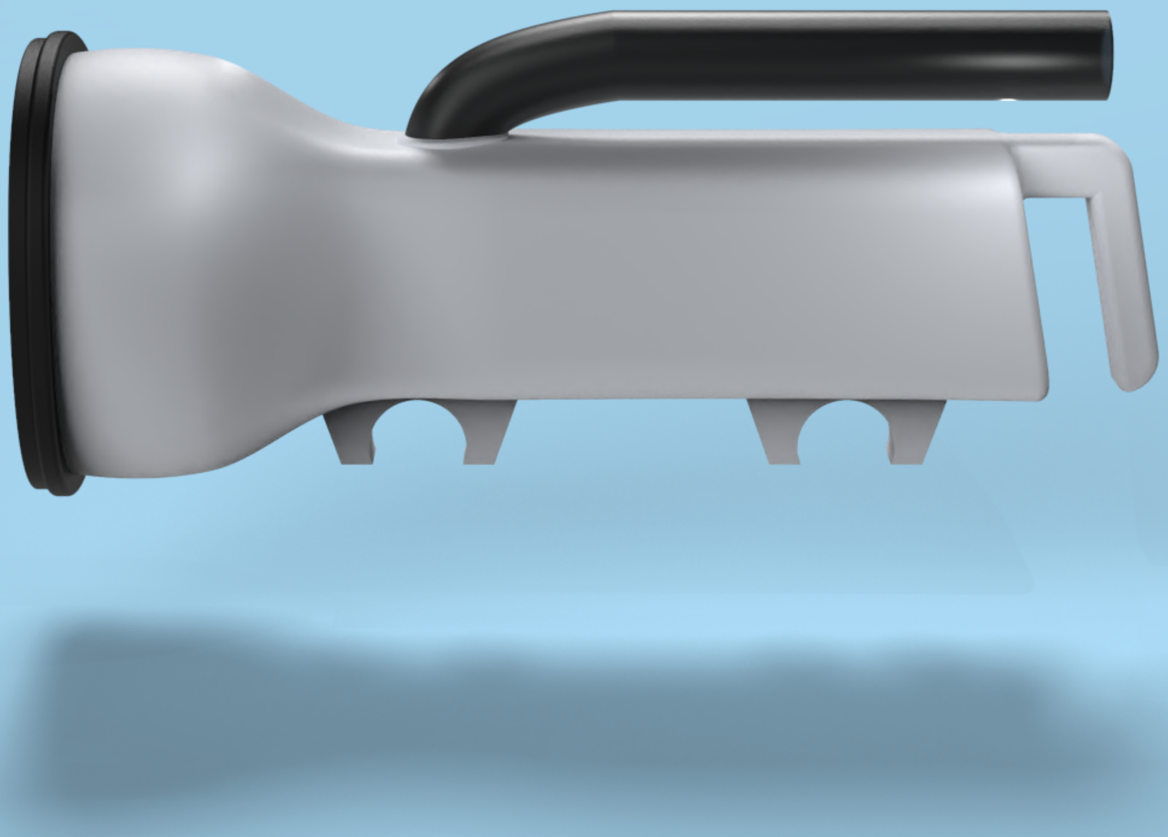
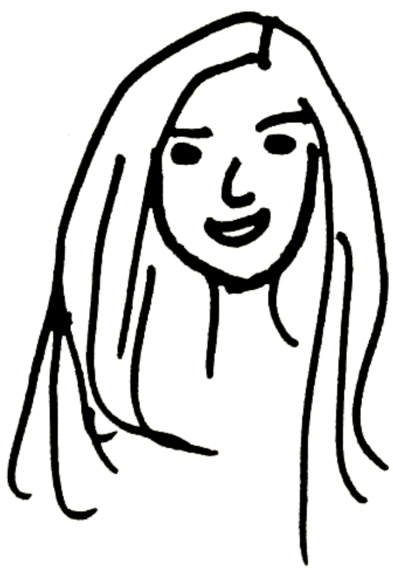


