

University of Wisconsin Madison

Engineering World Health: BrightWater Filtration

Biomedical Engineering

Clients: Dr. James Shropshire: University of Wisconsin Madison Dpt. Of Family Medicine

Advisors: Professor John Webster and Amit Nimunkar

Team Leader: Brad Lindevig

Communicator: Nick Shiley

BSAC: Karin Rasmussen

BWIG: Claire Wardrop

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Abstract

Water-related diseases are illnesses directly caused by consuming contaminated water. Although water-related diseases have largely been eliminated in developed nations, they remain a major concern in much of the developing world. Clean water is a pre-requisite for reducing the spread of water-related diseases. Our group has designed an innovative water purification system that is low cost, environmentally friendly, self-sustaining, efficient, and low maintenance. This design is currently targeted towards the Punta Gorda, Belize area but can be used in any region.

I. Introduction

Currently there are an estimated 1.1 billion people without access to purified drinking water, and 2.4 billion people living without adequate sanitation. Due to this lack of purified drinking water, many deaths worldwide result from consuming impure water. In a study by Lenntech (2004), an estimated 2,213,000 deaths occurred annually from water-related diseases. If safe drinking water was not made available, as many as 135 million people will die from water-related diseases by the year 2020 (Lenntech, 2004). These water-related diseases arise from human or animal feces, poor personal hygiene, parasites found in intermediate organisms, or insect vectors such as mosquitoes (Lenntech, 2004). Many of these deaths can be prevented with the introduction of a water purification system.

Popular methods for purifying water that are currently on the market are reverse osmosis, ultraviolet (*uv*) radiation, and chlorination. Osmosis occurs when fluids containing different concentrations of solute are separated by a barrier that is only permeable to water.

The uneven concentrations create an osmotic pressure gradient, and water flows from areas of low to high solute concentrations. As the name implies, reverse osmosis systems moves water from areas of high to low solute concentration. A semi-permeable membrane is inserted into the water system that contains pores that only allow molecules with a molecular weight under 100g/mol to pass through. Colloids, ionized salts, organic molecules, and certain bacteria are,



Figure 1: An example of a reverse osmosis system (APEC, 2011).

therefore, unable to enter the water system. Reverse osmosis is accomplished by creating a water pressure that is greater than the natural osmotic pressure created by the difference in solute concentration, and the filtered water that is free of bacteria and dirt flows into a separate piping system. Figure 1 shows a typical reverse osmosis system (APEC, 2011).

Ultraviolet light (uv) sterilization neutralizes hazardous bacteria using within a wavelength range of 200 to 300 nm. Impure water is exposed to uv radiation when flowing through a chamber containing a uv lamp enclosed in a protective quartz sleeve. Bacteria's DNA and RNA absorb the uv radiation at 254 nm. This interferes with DNA replication during cell division which causes the cell to be unable to proliferate.



Figure 2: An example of a UV Sterilization device (APEC, 2011).

Drawbacks of uv sterilization are that it does not remove dirt, minerals, or harmful chemicals. The water needs to be clear enough for the uv radiation to properly transmit through the water and affect the

bacteria. Finally, bacteria proliferate and grow back after exposure to uv is complete (Lenntech, 2011).

The chlorination method is considered the most effective type of sterilization. It is currently how tap water is purified in the U.S. (APEC, 2011). Chlorine kills bacteria by oxidizing their cell walls and disrupting their metabolic pathways. When chlorine is added to water, it follows the reaction: $Cl_2 + H_2O \leftrightarrow HOCl + HCl$. The hypo-chloric acid (HOCl) kills bacteria by oxidizing cell walls (GE, 2011). Not only does chlorine kill bacteria, it also removes ammonia, unpleasant tastes, reduces the color of the water, destroys organic matter, and oxidizes hydrogen sulfide, iron, and manganese (B&B, 2011).



Figure 3: An example of a chlorination device (APEC, 2011).

