Sustainable On-Site Bleach Generation Utilizing Salt and Sunlight

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Abstract- Access to clean water, free of biological contamination, is a serious problem in many parts of the world. Bleach (i.e. sodium hypochlorite) can be used to kill these biological contaminants. A simple, robust on-site method to generate bleach is presented. The system consists of a pair of electrodes, a solar panel and a disposable water bottle. Preliminary field testing in Uganda is discussed.

I. INTRODUCTION

One in six people in this world lack access to clean drinking water. A child dies every 15 seconds from preventable, water related diseases [1]. There are over 3 million people who die each year due to these water related diseases—that's comparable to the population of Los Angeles, California. These statistics illustrate the need for readily available disinfectant and clean, drinkable water throughout the world.

People have been trying to figure out ways to gain access to clean water for many centuries. There are numerous methods of achieving this goal. The first attempts were made by the ancient Greeks who knew that heating water helped with purification and that sand and gravel could be used as filters. Around 1500 BC, Egyptians discovered the technique of coagulation which uses a chemical additive to gather particles in clusters which trap impurities that will settle to the bottom. The Romans built aqueducts to transport water over long distances for use in the city and irrigation. Hippocrates around 500 BC invented the first bag filter which trapped sediments that caused bad tastes and odors, while Archimedes invented a screw that transports water from lower grounds to higher grounds. Water treatment took a massive pause and arguably a step backwards during the dark ages (500-1500AD) when many aqueducts and water treatment tools were destroyed due to war [2].

The microscope, for the first time in history, enabled observation of and experimentation on the pathogens which cause a variety of illnesses. However, it wasn't until 1854 after a cholera epidemic in London spread through water from a contaminated pump that chlorine was applied to the water for disinfection purposes. This outbreak also led to the installation of municipal water filters as the first act of government regulation of public water [2].

The US Centers for Disease Control and Prevention (CDC) states that the presence of chlorine residual in drinking water primarily indicates two things: chlorine was added initially to the water to inactivate the bacteria (and some viruses) present and that the water is now protected from recontamination during storage [3]. A correlation between the presence of free chlorine residual in drinking water and the absence of disease-causing organisms exists and is defined as the potability of the water.

When chlorine is added to water for potability, it undergoes a series of reactions. Chlorine first reacts with organic materials and metals in the water and is therefore not available for disinfection in the chlorine demand stage. Total chlorine is the left over chlorine after the demand is met and is broken down into two subcategories, free chlorine and combined chlorine. Combined chlorine unites with nitrogen in the water and is unavailable for disinfection, while free chlorine is available for inactivating disease-causing organisms. Therefore, free chorine is the measure used to determine the potability of water [3-7].

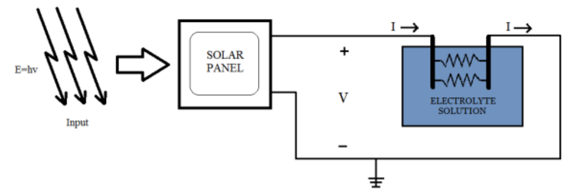

Fig. 1. Salt and Light component diagram.

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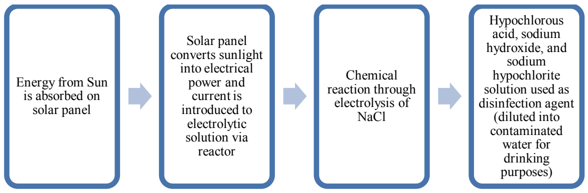

Fig. 2. Block Diagram of system operation.

The goal of the effort described in this paper is the development and characterization of a system which can provide sustainable on-site, on-demand formation of free chlorine. The system (referred to as Salt and Light) utilizes commonly available salt as the chlorine source and an electrochemical reaction powered by a solar panel to create bleach (i.e. sodium hypochlorite). Bleach is a chemical widely used for the disinfection of medical facilities such as clinics and to sanitize drinking water.

II. BASIC CHEMISTRY

The basic components of the system are a solar panel, metal rods (i.e. electrodes) to introduce current to the system, salt, and water. As shown in Fig. 1, optical energy of sunlight is converted to electricity via the solar panel. This serves as the system's energy source. The panel, which is electrically connected to the two electrodes, will utilize the energy from the sun to sustain a chemical reaction in the electrolyte solution. The solution is composed of a standard mixture of 0.5 L of water and 1 gm of sodium chloride (NaCl).

