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SPECIAL REPORT

DRINKING-WATER IMPROVEMENT IN THE AMERICAS WITH MIXED OXIDANT GASES GENERATED ON-SITE FOR DISINFECTION (MOGGOD)[1]

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Introduction

In 1982 the Pan American Health Organization began promoting development of technology for on-site generation of mixed oxidants to disinfect the drinking-water supplies of small or remote communities in Latin America and the Caribbean. This technology was given the acronym "MOGGOD" ("Mixed Oxidant Gases Generated On-site for Disinfection"), which is now widely used throughout the region.

The main reason for PAHO's interest in this new disinfection technology when so many conventional methods and "appropriate technologies" already existed was the simple statistical fact that over 75% of all disinfection facilities in Latin America and the Caribbean have failed to provide continuous and adequate disinfection despite more than 20 years of efforts to develop human resources, institutions, and supporting infrastructures. The basic theory behind PAHO's initiative is that high-level technology can serve to develop simple, practical, and effective disinfection methods capable of overcoming the problems peculiar to Latin America and the Caribbean—problems currently preventing conventional disinfection.

In December 1986 PAHO began the first phase of a demonstration project to introduce Member Country agencies and institutions to the MOGGOD concept and enlist their support in developing MOGGOD technology. Approximately 20% of the initial costs of the project were covered by a contribution of US$60,000 made by the United Nations Development Program (UNDP). As part of this phase, PAHO bought MOGGOD prototype devices and shipped them to participating countries for laboratory testing and also field testing under conditions that had led to the failure of existing conventional disinfection methods. This field demonstration of MOGGOD, designed to provide operational experience, familiarize the water supply sector with MOGGOD technology, and

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hopefully produce accelerated improvement and application of the devices, is currently underway.

The first international seminar on MOGGOD technology was held at PAHO's Center for Sanitary Engineering and Environmental Sciences (CEPIS) on 7–11 December 1987 in Lima, Peru. The aim of the conference was to exchange information and experience on MOGGOD and to make recommendations regarding future research, applications, improvements, and directions for development.

Overall, the goal of developing an innovative and effective disinfection technology within the Latin American and Caribbean context appears feasible because of the increased scientific knowledge and many technical advances made in related areas over the previous decade. Rapid feedback from the project's users to the developers has already resulted in a considerable number of significant improvements in design, methodology, and technological understanding. MOGGOD disinfection to date has been at least as effective as chlorine disinfection in both the laboratory and the field. Hence, at this early stage of the project the results have been very encouraging and appear to definitely merit continuation of the effort. It is also hoped that the MOGGOD effort might rekindle awareness of the importance of disinfection and possibly encourage improvement of conventional disinfection technology and practices as well.

Background

Although many of the small towns and communities of Latin America and the Caribbean have been served with community water systems, and most national plans aim at increasing the water supply coverage in small and rural communities, the disinfection of that water has been neither adequate nor reliable; more often than not it has not even been carried out. A participant survey at PAHO's workshop in May 1984 for the introduction of the new WHO Guidelines for Drinking-Water Quality 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 studies and investigations indicate a somewhat higher percentage of failure.

Failure to disinfect water supplies is one of the most serious problems affecting the health of the residents of small towns, rural areas, and marginal urban areas. Its importance has been proven in both theory and practice. It is a fundamental public health measure, and wherever carried out reliably and adequately it has assured health benefits for the users of the water supply.

There are more than 20 diseases related to drinking-water supply. Debilitating and in some cases deadly, they impose a terrible economic and physical handicap on everyone involved, especially upon the poor who can least afford it. The most serious and frequent of these diseases can to a very large extent be prevented through adequate disinfection.

Numerous studies have been performed over the past 50 years on the benefits of disinfection, but two of the most recent are of particular significance to our subject. One, an eight-year study by Bersch and Osorio *(1)* found an inverse relationship between the levels of residual chlorine and rates of diarrhea among children under five years of age. The other, a 1981 pilot project *(2)*, compared 300 families in West Bengal, India, that received disinfected drinking-water with 300 others that did not. 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, as compared to only a 5% reduction among the other children. In situations where water is the predominant vehicle for transmission of typhoid, paratyphoid, cholera, *Campylobacter*, enteritis, rotavirus diarrhea, hepatitis, dracontiasis, or giardiasis, adequate levels of disinfectant and adequate contact time will reduce the incidence of disease. Hence, the health benefits of more reliable, simpler, and cheaper disinfection are obvious.

Causes of Disinfection Failure

To resolve the problem of disinfection failure in Latin America and the Caribbean, it is first necessary to understand the causes of that failure. A number of commonly cited reasons for failure to disinfect *(3)* are as follows:

1 undependable or unavailable supply of chemicals;
2 unavailable spare parts;
3 operational requirements too complex for local operators;
4 repair of equipment too complex for local operators;
5 inadequate infrastructure to support the purchase, transport, and storage of chemicals, spare parts, and supplies;
6 user dissatisfaction with widely varying chlorine levels;
7 difficulties involved in local storage, handling, mixing, and dosing of chemicals;
8 limited equipment durability;
9 insufficient operator training and experience, as well as inadequate basic education;
10 inadequate safety considerations;
11 foreign exchange restrictions.

In almost all specific instances there are multiple underlying causes for the failure to disinfect—and all of them, both administrative and technical, must be resolved in order to obtain a satisfactory and lasting solution. A variety of approaches have been taken in the past to resolve this dilemma, including institutional and human resource development. The results have been less than satisfactory, having produced an increase of only a few per cent in the water systems adequately disinfected over the last 20 years.

A number of alternative technologies employing ozonation, ultraviolet light, halogenated resins, radiation, iodination, chlorine dioxide, chloramines, and appropriate technologies for hypochlorination have been introduced to overcome the problem, but they haven't really circumvented the major causes of the failures. Some have even added to them. Unfortunately, the great majority of advancements in disinfection technology have been aimed primarily at solving problems encountered in industrialized countries; they have not been directed at solving the specific and quite different problems of developing countries.

