2014 CFID SAFE DRINKING WATER PILOT PROJECT

Title: Electrochemical disinfection using copper and/or silver

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1. Background

In modern drinking water treatment, disinfection usually uses of strong oxidizing agents (e.g., ozone, hypochlorite, chlorine dioxide). These chemicals are difficult to handle and transport as they are present as gaseous (O_3, Cl_2) or aqueous forms ($HOCl/OCl^-$). As a result, communities in remote areas or underprivileged counties have a limited access to these disinfection chemicals and consequently safe drinking water.

Ultraviolet (UV) lights can be used as a primary disinfectant in drinking water treatment. UV disinfection does not require any toxic chemicals, and it is known to be effective for protozoan pathogens (e.g., cysts of *Cryptosporidium parvum* and *Giardia lamblia*), which are resistive in conventional chlorine-based disinfection processes. However, UV disinfection needs relatively intensive energy requirement to generate UV lights, making the technology available only in developed areas. Consequently, UV disinfection cannot be an affordable option for poor communities with continuing difficulties in producing safe drinking water.

2.1 Disinfection capacity and limitation of copper and/or silver

Copper is one of the oldest disinfection materials in human history. By storing water in a metallic copper container, a small amount of Cu^{2+} released into water can inactivate pathogenic microorganisms, making water safe for human consumption. The disinfection capability of Cu^{2+} has been demonstrated in literature with various pathogenic microorganisms (*Salmonella*, *Legionella*, *Vibrio*) at relatively low concentration. For more effective disinfection, high concentration of Cu^{2+} ions is necessary; however, highly concentrated Cu^{2+} ions can impose significant toxic effects on human health. As a result, disinfection using Cu^{2+} ions cannot be a practical option for drinking water treatment, resulting in limited applications mainly for controlling *Legionella pneumophila* in air conditioning systems.

Silver has an excellent antibiotic capability even at lower concentrations than copper. However, silver can also impose serious human health risks with continued consumption. Another challenge in using silver for disinfection is the relatively high cost of silver. Thus, silver disinfection cannot be employed in large scale drinking water treatment unless Ag^+ ions are simultaneously recovered after treatment.

2.2 Rationale of proposed copper disinfection

In this proposed work, an electrochemical method will be developed for effective disinfection of drinking water using copper. Fig 1 shows an electrochemical cell with the metallic copper anode and cathode. The anode and cathode are connected to an external power supplier that provides a small amount of electric energy to drive electrode reactions in the cell reactor. At the anode, metallic copper is oxidized to aqueous Cu^{2+} ions (Eq. 1). The aqueous Cu^{2+} ions released from the anode inactivate microorganisms (including pathogens) as an active disinfectant. Simultaneously, Cu^{2+} ions migrate toward the cathode where Cu^{2+} is reduced to metallic copper (Eq. 2). With this recovery of Cu^{2+} ions at the cathode, the disinfected water from the reactor will have sufficiently low Cu^{2+} concentration for safe human consumption.

$$Cu_{(s)} \rightarrow Cu^{2+} + 2e^- \quad (1)$$

$$Cu^{2+} + 2e^- \rightarrow Cu_{(s)} \quad (2)$$

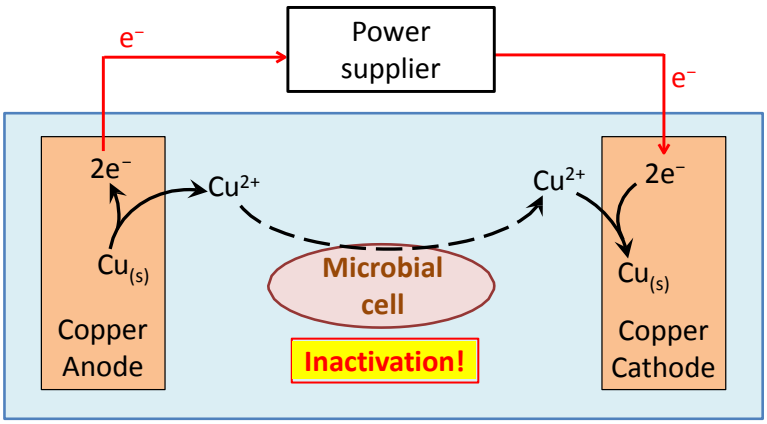

Fig 1. Illustration of electrochemical disinfection. Cu^{2+} released at the anode inactivates microorganisms. Simultaneously, Cu^{2+} is recovered as metallic copper at the cathode

2.3 Rationale of proposed silver disinfection

Silver ions (Ag^{+}) have a proven disinfection capability for various microorganisms. Previous studies have focused on its antibiotic capacity at relatively low Ag^{+} concentration (0.1 to 5 mg/L) mainly because of high expenses and adverse health effects. To increase Ag^{+} concentration during disinfection and simultaneously recover Ag^{+} ions, we will use the proposed cell reactor (Fig 1). Similar to the copper reaction, metallic silver is dissolved to Ag^{+} ions at the anode (Eq. 3) and Ag^{+} ions are recovered at the cathode (Eq. 4). Since electric charge is conserved, the amount of Ag^{+} ions released at the anode should be identical to that recovered at the cathode unless other electrode reactions are induced. Thus, the effluent water from the electrochemical cell will contain negligible amounts of Ag^{+} ions, allowing safe human consumption of treated water. Also, almost complete recovery of silver enables extended uses of the silver electrode without replenishment.