Salt is an ionic compound consisting of the two ions Na+ and Cl- in a crystal-lattice structure. Neither element (Na or Cl) exists separately and free in nature, but they bind together as sodium chloride. This compound is found in nature as the mineral halite (rock salt) and has multiple uses. The block diagram in Fig. 2 is a simplified exposition of the process for producing a solution that can be used to disinfect water or for cleaning purposes.

Electrical current is applied to the immersed pair of electrodes to initiate and sustain a series of chemical reactions. Fig. 3 is a pictorial illustration of the chemical reactions.

At the anode, oxidation reactions cause two chloride ions to be stripped of one electron each to yield chlorine gas:

$$2Cl^{-} \rightarrow Cl_2 + 2e^{-}. \qquad (1)$$

Chlorine production is then balanced by a reduction reaction carried out at the cathode, where water is converted into hydroxide ions and hydrogen gas, as previously mentioned above:

$$2H_2O + 2e^{-} \rightarrow 2OH^{-} + H_2\,. \qquad (2)$$

During this process, bubbles are readily visible and act as a simple visual cue that the reaction is occurring. The hydroxide ions (OH-) produced at the cathode react with the hypochlorous acid (HOCl) produced at the anode, yielding the hypochlorite anion (OCl-)

$$HOCl + OH^{-} \rightarrow H_2O + OCl^{-} \qquad (3)$$

which is balanced with sodium cations (Na+) that originally came from the salt. The hypochlorite anion (OCl-) then reacts to form a solution of sodium hypochlorite [8].

$$NaCl + H_2O \rightarrow NaOCl + H_2\,. \qquad (4)$$

The concentrated solution can now be utilized to treat drinking water or directly as a cleaner/disinfectant. Free chlorine dosages are measured to determine how much sodium hypochlorite (NaOCl) to add to drinking water in order to maintain free chlorine residual during the time of storage. Typically this time period is 4-24 hours. The Safe Water System (SWS) program recommends the following free chlorine residual measurements to ensure the safety of the drinking water [3].

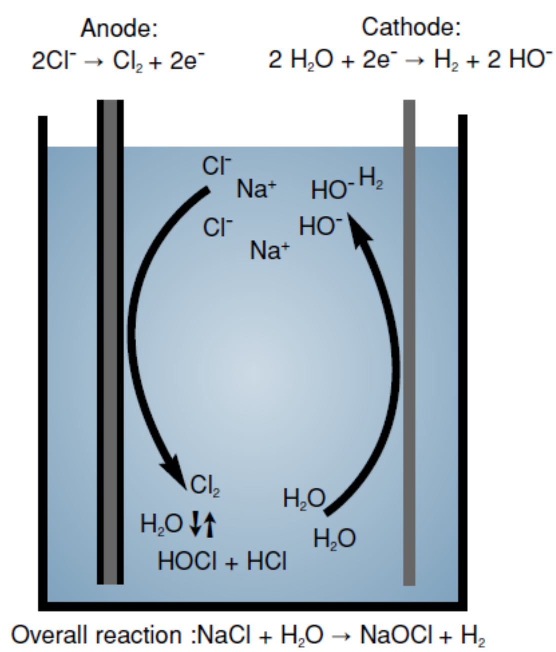

Fig. 3. Chemical reactions.

“1. At 30 minutes after the addition of sodium hypochlorite there should be no more than 2.0 mg/L of free chlorine residual present (this ensures the water does not have an unpleasant taste or odor).

2. At 24 hours after the addition of sodium hypochlorite to containers that are used by families to store water there should be a minimum of 0.2 mg/L of free chlorine residual present (this ensures microbiologically clean water)”[3].

These values were therefore chosen as the target concentrations of free chlorine.

III. PHOTOVOLTAICS (PV)

Photovoltaic devices (PV) convert solar radiation into DC electricity using semiconductors that exhibit the photovoltaic effect [9]. Materials commonly used for PV include but aren’t limited to monocrystalline silicon, polycrystalline silicon, or amorphous silicon. They each have certain advantages and disadvantages which make them more or less attractive depending on their application.