UV-C LED Water Treatment Device for Mid to Large Volume Tanks

By Ava Newell Bilimoria and Suyash Manoj Junnarkar

Table of Contents

About Us



AVA NEWELL BILIMORIA
bilimoria@gatech.edu

Master of Industrial Design Candidate
Georgia Institute of Technology

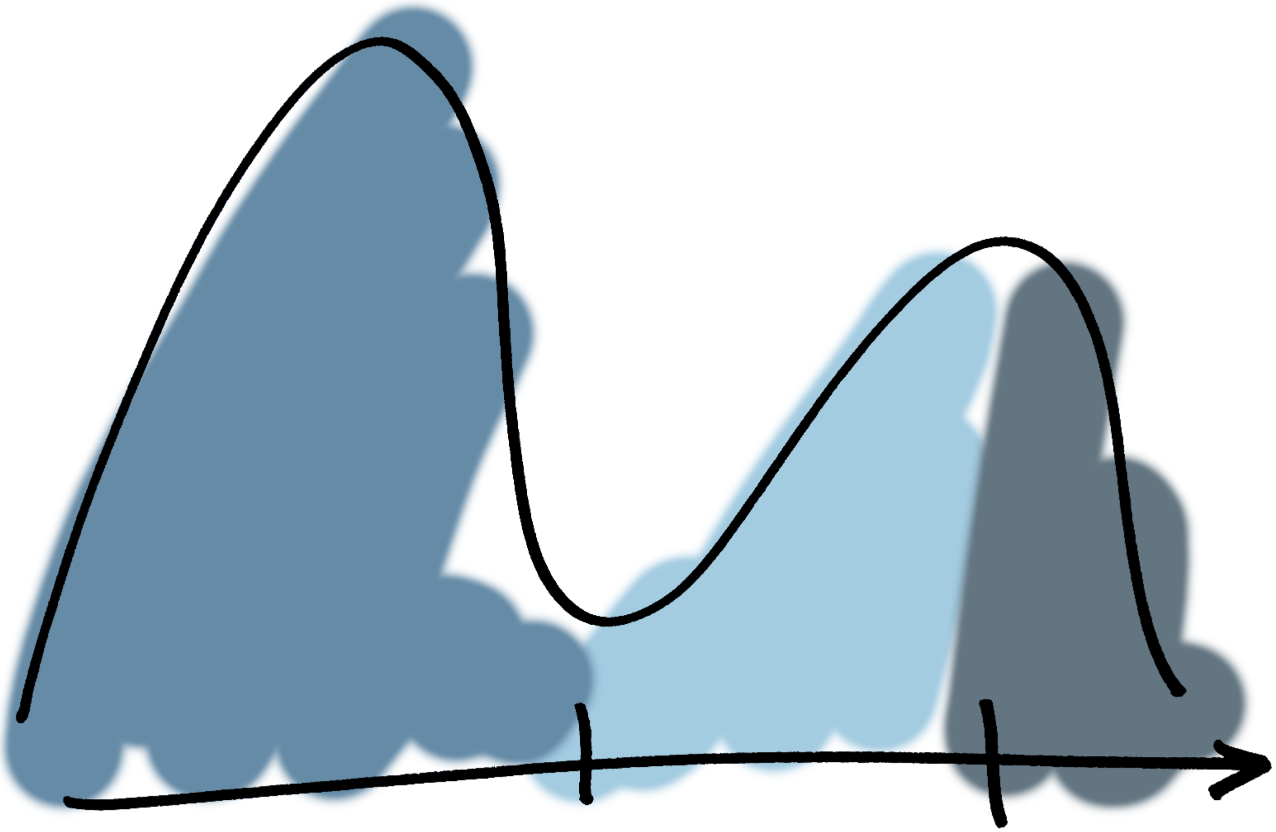
BS Mechanical Engineering 2014
Georgia Institute of Technology

SUYASH MANOJ JUNNARKAR
junnarkarsuyash@gatech.edu
https://suyashmj.com

Master of Industrial Design Candidate
Georgia Institute of Technology

B.Tech. Electronics Engineering 2019
Veermata Jijabai Technological Institute, Mumbai

Our Design Process



RESEARCH (3 WEEKS)
We begin our process with divergent thinking. We learn more about the problem and empathize with users' experiences. With this information, we converge to our refined problem statement and set specific objectives to solve.

IDEATE (2 WEEKS)
We let our imaginations run wild with as many ideas as we can possibly think of. There are no bad ideas, we do not limit ourselves, and no thought is too "crazy". We take 3 of the ideas forward into more thought-out concepts.

DEVELOP (2 WEEKS)
We select one concept to further develop. We attempt solving every issue with the product as best we can with the time we are given. How do parts connect? How much does it cost? Every detail is important and must be taken into consideration.