One major concern with the use of chlorine is the creation of the byproduct trihalomethanes (THM). It has been shown that THM can cause liver, kidney, and central nervous system problems, as well as increase the risk of cancer (Lenntech, 2011). According to the World Health Organization (WHO), chlorine is safe to use as long as it is used in concentrations less than 5 mg/L (Home Purifiers, 2011), but in the US it must remain under 4 mg/L (Lenntech, 2011).

Other concerns with the chlorinator, and other water purifications systems for that matter, is that they require replacement parts over time, chemicals and energy. Many of these items are expensive and difficult to order for citizens of developing regions around the world.

We have developed a prototype that demonstrates how to make a completely self-sustainable, affordable water filtration device that utilizes the sun's energy to purify water.

II. Design Criteria/Problem Statement

Our client, Dr. James Shropshire at the University of Wisconsin-Madison Department of Family Medicine, leads a group of medical students and other health care professionals on a medical mission trip every year to the developing region of Punta Gorda, Belize. The local clinic of Punta Gorda, called the Hillside Clinic, has an inadequate water filtration system and water filtration is non-existent in the surrounding regions. Dr. Shropshire provided multiple design criteria to purify the water supply at the Hillside Clinic:

1. The system must rid the water supply of bacteria, pesticides, viruses and other toxic chemicals comparable to other filtration methods.
2. It must be made from resources found locally in case the system requires repair it or an update. In order to incorporate this design into the local developing regions the water filtration system must be low maintenance and fairly simple to use.
3. The water filtration system design must be environmentally friendly.

III. *BrightWater* Prototype

The process of purifying water with the *BrightWater* prototype begins with impure water entering the main compartment, the 12.7 cm x 22.86 cm x 2.54 cm Plexiglas box, from a water storage tank as shown in figure 4. Plexiglas ridges spaced approximately 5 cm apart within the

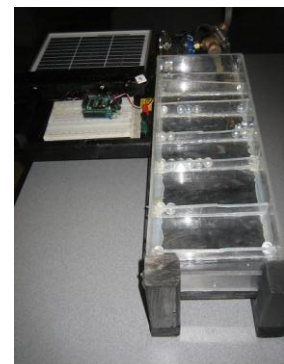


Figure 4: *BrightWater* prototype, main compartment seen on the right.

main compartment serve two purposes: to slow down the water flow to allow more purification time, and to hold the 6mm long, 2mm diameter, titanium dioxide (TiO₂) borosilicate resin glass beads in place.

TiO₂ degrades organic material by acting as a photo-catalyst to create hydroxyl radicals within the impure water when it reacts with *uv* radiation as shown in figure 5. The *BrightWater* prototype utilizes the sun as a *uv* radiation source. *Uv* radiation excites TiO₂, thereby freeing electrons from its conduction rings into its valence rings, this then creates a hole in the conduction ring (Sunada, 2002). TiO₂ is very unstable at this point so it searches for electrons to fill its hole. An electron from an H₂O molecule breaks free and fills the hole leaving behind reactive hydroxyl radicals (-OH) (Sunada, 2002).

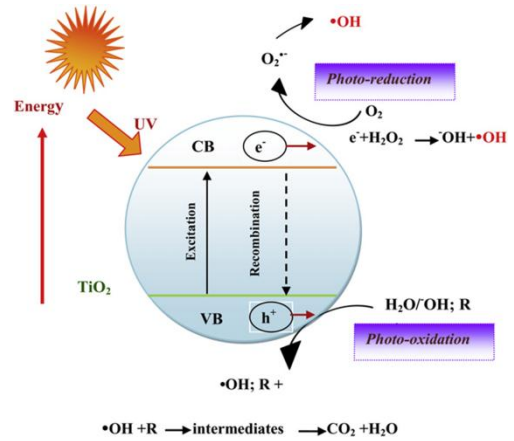


Figure 5: Schematic of TiO₂ and *uv* reaction (Ahmed, 2010)

Highly reactive hydroxyl radicals are oxidants meaning they successfully degrade organic contaminants in water. Hydroxyl and organic material reactions initially run at a lower rate and then speed up to a higher rate because the bacterial cell wall acts as a barrier to the reaction. The outer-membrane decomposes first. Subsequently, the reaction is carried inward, disordering the cytoplasmic membrane, thus destroying the bacteria (Sunada, 2002).

