Solar Powered UV Water Purification System

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1 Abstract

The goal of this project was to design and prototype a UV water purification system to be used in developing countries or environments such as refugee camps where there are little to no resources and no dependable electricity. To meet the needs of this given environment, the system needs to be durable, safe, affordable and sustainably powered so that safe drinking water is more dependable and easily accessible in rural areas with no safe water sources. I created a purifier that combines a gravity fed sand/gravel filter system and a disinfecting UV-C light to deactivate harmful microorganisms in the water available. Due to lack of availability of certain materials, the system was not effective enough to purify water to the point where it meets national health standards. But the UV irradiation did in fact deactivate a significant amount of bacteria (up to 70% at 1 L/min) and there was a very clear correlation between the exposure time to the light and the percent of bacteria deactivated.

2 Motivation and History

Over the summer I administered a workshop at the Singapore School of Science and Technology entitled "Design for Humanity." We assisted the different student groups in identifying an issue pertinent in any developing country and from there they were told to design and prototype a creative solution to that problem. We modeled this workshop after the Stanford D-School and had a really good time mentoring the students. I personally felt a bit of imposter syndrome, teaching these kids to apply design thinking to solve issues when I had never done so myself. So when brainstorming potential ASR projects, I knew that I wanted to take the opportunity to finally apply all I've learned in the lab throughout high school to make a positive change and solve a real global issue.

This paper was written for Dr. James Dann's Applied Science Research class in the spring of 2016.

I specifically focused on water purification as my problem because it seems like an issue common among all developing countries as well as other peoples such as refugees. By addressing water purification, I felt like I was working on something that could potentially help the greatest number of people.

The path to modern water purification methods has been long, but not a lot has changed as far as the basic technologies. Before there were any advanced biological methods of testing water quality, the primary focus was turbidity, or how cloudy the water looked. Very early on in 2000 BC, Greeks realized that the most effective way to purify water was to boil it and run it through a filter, which was some combination of sand and gravel, similar to a lot of modern filters (1). There were different iterations of this method throughout Egypt and in Europe dating back to 1500 BC. Then in the 1700s people discovered that charcoal had that capability to decrease iron content, so when the first domestic purifiers were produced, they employed charcoal as they do in many systems today (2).

Figure 1: *3rd Century BC water filter found in Greece.*

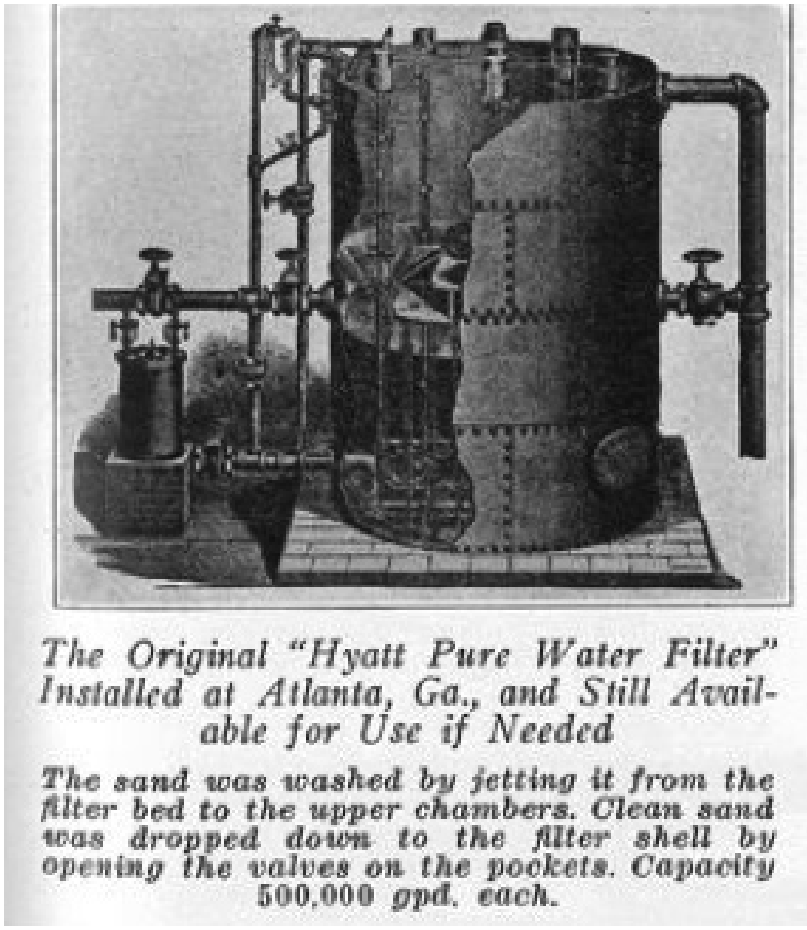

Figure 2: *The original "Hyatt pure water filter" developed in the U.S. in 1880 and patented in 1881 by John Wesley Hyatt. Used to remove particulates and organic matter from water (4).*

A more urgent problem in the history of water purification was the discovery in 1854 that the disease cholera was spread via water. As the epidemic unfolded, it became obvious that the spread of disease was less severe in places where governments employed municipal water purification systems that used sand filters. In the 1890s more governments started catching on and constructed municipal water filtration systems, using a combination of filtration and chlorination to purify the water, resulting in a notable dampening of the cholera and typhoid epidemics.

But soon the negative effects of chlorine use became clear, and researchers discovered chemical substitutes such as calcium hypochlorite, which didn't have the same negative effects as chlorine but held all the same sanitation benefits (5). Around the same time, in 1887 the germicidal effects of UV light were discovered, but they weren't implemented in water purification systems until 1910 in Marseilles, France (6).