Formulation of the MOGGOD Concept

Because no single conventional method of disinfection seemed to overcome a sufficient number of these causes, various combinations of them were explored. Unfortunately, this simple combination of methods usually resulted in much more complex operational problems that negated any advantages gained.

Another important factor to consider in selecting a suitable disinfection procedure for water distribution systems is the microbiologic control required. A number of bacteria (as well as molds and protozoa) are capable of aftergrowth even though the water may have been appropriately treated. The probability of this phenomena occurring is particularly likely where the water contains significant quantities of organic substances *(4)*, and where relatively warm water and ground temperatures prevail. The presence of these microorganisms not only reduces the water's organoleptic quality but may also pose a health risk. Since both warmer temperatures and relatively high levels of organic matter in water are the predominant conditions in Latin America and the Caribbean, it is important that a disinfectant methodology be effective, efficient, broad-spectrum, and that it provide adequate residual disinfection.

For these various reasons, PAHO began exploring the feasibility of innovative technology that might avoid a sufficient number of the aforementioned causes of failure in order to increase the likelihood of achieving successful sustained disinfection of small community water systems.

A list of desirable characteristics for a disinfection device suitable for small towns and rural areas in Latin America was prepared by PAHO to use in discussions with potential developers and researchers. These characteristics included (a) simplicity of operation and maintenance, and if possible avoidance of chemical and mathematical calcu-

lations; (b) robust and durable equipment that is easy to repair; (c) use of locally or readily available primary chemicals; (d) use of a reliable, effective, and safe disinfectant that will function over a wide range of typical physical-chemical conditions and that leaves an adequate residual. These criteria first led to consideration of existing devices for on-site generation of sodium hypochlorite, but experience showed the devices to be too complex for the targeted communities.

During subsequent review of the literature and followup discussions with agencies, institutions, scientists, and developers it became evident that it was usually simpler and cheaper to generate a mixture of disinfecting oxidants than a single pure oxidant. There were several additional potential advantages to the use of a mixture of oxidants, namely:

1 Different oxidants have somewhat different ranges of conditions within which they operate effectively as disinfectants. Combining them may broaden that range.
2 Combinations of oxidants can act synergistically as disinfectants.
3 Different oxidants leave residuals of different durability.
4 Different oxidants have differing affinities for different reducing agents; by combining oxidants, it may be possible to minimize undesirable by-products.
5 A group of oxidants can be more effective than a single oxidant against a broad spectrum of microorganisms.

The potential for overall improvement implied by all of this induced PAHO to pursue promotion and support for the development of a procedure using mixed oxidant gases generated on-site for disinfection (MOGGOD).

The Effectiveness of Mixed Oxidants

Table 1 shows the oxidation potential (in volts) and the relative oxidation power (compared to chlorine) of some of the strongest known oxidants. The hydroxyl radical, atomic oxygen, ozone, hydrogen peroxide, the perhydroxyl radical, hypochlorous acid, and chlorine are among the oxidants produced by MOGGOD devices. Although the proportions of the different species are still not precisely determined, all of them are strong oxidants. Hydrogen peroxide and the perhydroxyl radical are not effective disinfectants in water, but they do react with many reducing agents in water that would otherwise use up the more effective disinfecting oxidants.

Duguet, Brodard, Dussert, and Mallevialle *(5)* found that the addition of hydrogen peroxide to water during ozonation increased the rate of ozone transfer and the oxidation of organic compounds. They also found that the addition of hydrogen peroxide in the ozonation process resulted in significant reduction of precursors of trihalomethanes.

TABLE 1. Oxidation potential in volts and relative oxidation power compared to chlorine of various strong oxidants, including those produced by MOGGOD devices.

Oxidant species	Oxidation potential (volts)	Relative oxidation power
Fluorine	2.87	2.25
Hydroxyl radical[a]	2.80	2.05
Atomic oxygen[a]	2.42	1.78
Ozone[a]	2.07	1.52
Hydrogen peroxide[a]	1.77	1.30
Perhydroxyl radical[a]	1.70	1.25
Permanganate	1.68	1.23
Hypochlorous acid[a]	1.49	1.10
Chlorine[a]	1.36	1.00
Bromine[a]	1.07	0.79
Iodine	0.54	0.40

[a] Oxidants reported present in mixed oxidant gases generated on-site.

Charles P. Hibler *(6)* determined that in water with a turbidity of 0.53 to 0.73 nephelometric turbidity units (NTU) containing 10,000 to 40,000 *Giardia lamblia* cysts per gallon, the combination of photozone (0.3 to 0.6 mg/l) and chlorine (0.2 to 0.58 mg/l) for a period of 30 minutes of exposure was sufficient to kill or inactivate all of the *Giardia* cysts, while neither photozone nor chlorine alone was able to achieve inactivation. The biochemical mechanisms involved in the inactivation of the cysts is not yet well understood. It has been observed that long-duration contact time resulted in destruction of the cysts.

Pendergrass, Gram, Steele, and Talley tested mixed oxidant solutions generated in the electrolysis cell of the Los Alamos Technical Associates (LATA) in Los Alamos, New Mexico, USA (see p. 409) against *Legionella pneumophila, Escherichia coli, Giardia muris* cysts, *Pseudomonas aeruginosa*, and *Bacillus subtilis (7)*. The relative proportions of mixed oxidant components generated are shown in Figure 1. The effectiveness of the mixed oxidants against these organisms is indicated in Tables 2–4.

The 100% kill of *Giardia* cysts in clear 3 °C water (Table 3) after 30 minutes' contact with an initial concentration of 0.40 mg/l of short-lived oxidants and 0.44 mg/l of free chlorine is comparable to the results reported by Hibler *(6)*. Free chlorine by itself at 0.84 mg/l would have had virtually no effect on these cysts at 3 °C and very little effect at 20.5 °C. The effect on the spores of *B. subtilis* (Table 4), which are able to survive boiling water and elevated levels of chlorine, also attests to the effectiveness and possible synergism of the mixed oxidants.

