Engineering World Health Water Filtration Project

Mid-semester Report

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Abstract

Contaminate drinking water causes diseases and death around the world every year, especially in developing regions. All water born diseases and deaths are preventable with proper water purification systems. Here, we present an innovative water filtration system that is low cost, environmentally friendly, self-sustaining, efficient and low maintenance. This design is currently targeted to give the residents Punta Gorda, Belize, an adequate water filtration system.

Introduction/Background

Presently, 17.6 milliion people worldwide die every year due to inadequate access to clean water. These preventable deaths are due to contaminated drinking water and overall hygiene. The people most affected by these statistics live in poverty-ridden, developing countries, and in rural areas. Many of these deaths can be prevented with the introduction of a simple and effective water purification system (1).

Common water contaminants include bacteria, viruses, and various chemicals such as nitrates, sodium, sulfates, manganese, and iron. Common bacteria that are found in the water supplies are E.coli, Giardia, Cyptospridia, and Entamoeba, well as bacteria that cause cholera, campylobacteriosis, and leptospirosis. Although not much can be done with the removal of viruses from the water supply, interventions can be taken to remove harmful bacteria and chemicals (1).

Current methods of purifying water utilize techniques such as 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 concentration of solute to high concentration. As the name implies, reverse osmosis does the opposite and water moves from areas of high concentration of solute to low. A barrier 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 therefore unable to enter the water system. Reverse osmosis is accomplished by creating a water pressure greater than the osmotic pressure. The water pressure is high enough to overcome the osmotic pressure created by the difference in solute concentration, and the filtered water free of bacteria and dirt flows into a separate piping system. Figure 1 shows a typical reverse osmosis system (2).

Figure 1: An example of a reverse osmosis system (2).

UV sterilization uses ultraviolet light within the wavelengths of 200 to 300 nm to neutralize hazardous bacteria. The water is exposed to radiation by flowing through a chamber containing a UV lamp, which is enclosed in a protective quartz sleeve. As bacteria flows past the light, it's DNA and RNA absorbs the UV radiation at 254 nm. This interferes with DNA replication during cell division causing the cell to be unable to reproduce. The bacteria are now no longer considered a threat. The drawbacks of UV sterilization are that it only kills bacteria, it does not remove dirt, minerals, or harmful chemicals, and the water needs to be clear enough for the radiation to properly transmit through the water and affect the bacteria (3).

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

The chlorination method is considered the most effective type. It is currently how tap water is purified in the U.S. (2). Chlorine kills bacteria by oxidizing their cell walls and disrupting their metabolic pathways. When chlorine is added to water it follows the reaction $Cl2 + H20 \leftrightarrow HOCl + HCl$. As shown in this formula, hypochlorous acid (HOCl) is formed, which oxidizes the cell walls (1). Not only does chlorine kill bacteria, it also removes ammonia and unpleasant tastes and odors; reduces the color of the water; destroys organic matter; and oxidizes hydrogen sulfide, iron, and manganese (4).

The amount of chlorine added, the pH and temperature of the water, and the contact time between the water and the chlorine affect the ability of the chlorine to kill bacteria. The effectiveness of chlorine can be altered by adding more chlorine or increasing the contact time. Typically, a concentration of 2 to 3 mg/L is used. The pH of the system should be maintained between 6 and 7 in order for the chlorine to react properly with the water (5). The World Health Organization has determined that chlorination is most effective at a residual concentration greater than 0.5 mg/L after 30 minutes of exposure time at a pH less than 8 (2).

One concern with the use of chlorine is the creation of trihalomethanes (THM) as a byproduct. It has been shown that THM can cause liver, kidney, and central nervous system problems, as well as increase the risk of cancer (3). According to the World Health Organization, chlorine is safe to use as long as it is used in concentrations less than 5 mg/L (5), but in the US it must remain under 4 mg/L (3). Because chlorine is more effective the longer it is contact with the water, the concentration of chlorine and the possible hazardous risks of THMs, can be reduced by increasing contact time (2).

Two different modes of chlorination are currently in use. One type uses dry pellets of chlorine. The chlorinator is mounted on the well and electrically connected to the well's pump system, allowing it to supply chlorine in proportion to the amount of water being used. When prompted, the chlorinator drops a pellet into the well water, where it dissolves and releases chlorine. See Figure 3 for a picture of a device that uses this method (6).

The other type uses liquid chlorine. After water leaves the well, chlorine is injected into the water and enters a large storage tank allowing for proper amount of contact time. Chlorine is injected based on the flow rate of the water leaving the well. After a proper amount of time in the tank, which varies between different brands, the water enters the pressure tank of the water system. Usually, the chlorine level of the water is sampled before and after the retention tanks to ensure that the correct amount of chlorine enters the system.