TiO₂ is ordered in a “nano” powder form at a size around 8 nm (Lenntech, 2009). The optimal results for purifying water of bacteria, pesticides, viruses and other chemicals can be

achieved by treating impure water in a sealed borosilicate glass compartment, filled with TiO_2 coated borosilicate glass resin beads. Borosilicate glass is necessary because it permits uv penetration.

One major advantage of TiO_2 coated borosilicate glass over chlorination and uv -radiation is that bacteria is decomposed without leaving any harmful by products. TiO_2 acts as a catalyst which means the coating does not wear off the borosilicate glass. This means the user does not have to recoat the borosilicate glass, thus reducing the cost of use over time as compared to replacing semi-permeable membranes as seen in the reverse osmosis technique.

In order to make the *BrightWater* automated, a correlation between the uv radiation available in the environment and the amount of impure water it can purify in the main compartment must be determined. Once this correlation is determined, a 5 W solar panel and arduino microcontroller regulate the amount of impure water that is released into the main compartment as shown in figure 6. This mechanism is meant to verify the proper amount of uv radiation is available in the surrounding environment to purify the specific volume of water in the main compartment.



Figure 6: Solar panel and microcontroller of the *BrightWater* system.

This process initiates when the solar panel converts ambient light into a Voltage. An assumption is made that the amount of ambient light and uv radiation is proportional;

however, a correlation can be determined with a uv detector incorporated with the microcontroller. The rectified voltage from the solar panel is sent to the arduino microcontroller where it compares the rectified voltage to a voltage threshold preset by the user. If the rectified Voltage surpasses the threshold, then the arduino microcontroller sends a 5 V pulse to a servo motor to open a water valve half a turn. This releases a certain amount of impure water into the main compartment to be purified. If the environment does not have sufficient uv radiation to purify the water in the main compartment, such as during the night or a really cloudy day, the microcontroller will not send the pulse and the water valve will remain closed.

IV. Methods

In order to ensure that the system purifies water, testing was done at the Water Science and Engineering Laboratory at UW Madison. The following procedure was followed for each experiment:

1. Prepare 4 sets of 3 (12 total) agar plates.
2. Take sample of raw lake water obtained from Lake Treatment building.
 - a. Dilute sample using deionized water at a 1:100 ratio
 - i. Place 4.5 mL of sterilized dH_2O in a vial.
 - ii. Add 0.5mL of the sample to the vial. This creates a 1:10 dilution. Mix the sample thoroughly to ensure equal distribution of the water.
 - iii. Place 4.5 mL of sterilized dH_2O in a new vial.

- iv. Add 0.5 mL of the 1:10 dilution to vial created in 2aiii. This creates a 1:100 sample. Mix the sample thoroughly to ensure equal distribution of the water.
 - b. Create 3 agar samples each with 100uL of the diluted lake water
 - i. Remove the water from the top of the agar container using a sterilized wand.
 - ii. Add 100 μ L of the 1:100 lake dilution onto the agar plate. Using the wand, evenly distribute the water onto the entire agar place to ensure equal bacteria distribution.
 - iii. Do not forget to label and date each plate.
 - c. Set aside and repeat steps 2a. and 2b. using the Lake Treatment purified water. Use step 2 as controls.
 3. Perform the *uv* control test.
 - a. Thoroughly wash Plexiglas box.
 - b. Set the box at a six degree angle. Place the *uv* lamp (115V, 0.17 amps, SW 254nm) 19.7 cm above the box running parallel to the box. The produces a *uv* radiation index of 2-5 on the main compartment.
 - c. Connect the funnel to the top of the valve. Insert tube connected the bottom of the valve into the hole at the top of the main compartment.
 - d. Obtain 1200 mL of raw lake water from the same source in step 2. Record the amount and use the same amount for every subsequent trial.