$$Ag_{(s)} \rightarrow Ag^{+} + e^{-} \quad (3)$$

$$Ag^{+} + e^{-} \rightarrow Ag_{(s)} \quad (4)$$

2.4 Synergistic disinfection using both silver and copper

In research literature, Cu^{2+} and Ag^{+} ions are often examined together to magnify the disinfection efficiency. While microbial Inactivation mechanisms have not been clearly explained, it is evident that there exist synergistic effects on water disinfection when Cu^{2+} and Ag^{+} are provided simultaneously. Thus, we will examine such synergistic effects in the proposed electrochemical disinfection by using both metallic silver and copper as the electrode.

3.0 Research Goals

1. To develop an innovative disinfection method that is affordable for people in underprivileged communities. The proposed method uses inexpensive raw materials that are easily transportable to remote areas. In addition, active chemicals for disinfection are simultaneously recovered after disinfection, enabling extended uses of raw materials over time. We will also focus on demonstrating low energy requirement so that the proposed method can be used to provide safe drinking water for underprivileged communities.

2. To investigate if the proposed method can effectively inactivate *Cryptosporidium* oocysts and *Giardia* cysts. These protozoan cysts are practically impossible to inactivate in chlorine-based disinfection, requiring advanced methods such as ozone- or UV- based disinfection. Costs for ozone or UV treatment are still expensive for broad applications even in developed countries. Thus, the proposed method will also be examined with cysts of *Cryptosporidium parvum* and *Giardia lamblia*.

4.0 Hypotheses and Research Plan

1. Kinetic constants can be found for copper or silver disinfection - Kinetic studies are essential to evaluate the effectiveness of the proposed disinfection method On completion of the project, the rate of disinfection will be expressed as a function of Cu^{2+} (or Ag^{+}) ion concentration (C) and contact time (t). Kinetic study results will also be prepared for Ct values required to achieve certain degrees of microbial inactivation so that our disinfection performance can be compared with other established disinfection technologies.

2. Energy requirement for electrochemical disinfection can be low - Energy requirement for disinfection should be small enough to be used in undeveloped regions. We will try to demonstrate significantly low energy consumption so that even a bicycle generator can power the proposed system for water disinfection. In the proposed system (Fig 1), total energy consumption consists of energy losses for the electrode reaction and ionic transport between the electrodes. In experiments, we will focus on minimizing these energy losses while maintaining high disinfection efficiencies.

3. The proposed method can inactivate protozoan cysts - Conventional chorine-based disinfection cannot inactivate protozoan pathogens (e.g., cysts of *Cryptosporidium parvum* and *Giardia lamblia*). Active disinfectants during chlorination ($HOCl$ / OCl^{-}) are known to attack microbial cell membranes with their oxidizing capacity; thus, the protozoan cysts with resilient external wall layers can survive chlorine disinfection. However, the metal ions (Cu^{2+} and Ag^{+}) can effectively inactivate the protozoan cysts because their disinfection mechanisms are different from chlorine disinfection. In copper and silver disinfection, it is thought that Cu^{2+} and Ag^{+} ions diffuse into a microbial cell and form complex with proteins and nucleic acids, inactivating the microorganisms. Thus, we hypothesize that the proposed method can effectively inactivate the protozoan cysts.

5.0 Significance / Impact / Relevance

In this proposed work, we target to demonstrate effective disinfection of drinking water using metallic copper at substantially low energy requirement. Copper granules are inexpensive and transportable without any safety problems. In addition, the method will not lose copper with simultaneous recovery of Cu^{2+} ions. Thus, with successful experimental demonstration, the proposed disinfection system can be operated at a negligible expense, supplying safe drinking water to communities in less privileged and remote areas.

We will examine the proposed methods for inactivation of protozoan cysts. *Cryptosporidium* oocysts and *Giardia* cysts are very resistive in chlorine-based disinfection, requiring expensive ozone or UV disinfection. With successful experimental results with the resistive pathogens, applications of the proposed method will not be limited to underprivileged communities, allowing extensive uses as an inexpensive method for safe water production. The proposed work also includes various training components of HQP. One graduate student will be trained over 2 years in the project. The student will develop strong expertise in microbiology, electrochemistry and water treatment engineering. The student will be encouraged to take the following courses: CIV ENG 735 (Advanced Water and Wastewater Treatment Processes); CIV ENG 747 (Microbiology for Environmental Engineers); and MATLS 792 (Electrochemical Measurement Techniques). In addition, the student will build analytical skills for waterborne pathogens and metal ions.