Nice idea

Design and Construction of a Solar Water Purification System Using Ultraviolet Radiation

by

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ABSTRACT

This senior project discusses the design and construction of a solar powered water purification system. An ultraviolet water treatment system was designed and built to demonstrate the capability of off the grid water treatment. The system is specifically designed for the destruction of bacterial contaminants and to meet the needs of a family of four in third world countries. Only sunlight is required to power the purification system. A single 1m × 2m solar panel collects energy from sunlight and charges a 12V battery. The stored electricity is used to power a 12" ultraviolet bulb. The UV radiation disrupts the bacteria and produces a source of potable water.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Scarcity of water and quality of water have long been a concern for many people in the world. Population is increasing on an exponential scale which leads to a greater need for water reserves. Also with the large population increase there is more pollution emitted into the environment contaminating many streams, lakes, and rivers. Contaminated water can carry different types of waterborne diseases. Drinking from untreated water can cause illness which leads to extreme pain or even death. Even water sources that are away from densely populated areas can carry pathogens detrimental to human health. There are many areas in the world that need a solution to make their polluted water potable. These areas are located in the Figure 1. Even areas that currently do not need a way to provide safe drinking water may need it in the future with the rapid increase of pollution and scarcity of water.

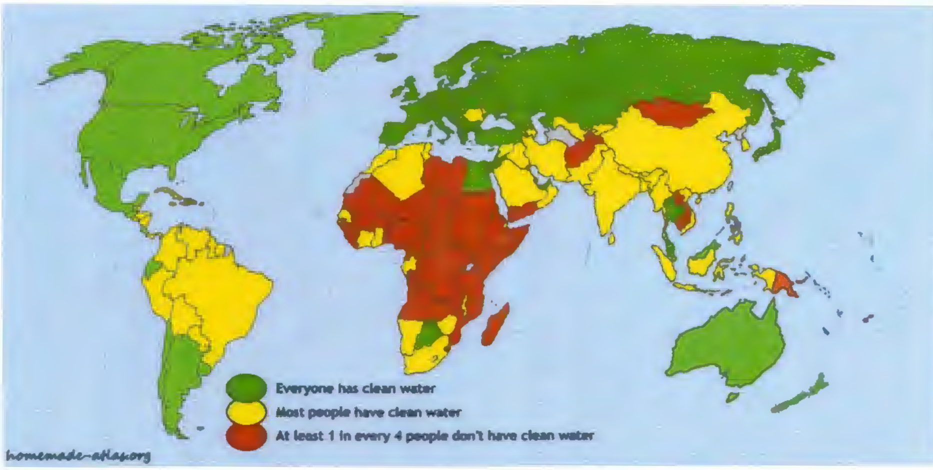


Figure 1. Countries without safe drinking water (Global Education Project, 2004).

Personal water purification systems allow families to provide themselves with a sufficient amount of safe drinking water that the body requires on a daily basis. It is very difficult and there are very high costs associated with completely repairing a natural reservoir even though it is a better for the environment. People need a quick solution to this problem while waiting for a more permanent fix. With a purification system, water sources that are normally too dangerous for consumption can now become useful. A personal system that is affordable for anyone can decrease the amount of preventable illnesses and deaths across the globe.

The goal of this project is to design a dependable way to purify water in locations that are off the grid and don't have constant sources of clean water. The design also needs to be able to be built on a low budget considering that most of the places that don't provide potable water to its citizens are frequently in the poor regions of the world. Understanding what kind of bacteria and viruses are present in water sources and how they can be eliminated will help with the selection of what type of system will be used. Finding a way to power the system without the use of a grid will allow the system to be

used anywhere. Designing a water purification system for use in areas where water is contaminated and scarce will be an interesting challenge and use of knowledge gained from the engineering courses taken at Cal Poly.

The objective of this senior project was to design and construct an ultraviolet purification system. The design parameters of this project include:

1. The system must kill all microorganisms in the water to make it safe for consumption.
2. The system must provide a source of power for portable use in all locations.
3. The system must have a low construction cost.
4. The system must be durable for outdoor conditions.
5. The system must provide enough potable water for an average sized family.

LITERATURE REVIEW

There are many existing solar panel systems that are implemented across the world. Most of which are used to produce electricity to homes or small gadgets. Other forms of solar systems can also be used to heat water or homes. It has become a recent concern and idea to use solar panels as an energy source for cleaning water in developing countries where most of their large water supplies have become contaminated from human activity. Developing countries tend to use more polluting processes to generate power and have lower standard for keeping the environment clean and healthy. This pollution is disposed into clean water sources and contaminates them. Over time this pollution adds up and these clean and drinkable bodies of water become completely useless and a great place for harmful organisms to thrive off of. People in some developing countries also use streams to wash themselves and clothes if they do not have a stable supply of water provided for them. This water flows downstream where others drink from. All of these activities worsen the problem of decreasing sources of natural potable water.

Solar panels are clean energy systems which can cut down the pollution problem and still give the opportunity to generate a reliable source of potable water. One of the main concerns about solar panels is its lower efficiency. Solar efficiency is measured at about 15-20% on average (Honsberg, 2013). PV panels produce electricity, but in the form of a direct current (DC). Most of the common appliances require an alternating current (AC) to work properly. An inverter converts the produced DC electricity into AC electricity. The process of PV panels capturing energy from the sun and converting it into usable electricity with the help of an inverter can be seen in Figure 2.

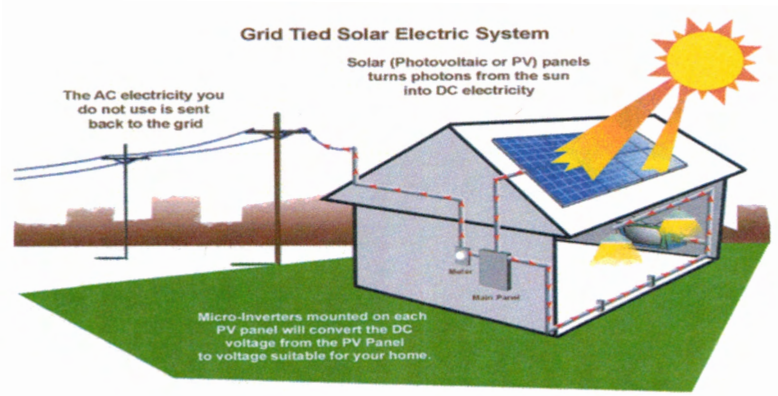


Figure 2. Solar panel conversion system (Jolapara, 2014).

An ultraviolet lamp is one of the manufactured products that will need an alternating current to function properly. The mercury within the bulb goes through mercury migration if DC is used. Mercury migration is when mercury moves in one direction to the same electrode which causes it to fall out of the arc (UVP, 2014). If this occurs, the intensity of the bulb is drastically reduced.

Ultraviolet light penetrates the outer cell membrane of the bacteria or virus and it passes through the cell body which disrupts its DNA, preventing reproduction of the cells (Weichenthal, 2014). UV light doesn't actually kill bacteria, but instead it prevents it from reproducing and disrupting the structure enough to cause it to become safe for consumption. The dissociation of DNA can be seen in Figure 3.