- e. Evenly distribute 15 marbles in the main compartment. 15 marbles corresponds to the same amount of volume taken up in the box as compared to the borosilicate glass beads.
 - f. Turn on the *uv* lamp and turn off all other light sources.
 - g. Pour the lake water into funnel and let run through box when the water valve is set at a half a turn.
 - h. Record the time it takes for the water to flow through the system.
 - i. Begin when water first enters the funnel.
 - ii. Stop when water first leave the box.
 - i. Obtain the sample midstream in a vial as it flows out of the bottom of the box.
 - j. (Optional) Let the water sit in the box for 20 minutes.
 - k. Collect a sample from the box.
 - l. Repeat Steps 2a and 2b to create agar plates of the midstream sample (and the 20 minute sample if taken).
4. Perform the TiO_2/uv test.
 - a. Repeat steps 3a – 3i but replace the marbles with TiO_2 covered beads.
 5. Perform regrowth tests.
 - a. Place the *uv* sample and TiO_2/uv samples in a secure location overnight.
 - b. Return the next day and repeat steps 2a and 2b for each sample.
 6. Incubate all samples for 5 days. Count and record the number of bacteria colonies on the fifth day.

V. Results

The results from the preliminary bacterial viability testing can be seen in (Figure 7). Pure water had the smallest average number of bacteria colonies with 128. The averages for raw lake water, *uv* only and *uv* with TiO₂ are 5293, 6125, and 5289 respectively (actual numbers can be found in the appendix). The collected data was not statistically significant in providing evidence that TiO₂ kills bacteria at a different rate than only *uv* radiation (p-value = 0.589).

As for the bacteria regrowth experiments, there appears to be less bacterial regrowth for the TiO₂ purified water when compared to the *uv* only water, as seen in figure 8, however, there were too many bacterial colonies to count.

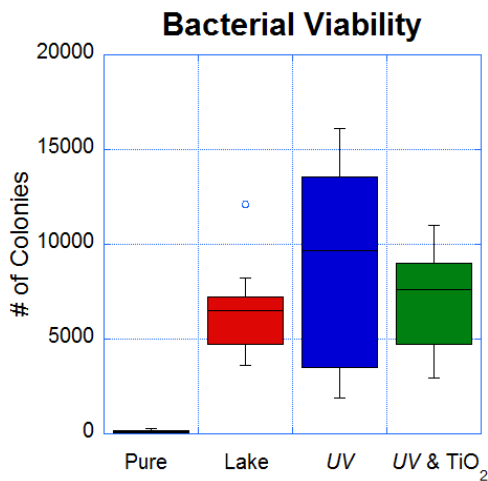


Figure 7: TiO₂ + *uv* and *uv* effect on bacterial viability using *BrightWater* prototype. Averages: Pure = 128, Lake = 5293, UV = 6125, UV & TiO₂ = 5289



Figure 8: TiO₂ + *uv* (left) and *uv* (right) effect on bacterial regrowth using *BrightWater* prototype.

Table 1 shows the amount of time each sample took to pass through the main compartment when the valve was a half a turn open.

Experiment Type	Time (Seconds)			
	Trial #1	Trial #2	Trial #3	Average
Control (No marbles or borosilicate glass beads)	82	-	-	82
<i>Uv</i> /TiO ₂ (Borosilicate glass beads)	196	245	256	232
<i>Uv</i> (Marbles)	196	214	226	212

Table 1: Water flow rate calculations for *BrightWater*

Each sample was exposed to *uv* radiation for approximately 4 minutes for each experiment.

