Electrochemcially Generated Oxidant Disinfection In the Use of Individual Water Purification Devices

Technical Information Paper # 31-003-0211

PURPOSE

This information paper provides an in-depth review of on-site electrochemically generated oxidants (EGO) as a disinfectant in potable water supplies. This paper is intended to assist the reader in evaluating the disinfection capabilities of Individual Water Purification Devices (IWPDs) using EGO to kill or inactivate disease-causing bacteria, viruses, and protozoan cysts.

REFERENCES

Appendix A contains a list of references.

INTRODUCTION

Background

Understanding the disinfection capabilities of EGO to kill or inactivate disease-causing microorganisms is important in protecting Soldiers, who are considering using this technology, from acute health threats posed by these microorganisms. Soldiers deployed beyond traditional field drinking water supplies must have access to microbiologically safe water. Using IWPDs is one way to provide microbiologically safe water in these situations. These IWPDs must protect the Soldier from acute microbial health threats. The U.S. Environmental Protection Agency (USEPA) Guide Standard and Protocol for Testing Microbiological Water Purifiers (reference 1) provides performance standards by which an IWPD using EGO can be evaluated. The performance standards are a minimum 6-log reduction/inactivation of bacteria, 4-log reduction/inactivation of viruses, and 3-log reduction/inactivation of protozoan cysts (typically *Giardia* or *Cryptosporidium*). The EGO-using IWPDs meeting these standards are considered effective against disease causing bacteria, viruses, and protozoan cysts. Some IWPD manufacturers test their devices using this protocol. This is the best way to evaluate the IWPDs disinfection capabilities. In the absence of that testing data, this information paper can be used to gain an understanding of EGO disinfection capabilities and help determine if an IWPD using EGO technology could successfully meet the USEPA Guide's minimum performance standards.

General

Electrochemically generated oxidant technology is well established. The technology dates back to the 1930's when it was primarily used for the disinfection of swimming pools (reference 2). Additionally, it is also extensively used in the wastewater and drinking water industries and has more recently been utilized in the food and agricultural industry (reference 3). Currently, there is only one Commercial-Off-The-Shelf (COTS) IWPD product using EGO technology.

USAPHC U.S. ARMY PUBLIC HEALTH COMMAND (Provisional)

ELECTROCHEMICALLY GENERATED OXIDANT CHEMISTRY

Electrochemically Generated Oxidant Production

In the simplest sense, EGO is formed by passing an electric current through a brine (NaCl) solution to produce oxidants to be used for disinfection. A reaction cell (also called an electrolytic cell) is where oxidant production occurs. In this cell, filled with a brine solution, are two electrodes (an anode and a cathode). When a voltage is applied between the electrodes, oxidant is produced. There are two basic types of EGO generators (reference 4). The most frequently employed is a two-cell EGO generator in which the anode and cathode are separated by a cationic membrane. A schematic of a two-cell EGO generator is shown in Figure 1. This type of EGO generator produces two solutions. One is a low pH, high oxidant concentration solution from the cell containing the anode and a high pH, low oxidant solution from the cell containing the cathode. The second type of EGO generator contains both the anode and cathode in a single reaction cell without a cationic membrane. The current COTS IWPD device uses the single cell EGO generator technology. The oxidant concentration is a function of the voltage applied between the electrodes and the salt (brine) concentration and quality. Higher currents and voltage will produce a stronger oxidant solution and food grade salt is preferred to optimize oxidant generation (references 2 and 5). There are several different EGO generator manufacturers and their reaction cells and operation requirements all differ. However, in general a wide range of salt solution and voltages are capable of producing adequate oxidants.

