Salt and Light Water Purification System

by

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Abstract

The need for a proposed solution to help mitigate the world's water crisis is presented. This need is not a new development in the 21^{st} century, nor is the process of using electricity and chemicals to sanitize water. However, a unique way to meet this need using sunlight and sodium chloride is considered new and explored in this document. The Salt and Light Water Purification System is low cost and reliable. The system targets third-world countries. Field testing in Uganda has determined these systems meet the need for inexpensive and effective water purification.

Basic electrolysis is carried out utilizing two titanium rods coated with a rare earth oxide to react sodium and chlorine atoms in water. The electrolytic reactions create free chlorine sources including sodium hypochlorite, hypochlorous acid, and dissolved chlorine gas. The electrical, biological, and chemical aspects of the entire process are detailed, as are the reasons for choosing each of the components for this system. Results from experimental testing are provided and explained in conjunction with the reason for this particular design. A conclusion captures the future vision for this system.

Acknowledgments

I would like to thank my father and mother, Jeff and Anne, for their support while pursuing an advanced degree. I would also like to thank my sisters Elizabeth and Kathleen and several friends for their encouragement and faith in me that I could accomplish the task at hand.

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Finally, a big thank you to Scott Fillmer for the pictures he took in Uganda and back in the United States to help with my work. I can now tell the story about Salt and Light through pictures, and teach people how to use the system without speaking their language. The fact that the language barrier can be broken through a set of pictures is invaluable to the deployment of this technology.

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CHAPTER 1

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 3.575 million people that die each year due to these water related diseases—that's equivalent to the population of Los Angeles, California. These numbers speak for themselves, and my heart breaks when I know that the technology exists to mitigate this situation. Jesus of Nazareth is often quoted as having said "To Him who much is given, much is required" (Luke 12:48) [2]. This statement embodies the responsibility of individuals who possess abundant resources to share with those who do not.

Much of the aid that the western world provides is not working [3]. William Easterly writes in the White Man's Burden about the two tragedies of global poverty, the first being that there are so many people seemingly fated to live horribly stunted, miserable lives and die early deaths from preventable diseases. The second is that 50 years and $2.3 trillion dollars of aid later, the west has remarkably little to show for helping change the first.

As a society, we have failed to provide 12 cent malaria medicine to children worldwide to prevent half of all malaria deaths, or 4 USD mosquito nets to protect poor families while they sleep. It is truly sad because so much well-intended compassion has failed to bring any lasting results. I do not intend for this introduction to be an indictment of anyone. I would be willing to bet that the majority of the western world does not really know the dire need for potable water experienced by the rest of the world's population. But hopefully, after reading this document, not only will the readers be more educated about the needs of the world, but they will have the opportunity to do something to help make a difference. Even if just one more system is built and deployed, this water purification system would have helped someone live a little longer or a little healthier.

In his book, Easterly, a former World Bank economist and current professor at New York University, describes two types of people who offer aid to the impoverished of the world. The first group is referred to as "planners" and the second group as "searchers." He describes the contrast between the two groups in the following ways: "In foreign aid, Planners announce good intentions but don't motivate anyone to carry them out; Searchers find things that work and get some reward. Planners raise expectations but take no responsibility for meeting them; Searchers accept responsibility for their actions. Planners determine what to supply; Searchers find out what is in demand. Planners apply global blueprints; Searchers adapt to local conditions. Planners at the top lack knowledge of the bottom; Searchers find out what the reality is at the bottom. Planners never hear whether the planned got what it needed; Searchers find out whether the customer is satisfied" [3].

These occur in stark contrast to one another, with the majority of western aid coming in the form of planners. The United States especially has a tendency to throw large amounts of money at a situation, thinking the money ended up in the right hands and is used to carry out its intended purpose. More times than not, especially in the last five decades, billions of dollars have been spent to help relatively few. This is a large part of the motivation for a product such as the Salt and Light Water Purification System. I have spent time on the ground with people in need of a system like this, gathering important feedback as to what works and what doesn't work. I have also performed several field tests and am confident that this system will impact and save many people's lives.

The purpose of this thesis is to characterize a problem and thoroughly document my solution to it. Through the Salt and Light Water Purification system, it is my dream that at least one life is saved in this world due to access to clean water. I will explain why I chose each of the components in this system, and why this system is ideal for developing countries that have an abundance of sunshine and salt.

1.1 Problem Identification

The statistics previously mentioned illustrate the need for clean water throughout the world. The Salt and Light system seeks to fulfill this need by providing a simple, reliable, low cost method to disinfect medical facilities such as clinics and to sanitize drinking water, specifically in developing countries.

I will speak of Uganda because of my personal experiences with the locality. It is also a good test environment due to the abundance of resources available and its similarity to many other developing countries in the world, such as those found specifically in Africa.

In a village outside of Kampala, the capital of Uganda, women and children must walk miles to fetch water. Most of the time, this walk is down a very steep hill and they know that once their water jug(s) is full, they must walk all the way back up it. To them, water means life—it is essential for drinking, cooking, bathing, and cleaning, and typically it is not easily accessible.

For the vast majority of people living in the United States, clean water is a comfort that is completely taken for granted. We turn the water in our kitchen or bathroom on and never have to worry about getting a deadly disease if a drop of that water enters our body. Most of us have never lived that way, and don't realize that the majority of the world does. I know that is harsh, but it is a reality, and one that breaks my heart. I grew up as a swimmer, so have been in or around water literally my entire life but my eyes were not opened to this crisis until I was well into my college education.

Before my first mission trip to Uganda a few years ago, I took clean water for granted. I didn't understand the crisis that continues to take innocent lives worldwide. However, I've had the amazing opportunity to do something to make a difference. It was previously stated "For whom much is given, much will be required" [2]. I have been given so many blessings in my life from my Lord, the chance to earn a top-notch education being one of them. The opportunity provided by Dr. Baginski to optimize and customize this system for a certain need is quite humbling, yet I know it's a way that I can help someone in this world. Even if it is just one person, or one family in a single village in Uganda, then the work will have been well worth it. However, how amazing would it be if this Salt and Light system spreads like wildfire and transforms villages and lives all over Uganda, and Africa, and the world? God's awesome hand will have been at work, and to Him belongs all the praise and glory.

1.2 Possible Solutions

Dating back to 2000 BC, people have been trying to figure out ways to gain access to clean water. There are numerous methods of achieving this goal. The first attempts were made by the ancient Greeks who knew that heating water helped purify it 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. During the dark ages (500-1500 AD), the water treatment process took a massive pause and arguably a step backwards in the sense that many aqueducts and water treatment tools were destroyed during wartime [4].

Coming out of the dark ages, experimentation was done on the microscopic level after the invention of the microscope, and for the first time in history, micro-level contaminants were observed. 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. The contaminated water from the pump did not smell or taste any different than normal, which led to the conclusion that taste and smell alone could not be used to guarantee the potability of the drinking water. This outbreak also led to the installation of municipal water filters as the first act of government regulation of public water [4].

As already established, water disinfection and sanitation is a major factor in reducing health risks to humans. Large metropolitan areas employ systems that use highly toxic chlorine gas to disinfect large quantities of water at a time. These systems are not practical for remote areas, especially in developing countries, which lack both the personnel and equipment necessary to provide required maintenance. Systems in these remote settings must also be capable of operating for long periods of time with minimal support in order to be a viable resource for disinfecting water sources such as streams, rivers, wells, and ponds.

Chlorine bleach is currently being used to disinfect water in many developing countries, but this method has several limitations. Adding chlorine bleach to the non-potable water does not change the appearance of the water, making it hard to convince people that it is ok to drink. Also, if there are an exceedingly high number of organics in the water, the taste and smell will be worse compared to other methods [5].

Another disadvantage associated with using bleach to disinfect water is the safety hazard of storage. In places where children are always present, having a container of bleach around can be dangerous. Not only is long term exposure to the skin harmful, it can be accidentally ingested causing severe poisoning.

Lastly, imagine a farmer in a remote village located 40 miles from a bigger village or town. Not only does he most likely not have the money to spend on an item such as a container of bleach, but it would take a significant amount of time and effort to personally acquire it. Seeing this first hand in Uganda convinced me that using bleach was not the best option for areas such as these.

Sand filters are also used to treat non-potable water. Generally they are 1 to 2 meters deep and can have rapid or slow flow rates. The rapid sand filters are more suitable for large urban areas and are more complicated to operate and maintain. Therefore they are not feasible for most developing places. Slow sand filters have the ability to remove particles that are smaller than the spaces between sand grains and are often called bio-sand filters. As bacteria, viruses, and parasites from the contaminated water travel through the filter, they collide and absorb onto the sand particles mostly in the top layers of the sand, forming a biological zone. In this region, the trapped microorganisms feast on the pathogens as they try to pass. Because of this process, slow sand filters do not require any chemicals or electricity to treat water, and require little or no training to operate. Coupled with minimal required maintenance, these advantages make this type of filter ideal for some developing areas.

Another water purification technique involves the addition of iodine to water in the form of tablets or crystallized solution. Iodine is light sensitive and must always be stored in a dark bottle [6]. It kills many of the most common pathogens found in natural fresh water sources, but not all. This method of purification is suitable primarily for campers or hikers who need an onsite and lightweight purifier. Most kits involving iodine tablets come with a second pill (commonly vitamin C) that will remove the iodine taste from the water after it has been treated. Treatment time for relatively warm and clear water is about 30 minutes, but significantly longer for cold turbid water. One of the disadvantages of iodine versus chlorine is that it is three times less effective as a disinfectant against some pathogens, namely *E. coli* [6].

Boiling of contaminated water has been proven effective in killing microorganisms such as giardia, bacteria, and viruses that lead to infections. However, this method will not improve the condition of toxic water or organically contaminated water without also filtering. According to the Wilderness Medical Society, water temperatures exceeding 160°F kill all pathogens within 30 minutes and temperatures above 185°F within a few minutes. Therefore, by the time water reaches its boiling point at 212°F, all pathogens will be effectively killed (however it is recommended to let the water boil for an additional minute to be sure) [6].

This method is simple and requires only the fuel needed to boil the water, whether its firewood or gas. It has been employed by people all over the world for many years and most people are comfortable continuing on in this manner. In Uganda they currently boil their water, but finding the wood to start a fire is sometimes very tedious. The entire process, from finding the wood, starting the fire, and boiling the water is time consuming, and the water is not drinkable until it has cooled down.

Ultraviolet light as a method for disinfecting water dates back to 1916 in the United States. UV disinfection works by using radiation to penetrate an organism's cell wall and disrupting the cell's genetic material, making the cell incapable of reproducing [7]. As with any method or system, there are inherent advantages and disadvantages. The method is approved by the Environmental Protection Agency and is considered a highly effective tool for Cryptosporidium control [7]. Compared to chemical disinfection, some advantages of using UV light to disinfect water include: the absence of byproducts after treatment, only requiring seconds to treat (versus minutes with some chemical treatments), eliminating the need to store hazardous materials, and improved taste with no odor in the final product.

However, the main disadvantages are that unsafe exposure to UV light can cause temporary and long term damage to humans, the system requires some amount of service time and supervision, and there are maintenance and operation costs to consider. In the United States and other developed countries, using UV to disinfect large amounts of drinking water is economical and efficient. In developing countries where most of the population is rural, a system like this would not work as well. UV bulbs require periodic replacement after only hours of use, and cost at least $50 (from several online sources). This is almost twice the amount it costs to send a child to school (where they get a meal a day and 2 uniforms per year) for an entire month. In addition, UV doesn't work as effectively if there is high microbial or chemical contamination. Finally, there are no technical databases that exist with information on how well the systems perform for various water quality conditions, and there is no standard mechanism used to measure, initially calibrate, or certify how well the equipment works before it is installed [7]. With the effectiveness of destroying bacteria and viruses depending on the energy dosage, it is crucial that the system be set up correctly.