Another group of tests *(8)*, reported in 1987, were carried out by Mexico City's General Water Works Administration (Dirección General de Construcción y Operación Hidraúlica—

FIGURE 1. Influence of electric current and voltage on the oxidant species produced in the Los Alamos Technical Associates (LATA) prototype electrolysis cell *(7)*.

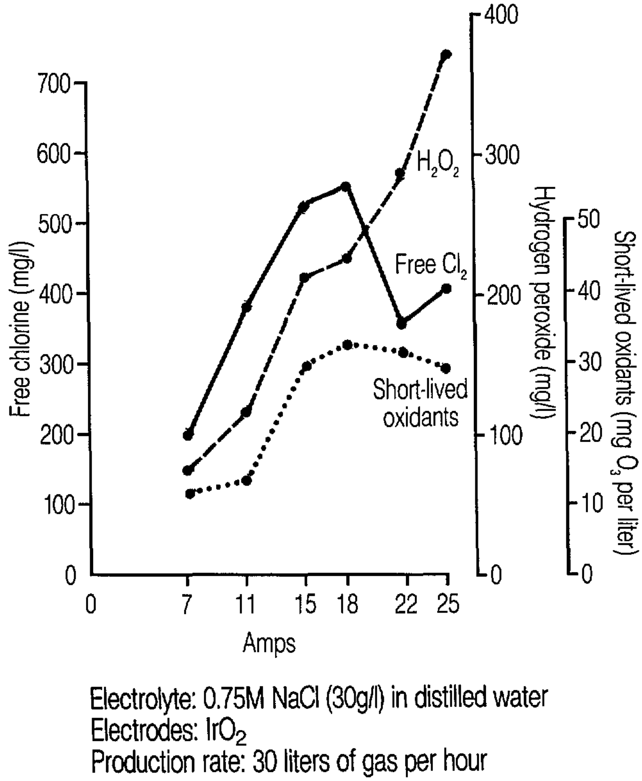


TABLE 2. Effectiveness of oxidants against *Legionella pneumophila* at a water temperature of 20 °C. The oxidants employed were chlorine dioxide, hypochlorous acid, and mixed oxidants generated by the LATA Mark II electrolysis cell at 20 volts and 7 amperes.

Solution	Total oxidant concentration (mg/l)	*L. pneumophila* present (colony-forming units/ml) after indicated exposure times			
		0 min.	2 min.	5 min.	15 min.
Mixed oxidants[a]	0.75	1×10^7	1.9×10^6	1.5×10^4	3.0×10^2
Chlorine dioxide (ClO_2)	0.75	1×10^7	2.0×10^6	1.0×10^5	1.0×10^3
Hypochlorous acid ($HOCl^-$)	0.67	1×10^7	8.0×10^6	6.0×10^6	1.0×10^6

[a] Generated from 0.75M NaCl at a flow rate of 30 l/hr using iridium dioxide (IrO_2) electrodes.

TABLE 3. Effectiveness of mixed oxidants generated by the LATA Mark II electrolysis cell at 20 volts and 7 amps[a] against *Giardia muris* cysts.

Water clarity[b]	Temperature	Initial oxidant concentration (mg/l)	% *Giardia muris* cyst viability after indicated exposure times[c]		
			0 min.	10 min.	30 min.
Clear	3 °C	0.84	40	24	0
Clear	3 °C	0.42	44	41	19
Clear	20.5 °C	1.58	58	4	0
Clear	20.5 °C	0.79	60	12	3
Turbid	3 °C	1.07	48	10	6
Turbid	3 °C	0.55	42	49	44

[a] Generated from 0.75M NaCl at a flow rate of 30 l/hr using iridium dioxide (IrO_2) electrodes.
[b] The turbidity cited was due to the presence of natural clay.
[c] In the two cases with no apparent survival (after 30 minutes' exposure), all 4,500 *Giardia* cysts tested under the indicated conditions were examined to verify the 100% kill.

TABLE 4. Effectiveness of mixed oxidants generated by the LATA Mark I electrolysis cell at 12 volts and 13.5 amps[a] against *Pseudomonas aeruginosa* (ATCC Strain No. 15442) and *Bacillus subtilis* (ATCC Strain No. 19859) at a water temperature of 20.5 °C.

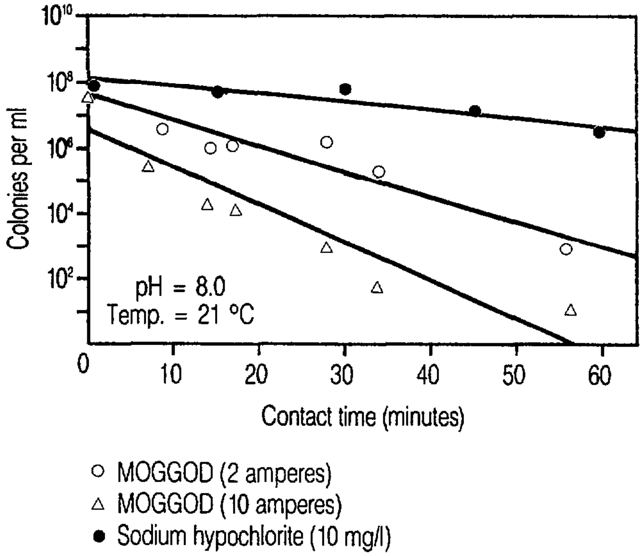
	Total oxidant (mg/l)	Bacterial concentration (colony-forming units/100 ml) after indicated exposure times		
		0 min.	10 min.	20 min.
P. aeruginosa:				
Mixed oxidant	0.8	6.8×10^4	<1	
	0.6	6.8×10^4	<1	
Control	0	6.8×10^4	6.8×10^4	
B. subtilis:				
Mixed oxidant	8	2.3×10^4		<1
	4	2.3×10^4		<1
	2	2.3×10^4		<1
	1.1	2.3×10^4		<1
Control	0	2.3×10^4		4.9×10^3

[a] Generated from 0.75M NaCl at a flow rate of 30 l/hr using iridium dioxide (IrO_2) electrodes.