Big strides were made in more recent history. In 1972 the Clean Water Act was passed in the U.S. and in 1974 the Safe Drinking Water Act (7). Thanks to acts like these the world's most developed countries have safe drinking water. But these acts have had little effect on the water quality in developing countries which also lack the medical resources to compensate for the negative effects of bad water quality. Since the early 20th century there have been many technological advancements to make UV water purifiers more efficient and effective, but as these technologies advance, they become less accessible to people in developing countries as they become more expensive. There are also very few easily transported and assembled filters that combine mechanical filtration and UV germicidal irradiation. The best water quality will come with a combination of those two methods, so the goal of this project is to design and prototype a filter that combines these two methods, is easily assembled, affordable and effective.

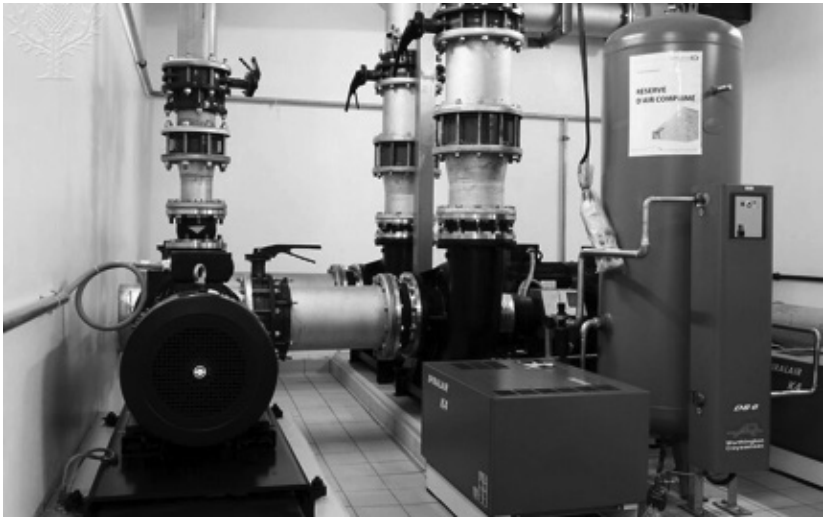

Figure 3: *A modern microfiltration water purification plant that employs small membranes and sand to filter the water (8).*

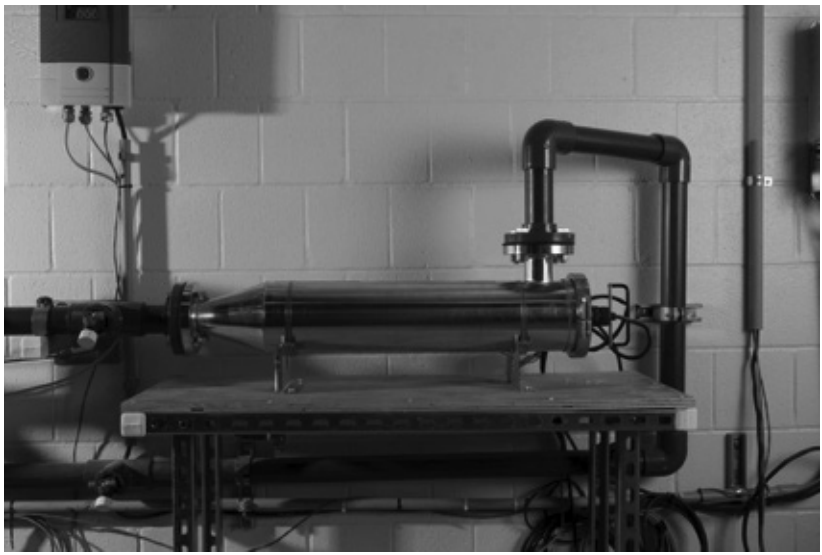

Figure 4: *Ultraviolet light treatment machine in a modern water treatment plant (9).*

3 Theory of Operation

The water purification system I designed uses sand/charcoal/gravel filtration and germicidal UV radiation to decrease the iron content in the water and to deactivate any threatening microbiological contaminants in the water.

In some cases, the sand/charcoal/gravel filtration pretreatment is unnecessary. But if the water has high turbidity, high iron content, or low UV transmissivity then it's necessary to employ some sort of pretreatment. Iron content specifically has major negative health affects. In an attempt to take maximum precaution and expecting that the users are collecting water from water sources with little or no sanitation, the purification system will include the pretreatment filter.

The gravity fed filter system is a mix of sand, charcoal and gravel. The sand is used to remove large particulates and to foster the precipitation of iron complexes in the water (10). This means that the iron (a cation) bonds with anions in the sand such as carbonate and hydroxide to create an insoluble precipitate (11).

Formula 1: $2OH^- + FeSO_4 \rightarrow Fe(OH)_2 + SO_4^{2-}$

The charcoal is meant to block or absorb certain organic contaminants like pesticides. Charcoal is made up of carbon and therefore is capable of bonding to organic material, essentially holding it in place and preventing that material from passing down through the rest of the system (12). And the gravel, at the bottom of the system, is just meant to prevent clogging of the pipe leading to the UV tank.

The UV germicidal light emits UV-C (254 nm) shortwave radiation, the only range of UV that has properties for germicidal irradiation (disinfection). UV-C rays have the capability of altering the DNA in certain microbiological organisms so that they no longer have the ability to reproduce and are therefore considered deactivated. The UV energy is absorbed by a double bond between thymine and cytosine, and the overwhelming energy then breaks that molecular bond within the DNA (13). Through a photochemical reaction, the UV thus produces thymine dimers which are unreadable by DNA polymerase, a major player in the reproductive process. The active site of the dimers do not properly fit with the polymerase, and the dimers thus create a kink in the reproductive system and prevent the organism from reproducing (14). The organisms remain in the water but are no longer harmful after the UV-C treatment.

The effectiveness of the UV is dependent on the dosage. The dosage is a function of the intensity of the light (in microwatts) delivered for a given time (seconds) over a given area (square centimeters) (15).