Campers and military personnel have benefited from a system called the MIOX purifier pen which was named the "Best of what's New" winner in 2003 [8]. MIOX stands for mixed-oxidant and the pen was developed in conjunction with the US military to reliably purify water in more rugged environments. This particular model (Figure 1.1) operates using camera batteries. It creates a mixed oxidant solution that is then added to untreated water in order to kill viruses, bacteria, giardia, and cryptosporidium.

Figure 1.1: MIOX PEN

The patent is for a "*portable oxidant generator for generating oxidants suitable for sterilizing contaminated drinking water, thereby providing potable water. The oxidant generator optionally compromises an electrolytic cell and a power supply or source for powering the generator. In a preferred embodiment, the cell holds an electrolyte solution such that the solution contacts an anode and a cathode. The power supply provided an electrical charge that is passed to the electrolyte solution and/or other electrolyte substance*" [9].

According to an article that appeared in the local Opelika-Auburn (OA) news in June 2011 by the Associated Press, the idea of using salt and few volts of electricity has been embraced by some food and hospitality businesses as they ‘look to save money and go green by swapping out conventional products’[10]. While the start-up costs of using salt and electricity to make a cleaning solution are greater than buying a bottle of bleach, this method effectively kills germs but is gentle on the skin. The idea is similar to that used in the Salt and Light system. The main difference is that these systems and the MIOX pen require batteries and electronics to provide the current through the electrodes.

The article says that this solution of hypochlorous acid and sodium hydroxide is currently used to clean kitchens, prison floors, and hotel rooms, but certain concentrations can lose potency over time. Viking Pure, a manufacturer of such systems, makes claims in their pending patent that the sanitizing solution their system produces is ‘effective against a long list of pathogens ranging from listeria to the swine flu virus.’ [11]. They also boast that one of the advantages of this technology is that there is no need for the transport of potentially harmful chemicals. This is one advantage that is embraced by several sources as being key to the adoption of on-site salt-based sanitizing systems.

All of these systems have their advantages and disadvantages depending on their application. For chemical treatment, the effectiveness is related to the pH level, clarity, and temperature of the water. The colder the water, the less effective the chemical is as a purifying agent. The ideal temperature is above 60°F [6]. If the water is cloudy or filled with large particles, it should be strained before treatment. Whatever the method, one should carefully analyze the needs and resources of the area before deciding which method is best for purifying water.

1.3 Overview of the Salt and Light Water Purification System

A motivation for the Salt and Light System was the need to piece together a functioning sanitizer that has as few potential failure modes as possible. 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 Figure 1.2, optical energy of sunlight is converted to electricity via the solar panel. This serves as the system's energy supply. The panel is electrically connected to the two electrodes that 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 16 ounces of water and 1 gram of NaCl. Section 3.4 will detail how this standard mixture was chosen. (Note: 1 g of NaCl is about 2 mL by volume)

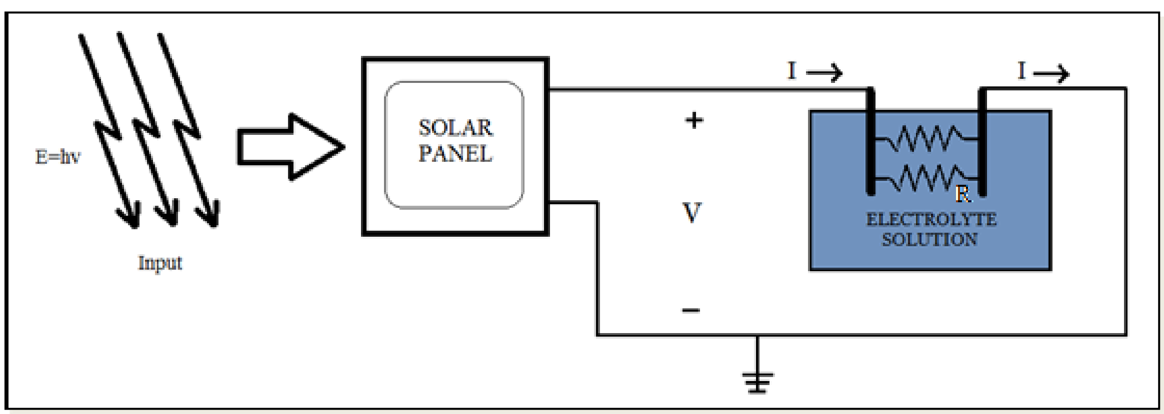

Figure 1.2: Salt and Light circuit diagram

The block diagram in Figure 1.3 illustrates the step-by-step process for producing a solution that can be used to disinfect water or for cleaning purposes. Chapter 2 will go into more detail about what is actually being produced through the electrolysis of NaCl but in general, the solution can be diluted to a ratio as low as 1:1000 (solution to non-potable water) in order to kill the bacteria and disease-causing pathogens in the water. The majority of the tests that have been performed to verify these claims are discussed in the electrical and biological chapters of this document (Chapters 3 and 4).

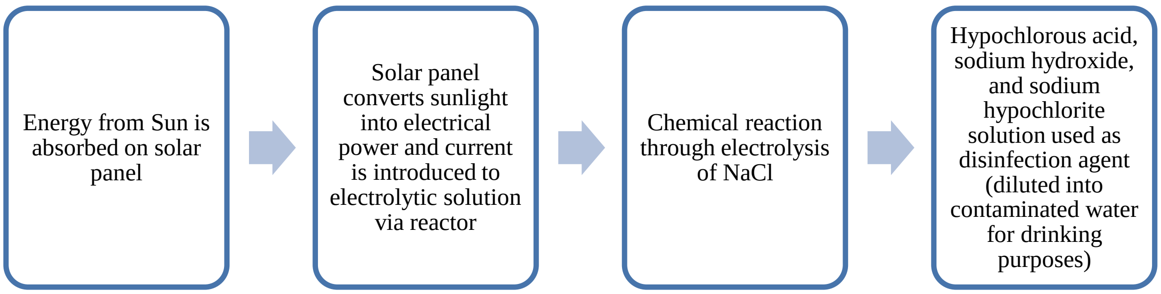

Figure 1.3: Block Diagram of Salt and Light system

In October 2011, twelve Salt and Light systems were assembled and ready for deployment to Uganda. These kits contained a solar panel (3 different ones were tested), a set of reactors, a plastic bottle, some packets of salt, and some free chlorine test strips. Figure 1.4 shows one of the panels that was tested, a set of reactors, and a water bottle.

Figure 1.4: Salt and Light kits assembled for Uganda

On the ground in Uganda, I spent time with many of my friends and distributed all the kits after teaching the proper use of the system. Not only did they understand the biblical reference to the name, they could see the chemical reaction occurring and believed that the system would do what I promised. At the time, I did not feel 100% confident about guaranteeing that their water was safe to drink after adding some of the solution because I did not have the means to test the biological contamination of the water before and after treatment.

It would have been nearly impossible to set up a lab and grow cultures to verify that all pathogens were deactivated. However, all the research I had done before the trip had convinced me that the water would be ok to drink after being treated with enough of the created solution.

A revelation was made during testing. The solution worked as a powerful, but safe cleaning solution (like a safe bleach). The pit latrines around the village in Uganda I visited are quite disgusting and require routine cleaning. 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!

At the end of my time in Uganda, I left the kits in their hands with the advice to: "*use them as much as you can to create a cleaning solution, useful for cleaning the pit latrines and any cooking or medical utensils they had, but to use it cautiously for drinking until I was able to analyze some water samples that I was bringing back."*

Thanks to the benefits provided by Facebook to communicate with friends nearly 8000 miles away, feedback about the systems has been received and I am pleased to share it here. In response to my question regarding use of the kits, my friend responded:

> *"Oh yes, to my side it worked for me and i have been using the water for drinking since this year started, it has been tooooooo hot here. The water was so good and i didnt get sick, so its working for me. thanks so much for your love and care!!,I am happy i have you as my big sister, may God be with you!"*

This is what this system is all about: being the salt and light of the earth, and bringing hope and health to people who are in dire need of basic human necessities. These systems have the potential to save lives, not because I think they will, but because my friends in Uganda have told me that they will. Figures 1.5-1.7 are photographs of field-tests in Uganda. If you would like more information regarding exactly how this system works, I invite you to read the following chapters.

Figure 1.5: Teaching ladies in Buloba about Salt and Light

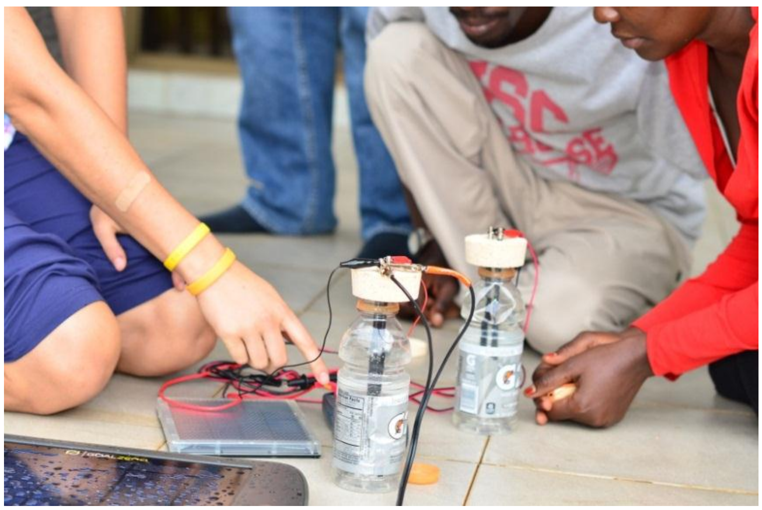

Figure 1.6: Testing two solar alternatives in Uganda

Figure 1.7: Testing the briefcase panel on the roof of our van at Kampiringisa

CHAPTER 2

Chemical Reactions Occurring in the Salt and Light Water Purifier

This chapter will outline the basic chemical reaction that takes place when electrolysis is used to separate sodium chloride (NaCl). It will also explain that the motivation for using this technology started with a study of MIOX Corporation and what kind of products they were selling to the United States military for water purification purposes.

2.1 Basic Reaction

Before we discuss the breakdown of salt and the electrolytic process, it is appropriate to mention several properties of this unique compound. 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.. In this chapter, I will explain a use as it pertains to the Salt and Light Water Purification System. (Appendix B gives more detail about the chemical characteristics of sodium chloride.)

Distilled water is free of salt and considered pure, therefore it is a poor conductor of electricity. It can become an electrolyte solution by adding salt to it, making it able to conduct electricity. For many years, dating back to the 1800s, electrolysis has been used as a method of separating bonded elements and compounds by passing an electric current through them. Electrical current is applied to an immersed pair of electrodes (6 inches in length and 1/8 inches in diameter for my design) and a chemical reaction occurs. The negatively charged electrode is called the cathode while the positively charged electrode is called the anode. In general, during the chemical reaction, hydrogen gas forms at the cathode and chlorine gas at the anode, while hypochlorus acid (HClO) and sodium hypochlorite (NaClO) are produced, creating a mixed oxidant solution. Since the pH of the solution is about 9.0 (verified during Uganda field testing), most of the solution is NaClO [12]. Both HClO and NaClO are sanitizing agents that are already commonly used in swimming pools, and can be used in this application to safely and effectively sanitize drinking water when added to untreated water in a particular ratio.