DGCOH) using a MOGGOD device produced by Oxidizers, Inc. (Virginia Beach, Va., USA). The device was tested on water from two contaminated wells (located in "colonias" Santa María Aztahuacán and Agrícola Oriental) that contained atypical (hard to kill) microbes. Water from the Santa María Aztahuacán well (pH 8.0, temperature 21 °C) was dosed with sodium hypochlorite (10 mg/l) or with mixed oxidants that were generated at 2 amps (equivalent free chlorine residual = 1.3 mg/l) or at 10 amps (equivalent free chlorine residual = 4.9 mg/l). The results are shown in Figure 2.

The tests of water from the more contaminated Agrícola Oriental well (pH 8.35, temperature 22.8 °C) unfortunately did not include a sodium hypochlorite baseline; but they did include

FIGURE 2. Relative survival rates of atypical (hard to kill) bacteria from the Santa María Aztahuacán well, in terms of colonies per ml, following 0–60 minutes of contact with sodium hypochlorite (10 mg/l) or with mixed oxidants generated at 2 amps or 10 amps by the Oxidizers Inc. MOGGOD device.

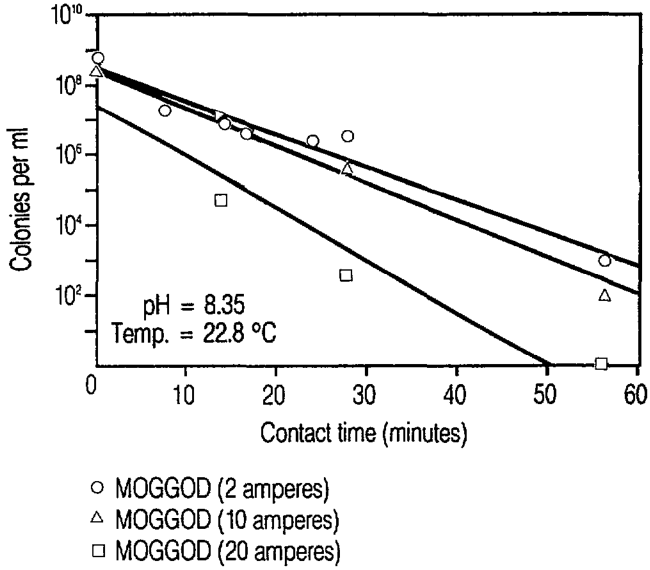


an additional dose of MOGGOD at 20 amps (equivalent free chlorine residual = 10.4 mg/l). The results of these tests are shown in Figure 3.

Other tests were conducted by Olivieri and Ramirez at the Johns Hopkins School of Public Health *(9)*. These tests compared the bactericidal and viricidal effects of a mixed oxidant gas diluted with air, a solution prepared from the mixed oxidant gas, and a solution prepared from chlorine gas. They concluded that the gas produced by their particular MOGGOD device rapidly inactivated *Escherichia coli, Pseudomonas aeruginosa*, and bacteriophage F_2 virus in water, and that the disinfectant activity of the gas appeared equivalent to chlorine solutions at an equal total oxidant residual under the same chemical and physical conditions. Their results are shown in Figure 4.

In unpublished work, Dr. Daniel V. Lim of the University of South Florida Department of Biology tested mixed oxidants produced by the Tetravalent Inc. (TVI) process against *Legionella pneumophila* and *micdadei, Bacillus subtilis, Escherichia coli, Vibrio cholerae, Salmonella typhimurium, Pseudomonas aeruginosa*, and *Candida albicans* using both 5% and 10% NaCl solutions in the anode compartment. Professor J. T. Patton of the University of Florida tested the TVI mixed oxi-

FIGURE 3. Relative survival rates of atypical (hard to kill) bacteria from the Agrícola Oriental well, in terms of colonies per ml, following 0-60 minutes of contact with mixed oxidants generated at 2 amps, 10 amps, or 20 amps by the Oxidizers, Inc. MOGGOD device.



dant solution against rotavirus. PAHO compared these two investigators' time-concentration values to those obtained with chlorine and found the TVI mixed oxidants to be superior.

Figure 5 consolidates various sources of data on MOGGOD effectiveness against *Giardia muris* and compares the resulting time-concentration curves to those obtained with ozone and chlorine.

In summary, the effectiveness of mixed oxidants generated on-site as a water disinfectant appears to equal or exceed that of chlorine. The mixed oxidants have also proven effective over a wide range of pH and temperature conditions, and also against a broad spectrum of microorganisms, some of which are among the more resistant to inactivation by chemical disinfection.

Development of MOGGOD Devices

Due in large measure to the normal course of scientific and commercial development, and in small measure to PAHO's encouragement and promotion, several fully functional proprietary devices for on-site generation of mixed oxidant disinfectants have been developed and improved.

Two distinct groups of devices that produce mixed oxidants for disinfection have evolved, one relying on electrolysis and the other on photolysis to generate the mixed oxidants. Of two

FIGURE 4. These three charts show typical survival rates of (A) *Escherichia coli*, (B) *Pseudomonas aeruginosa*, and (C) bacteriophage F_2 virus during parallel disinfection with MOGGOD (gaseous form), a MOGGOD solution, and a chlorine solution.