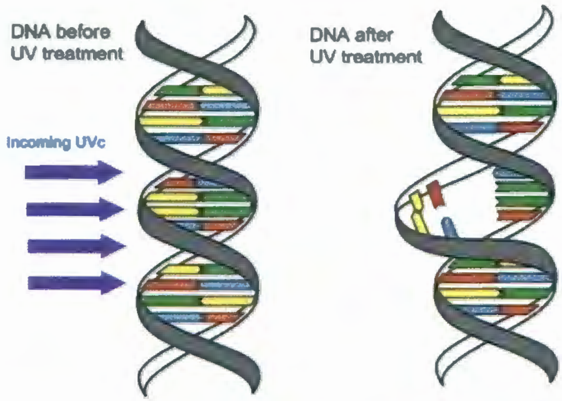


Figure 3. Disruption of DNA strand from UV energy (DaRo, 2010).

The dose of UV exposure to the water dictates the amount of disinfection of the water. The dose that the water receives is the amount of light intensity and the contact time with the UV radiation (DaRo, 2010). Different dosages are required to disrupt different types of bacteria and viruses since the resistance to UV radiation can vary within different microorganisms. The common wavelength that UV bulbs are designed to emit is 254 nm (DaRo, 2010). This wavelength is at the peak of cell inactivation and therefore is most effective at disrupting the DNA strands of microorganisms. The UV spectrum can be seen in the electromagnetic spectrum shown in Figure 4.

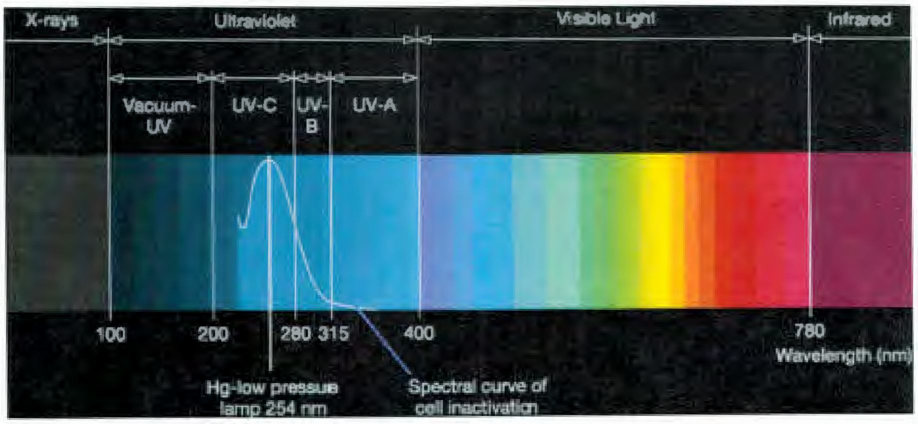


Figure 4. UV spectrum and cell inactivation curve.

The peak of the spectral curve of cell inactivation is found in the UV spectrum within the UV-C region at the 254 nm wavelength.

Thus while solar panel energy harnessing systems and UV bulb water purification systems both exist in the current market, there is a scarcity of systems which utilize both together in order to provide clean water to places which do not have access to an energy grid.

PROCEDURES AND METHODS

Many different types of purification processes were considered during the design process of this project. In order to design a system that can be used anywhere in the world, it is important to use reusable resources. Constructing a system that will purify water using UV bulbs includes determining how much contact time is necessary to destroy all present microorganisms in the water and make it safe for consumption.

Design Procedure

Type of Purification. The California Department of Public Health determines standards on what makes drinking water safe. There are many methods that can be used for purifying water. Salt water can be desalinated and bacteria infected water can be decontaminated. The areas that would be in need of this system are not always along the ocean so the system was designed with a focus on destroying bacteria and viruses. The method that was selected for this project was ultraviolet radiation for the inactivation of microorganisms. UV filtration doesn't alter the flavoring of the water as some chemicals do. A UV bulb can purify a large volume of water without the need for continually purchasing and applying chemicals to the tanks. UV rays at a calculated distance from the bulb with a determined contact time can disrupt microorganisms unseen by the human eye and make the water drinkable.

A pre-filter screen placed at the top of the settling tank will separate larger particles before the water is pumped into the UV tank. The hand pump pulls water from the low part of the side panel to allow for any particles to settle out at the bottom of the tank and not get pulled into the UV tank.

Photovoltaic Panel. A photovoltaic panel generates power for the ultraviolet bulbs and charges the battery. The panel generates the most amount of electricity when it is in direct sunlight and angled perpendicular to the sun. The panel is positioned on the top corner of the system so that it can rotate freely. It sits on a rotating rod about halfway up the panel and rotates around the rod. An extending rod is connected to the bottom so that is can be extended and locked at the optimum angle, perpendicular to the sun. A single panel can provide more than enough electricity for one UV bulb. The battery is charged to store power in case of cloudy days or for use during the night.

Sizing of the System. The photovoltaic panel collects the energy from the sun and converts it to electricity that can be used by the UV bulb. A single panel is able to power the entire system. The peak output wattage, voltage, and amperage of one panel is 435 Watts, 72.9 volts DC, and 5.97 amps respectively. While the sun is up, the average light intensity produced from it is about 500 W/m^2. The single 12 inch UV bulb was selected to be powered with these restrictions. The 12 V DC battery will be charged by the solar panel while power isn't being drained from it. This is stored for times when the panel is not in direct sunlight or and its peak hour. The inverter allows the direct current (DC) produced by the panel to be converted to an alternating current (AC) which allows the

bulbs to have continuous power and the battery to produce a higher voltage to the bulb. When the system isn't in use, the PV panel charges a battery for future uses when it is dark or cloudy and the panel can't collect enough energy from the sun.

This system is designed to produce enough fresh drinking water daily for an average family of four which is about 2 gallons per day. For larger families, the system can be run multiple times throughout the day to achieve the desired amount of water if a single tank isn't enough. The tanks used can hold up to three gallons of water. The dimensions of the contact range needed to disrupt the bacteria and the desired volume allows for a bulb length of 12 inches. The calculations for determining the rate of clean water produced by system can be viewed in Appendix B.

Pumping System. The system requires a way to pump water from the primary holding tank into the UV tank. Purchasing a pump is a possible choice, but that increases the overall price of the system and needs power to operate which could increase the number of required solar panels. With this consideration, building a hand pump was more appealing for cost-benefit reasons and still completes the same job as a mechanical pump.

The hand pump is constructed using different sizes of PVC piping. A 1"pipe fits into a 1¼" pipe to create the pumping action required for the transfer of water. A ¾" check valve placed on either side of the main tubes allow the water to be pulled from one tank and pushed into another tank. Check valves allow for flow in only one direction so it forms a suction and exertion force and the purified water can't get mixed up with the contaminated water.

A pipe connecting the UV tank to the pump and back to the UV tank gives the operator the option for making the water cycle through the tank to keep it constantly moving. The flow of water helps the water be well mixed and have a uniform destruction of bacteria.

Ultraviolet Bulbs. Ultraviolet bulbs commonly emit light at a wavelength of 254 nm. At this wavelength, DNA strands within bacteria can be deconstructed with the correct contact time at a certain distance from the bulb. The equation for determining this distance and amount of time needed to purify water is listed below (Clarke, 2011).

$$I(r) = \frac{PL}{2\pi r} e^{-aer} \tag{1}$$

Where: I(r) = UV intensity at a distance (r) from the lamp (mW/cm^2).
PL = UV power emitted per unit arc length of the lamp (mW/cm).
r = Radial distance from the lamp (cm).
ae = Base absorption coefficient of the water (1/cm).

Adjusting the volume of water in the tank and the length of the bulb, the radial distance can be determined knowing the exposure needed for cleansing common natural water. The bulb needs to be submerged in the water for direct contact. A secure chamber over the bulb connections is required to prevent any contact between the electrical wiring and the water.