To go into more detail about the reaction (see Figure 2.1), first we start with the overall chemical equation for the reaction:

$$NaCl + H_2O \rightarrow NaOCl + H_2.$$

At the anode, oxidation reactions cause 2 chloride ions to be stripped of one electron each to yield chlorine gas:

$$2Cl^- \rightarrow Cl_2 + 2e^-.$$

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:

$$2H_2O + 2e^- \rightarrow 2OH^- + H_2.$$

During this process, bubbles are visible (which is a reassuring factor in convincing people who do not know much about chemistry or water purification that something is in fact happening). These bubbles are primarily hydrogen gas which is expelled into the air. The hydroxide ions (OH^-) produced at the cathode react with the hypochlorous acid (HClO) produced at the anode, yielding the hypochlorite anion (OCl^-) which is balanced with sodium cations (Na^+) that originally came from the salt. This reaction is written below.

$$HOCl + OH^- \rightarrow H_2O + OCl^-$$

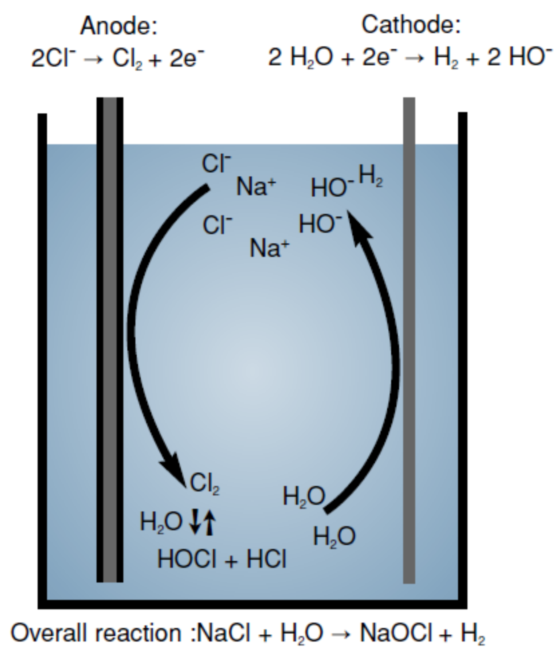

Figure 2.1: Electrochemical reactions that occur when power is applied to the electrodes [13]

It is important to note that the bottle/vessel in which the reaction taking place needs to be kept below 105° F (i.e. in the shade) during the formation of NaOCl. If the bottle is not kept below this temperature, then sodium chlorate ($NaOCl_3$) is also formed [14]. This compound is one of the primary ingredients in many herbicides and is considered very toxic to humans if ingested.

After this solution is diluted during the treatment of contaminated water, the resulting potable water will not taste salty. Depending on how much is used, the water might have a slight chlorine taste or odor, but nothing that would be deemed harmful. The US Dietary Guidelines for Americans published in 2010 stated that the recommended daily intake of sodium should be around 2,300 milligrams [15]. Thinking about how little salt goes into making this sodium hypochlorite solution, and then how much is actually consumed when drinking the now-potable water, sodium intake due to this system is negligible.

2.2 MIOX Contribution

In the 1970s, MIOX became the frontrunner in the exploration to make smaller electrolytic equipment that uses the century-old chemistry described above to move the process of disinfecting water on-site rather than transporting dangerous chemicals to the user. These on-site generators produce a chlorine-based disinfectant that is recognized and approved by the US Environmental Protection Agency for potable water applications

[12]. The four main benefits identified by MIOX for on-site generation are improved operator safety, higher quality chemicals, greener applications, and cost savings [13].

While these benefits pertain specifically to MIOX's on-site generators, some of them also are applicable to the Salt and Light Water purifiers. There is minimal chemical or electrical risk of injury to the operator, and there are significant cost savings because the system is so simple. Arguably, if one were able to quantify the cost equivalent time and effort it takes to fetch wood for a fire in order to boil water to make it potable, the cost of the Salt and Light system would be significantly less. As the years pass, it would pay for itself many times over.

The table below attempts to quantify the difference between using the Salt and Light system versus conventional boiling. While the allocated times are rough estimates, it still is easy to see that over the span of 20+ years, the Salt and Light system will save a person much time and effort.

Table 2.1: Approximate time and effort comparison between using Salt and Light system and boiling

With Salt and Light			
	Min Time	Max Time	Effort
Add water to 16 oz bottle	15 sec	30 sec	min
Add salt to bottle	3 sec	10 sec	min
Insert electrodes	1 sec	1 sec	min
Connect electrodes to panel	5 sec	10 sec	min
NaCl reaction	6 hours	8 hours	none
Disinfection time	30 min	4 hours	none
Quantity of clean water		**120 gallon**	

Boiling Water in 15 gallon pot			
	Min Time	Max Time	Effort
Fetch firewood	10 min	30 min	mod
Build a fire	3 min	5 min	mod
Boil 15 gal of water	45 min	1 hour	none
Water cooling	30 min	2 hours	none
Quantity of clean water		**15 gallons**	

This system would also save lives. Firewood is typically collected by young girls, and sometimes they must travel far away from their home to find some wood. In some areas, they are risking their lives to go find the resources necessary to make a fire. Eliminating the need for firewood in order to obtain potable water for drinking, cooking, and bathing would decrease the murder rate in these areas for these young children. This is a consequence that was brought to the forefront from Mr. Morton Archibald in conversation with Dr. Baginski and trumps the time and effort saved. One cannot quantify the value of a saved life compared to the time and effort saved from not having to boil water.

CHAPTER 3

Electrical Aspects of the Salt and Light Water Purifier

The purpose of this chapter is to provide a basic understanding of solar power through the study of photovoltaics and to explain the process by which the solar panel and electrode size were determined. Some of the process comes from methodical testing while other conclusions are based on simple common sense.

3.1 Solar Energy Basics

The collection of solar energy can be performed two ways, indirectly by the use of biofuels, wind, wave mechanics and hydroelectric generation, or directly through passive thermal and photovoltaics. Photovoltaics (PV) by definition is a method of converting solar radiation into DC electricity using semiconductors that exhibit the photovoltaic effect [16]. 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. 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 very 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 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. Figure 3.1 shows two examples of this type of panel.

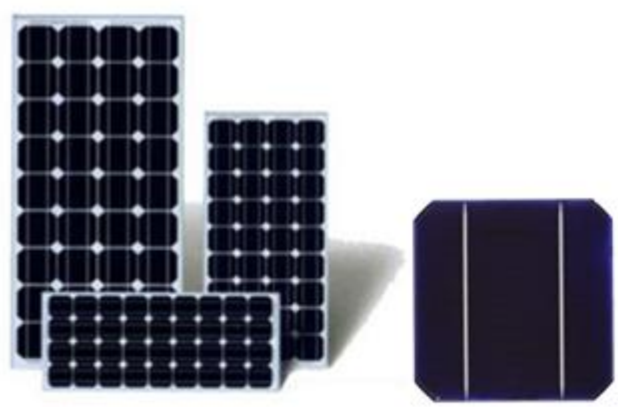

Figure 3.1: Examples of monocrystalline panels [17]

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 [17]. They have a distinguishable blue, scaly and shimmery appearance as seen in Figure 3.2. 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.

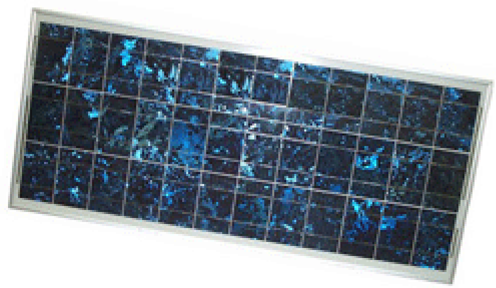

Figure 3.2: Example of polycrystalline panel [17]

A characteristic that both types of panels have in common is their sensitivty to extreme temperatures. Monocrystalline and polycrystalline panels suffer a reduction in output of 12-15% at temperatures greater than 115°F. The open circuit voltage (V_{oc}) decreases and the short circuit current (I_{sc}) hardly changes as temperature increases. The overall result is a decrease in output power as temperature increases [18].

A third type of panel currently in production is made from amorphous silcon 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 weak light than mono and poly-crystalline panels; however, it can only achieve about half the efficiency (6%) [18]. Figure 3.3 shows an example of these types of panels.

Figure 3.3: Example of amorphous panels [17]

3.2 Solar Panel Selection and Modifications

As mentioned in Chapter 1, the first decision to make was the method for collecting sunlight to convert into electrical energy. Three solar panels were tested: the Goal Zero 30 W briefcase panel, the Nomad Goal Zero 7 W foldable panel, and a 12 V panel from Academy Sports.

All three models were field-tested in Uganda, and it was determined that the 30W briefcase panel, while effective, was just too much of a risk to own. It measured 44.6 x 55.8 x 2.5 cm and weighed 12.2 lb (5.5 kg) and drew much attention, making it a safety threat to anyone who had it in their position because it looked like something worth a lot of money and made the user a target for thieves. Finally, the briefcase was held together with steel screws, which rusted after 1.5 months of testing. While the screws didn't cause a performance degradation, I see this as a potential problem in the future use. Also, the cost of the panel at $300 did not outweigh the benefit of a faster reaction, therefore this one was eliminated as an option for the Salt and Light purifier. Technically, the panel is rated as having a 17-18% conversion efficiency.

The 12 V panel from Academy, while cheapest, provided hardly any power on an overcast day, and barely achieved 1 W of power on a sunny day. The chemical reaction was possible with this panel, but the time it took to yield a strong enough solution that would be usable for the process was too long, and not feasible for a family that needed a strong enough solution to dilute many gallons of water at a time. Therefore, this panel was also eliminated as an option for this particular system.

The Nomad 7 W solar panel from Goal Zero has been adequately weather tested and is expected to withstand both the rainy seasons and the dry seasons of Africa. In Auburn, it was left outside in the sun and rain for several weeks and no noticeable degradation to the panel or performance was observed. It consistently yielded a power of 4W-5W during tests in Auburn, Alabama and achieved near maximum power on sunny days in Uganda, which is located at an altitude of 4000 feet and on the equator.

Therefore, the Nomad 7 W was the panel chosen as the component for the Salt and Light water purification system. The rated wattage output is 7 W and it is made using monocrystalline silicon. Like the 30 W briefcase panel, the open-circuit voltage (V_{OC}) is 12-18 V and the conversion efficiency is 17-18%.

Not only did this solar panel perform best in my tests, its size was found to be ideal for most applications. Even though the panel can produce up to 7W of power, the cell area is only 0.0394 m^2 and it weighs 0.8 lb (0.363 kg). The folded dimensions are 15 x 26 x 2.5 cm while the unfolded dimensions are 43 x 23 x 0.25 cm. This panel also has a large optimal operating temperature range, being from 0-120°F which means it will work well in the targeted geographical areas.

Figure 3.4 shows the panel in each configuration, folded and unfolded, and its size compared to a #2 wooden pencil. The 5 V voltage regulator is shown in this picture taken from the Goal Zero website. However, modifications were made to reduce the number of components that could fail or cause a problem when deployed. I decided to remove the 5 V regulator on each of the panels I used for testing and soldered lamp-cord cable directly to the cell's output. To the other end of the cable I soldered small alligator clips that are used to connect to the titanium rod pair. One observation noticed during testing was that the alligator clips have a tendency to rust, so they need to be protected from the rain when the system is not in use. Future clips will be nickel plated or hermetically sealed before being used. The outcome of this simple modification is shown in Figure 3.5.