The photovoltaic effect was recognized in 1839 but it wasn’t until 1883 that the first PV cell was built. The modern day PV cell was invented in 1954 at Bell Laboratories and initially was too costly for use in any major project other than early space satellites. Over time, the production process improved and the cost of manufacturing decreased. As the name suggests, monocrystalline PV cells are made from a single silicon crystal which makes the process of producing them complex and costly. They have a minimum lifetime of 25 years (up to 50 years maximum) and are used to form the most reliable and efficient solar panels for common terrestrial use in production today. Monocrystalline panels also work well in low light, and are preferred in most applications where cost isn’t a main priority. They are fragile and require rigid mounting and/or careful handling, but they perform well in weather tests.

Polycrystalline cells were first produced in 1981 and are made from a similar silicon material. The difference between these and their monocrystalline counterparts is that instead of being grown into a single crystal, the silicon is melted and poured into a mold, forming a rectangular block of silicon full of impurities and random crystal boundaries. The result of this technique is lower energy conversion efficiency (12-12.5%) compared to 17-18% of the monocrystalline type), meaning that it will take a larger sized polycrystalline panel to produce the same wattage output as a monocrystalline panel [9]. They are fairly comparable in longevity and reliability to monocrystalline panels and their lower costs allow them to give power to people who cannot afford the more expensive varieties.

A third type of panel currently in production is made from amorphous silicon and is less adversely affected by high temperatures. It is considered the first thin-film technology since silicon is deposited in thin layers during production. It is becoming increasingly popular due to its simplicity in manufacturing and low cost. It is a flexible panel that works better in diffuse light than mono and poly-crystalline panels; however, it can only achieve about half the efficiency (6%) [10].

A wide variety of commercially available panels were purchased and tested for output characteristics. Two monocrystalline panels were chosen for use, the Goal Zero 30W briefcase panel and the Goal Zero 7 W Nomad foldable panel. The briefcase measured 44.6 x 55.8 x 2.5 cm and weighed 5.5 kg. The foldable panel measured 15 x 26 x 2.5 cm and weighed 0.35kg. Fig. 4 illustrates the briefcase panel being tested in Uganda. Fig. 5 illustrates the Nomad 7 foldable solar panel.

In order maximize reliability of the fielded system, the solar panels were directly connected to the electrodes without the use of maximum power point tracking (MPPT). Although this reduced the solar energy conversion efficiency of the system, it also significantly increased the reliability by eliminating failures due to discrete circuit components, solder connections, printed circuit board traces etc. of the MPPT.

Fig. 4. Briefcase panel being tested in Uganda.

Fig. 5 The Nomad 7 foldable solar cell.

IV. ELECTRODES

Mixed metal oxide (MMO) electrodes were initially developed to prevent the passive film of titanium oxide that forms on the electrodes when polarized anodically in aqueous electrolytes [11]. Henri Beer pursued a variety of titanium coatings and discovered that ruthenium oxide coatings were superior to all others being used in the chlorine industry. He was granted a patent in 1965 that is directed to the 'co-deposition of oxides of ruthenium and titanium onto a titanium substrate' [12].

A second patent was granted to him in 1967 after further testing showed that the potentials at which chlorine was formed were dependent on how much ruthenium oxide was in the coating [13]. He realized that a thinner layer of the oxide would not only be cheaper but provided the same if not better performance with a longer lifetime. Iridium, which happens to be the second densest and one of the most corrosive resistant metals, also was found to work well with only a slight decrease in efficiency.

Iridium oxide coated rods were purchased and used for the Salt and Light Water purifier. Rods of 5mm diameter were chosen for ease of machining. The rods were cut into 15.25 cm long sections. The end of each rod had 1.25 cm of the coating removed using a grinder to provide an electrical connection point.

The electrodes were mounted in a cork as shown in Fig. 6.

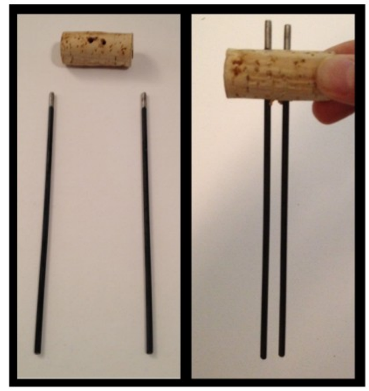

Fig. 6. Iridium oxide coated electrodes.

