectant in solution. Actually, there is some release of iodine from the resin into the stream as the water passes through the resin column. This can provide a residual of iodine in the treated water. The manufacturers of these resins claim very large reductions in most water borne pathogens, but it isn't altogether clear what proportion of the reduction of bacteria, virus or protozoa is due to filtration, to absorption, to adsorption, to demand release of disinfectant or to iodine residual.

Testing

There are several common tests for measuring the free iodine residual in water supplies. The term free iodine is used to denote iodine which is not combined chemically with substances other than with water and it can be determined by both amperometric titration and leucocrystal violet (LCV) colorimetric method. The DPD colorimetric method for determining the concentration of free chlorine has also been successfully used in both the field and the laboratory (74), correlating sufficiently well with standard samples tested by this method.

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2.6. MINOR AND EXPERIMENTAL DISINFECTION PROCESSES

Bromine

Characteristics

Bromine, an element of the halogen family, is a dark, red-brown liquid at atmospheric pressure and room temperature. This characteristic makes it, in some respects, easier to handle than chlorine gas; however, great care has to be exercised in doing so. Bromine is about 3.1 times heavier than water; its melting point is 7.3°C and the boiling point is 58.7°C. Its oxidation potential of 1.07 volts is lower than that of chlorine but higher than that of iodine (Table 1, Chapter 2), and, in general, its chemical properties are somewhere between those of chlorine and iodine.

Health effects

Liquid bromine vaporizes readily and the fumes are extremely irritating. The maximum concentration considered safe for long-term exposure in the air of the working environment is 0.1 ppm. The liquid can cause severe burns if it comes in contact with the skin. Bromine is slightly soluble in water. For use, saturated solutions can be obtained by bubbling water through liquid bromine. Like with chlorine, extreme care should be exercised in handling bromine and full body protection is recommended when dealing with significant amounts. Bromine, like chlorine, forms trihalomethanes. Under special conditions, the application of chlorine or ozone to water containing bromine may form chlorodibromomethane and bromodichloromethane. In the presence of fulvic acid and ammonia, below break-point, chlorine produces hardly any chloroform; in contrast, bromine readily produces significant concentrations of bromoform(75). All these compounds are of concern because of their possible carcinogenic effects.

Chemistry

Diatomic bromine (Br_2) hydrolyzes in water to produce hypobromous acid (HOBr) and bromine ion (Br^-). In turn, the hypobromous acid ionizes to form hypobromite ion (OBr^-). The ratios of the species depend on the pH of the water.

$$Br_2 + H_2O <==> HOBr + H^+ + Br^-$$

$$HOBr <==> OBr^- + H^+$$

Effectiveness as a disinfectant

The germicidal activity of bromine has been attributed to the hypobromous acid (HOBr) as well as to the hypobromite ion (OBr^-), both forms being effective bactericides. In concentrations below 6.0 mg/liter and in a pH range between 5.0 and 8.0, titratable bromine would exist primarily as Br_2 and

HOBr; however, bromine increases in effectiveness with increasing value of pH and is thus more effective at pH 9.0 than at pH 7.5 or 6.0, as reported by Sollo(76); the effectiveness of chlorine, on the other hand, increases with decreasing pH values. Bromine, like chlorine, reacts with ammonia to form dibromamine and monobromamine. The latter is considered to be as effective a disinfectant as free bromine is at high pH values; this characteristic is also in contrast with monochloramine, which is a very weak disinfectant.

Compared with chlorine and iodine, bromine has been found to be a more effective amoebic cysticide throughout the pH range. In distilled water buffered at pH 4.0, with a 10 minute exposure and a temperature of 30°C, a 1.5 mg/liter bromine residual was needed for 99.9% cyst mortality(26). Under similar conditions, 5.0 mg/liter of iodine residual and 2 mg/liter of free chlorine residual were required to achieve the same results. At pH 10.0, 4.0 mg/liter of bromine, 12 mg/liter of chlorine and 20 mg/liter of iodine produced the same mortality rate of 99.9%.

Although bromine was pioneered as a drinking water disinfectant in the 1930s, it is now used primarily for disinfection of cooling-water and swimming pools. Reports indicate that its residual is more persistent than that of chlorine and that it is less irritating on the eyes. Dosing a saturated solution of bromine at a constant rate is simple and can be done through a positive displacement pump or by bubbling a portion of the water flow through liquid bromine.

The use of bromine for the disinfection of drinking water has been considered for specific circumstances but few applications have been reported. More attention has been given to the disinfection of sewage and sewage effluents with bromine. As a consequence, little experience exists on the use of bromine for disinfection and other purposes in the drinking water treatment. More information on the germicidal, particularly on the viricidal and the cysticidal, effectiveness is required. Similarly, more knowledge is needed on the formation of undesirable by-products and their health effects.

One of the main disadvantages of bromine for drinking water disinfection is its high cost. It is estimated to be about 3.5 times as expensive as chlorine, although it could be less expensive than ozone. On the other hand, the cost of the dosing equipment and its operation, estimated on the basis of swimming pool disinfection installations, is likely to be relatively low.

The fact that bromine needs to be made available in glass or earthenware bottles of one, five or six pounds may render the transport too dangerous or difficult to be practical for remote areas and small towns. Cases of nine bottles are commercially available. Bromine is also available as a solid in compounds of various types. These are somewhat safer to handle but are much more expensive than liquid bromine.

In view of these limitations Bromine is not recommended for use in drinking water supplies.

Testing

The orthotolidine test can be used for detecting bromine; however, standards have to be prepared specifically for bromine. Alternately, chlorine standards may be used, provided the results are multiplied by an appropriate factor, usually 2.0.

Metallic ions

The cations of some metals, particularly gold, silver, mercury and copper, have been found to have antibacterial properties. The bactericidal activity of these metals in small amounts was observed long ago and designated "oligodynamic action". Of this group of four metals, only silver merits some consideration for the purpose of water supply disinfection. The toxicity of mercury, the very high cost of gold, and the low bactericidal effectiveness of copper and mercury (copper is a good algicide and mercury is a good fungicide) rule them out for practical purposes. The use of silver itself is questionable because of the cost and the limited effectiveness against a number of common waterborne pathogens.

Silver is not a particularly toxic substance to man and only relatively small fractions of ingested silver seem to be absorbed by the body. Poisoning with silver has occurred at extremely high dosages. The main effect of silver is argeria—a discoloration of skin, hair and nails; it may result from the administration of silver in high doses for medical purposes. No recommended levels are indicated for silver in the WHO Guidelines for Drinking Water(29), as it is very unlikely that intakes from water, air and food may be significant.

The process of disinfection with silver consists of adding very low concentrations of the metallic ion to the water to be treated, in the range of 25 to 75 micrograms/liter. This has been accomplished through addition of solutions of silver salts, or use of electrolysis or silver-coated releasing materials. The bactericidal effect is apparently due to the ability of silver to immobilize the sulfhydryl groups in the proteins and the enzymes of the microorganisms. The action of the silver ion is very slow. For *Entamoeba histolytica*, Chang and Baxter(77) reported that it took six minutes for a 106 mg/liter of Ag^+ to destroy 99% of the cysts in water at 23°C and pH 6.0. A concentration of 97 mg/liter of Ag^+ was about two thirds less efficient than that of a concentration of 10 mg/liter of iodine as I_2. Silver is not recognized as a good viricide. The effectiveness of silver diminishes with decreasing values of pH and temperature; very long contact times would be required at temperatures of 10°C or less.

Organic matter has been reported to interfere in the disinfection by silver, although silver may be less susceptible to it than chlorine. Silver may also be affected by the mineral content of water. An advantages of silver as a water disinfectant is that it does not produce tastes, odors, color, or subproducts. Residual silver may persist for a long time, but because of the slow reaction rate at the usual dosages, it would have little value as a protecting residual.

In general silver is not recommended for the disinfection of water supplies, although in the literature there exist reports of its use in a few instances, primarily in small water supplies (mostly private) in European countries. The cost has been estimated to be about two hundred times more expensive than other lower-costing disinfectants, such as chlorine.

In recent years interest has developed in the use of metallic ions for the disinfection of water, particularly of electrolytically-generated copper:silver ions in conjunction with chlorine. Preliminary results obtained in the disinfection of swimming pool water with copper and silver (about 400 micrograms/liter and 40 micrograms/liter, respectively), in conjunction with 0.2 mg/liter of chlorine, indicate that there may be a synergistic effect(78).

Dosing equipment can be relatively simple and economical. Operational requirements can also be simplified; however, the measurement of silver or copper in such low concentrations presents some complexities and is unlikely to be carried out in the field.

Heat

Boiling of water is an effective means of pathogen destruction. Pathogenic bacteria under favorable conditions can survive a wide range of temperatures, from below freezing to about 60°C. Thermophylic bacteria actually may grow at around 70°C and their spores may resist temperatures higher than 100°C. Fortunately bacteria associated with waterborne diseases are mostly non-spore formers. Experimental results of boiling water, obtained at the Water Engineering Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio, are shown in Table 11 (79). Boiling water vigorously for one to three minutes can be an effective means of disinfection. In this regard, consideration has also been given to the boiling temperature of water at higher elevations. Since the boiling temperature decreases at the rate of approximately 1°C for every 320 meters increase in elevation, at 3,200 meters above sea level the boiling temperature would only be about 90°C (100°C at sea level) but the boiling time required to inactivate the pathogens would be longer. However the three minutes indicated provide an adequate safety factor.

TABLE 11. Microbial Quality of Potable Water in a "Boil Water Order"

Water Temp. (°C)	Holding Time (seconds)	Surviving Organisms per ml (Standard Plate Count)
25	0	8,900
30	0	8,700
40	0	7,600
50	0	760
60	0	<1
70	0	<1
80	0	<1
90	0	<1
100	0	<1
100	30	<1
100	60	<1
100	120	<1
100	240	<1

Boiling will kill vegetative bacteria but spores may not be affected. Amoeba cysts are destroyed in 2 minutes in water at 50°C(27). Viruses are also inactivated in 1 to 3 minutes of boiling(79) and, according to Bingham(80), *Giardia* cysts are immediately inactivated when added to boiling water.

Compared to virtually all other methods of disinfection, boiling is usually the most costly, as it consumes large amounts of energy. It is also difficult and impractical to handle large quantities of boiling water. It has been estimated that about 1.0 kg of wood is needed to boil 1.0 liter of water. This cost alone makes it impractical for use on a community basis. Boiling is frequently appropriate under emergency conditions or in individual homes. The taste of boiled water may be disagreeable but aeration usually improves it somewhat.

The process of pasteurization of water is analogous to that of pasteurization of milk. Like in boiling water, complete sterilization is not attained. Time-temperature relationships apply and there is need to keep in mind that the required thermal death-time increases with the number of organisms present. This fact could be important when dealing with heavily contaminated water.

Goldstein et al.(81,82) designed and tested a continuous flow water pasteurization unit for use in homes. To avoid the need for holding a large volume of water at a lower pasteurization temperature, they selected the high-temperature, short time process (72°C for 15 seconds). The system is capable of producing 1,000 liters in a 12-hour period. A larger unit with a capacity to produce 4,000 liters per 12 hours was also designed.

The coliform destruction tests were satisfactory, as no organisms were found in 5/10 ml portions after filtration with slow sand filters and pasteurization. The system was effective even when high counts of bacteria, up to 110,000/100 ml, were added to the raw water. It is estimated that the slow sand filters accounted for approximately two orders of magnitude of reduction and pasteurization, for an additional two orders.

The average power consumption was estimated at 1.0 kw-hr per 100 liters of water disinfected. The cost of operation will vary with the cost of the electric energy in the particular location but, in any case, it is expected that disinfection by this method will be expensive compared with other methods, and not applicable to community water supplies; however, it might be appropriate for use in special cases. Pasteurization does not leave a residual and strict precautions are necessary to prevent recontamination.

Gamma radiation and X-rays

The wave length of gamma and X-rays used in water disinfection are between .01A and .001A. These types of radiation have greater penetrating power than UV radiation. Few data are available on the destruction of microorganisms in drinking water by these means. Even with relatively cheaper sources of radiation, such as Cobalt 60, the application of gamma radiation to the disinfection of water seems to be limited by practical reasons. Ridenour and Armbruster (83) reported that dosages of 50,000 reps[1] were sufficient to reduce by 99% five out of ten test organisms, and 100,000 reps reduced by 99% all these organisms, including the spore-forming *Bacillus subtilis*, in seeded river water. The more resistant were *Streptococcus faecalis* and *Bacillus subtilis*.

Two mechanisms have been recognized in the disinfection by ionization radiation(84): 1) The direct effect in which the DNA of the cell is damaged by the energy released by the radiation; and 2) the indirect effect in which hydrogen peroxide, organic peroxides, and free radicals produced within the cell menstruum react to form ozone.

Table 12 shows dosages of radiation for inactivation of various microorganisms, as reported by other researchers.

TABLE 12. Dosages of irradiation necessary for 99% inactivation of various microorganisms in distilled water

Microorganism	Radiation source	Required dose (rad[2])
Bacillus subtilis (85)	Cobalt 60	3.5×10^5
Escherichia coli (85)	Cobalt 60	6.5×10^4
E. coliphage T3 (85)	Cobalt 60	3.2×10^4
poliovirus 2 (86)	Van de Graff generator	3.0×10^5
S. typhimurium (86)	Van de Graff generator	1.0×10^4
coxsackie virus B3 (86)	Van de Graff generator	4.2×10^5
E. coli K12 (86)	Van de Graff generator	3.8×10^4

Ionizing radiation can be an effective drinking water disinfectant, but like in the case of disinfection with UV radiation, a residual to protect against later contamination is not provided and problems of after-growth could develop. Further, from the practical point of view, it also presents complex technical engineering problems for the installation and operation of the source. The provisions for the necessary safeguards are beyond the capability of even highly trained operators and are much less for operators. For these reasons ionization radiation is not considered appropriate.

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[1] A unit of radiation dose equal to the absorbed dose in water that has been exposed to one roentgen.

[2] A unit of energy absorbed from ionizing radiation; equal to 100 ergs per gram of irradiated material.

Natural sunlight

Natural direct sunlight is a powerful bactericide, primarily due to the ultraviolet and infrared sun-rays; however, the use of this source of energy for disinfection of drinking water, even for small groups of people, has very limited application. Diffused daylight also inhibits bacterial growth. Sunlight has limited effect on *Giardia lamblia*, *Entamoeba histolytica* and certain other protozoa found naturally in clear bodies of water. Several prototypes of devices for disinfection of drinking water with sunlight for individual households have been field tested and may be suitable for very small quantities of water under special conditions.

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3. UNDESIRABLE BY-PRODUCTS OF CHLORINATION

3. UNDESIRABLE BY-PRODUCTS OF CHLORINATION

It has been known for a long time that under certain conditions, the application of disinfectants to water, especially the halogens and particularly chlorine, can result in undesirable tastes and odors. In 1974 a new set of undesirable disinfection by-products associated with the halogens were identified (87,88), the trihalomethanes (THMs) and it is suspected that other undesirable by-products of disinfection also could result from chlorination and other disinfection processes. Research is still being conducted in this area; therefore, the potential for harmful by-products should be taken into consideration when selecting a disinfection process. In other words it will be necessary to know what by-products are formed under what conditions, what the health risks or other adverse effects are, and how these can be minimized. WHO recommends that a risk-benefit approach be used when considering disinfection, disinfection by-products, pathogens and water quality so as to balance the trade-offs between microbial and chemical risks.

Since chlorine is the most common as well as the most economical drinking water disinfectant in Latin America and the Caribbean, this chapter gives primary attention to the by-products of chlorination. By-products of other disinfectants have already been referred to under the discussion of specific disinfectants in section 2.

3.1. TASTES AND ODORS

Free residual chlorine in distilled water has little taste and odor at the normal desired residuals for disinfection purposes. The World Health Organization (5) reports that the average taste and odor thresholds concentration of free residual chlorine increased from 0.075 mg/liter to 0.450 mg/liter as the pH increased from 5.0 to 9.0. At pH 7.0 the average threshold was 0.156 mg/liter with a range of 0.02 - 0.29 mg/liter; however, when chlorine combines with phenolic and other organic compounds, unpleasant taste and odors can be greatly exacerbated.

The expression "free residual chlorine" is used to describe the HOCl and OCl^- species which are formed when chlorine is added to water. In natural waters these two forms of chlorine react readily with other substances for which they have affinity resulting in a reduction in the free chlorine. This reduction is called the "chlorine demand." Most natural waters contain organic matter, ammonia, or other substances which exercise this demand. Some reaction products such as ferric chloride have no disinfection properties, whereas others such as chloramines do. When disinfection properties are retained, the products are referred to as "combined residual chlorine." If chlorine is added beyond the point where only combined residuals are present, both combined and free available chlorine would be present. The graphic representation of the variation of the concentration and type of chlorine residuals (free and combined) is known as the "break point curve" (Figure 16). This curve normally has a hump and a return point. The top of the hump indicates the point where the combined residual starts to change from monochloramines to dichloramines, and the return point or "break point" indicates where free chlorine and possible THMs start to appear in the residual. Break point curves are specific for each water tested.

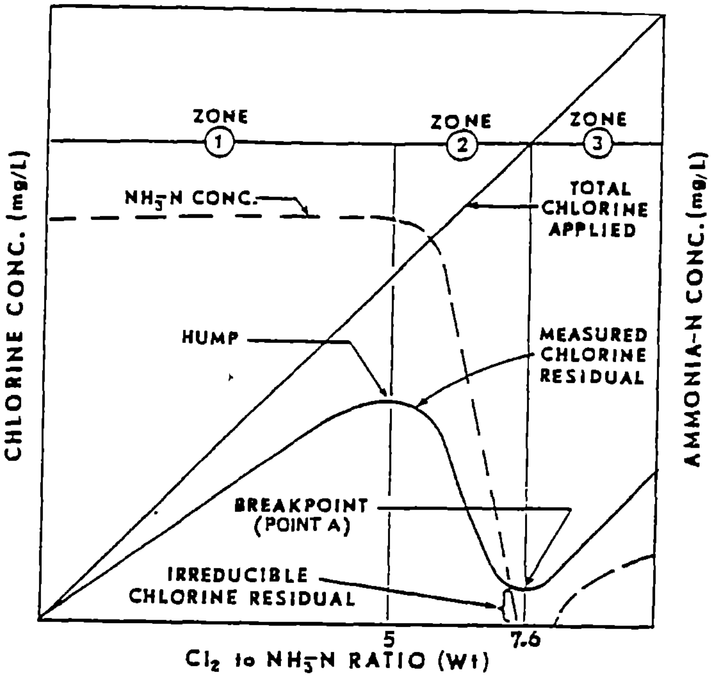

Figure 16. Theoretical breakpoint curve.

As used in actual practice, the breakpoint also denotes the level of irreducible chlorine residuals or "nuisance residuals"(89) which are of significance from the standpoint of tastes and odors. This curve is a valuable tool to predict how much chlorine will be required for disinfection in a specific period of time as well as to anticipate what by-products might be formed. Figure 17 depicts the changes in chlorine residuals versus dosages after 1 - 2 hours contact time in a water containing 0.3 mg/liter of ammonia and 0.3 mg/liter of organic nitrogen, at a pH 7 - 8 (89).

The first leg of the residual chlorine curve up to the first hump represents the combined residual chlorine predominantly made up of monochloramines. These compounds usually do not contribute substantially to the taste and odor problems but they have low disinfecting power. From the hump to the breakpoint the residual changes from mostly monochloramines to mostly dichloramines and organochloramines. Dichloramines are twice as germicidal as monochloramines but unfortunately they produce disagreeable tastes and odors even in low concentrations. After the break point, free chlorine and if formed, trichloramines appear.

The production of chloramines, particularly organochloramines, lowers the effectiveness of the total chlorine residual and increases the possibility of nuisance residuals, tastes and odors. In general, waters containing large amounts of organic matter, upon the addition of chlorine will produce larger nuisance residuals, dichloramines (taste and odor problems) and nitrogen trichloride, and will react with humic and fulvic acids to produce trihalomethanes.

Trichloramines (nitrogen trichloride) causes severe odor problems even in very low concentrations. White (89) estimates that tastes and odors are not likely to occur from the presence of chlorine compounds below the following levels:

Monochloramine (NH2Cl)	5.00 mg/liter
Dichloramine (NHCl2)	0.80 mg/liter
Nitrogen trichloride (NCl3)	0.02 mg/liter

It must be remembered, however, that some people are more sensitive than others to tastes and odors.

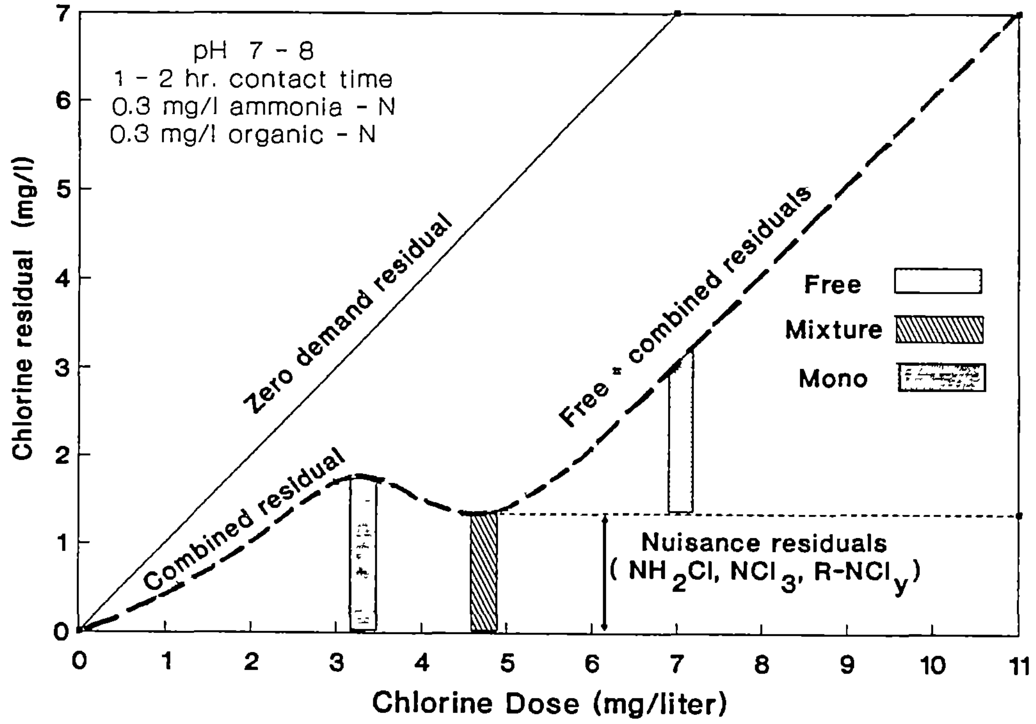

Figure 17. Relationship between ammonia nitrogen, organic nitrogen and chlorine.

White (89), in discussing breakpoint curves, emphasizes the difficulty in obtaining a clear breakpoint in waters with varied organic nitrogenous compounds, which react differently depending on the complexity of the organic matter. Under such circumstances flat curves rather than sharp changes may be obtained. The reason is that the rate of reaction of chlorine and ammonia may be completed within hours, while that of some complex organics may take days.

It has long been known that some of the worst taste and odor offenders are the phenolic compounds in reaction with chlorine. These compounds are usually present in industrial wastes. The addition of small amounts of chlorine to water containing such substances produce chlorophenolic compounds which give the characteristic and very objectionable phenolic tastes and odors. The chlorination of phenolic wastes has been studied extensively. Ettinger and Ruchhoft(90) demonstrated that as the addition of chlorine increased, the tastes and odors also increased up to a maximum and then decreased until they disappeared when sufficient chlorine was added and adequate time was provided for the reactions to go to completion. The intensity of the odors varied with the type of compounds. These reactions like other chemical reactions are concentration, time, temperature and pH dependant.

3.2. TRIHALOMETHANES

Concern about the toxicity of these compounds started with the disclosure of Rook(87) and *Bellar et al.*(88) that trihalomethanes, including chloroform were formed in chlorinated drinking water. Trihalomethanes (THMs) are not normally present in natural raw waters; they are undesirable by-products of the reaction of chlorine with THM precursors such as humic and fulvic acids. Under normal chlorination in water treatment, the yield of the haloform reaction was found to be low(87). The indicated precursors are rarely found in ground water, except in Karst topography. Chloroform is the most commonly found THM in chlorinated water. Others are bromodichloromethane, dibromochloromethane and tribromomethane. Subsequent studies have lead the scientific community to conclude that exposure to such compounds in drinking water poses a human health risk that needs to be evaluated and controlled. Chloroform is considered carcinogenic but not mutagenic, while the brominated haloforms are mutagenic. The latter have not been tested for carcinogenicity (91).

Trihalomethanes begin to form in the vicinity of the break point; therefore, the elimination of breakpoint pre-chlorination is being considered in many water systems in the U.S.A., Canada and Europe. Since it is usually simpler and less expensive to remove the THM precursors than THMs, modifications in both operation and unit processes are usually prescribed for reduction of THM.

In 1977, the Environmental Protection Agency of the United States of America(92) selected an interim maximum contaminant level (MCL) of 0.10 mg/liter for total trihalomethanes for community water systems that add disinfectant to the treatment process (ground or surface waters). Quantitative risk assessment had little to do with the selection of this value. It was established in consideration of the practical limits that utilities could obtain(93). By-products of other disinfectants are also being investigated. For example cyanogen chloride is formed at higher concentration with chloramine than with chlorine(93). Bromate is a by-product associated only with ozonation(93). There is inadequate evidence for the carcinogenicity of bromoform and chlorodibromomethane in humans and limited evidence in experimental animals but bromodichloromethane is possibly carcinogenic in humans.(94) The World Health Organization(5), based largely on the knowledge available on chloroform, gives a guideline value of 30 micrograms/liter for this substance (the most widely studied trihalomethane) in water. It also estimates that with an average consumption of 2 liters of water per day, after a lifetime of exposure, such a concentration would lead to one additional case of cancer in a population of 100,000.

The fact is that in small towns and remote water supplies of Latin America and the Caribbean, the risk of infection by waterborne pathogens and subsequent mortality and morbidity is much greater (usually thousands of times greater) than the risk of cancer due to THM(5). Therefore, disinfection in most instances is far more important for the health of the community than THM reduction; nevertheless, to minimize the possibility of formation of chlorinated by-products, chlorine dosages should be maintained as low as is compatible with requirements to assure the microbial safety of a water supply. Water sources should be selected and protected from THM precursors wherever possible. In few instances, where the content of precursors is especially high, chlorination of natural waters may not be a recommended process.

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4. DISINFECTANT DOSING DEVICES

4. DISINFECTANT DOSING DEVICES

In addition to the microbicidal efficiency of the disinfectant and the rational selection of the disinfectant based on knowledge of the water to be treated (pH, temperature, expected pathogens, turbidity, dissolved substances, etc) the selection of disinfection methods to be used is also strongly influenced by the practical aspects of equipment installation, requirements for operation and maintenance, equipment durability, safety aspects and the available infrastructure support. The salient features of chlorinators, ozonators, mixed oxidant generators, iodinators and ultraviolet light equipment are reviewed in this section giving consideration to the most commonly encountered and important factors which can ultimately determine the appropriateness of the selection.

4.1. CHLORINATION AND CHLORINATORS

Chlorine is the most commonly used disinfectant in small water supplies in Latin America and the Caribbean, be this in the form of chlorine gas (liquified) or hypochlorites which are available as powder, liquid, tablets or pellets. Table 13 shows the main characteristics of the chlorine forms most frequently used.

TABLE 13. Forms of chlorine frequently used for disinfection of small drinking water supplies in Latin America and the Caribbean.

Chemical name	Commercial or common name	Characteristics	Chlorine content	Usual packaging
Chlorine	Liquified chlorine, chlorine gas	Pressure liquified gas	99.8 %	40 and 70 kg cylinders[1]
Calcium hypochlorite	HTH, perchloron	Powder, granules, tablets, pellets. Reasonably stable but can initiate combustion.	65 - 70%	1.5 kg cans, 45 - 135 kg drums, plastic buckets
Sodium hypochlorite	Sodium hypochlorite, liquid bleach	Pale yellow liquid. Rapidly loses strength at concentrations higher than 7%.	1 - 15%	various sizes of plastic and glass bottles, jugs, and carboys.
Chlorinated lime	Chlorinated lime, bleaching powder	White powder, deteriorates rapidly under high temperature and light.	15 - 35 %	45 - 135 kg drums

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[1] Gas chlorine is also available in one ton, five tons and other containers especially for larger water treatment plants.

The first consideration in selecting chlorination equipment should be whether to use chlorine gas or hypochlorites, and this involves several factors. In this document special attention is being given to small towns and rural communities with populations up to 10,000 peoples. In many countries liquified chlorine gas is the most economical water disinfectant. It is available in relatively easy-to-handle cylinders with a net nominal capacity of 40 kilograms or 70 kg (150 lbs). The presently available dosing devices are reasonably safe to operate and maintain. They also offer flexibility; however, depending on the specific circumstances, hypochlorites could be more practical or economical. In the range of sizes under discussion hypochlorite feeders hereinafter referred to as hypochlorinators can also be attractive and for very low water flow, below the range of the gas feeders, they may be the only choice.

Hypochlorination requires close attention to ascertain that the chlorine solutions are prepared properly, are not exhausted or left standing for extended periods of time, as they loose strength; nonetheless, the educational level of the operator does not need to be as high as for the operation of chlorine gas systems. Although the cost of chlorination in its various forms is usually small, it may be a factor in reaching a decision. In Latin America and the Caribbean the cost of chlorine gas is typically one fourth to one half the cost of an equivalent of hypochlorite solution; however, the initial investment for a gas chlorination system and the installation requirements are usually higher than for hypochlorination facilities. From a standpoint of costs gas chlorination is closely competitive with hypochlorination in the range of community size of interest. Practical experience suggests that the break-even point of cost between gas and hypochlorination would be at a dosage rate of roughly 1.5 kilograms of chlorine per day. For medium size communities the choice of gas or hypochlorites will have to be studied carefully as advantages and disadvantages may overlap and the selection may have to be based on a number of factors. An important consideration in selecting one or the other should be the level of operator skills required and the community's ability to afford them. In each case a detailed analysis of all the important factors and special prevailing circumstances is required.