The tank containing the UV bulb is not enclosed under the shelves, but rather is attached along the side and hanging over the edge on the base panel. Opening a valve allows gravity to transfer the water from the UV tank to the storage tank. The tank can be easily monitored and visually checked to make sure the bulbs are working properly or replaced if broken.

Cart. A cart provides easy transportation and positioning of the entire system. It also provides shelter for the electrical components from intense sunlight and weather conditions over time. The initial idea was to design and build a cart from scratch. In the reusable and cost-effective mind set, a scrap cart was refurbished and altered to fit the needs of the system. This cut down the overall cost of the system to make it more affordable.

The photovoltaic panel is positioned on top of the cart for direct sunlight. An array of hooks along the top panel gives the adjustable rod that is attached to the panel an anchor to hold the panel upright at the desired angle. The inverter, charge controller, battery, and tanks are placed on the shelves inside of the cart. The hand pump is placed between the settling tank and the UV tank. The piston shaft of the hand pump runs vertically along the outside of the side panel. There is easy access to working the pump and is at a height for a comfortable pumping action while it still keeps the system enclosed. The pump is made of PVC and isn't as vulnerable as the other pieces of equipment. The cart design keeps the system compact and transportable.

Drawings. The design of the system was first constructed using AutoCAD to determine the layout and sizing of the components needed for a complete purification process. A few of the drawings are shown in Figure 5. All of the design drawings can be found in Appendix C.

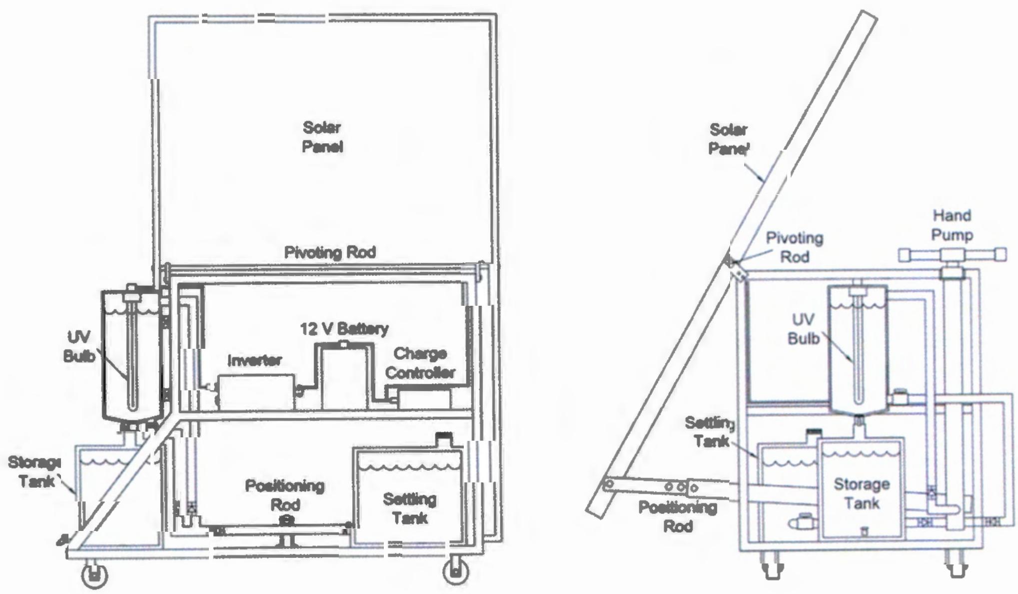


Figure 5. System design drawings.

Construction Procedure

Cart. The initial idea was to build a cart custom for the system but keeping the low budget design requirements in mind encouraged the idea of recycling an old shelf cart. The system had to be transportable so the stand used had to have wheels for ease of mobility. The cart used for the project was found in the Cal Poly University surplus yard and can be seen in Figure 6.

Figure 6. Purification system cart.

The side ladder was unnecessary for the system so it was removed. The surface of the shelves were wore and rough so they were cleaned up to give it a more presentable and appealing look. Holes were drilled throughout the cart during the construction process for all of the equipment added to the shelves. The system had to be fastened and secured correctly since the cart moves and is designed for all terrain and environments.

Pumping System. Building a personal pump was selected instead of purchasing a mechanical pump of an already built hand pump. Building a pump for the system allows for sizing the pump related to the volume of water and flow rate needed for the system. It is also a cheaper design and construction process.

The hand pump was designed and constructed out of PVC piping. The main shaft consists of a 1" PVC pipe that slides into a 1¼" PVC pipe. The 1" pipe was cut into a piece 26" long and the 1¼" pipe was cut into a 24" long piece. The smaller pipe needs to be slightly longer so that a handle can be attached to it. The 1" pipe is sealed at the bottom end with a 1" plug. When the 1" pipe is inserted into the 1¼" pipe there is a slight gap. This gap prevents the vacuum needed to pull and push the water from one location to another. At the bottom of the 1" pipe, two shallow incisions 1" apart were made around the perimeter of the pipe to create grooves. O-rings were stretched around the pipe and placed in the grooves. This produces a seal and allows the water to be pumped through the device.

At the bottom of the 1¼" PVC pipe, a 1¼" slip coupling is glued and a 1¼" × ¾" PVC bushing is glued to the slip coupling. One side of a threaded ¾" PVC close riser is attached to the PVC bushing and the other side is attached to a ¾" PVC FIPT × FIPT × FIPT (Female Iron Pipe Threaded) tee. The horizontal line of the tee is where the water

will enter and exit. The connection between the bushing and coupling of the pump and the tee where the inlet and outlet are can be seen in Figure 7.

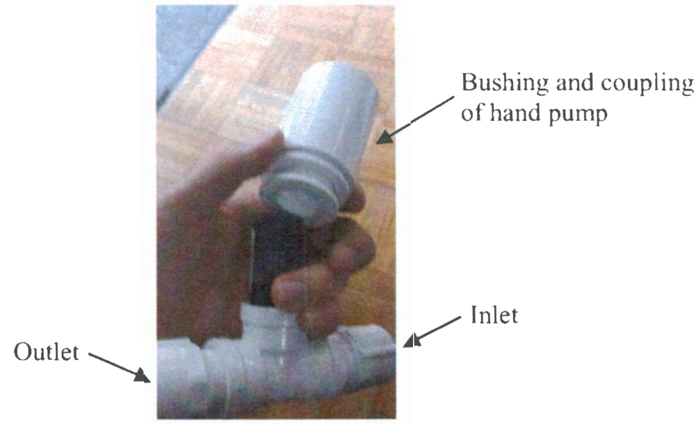


Figure 7. Hand pump and inlet/outlet connection.

The handle is made out of a 1" slip tee, two 1" caps, and two pieces of 1" PVC pipe 4½" long. The two pieces of 1" pipe are inserted to the opposite ends of the 1" slip tee. The caps fit over the other end of the 1" pipes. The remaining open part of the tee is where the shaft is connected. Before connecting the handle, a 1¼" slip cap with a drilled 1" hole is slid over the top of the shaft so that the 1" pipe fits through it but fits on the end of the 1¼" pipe. Once the slip cap it glued to the 1¼" pipe, the handle can be attached and glued to the top of the 1" pipe. The finished product is shown in Figure 8.