Figure 3.4: Panel configurations and size comparison

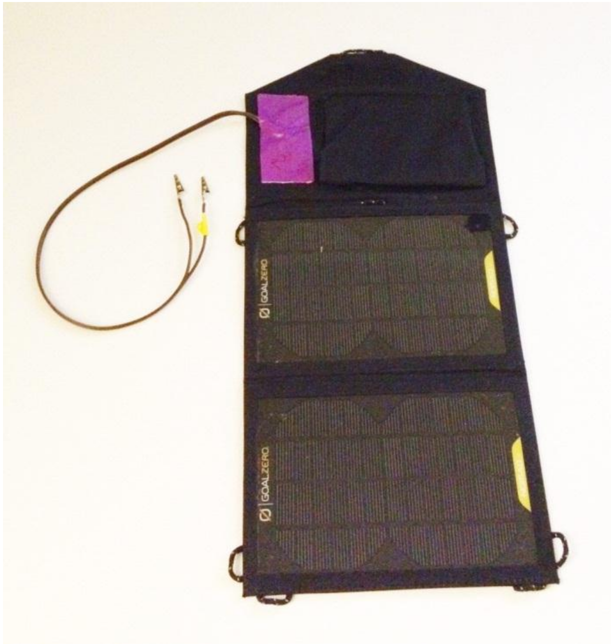

Figure 3.5: Panel modification- removed voltage regulator and added alligator clips

3.3 Electrode Selection

Next, a reactor had to be selected. A reactor is simply a device by which electricity is introduced to the solution and is a necessary component to this chemical reaction. (In this document, they are also referred to as electrodes.) The reactor is made from two rods mounted approximately 0.2 inches apart. The rods are purchased from DeNora (http://www.denora.it/) and come in 48 inch segments. They are considered mixed metal oxide (MMO) electrodes and are especially useful because they provide higher efficiencies for chlorine production [19].

MMO electrodes were initially developed to prevent the passive film of titanium oxide that forms on the electrodes when polarized anodically in aqueous electrolytes [19]. 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' [20].

A second patent was granted to him in 1967 after further testing showed that the potentials at which chlorine was formed were dependent on the how much ruthenium oxide was in the coating [21]. 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 coated rods are the ones purchased and used for the Salt and Light Water Purifier. About a half inch of the coating was removed using a grinder to provide an electrical connection point.

The electrodes were mounted in a cork as shown in Figure 3.6. Cork floats and is a cheap material. Oriented this way, it will keep the connection point of the rods above water.

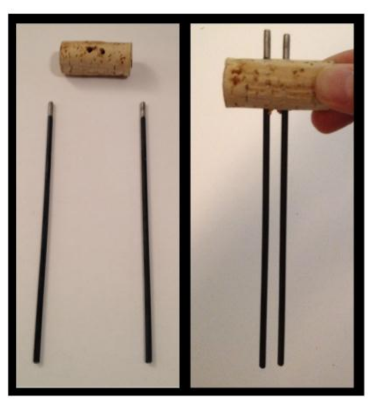

Figure 3.6: Iridium coated titanium reactors

Tests in the United States and Uganda were performed using different diameters and lengths of reactors, and the table below shows some of the results. I made the decision that a 48 inch rod will make 4 complete sets of reactors (8 x 6 inch rods, and 2 rods needed per set). This division was most logical as it doesn't make sense to use more material than necessary to do the job, especially when it could be at the cost of making an extra unit or two.

Table 3.1: Tested reactor dimensions

6 inches length, 1/8 inch diameter	8 inches length, 1/8 inch diameter
6 inches length, 1/4 inch diameter	8 inches length, 1/4 inch diameter

The diameter of the rods was another thing to be considered, as the larger diameters cost more and yielded a slightly stronger mixed-oxidant solution. Since there wasn't a significant difference in strength of the solution created by the two sizes, the smaller one was chosen in hopes of being able to make even more of these systems. Power measurements for the four sizes of rods are shown below in Figure 3.7 when using 2 mL (1 g) of salt in 16 oz of water. (The reasoning for choosing this ratio is explained later in this chapter.) The 6 inch long, 1/8 diameter rods yielded the highest power output.

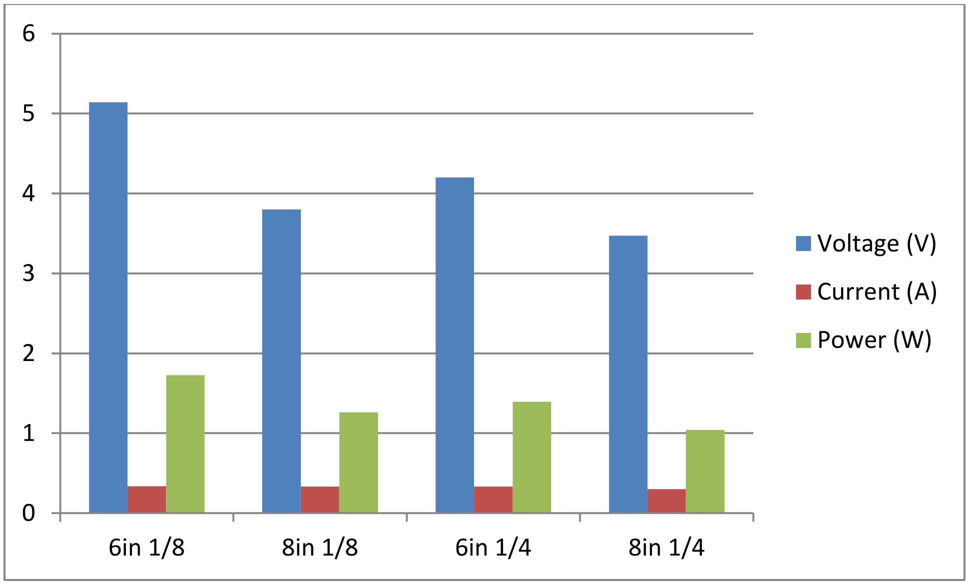

Figure 3.7: Power measurements with multiple reactors

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 16 oz of water. This amount of NaCl was selected after testing 2 mL, 3 mL, and 4 mL in 16 oz of tap water to determine the best ratio for the reaction. Testing began using salt packets from local fast food restaurants. While this was not an official measuring standard, the weight was fairly consistent, as were the ingredients, therefore it was convenient and easy to use. Figure 3.8 shows the results of this test.

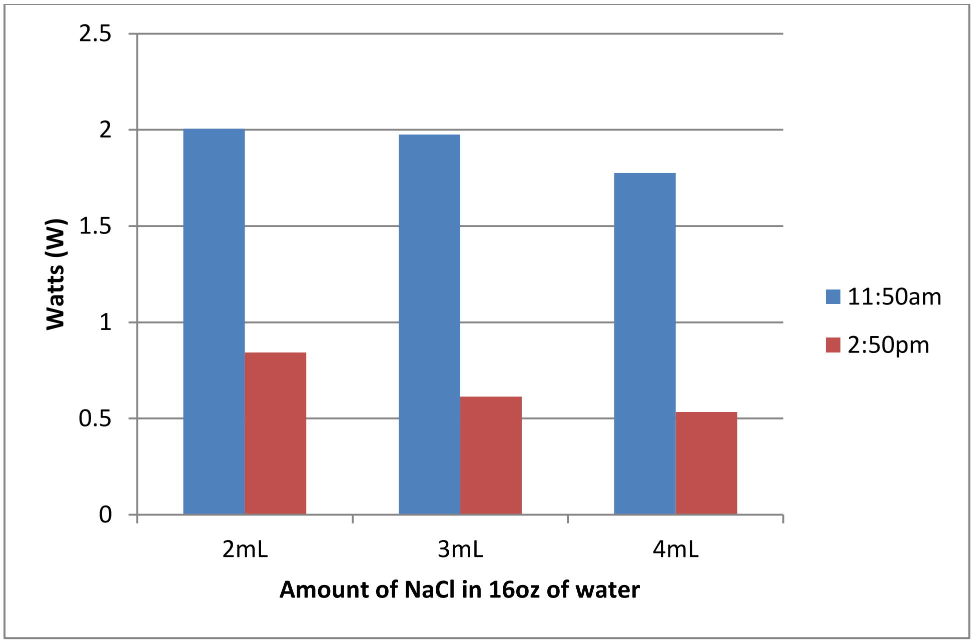

Figure 3.8: Power vs sodium chloride (Nomad 7 W panel, 6 inch long, 1/8 inch diameter rods used)

3.4 Set-up and Testing Procedure

I will explain the procedure for making a mixed-oxidant solution in words for the sake of this document; however a complete picture book is also available at the end of this thesis in Appendix A. If these water purifiers are going to be distributed for use around the world, a step-by-step instruction manual written in English might not be the most effective way of communicating how to set up and use the technology. I have experienced this first hand in Uganda, and that was the motivation for a picture-instructional book that will transcend the language barrier and make the system usable by more groups of people.

The following items are necessary to perform an experiment creating the sodium hypochlorite solution: a solar panel, a pair of titanium rods coated with iridium oxide, water, salt, and a cork. I attempted to optimize these inputs to create a strong MIOX solution, suitable for any environmental situation. As explained in Chapter 1, the components chosen for this process are:

- 16 ounce water bottle
- 2 mL salt
- 6 inch long, 1/8 inch diameter pair of rods mounted in a cork
- Nomad 7 W solar panel

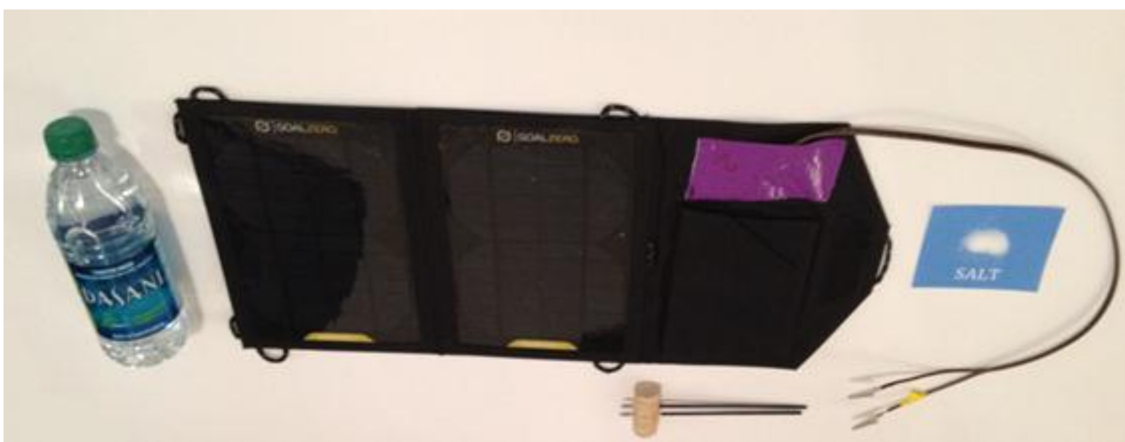

Figure 3.9: System components

Figure 3.10: Salt and Light system

Because there is a solar element to this process, it is meant to be performed outside. To begin, fill the water bottle with about 16 ounces of water and add 2mL of salt. Cover the top of the bottle, either with the cap or with your hand and shake the bottle for several seconds in order to dissolve the salt in the water. Reopen the bottle and insert the reactors. Ideally on a flat surface as to avoid the bottle tipping over and with the panel opened to receive the sunlight, attach the clips one at a time to the electrodes. Bubbles should start forming at the electrodes if the panel is correctly attached. The length of time for this reaction varies depending on the intensity of the sunlight. It was determined that the time required to yield a strong solution (classified as 1-2 parts per million (ppm) free chlorine after dilution) could vary between 4 hours and 6 hours.

One of the many advantages of this system is its ease of use. It requires very little set up and it does not require any monitoring. It just needs to be left outside in the sunlight on sturdy ground and it will do what it is designed to do.