Chlorine gas dosing devices

In recent years, chlorine gas dosing equipment has evolved, with experience and development of new materials, to more durable devices which are simple to operate, and require less maintenance and are considerably less expensive. Much of the older gas chlorination equipment is now obsolete and in many cases never really functioned for any significant period of time under the conditions found in small towns and rural communities. More recently, tank top and wall mounted chlorinators have been developed and are being used with considerable success in most countries. These are more economical to purchase and simpler to install operate and maintain, than other types of gas chlorinators.

To determine the capacity of a gas chlorinator, it is necessary to establish the maximum expected flow of water at any time. The flow in liters/second times the dosage in mg/liter, times 3.6 gives the grams per hour of chlorine to be fed.

Since the only way to determine the actual rate of chlorine gas being dosed is by weight, the use of appropriate scales is mandatory in gas chlorination.

Vacuum type solution feed chlorinators

This type of chlorinator requires a vacuum to activate a mechanism to release chlorine gas from a cylinder of liquified chlorine. The vacuum is created by water that is under pressure flowing through an ejector (venturi) or other similar device. The chlorine gas passes from the cylinder through the demand regulator (either directly mounted on the cylinder or indirectly connected with a feed-line tubing); then the gas passes through a vacuum-line tubing connecting the regulator to the venturi. The chlorine gas is drawn into the water passing through the ejector (venturi) and is mixed and readily dissolved at typical concentrations. The complete chlorine dosing system is essentially composed of a regulator, a rate control valve, a rate indicator, an ejector, a diffuser and the interconnecting tubing (Figure 18).

The regulator reduces the pressure of the chlorine gas from the tank pressure, which is temperature dependent, and directs the gas to the ejector where a partial vacuum is created. The role of the rate valve is to control the flow of gas being dosed into the system. The flow of water through the ejector is usually provided by a booster pump. The water leaving through the ejector is a strong chlorine solution which is directed to a diffuser which discharges into a large pipe conducting the water to be disinfected further mixing the strong solution, diluting it to the desired ultimate concentration.

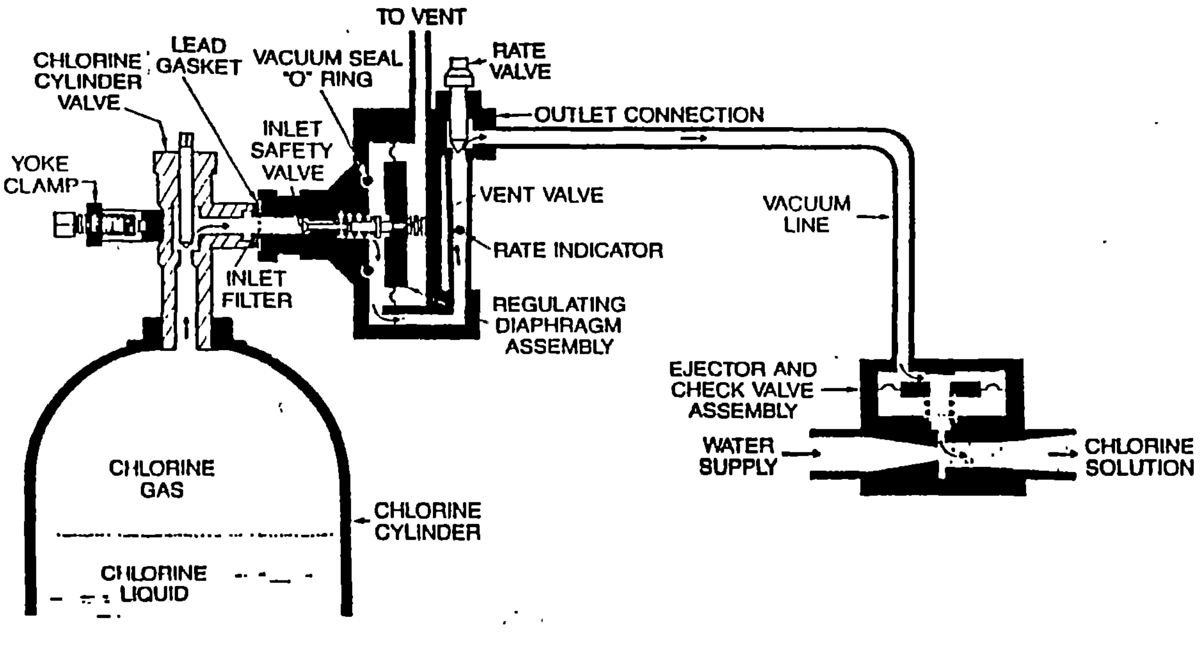


Figure 18. Vacuum type solution feed chlorination system.

A flow meter, usually a rotameter, is added to the system to indicate the rate of chlorine gas flow. An advantage of this device is that when no water is flowing through the ejector, there is no vacuum in the system and consequently no chlorine gas is discharged. To prevent a reverse flow of water through the suction port of the venturi when there is no water flow through the venturi, a check valve is placed at the ejector. These two important design features contribute to safety by preventing gas from being released when no water (from the booster pump) is flowing through the ejector and also by preventing the formation of the extremely corrosive, moist, chlorine gas which would attack the components of the system. For safety purposes a vent is provided from the chlorinator (regulator) to the exterior of the chlorination facility.

The typical range of feed rates for small vacuum type chlorinators is from about 3.5 to approximately 75 grams/hour. Larger capacities are available with chlorine dosing rates up to 100 kilograms per day.

The control of this type of chlorinator in small communities in Latin America is usually manual. The operator has to predetermine the amount of chlorine to be fed in a given period of time and observing the rotameter adjust the rate accordingly. For any change in water flow or chlorine demand the rate will have to be readjusted commensurately. In the simple start-stop control system, the flow of chlorine is activated by the operation cycle of a pump(s). When the pump begins operation, the chlorinator begins feeding a predetermined amount of chlorine gas. The rate of feed has to be preadjusted manually by the operator. More sophisticated automated controls can adjust the rate of feed according to the flow or even according to chlorine residual desired but because of their complexity and difficulty in maintenance, they are rarely found in small water supply systems of Latin America.

a) Energy requirements:

The energy requirement for the operation of the vacuum type solution feed chlorinators are relatively small, amounting to the energy needed to induce flow of water through the ejector (venturi). The required flow of water and pressure differential can be produced hydraulically or electrically with the aid of a small (usually 1 to 1-1/2 horse power) booster pump (Figure 19). In the selection of electrically operated equipment, the reliability and stability of the energy source is an important consideration.

b) Installation requirements:

Since the most accurate means of determining the actual rate of chlorine gas being dosed is by weight, the use of appropriate scales is mandatory in gas chlorination. Appropriate weighing will enable reliable and calculation of the amount of chlorine being fed over a given period of time and also indicate when or how soon it will be necessary to change cylinders. Scales should be considered an integral part of the gas chlorination equipment. Balance scales for small water supplies are designed to weigh cylinders of 45 or 70 kg. in the upright position. All gas chlorination installations should be provided with chains or other harnesses securely attached to a wall to prevent chlorine cylinders from tipping over if accidentally bumped (Figures 19 and 20).

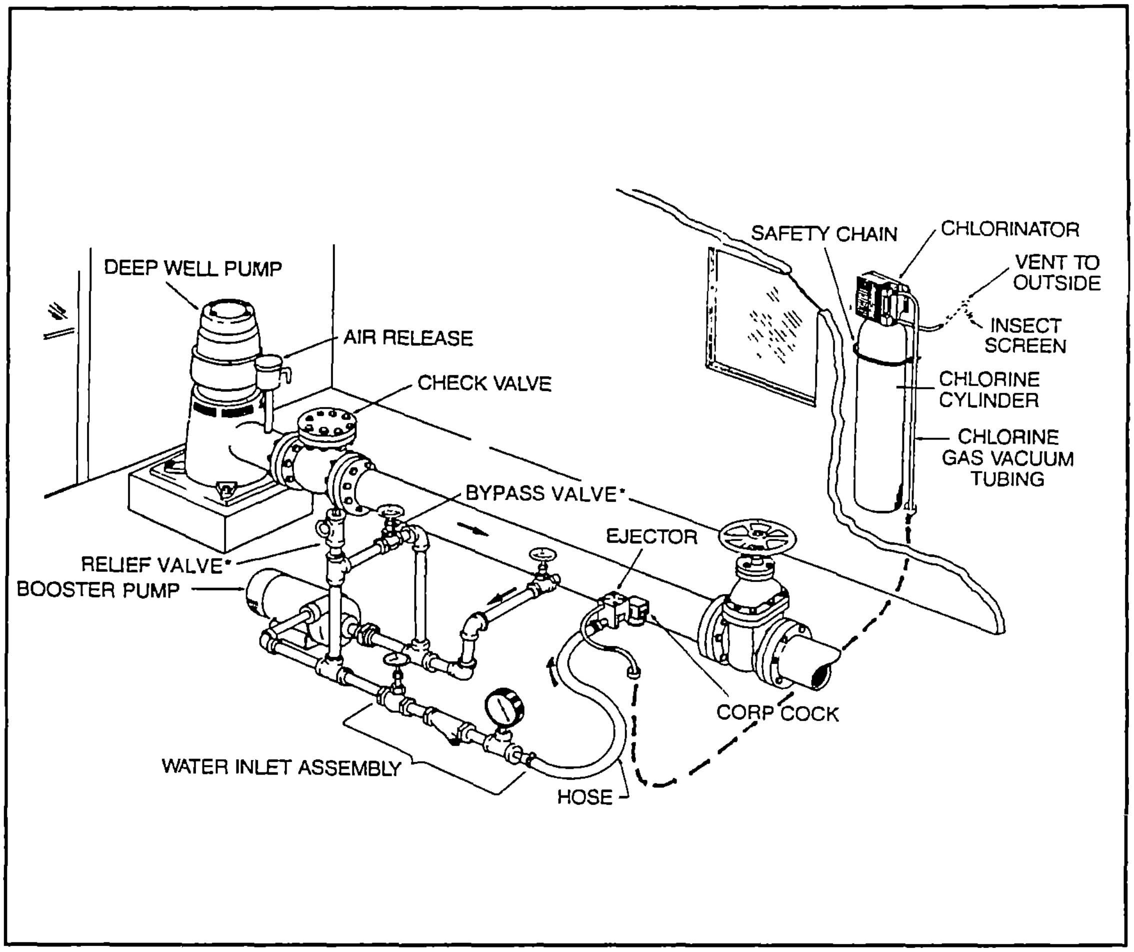


Figure 19. Tank top vacuum type gas chlorinator and booster pump.

Chlorine is a hazardous gas and, as such, must be handled carefully. There are several manuals that provide guidance for the design of chlorination and storage rooms. They are available from the Chlorine Institute, producers of chlorine, manufacturers of chlorination equipment, and professional associations. To insure the greatest safety and economy, the design and installation of a gas chlorination system should be carried out by experienced individuals. Provision must be made for adequate ventilation. A typical plan for a small gas chlorination facility is shown in Figure 20. The storage of cylinder should be done in a separate room specifically design for the purpose. Chlorine cylinders should never by stored in direct sunlight.

c) Operation and maintenance:

Installation, servicing and maintaining chlorine gas equipment should only be done by trained operators and in accordance with the manufacturer's instructions.

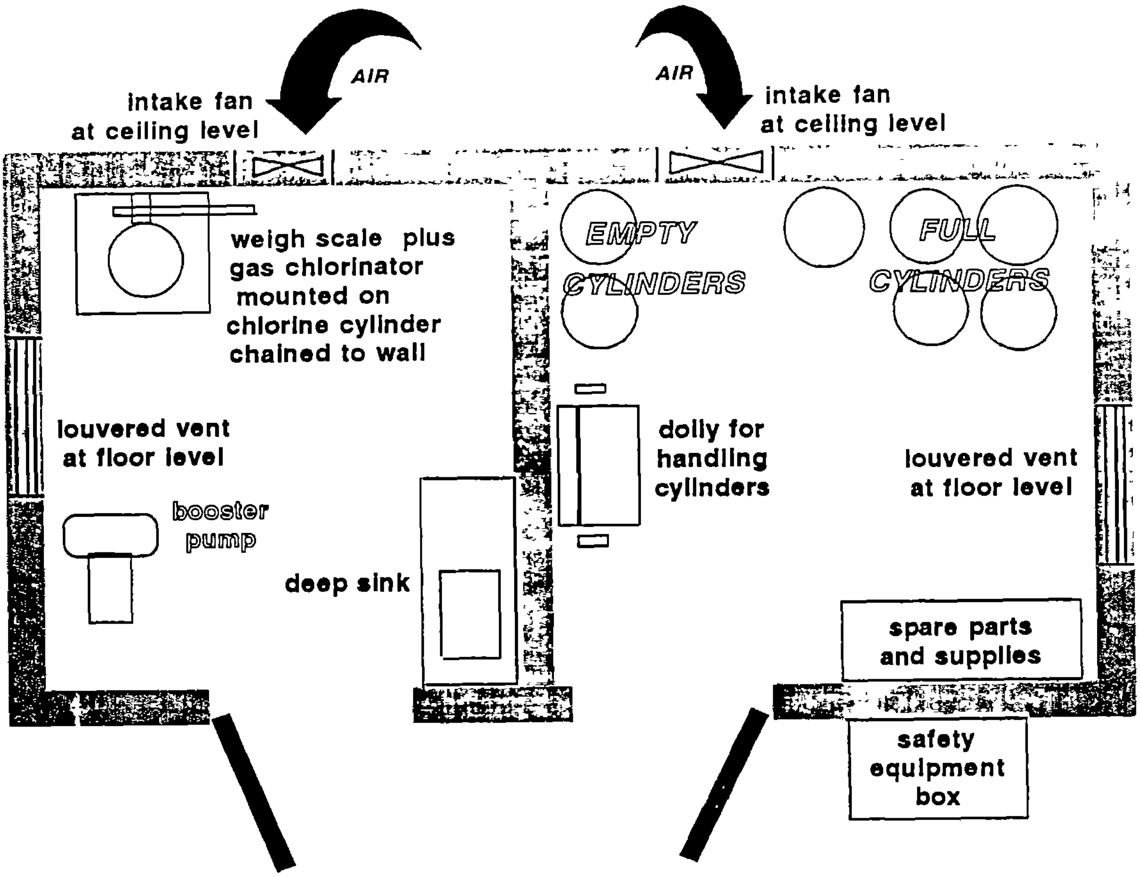


Figure 20. Typical plan for a small gas chlorination facility.

Vacuum type solution feed chlorination systems require regular inspection and maintenance by technicians or operators, trained according to the specific recommendations of the manufacturer, to assure proper operation and to avoid costly repairs and accidents. This type of system is usually long-lasting and relatively trouble-free. Of special concern is the need to avoid moisture mixing with the chlorine gas within the dosing system, as moist chlorine gas will rapidly corrode or cause deterioration of equipment, i.e. plastic parts, metal fittings, valves, flexible connections, etc. Chlorinator system materials, including spare parts and accessories, have to be suitable for handling moist and dry chlorine gas. Ferric chloride deposits in the lines, usually due to impurities in the chlorine, should be cleaned regularly. An adequate supply of spare parts should be readily available at all times. Flexible connections should be replaced as recommended by the manufacturer. Gaskets once disturbed or in need of repair should be replaced with new gaskets recommended by the manufacturers. Attempts to reuse old gaskets is probably the most common cause of gas leaks. The attention of a well-trained operator is required for this type of equipment.

It is common practice for an operator to check and if necessary adjust a gas chlorinator 3 or 4 times during an 8 hours shift. Routine change over from an empty to a full cylinder usually requires less than 30 minutes of an operator's time.

d) Safety:

Chlorine gas is marketed as a liquified gas in steel cylinders containing 40 or 75 kilograms of the substance. One ton and larger containers are also available for larger systems. At 68°C, cylinders filled according to specifications are completely full of liquid chlorine and temperature increases can result in rupture of the container.

Chlorine gas is always potentially dangerous because of its extreme toxicity. Because of the dangers of explosion, strict specifications must be followed in the filling of cylinders. Therefore, special rules and precautions also have to be followed in their handling, transportation, unloading, storage, installation and connection to the chlorinator, start up and shut down, disconnecting, removal as well as servicing and repair. Safety equipments (including gas masks) as well as maintenance and repair equipments should be provided; personnel should be trained and regularly drilled in all aspects of their use, including detection of leaks, handling of emergencies and use of personal protection equipment in the various processes. Programs for cylinder inspection, testing and replacement are required to prevent serious leaks or ruptures.

e) Cost:

Tank-mounted vacuum type chlorine regulators with the injector-diffuser currently cost about US$ 900 to US$ 1,200; a 70-kilogram capacity chlorine gas cylinder with valve, about US$ 350 to US$ 400; the weight scales, approximately US$ 220; and the booster pump and piping, about US$250. The cost of chlorine gas varies greatly from one country to another, with a range of from US$ 1.00 to US$ 6.00 per kilogram. Operation and maintenance costs vary widely from one country to another, mainly due to wide differences in electricity rates and labor costs.

Pressure feed type chlorinator

This type of chlorinator is usually recommended only for cases where there is no possibility of using a pressure differential or there is no electric source to operate a booster pump to produce the differential necessary for functioning of vacuum type chlorinators.

The system usually consists of a spring-loaded diaphragm actuated by a pressure regulator which reduces the pressure from the cylinder to about 1.46 kg/cm^2. With this device only low pressure is used in the system. The low pressure reduces the likelihood of leaks. Through this device the dose rate is maintained constant, regardless of any change in pressure in the chlorine cylinder. A rotameter indicates the rate of flow of chlorine and a vent in the chlorinator allows excess pressure to be relieved to the exterior. The chlorine gas is directed from the chlorinator to a diffuser through a check valve. The diffuser must be immersed in water. Usually this is done in a tank or channel but it can be inserted directly into a low pressure water main (less than 0.7 kg/cm^2). The smaller pressure feed type chlorinators have a capacity ranging from about 6.0 grams/hour to 120 grams/hour. Since chlorine gas pressure changes in the cylinder with ambient temperature, the maximum continuous feed rate will depend on the lowest expected ambient temperature. For a continuous chlorine gas feed of some 120 grams/hour the temperature of the environment has to be above -5.0°C. A manual pressure relief valve is placed between the chlorinator and the diffuser to vent (to the exterior of the building) the chlorine gas that may be in the line when changing cylinders. Figure 21 shows a schematic of a typical installation.

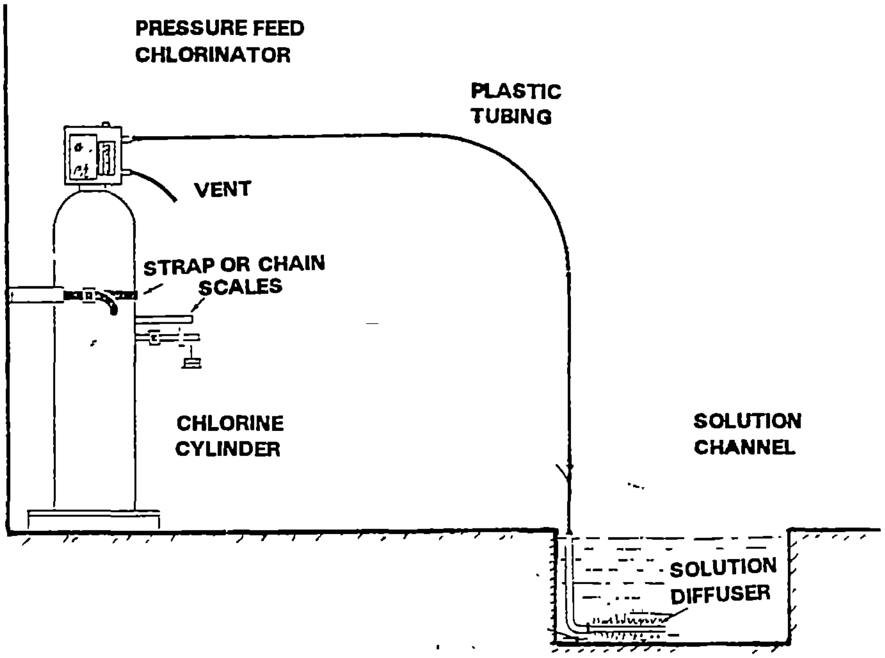


Figure 21. Schematic of the installation of a pressure feed gas chlorinator.

a) Energy requirements:

The pressure feed type gas chlorinator is activated by the pressure in the chlorine gas cylinder itself and requires no external energy input. This is advantageous where no source of hydraulic or electric energy is available to produce the pressure differential required by the vacuum type chlorinator.

b) Installation requirements:

Installation requirements and precautions are essentially the same as indicated for the vacuum type solution feed chlorinators. Figure 20 shows a typical small gas chlorination facility. In addition, it is important that the contact chamber, channel or tank be designed to always contain a minimum water cover of 0.5 meter over the diffuser to insure that all of the chlorine gas is dissolved thereby preventing its escape into the air.

c) Operation and maintenance:

The operation and maintenance requirements are basically those indicated for the vacuum type solution feed chlorinators. Additionally, the close attention of an operator is required to assure that the flow of chlorine gas is shut off during no flow condition. A full time operator is usually required.

d) Safety:

This type of chlorinator is not considered to be as safe as the vacuum type because it maintains positive pressure in the system and will not automatically shut off in the absence of water. This increases somewhat the possibility of leaks; nevertheless, they are safe if installed, operated and maintained according to manufacturers instructions. Safety considerations are for the most part the same as for vacuum type solution feed gas chlorinators. Additionally, special precautions should be exercised in systems which discharge chlorine directly into water tanks to prevent accumulation of excess chlorine gas when water levels are low. Operating procedures to insure maximum security and safety should be prepared and staff must be trained. The installation of a chlorine detector may be warranted.

e) Cost:

Operating costs of pressure feed type cylinder mounted chlorinators are slightly lower than those of vacuum type, because they do not require a booster pump. The labor costs are approximately equal. The total annual cost per person for equipment, installation, labor and chlorine ranges between about US$0.25 and US$1.00.

Hypochlorite dosing devices

There are several types of commercial hypochlorinators on the market as well as many locally made devices that function satisfactorily when properly installed and operated. The following are among those which are most commonly used in Latin America and the Caribbean.

Positive-displacement diaphragm type

This type of chlorinator uses a diaphragm type positive displacement pump schematized in Figure 22. The flexible diaphragm, which is made of a material that is resistant to the corrosive effects of hypochlorite solutions, is actuated by a cam or a piston rod attached to an eccentric. With each stroke, the flexing diaphragm pumps the hypochlorite solution into the water supply. A spring may be used to return the diaphragm to its original position. Two check valves, one in the suction and the other in the discharge, assure unidirectional flow of the hypochlorite solution. Depending on the design of the driving mechanism, the length or frequency of the stroke, or both, can be adjusted to precisely regulate the flow.

The most common method of actuating diaphragm pumps is with an electrical motor. Less commonly, they are hydraulically driven. The latter may be suitable where a reliable electric energy supply is not available. Another advantage is that with a special device the feed rate of hypochlorite can

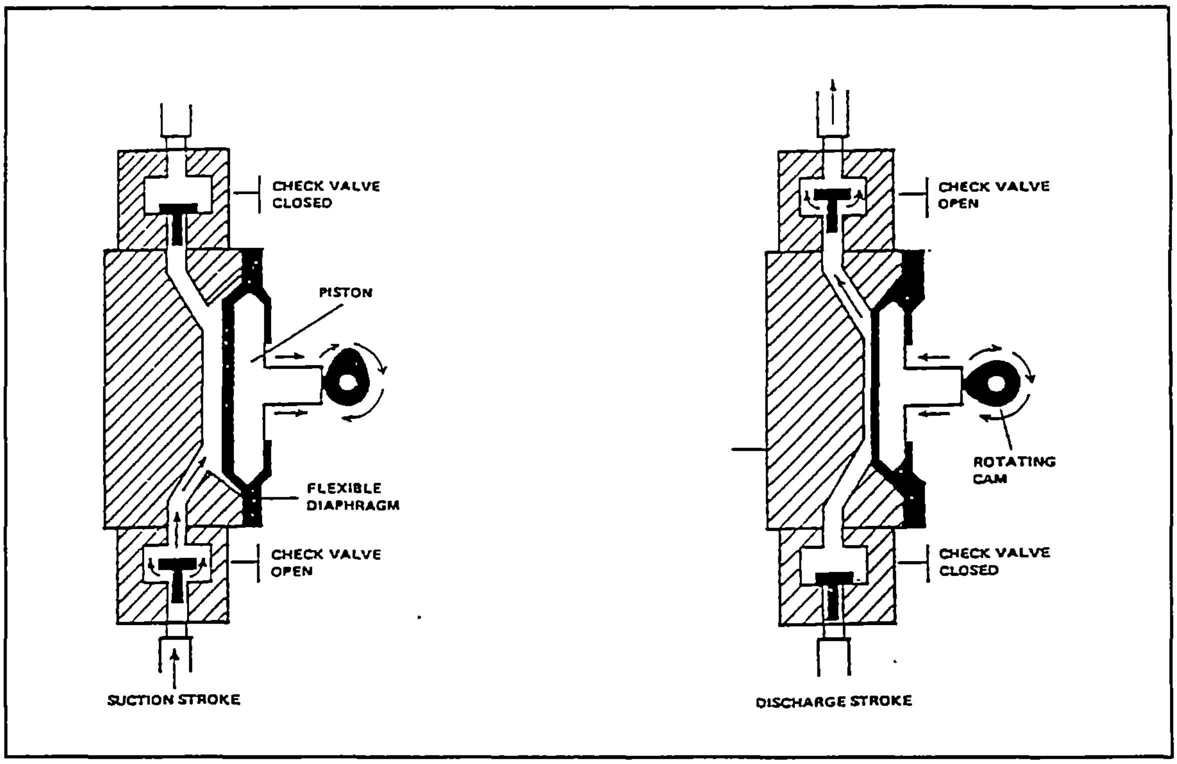


Figure 22. Schematic of the operation of a diaphragm pump.

be calibrated to the rate of water flow. The selection of the specific hypochlorinator-actuator will depend on the particular characteristics of each case.

The rate of flow of diaphragm pumps, can be controlled to adjust the dosage of the hypochlorite solution. This can be accomplished by controlling either the frequency or the length of stroke. Most of the commonly available hypochlorinator utilize variable speed motors to control the frequency of stroke. Some utilize mechanical means to adjust the length of stroke. A few use both. For most small water systems of Latin America controlling the frequency of stroke seems to be favored because of its simplicity. The start-stop control is typically operated manually as is the rate of dosage, but the start stop control may also be controlled automatically by means of a magnetically activated switch connected directly to the water pump's controller. If both the start-stop and the dosage is automatically controlled (usually not recommended for small communities) then the diaphragm pump utilizes controllers of both the variable stroke length and a variable speed drive. Figure 23 shows details of a typical motor driven diaphragm metering pump used for hypochlorination.

Diaphragm chemical feed pumps are manufactured in several countries in Latin America as well as in the U.S.A, Canada and Europe, and can be found with relative ease in most countries of the Region as there are quite a few makes available on the market. The range of sizes of this kind of hypochlorinator is broad, with the smallest delivering about one liter/hour and the larger ones about 200 liters/hour. Depending on the strength of the solution and the chlorine dosage desired, water flows as

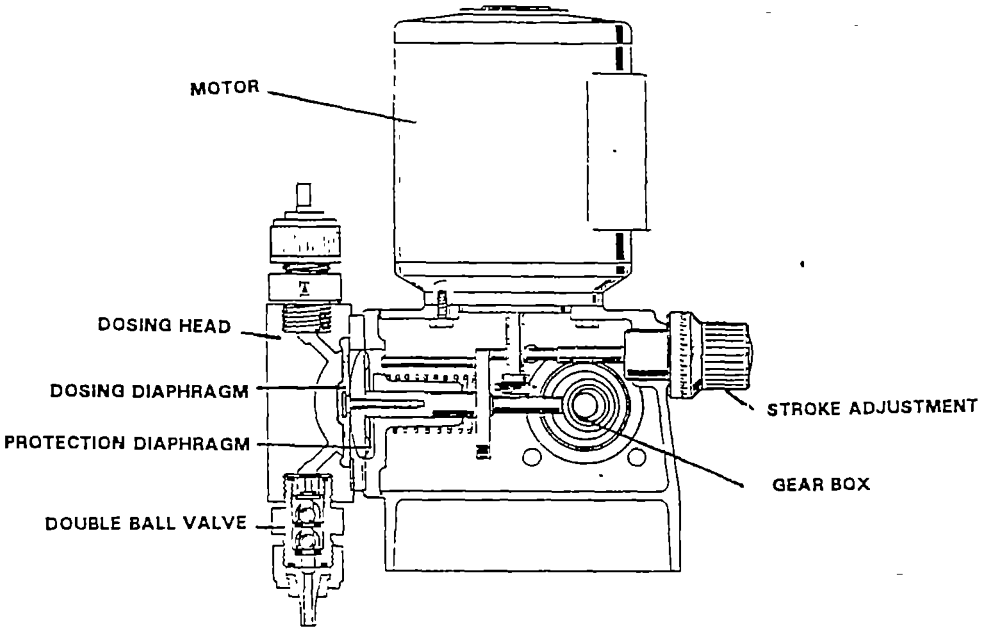


Figure 23. Schematic of a typical motor driven diaphragm metering pump.

low as one liter/second can be disinfected. A major advantage of this type of dosing device over most other hypochlorinators is that it can feed directly into water pipes pressurized up to 6.0 kg/cm^2.

a) Energy requirements:

Diaphragm pumps require a prime mover to activate them. By far, the most common, where electric energy is available, is an integrated electric motor. Where such a source of energy is not available, hydraulically operated pumps may be used; however, the latter are complicated and are subject to numerous operation and maintenance problems and do not have a good performance record in Latin America. The energy required to operate the hypochlorinator is relatively small usually from 1/4 to 3/4 horse power. In choosing this type of chlorinator it is important to consider the reliability and quality of the energy source.

b) Installation requirements:

A well designed installation should shield chemicals from sun light and provide conditions for easy handling and mixing of chemical solutions. It should also be properly ventilated and avoid undue high temperatures and humidity. The installation should be designed in a manner which will facilitate operation and maintenance, and minimize potential hazards. It is recommended to have a separate storage room for hypochlorite because of its corrosive and reactive nature. A sketch of a typical calcium hypochlorination installation feeding into a pressure line is shown on Figure 24.