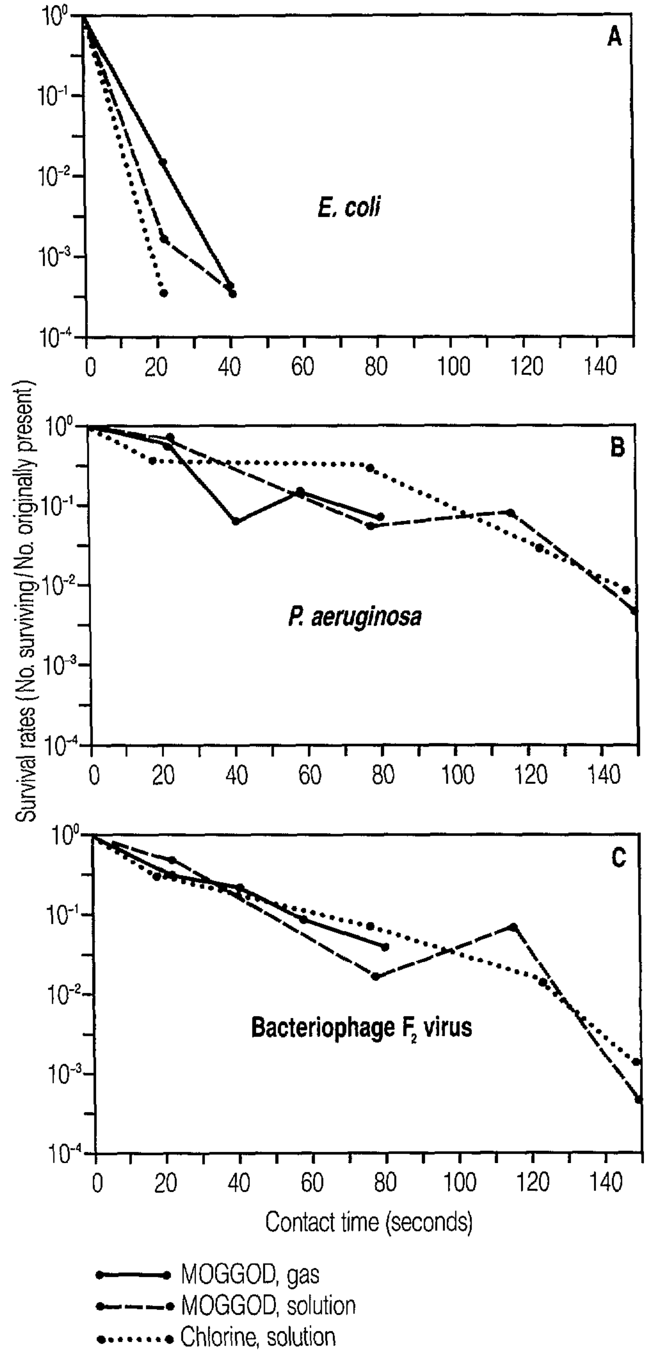
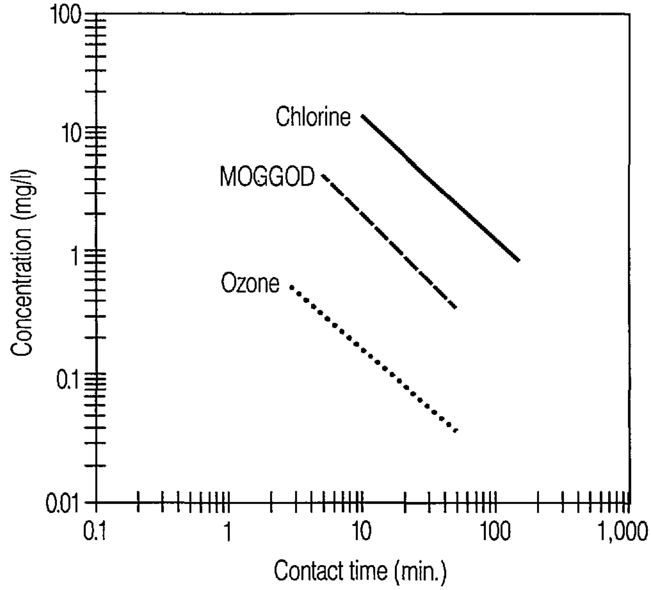


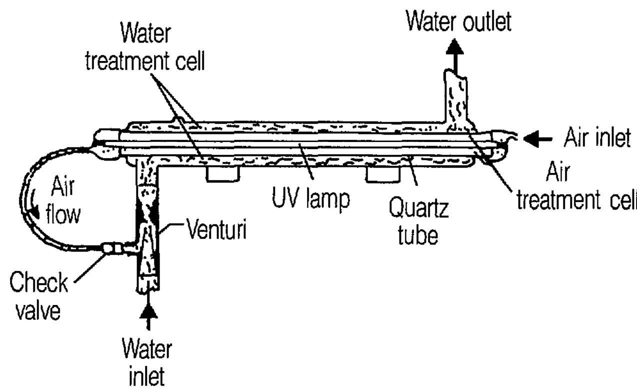
FIGURE 5. Consolidated data from several sources showing the concentrations of mixed oxidants, ozone, and chlorine needed to inactivate 99% of the *Giardia muris* cysts exposed at 3-5 °C and pH 8 for different lengths of time *(6, 7, 10-12)*.



types depending on electrolysis, one type produces mixed oxidant gases and the other produces a solution containing mixed oxidants. All of these various devices show considerable promise in terms of overcoming or circumventing many of the major problems and impediments to disinfection.

The photolysis ("photozone") process utilizes short-wave (< 185 nm) ultraviolet light to dissociate oxygen molecules into activated oxidant species. This process, a schematic of which is shown in Figure 6, entails passing ambient air along an ultraviolet lamp; the resulting plasma generated is then diffused into an aqueous solution that is further irradiated by the ultraviolet light, thereby boosting the oxidizing potential as well as contributing to the disinfection. The resulting oxidants in the water stream include ozone, the hydroxyl radical, hydrogen dioxide, hydrogen peroxide, and atomic oxygen. This mixture of oxidants has been found to have a greater oxidizing power than chlorine gas. It has also proven to be an excellent disinfectant. The photozone process typically uses some 7 to 11 kilowatt hours of energy to produce one kilogram of the photozone gas.

FIGURE 6. Schematic drawing of a photolytic MOGGOD device.



