PureWater: A Water Purification System for Developing Countries

PureWater

Sriram Murali

Murali Ramasubramanian

Mission San Jose High School

PureWater

Abstract: 780 million people around the world do not have access to clean water, forcing them to drink contaminated water, and often exposing them to waterborne diseases. Providing easy and convenient access to potable water for these communities will promote better health and well being. This paper describes a simple, inexpensive, and long-lasting system for the purification of contaminated water. This device will allow a user to pour contaminated water into a funnel, and immediately collect clean water from an output valve into a second container. Contaminated water is sent through a sediment filter to remove particulate residue and an ultraviolet bulb to kill organic contaminants. The device consists of a pair of lead acid batteries that are charged by a solar panel, which allows the device to function without access to the electrical grid. For mobility and ease of use, the device is mounted on a cart, which can be moved to receive optimal sunlight. One unit can supply 50 people with one gallon of potable water daily, lasting ten years with minor maintenance. This system combines readily available and inexpensive components into a practical solution that solves a fundamental worldwide problem. This devices addresses the needs of people with limited access to resources such as clean water and electricity.

Idea: Millions of people around the world do not have access to a clean water source (WHO, 2019). This lack of clean water gives those millions of people no other choice but to drink untreated water, leaving them vulnerable to waterborne diseases. Most current methods are either expensive, impractical, or of only one-time use. An ideal method would allow the user to purify an indefinite amount of water in a limited period of time, and with minimal required maintenance. Boiling water is a common and easily accessible method of purification. This removes almost all live contaminants from the water, but not other inorganic contaminants.

Boiling water is energy inefficient and the water needs time to cool before it is drinkable. This waiting period often causes the water to become re-contaminated. Another common purification method is carbon filtration, in which water is sent through activated carbon: a thin layer of carbon with an extremely high surface area to volume ratio. Particulate matter in the water gets stuck in small pockets of the carbon powder, allowing only clean water to pass through. While this method removes both organic and inorganic contaminants, it suffers from two major drawbacks that prevent it from being easily implemented worldwide: a need for pressurization to provide a reasonable throughput of water and a need for frequent replacement of the filters due to clogging and decreased effectiveness. Chlorine tablets and iodine drops are also used for water purification; however, the limited accessibility of these cleaning elements renders this method impractical. UV light-based purification systems use ultraviolet light to purify small quantities of water, which limits the system from being used for cooking and cleaning. The UV systems also need electricity, which is generally not available in areas with a lack of clean water.

In the proposed solution, contaminated water is poured into a funnel, and purified water is output through an exit valve. The device consists of a sediment filter to remove particulate matter and ultraviolet light to remove bacteria, protozoa, and viruses. This treatment method can be used for delivering a practically continuous supply of clean water because UV light can purify the water as it flows past a bulb. Benefits of this treatment are that it is fast, energy efficient, long lasting, and does not release any chemical residue, unlike currently existing solutions. Due to its low electricity usage, this filtering mechanism can be used in conjunction with a solar panel and lead acid battery so that it is self sufficient, allowing it to function without access to the electrical grid. Unlike most current filtration systems, this system is not pressurized, and instead relies on gravity to move water through the filter and the tube containing the UV bulb. This makes the system considerably cheaper and more energy efficient, which results in a low cost solution and in turn makes it more accessible.

Comparing current solutions to the proposed solution:

Item	Removes Bacteria, Protozoa, and Viruses	Reusable	Time Efficient	Works for Large Amounts (>20gal)	Self Sufficient
Boiling	Yes	Yes	No	Yes	Yes
Carbon Filtration	Yes	No	No	Yes	Yes
Chlorine Drops	Yes	No	Yes	Yes	No
Iodine Drops	Yes	No	Yes	Yes	No
UV Bottle	Yes	Yes	Yes	No	No
PureWater	Yes	Yes	Yes	Yes	Yes