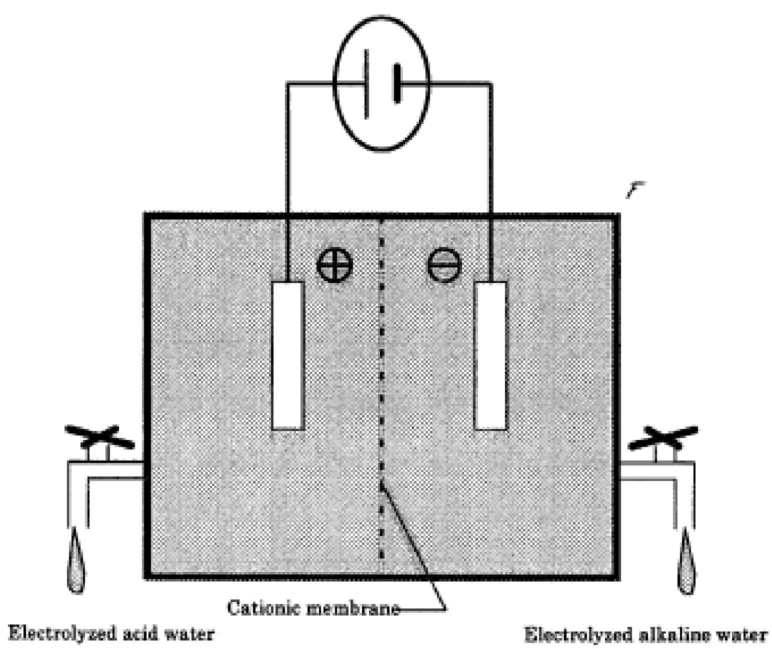

Figure 1. Schematic of a Two-Cell EGO Generator
(Source: Reference 4)

Oxidant Composition

The primary oxidant formed using EGO technology is chlorine in the form of hypochlorous acid, HOCl. It has been suggested that oxidants other than chlorine are produced by this technology such as ozone, chlorine dioxide, hydrogen peroxide, and hydroxyl radicals (reference 6). However, it has been clearly demonstrated in several studies that chlorine is the primary oxidant produced and other oxidants have not been measured at detectable levels (references 7-9).

DISINFECTION CAPABILITIES

General

Because the primary oxidant formed is chlorine, disinfection capabilities are similar, if not identical, to traditional chlorine solutions (i.e., solutions made from sodium hypochlorite, calcium hypochlorite, and chlorine gas). In the majority of research conducted on EGO disinfection effectiveness, the impacts of pH, turbidity, and temperature on disinfection effectiveness are similar to chlorine solutions. The disinfection capabilities of chlorine and the environmental effects on chlorine are well documented in the U.S. Army Public Health Command (USAPHC) Chlorine Disinfection Technical Information Paper and are summarized in Table 1 (reference 10). Because chlorine is the primary oxidant produced in EGO technology, this reference will provide the reader with a general understanding of the disinfection effectiveness of the EGO solutions. However, there are also studies suggesting that EGO technology produces a more effective disinfectant than typical chlorine solutions under the same conditions. The following discussion provides information from studies indicating EGO is more effective than typical chlorine solutions.

Disinfection Effectiveness Compared to Chlorine Solutions

Several studies were conducted comparing the disinfection effectiveness of EGO solutions to typical chlorine solutions. Results were variable. In all cases EGO solutions were as effective as or more effective than a chlorine solution as a biocide. One study showed a sodium hypochlorite solution was less effective than EGO when tested at the same chlorine concentration and water quality characteristics (reference 12). This study showed that a sodium hypochlorite solution needed 2-3 times greater CTs (disinfectant concentration times contact time) to achieve the same log inactivations as an EGO solution for various bacteria. The CT is the product of disinfectant concentration (C in milligrams per liter (mg/L)) and contact time (T in minutes (min)+). The CT product is a useful way for comparing alternative disinfectants and the resistance of various pathogens (reference 21). Another study showed an EGO solution provided a 3-log *Cryptosporidium* reduction with CTs of 75 mg-min/L, while a chlorine solution under the same conditions showed no *Cryptosporidium* reduction with a CT of 225 mg-min/L (reference 13). In contrast, other studies showed EGO solutions to be similar in disinfection effectiveness as chlorine. One study showed that chlorine solutions matched to the properties of EGO solutions were generally as effective as the EGO solutions in inactivating various pathogenic bacteria (reference 14). Another study showed similar inactivation results of pathogenic bacteria between chlorine solutions and EGO solutions (reference 15). There is also contrasting research between the EGO solutions. In disinfection studies, the general assumption is that greater CTs result in greater disinfection efficacy (i.e., greater log inactivation). However, available research shows EGO solutions with lower chlorine concentrations (i.e., lower CTs) have resulted in greater log inactivations than EGO solutions with higher chlorine concentrations (i.e., higher CTs) (references 12 and 13). Available research indicates variability in effectiveness of EGO solutions compared to chlorine solutions as well as variability in the effectiveness of similar EGO solutions. Therefore, it is difficult to predict the disinfection effectiveness of EGO solutions.