Formula 2:
UV Dosage (microwatt-sec/cm^2) = (Power (μW) / Area (cm^2)) x Time (sec)

Bacteria	UV Dose	Bacteria	UV Dose
Agrobacterium lumefaciens 5	8,500	Pseudomonas aeruginosa (Environ.Strain) 1,2,3,4,5,9	10,500
Bacillus anthracis 1,4,5,7,9 (anthrax veg.)	8,700	Pseudomonas aeruginosa (Lab. Strain) 5,7	3,900
Bacillus anthracis Spores (anthrax spores)	46,200	Pseudomonas fluorescens 4,9	6,600
Bacillus megatherium Sp. (veg) 4,5,9	2,500	Rhodospirillum rubrum 5	6,200
Bacillus megatherium Sp. (spores) 4,9	5,200	Salmonella enteritidis 3,4,5,9	7,600
Bacillus paratyphosus 4,9	6,100	Salmonella paratyphi (Enteric Fever) 5,7	6,100
Bacillus subtilis 3,4,5,6,9	11,000	Salmonella Species 4,7,9	15,200
Bacillus subtilis Spores 2,3,4,6,9	22,000	Salmonella typhimurium 4,5,9	15,200
Clostridium tetani	23,100	Salmonella typhi (Typhoid Fever) 7	7,000
Clostridium botulinum	11,200	Salmonella	10,500
Corynebacterium diphtheriae 1,4,5,7,8,9	6,500	Sarcina lutea 1,4,5,6,9	26,400
Dysentery bacilli 3,4,7,9	4,200	Serratia marcescens 1,4,6,9	6,160
Eberthella typhosa 1,4,9	4,100	Shigella dysenteriae - Dysentery 1,5,7,9	4,200
Escherichia coli 1,2,3,4,9	6,600	Shigella flexneri - Dysentery 5,7	3,400
Legionella bozemanii 5	3,500	Shigella paradysenteriae 4,9	3,400
Legionella dumoffill 5	5,500	Shigella sonnei 5	7,000
Legionella gormanil 5	4,900	Spirillum rubrum 1,4,6,9	6,160
Legionella micdadei 5	3,100	Staphylococcus albus 1,6,9	5,720
Legionella longbeachae 5	2,900	Staphylococcus aureus 3,4,6,9	6,600
Legionella pneumophila (Legionnaire's Disease)	12,300	Staphylococcus epidermidis 5,7	5,800
Leptospira canicola - Infectious Jaundice 1,9	6,000	Streptococcus faecaila 5,7,8	10,000
Leptospira interrogans 1,5,9	6,000	Streptococcus hemolyticus 1,3,4,5,6,9	5,500
Micrococcus candidus 4,9	12,300	Streptococcus lactis 1,3,4,5,6	8,800
Micrococcus sphaeroides 1,4,6,9	15,400	Streptococcus pyrogenes	4,200

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Mycobacterium tuberculosis 1,3,4,5,7,8,9	10,000	Streptococcus salivarius	4,200
Neisseria catarrhalis 1,4,5,9	8,500	Streptococcus viridans 3,4,5,9	3,800
Phytomonas tumefaciens 1,4,9	8,500	Vibrio comma (Cholera) 3,7	6,500
Proteus vulgaris 1,4,5,9	6,600	Vibrio cholerae 1,5,8,9	6,500
Molds	UV Dose	Molds	UV Dose
Aspergillus amstelodami	77,000	Oospora lactis 1,3,4,6,9	11,000
Aspergillus flavus 1,4,5,6,9	99,000	Penicillium chrysogenum	56,000
Aspergillus glaucus 4,5,6,9	88,000	Penicillium digitatum 4,5,6,9	88,000
Aspergillus niger (breed mold) 2,3,4,5,6,9	330,000	Penicillium expansum 1,4,5,6,9	22,000
Mucor mucedo	77,000	Penicillium roqueforti 1,2,3,4,5,6	26,400
Mucor racemosus (A & B) 1,3,4,6,9	35,200	Rhizopus nigricans (cheese mold) 3,4,5,6,9	220,000
Protozoa	UV Dose	Protozoa	UV Dose
Chlorella vulgaris (algae) 1,2,3,4,5,9	22,000	Giardia lamblia (cysts) 3	100,000
Blue-green Algae	420,000	Nematode Eggs 6	40,000
E. hystolytica	84,000	Paramecium 1,2,3,4,5,6,9	200,000
Virus	UV Dose	Virus	UV Dose
Adeno Virus Type III 3	4,500	Influenza 1,2,3,4,5,7,9	6,600
Bacteriophage 1,3,4,5,6,9	6,600	Rotavirus 5	24,000
Coxsackie	6,300	Tobacco Mosaic 2,4,5,6,9	440,000
Infectious Hepatitis 1,5,7,9	8,000	0	0
Yeasts	UV Dose	Yeasts	UV Dose
Baker's Yeast 1,3,4,5,6,7,9	8,800	Saccharomyces cerevisiae 4,6,9	13,200
Brewer's Yeast 1,2,3,4,5,6,9	6,600	Saccharomyces ellipsoideus 4,5,6,9	13,200
Common Yeast Cake 1,4,5,6,9	13,200	Saccharomyces sp. 2,3,4,5,6,9	17,600

Figure 5: *Necessary UV dosages to remove 99.9% of harmful organisms in water (5). These dosages assume a water depth of 6 cm.*

The UV light bar is powered by a 12 V solar panel, which supplies energy to four ultra capacitors, which store and then supply the energy to the UV light. The solar panel relies on the photovoltaic effect to convert

light into electricity. The solar cell is composed of two layers: p-type and n-type. The p-type layer is composed primarily of silicon, which has four valence electrons but the layer is doped with boron atoms, which have only have three valence electrons, so when boron is bonded with silicon there is an electron "hole" that offers a free positive charge which can conduct electricity. The n-type layer is also primarily composed of silicon but has some phosphorus atoms, which inversely have five valence electrons. The extra valence electron is not a part of any covalent bond between the silicon and phosphorus and is thus "free" and can conduct electricity. In the solar cell, the n-type layer is directly above the p-type layer. Because the n-type has free electrons (a negative charge) and the p-type has electron holes (a positive charge) there is a voltage instilled between the two. So when light hits the n-type layer, it imparts enough energy to the free the extra valence electrons so that they can then be herded to the p-type layer which lacks electrons. This flow of electrons is electric current which can then be directed to the ultra capacitor where the energy can be stored and effectively used later (17).