V. SALT CONCENTRATION

In order for a chemical reaction to occur by electrolysis, sodium chloride (NaCl) must first be dissolved in the water. A standard measurement of 2 mL of NaCl was used in 0.5 L of water. This amount of NaCl was selected after extensive empirical testing using the Nomad 7 panel as a power source. The selected sample of 2 mL resulted in maximum power transfer between solar panel and electrodes. It was therefore chosen as the standard, easily achievable salt dosage.

VI. FIELD TESTING

Initial field testing was performed in Uganda utilizing the Briefcase panel. Biological contamination of water sources in rural Uganda can be a serious problem, since many water sources are downhill or downstream of latrine areas. Also, rainwater catch systems in tropical areas are excellent breeding grounds for microbiological species. An interesting observation/conclusion was reached during testing in country. No one was willing to accept ownership of the briefcase panel. Local residents were convinced that the 30W briefcase panel drew too much attention because it appeared to be an item of economic value which would invite armed robbery.

Field testing was therefore continued exclusively with the Nomad 7 foldable panel. A picture book was used as a visual method for conveying proper system operation. Figs. 7 – 16 represent the sequence of operation conveyed to local residents. Fig. 17 portrays residents operating systems in Uganda. [14].

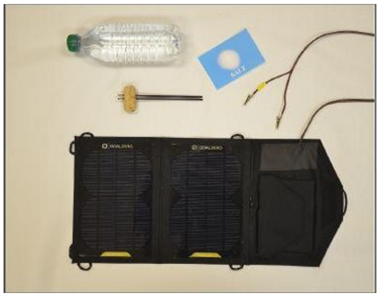

Fig. 7. Kit contents.

Fig. 8. Pouring water from jerry can.

Fig. 9. Pouring salt into bottle.

Fig. 10. Shaking bottle to mix salt and water.

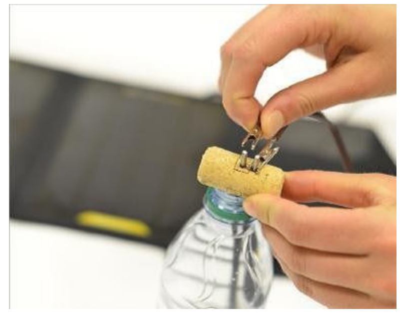

Fig. 11. Attaching electrical leads of solar panel.

Fig. 12. Set up the system in the morning.

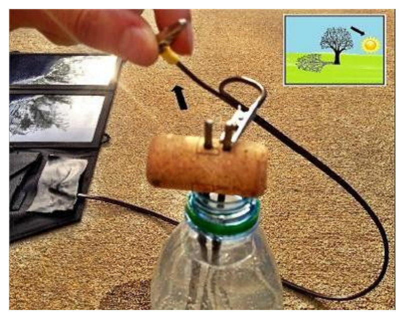

Fig. 13. At sundown disconnect solar panel.

Fig. 14. Pour 1/3 of bottle contents into jerry can.

Fig. 15. Allow the jerry can to sit overnight.

Fig. 16. After waiting overnight, the water will be safe to drink.

Fig. 17. Successful demonstration to local residents in Uganda.

Several months after the systems were left in country the following email was received: "*Oh yes, to my side it worked for me and i have been using the water for drinking since this year started, The water was so good and i didnt get sick, so its working for me. thanks so much for your love and care!!*

Also: *"We tested a bottle of the mixed-oxidant solution around the latrine to clean and help reduce the bad smell, and it worked very well, making the ladies extremely excited!"*

VII. CONCLUSION

Access to potable water is a serious, often life threatening problem in many parts of the world. Access to common bleach could significantly improve this situation. A low-cost, sustainable method to create bleach (i.e. sodium hypochlorite) using salt and sunshine has been demonstrated. The system was field tested in Uganda and has proven effective in producing a cleaner and disinfectant. Systems have also been deployed to Guatemala, Kenya and India. Feedback from these deployments will be utilized to further explore and refine the concept.

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