Figure 3: An example of a chlorination device (2).

Design Criteria/Problem Statement

Dr. Shropshire leads a group of medical students and other health care professionals on a medical mission every year to the developing region of Punta Gorda, Belize. The local clinic of Punta Gorda, 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. The system must rid the water supply of bacteria, pesticides, viruses and other toxic chemicals comparable to other filtration methods. It must be made from resources found locally in case the system requires a part to repair it or update it. In order to incorporate this design into local developing regions, the water filtration system must be low maintenance and fairly simple to use in to ensure long term use. Finally, our water filtration system design must be environmentally friendly.

Researched Method of Purification

The following innovative purification method we will employ has been thoroughly researched and offers a more simplistic, low maintenance, low cost way to purify water as compared to current methods. Titanium Dioxide (TiO2) catalyst inactivates organic materials. UV light excites TiO2 and causes charge separation generating very reactive hydroxyl radicals (·OH) and free oxygen radicals. The hydroxyl radical is an oxidant, and thus, it successfully degrades organic contaminants in water (Figure 4). It is ordered in a "nano" powder form at a size around 8 nm (2). The optimal results for purifying water of bacteria, pesticides, viruses, and other chemicals can be achieved by treating the contaminated water in TiO2 coated, approximately 1 μm thick, sealed borosilicate (Pyrex) glass. Borosilicate glass is necessary since this type of glass allows for UV penetration.

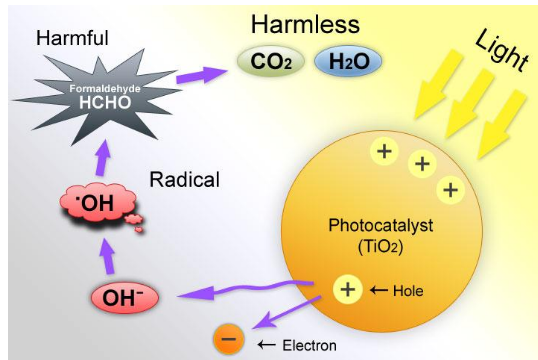

Figure 4: Schematic of TiO2 reacting with UV light and water (11).

One major advantage of TiO2 coated borosilicate glass over chlorination and UV-radiation is that bacteria is decomposed without leaving any harmful by products. Because TiO2 acts as a catalyst, the coating does not wear off the borosilicate glass. This means the user does not have to recoat the borosilicate glass, which reduces the cost of use over time when compared to having to replace semi-permeable membranes like the reverse osmosis technique (12).

The TiO2 catalyization involves two steps. The reaction starts out at an initial lower rate, and then speeds up to a higher rate. The difference in rates is due to the cell wall of the bacteria because it acts as a barrier to the reaction. The outer-membrane decomposes first, and then the reaction is carried inward, disordering the cytoplasmic membrane, thus destroying the bacteria (7).

Design #1

The simplest technique to purify contaminated water with TiO2 is to fill TiO2 coated plastic water bottles and leave them exposed to sunlight for a certain period of time (Figure 5). It is also possible to coat plastic with TiO2 and not just borosilicate glass. For example, a citizen of a developing region can fill multiple TiO2 coated water bottles with contaminated water and put them on top of a roof for a certain period of time depending on the volume of water. A large shipment of these TiO2 coated water bottles could last a long time in a small region.

Figure 5: Example of water bottles coated with TiO2.

One drawback to this system of water purification is that plastic water bottles degrade over a period of time (8). This suggests two concerns. First, is that when the plastic degrades what kind of chemicals does it put into the water and secondly, more TiO2 coated water bottles will have to be ordered assuming that region does not have the proper equipment to coat water bottles with TiO2. Another major drawback is that most developing regions around the world do not have proper recycling making this system not environmentally friendly.

Design #2

A water filtration system utilizes a TiO2 coated borosilicate glass cylinder to contain the reaction of the contaminated water. TiO2 is similar to the water bottle design; however, it addresses many of the problems. Borosilicate glass will degrade at a much slower pace as compared to plastics. Putting TiO2 borosilicate glass increases the surface to volume ratio allowing most of the water within the cylinder will react with TiO2 (Figure 6).

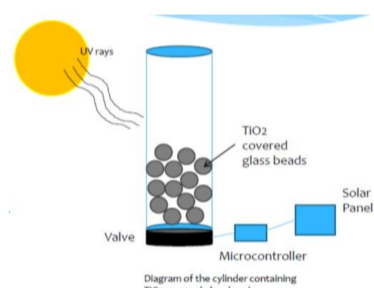

Figure 6: Diagram of the cylinder containing TiO2 coated glass beads

A solar panel monitors the amount of UV light available in the environment. Once there is enough UV light available to purify the specified volume of water within the cylinder, the voltage rectified by the solar panel will initiate a timer within a microcontroller. After a certain amount of time has passed, as determined by experimentation, the microcontroller releases the purified water from the cylinder by completing the circuit from a 12V battery to a solenoid water valve. The water valve will open for a certain amount of time to drain the purified water, and then close in time for the next round of purification.