Once the current is herded to the capacitor, the capacitor employs static energy to store that energy within an electric field. Within the capacitor, there are two conducting metal plates with opposite charges and a thin insulator in between them (made of either carbon, paper or plastic) which becomes polarized, separating the charges from the solar cell and thus creating an electric double layer when the capacitor is charged (18). The energy is stored in the form of electrical potential energy, which is acquired by doing work and transferring charges against the field from one plate to another. The charges that were separated by the capacitor will flow in one direction through the UV light to the opposite plate when the light is connected in the circuit, and this energy will continue to power the light until the capacitor is fully discharged (19).

The amount of energy that needs to be stored in the ultra capacitor is dependent on the necessary UV dosage. If the necessary dosage is 24,000 μW-s/cm^2, that means that it requires 0.024 J/s per square centimeter to properly purify the water, assuming a depth of 6 cm. To then find the total charge that needs to be stored in the capacitor, you multiply 0.024 J/s by the surface area of the base of the reactor chamber.

Assuming that the SA=200 cm^2, the total charge necessary to purify the water within the chamber at a given point in time would be 4800 J.

And to then determine the amount of time that the water has to remain in the chamber, you multiply the irradiance by the volume by 60 seconds and divide that by the necessary dosage (20).

Formula 3:
Flow Rate (liters/min) = ($Irradiance_{mid\text{-}level}$ x V_{DZ} x 60 sec/min) / Dosage

The UV-C bulb used in the system is 8 W and the surface area of the base of the reactor chamber is about 200 cm^2. Irradiance is watts per area, and typical mid-level irradiance of a UV light at 6 cm distance is 900 μW /cm^2. The volume of the reactor irradiation disinfectant zone is the surface area of the base (200 cm^2) times the height (6 cm) which equals 1200 cm^3 which is equal to 1.2 liters.

$Flow\ rate_{max}$ = (900 μW /cm^2 x 1.2 liters x 60 sec/min) / 24,000 μW-s/cm^2

$Flow\ rate_{max}$ = 2.7 liters/min

The system would have to run at no more than 2.7 L/min for the water to be disinfected to a safe concentration of bacteria. In this experiment, the water runs through the system at three different flow rates and tests to see which speed kills the most bacteria.

To find the exact amount of time the water is actually exposed to the light—therefore to find the amount of energy necessary to purify a given amount of water, use Formula 4.

Formula 4:
Time (sec) = UV Dosage (microwatt-sec/cm^2) / (Power (μW) / Area (cm^2))

= 24,000 μW-s/ cm^2 / (8000000 μW / 200 cm^2)

= 0.6 second per cm^2

Assuming that the necessary dosage to purify 99% of organisms in the given container is 24,000 μW-s/cm^2, and granted that the surface area is 200 cm^2 and the power of the bulb is 8 W, the necessary time of exposure is 0.6 seconds per centimeter squared. Formula 2 assumes a depth of 6 cm, so it's really 0.6 seconds per 6 cm^3 (1 cm^2 x 6 cm). Let's say you are trying to purify one liter (1000 cm^3), you would then divide 1000 cm^3 by 6 cm^3 to get 166.67 and multiply that by 0.6 seconds to get 100 seconds or 1.67 minutes to purify one liter of water.

To then calculate the amount of energy necessary to power the bulb for 1.67 minutes, multiply power by time.

Formula 5:
Energy (J) = Power (W) x Time (s) = 8 W x 100 seconds = 800 joules

Then comes the question of whether or not the 12V solar panel has the capacity to supply that amount of energy. The 12V solar panel, with an average of 0.4517 amps (0.4517 coulombs/second), gathers 5.43 joules each second (for amperage data see Figure 14, and for calculation of energy see Formula 5).

Formula 6:
Joules = Voltage * Coulombs = 12 V x 0.4157 coulombs = 5.42 Joules / second

With a 12 V solar panel, with an average of 0.4517 amps (0.4517 coulombs/second), 5.42 joules are being gathered each second (for voltage output see Figure 14, and for calculation see Formula 4). This means that the solar panel could gather enough energy to purify one liter of water in 147.6 seconds (800 joules/5.42 joules/second). So the solar panel can easily power the system, especially during mid-day when the sun is most powerful. If a particularly large amount of water needs to be purified, then energy could either be stored from the earlier and later parts of the day, or another solar panel could be connected in parallel to collect more energy at once.

4 Design

The water purification system consists of two 5-gallon insulated containers, connected by $^3/_4$-inch PVC pipes and Ts with a UV reactor chamber between the two containers. Each container is 1 foot in diameter and is 19 inches tall and made of plastic. One of the two containers is elevated, sitting on top of the wooden structure which holds them both. The top container contains a layer of sand (between the size of 40 and 16 mesh), charcoal and pea gravel, which each serve a certain purpose in the purification process (explained in section 3). There is a perforated PVC pipe which sits in the bottom of the container and stretches from one side to the other within the pea gravel and then extends out the side of the container (this junction is sealed with silicon sealant to prevent leaking) and connects to a valve which can be opened and closed to allow water to flow out of the container. The flow restrictor is connected directly to the valve. In this experiment there are three different flow restrictors, made of PVC with perforated quarters glued to the end—the number of $^9/_{64}$-inch holes in the quarter determines the flow rate (shown in Figure 6). The flow restrictor then connects to a PVC elbow and then a clear pipe which runs downward into the UV reactor chamber. At all of the junctions between pipes, silicon sealant is applied to prevent leaks.