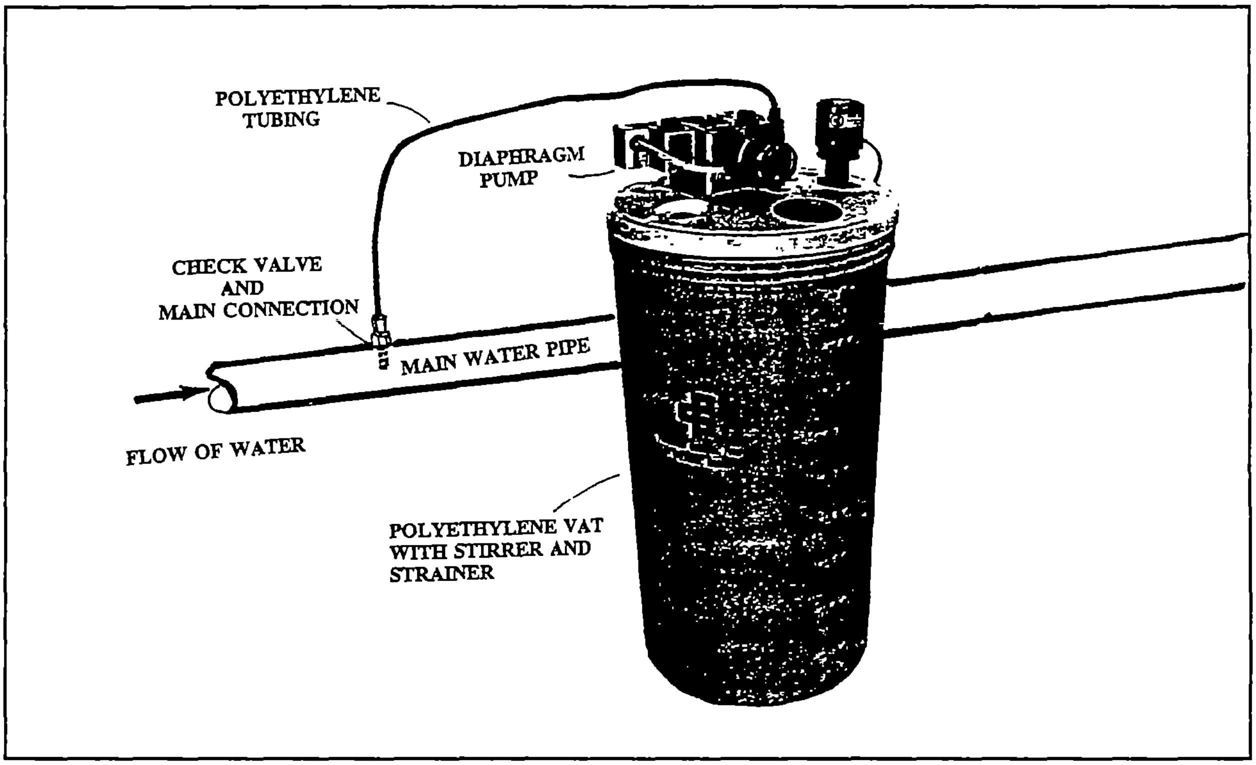


Figure 24. Positive displacement diaphragm type hypochlorinator feeding into a pressure line.

c) Operation and maintenance:

The operation and maintenance of diaphragm pump type hypochlorinators are relatively simple, but reliable routine maintenance is required. Accuracy and consistency of dosage can be obtained if the equipment is kept clean of precipitates and deposits in the poppet valves, check valves and strainer. A concentration from 1 to 3 per cent is usually recommended for calcium hypochlorite stock solutions so as to obtain a balance between reduced pumping cost and avoiding the precipitation of calcium in the poppet valves, the diaphragm chamber and the main return check valve. When the water used to make calcium hypochlorite stock solutions is unstable, hard or has high total dissolved solids, it will be necessary to settle precipitates immediately following the mixing of the solution to reduce problems with precipitation within the pump and its suction line and strainer. Chlorinated lime, in addition to precipitation problems, usually contains impurities which do not dissolve and should be removed from the stock solution through the settling-straining-decanting process prior to its use. Sodium hypochlorite solution presents less problem with precipitation and thus can be much stronger, but at higher concentrations the solution becomes unstable and rapidly loses strength; therefore, it is common practice to use concentrations of 10% or less.

The strength of the hypochlorite solution is an important factor in the durability of the parts of the pump. Usually the stronger the solution, the shorter the life. The diaphragm materials, have a relatively short life, because of the constant flexing and oxidation by the hypochlorite solution and needs periodic replacement. The poppet valves and check valves are subject to the deposit of calcium and require cleaning with an acid solution to avoid malfunction and eventual replacement when they lose their elasticity due to oxidation.

Care needs to be exercised in handling hypochlorite solutions. They are extremely corrosive and therefore the tools and containers used to prepare them should be made of plastic, ceramic or other corrosion-resistant material. Personnel must be trained in the handling of spills as well as correct procedures for operation and maintenance.

d) Safety:

High test calcium hypochlorite powder is usually obtained with 65% or 70% available chlorine. For safety reasons some countries limit the concentration to 65%. Under normal conditions, calcium hypochlorite itself is a relatively stable powder; however, in contact with organic material and other oxidizable substances, spontaneous combustion is possible. Oils, rags, activated carbon and oxidizable chemicals in general are particularly dangerous. For this reason hypochlorites should be handled carefully and according to clearly stated safety rules. Hypochlorites should be stored in air tight moisture-proof containers in clean, separate and specifically designed rooms, with appropriate ventilation and other safeguards. Hypochlorite should be stored separate from substances or materials that might ignite, as even small amounts of chlorine that may escape from them could be enough to react with other substances and start a fire or produce a violent explosion. Figure 25 shows a typical plan of a hypochlorination and hypochlorite storage facility.

Calcium hypochlorite should be purchased in durable, corrosion resistant drums which can be tightly resealed after initial opening. Plastic bags should be avoided because they can tear when handled. Like in the case of chlorine gas, personal protection equipment must be available and used when required. Sodium hypochlorite solution should be purchased in containers which are non-breakable, opaque and corrosion-resistant.

When handling or preparing hypochlorite solutions goggles, gloves and aprons of chlorine resistant material should be used. Splashing of solutions should be minimized as much as possible and accidental spills on persons should be taken care of immediately by removing contaminated clothes and thoroughly washing body parts affected.

e) Cost:

The installation cost of diaphragm pump type of chlorinators with electrical controls, plastic solution tank and piping currently ranges from about US$ 700 to US$ 1,000. The cost of hypochlorite compounds ranges from about US$ 2.50 to US$ 4.60 per kilogram.

Venturi type hypochlorinator

This type of chlorinator is based on the same principle as the ejector used in gas chlorinators. The vacuum created by the flow of water through a venturi sucks the hypochlorite solution and

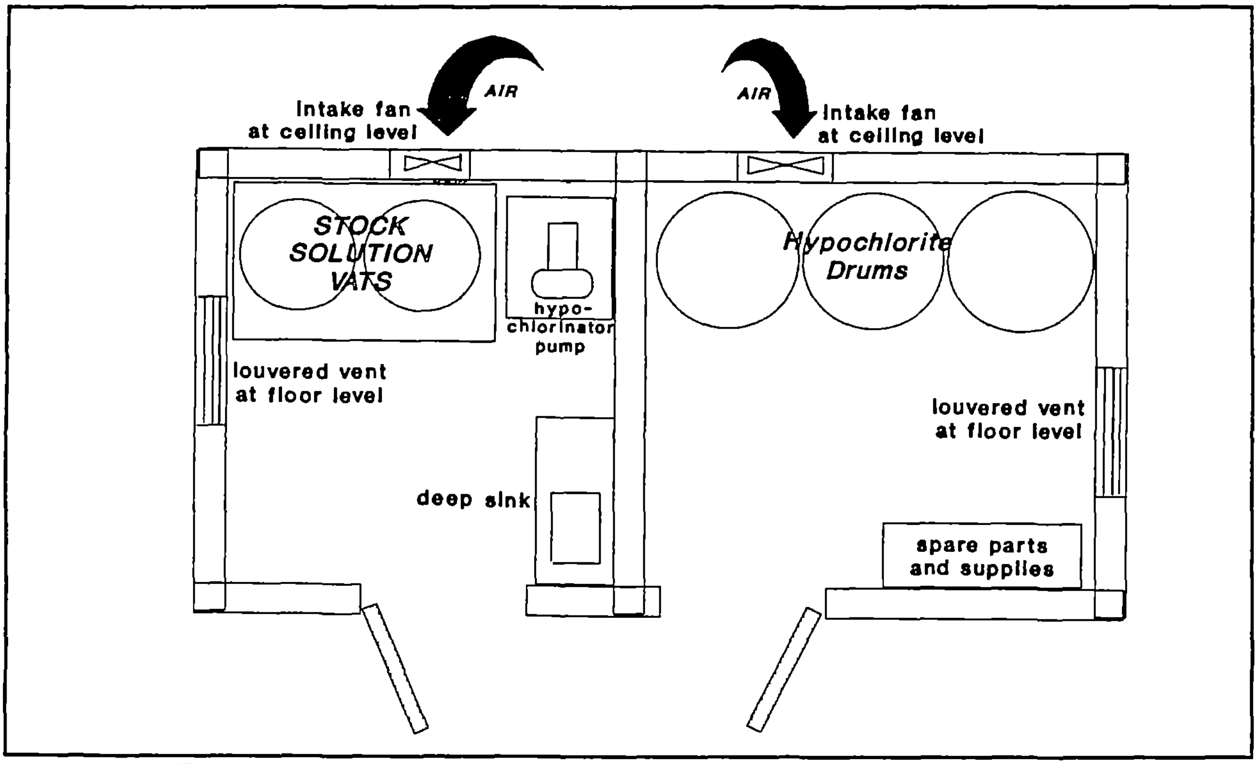


Figure 25. Typical plan of a hypochlorination and hypochlorite storage facility.

discharges it directly into the main water stream or a bypass stream. The dosage is controlled by the adjustment of a needle valve. Schematics of typical installations are shown on Figures 26a and 26b.

The venturi type chlorinator is readily available in the market and is produced by a number of manufacturers in several countries of the Region. The cost is relatively low, and it is easy to install, operate and maintain. The dosing rate ranges from about one to some 25 liters/hour. A major advantage is that if there is no flow of water through the device there is no chlorine solution delivery, thus reducing the probability of overdosage.

a) Energy requirements:

The venturi type hypochlorinator does not require a separate energy source if sufficient pressure is available in the water supply system at the point of application of the chlorine solution, to produce an adequate flow of water through the venturi. In other cases a reliable electric power source would be required to pump a small quantity of water through the venturi.

b) Installation requirements:

A venturi has a relatively narrow flow regime within which it operates efficiently. For this reason the venturi must be selected so its hydraulic requirements match the characteristics of the water

supply system. Venturis should not be utilized under conditions with wide fluctuations in flow and pressure. Use only venturis which are specifically manufactured for strong oxidant solutions.
The materials used in the construction of most other venturis are attacked by the hypochlorite solutions and therefore should be avoided, as these may be subject to early deterioration.

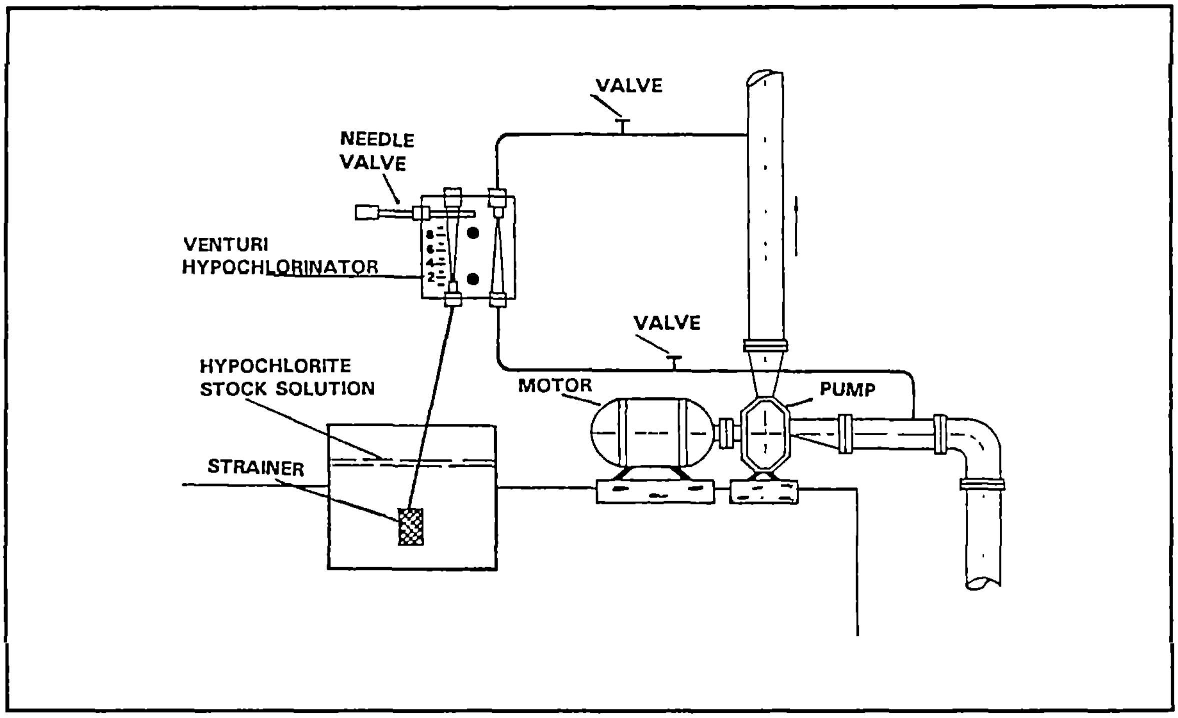


Figure 26a. Schematic of a venturi type hypochlorinator installation.

Some of the venturi hypochlorinators are wall-mounted. Others are installed directly in the piping system. The installation is sufficiently simple so as not to require a specialist. All piping and flexible plastic tubing should be done in a neat and orderly manner to facilitate operation and maintenance. Consideration should be given to easy removal of venturis for cleaning of precipitates or other deposits which might clog the orifice. As with all hypochlorinators, special precautions need to be taken in the design of the chlorination installation and storage facilities because of the nature of chlorine solutions.

c) Operation and maintenance:

The venturi type hypochlorinator is not very precise, especially when there are fluctuating flow conditions; therefore it requires vigilance and frequent adjustment of the dosages. The acrylic-body venturi is advantageous because it allows the operator to visually determine when cleaning is required, and it is very resistant to the hypochlorite. All venturis are sensitive to deposit of calcium which can occur either from the hypochlorite solution or from hard water. Venturis should be routinely cleaned, if necessary with acid to remove harder deposits and other precipitates or sediment. Most gaskets, check valves, springs and O-rings eventually deteriorate under contact with hypochlorite and should be routinely replaced. Such spare parts should be kept on-hand at all times.

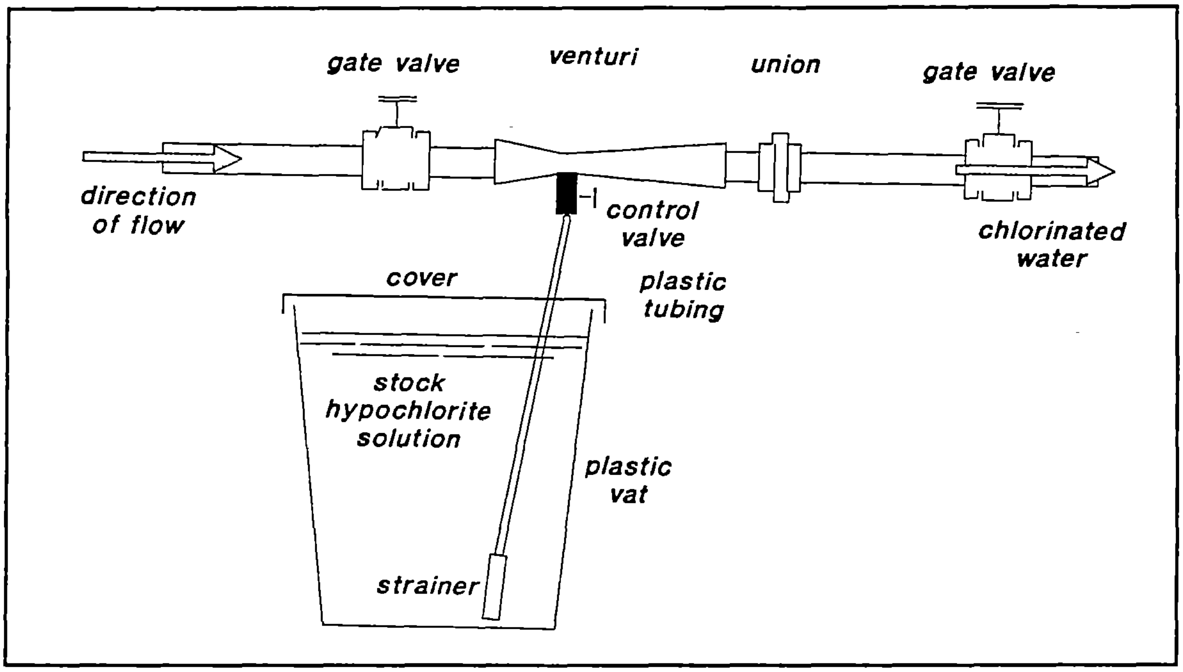


Figure 26b. Schematic of a venturi type chlorinator installation.

d) Safety:

This dosing device is very safe; however, when hypochlorite stock solutions are prepared or handled, the precautions discussed earlier should be taken into consideration. One of the advantages of this type hypochlorinator, as already noted, is that the hypochlorite dosing process stops when the water flow stops through the venturi, thus greatly reducing the likelihood of overdosing.

e) Cost:

The current cost of equipment varies from US$ 25 for a simple venturi with a control valve to US$ 150 for a venturi with an accurately controlled needle valve and a rotameter rate indicator. The cost of installation, including that of piping and a solution vat or tank, is around US$ 400. The cost of hypochlorite ranges form about US$2.50 to US$ 4.60 per kilograms.

Tablet erosion feeders and dry pellet feeders

A number of manufacturers produce disinfection devices which use tablets of HTH for various purposes. These have found an important place in the treatment of swimming pools, wastewater, as well as in application for disinfection of small community and individual drinking water supplies. Some water supply authorities in Latin America have developed their own designs and manufacture erosion tablet feeders using locally available materials.

Tablet erosion type chlorinators normally use high test hypochlorite tablets commercially available under different trade names; however, in some instances tablets are also manufactured locally by the user, by compressing HTH powder. Hypochlorite tablets can offer several advantages over other forms of chlorine, depending on the circumstances under which they are used. In general tablets are safer and easier to handle and store. Tablets are also quite stable and store well. Containers are of different sizes and vary from small cans to buckets and drums. The cost of tablets is usually higher than that of HTH in bulk but still reasonable. The solubility of the tablets is fairly constant at temperatures from near freezing to 25°C. This is an important consideration where water temperature variations are expected. Dosing devices are relatively inexpensive and durable since they usually are made of noncorrosive materials and have no moving parts. The dosing control mechanism is basically an adjustment of immersion depth which is simple but not especially accurate.

Tablet erosion feeders take advantage of the rate of solubility of the hypochlorite tablets in running water. Tablets are gradually dissolved at a predetermined rate as water flows around them, to provide the required chlorine dosage. As tablets are dissolved they are replaced by new tablets fed usually by gravity into the hypochlorinator solution chamber. The discharge from the feeder is a concentrated chlorine water solution that is then fed into a mixing tank, an open channel, a clear well or reservoir, as the case may be (Figure 27).

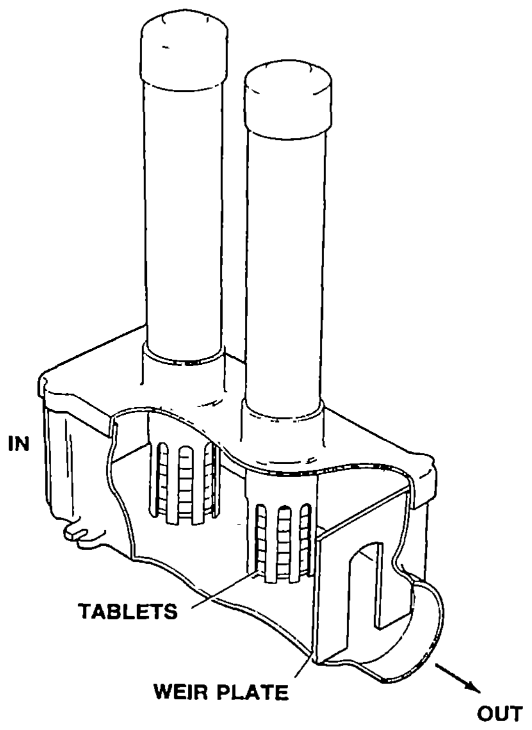


Figure 27. Typical chlorine tablet erosion feeder.

A similar device, the dry pellet feeder has been designed to feed pellets of calcium hypochlorite directly into deep wells at a constant rate which can be controlled. The pellets upon submergence dissolve slowly, providing a reasonably steady chlorine residual. These feeders are especially useful for wells which are contaminated with nuisance organisms. Pellet feeders can also be used to administer chlorine to water storage tanks.

a) Energy requirements:

Aside from the hydraulic energy needed to direct the water through the tablet erosion feeder, there are no other energy requirements. This type of chlorine feeder offers a considerable range of flexibility, both in respect to the amount of chlorine as well as the location of application points. For larger supplies several feeders can be used. The dry pellet feeders do require electrical energy for their operation.

b) Installation requirements:

The installation of this class of dosing devices requires minimal specialized training. In most cases an operator familiar with basic plumbing and piping can be trained; however, close attention to the manufacturer's instructions is required to insure proper installation, durability and operation according to specifications. Figure 28 illustrates a dry pellet feeder installation over a well and Figure 29 illustrates typical installations for tablet erosion type chlorinators.

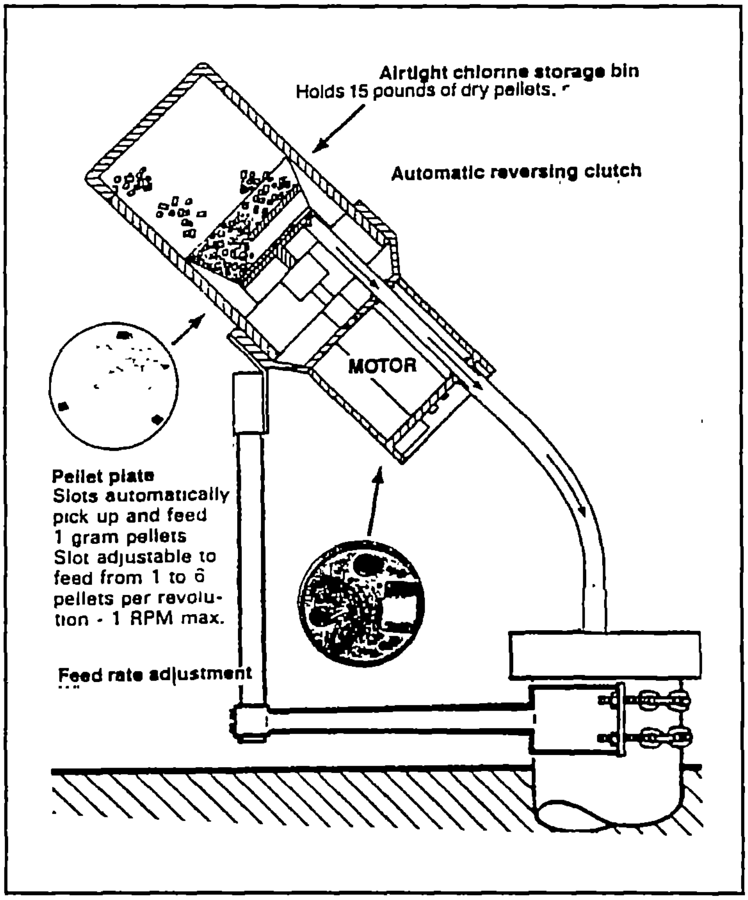
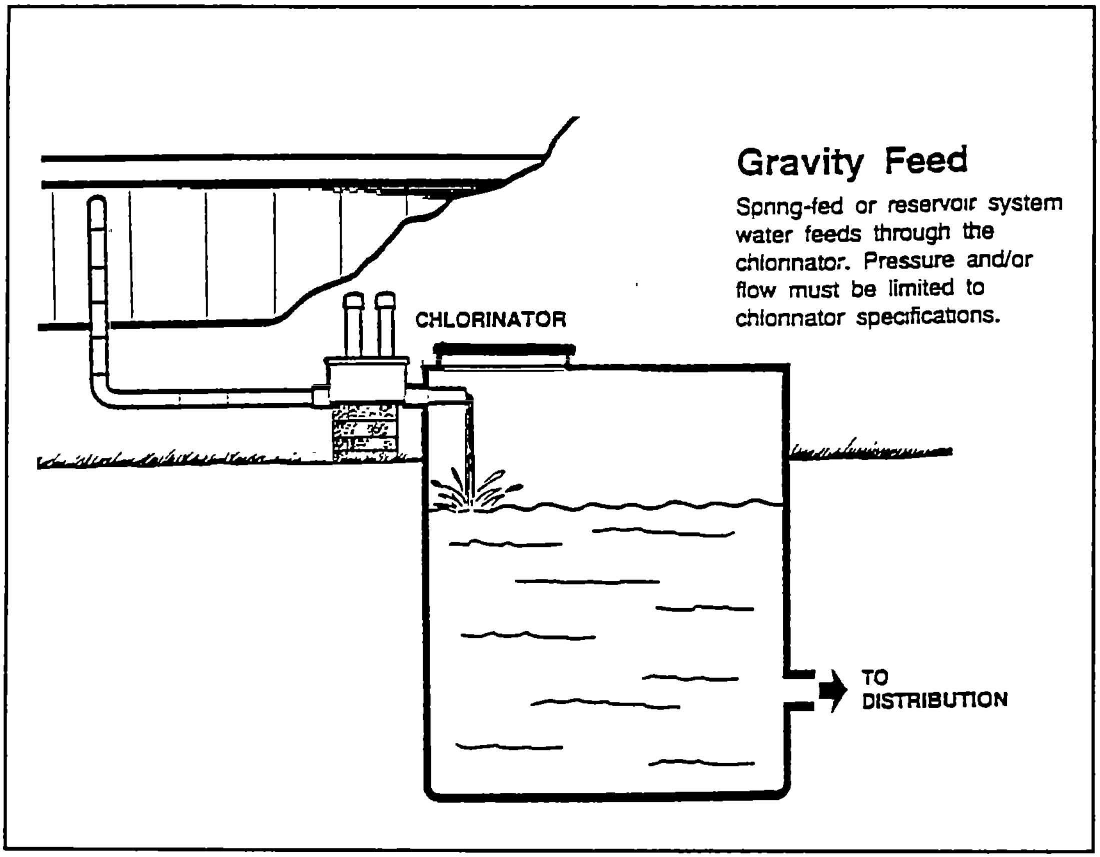


Figure 28. Typical dry pellet feeder installation.



Gravity Feed

Spring-fed or reservoir system water feeds through the chlorinator. Pressure and/or flow must be limited to chlorinator specifications.

Figure 29. Typical tablet erosion feed chlorinator installation in a water storage tank.

c) Operation and maintenance:

Tablet erosion feeders and pellet feeders are simple to operate. Once the equipment has been calibrated, if there are no significant flow variations, it will normally require little attention, except to make sure that it is filled with tablets to insure continuous dosing. The tablet feeder mechanism should be inspected for deposits of scales or possible clogging, taking care to thoroughly clean it, set it back to the appropriate position and calibrate it. Inspection and timing of refilling of tablets will depend on the particular installation and will be a function of the chlorine dosage and volume of water treated. Because of the simplicity of the equipment operation, personnel can be quickly trained.

d) Safety:

In general, hypochlorite tablets and pellets are easier and safer to handle and store than other chlorine compounds; nevertheless, minimal safety precautions need to be observed. **It is important not to use tablets meant for swimming pools which contain isocyanurate a stabilizing chemical not considered suitable for human consumption.**

e) Cost:

The cost of this type of hypochlorination device varies somewhat with different manufacturers and from one country to another; however, in general the device is relatively inexpensive. The on-site cost of the tablets in 1990 ranged from about US$ 3.00 to $ 6.00 per pound. The cost of tablet erosion devices range from about $300.00 to $400.00. The pellet feeders for wells cost about US$ 800.00 and the pellets, roughly US$ 4.50 to $ 5.00 per pound.

Gravity or drip type hypochlorinator

There are a number of simple hypochlorinators locally made from readily available materials. Practically all are designed to feed a hypochlorite solution at a steady rate. Such chlorinators usually have generic names, such as floating submerged orifice, floating platform, float valve, bottle solution feeder, v-notch constant-head solution feeder, floating bowl and others. Only the floating submerged orifice will be covered in detail, since in Latin America it has proven the most satisfactory of this group and is used in several countries of the Region.