Table 1. Chlorine Disinfection Capabilities (reference 10)

Parameter	Chlorine Disinfection
General Disinfection Capability	Cysts most resistant. Achieving cyst inactivation will ensure adequate bacteria and virus inactivation. Disinfection capability generally follows: Bacteria > Viruses > *Giardia* > *Cryptosporidium*
Bacteria	Effective at reasonable CT values for IWPD use.
Viruses	Effective at reasonable CT values for IWPD use. Use EPA SWTR CT table for recommended CT values (reference 11).
Giardia Cysts	Effective at reasonable CT values for IWPD use. Use EPA SWTR CT tables for recommended CT values (reference 11).
Cryptosporidium Oocysts	Ineffective, even at high CT values. Not practical for IWPD use.
Effect of Temperature	Colder water temperatures require higher CT values. Use a two-fold increase in CT for every 10˚ C decrease. Use longer contact time instead of higher dosages to achieve higher CT values.
Effect of pH	Disinfection efficiency increases with decreasing pH. Recommend pH less than 8.0 to ensure presence of hypochlorous acid (HOCl)
Effect of Turbidity	Higher turbidity generally reduces disinfection capability. Higher dosages may be necessary to ensure the presence of free chlorine after oxidation of organic matter.
Health Effects	Chlorine, THMs and HAAs have potential health concerns at elevated levels. IWPD manufacturer-recommended dosages are not likely to cause adverse health effects for healthy adults.

Cryptosporidium Oocyst Disinfection

Some manufacturers and vendors market EGO technology's ability to inactivate *Cryptosporidium* as a significant advantage over using typical chlorine solutions. It is well established that chlorine, as it is used in drinking water treatment, is not effective at inactivating *Cryptosporidium* oocysts (reference 10). As previously discussed, some research has shown that EGO technology can inactivate *Cryptosporidium* oocysts more effectively (i.e., at lower CTs) than chlorine solutions. However, due to contrasting research, the variable and unpredictable disinfection effectiveness of EGO technology suggests that EGO technology should not be relied upon to consistently provide adequate *Cryptosporidium* inactivation. Using EGO technology as an IWPD should be considered to be as effective as chlorine and, therefore, can be effective against bacteria, viruses, and *Giardia* cysts. Based on available research, EGO technology has the potential to be effective against *Cryptosporidium* oocysts, but because of the disinfection variability shown by the research, EGO technology should not be considered consistently effective against *Cryptosporidium*.

Explanation for Variable Disinfection Effectiveness

Currently, there are no proven explanations for the variable and unpredictable disinfection effectiveness of EGO technology. The most common hypothesis by authors of studies showing EGO technology's variability and unpredictability is that oxidants other than chlorine (e.g., ozone, chlorine dioxide, etc.) are generated at variable concentrations and are short-lived (references 12, 13, and 16). However, it has been thoroughly demonstrated in other studies that there is no appreciable formation of oxidants other than chlorine (references 7-9).