I used two methods to verify the level of free chlorine in the solution. Strength of the solution was measured throughout my experiments by strips that were purchased from Hach© (http://www.hach.com/) that turned varying degrees of purple when submerged into the solution; a dark purple indicated a strong solution. Another way to confirm the strength was by using a hand-held digital colorimeter, also sold from Hach. The test kit came with the colorimeter as well as 4-10mL vials. For convenience, I used these vials to measure 10 mL (1/3 ounce) of the solution. After diluting the solution in 2.5 gallons of water, the resulting ratio is approximately 1:950.

After extensive testing of the components and selecting what I believe to be an optimal combination of many variables, the obvious next step was biological testing to verify that the system performs as intended. Retrospectively, the effectiveness of the system could have been better verified by analyzing contaminated water before and after treatment. Chapter 4 on biology will discuss various tests that were performed throughout the duration of this project to verify free chlorine and bacterial levels in the samples.

CHAPTER 4

Biological Aspects of the Salt and Light Water Purifier

The following sections describe the basic biology involved in testing water sources after treatment, but does not include a complete review of all the methods that are currently in use. It focuses on what was used in the testing of the Salt and Light water purification system, and concludes with notes about what should be done in future testing in order to draw more detailed conclusions about the effectiveness of sodium hypochlorite for treating non-potable water.

4.1 How Free Chlorine Kills Bacteria

The US Centers for Disease Control and Prevention (CDC) states in their publication about chlorine residual testing 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 that cause diarrheal disease and that the water is now protected from recontamination during storage [22]. A correlation between the presence of free chlorine residual in drinking water and the absence of disease-causing organisms exists and it is this measure that defines the potability of water.

When chlorine is added to water for potability, it undergoes a series of reactions, as illustrated in Figure 4.1.

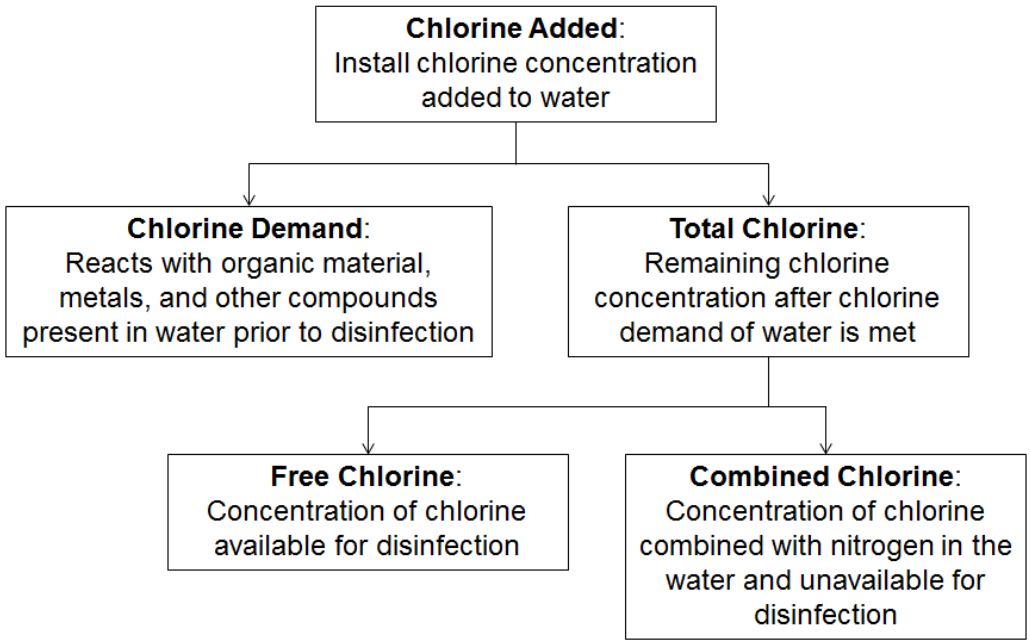

Figure 4.1: Chlorine Addition Flow Chart adapted from SWS Project

As you can see from the figure above, 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 [22].

Free chlorine dosages are measured to determine how much sodium hypochlorite (NaClO) 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:

"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)." [22]

4.2 Verification Methods

There are several ways in which free chlorine is measured. Pool test kits, color wheels, test strips, and colorimeters are some of the more common methods of testing. During the testing phase of the Salt and Light water purifier, test strips were initially used to determine the strength of the free chlorine.

The strips shown in Figure 4.2 were purchased from MIOX Corporation and are the same strips that are used in the field to test the potability of water. There are three levels of color that identify the strength of the free chlorine residual. The lightest pink indicates TOO LOW (~0.5 ppm) , a stronger purple indicates an OK reading (~2 ppm), and a dark purple indicates OK++(~5 ppm).

Figure 4.2: MIOX free chlorine test strips

Realizing this feedback was not sufficient enough to prove that microbial contaminants were disabled, a pocket colorimeter was purchased for more accurate, digital free chlorine measurements. A test kit purchased from Hach included a colorimeter as well as the vials and reagent needed to test the free chlorine concentration. The device has two channels in order to measure different chlorine concentration ranges, from 0.02 to 2.00 mg/L and 0.1 to 8.0 mg/L. It is battery operated, lightweight, waterproof, and rugged, therefore ideal for testing in the field. Below is an image of the kit that was purchased (Figure 4.3):

Figure 4.3: Hach Pocket Colorimeter

DPD (N,N diethyl-p-phenylene) is a reagent used in determining free chlorine residual for disinfection of drinking water, as it immediately reacts with chlorine. The addition of this reagent to a vial of sample water causes a color change to pink in the presence of free chlorine (as seen in the two 10mL vials in the Figure above). The vial is then inserted into the meter that reads the intensity of the color change by emitting a wavelength of light through the sample. The intensity is determined and therefore free chlorine residual is known and displayed. This system has many benefits including highly accurate readings, fast results, and it is EPA approved. However, they are more expensive than other methods (strips and color wheels) and may need to be calibrated depending on the application.

The first test performed with the digital colorimeter was determining the degree to which the quantity of NaCl affected parts per million of free chlorine. Figure 4.4 shows this relationship, illustrating that as intuition would suggest, the more NaCl available for reaction, the more free chlorine will be generated. This test was done in a shorter amount of time than normal (only 3 hours instead of 6-8 hours) therefore the ppm measurement did not reach the target level of 2 ppm after being diluted. Since the test kit came with 10mL vials, these were used for the sake of simplicity when treating the contaminated water. The ratio used to produce this data was 10 mL (1/3 ounce) of solution to 9.5 liters of water (or 2.5 gallons). Even though 4 mL of salt produced the highest ppm free chlorine measurement in this time, 2 mL will completely react in 6-8 hours, minimizing excess salt consumption. Why unnecessarily stretch a given salt supply when 2 mL will work?

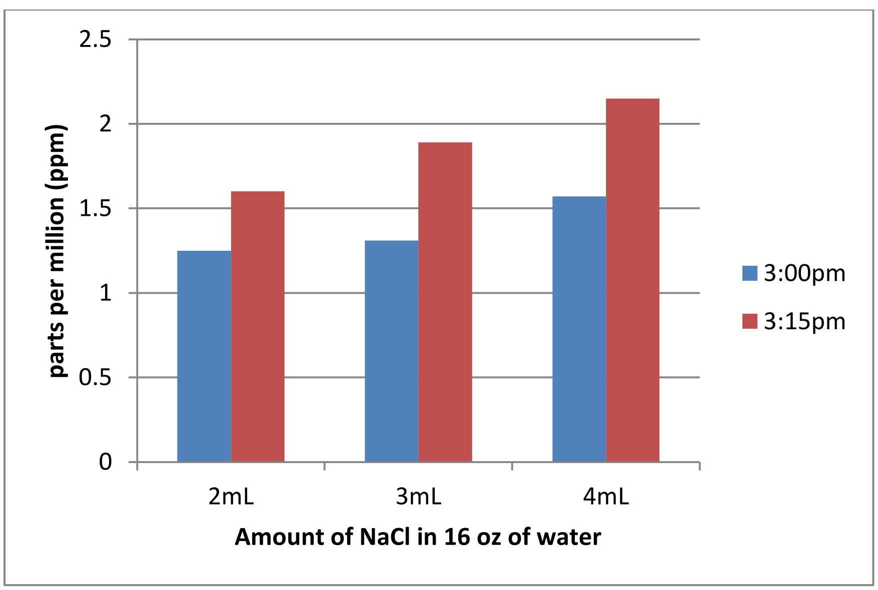

Figure 4.4: NaCl vs free chlorine (ppm)

The information in Figure 4.5 was gathered during the testing of pond water. Once the water purification system was standardized (16 oz of water, 2 mL of salt, 6 inch length, 1/8 inch diameter electrodes, and the Nomad solar panel), certain levels of sodium hypochlorite and by-products were produced repeatedly. The variable in the testing lies in the ratio of contaminated water to the amount of free chlorine solution added to the sample. The starting point for many tests was 10 mL of solution to 2 gallons of water and then it would increase up to 3 gallons or 5 gallons depending on what was being tested. Figure 4.5 shows the free chlorine residual in ppm in 5 gallons of pond water after adding 250 mL of solution (this ratio simplifies to approximately 75 parts pond water and 1 part solution). The red bar indicates a residual level above 2.2 ppm and therefore out of range for the colorimeter. After waiting 30 minutes, the ppm decreased to within range, and continued to decrease throughout the day. With a free chlorine residual measurement in the pond water of 1.66 ppm after 7 hours, it is safe to say with these methods the sample was determined to be potable.

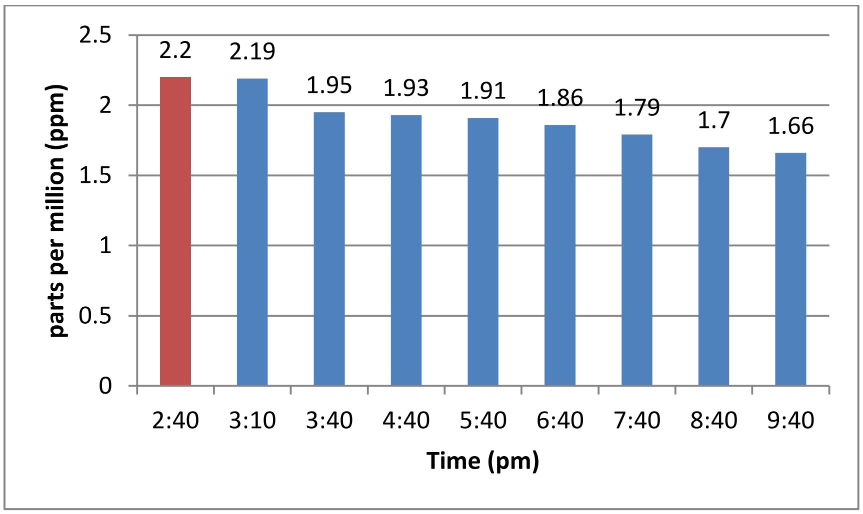

Figure 4.5: Pond water testing

4.3 Bacteria Testing

Chlorine has been proven to kill bacteria that cause disease in humans, however some bacteria are harder to inactivate than others. The table in Appendix C was compiled by the CDC and taken from many sources showing chlorine's effectiveness against different bacteria, viruses, and protozoa. The CT factor is used to compare the effectiveness of chlorine and is "calculated by multiplying the concentration of chlorine needed to inactivate a certain percentage of the pathogens by the time the pathogen was exposed to that concentration of chlorine. (CT = Concentration X Time) Higher CT factors indicate relatively higher resistance to chlorine, while lower CT factors indicate relatively low resistance to chlorine" [22].