There are many variations of the submerged orifice solution feed chlorinator. One successful design is shown in Figure 30. The rate of feed can be controlled by the depth of submergence and/or the number of orifices submerged. Once adjusted, since the depth of water over the orifices remains constant, so does the feed rate. Made out of plastic pipe, this type of feeder has a distinct advantage over others because it does not corrode; furthermore, there are no valves to malfunction and the feeder is easily cleaned of obstructions due to calcium or magnesium deposits (scale formation). The feed rate can be easily adjusted simply by changing the depth of orifice immersion. When properly designed, installed and maintained, this type of chlorinator has proven to be quite accurate and reliable. These devices can be fabricated of many different materials but it is essential that all materials be resistant to the corrosive effects of a strong hypochlorite solution. Floats have been successfully made of PVC pipe, styrofoam, and wood. Metals such as aluminum, steel, copper and even stainless steel should be avoided.

The tubing must be sufficiently flexible and must slope constantly downward from the floating submerged orifice to the outlet. It should not have any vertical loops which will entrap air and prevent a constant feed rate. The tubing should be counter-weighted to avoid the tendency to float and to assure that the float assembly remains level as the surface of the chlorine solution descends. Flexible vinyl tubing is commonly used. The outlet must be at the lowest point in the solution tank. The solution tank can be made out of any corrosion-resistant material, usually high density polyethylene, fiber glass or asbestos-cement.

For stock solutions made from calcium hypochlorite or chlorinated lime some designs use a single tank divided by a diffusion screen to separate the mixing zone and the feed solution compartments so as to avoid precipitants and sediments.

Others use two separate tanks, one for the mixing-settling process from which the supernatant is drained to a second solution tank containing the floating submerged orifice. For sodium hypochlorite solutions a single tank without a screen in all that is required because sediments and precipitates are minimal.

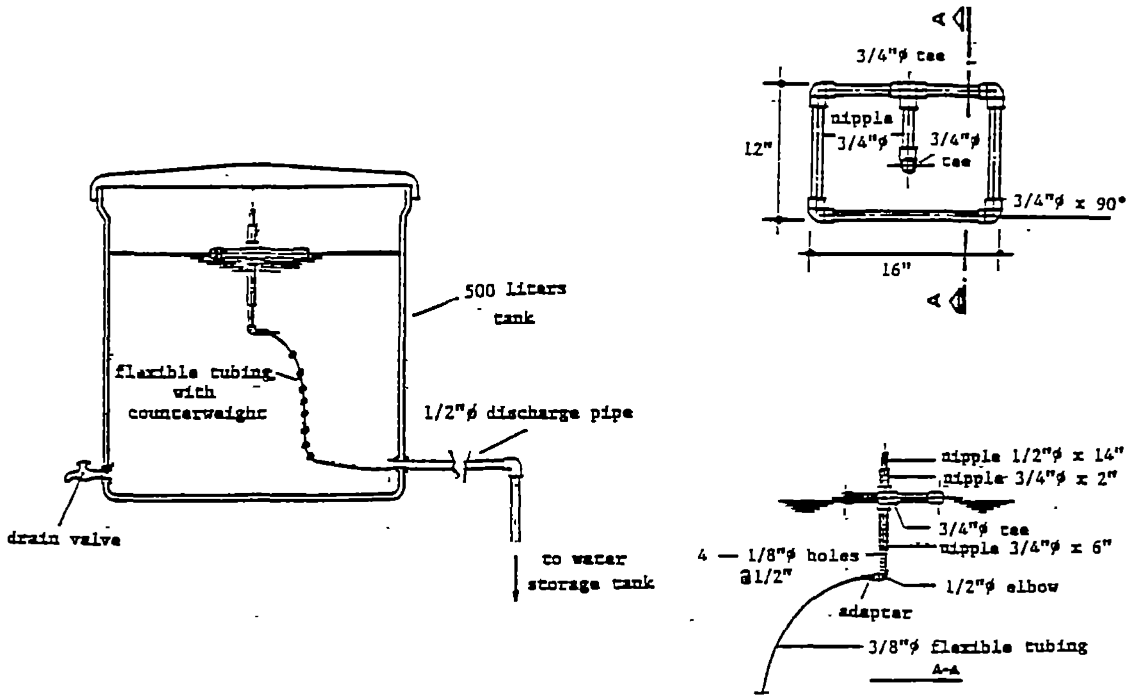


Figure 30. Submerged orifice solution feed hypochlorinator.

a) Energy requirements:

This type of chlorinator does not require external sources of energy, except perhaps for the operation of a mixer to facilitate dissolving calcium hypochlorite or chlorinated lime.

b) Installation requirements:

This equipment is simple to install. As the name--gravity feeder--indicates, its application is limited to situations where the hypochlorite,solution can flow by gravity into a mixing channel, a chlorine contact chamber or directly into a storage tank. The installation should incorporate an air break in the discharge pipe to preclude the possibility of siphonage. It should also be designed to preclude the possibility of the solution tank contents being accidently discharged into the mixing channel or contact chamber all at once in the event of a ruptured fitting, broken pipe or other spill. The design of the installation should facilitate the handling of chlorine compounds, mixing of solutions and adjustment of dosage. A faucet should be conveniently located to be used in making stock solutions and for general cleanliness.

c) Operation and maintenance:

The operation, maintenance and repair of equipment is quite simple and, therefore, specialized operators are not required. They can be trained easily in a short period of time; regular attention is required to make sure that the equipment, particularly the submerged orifice, is maintained clean; that the proper dosage is fed; that the solution in the tank is not exhausted or becomes decreased in strength; that there is no change in the flow; etc.

Manual preparation of the hypochlorite solution has to be done carefully as explained earlier. When using calcium hypochlorite the concentration of the solution should be between 1 and 2% of available chlorine to prevent excessive formation of calcium scale and sediment. Sodium hypochlorite solutions can be up to 10%, higher concentrations are not desirable because they loose strength rapidly and if sufficiently high may crystalize.

d) Safety:

These type of devices are quite safe. However, the precautions discussed for other hypochlorinators apply. The preparation of the solution is to be performed most carefully as heavy loads may have to be lifted and splashing and spilling is usually a hazard. The floor area should drain away from tanks, mixing channels and contact chambers. A faucet and sink should be located conveniently to wash off skin or clothing in the event of an accident. Rubber gloves, aprons and a face mask should be used in the preparation of stock solutions.

e) Cost:

The cost of a submerged orifice-constant head hypochlorinator, solution tank and piping, which is well designed and constructed, currently ranges from US$ 300 to US$ 600 depending on the complexity of the design, the capacity of the solution tanks and the material used.

On site hypochlorite generators

The idea of producing chlorine gas or hypochlorite locally for the disinfection of drinking water has been explored repeatedly over the years and many patents have been registered; however, except for very few devices, most have been too expensive or too complex technically to permit wide application, particularly in developing countries. In recent years, renewed interest in the matter has developed: first, because of the increased availability and use of titanium, for the production of DSA anodes and because of improvement in graphite anodes; and second, because of the development of more economical and durable cation-exchange membranes.

The reason for the renewed interest in local production is primarily that hypochlorite is not produced in many developing countries and has to be imported. Considering the related problems of foreign exchange restrictions, high transportation costs (particularly to remote areas and small towns), safety risks during storage and transport, and deterioration of the product with time, the on-site generation of hypochlorite solutions can be an attractive alternative to distribution from a large, central hypochlorite plant.

The above circumstances have revived optimism for the "in situ" production of hypochlorite through electrolysis of table salt, particularly for use in rural water supplies and small towns.

For hypochlorite generators to be effective and appropriate for the conditions in rural areas and small towns in Latin America and the Caribbean, they have to be:

- economical to purchase, operate and maintain
- simple to operate and maintain,
- reliable and durable, with consistent production,
- capable of using locally produced refined salt—(sodium chloride) and
- a production capacity between 0.5 kg and 2.0 kg of available chlorine as NaOCl in a 24 hour period.

Several commercial have been developed (including some in Latin America); however, not all of them meet the above criteria. The basic principle is the electrolysis of a solution of sodium chloride to produce chlorine in the sodium hypochlorite form. The application of these systems will be dictated by the characteristics and requirements of the specific water supply under consideration. Some of these devices utilize a membrane to obtain greater conversion of salt; others do not utilize a membrane, sacrificing efficiency for ease of operation and maintenance. The different devices produce from 0.5% to about 5% solutions of sodium hypochlorite.

a) Energy requirements:

The efficiency of the different types of equipment varies considerably. Experience indicates that from 5 to 6 kilowatt hours of electric energy are required to produce 1 kilogram of available chlorine as NaOCl. This small amount of energy can be secured from alternative energy sources such as solar cells, windmill generators, water power, gas or gasoline engines, and others; however, the energy source has to be reliable.

b) Installation requirements:

The equipment is usually simple to install and with the solution tanks requires about 3 square meters of floor space. There will be the need to store the stock of salt which will require additional space. Although the devices are easy to install, precautions need to be taken to separate these units from delicate equipment such as the electrical control units, pump motors, controllers and other devices made of metallic materials, since the immediate environment is usually very corrosive. Installations should be designed to facilitate the handling of salt and the transfer of hypochlorite solution. They should be well ventilated.

c) Operation and maintenance:

This type of equipment is usually quite reliable if built of materials resistant to the highly corrosive properties of the chemicals handled. Maintenance has to be carried out at regular specified times. One problem that may occur in certain types of devices is the fouling of the electrodes or the membrane because of the calcium and magnesium in the salt. The formation of scales can be avoided by using good-quality, refined salt and good quality, make-up water. Ion exchangers will facilitate the latter. Titanium anodes with oxide coatings are usually long-lasting (up to 5 or 6 years) and graphite anodes last about 1 year. Titanium anodes can be cleaned in a solution of muriatic acid.

d) Safety:

The devices being considered are quite safe in view of the fact that relatively small amounts of sodium hypochlorite are produced and for the most part this is used quickly if not immediately; however, precautions need to be taken, particularly when opening the electrolysis cell, as a significant amount of chlorine gas could accumulate there. The aforementioned precautions for use of sodium hypochlorite should be followed.

e) Cost:

Estimates for the total cost of on-site generation of sodium hypochlorite in Latin America and the Caribbean are based on limited experience but currently fall in the range of US$ 2.50/kg of available chlorine produced.

Diffusion-type hypochlorinators

For many years, diffusion type of hypochlorinators have been locally designed and fabricated in an attempt to gradually release hypochlorite into wells or storage tanks over a number of days. The most common designs of these devices are referred to as the pot type, the double jar type, the coconut type, and the perforated plastic pipe type; they are illustrated in Figure 31. These devices have been relatively simple to operate and maintain, but none of them has achieved a steady release of hypochlorite, as intended. Instead, upon installation, they tend to initially release large amount of hypochlorite; after which there is a steady decrease in the amount released, until the hypochlorite compound is exhausted several days later. Because this results in widely varying concentrations of chlorine over a few days (sometimes 0.1 to 25 milligrams per liter), these devices have not found widespread acceptance in Latin America and the Caribbean. Instead, they are usually removed and disinfectants are administered manually, or disinfection is abandoned altogether. Another alternative has been the use of slow-release chlorine tablets or briquettes, but this also has resulted in both overdosing as well as underdosing.

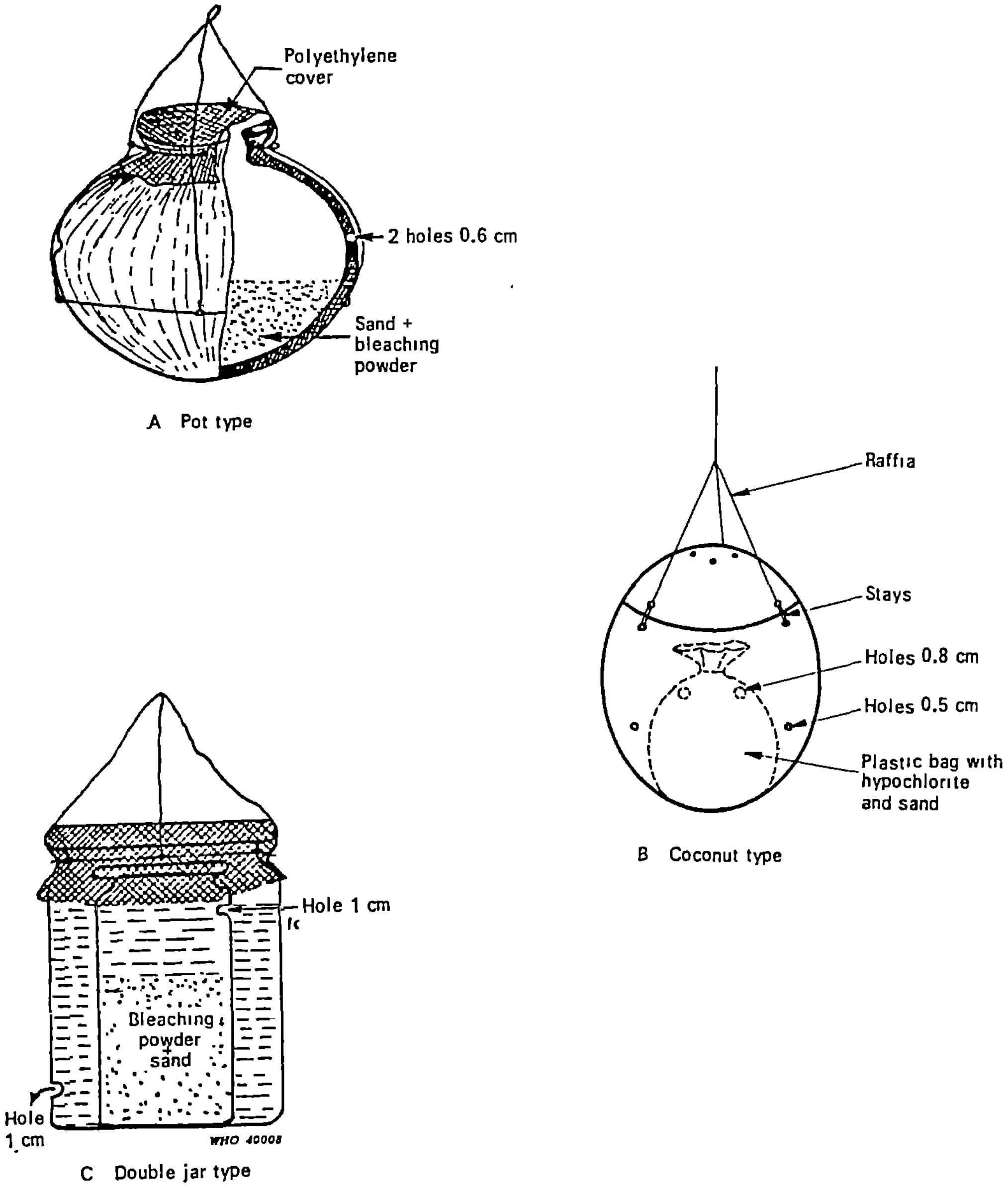


Figure 31. Common designs for locally fabricated diffusion type chlorinators which do not provide a sufficiently constant release of chlorine to be satisfactory.

More recently, a patented device by the name of DIFFU-MAX, which is manufactured in Germany, has been introduced (Figure 32). Actual use in the community is limited, but the device appears promising for disinfecting small quantities of water for household use. The DIFFU-MAX releases between 10 to 15 milligrams of hypochlorous acid over a 24-hour period. The design is based on the principle that only gaseous substances can diffuse out of the non-porous plastic walls used in its construction. The device contains two chemical reactants which are separated from each other until the device is actuated for use by twisting the cap in a clockwise direction (screwing it down), which results in the mixing of the halogen donor with the other solution—the activating reagent.

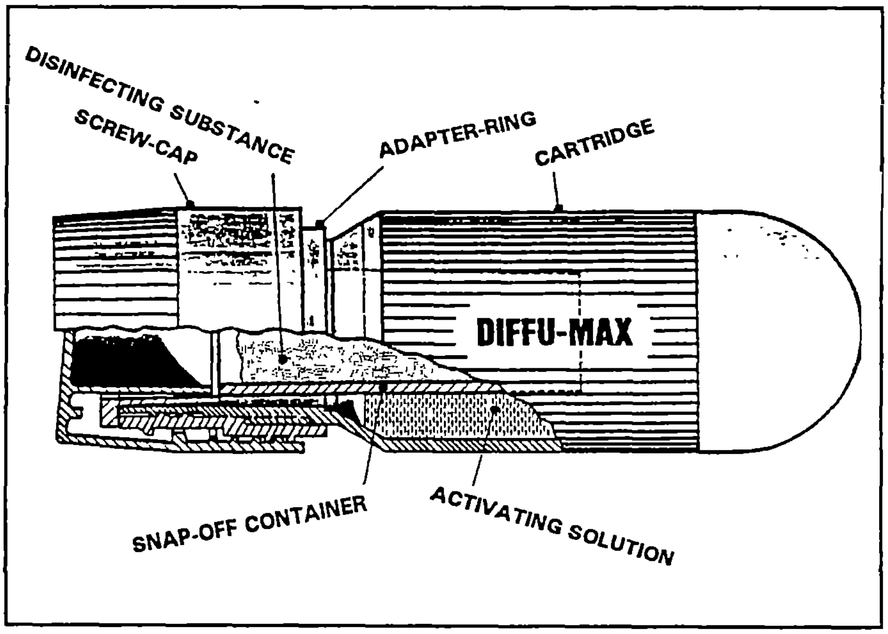


Figure 32. DIFFU-MAX.

The average life of a DIFFU-MAX cartridge is about sixty days. It is estimated that one of these devices can disinfect up to 15 liters per day, depending upon the chlorine demand of the water treated. Multiple units could be used to disinfect larger quantities of water.

a) Energy requirements:

There are no energy requirements for any of the diffuser type chlorinators.

b) Installation requirement:

Installation requirements are simple. The devices are simply lowered into the well or water tank. The primary concern is to use some mechanism to introduce the cartridges in the body of water and to extract the used ones without contaminating the water.

c) Operation and maintenance:

Once a diffuser type chlorinator is located in place, it should be observed periodically to assure that it has not been disturbed or that the water level has not dropped below the device. The chlorine residual should be monitored frequently to help avoid intolerable fluctuations in the chlorine residual. These devices must be replaced at appropriate intervals to assure continuity of service. The DIFFU-MAX device appears to be capable of continuous and adequate disinfection without a great deal of follow-up whereas the other locally fabricated devices require considerable effort to obtain even a somewhat steady residual.

d) Safety:

The safety precautions mentioned previously for handling and storage of hypochlorites should also be followed when locally fabricated diffusion type of chlorinators are being recharged with hypochlorite compounds. In the case of DIFFU-MAX, no special safety precautions are needed except for the manufacturer's recommendations for storage and handling.

e) Cost:

Reliable cost data for diffusion type chlorinators for Latin America and the Caribbean are currently not available.

4.2. OZONE DISINFECTION SYSTEMS

Description of ozonation system components

As the development of ozonation equipment has evolved, the types of ozone equipment and their range of capacity have expanded. Although not yet in widespread use in Latin America and the Caribbean, there is some experience, and ozonators and associated equipment for ozone systems with suitable capacity for the disinfection of small community water supplies are currently available on the commercial market.

Ozonation systems for water supplies include five basic components: the gas preparation unit (utilizing air or pure oxygen), the ozone generator, the electrical power supply, the contactor and the exhaust gas destruction unit. The relationship of the components is illustrated in Figure 33. In most situations, a secondary disinfectant is subsequently added to assure a lasting residual throughout the distribution system.

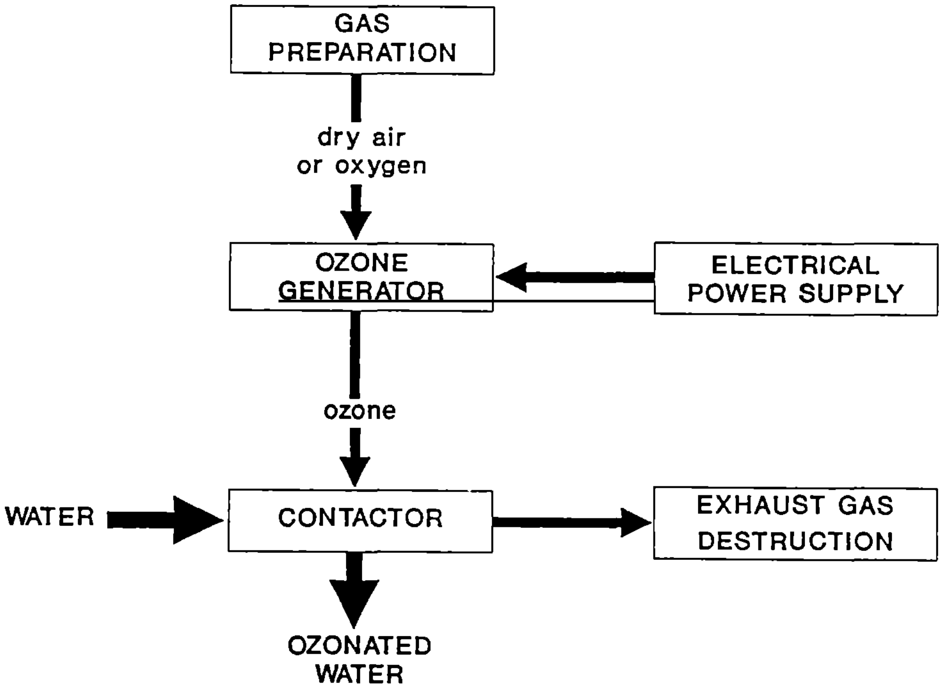


Figure 33. The basic components of the ozonation process.

Gas preparation

The purpose of a gas-preparation device is to dry and cool the oxygen-containing gas. Ozone generators of the corona discharge type utilize either dried air or pure oxygen for the source of oxygen to be converted into ozone. When air is used, it is imperative that it be dried to a dew point of -65°C in order to both maximize the ozone yield and minimize the formation of nitrogen oxides which would corrode the electrodes. The air must also be cooled because ozone quickly decomposes back to oxygen at temperatures above 30°C.

It is possible to use chemical desiccants instead of refrigeration for drying the air. The associated cost is somewhat higher, varying widely from location to location, but for small systems the increase in price may be offset by the simpler operation and maintenance requirements. With properly dried and cooled air, the output from an ozone generator will usually contain from 1% to 3.5% ozone. Pure oxygen can be used advantageously for the feed gas to increase the ozone to content as much as 7% in the same equipment. A zeolite molecular sieve has been used to produce essentially pure oxygen by stripping out the nitrogen in the air. Improvements which have potential of further increasing the ozone yield continue to be made but it seems equipment life generally decreases with higher ozone concentrations.

Ozone generators

All ozonation systems used in water supplies generate ozone on site and almost all do this by means of a corona discharge, through which an oxygen containing gas is passed. Ozone can also be generated by photolysis but in this document only the corona discharge type of generators is covered, the other types are not yet used to any great extent in drinking water supplies. Figure 34 conceptually illustrates the basic configuration of a typical corona discharge cell.

The proprietary ozone generators which are commercially available are primarily the tube, the Otto plate and the Lowther plate type. Schematics of the Otto plate and Lowther plate types are shown in Figure 35 and a tube type is shown in Figure 36. The Otto plate design, the oldest, operates at atmospheric or negative pressure and has the advantage that it can operate at dew points as low as -30°C without significant damage; but it is the least efficient of the devices and is gradually being phased out. The Lowther plate device, which is air-cooled and can use either atmospheric air or pure oxygen, has the lowest energy requirement of the four. It typically operates at a frequency of 2,000 Hz at 9,000 volts in a gas pressure of about 15 psi. It has been used in small water systems but there is little data on actual long-term operating experience. The horizontal tube, a water-cooled device, is most commonly used for industrial purposes and large water treatment plants but several smaller types have been developed for treatment plants of less capacity. One proprietary unit which uses small-diameter dielectric tubes is reported capable of generating up to 14% ozone from oxygen, which is the highest value reported to this date.

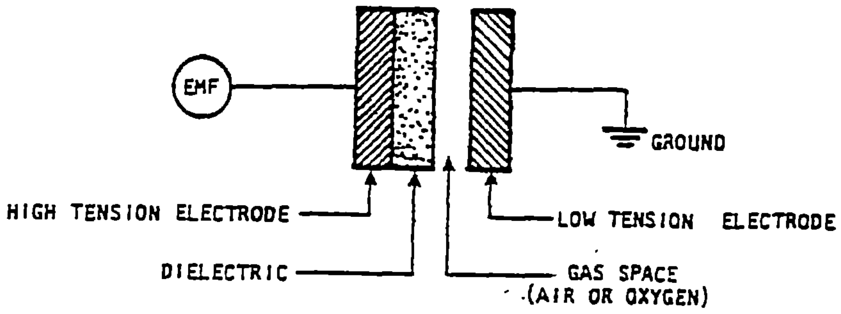
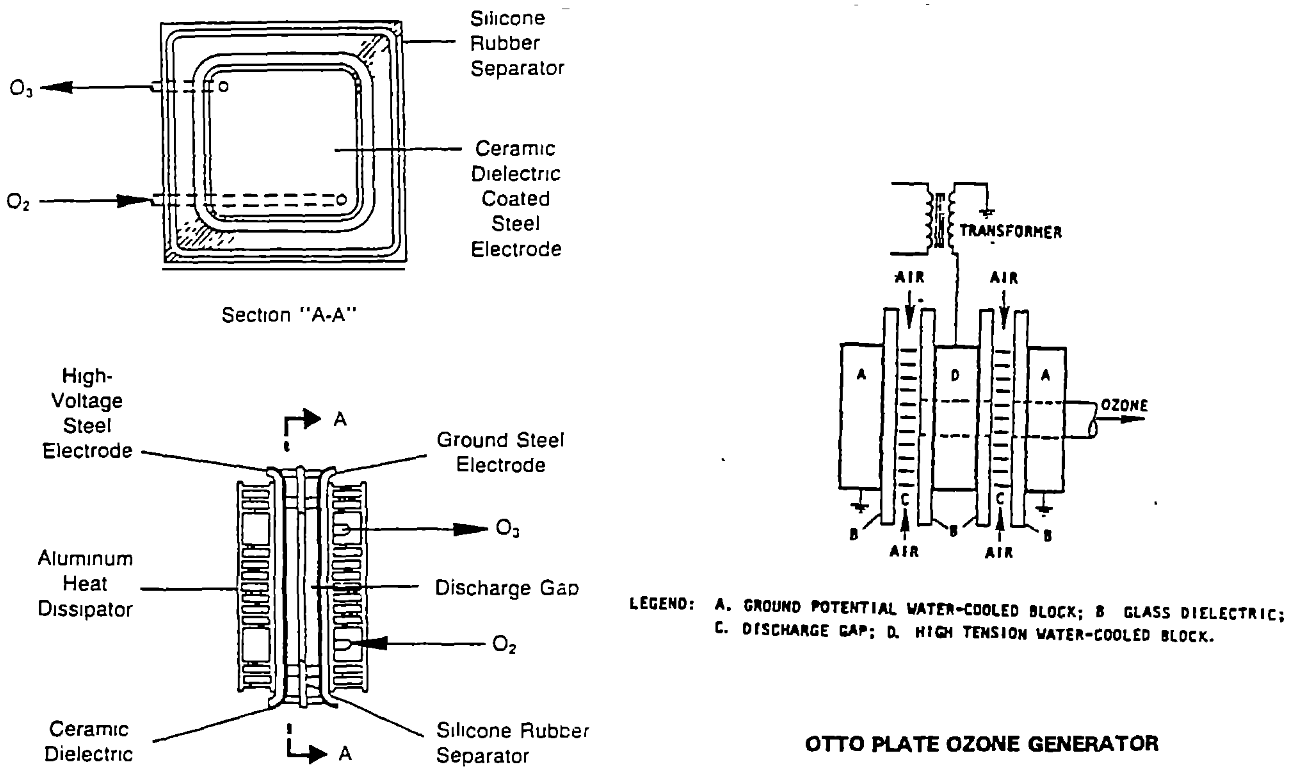


Figure 34. Typical configuration of a corona discharge cell for generation ozone.

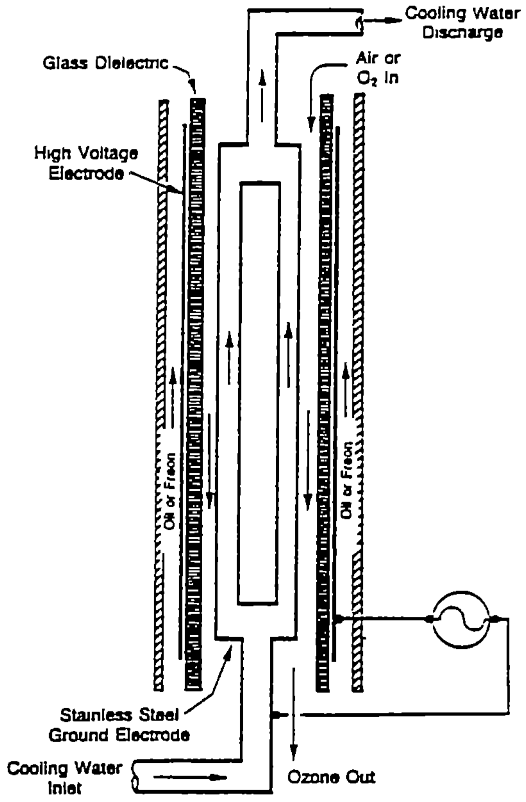


OTTO PLATE OZONE GENERATOR

Source Miller et al. (1978)

LOWTHER-TYPE AIR-COOLED PLATE OZONE GENERATOR

Figure 35. Two common plate type of ozone generators.



Source: Carlins and Clark (1982).

Figure 36. Tube type of ozone generators.

Electrical power supplies

Currently, low frequency (50 - 60 Hertz) high voltage (>20,000 volts) power supplies are the most common but recent improvements in electronics has resulted in devices which operate at high frequency (1000 to 2000 Hertz) and 10,000 volts. Higher frequency power supplies are generally more efficient and seem to be gaining favor in large water systems but have yet to be introduced on a large scale in small community water systems.

Contactors

All ozonation systems utilize contactors to transfer the ozone in the output gas into the water to be disinfected. The type of contactor depends upon the specific objective of the ozonation. These can be categorized as fast reactions—as in the case of inactivation of microorganisms; oxidation of iron, manganese and sulfides; and enhancement of flocculation--or slow reactions—as in the case of oxidation of more difficult substances such as pesticides, volatile organics and other complex organics which for kinetic reasons tend to require longer reaction times. In the latter reactions, ozonation is frequently supplemented by UV light or hydrogen peroxide and the combined effect is commonly referred to as an "advanced oxidation process".