Unfortunately, photozone does not include a durable residual among its mixed oxidants. Since an effective and durable residual is necessary in Latin American water systems because they are subject to recontamination, this device has not yet been installed in the demonstration project. It is mentioned here simply because it is an effective generator of mixed oxidants and because when chlorine was added by Hibler *(6)* the time-concentration values for *Giardia* cysts were similar to those obtained with MOGGOD.

On the other hand, electrolysis of a saturated salt solution is capable of generating oxidant mixtures in which a large portion of the oxidants do provide an effective residual disinfectant. The first written account of electrolytic generation of mixed oxidants was probably provided by Cruickshank, who described the odor of ozone in 1801 as characterizing gas formed at the anode during the electrolysis of water *(4)*. Generation of oxidants through electrolysis has been carried out on a commercial scale since the start of the twentieth century, and steady advances have been made, particularly in the chlor-alkalai industry. Introduction of the dimensionally stable anode and perfluorinated membranes in 1969 and their steady improvement has radically improved the efficiency of the electrolysis process, lowered its cost, and reduced the power required. Today 90% of the chlorine generated in North America is produced by means of this technology.

The advances involved have also made on-site generation of mixed oxidant gas disinfectants a feasible alternative. The same basic technology—adapted to insure operational simplicity, durability, and compatibility with conditions in remote, small, and poor communities—has been used to develop the MOGGOD units. To do this, some of the efficiency of the electrolysis process has been sacrificed; but this is more than compensated by gains in overall efficiency that relate to social factors

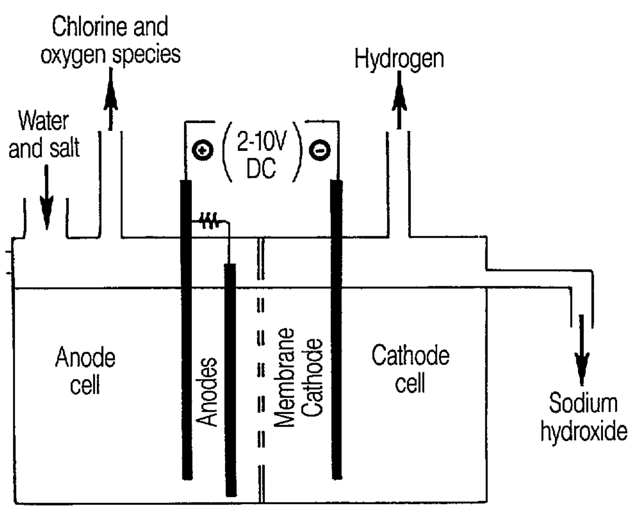
(community capabilities, storage and transport considerations, the national supporting infrastructure, local conditions, and the human element).

A number of prototypes have been produced by different entities. Those are now well beyond the laboratory bench model stage, with several units being produced commercially. Indeed, commercial electrolytic MOGGOD devices are currently being manufactured by LATA; Oxidizers, Inc.; Tetravalent, Inc. of Round Rock, Texas, USA; FENAR of Argentina; and Centro de Desarrollo y Aplicaciones Tecnológicas (CEDAT) of Mexico City, Mexico. The major differences between these devices are in the anode configuration, the cell geometry, and the electrical controller.

Because MOGGOD devices are now being sold commercially, PAHO has no exact record of the numbers installed in Latin America and the Caribbean. However, at present there are at least 20 MOGGOD demonstration projects that are being used to produce bacteriologically safe water and to obtain information about the practical aspects of this technology. The first installation has been operating for more than four years and continues to function exceptionally well, exceeding the efficiency of the conventional chlorination methods previously used.

A schematic drawing of a typical MOGGOD electrolysis unit showing the relation of the electrolytic cell components and the input and output of chemicals appears in Figure 7. The cell is divided into anode and cathode compartments by a selective semipermeable membrane, usually made of Nafion®, which is a composite of perfluorinated cation exchange copolymer. The unit typically incorporates either a dimensionally stable titanium anode (ELTECH TIR-2000) or a graphite anode and a stainless steel cathode. In addition, auxiliary electrodes

FIGURE 7. Schematic drawing of an electrolytic MOGGOD cell.



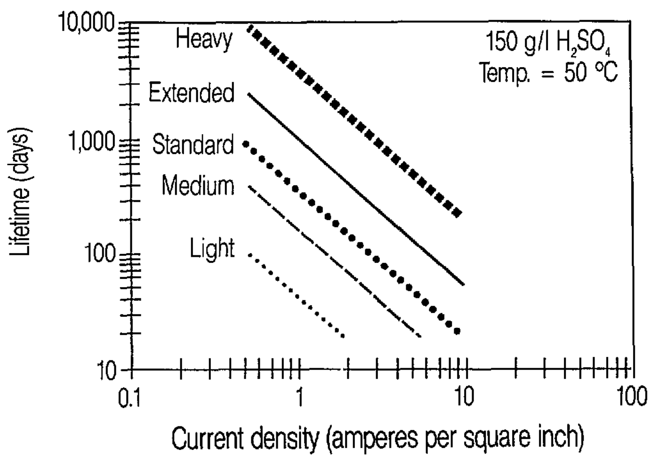
operated at a lower EMF than the primary anode may be located between the anode and the membrane.

A saturated sodium chloride solution is maintained in the anode compartment by adding water to an excess of sodium chloride. A 10% solution of sodium hydroxide is maintained in the cathode compartment by diluting with sufficient water and drawing off excess liquid. Chlorine and activated oxygen species (the mixed oxidant gases) are generated at the anodes, while hydrogen gas and sodium hydroxide are formed at the cathode. In the MOGGOD 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 for other applications or for disposal.

A somewhat similar cell was described by Michalek and Leitz *(13)* in 1972, but no mention was made of oxygen species being generated at the anode. This could have been due to the absence of auxiliary electrodes and the use of a dimensionally stable anode developed specifically for the generation of chlorine rather than for the generation of oxygen.