Plan: This device consists of three parts: a purification system, solar panel, and pair of batteries. The purification system consists of a sediment filter and a 10W UV bulb controlled by an on-off switch. The UV light bulb is encased in a 2.5 inch diameter tube, through which the water flows. Water enters this tube through a funnel, first passing through the sediment filter, which removes dirt and particles greater than 0.625 mm. The sediment filter is a simple tea strainer that allows water but not particulate matter to flow through. Water then flows through the tube containing the UV light, where it is purified of harmful organic contaminants. After the water flows through the tube, it is output through an exit pipe with a valve, where the users can collect their clean water. The system is powered by two lead acid batteries, which are subsequently charged using a solar panel. A solar charge controller is used to determine when the battery needs to be charged by the solar panel and to prevent overcharging. A DC to AC adapter is also needed to convert the direct current produced from the solar panel to the alternating current required by the UV light bulb. Lead acid batteries are used to power the purification system due to their relatively low cost and ability to withstand the higher temperatures necessary for a product staying in the sun all day. A single lead acid battery could technically function, but discharging a lead acid battery below 40% reduces its cycle life significantly, so connecting two batteries in series will ensure that the charge level will not go below 50% (BU-808, 2019). The charge level varies based on use, but at 50 gallons per day, the batteries are sized such that they can last for six days without a recharge. The solar panel is placed at an angle of 45 degrees from normal because this is the average of the most energy efficient angle for use throughout the year (EnergySage, 2019).

Design Considerations: In order to adequately design a system that is capable of producing a minimum of 50 gallons of clean water per day, the components of the device need to meet the following specifications:

Item	Equation	Dimensions	Result	Citation
1. Flow rate through a 2.5” diameter pipe with 1.2” diameter bulb in the middle	$C_c * C_v * A *(2*g*h)^{1/2}$	C_c = Constant (0.62) C_v = Constant (0.97) A = (Area of pipe - Area of bulb) = 3.78 in^2 h = height of tube (12”)	0.757 gal/min	(Engineering Toolbox, 2019)
2. Energy used to purify 50 gallons of water	Bulb Energy consumption, E (W) * time to pass 50 gallons though bulb (hr)	E = 12W T = 1.1 hrs	13.2 Wh	None
3. Battery Utilization	Wh/battery * number of	Wh/battery = 84 #Batteries = 2	6.36 day runtime	None

	batteries * minimum state of charge/ Wh needed per day	Minimum state of charge = 50% Wh needed per day = 13.2	without recharge	
4. Solar Panel Capacity	(hrs Sun/day) * solar panel W capacity	Hrs Sun/day = 5 Solar panel W capacity = 20	100Wh/day	None

Key insights from design calculations:

1. 0.757 gal/min flow rate is less than 1 gal/min bulb rating, ensuring adequate cleaning
2. 13.2 Wh energy is needed to purify the daily design capability of 50 gal of water
3. The battery system can last 6.36 days without a recharge, while ensuring >50% minimum state of charge
4. The solar panel chosen is capable of producing 100Wh/day, (~8 times the requirement), which provides enough safety margin for the battery to be fully charged in a single day.

Diagrams:

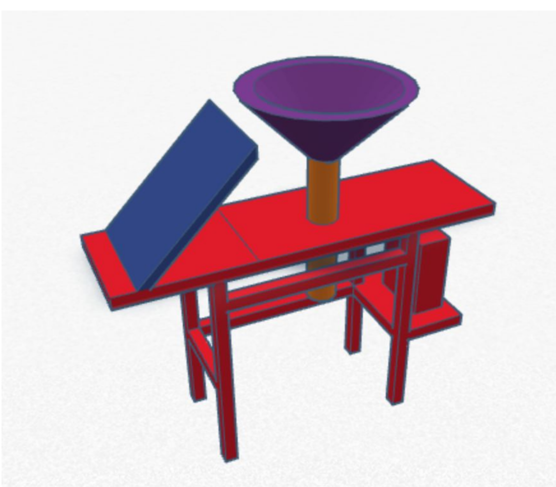

Figure 1: A 3D representation of the model

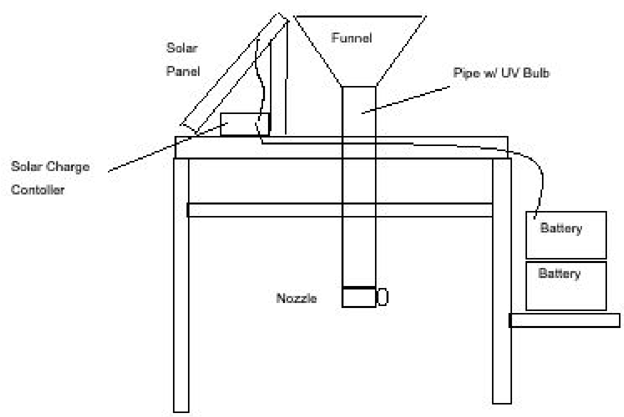

Figure 2: A diagram of the device

Resources:

1. 20W Solar Panel
2. 12W 1 GPM UV Bulb
3. 2 x 12V/84Wh lead acid battery
4. 12” of 2.5” PVC piping
5. Tea Strainer
6. Solar Charge Controller
7. DC to AC Adapter
8. On-Off Switch
9. 2.5" PVC Pipe valve
10. Funnel-15" vinyl sheet
11. 18” metal rolling cart

These resources will be acquired through websites linked above

Goals/Completion Criteria:

1. No large particles (>0.625mm)
2. Collect water from a local lake/ create contaminated water
3. Place 3 drops of this water onto a soy agar plate, and let it sit for 72 hours
4. If colonies grow, then this water has bacteria, and needs to be treated
5. Pour one gallon of this water into the filtration machine
6. The water should be output in one minute or less
7. Collect the water and test it on an agar plate for 72 hours
8. The water should not grow any colonies for this project to be called a success

Risks: During the testing and implementation phase, many issues might be encountered. One possible problem is that the water continues to grow bacteria after passing through the filter. Potential solutions to this can be achieved either by thickening the sediment filter so that water flows slower or reducing the diameter of the tube holding the UV bulb to decrease the water flow rate and increase the residence time of the water in the UV chamber. Another potential problem is in the electrical connections of the UV bulb. Because it is in a tube where water is flowing through, the connections need to be sealed properly so that the bulb does not short out with the water. To prevent this, additional liquid electrical tape can be applied to the connections, which will avoid shorting in the system. The device as designed may not be adequately balanced, which would make it prone to tip over. To solve this, the batteries can be moved to counterbalance the solar panel, so the device is steady. A final risk is the sediment filter being clogged up, stopping the system. After multiple cycles, sediment may pile up in this filter, but a lower flow rate will not affect the cleanliness of the water. Additionally, the filter is easily removable and can be cleaned when sediment is piled up.

16 Week Timeline:

Week	**Item**	**Criteria**
1	Materials	Have all materials required, be ready for assembly
2	Solar	Calibrate the solar panel and confirm it works by connecting it with the battery through the charge controller
3	UV	Install the UV bulb within its piping and connect it to the solar battery
4	UV	Waterproof the UV bulb connections and test w/ water, Complete Interim report part 1
5	Filter	Attach the sediment filter and adjust the flow rate to 1gal/min

6	Switch	Connect the on/off switch and confirm it controls the UV light
7	Connections	Seal all electrical connections, test whole system
8	Funnel	Install the funnel and ensure water does not spill out, Complete Interim report part 2
9	Test	Test whether it meets completion criteria
10	Test	Continue testing whether it meets completion criteria
11	Adjust	Fix any problems with the device
12	Re-test	Fulfill all completion criteria, Complete Interim report part 3
13	Report	Write up findings and summarize results
14	Report	Draw conclusions based on findings
15	Report	Summarize the project + Next steps
16	Report	Complete Final Report

To ensure the schedule is met, interim reports will need to be completed each four weeks detailing the progress that has been made.

Current Progress and Need for Funding: The project is currently in its planning phase. Prior to this phase, multiple concepts had been proposed, and the pros and cons evaluated before deciding on the current approach. Initially, the idea was to boil the water instantly instead of using UV light, still utilizing a solar panel-battery combination, but this system was not energy efficient, which made me pivot towards using a UV light for purification. Once I had decided upon a UV light, an issue arose about what type of battery would best suit this device. My initial solution was to use a lithium-ion battery, which would provide a smaller size and larger number of cycles. However, some research showed me that lithium ion batteries are expensive and do not function well in the heat, with cells at 30°C losing 20% of their cycle life compared to their life at 25°C (Battery University, 2018). This loss of function at higher temperatures caused me to switch towards lead acid batteries, which can withstand a much larger temperature range.