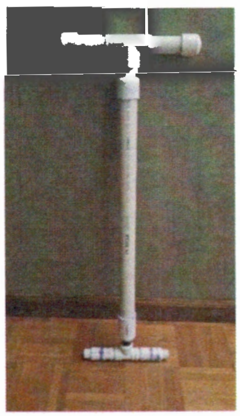


Figure 8. Hand pump.

All gluing of PVC parts require PVC cement. Purple primer was used to ensure the strength of the seal.

A 2"×4½" sheet of metal was used to attach the hand pump to the side of the cart next to the UV tank. A 1½" hole was cut out of one side of the sheet and two ¼" holes were drilled on the other side. The sheet was bent 90° 1" away from the two ¼" holes. The handle and cap was removed from the hand pump and the 1¼" shaft slid through the

larger hole of the metal sheet. The handle and cap were place back on and since the cap is slightly larger, it doesn't slide off. The two smaller holes were used to bolt the bracket to the side of the cart and hold up the pump. Figure 9 shows how the hand pump is connected to the cart using the fabricated bracket.

Figure 9. Hand pump connected to the side of the cart.

Check Valves. A check valve is a device that allows a liquid or gas to flow in only one direction. Check valves are simple to build and much cheaper than buying them already built so these too were designed and constructed to help cut down on overall costs.

The parts needed for building a single check valve include: (2) ¾" male PVC slip adaptor, ¾" PVC pipe (1½" long), ¾" acrylic ball, pin, and rubber O-ring. A 1/16" hole is drilled about 5/8" from the edge of the ¾" pipe. A pin is pushed all the way through the hole. The pin prevents the ball from freely rolling throughout the pipe and plugging both openings of the pipe. The O-ring is placed in one of the male slip adaptors and the acrylic ball is placed on top of the O-ring. Once these are in position, the pipe is primed and inserted into the adaptor to the point where the pin is covered by the pipe. The remaining male slip adaptor is glued to the open side of the pipe.

Two check valves were built and were threaded to the opening ends of the ¾" PVC FIPT × FIPT × FIPT tee on the hand pump mentioned in the pumping system section. This connection is shown in Figure 10.

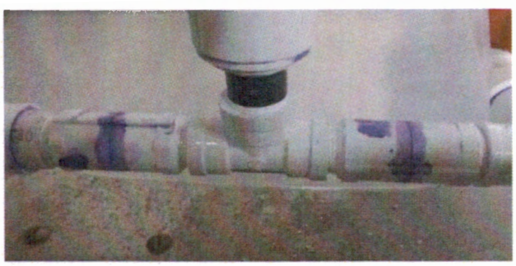


Figure 10. Check valves for inlet and outlet of hand pump.

Ball Valves. A single pump is being used to pump water from the settling tank to the UV purification tank and also for pumping and circulating the water within the UV tank during the cycle. These two different processes need to be sectioned so that only one is pumping at a time. Ball valves allow for either free flow within the pipe or blockage and restriction of any flow. These will be used within the plumbing to allow or restrict flow depending on if the UV tank is being filled before purification or being cycled during the process.

Four ball valves were purchased for the piping system. Two we placed before the first check valve, one on each side of tee before they join into a single pipe where the check valve is. Only one of these valves will be open at a time so that the inlet water comes from only one of the tanks. The placement of these can be seen in Figure 11. The third ball valve was placed on the side at the bottom of the UV tank where the water enters a pipe for the circulation during purification. This is opened after the UV tank is filled, the UV light is turned on, and the water is ready to be circulated. The valve is closed before the purification is over and all of the water is then pumped into the UV tank. This way there is no water left in the pipe and all of the water is in contact with the bulb before it is sent to the storage reservoir. The fourth and final ball valve was placed on the bottom of the UV tank where the water can be allowed to flow into the storage reservoir after it has been fully purified. It is then closed before the next cycle.

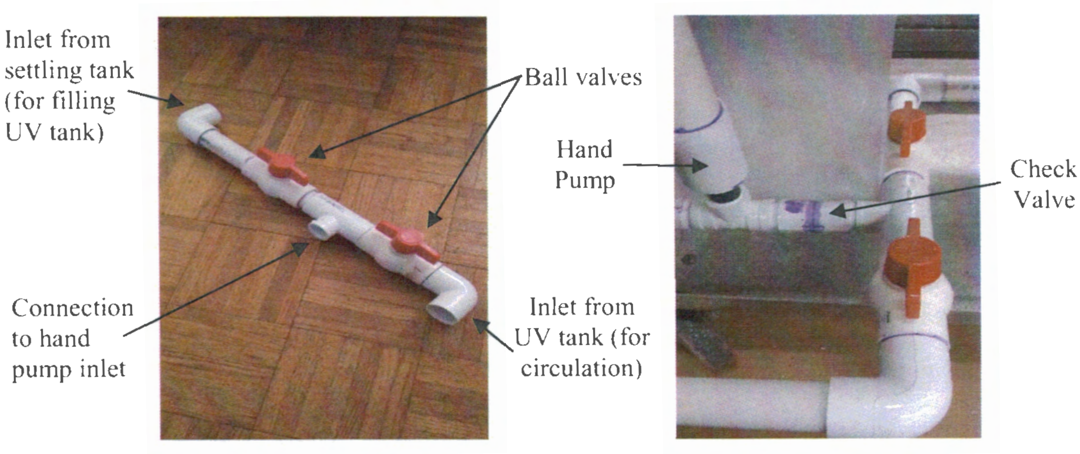


Figure 11. Ball valves for inlet water to the hand pump.

UV Tank. The tank was designed based on the amount of water desired to be produced for a day's worth of drinking water for a single family.

The ultraviolet bulb was purchased online. Hikari G10T8 - germicidal tube lamp with a medium Bi-Pin base was the selected bulb. The selection was based on the dosage and volume calculations found in Appendix B. The specifications of the bulb are: length is 12.99", 6000 life hours, wavelength of 254 nm, required wattage of 9.5 Watts, diameter is 1", and ultraviolet output is 2.7 Watts. The illuminated bulb can be viewed in Figure 12.

The actual length of the bulb that emits UV light is 12" long. The other 0.99" is the covered part of the bulb were the prongs extrude from both sides. This determines the

overall height of the tank to be 12" tall. To hold the desired amount of water per cycle, a 6" diameter pipe was selected for the tank. A 6" cap was placed on each end of the pipe. With the volume subtracted from the space the bulb occupies, the volume per cycle was calculated to be 1.96 gallons/treatment process. This is slightly less than the desired amount but the process is so quick that a second cycle can easily be completed.

A 6" pipe gives a light contact maximum distance of 2.5 in. or 6.35 cm. At this distance, the dosage at 30 seconds is measured to be 50.7 mW•s/cm^2. This is well over the maximum required dosage to kill the strongest type of bacteria which is 26.4 mW•s/cm^2. This time interval gives a dosage factor of safety of 1.92.

The center of the caps were drilled with a ⅝" drill bit. The UV bulb has the same width and was slid through the holes with the pins sticking out from the holes in the top and bottom caps. The pins stick out of the tank so that they can be connected to UV bulb bi-pin lamp holders which feed electricity to the bulb from the ballast.

The tank it fastened to the cart using three straps which will support the weight of the tank when it is filled with water. These straps are screwed to the middle shelf of the cart. The bottom strap is shown in Figure 12.

Figure 12. Tank holding straps and illuminated UV bulb.

<u>Settling and Storage Tanks</u>. The tanks were purchased online. The settling tank is a 2.5 gallon tank and the storage tank is a 5 gallon tank. The storage tank is bigger so that you can run through more cycles and store enough potable water for a few days. The settling tank doesn't need to be as large because water is added as it is needed. Both tanks sit on the bottom self of the cart.