The 12 Volt battery is recharged by the solar panel when the system is not in use, thus making the overall water purification system self-sufficient and environmentally friendly. Due to its small size, it is convenient to hang on the side of a house or set up at the local well. All components of this device are inexpensive as compared to current methods of water filtration systems.

One drawback to this system is that when the contaminated water is in the cylinder it is stationary. There is no way to verify that all of the contaminated water will interact with the TiO2. The system also requires the user to individually pour contaminated water into the cylinder, one volume of contaminate water at a time, making the entire system inefficient as compared to current methods.

Design #3

This design utilizes a stable platform with ridges to act as a trickle down system. A plexyglass platform will be lined with one layer of TiO2 coated borosilicate glass beads. The plexyglass ridges are secured to the platform to slow the incoming contaminated water down and maximize the surface to volume ratio of contaminated water to TiO2 (Figure

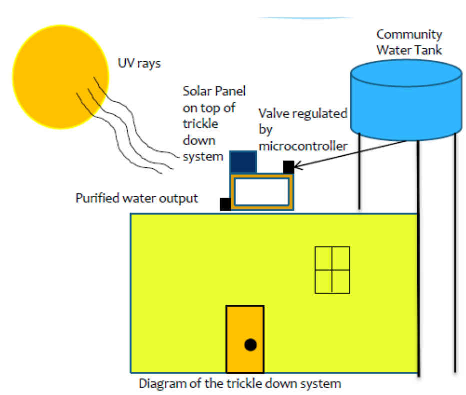

Figure 7: Diagram of the trickle down system implemented in Punta Gorda Belize.

7). It is similar to a creek flowing over a bed of rocks. The UV light is monitored by a solar panel and the valve is controlled by the microcontroller as described previously.

This system is completely self-sufficient, low maintenance and efficient. The flow rate can be measured by experimentation and correlated to the amount of UV light needed to purify a certain volume of water.

One drawback to this design is that it is cumbersome, meaning it will need a stable structure to rest upon at all times. In order to have continuous flow of water there needs to be a water source available, such as a local water holding tank. There also must be a system in place to pump the contaminated water from the water source into the trickle down system.

Design Matrix

A design matrix was created to assess which design alternative should be further researched. Each design was weighted accordingly in a certain category that relates to the problem statement (Table 1). Based upon the scores the trickle down system resulted in the highest score. The deciding factors between using the trickle down system as compared to the glass cylinder were the usability and effectiveness. The trickle down system offers a way to automatically deliver purified water without having to physically pour contaminated water into a system. This allows for a more accurate and efficient way to purify water.

Design	Simplicity (10)	Effectiveness (20)	Usability (10)	Reliability (20)	Total (60)
Plastic bottles	10	16	3	16	45
Borosilicate Glass Cylinder with Borosilicate Glass Beads	8	17	6	18	49
Trickle Down System	7	19	8	18	52

Table 1: Design Matrix

Future Work

In order to program the microcontroller to release only clean, safe water, we need to test the rate of purification for the coated glass. The amount of UV necessary to successfully kill the bacteria needs to be experimentally calculated. To do this, water will be collected from Lake Mendota. A gram positive test will be run on the lake water prior to any purification treatment to affirm the presence of bacteria. 100mL of water will be partitioned and put into a non-coated borosilicate glass dish and subjected to UV light for one hour to see if any bacteria is killed using simply the UV light. Next, 100mL of water will be placed inside the coated borosilicate dish and subjected to the same UV light conditions used for the control. A sample of water will be taken every 15 minutes for two hours. Each sample will be inspected under a microscope and the bacteria will be counted. From this information, we are expecting to be able to tell the rate at which the bacteria are degraded at the set UV intensity.

A gram stain test is a differential stain. Gram positive bacteria cell walls have a strong desirability for crystal violet after the application of iodine. They will retain the violet color after rinsing with ethyl alcohol. The color is obtained by the cell wall (9). Therefore, if the bacteria are indeed degraded via TiO_2 reaction, the test would show no signs of bacteria.

In order to compare the results of the trickle down system experiments to results from a chlorinator, a custom built chlorinator must be made. Liquid chlorine instead of pellets will be used as the method of chlorination because it is more flexible mode of delivery than pellets, allowing the amount of chlorine added to be varied easier. This is an important characteristic because the actual amount of chlorine that will be added is based on the starting quality of the well water, the flow rate of the system, and the length of time the water sits in the holding tank, which will be determined once at the clinic. Also, liquid chlorine is more accessible than pellets and cheaper.