For disinfection purposes the usual strategy is to add sufficient quantities of ozone as rapidly as possible, and in a manner which satisfies the ozone demand and which maintains an ozone residual for a sufficient period of time to assure inactivation or destruction of the target organisms. The ozone demand for the great majority of water systems is generally higher than the chlorine demand because of the stronger oxidation potential and typically ranges between 3 and 9 mg/liter. Usually, ozone disinfection processes establish a target residual between 0.4 and 0.5 mg/liter after 10 to 20 minutes of contact with the water.

A significant portion of the failures of ozone disinfection systems has been due to faulty contactor design and construction. There are three basic contactor designs: the baffled chamber-diffuser contactor (Figure 37), the stirred turbine reactor and the multiple column bubble diffuser. Studies by Venosa have shown that the multiple column bubble diffuser has the best transfer efficiency. In a small water treatment system, the ozone is frequently generated at a pressure of 15 psi and is diffused into fine bubbles of water upon discharge into a 5 meter high column where oxidation and disinfection take place. Packed columns, static mixers and propeller diffusers may be used to accelerate solution of ozone gas and to help assure mixing and contact. Most of the small-package ozonator plants use a version of the bubble column diffuser and transfer efficiencies of 90% or more are attainable . A contact time of ten to twenty minutes is a commonly accepted ozonation practice for oxidation-disinfection of small water supplies. In all three use is made of countercurrent flow where the water flows downward and the air bubbles rise, so as to maximize the contact time.

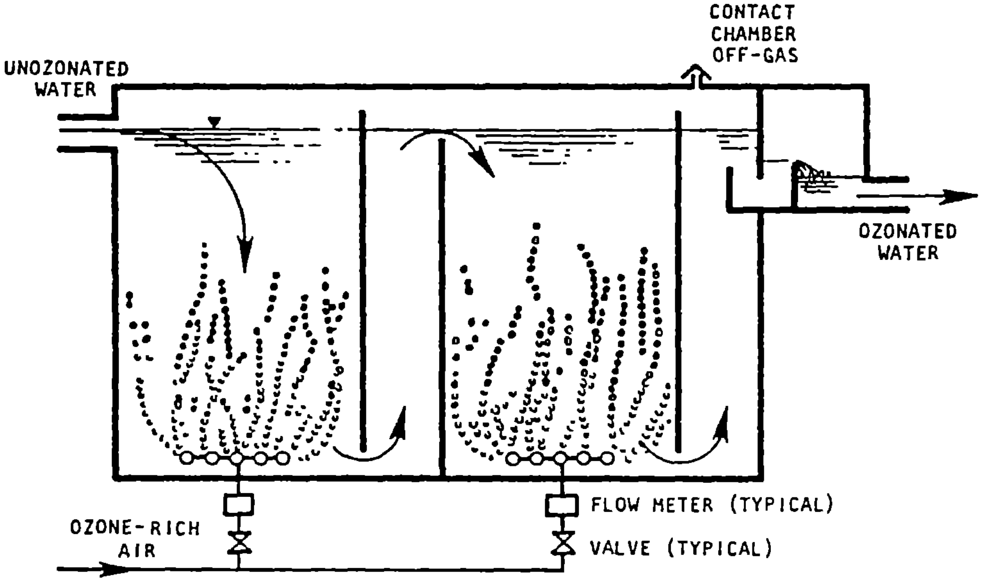
Exhaust gas destruction

Gas solubility is governed by Henry's Law, which means that the achievable concentration of dissolved ozone will be directly proportional to the partial pressure of the ozone gas above the water. Thus even with a transfer efficiency of 90%, the off-gas (ozone and/or air which has not been dissolved) may contain 500 to 1000 ppm by weight of ozone. Frequently the ozone-containing excess gas is recirculated into an earlier unit process for oxidation or flocculation enhancement so as to recapture as much of it as possible for a useful purpose.

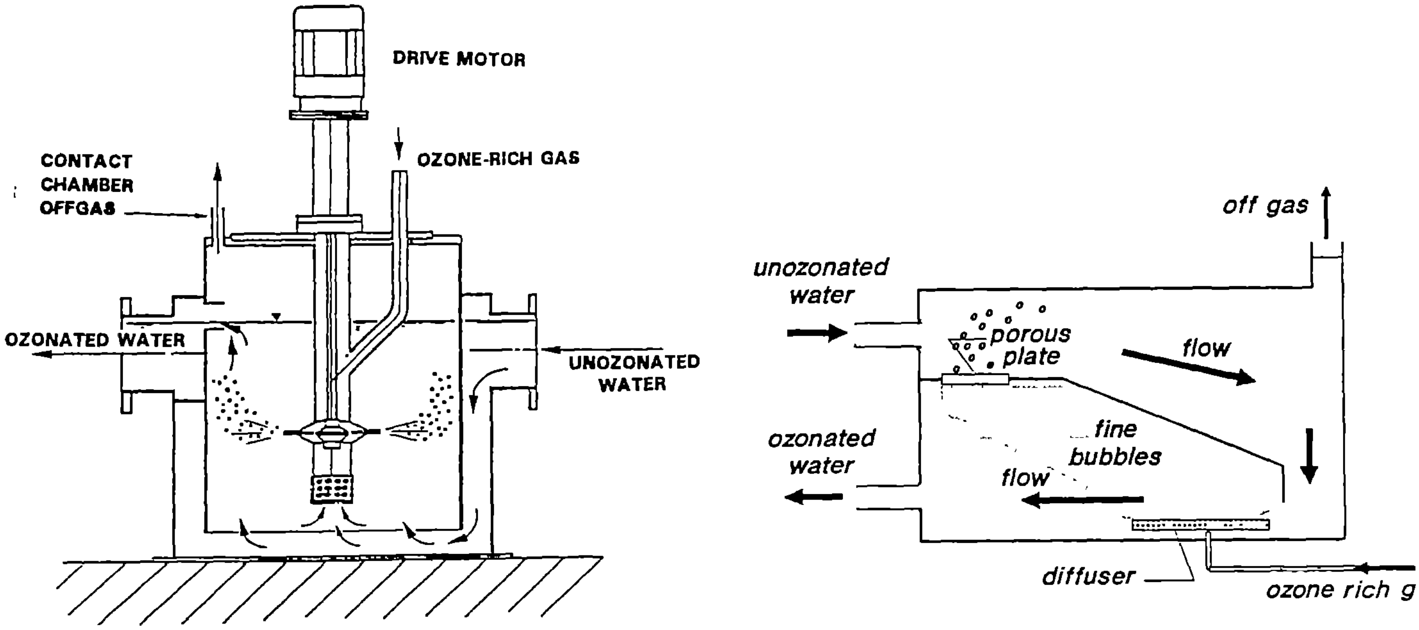
There will nonetheless be some excess ozone which should be either destroyed or sufficiently diluted for safety reasons. In small water treatment plants dilutions with air may be feasible. In most water treatment plants, one of three methods is used to destroy the ozone discharged in the off-gas: thermal decomposition by elevating the temperature above 300°C, catalytic decomposition by metals or metal oxides and adsorption on wet granular activated carbon.

a) Energy requirements:

The energy/power requirement for just the generation of the ozone itself is rather small but the energy required for the drying of the air is considerable. The combined consumption of energy is about 25 to 30 kilowatt hours of electricity per kilogram of ozone generated respectively for oxygen fed and air fed systems.



a) Baffled chamber-diffuser contactor[1].



b. Turbine type contactor

c. Two level ozone contactor

Figure 37. Schematics of typical ozone contactors used in small water systems.

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[1] G.W. Miller, R. G. Rice, C. M. Robson, R. L. Scullin, W. Kuhn and H. Wolf, "An Assessment of Ozone and Chlorine Dioxide Technologies for Treatment of Municipal Water Supplies", U.S. EPA Report No. 600\2-78-147 (1978). U.S. EPA, Municipal Environmental Research Laboratory, Drinking Water Research Division.

Because of the importance of maintaining disinfection at all times the water is flowing, standby generators might have to be provided where electricity is erratic or undependable to guarantee continuity of disinfection. This could be an important consideration in small communities of Latin America where electricity frequently is not reliable.

b) Installation requirements:

For the quantities of ozone required by the small communities and towns which are the subject of this paper (< 10,000 persons), all items except the contactor can be assembled on a skid-mounted unit and hauled to the site. This is usually the least expensive method for installing small ozonation systems. Since contactors for small ozonation plants can be constructed of concrete, reinforced fiberglass or PVC pipe, they are often constructed on-site.

For a small, ozonation system, (not including the contactor) a minimum of about 20 square meters of floor space is necessary. The building should be well ventilated, using a fan and the doors should open outwardly. All ozone gas piping should be 304-L and 316-L stainless steel for dry and wet services, respectively. Consideration of floor plan for layout of equipment should be given to allow sufficient space for the removal and replacement of components of the ozone generators, especially when they are tube type generators. The building should be constructed of corrosion-resistant materials such as bricks or concrete blocks.

c) Operation and maintenance:

On a day to day basis, the operational requirements of small ozonator systems can be minimal. Singley estimates that it will take about 0.5 hour per day for daily maintenance. This low figure is partly due to the fact that much of the operation is automated and black-boxed; however, when it becomes necessary to repair or service the air-preparation equipment, the ozone generator, the automated monitoring or the control system, a highly skilled technician is required.

Today, complete automation of monitoring and adjustment of dosage is the most common practice followed, even on the smallest systems, but this is only feasible where excellent customer support by the supplier or manufacturer is readily available. In Europe, the United States and Canada, contracts for follow-up inspection and routine maintenance, as well as for replacement and repair, are available. This arrangement has been enabled by the reliability and long life of the equipment, as well as by readily available servicing technicians, and it is particularly appropriate for small communities which lack the necessary technical skills to maintain and repair such equipment at the local level—however, such a service contract is not known yet to be widely available in Latin America. Many ozone-generator failures are caused simply by blown fuses which go undetected by the operator. The electronics would probably be too complicated to be repaired by an average treatment plant operator in a small town of Latin America. Also, system instrumentation must be continually adjusted or calibrated and air-drying equipment must be kept in very good condition to prevent premature dielectric failure caused by moisture.

d) Safety:

For the small treatment plants which are the subject of this report, ozone would be considered a very safe method of disinfection. Only slightly more ozone than the amount that is necessary for oxidation and disinfection would be generated. Upon generation this is immediately mixed with the water to be disinfected, so there is little chance of it combining with another substances to create a safety hazard. Even though the discharge of the excess gas would have to be disposed of safely, the quantity of the excess gas would be so small that the task would be relatively simple. The excess ozone could be destroyed (converted back into oxygen) through any of the aforementioned processes such as thermal destruction and in most cases the ozone could even be sufficiently diluted with air (dilution ratios of ozone:air between 100:1 and 200:1 are usually adequate) to reduce it to a concentration below the maximum allowable level of 0.1 ppm.

Another special safety consideration for waters containing volatile organics is monitoring the gas in the contacting chambers for hydrocarbons, to avoid conditions which might lead to explosion. This would be unlikely for the size of plants under consideration.

Ozone, unlike chlorine, has never caused a crisis situation, for the simple reason that it has never been stored in quantity. It is generated on site and is used as it is generated. For this reason it should be considered a very safe method of disinfection for the small community.

e) Costs:

The minimum production rate for ozone generators typically ranges between 10% and 15% of their maximum production capacities, with the most cost effective production occurring in the neighborhood of 60% to 70% of maximum production.

The current, capital cost of the ozone generator alone can range from a low of about $1,500/kg capacity per day for a large system up to about $8,000/kg capacity per day for a small system. The cost of the contact chamber is estimated to range between $8,000 and $12,000 for a plant which handles 1,000 m^3/day. The cost of a completely automated monitoring and control system is from $10,000 to $15,000, regardless of the plant capacity. The capital cost for a system to serve a community of 10,000 people, where the average daily per capita use is 100 liters, would be in the neighborhood of US$ 50,000. The total operating and capital cost varies considerably, depending upon the amount and cost of energy and maintenance required for the specific system. Also, because of the many options available for air pre-treatment, ozone generators, ozone contactors, off-gas destruction, and monitoring and control systems, there is considerable variation in cost. The operation and maintenance cost would range between US$ 4,000 and 8,000 per year, depending upon the costs of labor and energy, and the need for repairs and replacement of components. The total cost of ozonation in small water treatment plants has been estimated to range from about $0.03 to $0.06/$m^3$ of water treated. Operation and maintenance costs (excluding energy) of small ozone plants are about $.003 to 0.006 per m^3 of water treated[2].

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[2] Singley, Edward A. J. *Métodos Químicos y Físicos de Desinfección del Agua.* Memorias Taller Internacional sobre Actualización en Desinfección de Aguas. April 25-29, 1988. ACODAL. Cali, Colombia.

4.3. MOGOD SYSTEMS

The term MOGOD is an acronym for "mixed oxidants generated on-site for disinfection." It was coined by the Pan American Health Organization to cover a wide range of devices which generate this mixture of oxidants through electrolysis, photolysis or chemical reactions. There are a number of proprietary devices available on the open market. In addition a number of government agencies have developed such devices. The majority of them utilize electrolysis of a solution of salt but at least one uses photolysis of air or oxygen. Mixed oxidant technology is still in the developmental stage but a number of these devices have reached the stage where they provide effective, reliable and low-cost disinfection and are being used with considerable success.

Under proper conditions, electrolysis of a solution is capable of generating a mixture of oxidants, which act together as a powerful disinfectant. The generation of oxidants through electrolysis has been carried out on a commercial scale since the turn of the century. Probably the first generation of mixed oxidants by electrolysis was noticed when Cruickshank, in 1801, observed and described the odor of ozone (before it was given its name) in the gas formed at the anode in the electrolysis of water. Steady advancements and improvements have been made in the production of oxidants through electrolysis, particularly in the chlor-alkali industry. The introduction in 1969 of the dimensionally stable anode and the perfluorinated membranes and their steady improvements have increased the efficiency, lowered the cost of production, and greatly reduced power requirements of the electrolysis processes. Today, more than 90% of the chlorine capacity of North America is produced utilizing this technology.

MOGOD equipment

These advancements have made the on-site generation of mixed oxidants a feasible alternative for disinfection of water supplies. Basic electrolysis technology, has been adapted to insure operational simplicity, durability and compatibility with conditions in remote, small and poor communities. In doing this, some of the efficiency of the electrolysis process has been sacrificed but that has been more than compensated for by a gain in overall efficiency as it takes into consideration community capability, storage, transportation, national supporting infrastructure, local conditions and the prevalent human element. A number of prototypes have been produced by different groups and they are considerably beyond the laboratory-bench-model stage, with a number of units being produced and sold commercially. PAHO has no exact figure of their number of installations in Latin America and the Caribbean but there are more than 100 installations of mixed oxidant devices in use. Some are primarily to obtain data and information about the practical aspects of this technology, and others simply to produce a bacteriologically safe water. The first installation has now been in operation for more than 6 years and continues to function, exceeding the efficiency and effectiveness of the conventional chlorination which had previously been used but failed to perform satisfactorily.

Figure 38 is a schematic drawing of a typical gas producing mixed oxidant electrolysis unit depicting the relation of the electrolytic cell components and the input and output of chemicals. The electrolysis cell is divided into the anode and cathode compartments by a semipermeable membrane (Nafion) which is a high-performance, reinforced composite of perfluorinated, cation-exchange copolymer. Such units typically incorporate either a TIR-2000 DSA anode (ELTECH) or one made of special graphite.

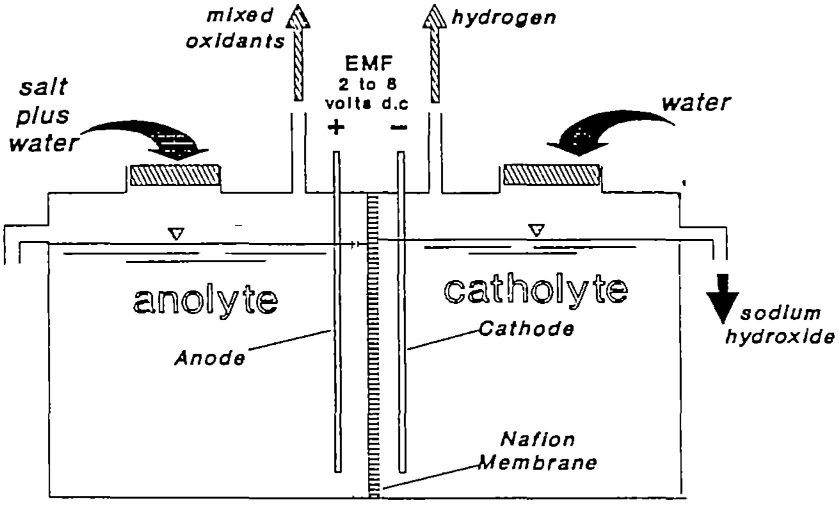

Figure 38. Schematic of typical MOGOD electrolysis cell.

The oxidants generated by the electrolysis saturate the anolyte and are given off as a gas. Auxiliary electrodes which operate at a lower EMF (electromotive force) than the primary anode are sometimes used as a means of producing a higher percentage of oxygen species and they are located between the primary anode and the membrane. The cathode is 440 stainless steel. A saturated solution of sodium chloride is maintained in the anode compartment by the addition of water and excess sodium chloride. Sodium hydroxide is generated in the cathode compartment. A concentration of sodium hydroxide above 10% requires considerably more energy and leads to temperature rise so it is typically maintained at a concentration between 8% and 10% by the addition of water and draw-off of excess liquid. Chlorine and activated oxygen species (of the mixed oxidant gases) are generated at the anodes while hydrogen gas and sodium hydroxide are formed at the cathode. In this particular process, the mixed oxidant gases are injected into the water to be disinfected; the hydrogen gas is vented to the atmosphere; and the excess sodium hydroxide is collected to be utilized for other purposes or to be disposed of.

Figure 39 is a graph which shows the useful life of the TIR-2000 anode as a function of the current density (in amperes per square inch of the anode surface) in a solution of 15% sulfuric acid. Increased thickness of the iridium oxide-based coating increases the useful life- expectancy of the anode. Since the operational current density of the MOGOD unit ranges between 0.6 and 1.0 amps per square inch, the life of the anode will range between about 3 and 8 years for the extended-life coating and between 7 and 12 years for the heavy coating, if the electrodes are in operation 24 hours a day.

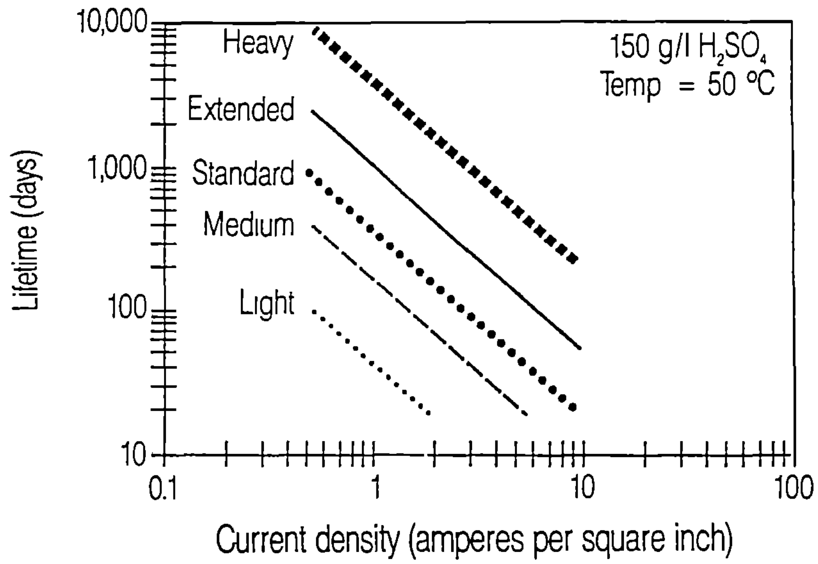

Figure 39. TIR-2000 Lifetime vs. Current Density.

Graphite anodes will last between 9 months and 1 ½ years depending upon current density and the quality of graphite. Another method, developed by the Los Alamos Technical Associates, generates a solution of mixed oxidant disinfectants instead of mixed oxidant gases. This is accomplished with an iridium oxide-coated titanium cell which takes advantages of laminar flow through the cell to electrolytically separate the oxidant species and divide the flow of a salt solution into oxidants on the anode side of the cell and into sodium hydroxide in the caltrode side. This device, which has functioned well in the laboratory and in field trials in the United States, has yet to be field-tested in Latin America. The disinfectant solution produced has been tested for effectiveness and considerably exceeds that of hypochlorite solutions. This technology holds considerable promise for conditions where a solution of oxidants would be advantageous over gas.

a) Energy requirements:

The electrical energy consumed between the anode and cathode of the electrolysis cell of the different mixed oxidant generating devices will vary depending upon the specific design of the cell, including the electrode material, the surface area of the electrodes, the electrode configuration, the cell geometry, the membrane material and the normality(N) or concentration of the anodic and cathodic solutions. Practical operation of commercially available devices indicate that the energy consumption in the cell ranges from about 5.0 to 7.5 kilowatt hours per kilogram of mixed oxidants produced. Under operating conditions, if calcium, magnesium, iron or manganese are allowed to accumulate on the membrane, the power consumption will rise accordingly.

The energy consumed by the electrical controllers for the various MOGOD devices will range from about 2 to 3 kilowatt hours per kilogram of oxidants produced; the total energy consumed by the electrolysis cell and the controller typically ranges from about 5 to 8 kilowatt hours per kilogram of oxidants produced.

The dependability of the electricity is also important particularly in a situation where the water source flows around the clock.

b) Installation requirements:

The minimum amount of space necessary for the combined installation of the electrolysis cell and the electrical controller is little less than two cubic meters; however, the electrolysis cell should be located in a well-ventilated space which is isolated from electrical controls (including the power supply/controller), electrical equipment such as pumps and control panels, and other materials which can be damaged by corrosion.

Figure 40 illustrates a typical stand-alone enclosure developed in Latin America, for use where there is no existing, protective shelter and which houses the electrolysis cell in the lower compartment and the electrical control unit in the upper compartment. It is important that both compartments be completely isolated from each other with no possibility of air circulating between the compartments; separate entrance doors are recommended, and all wiring and tubing between the two compartments should be caulked and sealed. The enclosure should be made of corrosion-resistant material such as brick, vitrified clay tile or concrete block. Both compartments should be well ventilated but forced ventilation such as is used in gas chlorination is not necessary because the amount of gas "on-hand" at any time is so small, being only the amount necessary for disinfection needs of the moment.

Existing, well-ventilated space, such as chlorination rooms, can be utilized for installation of the electrolysis cell but the electrical controller and all other electrical equipment such as controls and pumps must be located in a separate room to avoid corrosion problem.

The selection and installation of the venturi is usually the most troublesome part of the installation. The venturi must be carefully matched to the existing hydrodynamic conditions of the piping system into which it is to be installed. In most circumstances the venturi with the lowest friction loss is preferred. Figure 41 is a characteristic curve of the possible range of operation of a typical venturi.

The pipe and fittings used in the plumbing of the venturi should be of corrosion-resistant material, such as PVC or CPVC. This arrangement should include shut-off valves and a union for easy removal of the venturi for cleaning or replacement, and also include sampling cocks located before and after the venturi. In addition, there should be a hose bib and a short length of hose to facilitate the cleaning of the electrolysis cell and the adding of water to the anode and cathode compartments. Figures 42, 43, 44 and 45 illustrate typical venturi plumbing for various installations.

The suction tubing from the electrolysis cell to the venturi should be made of either teflon or high-density polyethylene, the two materials which can best resist oxidation by the mixed oxidants.

Although the amount of hydrogen generated by MOGOD is small, this gas should be ventilated to the atmosphere with vertical or near vertical PVC pipe to preclude any possibility of ignition.

It is a good idea to install the electrical controller slightly lower than at eye level to allow for easy reading of the indicators and easy manual adjustment.

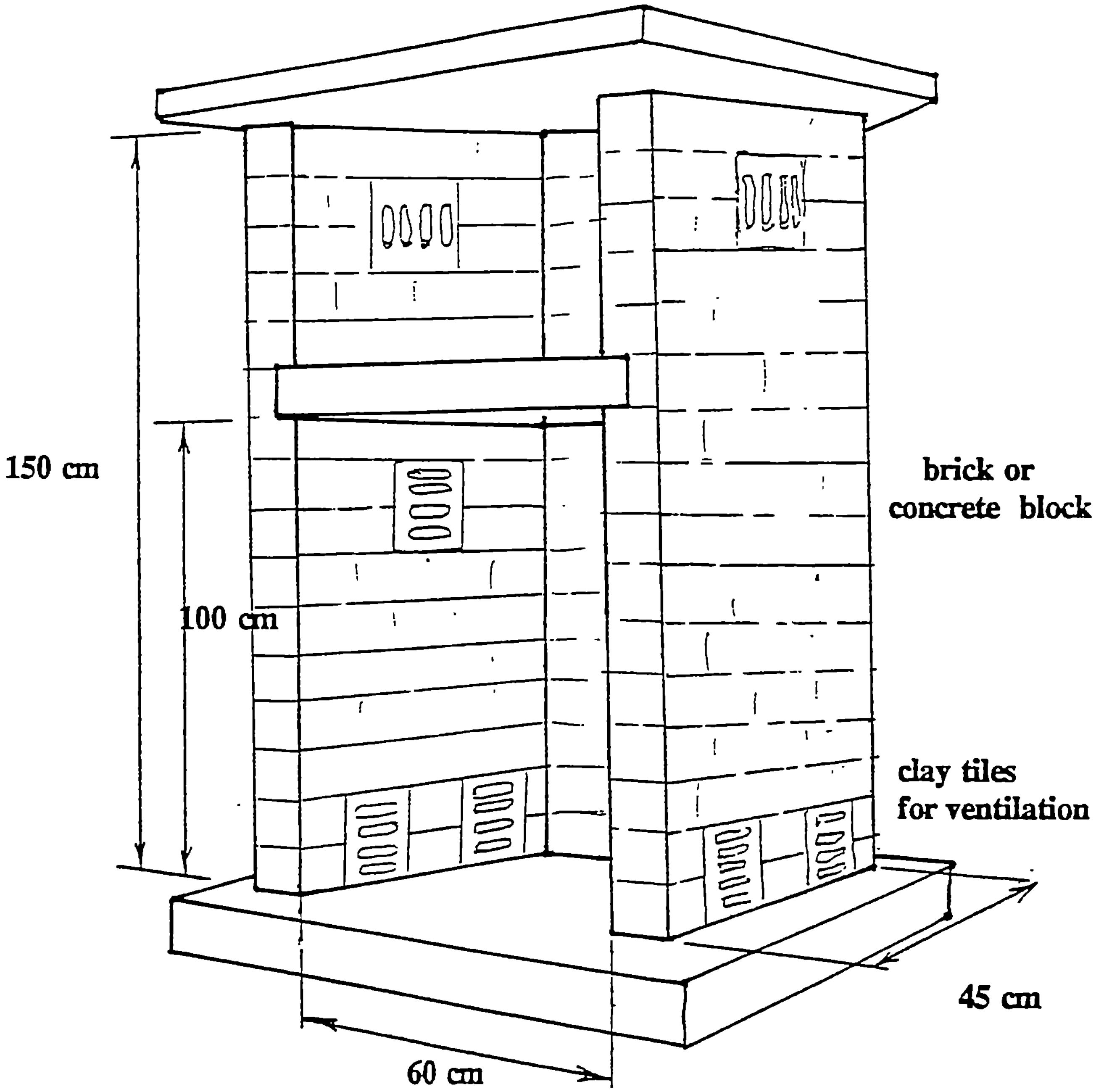

Figure 40. Typical stand-alone protective enclosure for MOGOD disinfection equipment.

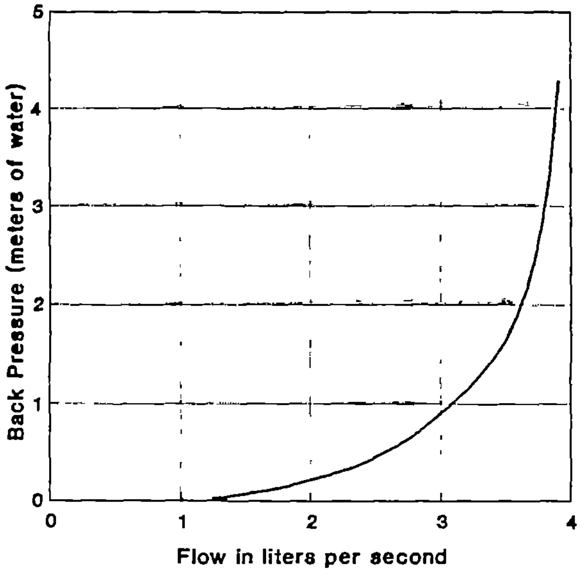

Figure 41. Typical characteristic curve for a venturi.

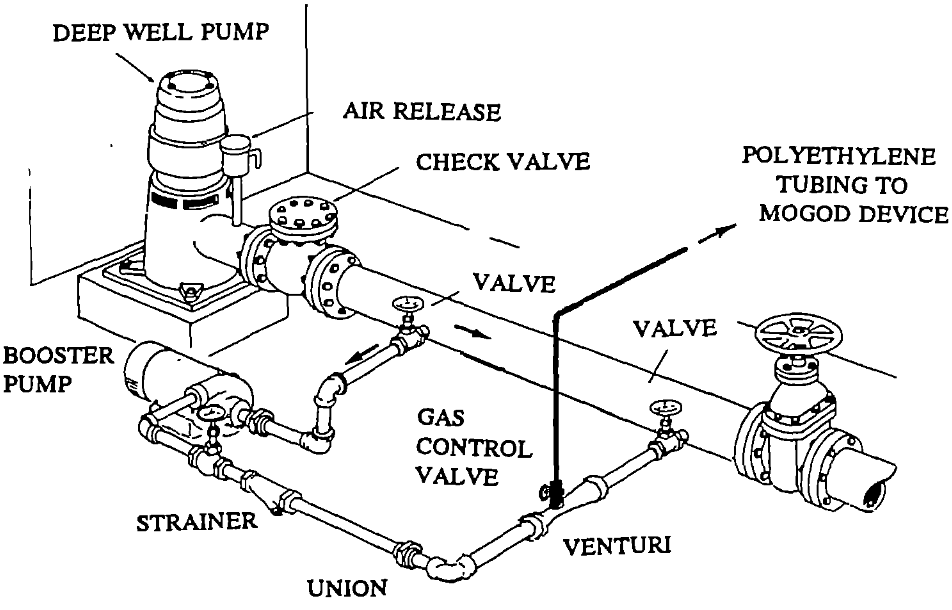

Figure 42. Typical venturi installation with booster pump.