A 1" hole was drilled on the side at the bottom of the settling time for a 1" pipe to fit in for the water to be pumped to the UV tank. A ¾" hole was drilled on the side at the bottom of the storage tank for a ½" spout to connect where the potable water is dispersed for consumption. All holes were sealed so that no leaking would occur.

Plumbing. The pipes used for the water transfer between the tanks are 1" PVC. The lengths were measured out and cut to match the distance between the hand pump and the tanks. PVC elbows were used where the pipe needed to change direction between the tanks and the hand pump and also to be extended vertically to reach the UV tank. All of the connections were glued together using purple primer and PVC cement.

Battery. The PV panels produce voltage in the form of a direct current (DC). A 12 volt DC battery is common and easy to find so it was selected for this system. This works properly for solar arrays. The battery is heavy and stays in place so it is placed on middle shelf without any type of fastener. There are two extruding prongs from the top of the battery. The red colored prong represents the positive charge connection and the black colored prong represents the negative charge connection. The connections have to complete a full circuit for the electrons to flow and the battery to function. The battery is connected to the charge controller and the inverter. The battery can be seen in Figure 13 within the ballast section below with these connections.

Charge Controller. A charge controller is used for a power system that charges a battery, such as photovoltaic panels. It keeps the battery properly fed by the power source and safe for reuse. The charge controller for this system is rated for a 12 volt, 30 amp power source. This fits with the battery selection previously made.

The shorter the connecting wires between the charge controller, battery, and solar panel array are, the better the charge controller will work. According to the device manual, the longest wire length to use can be up to 2 feet long. Strips of wire were cut for a direct and short connection length. Both ends of each wire were stripped to be attached to the devices. There were a total of four wires needed for the charge controller connections. A positive and negative connection runs to the battery and a positive and negative connection runs to the solar panel array. Each wire end was wrapped around and fastened securely with the screws provided on the controller. The charge controller can be seen in Figure 13 within the ballast section below.

Inverter. An inverter changes the voltage collected from a DC source to an alternating current (AC). This is needed for the UV bulb to work properly and generate the desired wavelength for the destruction of bacterial DNA structures. The inverter came with holes in the bottom plate already drilled out so that it could be fastened to the system. It was secured to the middle shelf of the cart by drilling ¼" holes in the cart and bolting it down. The inverter can be seen in Figure 13 within the ballast section below.

Ballast. The ballast was placed close to the inverter and the UV tank. One end of the ballast is wired to the outlet of the inverter where it gets the power from. The wires had to be attached to a plug for it to be plugged into the inverter. The other end is wired to two separate UV bulb bi-pin lamp holders. These lamp holders connect to the top and bottom pins of the UV bulb. The ballast can be seen in Figure 13.

Figure 13. Charge controller, battery, inverter, and ballast.

Wiring. 12-gauge wire is used for the connection between the solar panel, charge controller, and battery. 14-gauge wire is used for the connection between the battery and the inverter. The wire was stripped on the ends to expose the wire where is was going to be connected to the components. Electrical tape was used to cover all exposed wire to prevent anyone from touching them and getting shocked and to prevent a wire shortage if there is a water spill.

PV Panel Positioning System. A single photovoltaic panel generates power for the ultraviolet bulb and charges the battery while the bulb is not in use. The bottom of the solar panel is connected to an extending rod that allows the panel to be manually angled towards the sun depending on your location relative to the sun. The middle of the solar panel is attached to a rotating rod at the top edge of the cart. The rod allows the panel to rotate around that axis for positioning.

The extending rod consists of three PVC pipes of different sizes. The pipe sizes are 1¼", 1", and ¾". The pipes slide into each other which allows it to be extended out or contracted together. Holes were drilled 1" apart in all three pipes with a ⅜" diameter drill bit. A ⅜" pin fits in all of the holes and can be placed wherever is needed to lock the position of the mechanism. One pin is used to lock the large and medium pipe and another pin is used to lock the medium and small pipe. The bottom of the extending rod, the larger pipe, was drilled and bolted to two pieces of metal with a ⅜" bolt. The pieces of metal were bent and two ¼" holes were drilled on the other end to be bolted to the cart. The pipes partially extended and how the rod connects to the cart can be seen in Figure 14.

Figure 14. Extending rod for solar panel.

The rotating rod is a steel ⅜" rod that was cut to be 42" long. Two connectors had to be made for the rod so that it is held out from the cart and the solar panel would have room to rotate freely and still be attached to the cart. These pieces of steel were cut to be 2" wide and 4" tall. A ¼" hole was drilled at the bottom where it could be bolted to the cart. A ⅜" hole was drilled at the top where the steel rod could fit through and be held up. The pieces that were made to hold the rod were angled at 45° when bolted to the cart to allow the panel to be able to rotate the full 90° from the side of the cart to the top of the cart if needed. The rotating rod and connectors are shown in Figure 15.

The solar panel was lined up to the rotating rod and a ⅜" hole was drilled on each side panel of the solar panel. The rod was slid through the holes of the side panels and the connectors. When the solar panel was positioned, clamps were put on the rod on both sides of each connector to prevent the solar panel from sliding off and getting damaged.

Figure 15. Rotating rod and clamps for solar panel attachment.

<u>Final Project Picture</u>. The completed system can be viewed in Figure 16.

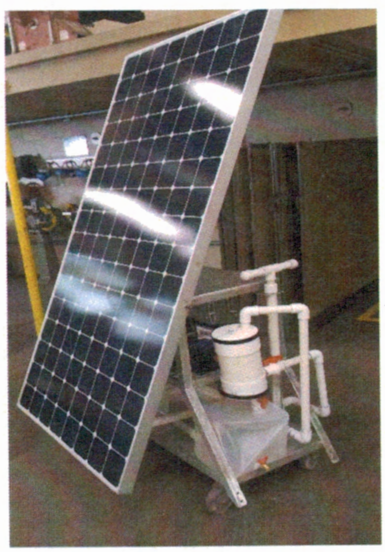


Figure 16. Completed water purification system.

RESULTS

Testing Procedure

There were four tests completed at the end of the construction process. The first was testing for leaks from any of the pipes or tanks. The second was testing how well the hand pump worked. The third was testing if the solar panel would charge the 12 V battery. The fourth was testing if the UV bulb would turn on and off by the switch on the inverter.

Water was added to the settling tank and it was inspected for any leaks. The hand pump was used to transfer water from the settling tank to the UV purification tank. The hand pump was inspected for any leaks or problems with actuating the pumping shaft. The hand pump was also used to cycle the water through the UV tank and was inspected again. The ball valve was opened at the bottom of the tank to let the water flow into the storage tank. The storage tank was checked for any leaks. All of the pipes were checked during the entire process to make sure all of the connections were cemented together properly.

The system was brought outside and the solar panel was positioned perpendicular to the sun. The charge controlled was turned on and the readings on the display were recorded. The charge controller was checked periodically to see if the battery was being charged by the solar panel.

Once the battery was charged up, the plug from the ballast was plugged into one of the inverter outlets. The power was switch on and the bulb was visually inspected to make sure it was producing a strong and constant source of light. The UV tank was closed back up and strapped to the cart.

DISCUSSION

Filtration System Cost Analysis

The system can be personalized and altered for the amount of water needed to be produced determined by the population size. The economic analysis of this system is based on the use of a single photovoltaic panel and a purification process producing about 2 gallons of potable water per session.