Cryptosporidium is shown to have a CT factor of 7,200, by far the highest other than toxoplasma gondii. This means that it requires a much longer exposure to higher chlorine concentrations that most of the other protozoa, bacteria, and viruses. The company MIOX claims that their products are effective against cryptosporidium. Comparable performance is expected from the Salt and Light system since it utilizes very similar chemistry to generate the same oxidant species. However, this has not yet been proven by growing cultures and studying the contaminated sample before and after treatment, which is something that needs to be done in the future.

In the meantime, bacteria test strips from Silver Lake Research Company that "detect E. coli, Pseudomonas aeruginos, species of Shigella, Enterobacter, and many other coliform and non-coliform bacteria" were purchased and used for testing the bacteria level of various samples [23]. Figures 4.6, 4.7 and 4.8 show the product that was used in this step of the bacteria testing process.

Figure 4.6: Water Safe Test Strips

Running a test requires 6 steps:

1. Open foil pouch and take out all contents. (Figure 4.7)

Figure 4.7: Bacteria test kit

2. Using a clean dropper, place exactly one dropper-full of water into the sample vial. To draw up sample, tightly squeeze the bulb at the end of the dropper and

place the open end into the water sample. Release the bulb to pick up sample, then squeeze again to expel the sample into vial.

3. Gently swirl vial. Let stand seven minutes. Swirl vial again and return vial to flat surface.
4. Place test strip into sample vial with arrows pointing down.
5. Wait 10 minutes. Do not disturb strip or vial during this time. Reddish lines will appear on strips.
6. Take strip out of the vial and read the results:
    a. If only line 2 is present, test is Negative. If line 1 and line 2 are present, test is Positive. (Figure 4.8 shows a positive read).

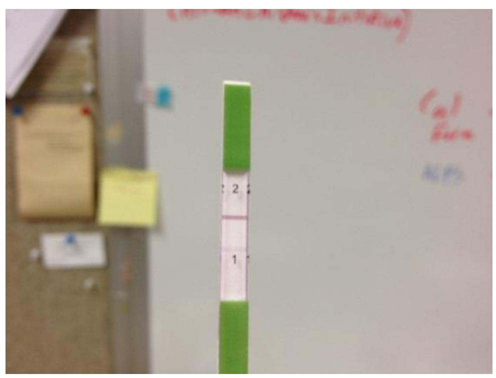

Figure 4.8: Positive bacteria test strip

There are many ways that one could go about testing the potability of a water source. The Salt and Light water purification system will work just as effectively as other companies who implore the same chemistry that has been around for over one hundred years. Given enough time for the NaCl to completely react and for the sodium hypochlorite solution to work on the contaminated water, this system will effectively treat non-potable water. The ratios and quantities presented in this document are not perfect and were chosen for the sake of simplicity in standardizing this reaction.

They were chosen logically in some cases, and verified through testing in others. There is still a lot that can be learned on the biological side of this project, and it is my hope that a team of Innovative Humanitarian Products Organization (IHPO) students will be able to assist with that in the future.

CHAPTER 5

Future Developments

As mentioned in the previous chapter, there is still work that could be done to improve this system. One of the primary goals moving forward is thorough biological testing of a contaminated water sample before and after treatment with the solution made using the Salt and Light water purification system. This must be done with samples in order to verify that 100% of the disease-causing agents are killed and that the water is indeed safe to drink. I worked with a basic understanding of the chemistry and biology involved, however I am confident that someone with a professional level of expertise in this field could make valuable contributions. One of the most wonderful things about working on a project at Auburn University is the abundant resources (in our teaching and research faculty) who are typically very willing to help. I urge anyone who is going to continue working on this project to make as many contacts as you can and learn as much as possible from each of them.

The exact shelf life of the solution needs to be determined. Using the free chlorine test strips, I was able to observe that a standard solution (using 16 oz of water, 2 mL of salt, Nomad 7 W panel, 6 hour reaction time) kept a high level of free chlorine after 3 weeks of sitting in an open container on a desk. Even though the free chlorine count was still high, I do believe that an equivalent dilution strength would be impossible to reach. An idea moving forward, maybe with the help of a student organization such as

IHPO, is to determine the exact shelf life of a given solution through chemical analysis.

It would be beneficial to determine the maximum amount of solution a certain solar panel could produce in a given day with a given rod size. This solution needs to be strong enough so that a small amount can be applied to a much larger amount of contaminated water and still effectively treat the water.

Additionally, a test to determine the effectiveness of the system as a function of solution temperature would valuable to perform in the future.

There are a few hardware changes that need to be implemented in the future. They would benefit this system and its users and should be in place before any of the units are deployed in the future. These few modifications would theoretically increase the life of the systems and make for easier use.

During testing, it was noted that the steel alligator clips used started to rust after a few months of testing and being exposed to moisture. Nickel or copper plated clips would not have this problem and are just as easy to solder to the cord attached to the solar panel output. These upgraded clips would be slightly more expensive, but well-worth the couple extra cents to avoid degradation issues due to rust and corrosion in the future.

The Nomad 7 W panels used in the majority of the tests were modified to simplify the panel and reduce the number of electrical components that could potentially fail. The removal of the voltage regulator left a large hole in the packaging of the panel. During testing in the US, duct tape was applied to the opening and that was sufficient. However, for permanent deployment, epoxy can be used to better seal this hole in hopes to prevent damage due to moisture close to the leads of the cells.

Cork was the primary material used to house the two titanium rods thus far in testing. There is concern about how well the cork would hold up over time. Auburn University's Electrical and Computer Engineering department has the capability to print plastic 3D pieces that can more securely hold the rods. One of these pieces is picture in Figure 5.1. This type of holder will probably be used in future systems instead of cork. We gratefully acknowledge Mr. Grant Moore and his design team for developing and fabricating this product.

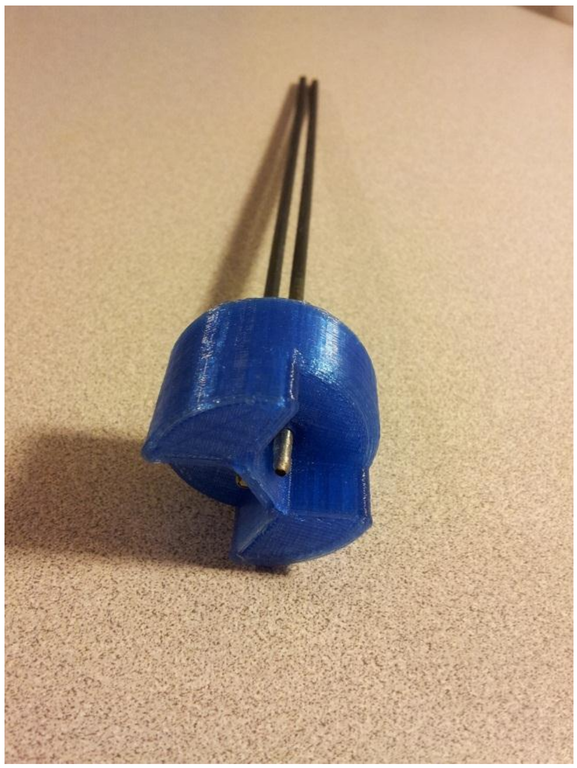

Figure 5.1: 3D plastic component to house reactors

A cost analysis was performed on the current system and the results, component by component, are displayed in Table 5.1. If we were to have the capability to purchase these parts in bulk, I believe that the cost of the components would significantly decrease, hopefully to the levels found in Table 5.2. Taking a look at these numbers is quite valuable when viewed with the future goal in mind. The goal and motivation behind making and documenting this system is to save lives by providing a method to purify water, giving the gift of potable water to people around the world who do not have such a necessity.

Table 5.2: Original cost analysis

Salt and Light Cost (current)	
Nomad 7 W Solar panel 1	$70.00
DeNora Titanium Rods 2	$10.00
Cork	$0.01
Bottle to hold water 3	$0.05
Salt	$0.05
2 Alligator clips	$0.50
Cable (1.5 feet) 4	$0.45
Total *5*	$81.06

1 including shipping and handling
2 rods coated in ruthenium, 1/8inch diameter and cut to 6 inches in length
3 16 ounce bottle
4 approximately $0.3/foot
5 excluding labor

Table 5.3: Theoretical future cost analysis

Salt and Light Cost (future)	
Solar Panel 1	$50.00
DeNora Titanium Rods 2	$7.00
3D plastic housing	$0.05
Bottle to hold water 3	$0.05
Salt	$0.05
Total 4	$57.15

1 $35 for the solar panel, $15 for shipping and handling
2 rods coated in iridium 1/8inch diameter and cut to 6 inches in length
3 16 ounce bottle
4 no additional labor required

On my second visit to Uganda, I had the chance to talk with several ladies in Buloba during their weekly meeting at the local church. I was able to ask them if there were any skills they would be interested in learning, or anything that they would generally like to know more about. The first thing that was mentioned was the desire to generate a small amount of income by starting a small business. Many of these ladies are single mothers who do not have time for much more than raising their children. Taking trips to fetch water for cleaning and cooking and finding the firewood to boil the water sometimes takes most of the day. Therefore having an actual 9 to 5 job might not be realistic.

However, we realized that there was a potential for them to develop a small business model around the Salt and Light Water Purification System. For less than $100, a solar panel and electrodes could be provided to a group of ladies that could generate approximately a gallon of this sodium hypochlorite solution per day that would be available to sell.

There are a variety of micro-lending firms that offer loans to people in developing countries, giving people a chance to borrow money in order to "grow and sell produce, open small shops and roadside food stands, raise chickens, tailor clothes, open beauty salons and carpentry shops and grow coffee" [24]. The women using these loans from the Women's Microfinance Initiative in Uganda use their profits to buy better food, improve their living conditions, obtain healthcare for their families, and expand their businesses.

There is a lot to explore as far as this idea is concerned, but I am confident that there is value in the proposition. With the relationships I already have formed in Buloba, it would not be hard to properly train the ladies of the village to manage a system like this and how to properly sell it to those who do not have a panel for their homes. I am hoping that this idea will produce fruitful conversations that lead to it actually being carried out. The only foreseeable sustained cost of using the Salt and Light water purification system is the cost of the salt and the cost of test stripes to verify the strength of the solution. Ideally, the ladies would make enough profit to cover the cost of these strips and the small quantity of salt they use. Quality assurance would need to be explored to keep them safe in case someone got sick and tried to pin it on their drinking water, but also as a teaching mechanism for accountability. I love the image of teaching someone how to use this system for a small business application, and then that person in turn teaching someone else the principles of running a small business. It goes back to the same concept that I opened this document with: “To him who much is given, much is required.” Once you have been gifted with a certain set of skills and resources, it becomes your responsibility to share that with others and to keep that ball rolling.