Figure 6: *The three different flow restrictors. A 2-inch long piece of PVC is glued to a quarter with the proper number of $^9/_{64}$ -inch holes. Each hole allows 1 liter to flow per minute so the leftmost flow restrictor is 1 liter per minute, the middle is 2 liters per minute and the rightmost is 3 liters per minute.*

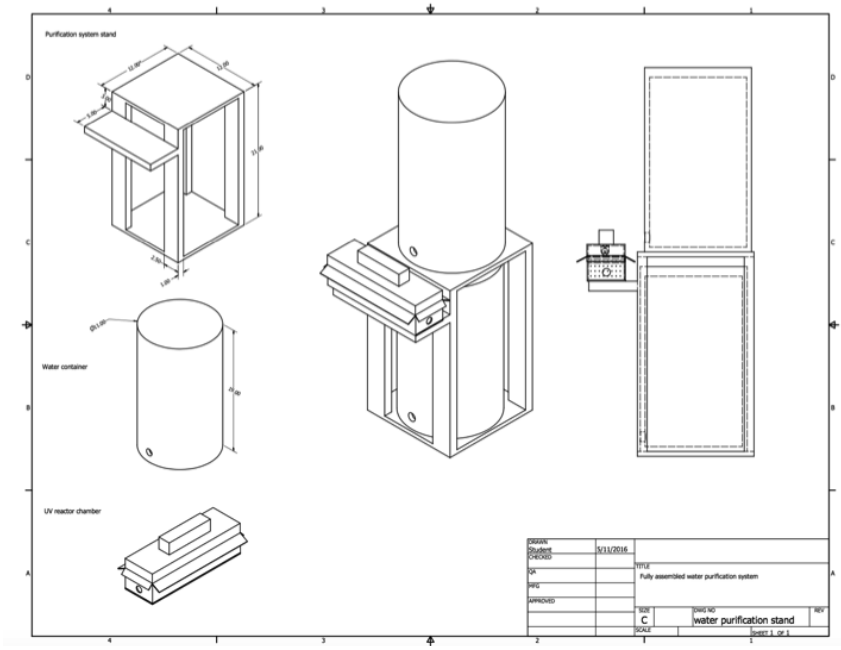

Figure 7: *UV Water Purification System Design. Bottom left shows the general dimensions of the UV reactor chamber which contains the UV bulb. Above that is a schematic for the water containers, one of which sits on top of the stand and holds the sand and gravel and one of which is on the bottom of the stand and eventually holds the post-treatment water. Above that shows the plywood stand which holds everything. And to the right shows all the pieces put together, not including the PVC pipes, valves and elbows which connect everything.*

Figure 8: *Fully Assembled System. Left shows the reactor chamber in the front. Water runs from the valve on the right, through the chamber, and out the left into the bottom container. Top right shows a close-up of the reactor chamber. Bottom right shows the different PVC parts connected. It goes from the perforated PVC that comes out of the container to the valve to the flow restrictor to the elbow to a small ¾-inch piece to the clear tube that runs directly into the reactor chamber.*

The UV reactor chamber is a small container made of steel, which is 3.93 x 2.36 x 12 inches and holds approximately 1.2 liters at a time. The design for the reactor chamber is largely based on one used in a system designed by MEDRIX, but has a good number of modifications due to lack of availability of certain materials, parts or tools. The chamber is covered by a reflector hood on which the ballast sits. The reflector hood is polished as much as possible on the inside to maximize how reflective it is so that it will therefore maximize the amount of UV energy delivered to the water. Small T5 lamp sockets and hangers are installed under the reflector hood to hold the light bulb. Two screw-type fluorescent light socket lamp holders are connected to the T5 UV long bulb so that the bulb can connect to the ballast which connects to the capacitors which are then powered by the 12 V solar panels. The optional ballast cover lays over the wires and power source for safety precautions. After

the water flows through the reactor chamber, it flows through another pipe downward into the top of the insulated collector container which sits directly under the top container and holds the purified water.