Table 1. Parts list and associated costs.

Part	System Cost	General Cost
Cart	Donated	~$40
Ultraviolet bulb	$10.51	$10.51
1¼" × 10' PVC pipe	$4.39	$4.39
1" × 10' PVC pipe (2)	$3.76 each	$3.76
¾" × 2' PVC pipe	$1.24	$1.24
1¼" × 1" PVC bushing, SPG × Slip	$0.97	$0.97
1¼" × 1" PVC coupling, Slip × Slip	$0.65	$0.65
1" PVC coupling, Slip × Slip	$0.43	$0.43
1¼" PVC slip cap	$0.78	$0.78
1" PVC slip cap (2)	$0.57 each	$0.57 each
1" PVC ball valve, Slip (4)	$5.41 each	$5.41 each
1" PVC 90° elbow (2)	$0.68 each	$0.68 each
1" PVC female adaptor, Slip × FPT (2)	$0.96 each	$0.96 each
¾" PVC female adaptor, Slip × FPT (2)	$0.42 each	$0.42 each
1" male adaptor, Slip × MPT (2)	$0.65 each	$0.65 each
¾" male adaptor, Slip × MPT – 10 pack	$2.36	$2.36
1" PVC tee, Slip × Slip × Slip (2)	$0.90 each	$0.90 each
¾" PVC tee, Slip × Slip × Slip	$0.97	$0.97
¾" PVC tee, FPT × FPT × FPT	$1.87	$1.87
¾" × 2" PVC riser	$0.51	$0.51
6" × 2' PVC pipe	$8.97	$8.97
6" cap (2)	$5.99 each	$5.99 each
PVC cement/primer combo	$8.27	$8.27
#218 O-ring - 10 pack	$2.27	$2.27
Distributor O-ring assortment – 12 pack	$4.99	$4.99
½" hose bibb valve, MPT	$5.98	$5.98
1" – 6" universal pipe hanger (2)	$2.48 each	$2.48 each
Bi-Pin UV lamp holders – 2 pack	$2.38	$2.38
120 V, 1 or 2 lamp T8 ballast	$13.97	$13.97
12 V, 30 Amp charge controller	Donated	~$80
Battery	Donated	~$110
Pro-1200W power inverter	Donated	~$75
1m × 2m SunPower photovoltaic panel	Donated	~$230

⅜” hitch pin (2)	$0.75 each	$0.75 each
⅜” universal clevis pins - 2 pack	$1.98	$1.98
Surround adhesive	$5.21	$5.21
48” × ⅜” round steel rod	$6.57	$6.57
48” × ¼” slotted angle zinc	$9.48	$9.48
2.5 gal tank	$14.99	$14.99
5 gal tank	$19.99	$19.99
Few small pieces of scrap metal	Free	Free
Total:	$149.82	$684.82
Tax (at 8.00%):	$11.99	$54.79
Final Total:	$161.81	$739.61

The total cost of the system that was designed and constructed resulted in $164.48. Since a few of the more expensive components were donated for the project, the cost of this system was greatly reduced. For an identical system to be built without any donations, the cost would be $577.80 more expensive. One of the main objectives of this project was to keep the price as low as possible and find any free parts or anything that can be made using cheaper parts instead of prebuilt devices. Devices that are prebuilt are more expensive. The idea was that people from third world countries could build a similar system as cheap and affordable as possible.

Design Changes

A few changes were made to the design during the construction process. As problems arose, changes had to be made to ensure the system would function properly.

The solar panel was initially designed to sit on the top shelf and use a supporting rod with a linear array of hooks along it to change the angle of the panel. The size of the panel would have made the supporting rod to be very log and stick out from the cart. This would make the cart more difficult to transport. The panel was moved to the side of the cart and supported by a rod that was attached to the top edge of the cart. The supporting rod became an extending rod and the pin and hole design replaced the hook design. This made the construction simpler, and easier for the operator to use.

The hand pump had to be moved to the side where the UV tank is positioned. The initial side that it was on would restrict the operator from using the pump during the purification process if the solar panel was angled closer to the horizontal axis. The panel would be directly above the handle of the pump and it couldn’t move vertically. On the side, the hand pump isn’t restricted by the angle of the panel.

The position of the settling and storage tanks were rearranged a few times. The design plan was to make the flow of water be as direct as possible. Both of these tanks were placed on the bottom shelf of the cart. The settling tank had to be close to the edge of the cart so that water could be poured into it. The storage tank was placed directly below the UV tank to take advantage of gravity and let the water flow into the storage by simply opening a valve.

RECOMMENDATIONS

The system design and construction was fluent and efficient. There were a few problems along the way but they were quickly solved. There are a few recommendations on the construction process and what could be added to make the system more durable and universal.

Cover panels could be placed on the sides of the cart with hinges. The cover would prevent weathering effects on the internal and electrical components. Since there are exposed electrical devices, rain could possibly damage the expensive equipment. The hinges would give access to the inside and still be able to turn the UV bulb off and on. There would have to be a slit in one of the side panels where the extending rod protrudes and can still move vertically.

The 6" pipe for UV tank could be longer to increase the total volume per cycle. This would decrease the amount of cycles needed to be completed and produces more potable water. Larger volumes of water would provide for larger families and give more security for future consumption. A longer pipe would also require the bulb to be longer so that the UV dosage is still consistent with the volume of water.

The holes that are drilled into the extending rod have to match up with every other hole. When the rod is either extended or contracted and the holes are lined up, they have to match perfectly for the pin to fit all the way through both holes of each pipe. To make sure the holes would line up, the pipes can be lined up with every configuration and made sure that the drill fits through each hole. This process takes more time but is more precise. Another method is to drill holes using a larger drill bit than a ⅜" bit. The holes are larger than the pin but it will for sure fit in each hole. When the pin is inserted and clamped, the size difference wouldn't make a significant difference.

The holes that are drilled in the caps of the UV tank for the bulb have to align from the top cap to the bottom cap, otherwise the bulb will not be able to slide all the way through the tank. The bulb isn't flexible so these holes have to align exactly.

Overall, this system can be altered and personalized to fit any size of family.

REFERENCES

AquaNetto. "Ultraviolet Irradiation." *Water & Air Treatment*. Conchita-plus, 2012. Web. May. 2014.

Clarke, Steven H. "Ultraviolet Light Disinfection in the Use of Individual Water Purification Devices." *U.S. Army Public Health Command*. U.S. Army Medical Department, Jan. 2011. Web. May 2014.

DaRo UV Systems LTD. "UV General Information." *About Uvwatertreatment.co.uk – UV Water Treatment Applications*. Daro UV Systems, 2010. Web. Apr. 2014.

Honsberg, Christiana, and Stuart Bowden. "Efficiency and Solar Cell Cost." *PVEducation*. N.p., Mar. 2013. Web. Apr. 2014.

Global Education Project. "Human Conditions." *Life Expectancy, Food and Hunger, Access to Safe Water, AIDS, Population, and*. Planet Earth, 2004. Web. May. 2014.

Jolapara, Kamlesh. "Energize Your Home with Solar Power." *Futureenergyblogcom*. WordPress, 16 Sept. 2014. Web. Sept. 2014.

UVP. "Pen-Ray® FAQ Sheet." *UVP, LLC*. Analytik Jena, 2014. Web. May 2014.

Weichenthal, Michael, and Thomas Schwarz. "Phototherapy: How Does UV Work?" *Photodermatology, Photoimmunology and Photomedicine* 21.5 (2005): 260-66. *Ultraviolet Disinfection*. Edstorm Industries, 2014. Web. May 2014.