Projected Budget:

Item	Amount	Cost
20W Solar Panel	1	$30.50
12W 1 GPM UV Bulb	1	$19.99
12V lead acid battery	2	$37.62
2.5” PVC piping	12”	$0.99
Tea Strainer	1	$4.99
Solar Charge Controller	1	$12.59
DC to AC Adapter	1	$29.99
On-Off Switch	1	$2.33
Funnel-vinyl sheet	15”	$3.70
2.5" PVC Pipe valve	1	$10.63
18” metal rolling cart	1	$21.95
Total:		$175.27

Personal: This idea was formed when my family and I went backpacking for the first time. We could not carry all the water we needed for the duration of the trip, so we brought a portable filter and planned to purify water from a nearby lake. However, it was a squeeze based water filter, and it took an hour of hard work to purify enough water for our whole family. Because of our struggle for purification with the help of a filter, I started to wonder how much harder it must be for people without access to a filter to decontaminate their water. This backpacking experience was when I first saw the need for easy access to clean water, and after doing more research on the problem, I was inspired to work on this project.

References

AMSI. History and applications of Newton's law of cooling. (n.d.). Retrieved from https://amsi.org.au/ESA_Senior_Years/SeniorTopic3/3e/3e_4history_3.html.

Bacteria, Viruses, and Parasites in Drinking Water. (n.d.). Retrieved from https://www.health.state.mn.us/communities/environment/water/contaminants/bacteria.html.

BU-808: How to Prolong Lithium-based Batteries. (2019). Retrieved from https://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries.

Chaurasiya, R. R. (2018). Design of Water Purification System Working on Solar Radiation. *International Journal for Research in Applied Science and Engineering Technology*, *6*(4), 4298–4306. doi: 10.22214/ijraset.2018.4705

Danjuma, S. (2016). Design, Construction and Testing of Solar Water Distillation Unit for Rural Water Purification in Nigeria. *Proceedings of the ISES Solar World Congress 2015*. doi: 10.18086/swc.2015.10.45

Discharging at High and Low Temperatures. (2018). Retrieved from https://batteryuniversity.com/learn/article/discharging_at_high_and_low_temperatures.

EnergySage. (2019, July 2). Solar Cost Terminology: Price Per Watt, $/W and LCOE: EnergySage . Retrieved from https://news.energysage.com/measuring-the-cost-of-solar-power-dollars-per-watt-w-and-levelized-cost-of-energy-lcoe/.

Five Water Purification Designs. (2017, February 14). Retrieved from https://ufonline.ufl.edu/infographics/five-water-purification-designs/.

Flow of Liquids from Containers. (2019). Retrieved from https://www.engineeringtoolbox.com/flow-liquid-water-tank-d_1753.html.

How can water be contaminated? (n.d.). Retrieved from https://www.webmd.com/women/qa/how-can-water-be-contaminated.

Miller, T. (2013, June 24). Afraid of Contamination? How to Test the Water in Your House. Retrieved from https://lifehacker.com/afraid-of-contamination-how-to-test-the-water-in-your-5927732.

Nolt-Helms, C. (2008, August 4). Final Report: Low-Cost Water Purification System: Developing an Effective Water Purification System for Local Production Which Offers Sustainable Economic Stimulus. Retrieved from https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/8109/report/F.

Oram, B. (n.d.). Mr. Brian Oram, PG. Retrieved from https://www.water-research.net/index.php/water-treatment/water-disinfection/uv-disinfection.

Petronzio, M. (2014, January 13). 11 Ingenious Solar Projects Impacting the Developing World. Retrieved from https://mashable.com/2014/01/13/solar-energy-developing-world/.

Solar Panel Cost. (n.d.). Retrieved from https://www.solar.com/learn/solar-panel-cost/.

Solar Power Water Generator: Water From Air: Aldelano. (2018, June 7). Retrieved from https://solarcoldbox.com/solarwatermaker.

Thompson, M. (2014). A critical review of water purification technology appropriate for developing countries: Northern Ghana as a case study. *Desalination and Water Treatment*, *54*(13), 3487–3493. doi: 10.1080/19443994.2014.922309

Ultraviolet Water Purifiers. (n.d.). Retrieved from http://www.waterpurifier.org/ultraviolet-water-purifiers/.

Understanding UV Water Purification. (n.d.). Retrieved from https://www.espwaterproducts.com/understanding-uv/.

Water sanitation and health. (2019, December 12). Retrieved from https://www.who.int/water_sanitation_health/en/.

Wilson, B. (2014). Design and Construction of a Solar Water Purification System Using Ultraviolet Radiation. *BioResource and Agricultural Engineering Department*. Retrieved from http://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1145&context=braesp