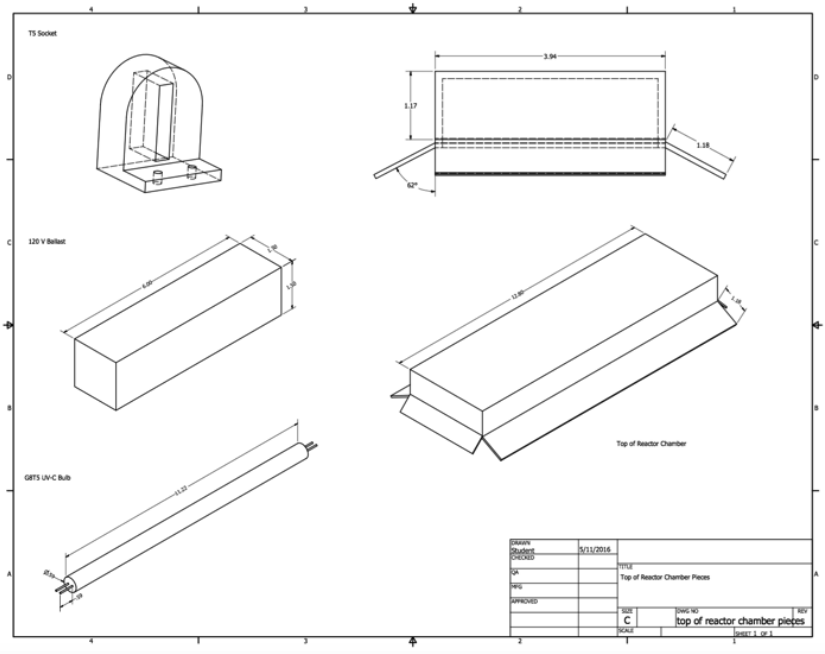

Figure 9: *Top of Reactor Chamber Parts. In the top left is the schematic for the T5 socket/lamp hangers which connect the bulb to the ballast. Below that shows the dimensions of the ballast and below that the dimensions of the UV bulb used in this design. Top right is a front view of the reflector hood of the UV reactor chamber. The chamber itself is 3 cm deep but also has 3 cm angled lips on each side which, a) protect the surrounding area from UV light, and b) suspends the reflector hood above the reactor chamber base so that the bulb has some extra distance from the water.*

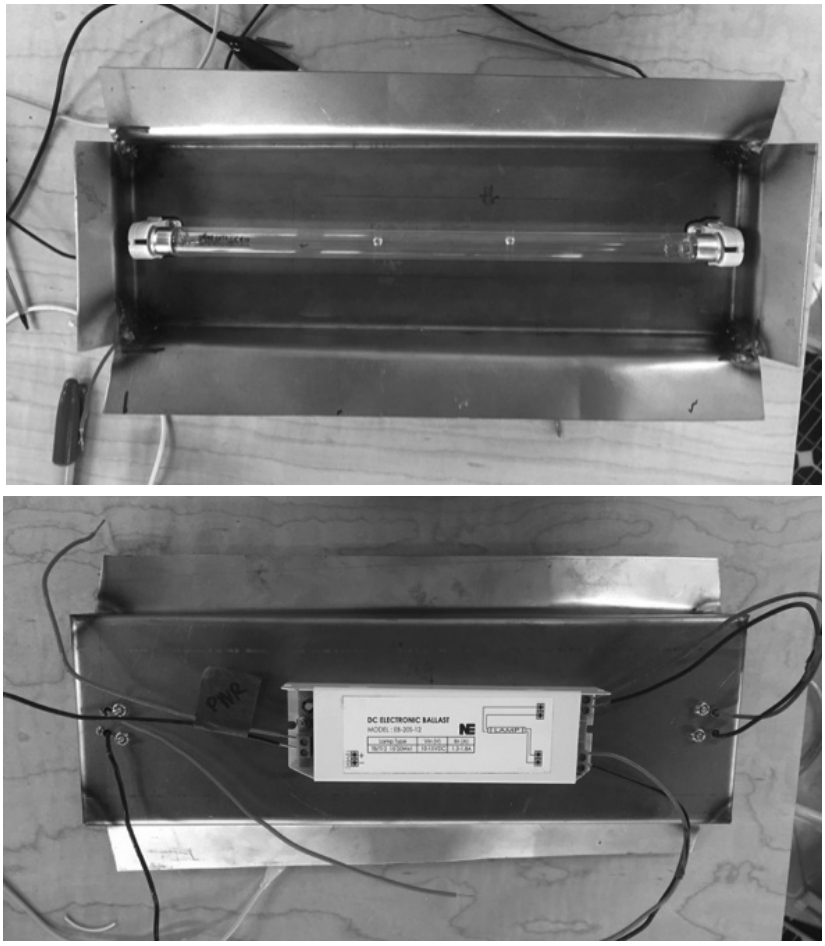

Figure 10: *Top of the reactor chamber fully constructed (not attached to power source).*