RESEARCH

Let’s take a deep dive into the world of water sanitation...

What’s the problem?
Why is this important?
Who is affected by this?
What is their experience like?
What current solutions are on the market?
What preliminary calculations are needed?

Given Problem Statement

This project was done in partnership with the Centers for Disease Control and Prevention (CDC). The CDC is nation's health protection agency, working 24/7 to protect America from health and safety threats, both foreign and domestic. The following is the problem statement given to us by the CDC:

The goal is to create a cost-effective, UV LED water treatment device that emits UV-C pulses at wavelengths of 264 nm. The target volume of water to treat is 5000 liters.

CHALLENGE

- Is your solution scalable and easily deployable?
- What would be needed to treat up to 100,000 liters of water?

ADDITIONAL REQUIREMENTS

- Simple technology options
- Long battery life/replaceable parts
- Minimal operator/user training required
- Secure against theft

Given Problem Statement

WHAT IS CHOLERA?
Cholera is an acute, diarrheal disease often presenting with symptoms of dehydration and watery diarrhea. Safe drinking water is critical to the control of spreading cholera. While there are many education campaigns encouraging households to treat their water, there is a need to improve the community-level water supplies available at a given time.

Researchers estimate that 1.3 million to 4.0 million cases and 21,000 to 143,000 deaths occur due to cholera annually.

WHAT IS CURRENTLY BEING DONE?
Many cholera outbreak responses focus on chlorine treatment as it has proven cost-effective and efficient at inactivating the etiologic agent of cholera. However, there are ongoing challenges with pursuing chlorine-based solutions such as measuring inconsistencies, mixing issues, and often human error in abiding to a dosing schedule. During a cholera response, local water utility companies may provide large-volume tanks filled with chlorine treated water distributed throughout a district. Tanks are filled on a regular schedule and allow nearby households to access treated water.

WHAT SHOULD WE TRY NEXT?
There are barriers to the success of the chlorine treatment option, and the CDC would like us to explore the idea of using a non-chlorine-based treatment option, such as UV-C LEDs, to be used at the tank-level.

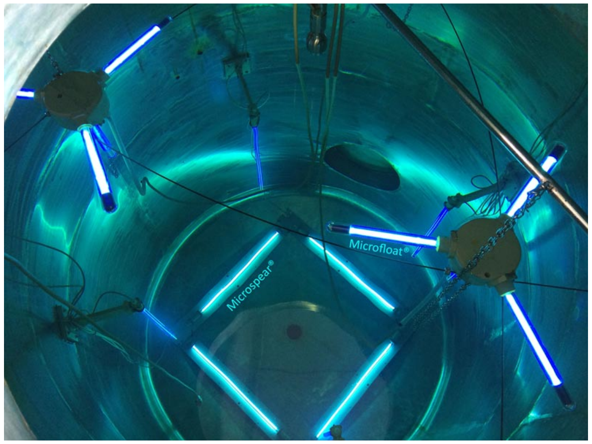
Existing Solutions

CHLORINE TREATMENT
As mentioned on the previous page, chlorine-based water treatment has many issues, including measuring and dosing schedule inconsistencies, mixing issues, and bad-tasting water.

ENVIOLET MICROFLOAT
These are UV-C LED water disinfecting devices used for tanks.

AQUISENSE TECHNOLOGIES
This company develops a variety of UV-C LED water disinfection solutions. These are all in-line systems and are mainly for residential use.

SUNSPRING HYBRID
This portable solar-powered microbiological water treatment system uses membrane technology similar to what is used in large-scale water treatment plants.



Journey Map

1 FILTRATION PLANT
Membrane filtration or separation. Turbidity usually between 0 - 5 NTU.

2 WATER TRUCK TRANSPORTATION
Drivers have high school education at best. Possibility of bio films or bacteria growth along linings.

3 FILLING WATER TANKS
Water transferred from trucks to tanks using a pipe. Bacteria growth possible along the lining.

4 TANK USAGE
People use the tank taps oto dispense water.

5 TANK MAINTENANCE
Tanks needs cleaning on a fixed schedule. Cleaning is mandatory to prevent growth of bacteria.

Key Features

After performing our research, we determined the following six key features to focus our designs on:

1 MINIMAL MAINTENANCE

Design system to require minimal maintenance and take into account high school level of education for those working to maintain and install the system.