APPENDIX A

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

Major Design Experience

The BRAE senior project must incorporate a major design experience. Design is the process of devising a system, component, or process to meet specific needs. The design process typically includes the following fundamental elements. This project addresses these issues as follows.

Establishment of Objective and Criteria. Project objectives and criteria are established to meet the needs and expectations of Dr. Schwartz for his Energy for a Sustainable Society class lab. See "Design Parameters and Constraints" section below for specific objectives and criteria for the project.

Synthesis and Analysis. The project will incorporate power conversion calculations, pumping design with calculations, and the consideration of alternate water cleansing methods.

Construction, Testing and Evaluation. The solar powered water cleansing system will be designed, constructed, tested and evaluated.

Incorporation of Applicable Engineering Standards. The project will utilize California Department of Water Resources' standards for allowable water quality and California Department of Public Health's standards for allowable water contamination.

Capstone Design Experience

The engineering design project must be based on the knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses). This project incorporates knowledge/skills from these key courses:

- BRAE 129 Lab Skills/Safety
- BRAE 133 Engineering Graphics
- BRAE 151 AutoCAD
- BRAE 216 Fundamentals of Electricity
- BRAE 234 Intro to Mechanical Engineering in Ag
- BRAE 320 Principals of Bioresource Engineering
- BRAE 348 Energy for Sustainable Society
- BRAE 421/422 Equipment Engineering
- ME 211/212 Engineering Statics/Dynamics
- CE 204/207 Mechanics of Materials/Strength of Materials
- ENGL 149 Technical Writing

Design Parameters and Constraints

The project addresses a significant number of the categories of constraints listed below.

Physical. The panels and system must fit into the BRAE labs. It must be easily assembled for a class lab and easily disassembled when the lab is completed. The water must meet the goal treatment level so it is safe to drink.

Economical. The cost of operation must not exceed the budget. The solar panels have been donated to the program. A student, with the help and direction of the professor, must be able to operate the system.

Environmental. A benefit of the project will be to treat polluted water and increase the amount of clean, reserved water in our society. The system will convert the contaminated water into clean and safe drinkable water.

Sustainability. The system will convert the contaminated water into clean and safe, drinkable water.

Manufacturability. N/A (every system is designed and scaled corresponding to the cite and amount of water needed at a period of time)

Health and Safety. The water system will consider water quality and standards accounting for the process of contaminated water, how many different types of contaminants need to be tested for and treated, and any health concerns associated with the water.

Ethical. N/A

Social. Interaction and communication between students.

Political. Reduced water pollution.

Aesthetic. The finished solar panel system will look will be designed and set up for easy accessibility and take up as little space as possible. The panels and system will collapse together for easy storability. The electrical wires will be covered and hidden for a more pleasant appearance.

Other - Productivity. The system must be able to pump water through the system and clean it to the classified standards. The cleaning process will need to be fast enough to be completed within a standard lab period.

APPENDIX B

DESIGN CALCULATIONS

Determination of tank size based on required dosage

	A	B	C	D	E	F	G	H	I
1	I(r) = (PL)/(2pi(r)*e^(-aer))								
2	PL (mW/cm) =			75					
3	Time (s)=			30					
4	ae (1/cm)		0.001	0.005	0.01		0.001	0.005	0.01
5	r (cm)	r (in)	I(r) (mW/cm^2)				Dose (mW-s/cm^2)		
6	0.63	0.25	18.8	18.9	18.9		564	566	568
7	1.27	0.50	9.41	9.46	9.52		282	284	286
8	1.90	0.75	6.28	6.33	6.39		188.3	190	192
9	2.54	1.00	4.71	4.76	4.82		141.3	142.8	144.6
10	3.17	1.25	3.77	3.82	3.88		113.1	114.6	116.4
11	3.81	1.50	3.14	3.19	3.25		94.3	95.8	97.6
12	4.44	1.75	2.70	2.75	2.81		80.9	82.4	84.2
13	5.08	2.00	2.36	2.41	2.47		70.9	72.3	74.2
14	5.71	2.25	2.10	2.15	2.21		63.0	64.5	66.3
15	6.35	2.50	1.89	1.94	2.00		56.8	58.2	60.1
16	6.98	2.75	1.72	1.77	1.83		51.6	53.1	55.0
17	7.62	3.00	1.58	1.63	1.69		47.4	48.8	50.7
18	8.25	3.25	1.458	1.507	1.57		43.7	45.2	47.1
19	8.89	3.50	1.355	1.404	1.468		40.6	42.1	44.0
20	9.52	3.75	1.265	1.314	1.378		38.0	39.4	41.4
21	10.16	4.00	1.187	1.236	1.301		35.6	37.1	39.0
22	10.79	4.25	1.118	1.167	1.232		33.5	35.0	37.0
23	11.43	4.50	1.056	1.106	1.171		31.7	33.2	35.1
24	12.06	4.75	1.001	1.051	1.116		30.0	31.5	33.5
25	12.70	5.00	0.952	1.002	1.067		28.6	30.0	32.0
26	13.33	5.25	0.907	0.957	1.023		27.2	28.7	30.7
27	13.97	5.50	0.866	0.916	0.983		26.0	27.5	29.5
28	14.60	5.75	0.829	0.879	0.946		24.9	26.4	28.4
29	15.24	6.00	0.795	0.845	0.912		23.9	25.4	27.4
30	15.87	6.25	0.764	0.814	0.881		22.9	24.4	26.4
31	16.51	6.50	0.735	0.785	0.853		22.1	23.6	25.6
32	17.14	6.75	0.708	0.759	0.826		21.2	22.8	24.8
33	17.78	7.00	0.683	0.734	0.802		20.5	22.0	24.1
34	18.41	7.25	0.660	0.711	0.779		19.8	21.3	23.4
35	19.05	7.50	0.639	0.689	0.758		19.2	20.7	22.7
36									
37			Need 26.4 mW-s/cm^2 to kill all types of bacteria and viruses						
38									