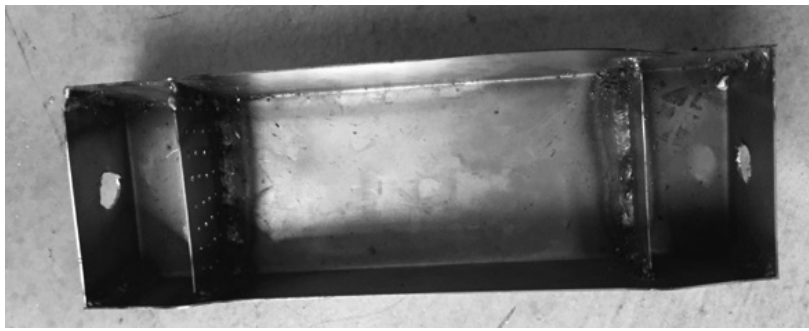

Figure 11: *Bottom of reactor chamber.*

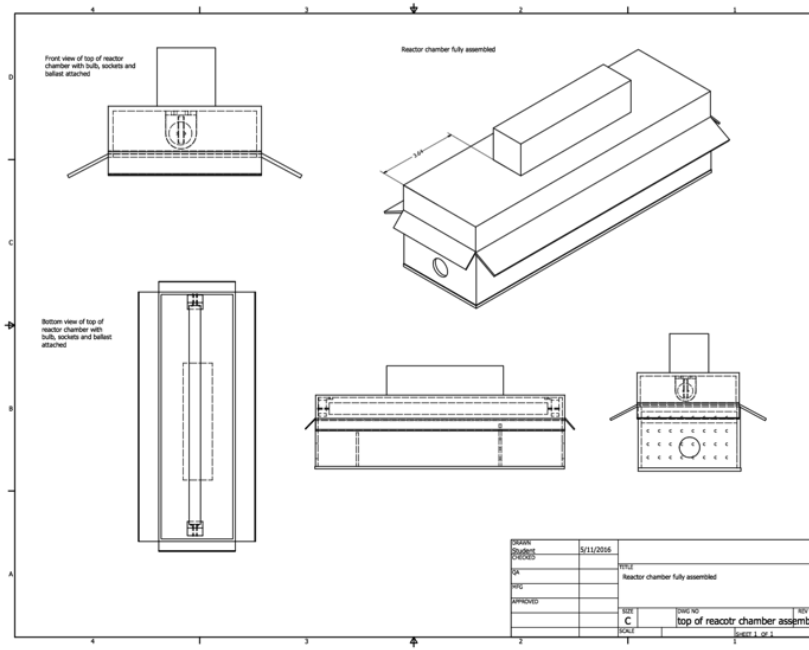

Figure 12: *Fully Assembled Reactor Chamber. The left shows the top of the reactor chamber assembled. The lamp hangers are screwed into the top of the reflector hood and hold the bulb approximately 1.5 cm below the hood. The ballast is screwed into the top of the reflector hood and is connected to the lamp through* $^{9}/_{64}$ *-inch holes for the wires to run from the inside to the outside of the reflector hood. On the right you see the fully assembled reactor chamber including the base which has two walls within it—the inlet wall is perforated with 32* $^{3}/_{16}$ *-inch holes which let the water flow in, the outlet wall has no holes but it slightly shorter so that water can flow out but it makes it more difficult than if it was perforated so that the water sits there for an amount of time and is exposed to the light.*

The light bulb is an 8W T5 11.3-inch long germicidal UV-C (254 nm) lamp and is powered by 12V solar cells which deliver on average 0.4517 amps, which would equate to 1626.12 coulombs per day (see Figure 14). The energy is collected in four 350 F, 2.7V ultra capacitors, which are organized in series pairs and the two pairs are in parallel and have the capacity to hold a typical amount of charge from the solar cells each day. The energy can then be pulled from the capacitor to the bulb when the switch is turned on. The current goes through the switch to a resistor and then to the UV bulb, which is in the UV reactor chamber between the two containers. The bulb requires a total of 8W to be powered, which is easily supplied by the 12V panel.

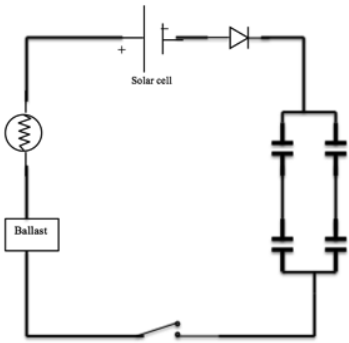

Figure 13: *Circuit Design. Power source is a 12 V solar cell which then is connected to the collection of ultra capacitors. These are then connected to a switch which is then connected to the ballast. The ballast is attached to the UV light bulb which performs germicidal irradiation in the UV-C reactor chamber.*

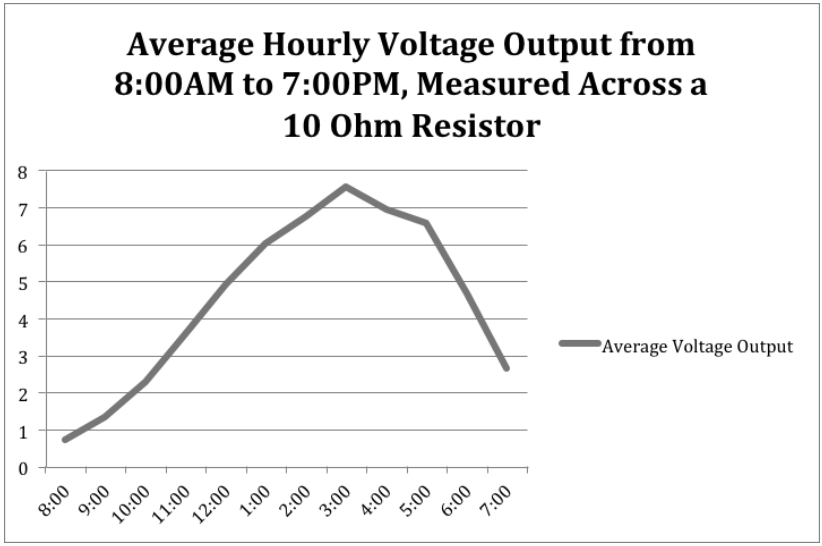

Figure 14: *Average hourly voltage output from the solar panel from 8:00 AM to 7:00 PM, measured with a multi-meter across a 10 ohm resistor. The averages were taken by recording 6 different voltages each hour. The overall average output is 4.517V which equates to 0.4517 amps with a 10 ohm resistor.*

4.1 Procedure for Quantifying Results

In order to test the effectiveness of the water purification system, use agar plates to indicate the amount of bacterial growth before and after running water through the filter.

First, create an HB101 solution that contains 6 grams of agar powder, 10 grams of LB broth and 400 ml of water and a sample from an overnight HB101 culture. Then create serial dilutions of this solution and spread 100 micro-liter samples of each dilution onto agar plates. Incubate the plates overnight and the next morning, see which plates have singular bacterial colonies that are countable. The higher concentrations will most likely grow bacterial lawns which are not easily quantifiable and therefore should not be used as the control in this experiment. Choose a concentration that is the highest able to be counted. This is your control—the solution which will be passed through the

system. In this experiment, a 1/50,000 concentration of HB101 was used, as determined by counting the colonies from 6 different concentrations (see Figure 15).

Figure 15: *The six different concentrations of HB101 solution that were plated on agar and incubated overnight. The final and least concentrated solution, shown in the bottom right was used as the initial condition sample to run through the system because at that concentration, the colonies were most easily countable.*

Once the concentration is determined, create an HB101 overnight culture. Dilute the culture to the point where it is at the concentration determined inititally. In this experiment, 4.5 liters of the solution were created so that there could be three different trials, running 1.5 liters through the system at three different flow rates.

Keep a small amount of the solution (about 400 micro-liters) to plate from each 1.5 liter solution as the initial condition for the solution. Incubate these initial samples.