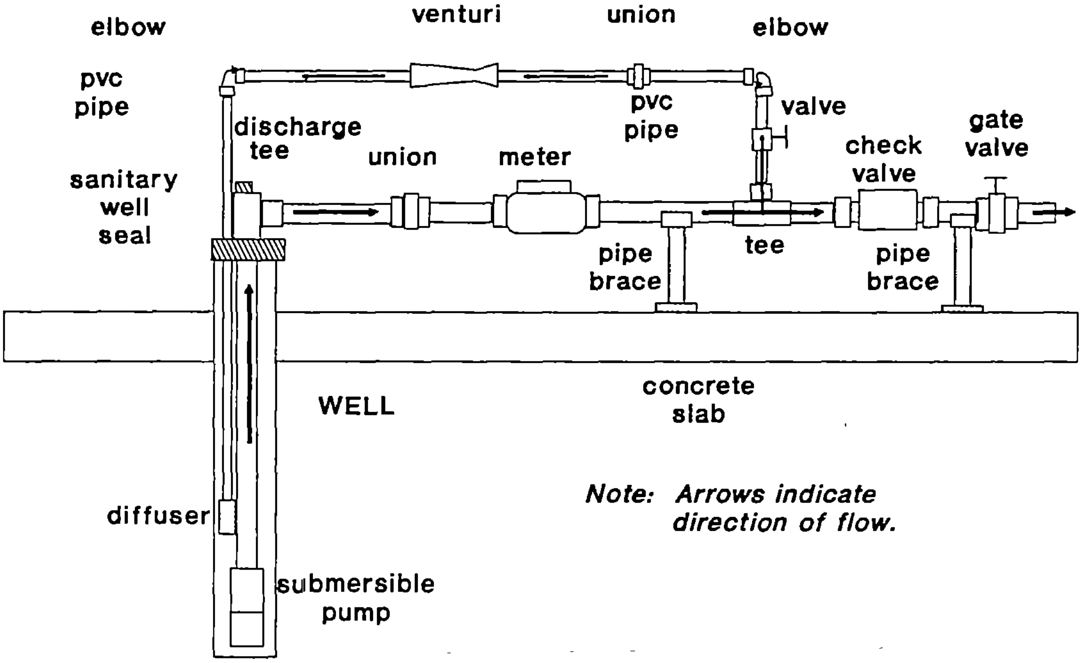

Figure 43. Typical plumbing for MOGOD venturi feeding directly into a well.

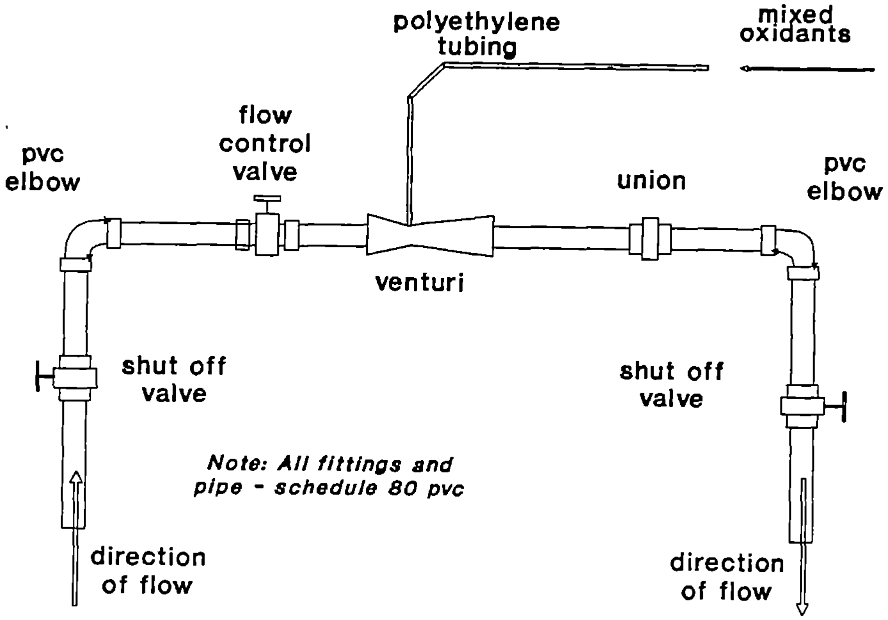

Figure 44. Typical plumbing requirements for MOGOD venturi.

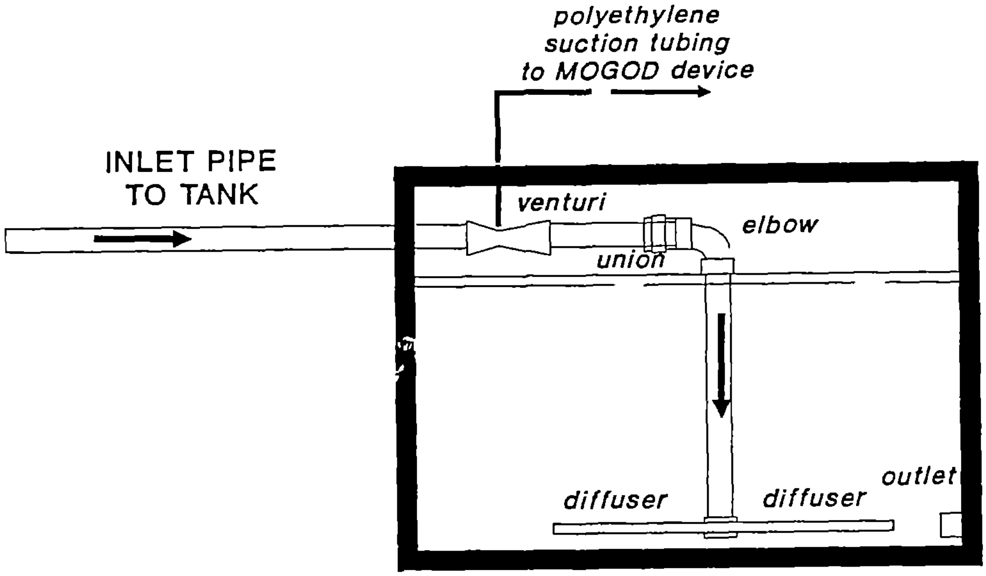

Figure 45. Typical MOGOD venturi installation to feed into a gravity flow storage tank.

Provision should be made for collection of the overflow from the cathode compartment when the sodium hydroxide is being diluted. This overflow can be discharged into a plastic collection vessel and used for other purposes.

The prime material used in the electrolysis cell is salt (sodium chloride). This is usually packaged in plastic bags or drums which are easy to handle and store. Salt is not hazardous and requires no special storage, except to keep it from getting wet and to prevent vandalism and theft. For convenience, at least one-month supply of salt should be stored reasonably close to the electrolysis cell.

c) Operation and maintenance:

There are two basic types of devices for mixed oxidants that are commercially available. One is highly automated and is primarily for use in industry. The other is manually controlled and is intended for use in water systems serving small communities. The automated unit is not usually recommended for small communities because of the difficulty of repairing and replacing the automated components when they eventually fail. Automated units may be appropriate where a maintenance-service contract is utilized.

The manually controlled units have the following operational and maintenance requirements:

1. Add salt (NaCl) to the anode compartment when the amount becomes low.

2. Add water to the anode compartment when the water level drops below the indicated minimum level (once a day to twice a week, or as needed).

3. Check the concentration of the sodium hydroxide solution in the anode compartment with a hydrometer (every day).
4. Add water to the cathode compartment when the concentration of the sodium hydroxide solution exceeds 10% (once or twice a week, or as needed).
5. Drain the electrolysis cell and flush it out with water; refill the cell and add a sequestering agent to the anolyte (once a month or as needed).
6. Check the ammeter indicator and adjust if necessary to obtain the desired production of oxidants (daily).
7. Check the residual level of oxidant in the distribution system (as prescribed by the health authority or at least once a week, or as needed).

d) Safety:

Disinfection with mixed oxidant generated on-site is one of the safest methods of disinfection because only enough oxidant are generated for immediate use and the prime materials salt and water are not reactive. However, there are two aspects which warrant safety consideration. The operator should avoid direct inhalation of the gases when adding water or salt to the anode compartment or when cleaning the electrolysis cell. This can be accomplished by shutting off the power supply cell and allowing continuous suction of the gases by the venturi during replenishment of the salt and water. Before beginning the monthly cleaning and flushing of the membrane, the operator should neutralize the oxidant gases in the anode compartment by adding about 50 cc of the liquid from the cathode compartment; this will prevent problems from inhalation of the mixed oxidant gases. Rubber gloves and goggles should be worn as a precaution against accidental spills or other contact with the sodium hydroxide. The enclosure should also be well ventilated to dilute whatever gas will escape from the cell.

The operator should also take care not to spill the excess liquid generated by the cathode. It should be collected in strong polyethylene bottles or buckets. This is 10% sodium hydroxide which can cause serious burns to the skin and the eyes. It should be treated with the same caution as a strong drain cleaner for which it can also be used.

Mixed oxidant devices, like any other disinfection unit should be protected from tampering or vandalism by locating it in a locked enclosure, preferably inside a fenced area such as would normally be provided for other water system components. This form of disinfection poses virtually no danger to the surrounding public because of the very limited quantity of mixed oxidants being generated. The gas is used immediately and is not stored at the site.

e) Costs:

The following cost data is for mixed oxidant gas devices. It has been collected from various Latin American countries. Little information is available for devices which generate a solution of mixed oxidants but the cost appears comparable.

The cost of the various devices to generate mixed oxidants on-site complete with electrolysis cell, electrical controller and venturi ranges from roughly US$800 to US$1,500 for a unit which produces 1/2 kilogram chlorine equivalent of mixed oxidants over a 24 hour period and US$ 1,400 to US$ 1,800 for units which produce 1 kilogram of chlorine equivalent over a 24 hour period. Units which produce 2 kilograms per 24 hours range from about US$ 2,000 to US$ 3,000. The units are not currently mass produced; the prices fluctuate considerably with the quantity purchased.

The conversion of salt and water to mixed oxidant gases ranges from 0.7 to 0.9 kilograms of salt consumed for each kilogram (chlorine equivalent) of mixed oxidant produced. The variation depends upon the proportion of chlorine and oxygen species generated. Devices which produce mixed oxidant solutions require about 3 kilograms of salt for each kilogram of mixed oxidant produced. The price of a kilogram of industrial high purity salt ranges from about US$0.16 to roughly US$ 0.30 depending on the location and country involved. In almost all cases it is less expensive to use a high purity salt than one of insufficient purity which necessitates more frequent changes of the membrane.

The energy consumed ranges from about 5 to 8 kilowatts hours of energy for each kilogram of mixed oxidant produced. Approximately one quarter of this energy is consumed by the electrical controller. The electrolysis cell by itself accounts for about 3.6 to 4.5 kilowatts hours.

The estimated overall costs of these systems based on actual operating experience in various countries, including installation and housing, amortized over a 10-year period, plus the cost of operation and maintenance has ranged from about US$0.75 to US$1.85 per kilogram of oxidant produced; depending on cost of electricity, salt, labor, construction materials and complexity of the installation. Since the oldest operating installation was only 7 years old as of 1991, more experience and data will be required to derive reliable cost data.

4.4. ULTRAVIOLET DISINFECTION SYSTEMS

Description of Equipment

The ultraviolet equipment on the market today utilizes low pressure mercury arc lamps which emit their maximum energy output at a wavelength of 253.7 nm and at an operating temperature of about 40°C. The efficiency drops off to about 50% at 24°C and 60°C. Lamp efficiency also drops off with usage, primarily because the glass gradually changes from exposure to UV light and the useful wave length is attenuated by the glass. Lamps rarely burn out but they are normally replaced after they have lost 35 to 40% of the UV output they had when they were new. These lamps have a useful life ranging from about 9 months to 1 year depending upon the manufacturer.

There are two basic type of UV contact chambers, those in which the lamps are immersed in the water and those in which they are outside of the water. In UV units in which the lamps are immersed, an insulating space must be provided to maintain temperatures near the optimum and this is accomplished by use of a quartz or high silica glass sleeve which surrounds the lamp, providing sufficient air space so as to insulate the lamp from the cool water and thus allowing it to operate at near optimum temperatures. In the other units the lamps may either be suspended above the water being treated or the water may be confined in either teflon or quartz pipe used to conduct the water past the UV lamps (Figure 46). Although teflon does not pass UV light as efficiently as quartz, it is considerably less expensive and it is not so fragile. The teflon tubing method is more common in small water supplies.

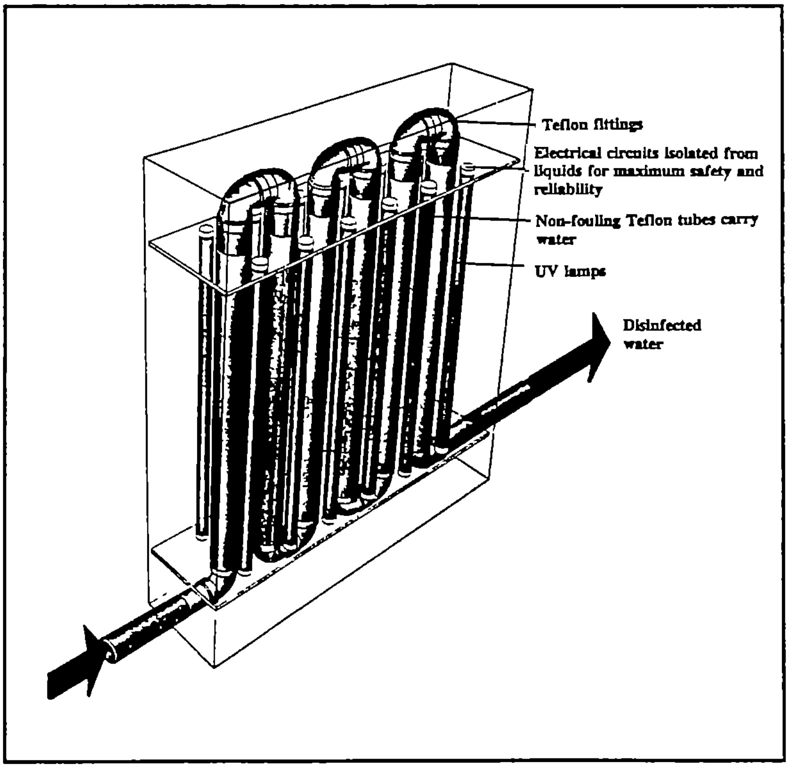

Figure 46. Contact chamber with flow in clear teflon tubes.

An important consideration in the design of UV disinfection equipment is assuring that every microbe in the contact chamber receives the biocidal dose of UV radiation. This is accomplished by the proper spacing of the lamps and reflective surfaces of the chamber interior, and by adequate agitation of the water as it flows through the chamber. UV equipment with immersed lamps can be of either of two basic flow configurations: the flow of water can be either parallel or perpendicular to the length of the lamps. If the flow is perpendicular, the lamps/sleeves themselves can produce the necessary turbulence to assure that all of the water is exposed to the biocidal dose. When the flow is parallel to the length of the lamps, it is necessary to utilize static mixers to provide the necessary turbulence. This concept is illustrated in Figure 47.

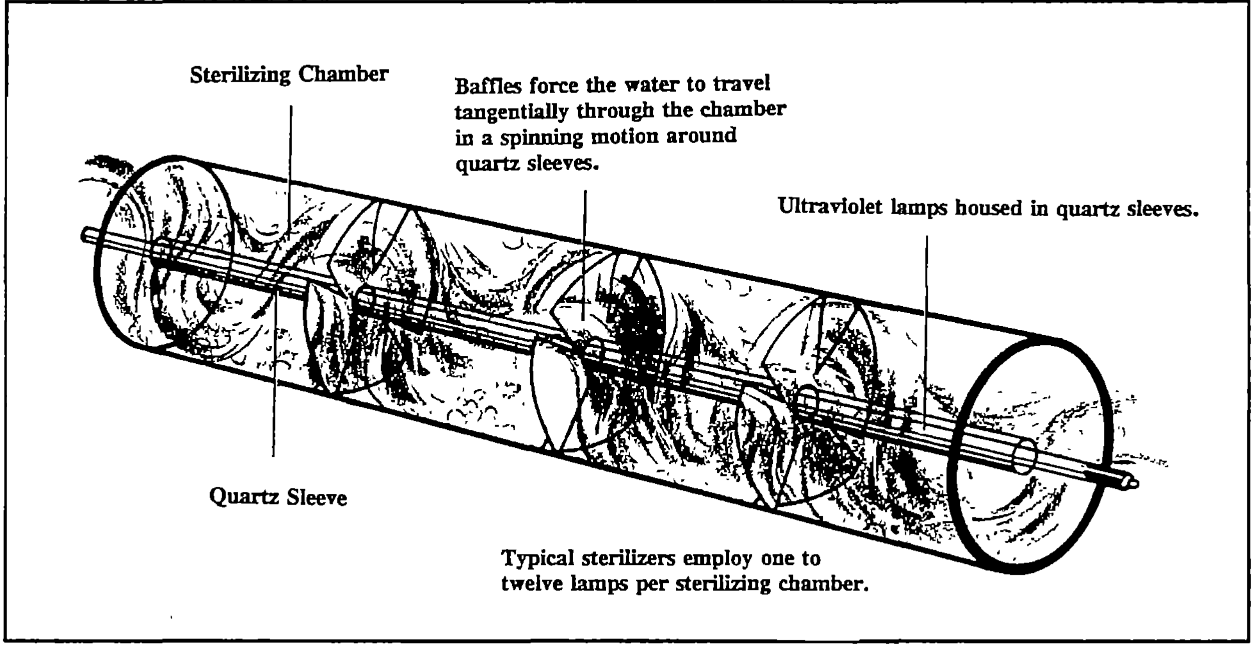

Figure 47. Contact chamber with flow parallel to the ultraviolet lamps using baffles to create turbulence.

Equipment specifications should require that after 1 year of operation with the same lamps, the exposure provided remain above 30,000 microwatt seconds per square centimeter to assure an adequate biocidal dose for clear water (< 2 NTU turbidity). In the selection of UV equipment, consideration should be given to devices which permit easy changing of the lamps and easy cleaning of the quartz sleeves or the teflon piping. It is recommended that the specifications incorporate provisions for a viewport to allow visual verification that all UV lamps are operating.

a) Energy requirements:

The energy requirements for UV disinfection will vary somewhat with the quality of water to be treated but it should be in the range of 22 watt hours for each cubic meter of water treated.
More importantly, the fact that UV leaves no residual necessitates that the electrical energy source must be extremely reliable at all times during which water is flowing through the disinfection unit. This means that when electrical water pumping is utilized, a cutoff switch should be installed which will

automatically shut down the water pump whenever the UV unit is inoperative or when the UV dose drops below the prescribed level.

An independent emergency power source should be provided in communities with unreliable electricity to assure continuity of disinfection at all times.

b) Installation requirements:

UV equipment should be installed in a building or enclosure to protect it from the elements and vandalism. The shelter should not subject the equipment to extreme temperature or other conditions which could cause it to malfunction.

The space requirements for UV disinfection equipment is rather small because the necessary contact/exposure time is quite short. A unit capable of treating 100 cubic meters per hour typically occupies a volume of 0.6m x 0.6m x 1.0m (or a floor space of 0.6m x 1.0m). Of all the disinfection technologies UV has the lowest space requirements. Adequate space should be reserved for the process of removing the lamps. It is a good idea to have a secure storage space sufficient for a 2 year supply of lamps.

From a practical standpoint a certain level of automation and sophistication of the control system is necessary. The control system should include UV sensor monitors which visually report sufficient levels of UV necessary to achieve disinfection. This simply cannot be done manually. The control system should let the UV lamps warm up at least 5 minutes prior to treatment of water. For systems which treat variable flows of water, the control system should be capable of switching on and off lamps to achieve the necessary dose proportional to flow. It is also a good idea to have a sensor to automatically shut down the flow of water during any failure of the UV system to produce adequate dosage for disinfection.

A standby power source to assure continuity of disinfection might be necessary where the electricity is unreliable.

Redundancy of modules might be advantageous in larger installations to allow for the replacement of failed lamps without interrupting operations.

c) Operation and maintenance:

The operation and maintenance requirements of UV disinfection systems are minimal but critical for adequate performance. It is necessary to assure that the quartz sleeves or teflon pipe are kept free of sediment or other deposits which attenuate the UV light. Deposition of particles might occur on either the air or the water side of the sleeves. For small systems this is typically done manually. It is usually necessary to wipe the quartz jacket of the lamp at least once a month and in exceptional circumstances 2 or 3 times per week. It is recommended that special, manually operated cleaning devices to accomplish this be incorporated into the design by the manufacturer.

The operator should read the dosage monitor on a regular basis, to assure appropriate reliability for the particular system in which it is installed. Lamps should be replaced at the intervals necessary to guarantee 30,000 microwatt seconds per square centimeter of exposure at all times. This will vary from one piece of equipment to another but is usually scheduled for the average interval when their intensity decreases to less than 70% of their rating. In very cold water replacement might have to be more frequent.

Since no residual is provided by UV light, it is imperative to thoroughly sterilize the entire system with a suitable chemical disinfectant prior to the initial activation of an UV disinfection unit. If there is any external contamination of the distribution system from back siphonage or cross connection, chemical disinfection will also be required there before start up.

It is advisable to use a secondary chemical disinfectant such as preformed chloramines in addition to UV disinfection, if there is likelihood of subsequent recontamination or regrowth of bacteria. Intermittently pressurized systems, systems which have leaks, and systems with significant residence times should be supplemented with such a chemical residual.

d) Safety:

Operators should be instructed about the dangers of UV to the eyes and skin and be provided with proper protective goggles to shield the eyes and adequate protective clothing.

A storage and disposal system for used mercury vapor lamps should be provided. Used lamps should be disposed of in a manner which precludes environmental contamination by the mercury.

e) Costs:

A complete UV disinfection system, including UV reactor, cleaning system, power supply and switch gear, controls and necessary instruments, currently costs about US$7,500 per kilowatt rating. The annual cost of operation and maintenance including electricity, labor and lamp replacement is about US$900 per kilowatt rating of the UV system.

The total cost of UV disinfection of clear water (without a secondary disinfectant to provide a residual) ranges from US$10 to US$20 per cubic meter of water disinfected depending upon the capital recovery factor, the cost of electricity, the cost of labor and the cost of lamp replacement at the site. At small water treatment plants such as are covered in this document the cost of bulb replacement amounts to from 10% to 20% of the total O & M costs whereas in larger plants it can be as high as 50%.

4.5. IODINATION SYSTEMS

Iodine has never been used continuously for long periods of time in community water systems, so the dosing devices have never really been tested under long-term field conditions; nevertheless, the saturator type of systems which have been used for the application of iodine have been tested for fluoride application and for hypochlorinators, so there is little doubt about the effectiveness, efficiency, reliability or durability of these devices to also dose iodine. The saturator is probably the most appropriate device for the dosing of iodine into small community water systems. Systems which utilize iodinated resins have been proposed but not yet used in disinfecting small community water systems.

Iodination equipment

In a saturator, water is passed through a bed of iodine crystals at a flow rate determined to result in a saturated solution when it exits the bed. Iodine, which is the least soluble of the halogens, has a saturation level of approximately 200 to 400 mg/liter over the range of water temperatures commonly encountered in Latin America and the Caribbean (see Figure 12). This saturated solution is then dosed into the water system by either a positive displacement metering pump, a valving system or an adjustable venturi, to provide a predetermined residual somewhere between 0.3 and 0.8 mg/liter in the distribution system. Because iodine is a relatively weak oxidant, it doesn't combine readily with ammonia, organics or most other substances commonly present in potable water systems; therefore, the iodine demand is usually quite small. Once the dosage is adjusted to obtain the desired residual in a particular distribution system, this same dose rate can be utilized over long periods of time. White recommends the use of metering pumps over injection devices that produce a vacuum by means of water pressure, because he feels that these devices cannot provide equal dependability of accurate feed rates (82). Figure 48 illustrates a saturator which utilizes a valving system to dose the iodine solution; Figure 49 illustrates a saturator which utilizes a diaphragm metering pump; and Figure 50 illustrates a typical iodinated resin disinfection system.

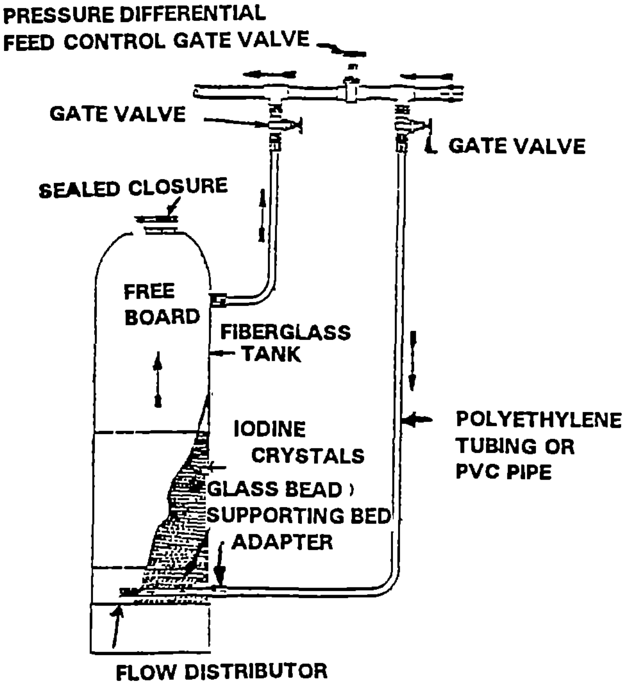

Figure 48. Iodine saturator--pressure differential feed type.

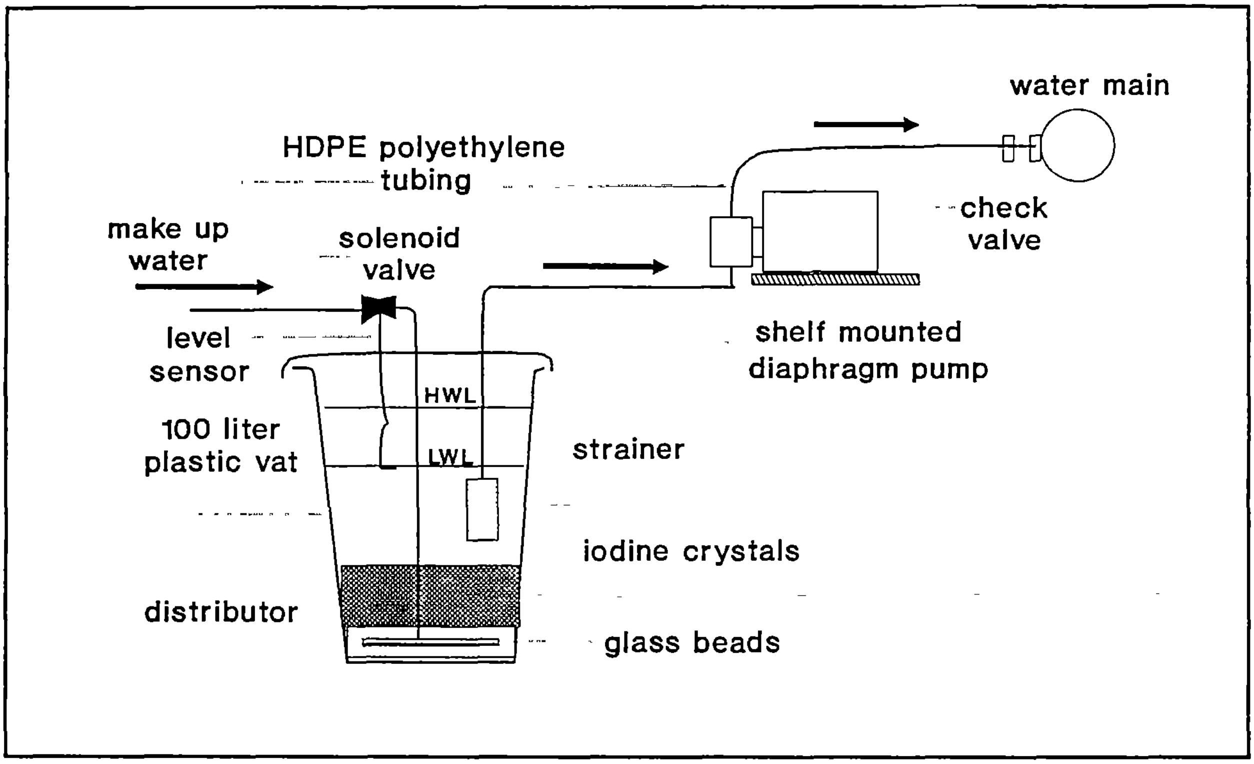

Figure 49. Iodine saturator and diaphragm pump dosing device.