VI. Conclusion

The coated beads and marbles were handled with hands and thus, had different amounts of bacteria present at the start of the experiments. Also, the volume of the marbles and beads were set to be equal, but this resulted in the surface area being unequal. The coated beads had a larger surface area in contact with the water. Lastly, the water samples were all diluted at a 1:10 ratio for the first set of experiments making it difficult to count the bacteria accurately. More bacteria viability experiments are needed. The experiment procedure needs to be refined in order to obtain more accurate data.

VII. Future Work

The next main step for continuing with the *BrightWater* purification system is to order a custom made borosilicate glass cover to seal shut the main compartment. Theoretically, the system needs to be air tight in order to kill the bacteria and organics the most effectively and efficiently. Also, the water valve will be replaced with a 12 V water solenoid valve for more accurate turns per Voltage. Upon replacement, the valve will be relocated to the bottom of the main compartment. This will allow for more control of the water purification rate. For example, if a cloud were to pass by mid-day and the UV radiation level decreased suddenly, the water in the tank would remain in the tank.

In the future the system is going to be self sufficient. In order to accomplish this, the system will incorporate a rechargeable car battery with the solar panel. The car battery will act as the power source for the motor and microcontroller. In doing so, the solar panel will then be bifunctional; it will monitor the UV intensity via correlation to ambient light and will supply the energy to recharge the battery. The microcontroller and valve will be dynamic with the amount of UV radiation available in the environment.

VIII. References

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IX. Appendix

Materials

- Funnel
- Water Valve
- Tubing to connect the valve to the system
- Plexiglas box with ridges
- TiO₂ coated borosilicate resin beads
- Marbles (quantity should be adjusted so that total volume of the marbles is the same as the total volume of the beads)
- *Uv* lamp
- 12 agar plates
- Glass vials
- Sterilized deionized water
- Lake water from Lake Mendota
- Purified water from the UW Madison Water Treatment plant

X. PDS

Product Design Specifications: PDS

Engineering World Health (EWH) Water Filtration Project

Team Roles:

Team Leader: Brad Lindevig

Communicator: Nick Shiley

BSAC: Karin Rasmussen

BWIG: Claire Wardrop

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Problem Statement:

Many people in developing regions around the world have either limited access or one at all to purified drinking water due to contaminated water sources. This problem results in preventable diseases and even death. Water filtration systems are necessary to rid the local water from bacteria, pesticides and viruses. In order to make these systems effective in the respective regions they must be made from material found near the region of interest, require low maintenance and be efficient.

Function:

Our design filters dirt particles, bacteria, pesticides and other toxic chemicals from water. It is completely self-sufficient because it uses solar energy and a photo-catalyst.

Client Requirements:

- Sterilizes water found all around the world.
- Can transport the device, or sterilized water to rural regions of developing countries

Design Requirements:

1. Physical and Operational Characteristics

- Performance Requirements:** Must produce purified water at an efficient rate. The water will be used to drink from and clean infections and wounds.
- Safety:** It must clear the water of bacteria such as giardia and e-coli, pesticides and other toxic chemicals.
- Accuracy and Reliability:** A system must be in place to measure the purity of the water from time to time.
- Life in Service:** Must last at least a year in service. Health professionals are only able to make one trip a year to developing regions. If it breaks down we cannot expect the people there to fix it no matter how easy it is.
- Shelf Life:** Storing the product will have no effect on its ability to perform.
- Operating Environment:** This device will be used in developing countries around the world, specifically outside on the sides of houses.
- Ergonomics:** The device should be able to be operated by an untrained adult, but settings should be determined by a professional.
- Size:** The device should be compact and easily portable.
- Weight:** The device should be light enough to be lifted by a child.
- Materials:** The device should utilize materials that can be found in the area it is used in.
- Aesthetics, Appearance, and Finish:** Not applicable.