Take the remaining amount of your solution and run it through the system as soon as possible after the bacteria are still alive and collect the water at the end of the system. Take samples of each trial and put 100 micro-liters on a plate and incubate it over night with the initial condition samples.

The next day, quantify the amount of bacteria on each plate and compare them to gather results.

5 Results

Unfortunately something went wrong in the result-gathering process and all three of the pre-treatment samples of HB101 solution did not grow any bacteria despite the fact that they were supposed to grow somewhere around 174 colonies, as happened in the standard curve sample of 1/50,000 concentration (shown in bottom right of Figure 15). So no strict conclusions can be drawn regarding the effect that the system had on specific samples. But assuming that the initial samples had the same bacterial concentration as the standard curve sample (174 colonies in a 100 micro-liter sample), as they were supposed to, then the 3 L/min trial added bacteria, the 2 L/min trial killed 13.2% of the bacteria and the 1 L/min trial killed 69.5% of the bacteria.

Flow rate	Pre-treatment colony count (assuming the same as standard curve sample)	Post-treatment colony count	Percent of bacterial colonies deactivated
3 L/min	174	Lawn	>0%
2 L/min	174	151	13.2%
1 L/min	174	53	69.5%

Figure 16: *Results from the three trials of differing flow rates.*

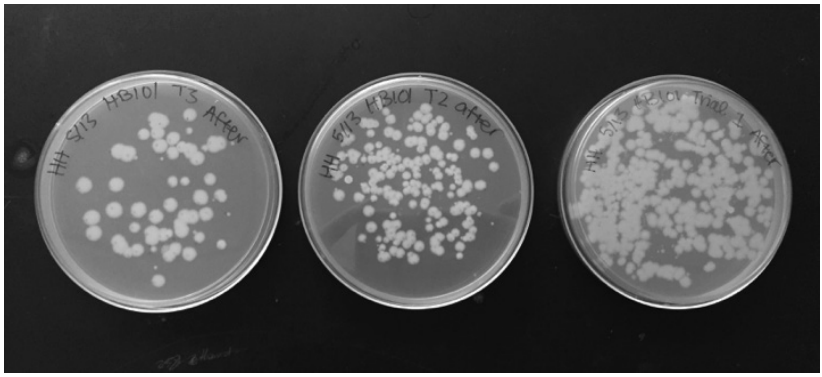

Figure 17: *Results from the three trials of differing flow rates. From left to right is 1 L/min, 2 L/min and 3 L/min.*

Despite the fact that no definite conclusion can be drawn regarding the effectiveness of the system on specific samples of HB101 solution, a very clear conclusion can result regarding the effectiveness of the UV-C bulb to deactivate the bacteria in general. Very clearly, when the bacteria were exposed to the light for longer, a much larger percent of the bacteria were killed (1 L/min killed the most, 3 L/min the least).

6 Conclusion

The main goal of this project was to design a system which is durable, affordable, easily assembled, self-sustaining, sustainably powered, composed of materials easily accessible anywhere, and effective in producing water up to National Health Organization standards.

The design succeeded in being durable, affordable, self-sustaining and being composed of materials which are accessible anywhere. All together, the materials for making the system cost only $96.00. At a 2 L/min flow rate this system could easily supply enough water for a full family and therefore this system would only cost somewhere around $20 per person and would last somewhere up to 3 years, only having to replace the sand and gravel 6-7 times, and the cost would decrease if it were to be mass produced. All the materials (PVC, plywood, steel, solar panels, bulbs, capacitors, ballasts, plastic containers, gravel, sand) are easy to find and distribute.

More or less, the system is easy to assemble. The reactor chamber does require welding, which is not easily performed in desolate places or places without electricity. Hypothetically, the reactor chamber could be produced somewhere separate from the location of the system and distributed. But other than the reactor chamber, all that's required is a drill and a PVC cutter.

But the system did not succeed in being completely effective up to national health standards. One of the large sources of error (which may have caused the system to be less effective) was the lack of availability of stainless steel to create the reactor chamber. Stainless steel requires a TIG welder but the ASR lab has a MIG welder so the design had to be revised to use carbon steel. Carbon steel is far less reflective and also rusts. The MEDRIX design, which provided the equation I used to determine the proper flow rate, assumed that stainless steel was used. Since carbon steel was used, less light was reflected and therefore less light was absorbed into the water. Therefore, the effect of the light is diminished by using carbon steel as opposed to stainless steel. Also, carbon steel rusts extremely easily, producing iron bacteria. So effectively, the rusting of the reactor chamber combats the effect of the UV-C light by introducing new bacteria to the water. In the second and third trials, the effect of the bulb outweighed the effect of the rusting as there was a decrease in bacterial growth after going through the system. But for the first trial, the effect of the rusting overpowered the effect of the UV-C light and there was in fact more bacteria after going through the system than there initially was in the water. So, to make the system more effective, there would need to either be an increase in UV dosage (longer exposure time via slower flow rate) or the reactor chamber would need to be made of stainless steel.

So ultimately, this iteration of the system could not effectively purify water to health standards and therefore does not fully reach the initial goal of this project. But after possibly a few more versions, this design could effectively purify the water with a change in materials and with recalculation of UV dosage, and then it would help to provide pure water in locations with no electricity and scarce resources.

6.1 Next Steps

As explained in the conclusion, the first thing I would do in the next version of this system would be to use stainless steel to create the reactor chamber. I believe that this change in material would greatly decrease my margin of error, resulting in the deactivation of a larger portion of the bacteria. I would also like to consolidate the system if possible, integrating the solar panels and capacitors into the design as opposed to having them separate, so that the capacitors could also be properly protected from weather. And if I had time, given the design I have now, I would do three more trials and hope that the "before" samples worked so that I could accurately compare each specific sample before and after it went through the system.

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