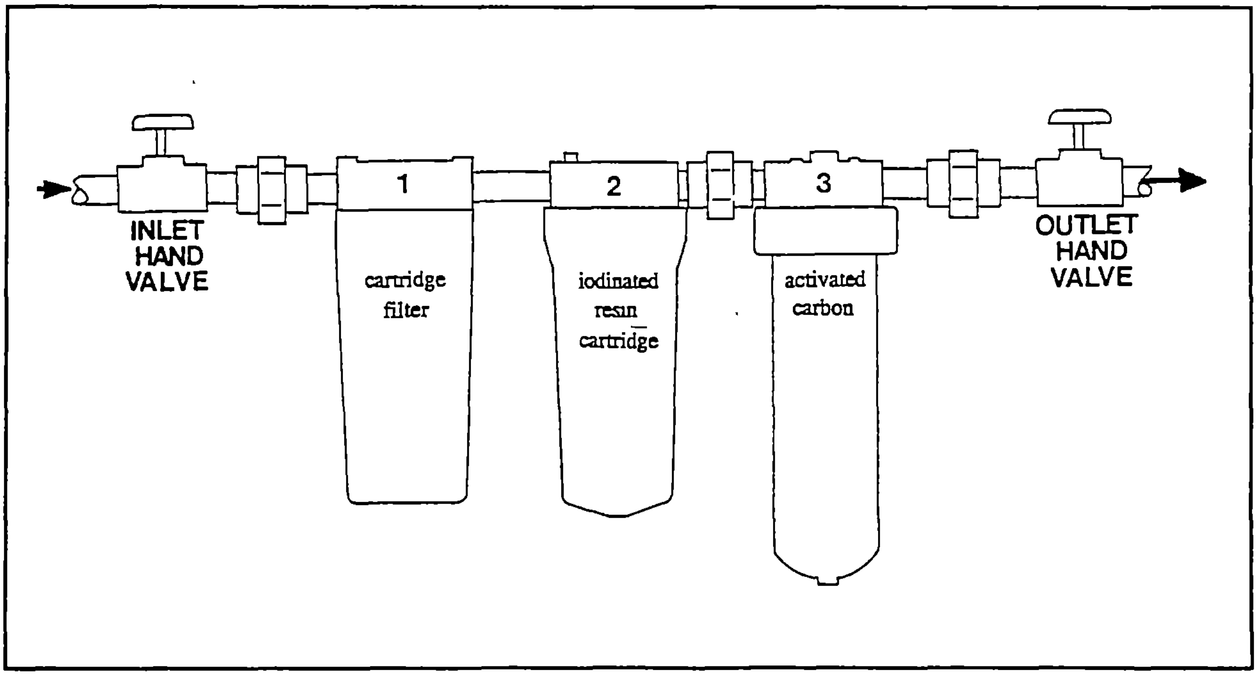

Figure 50. Typical iodinated resin disinfection system.

a) Energy:

The energy required to dose iodine into a water system is the energy necessary to drive a metering pump or the energy necessary to divert the flow around a control valve or drive a venturi. This compares with the energy necessary to inject hypochlorite into a water system and depends primarily upon the internal pressure of the pipe into which it is to be injected.

The energy required for an iodinated resin disinfection system in proportional to the total head loss due to the cartridge pre-filter, the iodinated resin cartridge and the activated carbon cartridge. A booster pump may be required in low pressure distribution systems.

b) Installation requirements:

Iodine disinfection devices, have simple requirements for installation.

Because iodine is a solid, it does not lose strength with storage (but it sublimes); therefore, it should be stored in sealed, water-tight containers. A separate storage room for the iodine drums is recommended. No special ventilation equipment is required in either the storage area or the dosing area.

Because it is necessary to handle saturated solutions of iodine and there is the chance of spilling some of this saturated solution, it is important that the dosing area be designed with a floor drain and the floor sloped towards the drain. It is also good practice to install a deep utility sink in the dosing room which would be used for cleaning equipment and their various parts from deposits of iodine. The deep sink spigot(s) should have a hose bib (with a siphon breaker) to allow connection of a hose for cleanup purposes and to be used for filling static type saturators with water. All hose bibs should be furnished with anti-siphon devices.

Iodine is the weakest oxidant of the halogens, and is not particularly corrosive; nevertheless, it is recommended that schedule 80 pvc or cpvc pipe be used for all piping which will conduct or be otherwise subject to contact with strong iodine solutions. Connections should be made by threads with teflon tape rather than with solvent weld connections. The discharge line from the dosing pump or the suction line from the venturi should be either polypropylene, teflon, or high molecular weight polyethylene tubing. Vinyl tubing is not recommended.

The iodinated resin disinfection systems usually come as a complete package that is ready to be connected at the inlet and the outlet. Adapters to connect to the existing piping system are the only special requirements other than electrical requirements if a booster pump is required.

It is important to note that the entire stream (flow) of water to be disinfected must pass through the iodinated resin system. A bypass to such as is commonly used on most other disinfection systems to apply disinfectant into a slip stream to later be combined with the main stream of water cannot be used for iodinated resin disinfection systems. This limitation usually restricts iodinated resin systems to point of use treatment.

c) Operation and maintenance:

The operation and maintenance requirements of an iodine saturator are minimal. They consist basically of assuring that the saturator has an excess charge of iodine crystals at all times and an adequate supply of water, and that the dosing pump or venturi is functioning properly and that the cleaning of the poppet valves in the pump or the entrance of the venturi is provided, as necessary. Although it is possible for a saturator to run unattended for a week or more, it is recommended that it be checked on a daily basis. In general a venturi dosing device requires more frequent attention than a positive displacement dosing pump.

The operator should also sample and test the finished disinfected water in both the treatment area and in the system to assure that the predetermined residual is being maintained. This should be closely monitored to assure that a minimum residual of 0.5 mg/liter is maintained and that the residual does not exceed 0.8 mg/liter anywhere in the system.

For an iodinated resin system, it is important that the pre-filter, the iodinated resin cartridge and the activated carbon cartridge be changed at the intervals recommended by the manufacturer. This will be on the order of weeks or months depending upon the flow treated and the quality of the water. Nevertheless it is recommended that the system be checked by the operator on a daily basis to assure that the system is functioning properly and to take water meter readings which will be utilized in determining the frequency of cartridge replacement.

In all of the iodine disinfection systems it is important that good control of the iodine residual be maintained.

d) Safety:

Iodine crystals are easy and safe to handle. Rubber gloves and a surgical mask are recommended precautions to be taken when iodine crystals are being handled, because iodine is a toxic substance and should not be ingested. Care should be taken to never store ammonia in the vicinity of iodine crystals because their accidental mixing may result in the formation of an explosive product.

The iodinated resin disinfection systems are particularly safe, due to both the chemical nature of the resins and because of their packaging.

Because of the paucity of experience with iodination, it is recommended that any installation of this method of disinfection in Latin America be considered experimental and that a special program be developed to closely monitor and record all aspects of this alternative method of disinfection.

e) Cost:

Currently the cost of iodine is about ten times as expensive as chlorine gas. It is commonly available in 100 pound drums. Its 1990 cost F.O.B. New York was about US$12/kilogram for USP granular iodine and roughly US$8/kilogram for unrefined iodine crystals. The cost of iodination lies primarily in the chemical cost. The total, current cost of iodination, including capital recovery of equipment, labor, energy and the iodine itself, is estimated to range from about US$7 to US$12 per 1000 m^3 of water disinfected.

The labor cost associated with iodine disinfection is quite low. The saturator, once adjusted, requires little attention and can be charged with a sufficient quantity of iodine to last a week or more between refills. Unlike hypochlorite solutions the iodine solution does not lose its strength with time to any significant degree; however, it is a good idea to check on the apparatus once a day to assure that the venturi, poppet valves, or the tubing does not clog with precipitates.

The total cost of iodinated resin systems per cubic meter of water treated is quite high in comparison to all other disinfection systems. At the replacement rate of the iodinated resin cartridge as recommended by the various manufacturers of these systems the cost of the iodinated resin alone is from about US$ 0.30 to US$ 0.50 per cubic meter of water treated. When the cost of the pre-filter and the activated carbon cartridge replacement at the rate recommended by the various manufacturers is included the cost of water treated ranges from about US$1.20 to as much as US$ 4.00 per cubic meter of water treated. This would preclude the use of iodinated resin for piped community water distribution systems. It has been used few special situations where dependability and simplicity of operation and maintenance is of paramount importance such as in clinics, schools and hospitals and few point-of-use treatment.

5. SELECTION OF DISINFECTION SYSTEMS

5. SELECTION OF DISINFECTION SYSTEMS

Ideally, the objective in selecting a disinfection system is to obtain maximum reliability; best overall economy; minimal undesirable effects on the water to be treated; and maximum effectiveness of the disinfectant over the widest range of expected conditions. Under normal circumstances no single disinfection system will achieve all of these goals. It is a good idea to first consider the hierarchical importance of the objectives for the specific application(s) and then to establish a reasonable balance among the performance priorities. This requires a thorough understanding of the properties and characteristics of the different disinfectants; knowledge of the organisms targeted for disinfection; comprehensive information on the existing conditions (physical and socio-economic); and in-depth knowledge of disinfection equipment.

The selection of disinfection systems can be made on a large scale, such as for national or regional applications as well as for a specific application. The first can be thought of as a general rule and the second, as the specific decision. There are many advantages to standardization of disinfection equipment and supplies, especially for smaller countries, but because no single method of disinfection is the most suitable for every situation, it will usually be necessary for a country or a national agency to utilize more than one method of disinfection.

General Conditions

Information on the general conditions pertinent to the selection of disinfection systems may include climate, rainfall, temperature, humidity, topography, communication, transportation, commercial infrastructure, and the availability and reliability of electricity. It is also necessary to have information on the type, capacity and quantity of water sources; on their chemical, biological and physical quality; and on the present and potential level of contamination. Further, it is helpful to know the incidence of various diseases which may be transmitted by water. All this information is important to determine the adequacy of the water supply, the feasibility of dependable disinfection, and processes that may be required to modify the situation to assure dependable and effective disinfection.

The selection of the most appropriate disinfection technology also requires that physical, social, technical and economic factors be taken into consideration. Physical conditions may affect the selection of a given system or favor that of another. For example, the lack of adequate roads to facilitate the transport of chlorine cylinders may favor the use of calcium hypochlorite or perhaps a disinfectant generated on-site; but the non-availability of reliable electricity may preclude the use of the latter. Likewise the social organization, available skills and infrastructure, in some instances, may not be adequate to cope with the technical requirements of an otherwise efficient disinfection system necessitating the choice of a less efficient system but one which overall is more appropriate for the situation.

In large-scale national programs, the organizational, technical, and economic restrictions can sometimes be overcome through specific program components designed to remove or resolve them. It may be cost effective to provide training; to strengthen infrastructure; to make provisions for chemical supplies and replacement parts; to insure community participation and to overcome inadequacies in the support systems. It may even be feasible to produce the necessary components and chemicals for the disinfection systems in the country.

For small, local projects concerned with the installation, operation and maintenance of only a few disinfection systems at individual locations, the selection of an appropriate technology is usually somewhat restricted by the limitations of the local infrastructure, technical capabilities, skills, and available material. The installation of a disinfection system that has operation and maintenance requirements beyond these limitations could lead to failure of equipment and wastage of funds.

It should be emphasized that disinfection cannot be separated from the overall situation of the water supply services; both have to be in tune. The incorporation of disinfection in an otherwise well operated and maintained water supply system should be relatively simple but an attempt to insert it into a poorly operated facility which relies upon inadequate management is to invite failure.

A careful analysis should be made of all relevant factors which might have an influence on the appropriateness of the selection. Sometimes one or more disinfection systems will stand out in light of local conditions and needs, and the systems can be preselected. More frequently the decision will not be so easy and it will be necessary to field-test a number of disinfection systems to determine their overall suitability. Field trials and pilot projects are always recommended where new technologies are being considered. To develop a corps of capable and qualified personnel necessary for the expansion of disinfection programs, demonstration projects may be especially relevant where there is limited experience in the use or selection of disinfection technologies.

Economic aspects

In the case of disinfection, the least expensive technology may not necessarily be the most appropriate. Disinfection is so important that reliability, sustainability and effectiveness usually have primacy over initial cost or the cost of operation and maintenance. Depending on circumstances, a more expensive solution could be desirable if the reliability, durability, simplicity of operation, and availability of spare parts and supplies are better than those of the less costly system. It is usually advantageous to pay a little more if the extra investment will assure success; in the long run it may prove to be more economical, particularly if health is taken into consideration.

The capital cost of disinfection equipment and its installation, as well as the recurring cost of operation and maintenance of a properly selected disinfection system, are relatively low, constituting only a small percentage of the cost of construction, operation and maintenance of a water supply service. Even the cost of the more expensive methods of disinfection appear rather modest in comparison to the medical and social cost associated with waterborne diseases such as cholera, typhoid, and other waterborne disease. Thus it is important to determine the cost of disinfection both comparatively and quantitatively. These costs will vary considerably depending on local conditions, availability of nationally manufactured disinfection devices, availability of disinfection materials, infrastructure and other factors.

In some cases the costs can be reduced by manufacturing the equipment and producing disinfection materials within a country. Production of various disinfection devices is being carried out in several Latin American countries with minimal dependance upon imported components and in some countries this is attaining a considerable degree of success. The level of costs and the simplicity of some of the disinfection technologies indicate that, eventually, appropriate equipment could be manufactured in a number of the countries of the Region. Further developments are to be expected in the near future. Unfortunately concrete information on this experience is not readily available to help assess the economic feasibility and capacity of local production. Start-up of local production of the more complex equipment is not easy; it can be capital-intensive; and it may not always be possible due to lack of raw materials, essential components and expertise. In the initial stages of a disinfection program the initial demand for such equipment may be low, resulting in higher production costs. For these reasons the lesser developed countries would probably be well advised to initially enter the production of the simpler disinfection equipment rather than that which is technically advanced.

Energy aspects

The availability and reliability of an energy source is frequently a determining factor which governs the selection of some disinfection technologies for small community water systems. For example the absence of reliable electricity could preclude the use of ozone, ultraviolet light, devices for on-site generation of disinfectants and chemical pumps. Various devices for hypochlorination and pressure chlorine gas feed regulators which do not require electricity for their operation would most likely be preferable devices for such a circumstance.

Significant progress has been made in recent years in the development of alternative sources of energy such as photovoltaics and micro-hydroturbines. One manufacturer has coupled photovoltaics to a metering pump for sodium hypochlorite which is suitable for flows up to 2 gallons per minute and pressures up to 25 psig. Currently The Pan American Health Organization jointly with Sandia Laboratories is conducting field trials to evaluate the feasibility of utilizing photovoltaics as an energy source for on-site generation of mixed oxidants for disinfection. Another demonstration project using a micro-turbine for energy has been initiated. In a number of situations the use of such alternative energy sources may be appropriate but more experience and operating time will be necessary to enable a thorough evaluation. Alternative energy applications for disinfection warrant consideration for demonstration or pilot projects because of the large number of systems which need disinfection but which lack dependable electricity.

Technical considerations

Drinking water disinfection devices for small communities vary considerably in their technical complexity and operation and maintenance requirements. In general more complex disinfection systems require better qualified staff than simpler ones, although the latter may require more frequent attention.

Table 14 summarizes the characteristics and relative effectiveness of disinfectants commonly used in drinking water supply. This information provides first level data for the selection of disinfectants. For instance, chlorine as gas or hypochlorite is a good disinfectant against bacteria, viruses, some protozoa and helminths, but it is not very effective against giardia and cryptosporidium. Ozone which is much more effective against all micro-organisms, particularly protozoa and viruses, does not provide a lasting residual. It also requires dependable electricity for its generation and better qualified technicians than hypochlorination installations. Ultraviolet disinfection installations have an advantage that they can run for long periods of time without the need for adjustments and because it is a physical rather than a chemical process, it can usually be operated and maintained by minimally trained technicians. However, dependable electric energy is required and the addition of a secondary disinfectant is necessary, which brings its own operational complications.

To insure dependable, effective, and sustainable water supply disinfection, the type of back-up service for maintenance and repair, whether centralized or decentralized, has to be available when needed; must be effective from the beginning of the operations; and must be consistent with the complexity and frequency of maintenance requirements. Doing things right from the outset will usually result in satisfied customers, whereas undependable and slipshod service is almost certain to alienate them. The technical and organizational capacity of the communities is one of the most important factors in the selection of a disinfection system. Other factors are the available infrastructure (both government and private), the social organization of the communities, transport facilities and costs, and maintenance structure.

Installation of the more complex disinfection systems may require special expertise, which often may not be readily available within the national organization or water supply agency. Initially it may be necessary to utilize private consultants. In national programs the recommended practice is to institute the necessary training to develop the capacity to ensure both quality and reliability of installations. In small projects and isolated cases, this practice is usually not feasible.

Community perceptions and social considerations

In some instances the social organization, available skills, and infrastructure which supports small communities may not be adequate to cope with the technical requirements of certain disinfection systems. This possibility should be investigated during the selection process.

Arrangements for operation and maintenance must be compatible with the local situation. It is important to insure that the community, the water supply agency, and local authorities, as appropriate, have accepted clearly defined responsibilities for disinfection. Plans for disinfection should be made in consultation with the local authority, so that all concerned are informed of and agree with their responsibilities and rights.

It may be advantageous for a local organization, such as the water committee, to participate in the selection of the disinfection system and to be aware of and agree to the implications, including the financial needs and other support required. Ideally this should be the same organization that is responsible for insuring that the minimum skills required at local level are available to guarantee proper use and maintenance of the disinfection system.

Knowledge of the community's aspirations, expectations and perceived needs is important. Their views on health, environmental health, basic sanitation, disinfection of drinking water, tastes and odors, toxic or deleterious substances in the water should be taken into consideration. The receptiveness, political support and levels of education of the community can also be important factors which influence the final decision. The availability of such information can facilitate and orient the responsible agency's discussions with the community leaders, so that proposals can be developed and implemented jointly.

The above considerations may require extensive discussions with future users, but two way dialogue is necessary in order to reach an understanding with the community of the benefits of disinfection, as well as the implications of adopting it, and to obtain a strong community commitment to support and assure reliable disinfection. A guiding principle for water supply programs for small communities is to have them actively participate in the selection of the kind of water supply that is to be constructed, so that local needs and preferences are taken into account and the consequences of the various options are known to the users beforehand. It has been postulated that without such community participation, the chances of failure are very high.

Feedback of information

The feedback of information from the actual operation and maintenance of disinfection facilities to the designers, purchasers, planners, manufacturers, service representatives and suppliers is essential for progressive and timely improvement of disinfection facilities and programs. This remains one of the weakest links in the chain of events necessary to achieve sustainable programs for disinfection. Objective reporting of both the negative and positive aspects, along with constructive criticism and recommendation for improvement by the operators of the disinfection equipment and the public health inspectors should be incorporated into national disinfection programs. This will foster improved installations as well encourage as better designed and higher quality equipment.

An effective system for information feedback will take advantage of the entire disinfection program to gather information in much the same manner that a demonstration project does. It is important that the data and experience be dependably recorded in a manner which will assure its accuracy and ready accessibility. This information should be routinely reviewed and analyzed by the personnel responsible for selection and design of disinfection facilities.

Laboratory tests and demonstration projects

In a preliminary comparison and evaluation of disinfection methods being considered for use in a national water supply program for small towns and rural areas, rarely will one stand out in light of the variance in local conditions. More often than not several alternatives will appear promising or have potential for use and the best decision may not be readily apparent. It will then be necessary to preselect several of the most promising systems and subject them to testing to identify factors and characteristics which affect performance under specific conditions and to determine their overall suitability. In such cases, demonstration projects might be warranted to closely assess the performance of each alternative under actual field conditions, to confirm the technical feasibility, to determine accurate cost estimates, to investigate operational characteristics, to evaluate community acceptance and to develop adaptations or adjustments to the technology.

Testing of disinfection equipment in the laboratories of universities and research institutions is done primarily to gain scientific knowledge, to develop technology, to evaluate effectiveness against specific organisms, and to improve designs. Even though valuable information is gained, laboratory testing will not be sufficient in itself to establish how satisfactory or feasible a disinfection system will be under field conditions.

Field tests are essential to determine real operational and maintenance requirements; to ascertain equipment durability and reliability and to identify limitations and other pertinent factors. To be meaningful for large scale applications, both short-term and long-term field testing should be carried out under a range of conditions which are representative of the situations in which the equipment will be used. Field tests also verify disinfectant and disinfection system reliability and the availability and adequacy of infrastructure support. To be most meaningful for large scale applications, field testing should be carried out under a range of conditions representative of those which will be encountered in the program.

Well planned and executed demonstration projects and field tests pay for themselves many times over. They are always recommended where new technologies are being considered and they are particularly relevant for rural water supply programs in countries with little experience in the use of the disinfection technologies under consideration. However, demonstration projects are of value only if they are closely and objectively monitored and adequate training, technical support, follow-up, analysis and adjustments are included as essential project components.

Standardization

The advantages of standardization generally outweigh the disadvantages. Any country which has an active national water supply construction or improvement program should give serious consideration to at least a degree of standardization of disinfection equipment and installations. It is usually advantageous, convenient, expedient and most economical to standardize on one or two methods of disinfection to cover the average situation, but with allowance for other methods to be considered for specific exceptional circumstances.

The major advantages of standardization are:

- Training of operators and technicians is easier and less expensive.
- Spare parts are interchangeable and usually more readily available.
- Mass purchasing will usually result in lower prices.
- It is easier to stockpile chemicals in convenient locations.

The major disadvantages are:

- There is a tendency to use standard systems and equipment even in situations where they are not suitable.
- Improvements in equipment and installations are realized more slowly.
- Inadequacy in a non-standard situation may not be tolerable.
- Nothing is universally applicable to all situations.

Precautions to consider when standardizing:

- Do not preclude competition or prices will go up and service by the suppliers will go down.
- Continue to have pilot projects of other methods of disinfection for unusually difficult situations.

Final selection

The selection process for disinfection systems for national programs should take into consideration the aforementioned main factors to ascertain that disinfection is feasible, under the existing conditions in the country and under the provisions of the program; however, the selection of systems for regional or local situations is inherently specific and hence must take into consideration the particular local technological, physical and economic limitations and restrictions. The system must be compatible with the available technical skills, suppliers of parts, repair facilities, and capabilities for operation and maintenance. These constraints are likely to significantly limit the technical feasibility of the disinfection systems under consideration. Under severe circumstances it may even be necessary to accept the fact that community water supply disinfection is not feasible at the time, thereby avoiding the installation of devices and systems that surely would be doomed to failure. Alternatively, disinfection at the household level may be more appropriate.

To facilitate comparison, Table 14 summarizes the effectiveness and important characteristics of disinfection systems and can serve as a guide for initial comparison but more importantly as a check list to alert the decision makers to what detailed information will be needed for determining the suitability of the various disinfectants and devices.

The selection of disinfection systems can be broken down into a series of decision making steps which are depicted in Figure 51, An Algorithm for Disinfection System Selection. The order in which the decisions are presented is important and should be maintained.

The first decision is to determine if the disinfectant is effective against the suspected pathogens under the prevailing conditions. To do this, it is first necessary to have a good idea of the prevailing pathogens which are commonly present in the waters being disinfected. Such information may have already been determined by a comprehensive water quality monitoring program or through special studies. If not it will probably be necessary to deduce which organisms are likely to be present from other reliable and relevant information sources, such as the public health department, local hospitals and clinics. A good deal of mature judgement is needed for this first step. For example, there is a great deal of difference in the pathogens which are likely to be present in the water from a well which taps a deep aquifer of sand than those which are likely to be present in water derived from a river which receives untreated sewage effluent from municipal areas. The water in the first situation would most likely contain few, if any, pathogens and the disinfectants primary purpose would be to safeguard against contamination of the well, to provide a disinfectant residual therefore would necessitate a disinfectant primarily as a residual to prevent the growth of bacteria in the distribution system and to serve as an indicator (by its absence) of contamination from cross connections or back siphonage.

TABLE 14 A
CHARACTERISTICS OF DISINFECTANTS AND DISINFECTION SYSTEMS

DISINFECTANTS:	CHLORINE	HYPOCHLORITE	CHLORAMINES
CHARACTERISTICS			
CLASS OF DISINFECTANT	Primary and Secondary	Primary and Secondary	Secondary only
EFFECTIVENESS AGAINST:			
Bacteria	Very good as HOCl	Very good as HOCl	Poor
Viruses	Very good as HOCl	Very good as HOCl	Poor
Protozoa	Fair	Fair	Very poor
Helminths	Good	Good	No information
INFLUENCE OF:			
pH	Increase in pH decreases efficiency	Increase in pH decreases efficiency	pH > 7; monochloramines pH < 5, dichloramines
Increased turbidity or suspended solids	Protects microorganisms against disinfectant.	Protects microorganisms against disinfectant	Protects microorganisms against disinfectant.
Temperature decrease	Decrease efficiency	Decrease efficiency	Decrease efficiency
Ammonia/organics	Organochlorine compounds formed	Organochlorine compounds formed	Little effect
DISINFECTANT ITSELF			
Health effect	None at normal dosage	None at normal dosage	None at normal dosage
Taste and odor	Negligible in absence of organics	Negligible in absence of organics	Negligible
UNDESIRABLE BY-PRODUCTS			
Tastes/odors	From reaction with organics and phenols	From reaction with organics and phenols	None
Trihalomethanes	Can develop with precursors present	Can develop with precursors present	Not formed
TYPICAL DOSE	2 0 - 5.0 mg/L	2.0 - 5.0 mg/L	1.0 - 2.0 mg/L
TYPICAL SYSTEM RESIDUAL	0.2 - 0.5 mg/L	0 2 - 0.5 mg/L	1.0 - 2.0 mg/L
TYPICAL CONTACT TIME	30 minutes	30 minutes	Not applicable
PRECONDITIONING REQUIREM.	< 1 NTU Turbidity pH 6 5 < 7.8	< 1 NTU Turbidity pH 6 5 < 7 8	< 1 NTU Turbidity pH 6.5 < 7 8
CHEMICAL PREPARATION	Not required	Batch mixing	Proportioning ammonia & chlorine
FOREIGN SUBSTANCES INTRODUCED	Chlorine	Chlorine and sodium or calcium	Ammonia and chlorine
TESTING FOR RESIDUAL	Relatively easy	Relatively easy	Relatively easy
EFFECT OF OVERDOSE	Taste and odors/THMs in presence of organics/precursors	Taste and odors/THMs in presence of organics/precursors	No taste and odors or THMs
ENERGY REQUIREMENTS	Yes, for booster pump	Depends on equipment	None
PACKAGING OF CHEMICALS	100 & 150 lb & ton cyl	HTH powder; 45 kg drum HTH tablets; 60 lb drum NaOCl; 1 gal or 100 L	Same as for chlorine or Hypochlorite, Ammonia in cylinders
LAC EXPERIENCE	Wide experience	Wide experience	Little experience
TYPICAL COSTS ($/KILOGRAM)			
At production site	0 70 to 1.50	1.20 to 8.00	No information
Relative to chlorine gas	1.00	2 to 4	3 to 4
OBSERVATIONS	Reduces tastes and odors above the breakpoint but may produce THMs.	Reduces tastes and odors above the breakpoint but may produce THMs.	Weak disinfectant, may allow regrowth of bacteria

TABLE 14 B
CHARACTERISTICS OF DISINFECTANTS AND DISINFECTION SYSTEMS

OZONE	MOGOD	UV LIGHT	IODINE
Primary only	Primary and Secondary	Primary only	Primary and Secondary
Excellent	Very good	Very good	Very good
Excellent	Very good	Very good	Good
Very good	Good	Fair	Good
Excellent	Good	No information	No information
Change in pH has little effect	Less affected by pH change than chlorine	No effect	Increase in pH decreases efficiency
Protects microorganisms against disinfectant	Protects microorganisms against disinfectant	Protects microorganisms against disinfectant	Protects microorganisms against disinfectant
Decreased efficiency	Decreased efficiency	Little effect	Decreased efficiency
Exerts an ozone demand	Less affected than chlorine	No effect	Little effect
None at normal dosage	None at normal dosage	None	Some people are iodine sensitive
None	Not detectable	None	Slightly medicinal
Improves	Improves	None	Slight
Not formed	30% - 50% of level developed by chlorine	None	Not formed
4.0 - 8.0 mg/L	1.0 - 3.0 mg/L	30,000 microwatt-sec	0.5 - 1.0 mg/L
None	0.1 - 0.2 mg/L	Not applicable	0.1 - 0.2 mg/L
10 - 20 minutes	15 - 20 minutes	Not applicable	30 minutes
< 1 NTU Turbidity pH 6.0 < 9.5	< 1 NTU Turbidity pH 6.0 < 8.5	< 1 NTU Turbidity Color removal	< 1 NTU Turbidity pH 6.5 < 8.5
Dessication and cooling of air	Batch mixing of salt solution	Not required	Batch mixing
Ozone and oxygen	Chlorine, peroxides and ozone	None	Iodine
Quite difficult	Relatively easy	Not applicable	Difficult
No effect	Less than for chlorine	No effect	Taste and odor. Possible health effect
Yes	Yes	Yes	Depends on equipment
None required	NaCl in 80 lb. bags	None required	25 kilo drums
Limited experience	Limited experience	Limited experience	Very little experience
2.50 to 5.00	0.50 to 1.00	Not applicable	10.00
3 to 5	0.8 to 1.5	3 to 5	6 to 10
Breaks organic molecules into more biodegradable form. Possible regrowth	Efficient disinfectant but the effect of differing proportions of oxidants not well understood.	Dosage is difficult to measure and assure.	Narrow range of dosage due to low toxic threshold

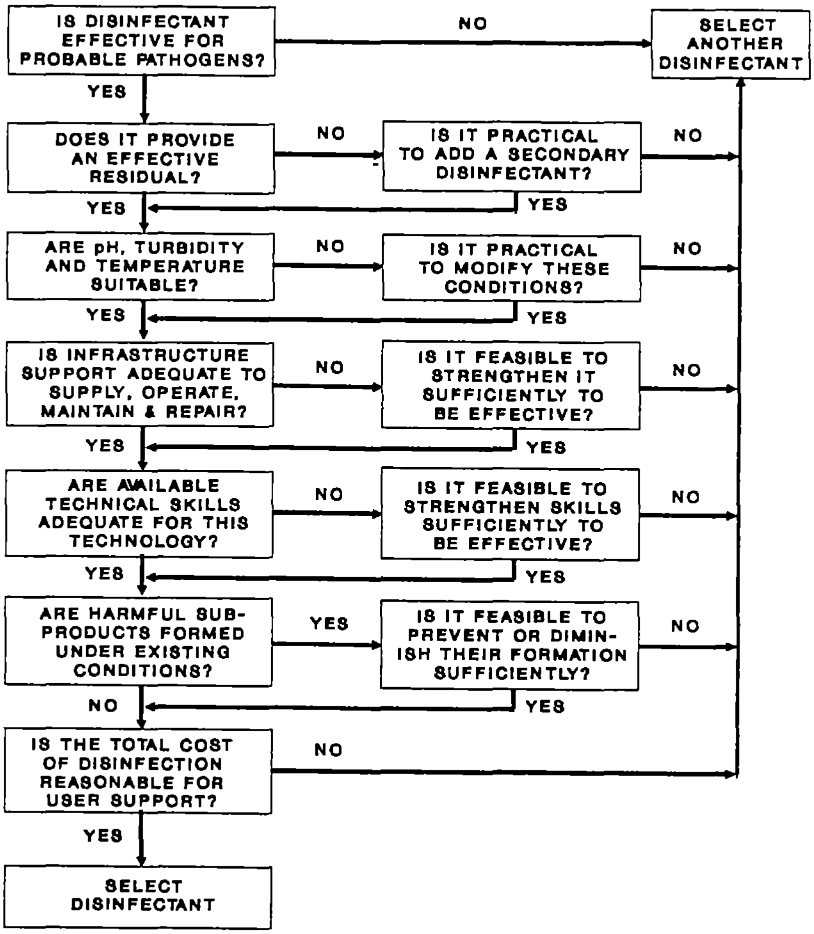

Figure 51. Algorithm for disinfection system selection

Any of the chlorine compounds could accomplish this. On the other hand, the river water should be presumed to be contaminated with pathogens of water-borne diseases. If *E.histolytica* or *Giardia lamblia* cysts are present, and there is inadequate treatment for their removal then it may be necessary to choose one of the stronger disinfectants such as ozone or mixed oxidants, or to install slow-sand filters or diatomaceous earth filters in the treatment process before disinfection and to increased the chlorine dosage and extended the contact time.