The downside of using liquid chlorine is that the chlorine breaks down over time so the liquid would become less concentrated and therefore less effective. The breakdown process is enhanced by increased temperatures. This issue can be decreased by storing the main supply inside the clinic, and periodically refilling the tank that supplies the water system. Another concern is that when mixed with acids, toxic chlorine gas will be created. This can be avoided by ensuring that the chlorine is not stored near acid.

In the water system at the clinic, water is pumped from a well into a 200 gallon holding tank on top of the clinic. From there, water is pumped down into the clinic as needed. The chlorinator will be on the roof along with the holding tank and will be implemented before the water enters the holding tank. See Figure 4 for a diagram of the system. This placement allows the holding tank to act as the holding tanks adequate contact time between the chlorine and the water. The chlorinator will consist of a jug containing a sealable top, a valve, piping, PVC piping, and a corkscrew. The jug will contain the chlorine, and the removable top will allow the jug to be refilled. The valve will release a small constant drip of the chlorine into the system. The different levels of the valve opening allows adjustment of the drip rate, which will ensure a concentration of 2 mg/L of chlorine is maintained in the water. The chlorinator will sit on top of the piping, which will connect it into the water system. The corkscrew will sit horizontally in the piping and will mix the chlorine with the water.

References

1. Water Supply, sanitation and hygiene development. 2011. World Health Organization. 23 February 2011 <http://www.who.int/water_sanitation_health/hygiene/en/>.

2. Water Treatment Chemicals. 2009. Lenntech. 10 February 2011 <www.lenntech.com/products/chemicals/water-treatment-chemicals.htm#Disinfectants>.

3. Ultraviolet Water Purification – UV. 2010. Home Water Purifiers and Filters. 12 February 2011 <http://www.home-water-purifiers-and-filters.com/ultraviolet-filter.php>.

4. Integrated Water Solutions. GE Power and Water. 6 February 2011 < http://www.gewater.com/index.jsp>.

5. Free Drinking Water. APEC. 3 February 2011 <http://www.freedrinkingwater.com/water-education/quality-water-purification.htm>.

6. How a Dry Pellet Chlorinator Works. 2009. B & B Chlorination. 13 February 2011 < http://www.bbchlor.com/how.htm>.

7. Sunada, K., T. Watanabe, and K. Hashimoto. "Studies on photokilling of bacteria on TiO2 thin film." Journal of Photochemistry and Photobiology. (2002).

8. Xu Z. Zongwei L. Yi C. Liyi S. and Yongfa Z. 2008. "Enhancement of photocatalytic degradation of polyethylene plastic with CuPc modified TiO2 photocatalyst under solar light irradiation." *Applied Surface Science.* Vol 254 (6):1825-1829.

9. Rapp, Lisa Ph.D. "Biotechnology." 20 February 2011 < http://faculty.stcc.edu/rapp/>.

10. Stenner. 2011. Clean Water Store. 17 February 2011 <http://www.cleanwaterstore.com/stenner-chlorinator.html>.

11. TouchClean Anti Bacterial Finish. James Gibbons. 26 February 2011 <http://www.jgf.co.uk/touchclean.htm>.

12. Jafry, H.R., M.V. Liga, Q. Li, A.R. Barron. "Simple Route to Enhance Photocatalytic Activity of P25 Titanium Dioxide Nanoparticles by Silica Addition." Environmental Science & Technology. December 2010.

Appendix/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
Last Update: March 3rd, 2011
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
a. **Performance Requirements:** Must produce purified water at an efficient rate. The water will be used to drink from and clean infections and wounds.
b. **Safety:** It must clear the water of bacteria such as giardia and e-coli, pesticides and other toxic chemicals.
c. **Accuracy and Reliability:** A system must be in place to measure the purity of the water from time to time.
d. **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.
e. **Shelf Life:** Storing the product will have no effect on its ability to perform.
f. Operating Environment: This device will be used in developing countries around the world, specifically outside on the sides of houses.
g. **Ergonomics:** The device should be able to be operated by an untrained adult, but settings should be determined by a professional.
h. **Size:** The device should be compact and easily portable.
i. **Weight:** The device should be light enough to be lifted by a child.
j. **Materials:** The device should utilize materials that can be found in the area it is used in.
k. **Aesthetics, Appearance, and Finish:** Not applicable.

2. Production Characteristics
a. **Quantity:** Our team will be developing one water filtration device.
b. **Target Product Cost:** $100
3. Miscellaneous
a. **Standards and Specifications:** Not applicable
b. **Customer:** The client wants to be able to either transport sterile water long distances or have a portable device that sterilizes water on the spot.
c. **Patient-related concerns:** Not applicable
d. **Competition:** Not applicable