Figure 8 shows a graph portraying the useful life of the TIR-2000 anode as a function of current density in amperes per square inch of anode surface in a solution of about 15% sulfuric acid. Increased thickness of the iridium oxide-based coating yields an increased useful life expectancy for the anode. Since the operational current density of the MOGGOD unit ranges between 0.6 and 1.0 amps per square inch, the life of the anode will be in the general range of three to eight years for the extended-life coating and from seven to 12 years for the heavy coating if the electrodes are in operation 24 hours a day.

FIGURE 8. A chart showing the useful life of the TIR 2000 anode with iridium oxide-based coatings of different thicknesses, as a function of current density in amperes.



Another method that is being developed by LATA to generate a solution of mixed oxidant disinfectant uses an iridium-coated titanium cell with laminar flow. This device, which has functioned well in the laboratory, has yet to be field-tested in Latin America. As indicated earlier (see p. 399), the disinfectant solution produced by the device has been tested and found at least as effective as chlorine.

PAHO's Project for Development of MOGGOD Technology

Purpose. The overall goal of the development project is to foster and accelerate the development of MOGGOD technology to serve the needs of small towns, communities, and rural villages of Latin America and the Caribbean. Specific intermediate objectives are as follows:

1 Test various MOGGOD devices under as wide a range of actual but typical field conditions as possible to determine their advantages and disadvantages, strengths and weaknesses, and make recommendations for their improvement.
2 Gain a better understanding of the technologies for producing and using mixed oxidants.
3 Disseminate information about MOGGOD to potentially interested institutions and agencies of the Americas.
4 Encourage international collaboration in developing this technology.
5 Provide data on which to base installation criteria, operation and maintenance instructions, and further improvements in design and manufacture.
6 Determine the feasibility of manufacturing the equipment locally.
7 Develop parametric relationships for equivalent mixed oxidant residual and free chlorine residual.
8 Determine the minimum mixed oxidant residual needed to guarantee pathogen-free water.
9 Feed back field performance characteristics to manufacturers so as to help improve equipment performance, equipment reliability, and manufacturer support services while reducing costs.
10 Determine and understand the complex chemical reactions of MOGGOD.
11 Develop a data base for installation, operation, and maintenance costs.
12 Define commercial quality standards for manufacturing MOGGOD devices and improve technical specifications.
13 Determine the practical upper limits of MOGGOD device capacity.
14 Determine the effectiveness of MOGGOD against specific waterborne pathogens under varying conditions of turbidity, pH, and temperature.
15 Investigate MOGGOD's potential for removing undesirable substances such as iron, heavy metals, phenols, cyanides, etc., from drinking-water.

Activities. The initial phase of the MOGGOD development project sought to promote the MOGGOD concept and procure contributions from government agencies, academic institutions, professional organizations, and private industry. This was done primarily through personal contacts and by sharing information.

The project was also incorporated into PAHO's program for improvement of drinking-water quality, and the MOGGOD concept was introduced at PAHO workshops, conferences, seminars, and other meetings that dealt in any way with drinking-water, water quality, water treatment, or water distribution systems. Advances in all related areas of technology were closely monitored. Sites where MOGGOD-type devices had been installed by the private sector were visited. Some of the more promising prototypes and second generation MOGGOD devices were purchased, and limited testing was carried out by PAHO workers. Many project proposals for MOGGOD development were prepared and submitted to funding agencies.

A total of four MOGGOD devices were purchased by PAHO for use in areas affected by natural disasters for temporary disinfection of water supplies. This was done because shipment of chlorine products by air freight was prohibited and the MOGGOD devices used salt as their primary material. The devices functioned well, but their length of operation was too short to draw many conclusions about durability, continuity of operation, repairs, or maintenance problems.

In July 1986 PAHO awarded a research grant for investigating the effectiveness and efficiency of a MOGGOD device relative to chlorination. In December 1986 advance funds were received from the United Nations Development Program (UNDP) under the Critical Poverty Program. Matching funds were obtained from country offices. So far more than 40 MOGGOD devices have been purchased and sent to Latin America and the Caribbean for demonstration projects, field testing, and laboratory analysis. The countries that have received these devices include Argentina, Bolivia, Brazil, Colombia, Costa Rica, Ecuador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Panama, Peru, and Saint Lucia. Most of these have agreed to collaborate in the demonstration/development project and have commenced various activities. Collaboration is under consideration in Barbados, Chile, Cuba, Paraguay, and Venezuela. Research has been carried out in Argentina, Mexico, and the United States, and more is in the formative stages in Argentina, Brazil, Colombia, Cuba, Ecuador, Guatemala, and Peru.

The following is a more specific list of principal project activities as of 31 December 1987:

1 Lecture-demonstrations of MOGGOD technology were carried out in 12 countries.
2 Field visits were made to a total of 20 potential field demonstration sites and instructions for site preparation and MOGGOD installations were provided.

3 Forty-seven MOGGOD units and accessories were purchased and sent to Argentina, Bolivia, Brazil, Colombia, Costa Rica, Ecuador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Panama, Peru, and Saint Lucia.
4 Models of easy-to-understand manuals for (a) installation and (b) operation and maintenance of typical MOGGOD units were prepared under contract in both Spanish and English.
5 Technical information on MOGGOD was provided to all of the pertinent agencies of the countries participating in this project.
6 Draft terms of reference for participation in a regional MOGGOD demonstration project were developed and provided to eight countries.
7 Three MOGGOD research projects were implemented; five additional research proposals and protocols are in the stage of soliciting funds.
8 As a direct result of this project, manufacturing of MOGGOD devices has been initiated by private industry (FENAR) in Argentina and is being explored in Mexico by CEDAT. CEDAT has developed a number of prototypes that are being field-tested. Manufacturing is also under consideration in Colombia.
9 MOGGOD devices have been installed in seven of the participating countries and field-testing is underway.
10 An international seminar on disinfection of small community water supplies with MOGGOD was held almost exactly one year after the demonstration/development project was initiated.