EGO SOLUTION TOXICITY

Because the primary oxidant generated by EGO technology is chlorine, toxicity concerns are similar to those for typical chlorine solutions. When added to water, the chlorine in the EGO solution reacts with natural organic matter to primarily form trihalomethane (THM) and haloacetic acid (HAA) disinfection by-products (DBPs). Ingestion of chlorine and its halogenated by-products, including THMs and HAAs, can result in adverse health effects when consumed in large enough quantities for long periods of time. The USEPA regulates chlorine, total trihalomethanes (TTHMs) and (the sum of) five HAAs (HAA5) in drinking water systems that use chlorine for disinfection. The USEPA established a maximum residual disinfectant level of 4.0 mg/L for chlorine and maximum contaminant levels of 0.80 and 0.60 mg/L for TTHM and HAA5 compounds, respectively (reference 17). Potential health effects from ingestion of water containing free chlorine above 4.0 mg/L include eye, nose and throat irritation, stomach discomfort, nausea and vomiting. Evidence from animal and human studies suggests that chlorine and hypochlorite solutions themselves probably do not contribute to the development of cancer or any toxic effects (reference 18). Potential health effects from ingestion of water with elevated levels of TTHMs over a long period of time include liver, kidney or central nervous system problems, as well as the increased risk of cancer. Some studies also show an association between high levels of TTHMs and an increased risk of early term miscarriage (references 17-19). Potential health effects from ingestion of water with elevated levels of HAA5 compounds over a long period of time include the increased risk of cancer (reference 19). Generally, short term exposure to elevated levels THMs and HAAs for healthy adults does not result in adverse health effects (reference 20). For IWPD use, the risk of illness and death resulting from exposure to pathogens in drinking water is very much greater than the risks from chlorine and its DBPs (reference 20). However, manufacturer recommended EGO dosages should be followed to minimize the potential for DBP formation and exposure.

CONCLUSIONS

The use of EGO technology results in the production of primarily a chlorine disinfectant. For this reason an EGO solution, in general, has the same disinfection effectiveness and experiences the same impact of environmental effects on disinfection effectiveness as typical chlorine solutions. Research shows the disinfection effectiveness of EGO solutions to be variable and unpredictable. In general, the disinfection effectiveness of EGO solutions is as effective, or can be more effective, than typical chlorine solutions. Using EGO technology as an IWPD should be considered to be as effective as chlorine and, therefore, can be effective against bacteria, viruses, and *Giardia* cysts. Based on available research EGO technology has the potential to be effective against *Cryptosporidium* oocysts, but because of the disinfection variability shown by the research, EGO technology should not be considered consistently effective against *Cryptosporidium*. Generally, short term exposure to elevated levels of THMs and HAAs for healthy adults does not result in adverse health effects. For IWPD use, the risk of illness and death resulting from exposure to pathogens in drinking water is very much greater than the risks from exposure to chlorine and its DBPs. However, manufacturer recommended EGO dosages should be followed to minimize the potential for DBP formation and exposure. Table 2 provides a summary of the disinfection capabilities of EGO Solutions.

Table 2. Summary of Disinfection Capabilities of EGO Solutions

Parameter	EGO Solutions
General	As effective or can be more effective than chlorine. Disinfection capability generally follows: Bacteria > Viruses > *Giardia* > *Cryptosporidium*
Bacteria	Effective
Viruses	Effective
Giardia Cysts	Like chlorine, consider providing additional contact time beyond IWPD manufacturer recommended CTs.
Cryptosporidium Oocysts	Effectiveness is variable and unpredictable. Considered not consistently effective...
Effect of Temperature	Like chlorine, colder temperatures can reduce effectiveness. Higher CTs will ensure for colder temperatures increases effectiveness.
Effect of pH	Like chlorine, higher pH decreases effectiveness. pH less than 8.0 ensures presence of the most effective chlorine species, hypochlorous acid (HOCl).
Effect of Turbidity	Like chlorine, higher turbidity reduces effectiveness. Higher dosages may be necessary to ensure effectiveness.

PREPARED BY: Steven H. Clarke, Environmental Engineer

DATED: March 2006, updated January 2011

APPENDIX A
REFERENCES

1. U.S. Environmental Protection Agency (USEPA), Registration Division Office of Pesticide Program, Criteria and Standards Division Office of Drinking Water, 1987. *Guide Standard and Protocol for Testing Microbiological Water Purifiers*. Washington, D.C.

2. White, G.C., 1999. Handbook of Chlorination and Alternative Disinfectants, Fourth Edition. John Wiley & Sons, New York, NY.

3. Len, S., et. al., 2002. Effects of Storage Conditions and pH on Chlorine Loss in Electrolyzed Oxidizing (EO) Water. *Journal of Agricultural and Food Chemistry*, 50(1), 209-212.

4. Morita, C., et. al., 2000. Disinfection potential of electrolyzed solutions containing sodium chloride at low concentrations. *Journal of Virological Methods*, 85, 163-174.