The second step in the selection process is to check for an effective residual. If the primary disinfectant does not have an effective residual then the practicality of adding a secondary disinfectant should be considered. The feasibility of monitoring the residual at the field level should also be taken into account at this time.

The third step is to determine if the prevailing conditions of pH, temperature and turbidity of the water to be disinfected are compatible with the disinfectant under consideration. If not, is it more feasible to change or modify these conditions, or to change to a more suitable disinfectant? This step requires a very good understanding of the limiting factors of each of the disinfectants and a thorough knowledge of the water conditions to be expected throughout the year. Table 14, which summarizes the effect that each of these factors have on the effectiveness of the various common disinfectants, should be consulted to identify when it is probably necessary to adjust one or more of these three parameters.

The fourth step is the analysis of the adequacy of the existing infrastructure to support the disinfection system. This is probably the most complicated and difficult determination, as it must take into consideration not only the support services of the equipment and chemical suppliers, but also the transportation and communication systems serving the subject communities. It may also be necessary to evaluate the electric power supply, the political/administrative organization and the average education level of the residents of the community. Will the support services be based in the private sector or the government sector? Are there dependable representatives for equipment and chemicals that stocks spare parts and supplies? Can they provide repair service and technical support for the operators? Will it be necessary to import spare parts and supplies? If so, is the warehousing capacity sufficient to assure replacement parts in a timely manner? If this is not the case, then is it feasible to adequately strengthen the supporting infrastructure? These issues must be addressed.

In the fifth step it is necessary to evaluate the available technical skills and to determine if they are adequate to carry out the necessary operational requirements, maintenance and repairs. If this is deficient, is it feasible to carry out the necessary training to enable the managers and operators to do the required work in an acceptable manner? How much and what kind of training will be necessary? How will it be funded? Who will carry it out?

The sixth step should consider the formation of harmful or otherwise undesirable disinfection byproducts. Will the products be formed? How much of a health risk do the by products pose? Is the level of the byproducts sufficient to cause a health problem? Does the water contain phenolics or other substances which react with the disinfectant and cause severe taste and odor problems? If so it should be determined if measures can be taken to eliminate the problem or reduce it to a tolerable level.

The seventh step is to consider the cost of the disinfection. On a per capita basis, all of the forms of disinfection of community water systems are a bargain, ranging from a low annual figure of about US$ 0.50 to a high of about US$ 2.50 per person. The cost:benefit ratio is overwhelmingly favorable.

CONCLUSIONS

Disinfection of community water systems remains one of the most important public measures taken to prevent outbreaks and epidemics of a large number of diseases. It is also one of the most cost effective. This has recently been demonstrated in Latin America where cholera has provided incentive to assure reliable, continuous effective disinfection which in turn resulted in decreases in other diseases such as typhoid, paratyphoid, hepatitis, and diarrheal diseases.

The microbiological quality of water is influenced by both natural processes and human activities but primarily those which are anthropogenic. Urbanization and demographic explosion by themselves are sufficient to further exacerbate microbiological pollution of the world's freshwater resources and this problem will surely become more severe in developing countries throughout the next decade. Agricultural development can also contribute to increased microbial pollution of water resources.

To minimize the possibility that waterborne pathogens are able to complete their life cycle by infecting human beings, it is preferable that multiple barriers be set in place, including sewage treatment and physical-chemical treatment and filtration of water supplies. Whether these processes are in place or not, the disinfection of water supplies is the final barrier which separates people from waterborne diseases. A hard fact is that for many community water systems, disinfection is the only feasible treatment.

A strong government policy which fosters the disinfection of water is needed to avoid any confusion over its importance. Community based support is essential to assure reliable continuous disinfection. The health sector should take a decisive and lead role in establishing government policy related to health, water quality and disinfection. The health sector should also avoid exaggerating the significance of health risks from disinfection by-products. Such risks are extremely small when compared to the microbial risks when there is no disinfection. It is important to compare these two issues through a risk-benefit approach.

Fortunately, disinfection is both effective and affordable. No community water system should be without it. Determining and achieving the most suitable method of disinfection for a community water system should be assigned one of the highest priorities among country's efforts for sustained development.

ANNEXES

ANNEX 1

TRANSITIONAL AND EMERGENCY DISINFECTION

Background

Under certain circumstances it becomes necessary to disinfect water at the household level or at the point of use. Such situations can be the result of emergencies brought about by a natural disasters, accidents or failures of water system components and they typically last a number of days or weeks until reliable service is restored. The need to disinfect at the household level or point of use can also be the result of long term, chronic socio-economic deficiencies which are likely to go unresolved for years. Even though both situations appear quite similar there are some basic difference which should be taken into consideration when the disinfection method is being selected.

There are a large number of households in Latin America and the Caribbean that currently do not enjoy the benefits of being connected to a safe and reliable piped community water system. This segment of the population obtains water from water vendors, intermittent distribution systems, public standposts, communal wells, springs, streams, rivers, lakes and irrigation ditches, of which almost all are of questionable microbiological quality. It has been estimated that at least 40% and possibly as high as 60% of the population of the developing countries of the Americas utilize such unsafe supplies of water.

In almost all of the deficient situations mentioned, the households have to store water in some type of container within the house to satisfy their basic needs . The container is usually selected more on the basis of availability and convenience than upon consideration to protect the contents from contamination. Studies carried out by PAHO as well as others have arrived at the conclusion that the water in household containers are frequently contaminated both before and after the water is placed in the containers. Such contamination has been identified as a frequent cause of the transmission of waterborne diseases particularly cholera and other diarrheal diseases. Due to the importance of water as the vehicle of transmission of a large number of diseases, the disinfection of water in these containers as a barrier to their propagation constitutes one of the most important interventions to control their incidence.

Even though it has long been recognized that a high level of public health requires the provision of a continuous safe supply of water, it is not realistic to expect that the "unserved" segment of the population, especially those in the poor marginal urban areas, will be able to receive such water supply service in the near future. This reality should dictate that a short term strategy be adopted to set in place transitional measures to assure a microbiologically safe water supply. To be sustainable they must be effective measures that can be implemented rapidly, at low cost and for the most part by household members. Such a program is within the capacity of virtually every community to plan, organize, implement and manage at the local level at an annual household cost of less that US$ 2.00. This can be accomplished through a program to enable households to disinfect their water supply in special containers which are designed to prevent contamination and to facilitate disinfection.

The importance of disinfection and safe storage of water in the household

The fundamental reason for disinfection of water is to eliminate the pathway of the propagation of waterborne diseases by the destruction or inactivation of the pathogenic organisms which are present in the water which will be ingested or be in contact with food to be eaten. The storage container also plays a critical role in that it should prevent the recontamination of the contents and facilitate the disinfection process. Both of these considerations should be addressed in any program or project which is to counteract the adverse effects of unsafe water supplies.

Alternatives for household disinfection of water and their characteristics

Their are a number of alternatives which have been successfully utilized for the purification of water on a small scale that can be applied in the household; several of them are affordable even for poor families, others are quite expensive.

Boiling

Boiling of drinking water is the most widely used and best understood of the methods to make drinking water microbiologically safe. It is a very effective means of pathogen destruction which is easily understood by almost everyone.

Pathogenic bacteria under favorable conditions can survive a wide range of temperatures, from below freezing to about 60 °C. Thermophylic bacteria actually may grow at around 70°C and their spores may resist temperatures higher than 100°C. All except a few very rare waterborne pathogens are rapidly killed or inactivated by exposure to the temperature of boiling water. All of the common waterborne pathogens are inactivated in water at temperatures of 100° C for several minutes. Experimental results of boiling water, as carried out by the Water Engineering Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio demonstrated that the surviving organisms per milliliter in a standard plate count were reduced from 8,900 at 25°C to less than 1 (the detection limit) when the water temperature was elevated to 60°C.

Amoebic cysts are destroyed in 2 minutes in water at 50°C and viruses are inactivated at 100°C in 1 to 3 minutes of boiling.

Boiling of water has several disadvantages. The most important is that it does not provide protection against recontamination. Next most important is that boiling of water is also one of the most expensive means of disinfection and in most instances is not ecologically sound. It is estimated that under prevailing conditions, roughly 1 kilogram of wood is required to boil one liter of water. Using other fuel for combustion, such as coal, propane, methane or electricity the cost ranges from about US$ 0.02 to 0.10 per liter of water. An economically disadvantaged family typically uses about 20 liters of water for purposes for which the microbiological purity is very important, such as drinking, food preparation, washing of dishes etc. At a cost of US$ 0.02/liter the annual cost would amount to US$ 146.00 which is beyond their capacity to pay. Thus whereas boiling of water can be affordable for a short period of time it is doubtful if the poor segment of the population could sustain this cost for months or years.

Chlorine

Chlorine is not only one of the most effective water disinfectants but it is also one of the least expensive. Chlorine is available in several different forms. For disinfection of household water supplies the hypochlorites of calcium and sodium would be more suitable than liquified gas. There are also more complex compounds of chlorine which are sold specifically as a household/individual water supply disinfectant. They will be covered separately.

Sodium hypochlorite is a solution which can be obtained in concentrations of from 1 to 10 percent. At concentrations higher than 10% it is unstable. Commercial solutions of sodium hypochlorite may be suitable but if they are produced specifically for laundry and general household cleaning they frequently contain other substances which may be toxic, in which case they should not be used for the disinfection of drinking water.

Calcium hypochlorite is available in powder or granular form with concentrations of 20, 35, 65 and 70 percent available chlorine and in tablets with concentrations of 65 or 70 percent available chlorine. From a practical standpoint it is usually much easier and more accurate to administer a solution of hypochlorite than a powder or granular form when disinfecting at the household level. Thus it is common practice to prepare a stock solution with an available chlorine concentration of 1% to be used for this purpose. Table I-1 summarizes the data of the quantity (grams) of various forms of calcium hypochlorite which added to one liter of water would yield a 1% stock solution. Other concentration of a stock solution could be obtained by proportionately increasing the quantity of compound added. A 1% stock solution has a longer shelf life than higher concentrations.

TABLE I-1
PREPARATION OF 1 LITER OF A 1% STOCK SOLUTION OF HYPOCHLORITE FROM VARIOUS COMPOUNDS OF CALCIUM HYPOCHLORITE

NAME OF COMPOUND	AVAILABLE CHLORINE (%)	GRAMS OF CHLORINE COMPOUND PER LITER OF WATER
CHLORINATED LIME	20	50
CHLORINATED LIME	25	40
CALCIUM HYPOCHLORITE	35	28.6
CALCIUM HYPOCHLORITE (HTH)	65	15.4
CALCIUM HYPOCHLORITE (HTH)	70	14.3

Table I-2 provides data for the amount of various strengths of hypochlorite solution to be added to various volumes of household containers in order to dose the container with 2 mg/liter and 5 mg/liter of available chlorine.

TABLE I-2.
DISINFECTION OF WATER IN HOUSEHOLD CONTAINER OF VARIOUS CAPACITIES WITH DIFFERENT CONCENTRATIONS OF HYPOCHLORITE SOLUTIONS TO DELIVER DOSES OF 2 AND 5 MG/LITER.

Desired dose: 2 mg/liter of chlorine
(for low turbidity but contaminated water)

FREE AVAILABLE CHLORINE	VOLUME OF THE CONTAINER IN LITERS			
	1	10	15	20
0.5%	8 drops	(4 ml)	(6 ml)	(8 ml)
1%	4 drops	40 drops (2 ml)	(3 ml)	(4 ml)
2%	2 drops	20 drops (1 ml)	30 drops (1.5)	40 drops (2 ml)
5%	1 drop*	8 drops	12 drops	16 drops (0.8)
10%	1 drop*	4 drops	6 drops	8 drops

*minimum dose possible

Desired dose: 5 mg/liter of chlorine
(for turbid and contaminated water)

AVAILABLE FREE CHLORINE	VOLUME OF THE CONTAINER IN LITERS			
	1	10	15	20
0.5%	20 drops	10 ml	15 ml	20 ml
1%	10 drops	5 ml	7.5 ml	10 ml
2%	5 drops	2.5 ml	3.75 ml	5 ml
5%	2 drops	20 drops (1 ml)	1.5 ml	2 ml
10%	1 drop*	10 drops (0.5 ml)	15 drops (0.75 ml)	20 drops (1 ml)

Immediately following the application of the hypochlorite solution the water should be thoroughly mixed and allowed to set for at least 30 minutes prior to its use to assure adequate time for the chlorine to be in contact with the micro-organisms to assure their inactivation or destruction.

Chlorine has several advantages in disinfecting household water containers over disinfecting a distribution system. Generally the water temperature in a household container is higher and the contact time might be considerably longer than for a water system, both of these factors increase the effectiveness of the chlorine as a disinfectant and this will help to assure disinfection of the more resistant micro-organisms. A well designed container can also be cleaned and disinfected more easily than a piped water distribution system.

The cost of sodium hypochlorite solutions is typically US$ 2.50 to US$3.00 per kilogram of available chlorine. At these prices and a dosage of 5 mg/liter and a daily use of 40 liters of water per family for drinking, cooking and essential hygiene the annual cost per family for disinfection would only be US$ 0.18 to US$ 0.22. If the price of hypochlorite solution was quadrupled for distribution and profit it would still be affordable.

Iodine

Iodine is an excellent disinfectant. It is efficient against bacteria, virus, protozoa and their cysts and other microorganisms implicated in waterborne diseases. Nevertheless its use has been limited, usually to emergency disinfection for short periods of time or for disinfection of individual water supplies in isolated or remote areas. The use of a 2% solution of tincture of iodine is a practical means for disinfecting small quantities of water. A dose of 2 drops per liter is sufficient to disinfect water which has little turbidity. As with chlorine, it would be desirable to filter water to reduce the turbidity prior to the application of iodine. After application the water should be thoroughly mixed and allowed to stand for 15 to 20 minutes.

The cost of crystalline iodine is its greatest drawback, ranging in the vicinity of US$ 12.00 per kilogram. Its major use for water disinfection has been in tablets for disinfection of individual water supplies and for emergency disinfection. This will be covered in the section on commercial disinfectants.

Commercial disinfectants for individual and household use

There are a number of commercially disinfectants which are utilized for disinfection of small volumes of water, usually on an individual or household basis. These disinfectants are effective against the majority of pathogens transmitted by water at the temperatures and contact times recommended by the producers. When such disinfectants are employed it is very important to closely follow the instructions. The majority of these disinfectants are compounds of chlorine and compounds of iodine.

The following table is a summary of the principal characteristics of the most common commercial disinfectants for individual use.

TABLE I-3.
COMMON COMMERCIAL DISINFECTANTS FOR INDIVIDUAL AND HOUSEHOLD USE

Commercial name and active chemical ingredients	Packaging and recommended dose[1]	Cost/tablet (US $)
HALAZONE	bottle of 100 tablets	
(p. carboxybenzenesulphor-dichloroamide)		
4.0 mg tablet		
160 mg tablet	1 tblt/liter of water	0.02
	1 tblt/40 liters of water	0.05
POTABLE AGUA OR GLOBALINE	bottle of 50 tablets	
(tetraglycine hydroperiodide)		0.05 - 0.10
8.0 mg tablet	1 tblt/liter of water	
AQUATABS	foil strips of 50 tblts:	
(sodium dichloroisocyanurate)	1 tblt/5 liters of water	0.0065
17 mg tablet	1 tblt/25 liters of water	0.0158
85 mg tablet	tubs:	
167 mg tablet	1 tblt/50 liters of water	0.005
CHLOR-FLOC	hermetically sealed	
(sodium dichloro-s-triazinetrione)	package of 10 tablets	0.05 to 0.10
600 mg tablet		per tablet
(also contains flocculating agents)	1 tblt/liter of water	

[1] The dose can vary depending on the quality of water being treated

These disinfectants are commonly used by armed forces, hunters, campers, hikers and other outdoorsmen as well as for emergency conditions following natural disasters. They are conveniently packaged and are easy to apply. Most of these commercial disinfectants are generally costly if used on a continuous basis. The dosages recommended by the producers are for the most part for short periods of time, not for prolonged use.

The most economical of the commercial disinfectants for individual household use appears to be the Aquatabs. Its active ingredient sodium dichloroisocyanurate is not accepted in every country as a drinking water disinfectant but it is utilized extensively for this purpose in others. It has a long shelf life relative to the other commercial disinfectants for individual use. Halazone has been widely used for emergency disinfection and was used for many years by the military sector. It is produced in only two sizes, 4 mg for disinfection of 1 liter and 160 mg for disinfection of 40 liters. Currently the armed forces of the world are mostly using Globaline and Chlor- floc for disinfection of personal water supplies. With Chlor-floc, the precipitate will have to be settled and removed before consumption of the treated water.

Importance of the household container

It has been found in a number of field investigations that the type of household container used has a strong influence on the water quality. Frequently even though the water which is used to fill the container is of good quality, even containing a disinfectant residual, the contents rapidly becomes contaminated through contact with "dirty" hands and utensils used to extract the water. There are a number of characteristics or inherent factors in the design of household water containers which strongly influence the likelihood that the container will suffer from re-contamination of its contents. These factors are inter-related with disinfection. The following list, itemizes the most important desirable characteristics to be incorporated into these household containers.

Desirable Characteristics of Containers for Water Storage in the Household

- The form and dimensions of the container should be appropriate for household use, with a strong handle to facilitate lifting and carrying the container while full. Ideally it should be of a form which is structurally strong, stable and yet has a high volume to surface area so as to minimize the cost of material. The volume should be between 10 and 20 liters for a household and 50 liters to 100 liters for schools, clinics and other such institutions.

- The material from which the container is made should be durable, impact resistant, and resist oxidation. It should be an opaque color which excludes light and is aesthetically attractive but allows the water level to be observed. The material should not react with the disinfectant to be used. High density polyethylene or polypropylene are two suitable materials as they not only meet these requirements but can be readily blow molded in most of the countries.

- The opening(s) should facilitate easy filling of the container but also prevent the immersion of objects and hands for extraction of water. Preferably a spigot should be provided for drawing water from the container.

- The spigot should be easy to open and close, it should be a material which resists oxidation and corrosion and it should be easy to clean and durable.

- The lids or caps should preclude the entrance of dust, insects and other extraneous material. They should be strong, made of durable material and should be attached to the container so that they will not be lost or become soiled during use.

- The container should have an air inlet device or vent cap to facilitate the drawing of water through the spigot.

- The container should have a built in device to measure and introduce the disinfectant. If a sodium hypochlorite or other solution is to be used, this could be in the form of a cap which also serves as a measuring cup or a siphon which can be filled to dose the correct volume of disinfectant.

- Instructions for sanitary use, cleaning of the container and application of disinfectants should be printed on plastic which is permanently attached to the container.

- A certification by the appropriate health agency should be fixed to the container to indicate that it complies with health agency criteria.

Community based management

It is important that the community be the center for the promotion, education and monitoring of disinfection at the household level if this is to be carried out on a long term basis in all of the households. If possible the production, preparation and/or distribution of disinfectants and the furnishing of suitable household containers should be a community based operation preferably as a cooperative venture or a micro-enterprise.

It is important that the schools, health clinics (or hospitals) and community centers be included in the community education and promotion of household disinfection to obtain the greatest participation possible by the individual households. This is necessary to obtain a continuing education and motivation of children and newcomers to the community in regards to the importance and benefits of household disinfection as well as the technical aspects of its implementation.

ANNEX 2

DESCRIPTION OF DISEASES CAUSED BY BOTH, POOR SANITATION AND WATER CONDITIONS

Amebiasis: **Agent** - *Entamoeba histolytica* (protozoan)

Symptoms - Varying severity, from acute or fulminating dysentery with fever, chills and bloody, mucoid diarrhea to mild abdominal discomfort with diarrhea containing blood or mucous with periods of constipation or remission. Long term infection can cause ulcers or abscesses which often lead to secondary infections. Death from amoebic dysentery is rare.

Transmission - Through fecally contaminated water or food handlers that are carriers and do not follow proper hygiene. There are two life stages which can transmit the infection - the cyst and trophozoite. The trophozoite is sensitive to low pH and oxidizing agents. Cysts are quite stable in the environment and resistant to disinfection. Cats, dogs and other mammals have been implicated as carriers to humans. Epidemics most commonly are spread through drinking contaminated drinking water. Asymptomatic cases can be carriers for years.

Ascariasis: **Agent** - *Ascaris lumbricoides* (roundworm)

Symptoms - Live worms passed in stools or sometimes the mouth or nose; most cases (approx. 85%) are asymptomatic. Especially in children, causes malnutrition, restlessness and insomnia. Advanced cases exhibit bowel obstruction, severe nutritional deficiency; if migrate to lungs, coughing and wheezing may occur. Worldwide occurrence, with highest incidence in tropical areas.

Transmission - Ingestion of infective eggs from soil or un/under cooked food; passed between children by handling fecally contaminated toys and defecation in communal areas. Eggs are viable for several months. Especially prevalent in children 3-8 years in hot, moist climates. Humans are the only known reservoir, but domestic animals such as dogs, pigs and chickens may serve as vectors by carrying human feces containing ascaris eggs. In several countries of Latin America untreated water supplies have been implicated in the transmission of the eggs.

Balantidiasis: **Agent** - *Balantidium coli* (protozoan)

Symptoms - Diarrhea, nausea and vomiting; stools may contain blood. As in amebiasis, may cause dysentery and has two infective stages (cyst and trophozoite). Often confused with amebiasis.

Transmission - Ingestion of cysts from fecally contaminated food or water. Especially prevalent where sanitation is poor and where water supplies are contaminated by swine feces.

Cholera: **Agent** - *Vibrio cholerae* (bacteria)

Symptoms - Acute and sudden onset of watery "rice stool" diarrhea, with rapid dehydration and occasional vomiting. Two types of disease - El Tor and Classic. The former, which has caused the epidemic in South America beginning in 1991, is less severe than the Classic type. Mortality rate can be as high as 60%, but with prompt treatment by rehydration can reduce the fatality rate - case fatality can be reduced to <1%.

Transmission - Ingestion of water or food contaminated by the feces or vomitus of infected individuals; handling of food with unhygienic methods; consumption of raw shellfish. Fomites, such as patient's linens, clothing and bandages can also transmit the disease. Organism survives longer in brackish and alkaline waters.

Cryptosporidiosis: **Agent** - *Cryptosporidium* (protozoan)

Symptoms - Watery or mucoid diarrhea lasting from 3-14 days; vomiting, anorexia and abdominal pain; cough and abnormal chest x-rays may indicate pulmonary infections; often significant weight loss. Can cause severe symptoms in immunocompromised hosts.

Transmission - Fecal-oral route. Cysts are highly resistant to standard water treatment; agent has frequently been identified in water sources contaminated by cattle waste. Foundery and veterinary workers are at higher risk.

Dracunculiasis: **Agent** - *Dracunculus medinensis* (nematode)

Symptoms - This disease is not found in Latin America, but is common in Africa and Asia. Blister (often with duration of several months), usually on the lower leg or foot where female worm discharges larvae, accompanied by burning and itching; fever, diarrhea, and vomiting; general malaise. This disease is usually not fatal, but can result in chronic arthritis, tetanus, and secondary infection. If the worm is killed before removal can result in gangrene and amputation.

Transmission - Only disease to be spread solely by drinking water; larvae discharged from infected person are eaten by fresh-water copepod and this agent is then ingested by humans when drinking infected water supplies. Copepod favors stagnant water - therefore open wells, dam sites and lagoons may be prime location for propagation of the disease.

Escherichia coli: **Agents** - [bacteria] -

enteroinvasive - (shigella-like toxins)
enterotoxic - (similar syndrome to *Vibrio cholerae*; a.k.a. traveler's diarrhea)
enteropathogenic - (shigella-like toxins; known to cause infantile outbreaks in nurseries)
The types can be distinguished serologically by clinical tests.

Symptoms - Invasive and pathogenic types cause fever, diarrhea (sometimes bloody). Toxic type causes acute onset of watery diarrhea, cramps, and vomiting usually lasting 1-3 days.

Transmission - Spread by contaminated food, water and fomites. Humans are the major reservoir. All age groups are susceptible, and acquired immunity is not permanent.

Giardiasis: **Agent** - *Giardia lamblia* (protozoan)

Symptoms - Chronic diarrhea, frequent loose, pale, greasy malodorous stools, fatigue. Disease can last more than three months, but is not fatal. However, it can exacerbate malnutrition and fatigue, and is rampant in day care centers.

Transmission - Fecal-oral by water, food and hand to mouth. Animals such as beavers and rats are known carriers. Outbreaks have occurred through contaminated water sources, and by food handlers with contaminated hands. Infected individuals shed large quantities of cysts throughout the duration of their illness.

Hepatitis: **Agent** - Hepatitis A virus

Symptoms - Jaundice, mild to severe fever, malaise and duration of sometimes several months. More severe symptoms manifested in adults than children. Disease is endemic worldwide.

Transmission - Fecal-oral route, especially contaminated water and food particularly shellfish. Incubation period of approx. one month, with highest shedding of virus two weeks after exposure.

Leptospirosis: Agent - *Leptospira interogens* (spirochete)

Symptoms - Fever, headache, severe malaise; conjunctival suffusion; sometimes meningitis or jaundice and rash. Clinical symptoms may last from several days to weeks. Death is rare, but increases with individuals having kidney problems or the elderly.

Transmission - Contact of skin or mucous membranes with water, moist soil or vegetation contaminated with infected urine of farm or wild animal; ingestion of contaminated with urine of infected rats. Incubation period averages 10 days.

<u>Paratyphoid</u>: **Agent** - *Salmonella paratyphi* types A, B and C. (bacteria)

Symptoms - Continuous fever, headache, malaise, sometimes rose spots on trunk. Rarely fatal. Relapses may occur in 3.5% of cases.

Transmission - Contact with contaminated food or water. May be spread by feces or urine of infected person. Asymptomatic individuals often spread the disease (esp. food handlers, as happened with famous case of Typhoid Mary). Incubation period of 1-10 days for gastrointestinal disorder and up to 3 weeks for enteric fever.

<u>Typhoid</u>: **Agent** - *Salmonella typhi* (bacteria)

Symptoms - Same as Paratyphoid, only more severe; fatality rate may be as high as if antibiotics are not administered. Constipation is more common than diarrhea.

Transmission - See Paratyphoid; milk and shellfish have also been implicated. Clinical symptoms usually develop between 14-21 days after exposure. Peak transmission occurs in warmer season.

<u>Poliomyelitis</u>: **Agent** - Poliovirus types 1, 2, and 3. (virus)

Symptoms - Muscle pain and spasm, fever, stiffness of neck or back which may progress to paralysis; nausea and vomiting. Nonparalytic cases manifest as aseptic meningitis. Paralytic cases comprise less than 1% of all contracted cases. Effective vaccine exists.

Transmission - Direct contact through close association; fecal-oral route. Irrigation with untreated sewage effluent has been implicated in Mexico. Incubation period for paralytic cases is 7-14 days.

<u>Rotavirus</u>: **Agent** - Rotavirus of reoviridae family

Symptoms - Especially prominent in infants and young children, causes severe diarrhea, anorexia and dehydration. Some cases may exhibit gastrointestinal bleeding, fatal Reye syndrome, encephalitis and upper and lower respiratory illness.

Transmission - Fecal-oral route, and possibly fecal-respiratory. Incubation period of approx. 48 hours. Peak occurrence in cooler months in temperate areas.

Shigellosis: **Agent** - *Shigella dysenteriae, flexneri, boydii, and sonnei* (bacteria)

Symptoms - Diarrhea accompanied by fever, cramps, nausea and sometimes tenesmus. Convulsions in young children; There is often mucous and pus in the stools. Worldwide occurrence, with a case fatality rate as high as 20%.

Transmission - Direct or indirect fecal-oral transmission, with a dose as low as 10-100 bacteria causing infection. Survives well at low temperature, high humidity and even low pH (such as citric juice). Water, milk and wastewater used in irrigation all can serve as vehicles of transmission. Incubation of 1-7 days.