Findings. It seems clear that improved disinfection through MOGGOD offers several potential economic benefits. These include the low cost of the disinfectant itself (due to the low cost of salt and the simplified operation and maintenance requirements of the apparatus); elimination of the need to spend foreign exchange (for those countries that import chlorine or chlorine products); and, finally, the intuitively obvious but less definitive economic benefit of a healthier people.

Although more time is needed to sufficiently test the components of the MOGGOD operating devices, it now appears that the usual total cost of MOGGOD disinfectant ranges from US$0.25 to US$0.60 per kilogram. (This cost can be expected to vary widely in response to variations in the unit costs of salt, electricity, and labor.)

Certain specific advantages offered by MOGGOD should help avoid a number of the problems encountered in sustaining conventional chlorination, particularly in small, remote towns and communities. Among them:

- The only makeup chemicals are salt (sodium chloride) and water. Sodium chloride is available almost everywhere; is easily transported, stored, and

handled; poses minimal hazard to the environment and none to the worker; and is very cheap.

- Power requirements are extremely low. The units need only 5 to 10 volts at the electrodes and draw about 24 amps per kilogram of disinfectant generated over a 24-hour period. If conventional electricity is not available, it is feasible to utilize photovoltaics or minigenerators on the water transmission line as power sources.
- Operational requirements are visually oriented; mathematical and chemical skills are not essential. That is, it can be determined visually when sodium chloride should be added. The operator merely looks to see if the salt crystals or water level is getting low and adds some more if necessary. The amount of disinfectant applied is determined by the adjustment of a dial (rheostat) to obtain a predetermined current indicated by a needle. All of this simplifies operation for the operator, who in most cases lacks much education.
- The chlorine species act primarily as a residual. The oxygen species of the mixed gas disinfectant are the dominant species and tend to react with organics and other substances before the chlorine species. This generally results in improved water taste and odor that enhances user support for continuous and reliable disinfection.
- The anode-to-cathode power consumption in the MOGGOD units typically falls in the range of four to four-and-a-half kilowatt-hours per kilogram of oxidant produced.
- The MOGGOD device produces only the amount of oxidant needed at any given moment, thereby eliminating the problem of storing large quantities of highly reactive substances.

To date it has been determined that MOGGOD disinfection is at least equivalent to disinfection with chlorine in both the laboratory and actual field installations. Additional experiments are necessary to check its effectiveness against various specific pathogens. (MOGGOD has been found far more effective than chlorine against algae.)

Problems. Despite the simplicity of the MOGGOD devices' operation and maintenance, they require attention at least once and preferably twice a week. Training is absolutely necessary for new users of this technology.

Also, even though instructions and installation drawings have been provided, a number of installations have been poorly designed and constructed. A number of units were installed in small, unventilated enclosures, despite clear written instructions that the enclosure should be well-ventilated. This situation caused corrosion of almost everything placed in these enclosures.

The most common mistake made in MOGGOD installation is improper installation of the venturi, which is frequently mismatched with the prevailing hydraulic conditions. Venturis have specific and limited flow ranges, and they must be properly selected. The plumbing of the venturi has often been poorly done, with no provision for withdrawal of samples, maintenance, or repair and replacement. The

plumbing is simple, but it should be done neatly, made free of leaks, and designed to accommodate sampling and extraction of water for the MOGGOD unit's maintenance.

Because of potential problems such as these, a technical expert should be present when the first unit is installed in a country or region of a country. Also, a concerted collaborative effort should be made to develop a good selection of standard drawings for typical installation conditions in Latin America and the Caribbean.

The weakest component of the MOGGOD device itself is the membrane. Care must be taken to not puncture it. Even though appropriate training and warnings have been given about the membrane's fragility, it has been punctured on occasion when an operator tried to clean off deposits with something other than water (such as a brush or screwdriver). Some of the techniques used for installing and replacing membranes do not lend themselves to easy repairs.

The use of impure salt (sodium chloride) has produced more problems than any other factor by causing clogging of the membrane. Apparently there is a great temptation to use impure salt, and the unit will function with it for quite some time; but the decrease in useful membrane life is directly proportional to the increase in impurities. It is possible to clean the membrane with an acid solution, but the inconvenience and labor costs involved are greater than the difference in value of pure and impure salt.

In one installation, the water used to make up the salt solution had a hardness of 650 mg/l, which caused a precipitate to form upon the membrane and resulted in a need for weekly cleanings. If the makeup water for the salt solution has a hardness exceeding 100 mg/l, it would be a good idea to employ a water softener to remove the calcium and magnesium from any water used in the anode compartment. Recently, it has been found that adding a small amount of a sequestering agent such as sodium hexametaphosphate to the anode compartment greatly reduces problems with buildup on the membrane.

One manufacturer has informed PAHO that he has developed a membrane that can utilize any kind of salt, but PAHO has not yet arranged for field testing.

Evaluation

MOGGOD devices do not constitute a panacea for disinfection and water treatment, but they do offer a good alternative for disinfection of small community water systems. Since their

technology is rather new, however, their development is in its infancy. With increased operating experience and collaboration among different countries, water agencies, universities, and the private sector, it seems reasonable to anticipate rapid advances and improvements in all aspects of MOGGOD.

To determine if the development of MOGGOD is worth the effort, the fundamental questions to be asked are as follows:

1 Does MOGGOD provide equally efficient or more efficient disinfection than what is currently being used in Latin America and the Caribbean?
2 Is MOGGOD reliable and safe?
3 Does MOGGOD cost less than current methods?
4 Will MOGGOD resolve or avoid enough of the disinfection problems cited previously to warrant continued development efforts?

The answer to the first two questions is "yes"; the answer to the third is "maybe"; and the answer to the fourth can only be determined by additional experience. Along this line, PAHO would like to see the MOGGOD demonstration project proceed for at least two more years, but only if it continues to receive the interest, support, and cooperation of key institutions and agencies of Latin America and the Caribbean.

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