5. U.S. Army Belvoir Research, Development and Engineering Center, 1994. *Design, Fabrication, and Testing of a Laboratory Test Electrolytic Water Disinfection Unit (EWDU): Addendum Number 2 Results of Reinfection Studies*. (Report Number LATA/MX-94/0009). Prepared by Bradford, W.L. and Baker, F.A., Los Alamos Technical Associates, Inc.

6. Reiff, F.M., 1988. Drinking-Water Improvement in the Americas with Mixed Oxidant Gases Generated On-Site for Disinfection (MOGGOD). *Pan American Health Organization Bulletin*, 22(4), 394-415.

7. Gordon, G., Bolden, R., and Emmert, G., 2002. Measuring Oxidant Species in Electrolyzed Salt Brine Solutions. *Journal of American Water Works Association (AWWA)*, 94(10), 111-120.

8. Stan, S.D., Woods, J.S., and Daeschel, M.A., 2005. Investigation of the Presence of OH Radicals in Electrolyzed NaCl Solution by Electron Spin Resonance Spectroscopy. *Journal of Agricultural and Food Chemistry*, 53(12), 4901-4905.

9. Stan, S.D. and Daeschel, M.A., 2005. 5,5-Dimethyl-2-pyrrolidone-*N*-oxyl Formation in Electron Spin Resonance Studies of Electrolyzed NaCl Solution Using 5,5-Dimethyl-1-pyrroline-*N*-oxide as a Spin Trapping Agent. *Journal of Agricultural and Food Chemistry*, 53(12), 4906-4910.

10. U.S. Army Public Health Command, 2011. *Technical Information Paper: Chlorine Disinfection in the use of Individual Water Purification Devices*, Aberdeen Proving Ground.

11. EPA, 1991. *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems using Surface Water Sources.* (Contract No. 68-01-6989). Prepared by Malcolm Pirnie, Inc., and HDR Engineering, Inc.

12. Venczel, L.V., Likirdopulos, C.A., Robinson, C.E., and Sobsey, M.D., 2004. Inactivation of Enteric Microbes in Water by Electro-chemical Oxidant from Brine (NaCl) and Free Chlorine. *Water Science and Technology,* 50(1), 141-146.

13. Sobsey, M.D., et. al., 2000. Inactivation of *Cryptosporidium parvum* Oocysts and other Waterborne Microbes by Oxidants Generated Electrochemically from Sodium Chloride from Portable Pen and Bench Scale Systems. *Proceedings from the AWWA Water Quality Technology Conference*.

14. Kim C., Hung Y., and Brackett R.E., 2000. Efficacy of Electrolyzed Oxidizing (EO) and Chemically Modified Water on Different Types of Foodborne Pathogens. *International Journal of Food Microbiology*, 61, 199-207.

15. Venkitanarayanan K.S., Ezeike G.O., Hung Y., and Doyle M.P., 1999. Efficacy of EO Water for Inactivating *Escherichia coli* O157:H7, *Salmonella enteritidis*, and *Listeria monocytogenes*. *Applied and Environmental Microbiology*, 65(9), 4276-4279.

16. Venczel L.V., Arrowood M., Hurd M., and Sobsey M.D., 1997. Inactivation of *Cryptosporidium parvum* Oocysts and *Clostridium perfringens* Spores by a Mixed-Oxidant Disinfectant and by Free Chlorine. *Applied and Environmental Microbiology*, 63(4), 1598-1601.

17. Title 40, Code of Federal Regulations, Part 141, National Primary Drinking Water Regulations, 2004.

18. Waller, K., Swan, SH, Hopkins, B., Windham, G., Fenster, L., Schafer, C., Neutra, R., 1998. A Prospective Study of Spontaneous Abortion: Relation to Amount and Source of Drinking Water Consumed in Early Pregnancy. *Epidemiology* 9(2):126-133.

19. Federal Register, 2003. National Primary Drinking Water Regulations: Long-Term 2 Enhanced Surface Water Treatment Rule; Proposed Rule. 68(154), 47640-47795.

20. World Health Organization (WHO), Environmental Health Criteria 216, 2000. *Disinfectants and Disinfectant By-products*. ISBN 92 4 157216 7. WHO Library Cataloguing-in-Publication Data.

21. Crittenden, J.C. et al., 2005. Water Treatment: Principles and Design Second Edition. John Wiley & Sons, Inc. Hoboken, NJ.