	K	L	M	N	O	P	Q	R	S	T	U
1											
2	Bulb length =			12 in							
3											
4			1 bulb					2 bulbs			
5	r (cm)	r (in)	Length (in)	Width (in)	Vol. (in^3)	Vol. (gal)		Length (in)	Width (in)	Vol. (in^3)	Vol. (gal)
6	0.63	0.25	12.0	1.50	12	0.05		12.0	3.00	66	0.29
7	1.27	0.50	12.0	2.00	25	0.12		12.0	4.00	132	0.57
8	1.90	0.75	12.0	2.50	49	0.21		12.0	5.00	217	0.94
9	2.54	1.00	12.0	3.00	75	0.33		12.0	6.00	320	1.39
10	3.17	1.25	12.0	3.50	106	0.46		12.0	7.00	443	1.92
11	3.81	1.50	12.0	4.00	141	0.61		12.0	8.00	584	2.53
12	4.44	1.75	12.0	4.50	181	0.79		12.0	9.00	745	3.22
13	5.08	2.00	12.0	5.00	226	0.98		12.0	10.00	924	4.00
14	5.71	2.25	12.0	5.50	276	1.19		12.0	11.00	1122	4.86
15	6.35	2.50	12.0	6.00	330	1.43		12.0	12.00	1338	5.79
16	6.98	2.75	12.0	6.50	389	1.68		12.0	13.00	1574	6.81
17	7.62	3.00	12.0	7.00	452	1.96		12.0	14.00	1828	7.92
18	8.25	3.25	12.0	7.50	521	2.25		12.0	15.00	2102	9.10
19	8.89	3.50	12.0	8.00	594	2.57		12.0	16.00	2394	10.36
20	9.52	3.75	12.0	8.50	672	2.91		12.0	17.00	2705	11.71
21	10.16	4.00	12.0	9.00	754	3.26		12.0	18.00	3035	13.14
22	10.79	4.25	12.0	9.50	841	3.64		12.0	19.00	3383	14.65
23	11.43	4.50	12.0	10.00	933	4.04		12.0	20.00	3751	16.24
24	12.06	4.75	12.0	10.50	1030	4.46		12.0	21.00	4137	17.91
25	12.70	5.00	12.0	11.00	1131	4.90		12.0	22.00	4543	19.67
26	13.33	5.25	12.0	11.50	1237	5.35		12.0	23.00	4967	21.50
27	13.97	5.50	12.0	12.00	1348	5.83		12.0	24.00	5410	23.42
28	14.60	5.75	12.0	12.50	1463	6.33		12.0	25.00	5872	25.42
29	15.24	6.00	12.0	13.00	1583	6.85		12.0	26.00	6352	27.50
30	15.87	6.25	12.0	13.50	1708	7.39		12.0	27.00	6852	29.66
31	16.51	6.50	12.0	14.00	1838	7.96		12.0	28.00	7370	31.91
32	17.14	6.75	12.0	14.50	1972	8.54		12.0	29.00	7907	34.23
33	17.78	7.00	12.0	15.00	2111	9.14		12.0	30.00	8463	36.64
34	18.41	7.25	12.0	15.50	2255	9.76		12.0	31.00	9038	39.13
35	19.05	7.50	12.0	16.00	2403	10.40		12.0	32.00	9632	41.70
36											
37			Volume needs to provide for a family of four. Each person drinks about 0.5 gal/day								
38			Vol. min ≈ 2 gal								
39			Pipe Inside Diameter = 6 in								

Volume of water being pumped

	A	B	C	D	E	F	G	H	I	J
46										
47	Shaft:		Length =	26	in					
48			Radious =	0.625	in					
49			Volume =	31.9	in^3					
50			=	0.138	gal/pump					
51										
52	Volume of UV tank=			1.96	gal					
53	# of pumps =			14	pumps					

List of Equations

Equation 1:

$$I(r) = \frac{PL}{2\pi r} e^{-aer} \qquad \text{(Clarke, 2011)}$$

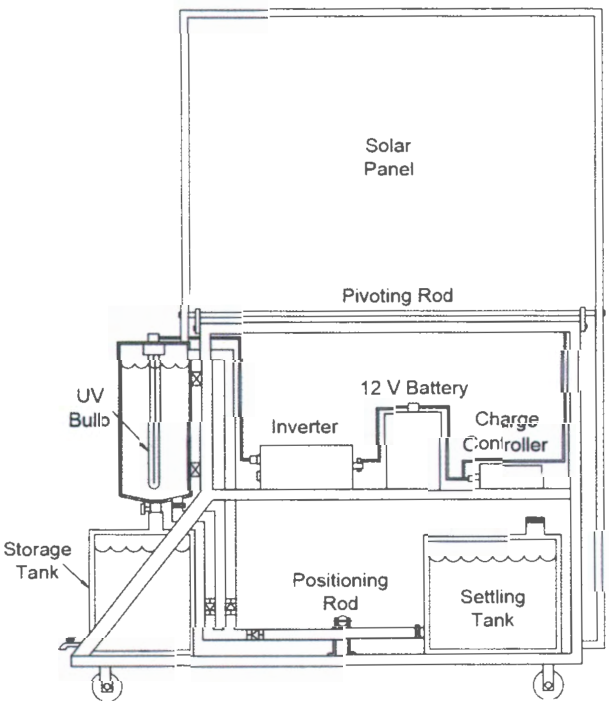
Where: I(r) = UV intensity at a distance (r) from the lamp (mW/cm^2).
PL = UV power emitted per unit arc length of the lamp (mW/cm).
r = Radial distance from the lamp (cm).
ae = Base absorption coefficient of the water (1/cm).

APPENDIX C

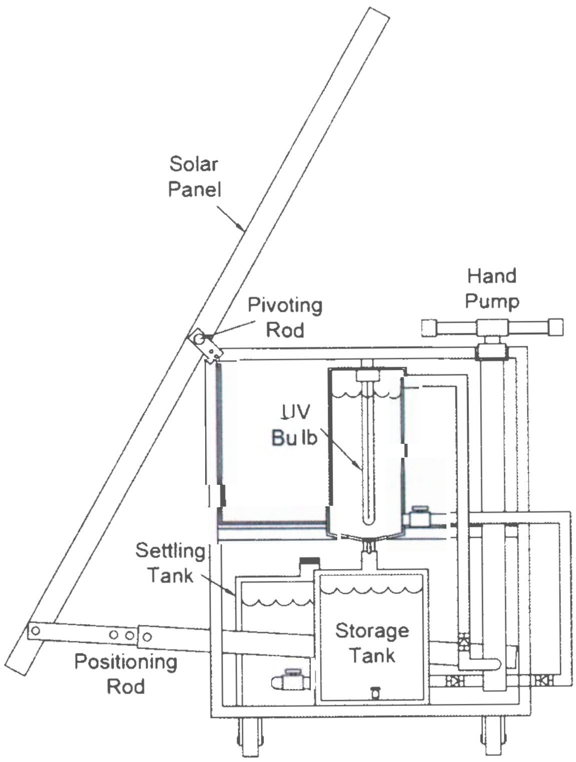
CONSTRUCTION DRAWINGS

Purification System

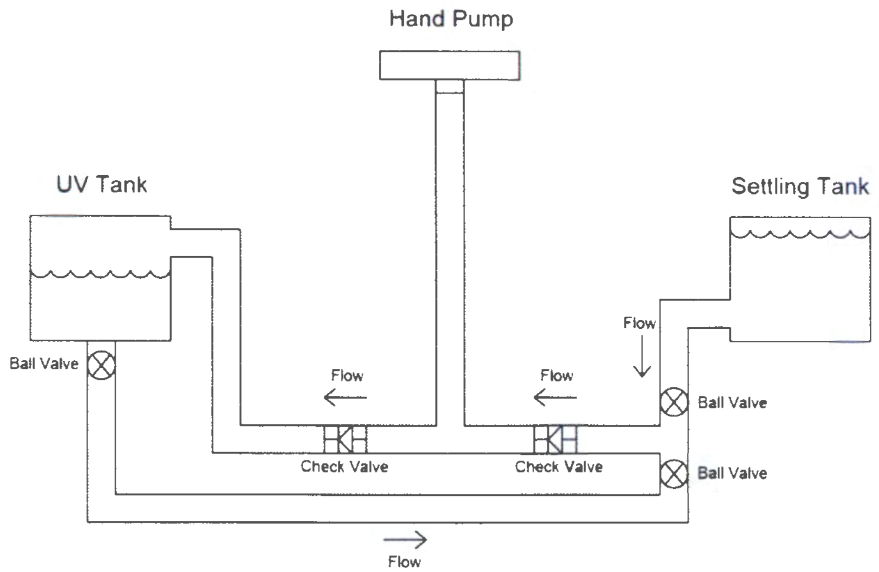
Side View



Front View



Hand Pump



Solar Panel Positioning System