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APPENDICES

APPENDIX A

Picture Instructional Manual (to be distributed with each kit)

Figure A.1: Front and back covers (book dimensions: 3.5 x 2.6 inch)

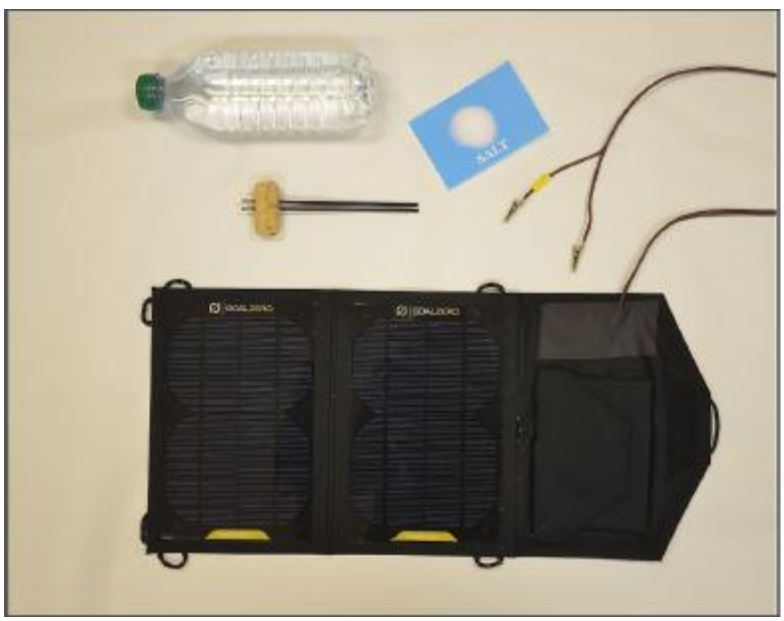


Figure A.2: Kit contents

Figure A.3: Pouring water from jerry can

Figure A.4: Pouring water into bottle for reaction

Figure A.5: Pouring salt into bottle


Figure A.6: Shaking bottle to mix salt and water

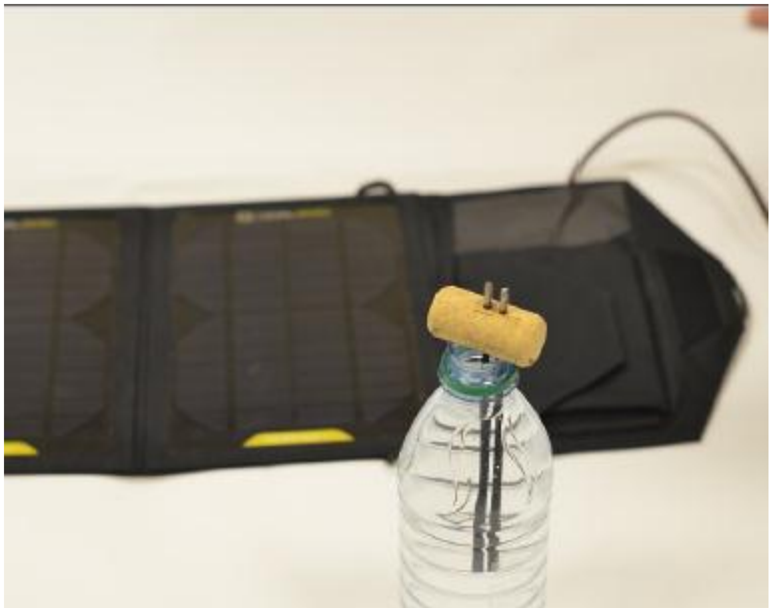


Figure A.7: Insert electrodes into bottle

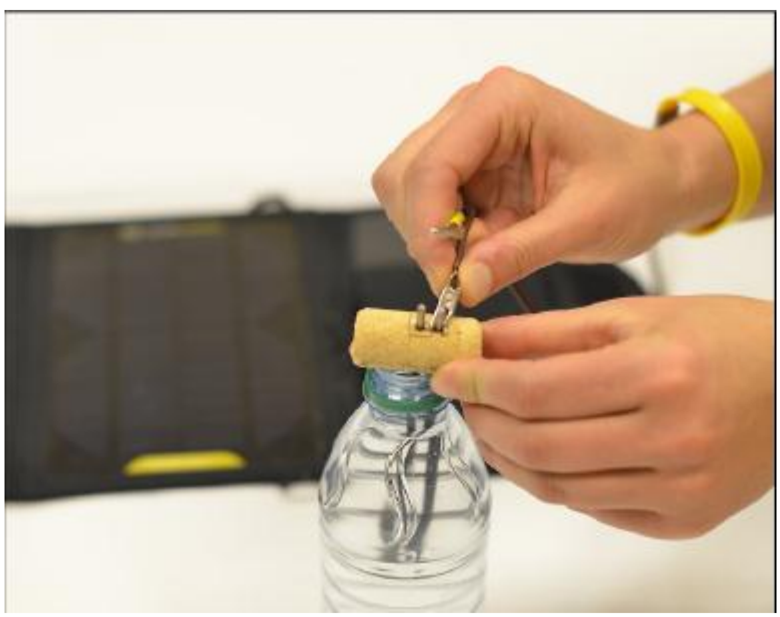


Figure A.8: Attaching first clip

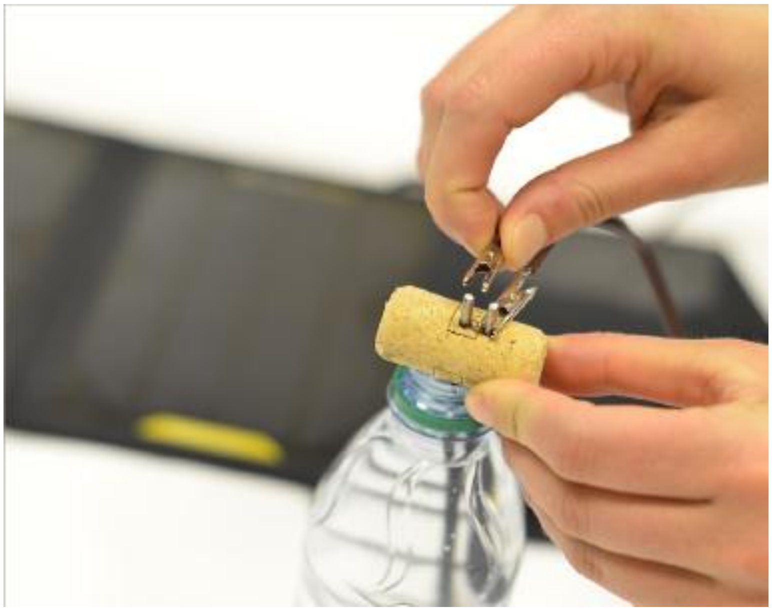


Figure A.9: Attaching second clip

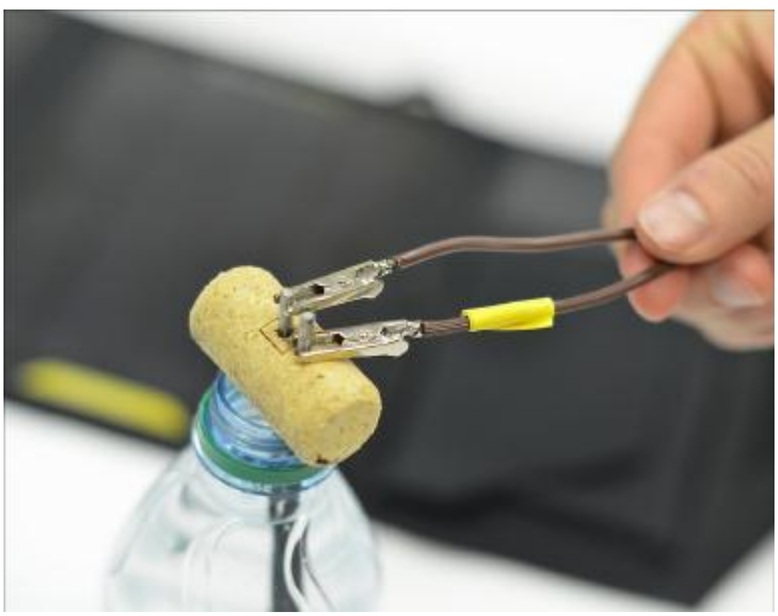


Figure A.10: Showing that the clips do not touch

Figure A.11: Bubbles will form if set up correctly

Figure A.12: Set up the system in the morning

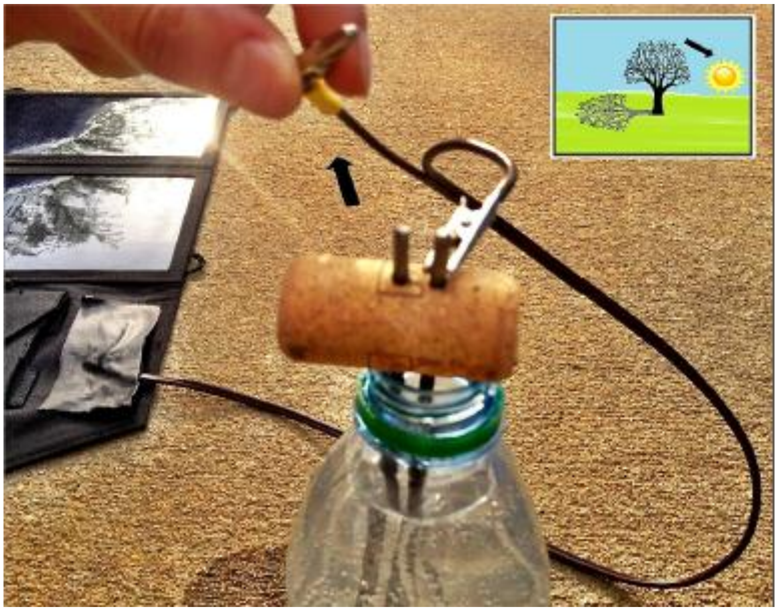


Figure A.13: At sundown, stop reaction by disconnecting first clip

Figure A.14: Disconnect second clip

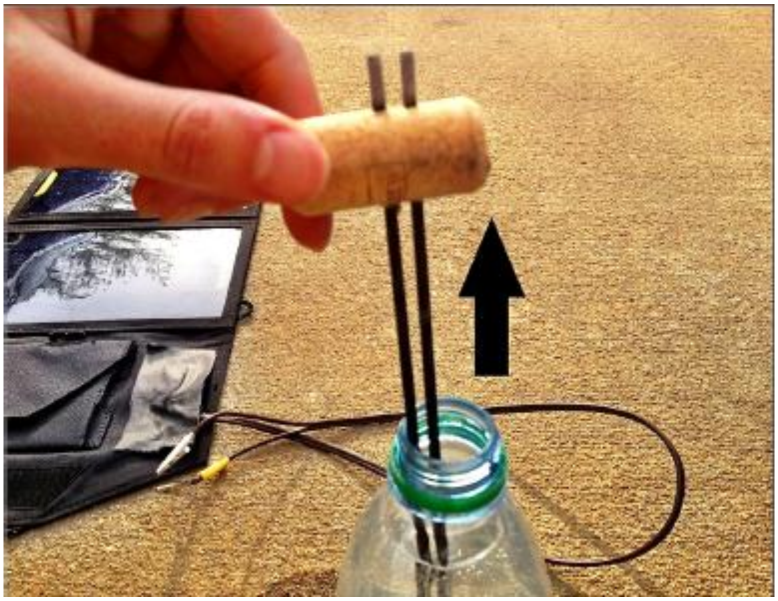


Figure A.15: Remove electrodes from bottle

Figure A.16: Pour about 1/3 of solution into jerry can

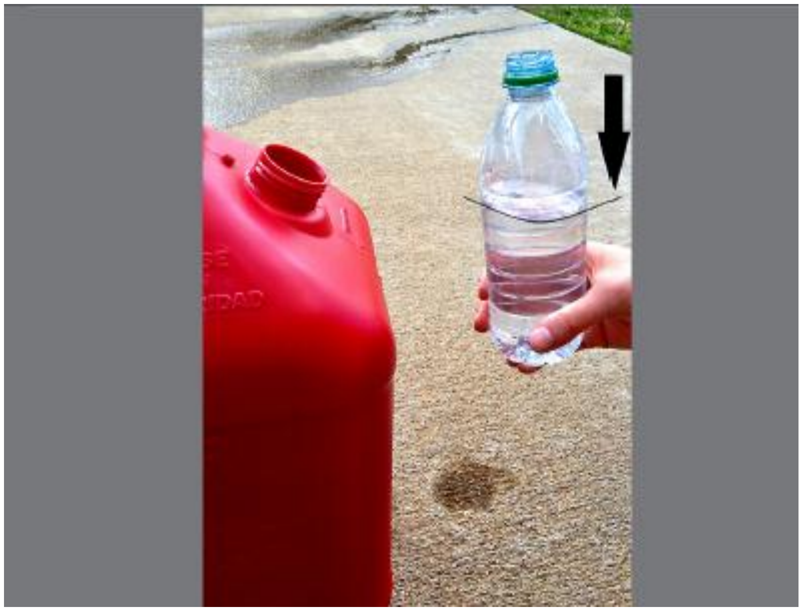


Figure A.17: Illustrating that about 1/3 of the solution was used

Figure A.18: Allow the jerry can to sit overnight

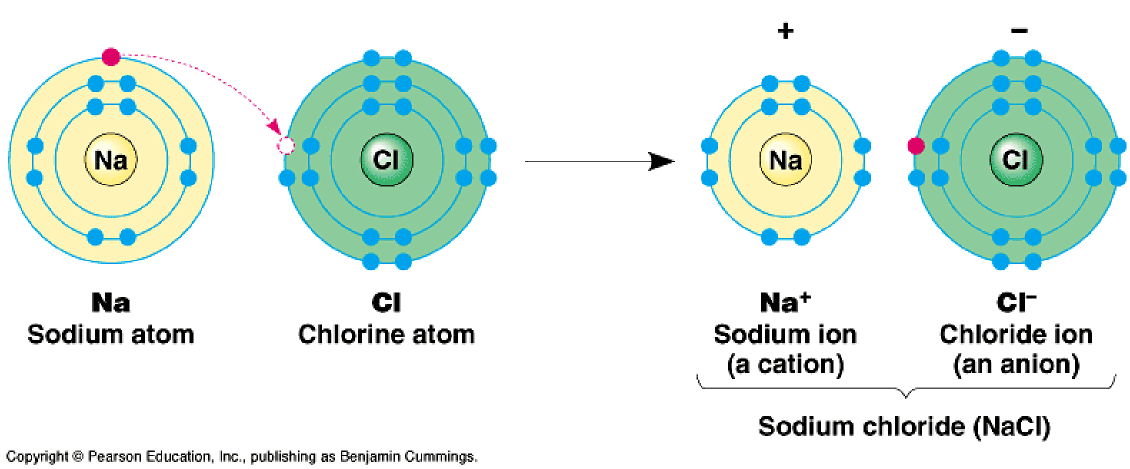
Figure A.19: After waiting overnight, the water will be safe to drink

Figure A.20: Last page with acknowledgments

APPENDIX B

CHEMICAL MAKEUP OF SODIUM CHLORIDE

Property	Sodium (Na)	Chlorine (Cl)
Atomic Weight	22.98977	35.4527
Atomic Number	11	17
Periodic Table Group Number	1 or 1A	17 or 7A
Cation (+) or Anion (-)	Cation (+)	Anion (-)
Atomic radius (nm)	0.186	0.099
What is the size ratio?	2	1



(http://kentsimmons.uwinnipeg.ca/cm1504/introchemistry.htm)

APPENDIX C

Safe Water System (SWS) –Effect of Chlorination on Inactivating Selected Pathogens

PATHOGEN	FROM WHO GUIDELINES FOR DRINKING-WATER QUALITY				CONCENTRATION OF CHLORINE (MG/L)	TIME OF CHLORINE EXPOSURE (MIN)	CT FACTOR	% INACTIVATION	VARIABLES AFFECTING CT FACTOR		PATHOGEN SUBCLASSIFICATION AND/OR EXPERIMENTAL DESIGN	SOURCE
	Health significance	Persistence in water supplies	Resistance to chlorine	Relative infectivity					Temp (°C)	pH		
BACTERIA												
Burkholderia pseudomallei	Low	May multiply	Low	Low	1.0	60	60	99%	22.0-25.0	6.25-7.0	45 pooled clinical and environmental samples	Howard, 1993
Campylobacter jejuni	High	Moderate	Low	Moderate	0.1	5	0.5	99-99.9%	25.0	8.0	Serotypes PEN1, PEN2, PEN3 isolated from patients	Blaser, 1986
Escherichia coli	High	Moderate	Low	Low	0.5	<0.5	<0.25	99.999999%	23.0	7.0	Strain ATCC 11229	Zhao, 2001
E. coli (enterohemorrhagic)	High	Moderate	Low	High	0.5	<0.5	<0.25	99.98-99.999999%	23.0	7.0	Strains isolated from six human patients	Zhao, 2001
Salmonella typhi	High	Moderate	Low	Low	0.05	20	1	99.2%	20-25	7.0	Two isolates – one from patient blood sample	Butterfield, 1943
Shigella dysenteriae.	High	Short	Low	Moderate	0.05	<1	<0.05	99.9%	20-25	7.0	Three isolates from patient stool samples	Butterfield, 1943
Shigella sonnei	-	-	-	-	0.5	1	0.5	99%	25.0	7.0	Water Engineering Research Laboratory isolate	King, 1988
Vibrio cholerae (smooth strain)	High	Short	Low	Low	0.5	<1	<0.5	100%	20.0	7.0	O1 El Tor Inaba strain N16961	Morris, 1993
Vibrio cholerae (rugose strain)	High	Short	Low	Low	2.0	20	40	99.999%	20.0	7.0	O1 El Tor Inaba strain N16961/Ru	Morris, 1993
Yersinia enterocolitica	High	Long	Low	Low	1.0	>30	>30	82-92%	20.0	7.0	3 strains: ATCC 9610 O:8, 632 O:25,35 and IM 69/85 O:3 Lis VIII	Paz, 1993
VIRUSES												
Enteroviruses												
Coxsackie A	High	Long	Moderate	High	0.46-0.49	0.3	0.14-0.15	99%	5.0	6.0	Coxsackie A9	Engelbrecht, 1980
Coxsackie B	High	Long	Moderate	High	0.48-0.50	4.5	2.16-2.25	99%	5.0	7.81-7.82	Coxsackie B5	Engelbrecht, 1980
Echovirus	High	Long	Moderate	High	0.48-0.52	1.8	0.86-0.94	99%	5.0	7.79-7.83	Serotype 5	Engelbrecht, 1980
Hepatitis A	High	Long	Moderate	High	0.41	<1	<0.41	99.99%	25.0	8.0	Strain from one patient sample	Grabow, 1983
Poliovirus	High	Long	Moderate	High	0.5	12.72	6.36	99.99%	5.0	6.0	Poliovirus type 1	Thurston-Enriquez, 2003
Adenoviruses	High	Long	Moderate	High	0.17	4.41	0.75	99.99%	5.0	7.0	Adenovirus 40	Thurston-Enriquez, 2003
Noroviruses	High	Long	Moderate	High	1.0	0.07	0.07	99.99%	5.0	7.0	Feline calicivirus used as a model	Thurston-Enriquez, 2003
Rotavirus	High	Long	Moderate	High	0.20	0.25	0.05	99.99%	4.0	7.0	Human rotavirus type 2 (Wa)	Vaughn, 1986
PROTOZOA												
Entamoeba histolytica	High	Moderate	High	Low	2.0	10	20	99%	27-30	7	Viability assessed by in vitro excystation assay	Stringer, 1975
Giardia lamblia	High	Moderate	High	Low	1.5	10	15	99.9%	25.0	7.0	Viability assessed by excystation	Jarroll, 1981
Toxoplasma gondii	High	Moderate	High	Unknown	100	1440	>144,000[1]	-	22.0	7.2	Viability assessed by mouse bioassay	Wainwright, 2007
Cryptosporidium parvum	High	Long	High	Low	80	90	7,200[1]	99%	25.0	7.0	Viability assessed by excystation and mouse viability assays	Korich, 1990

“Chlorine inactivates most pathogens that cause diarrheal disease in humans. The table below details the effectiveness of chlorine against disease-causing bacteria, viruses, and protozoa. The CT factor can be used to compare the effectiveness of chlorine against different pathogens, and is calculated by multiplying the concentration of chlorine needed to inactivate a certain percentage of the pathogens by the time the pathogen was exposed to that concentration of chlorine. Higher CT factors indicate relatively higher resistance to chlorine, while lower CT factors indicate relatively low resistance to chlorine. The CT factors shown in the table below were calculated from data in peer-reviewed research articles (references below).The efficacy of disinfection using chlorine is dependent not only on the pathogen itself, but also on the pH and temperature of the water. In general, disinfection is more effective at higher temperatures and lower pH. Attachment to particulate matter, aggregation, encapsulation of the pathogen, ingestion by protozoa, and water turbidity may also affect chlorine efficacy. The results below reflect conditions of low water turbidity (<1 NTU), demand-free water systems. The Safe Water System accounts for variations in water quality by doubling the chlorine used in turbid drinking water. The maximum CT factor created by adding 1.875mg/L sodium hypochlorite to water for 30 minutes (the minimum chlorine dosage recommended by the Safe Water System for clear, non-turbid, demand-free water) is 56.25 mg·min/L (Lantagne, in press). For turbid water, the dose is doubled to 3.75mg/L, with a resulting maximum CT factor of 112.5 mg·min/L.”

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APPENDIX D

Salt and Light

The name for the Salt and Light Water Purification comes from a famous sermon in the Bible given by Jesus and can be found in the book of Matthew chapter 5, verses 13 through 16. He says,

[13] *"You are the salt of the earth. But if the salt loses its saltiness, how can it be made salty again? It is no longer good for anything, except to be thrown out and trampled underfoot.*
[14] *"You are the light of the world. A town built on a hill cannot be hidden.* [15] *Neither do people light a lamp and put it under a bowl. Instead they put it on its stand, and it gives light to everyone in the house.* [16] *In the same way, let your light shine before others, that they may see your good deeds and glorify your Father in heaven.*

Jesus introduces the phrases "salt of the earth" and "light of the world" in these statements. Back in Jesus's time, salt was often used for three main things: as seasoning to add flavor and goodness to food, for preserving meat and other foods, and as a disinfectant, often times being rubbed into wounds to cleanse them. Likewise, Jesus speaks about light in terms that his followers would understand. In that time, light was not all around like it is today—they were used to living without much light. They could not simply turn on a switch and the room be illuminated like it is today. And Jesus tells his followers then, and is telling us now, "You are" the light, you are the ones that I have sent into dark places to shed light and bring hope.

One of my favorite things about this passage is that Jesus says "<u>You are</u>." *You are* the salt of the earth…you are the ones that add flavor and bring goodness to things, you are the ones that preserve life and hold back destruction and decay, you are the ones that are poured into wounds and places of hurt to bring cleansing and healing. As a follower of Jesus, there is no choice associated with this "you are" statement. He has made us to be His hands and feet here on this earth. This is a beautiful image and blessing!

It makes sense that neither salt or light have any use when they stay in an container or under a bowl. Likewise, we are not called to be stagnant and complacent with the way things are in our world. We can make a difference because God has given us the ability to change the status quo. It is more often times than not just a matter of opening our eyes and hearts to see the rest of the world as He sees His creation.

Hopefully, it is easy to see why this system is named the Salt and Light Water Purification System. It only needs to basic things to work: salt and light. It is so simple, and the result of using the system provides people with pure, clean water. It can also be used as a tool not only to tell others about what it means to be the salt and to be the light, but also gives people an opportunity to put those two phrases into action.

APPENDIX E

Disclaimer

This document is intended for educational purposes only. Any substance intended for human consumption should be verified as safe by appropriate, professionally certified government or civilian organizations before being utilized.