2 GLOBAL PARTNERSHIPS

Partner with local manufacturers to reduce cost and employ third party management services to look after the quality and throughput of the system.

3 CENTRAL MANAGEMENT

Control systems that are spread across many villages using a central management system. Deploying cloud based architecture to keep track of and maintain each system to ensure utmost water filtration.

4 COST-EFFECTIVE

Keep the overall cost minimal. Use common and purchased parts as much as possible while minimizing the use of custom parts.

5 RESPONSE GROUP

Put a system in place to go out and physically maintain the systems and ensure proper functioning and proper installation.

6 ANTI-THEFT SECURITY

Develop the system so that it and its components are not easily stolen.

Refined Problem Statement

Develop a cost-effective, UV-C LED water disinfection device to be used in tanks for a target volume of 5000 liters. The device should require minimal maintenance, ease of installation, and anti-theft security.

DESIGN OBJECTIVES

- Device must be able to treat 5,000 liters of water.
- Device must use UV-C pulses at wavelengths of 264 nm.
- The UV-C LED must be used at an L90 level and thus be used at a current level of 350 mA or lower.
- Device should not be more than 2 mm from surface of water.
- Device should have exposure time of at least 25-30 seconds.
- Device should be cost-effective.
- Device should be secure against theft and misuse.
- Device should be remotely configurable to control UV exposure in proportion to the water level.
- Device should be easy to install.
- Device should be easy to maintain (long battery life, replaceable parts).
- Device should be able to be used with minimal operator training.

IDEATE

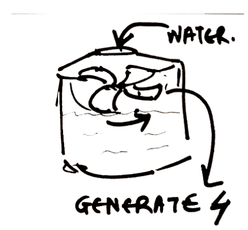
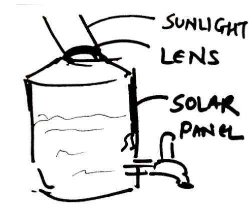
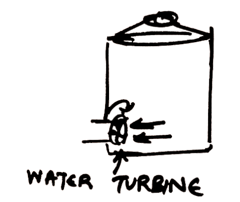
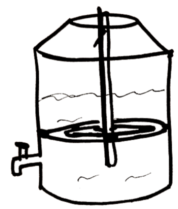
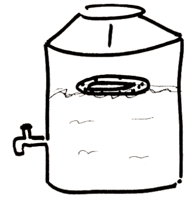
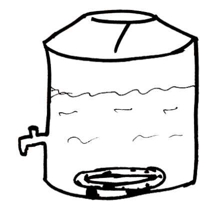
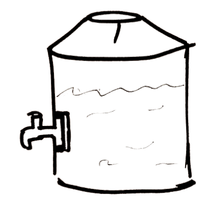
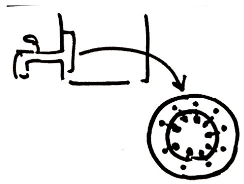
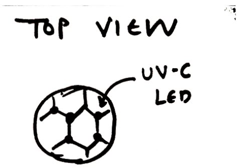
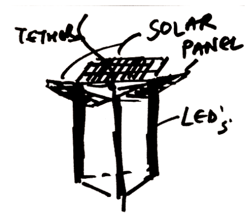
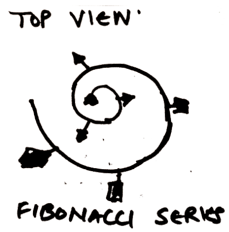
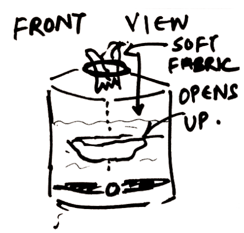
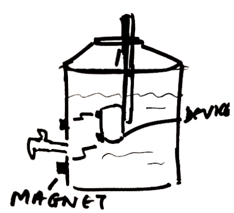
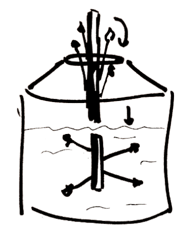
We are always asking questions and always learning more...

How might we better sanitize water at a community tank level?
Where should the device be located?
How can we make the device as simple as possible to install?
Can we use a renewable energy source?
How often are the tanks refilled?

Initial Ideation

Morphological Matrix

A morphological matrix is a useful tool during ideation. We identified critical functions (each row) for our design and then develop a variety of solutions (each column) for each of these functions.

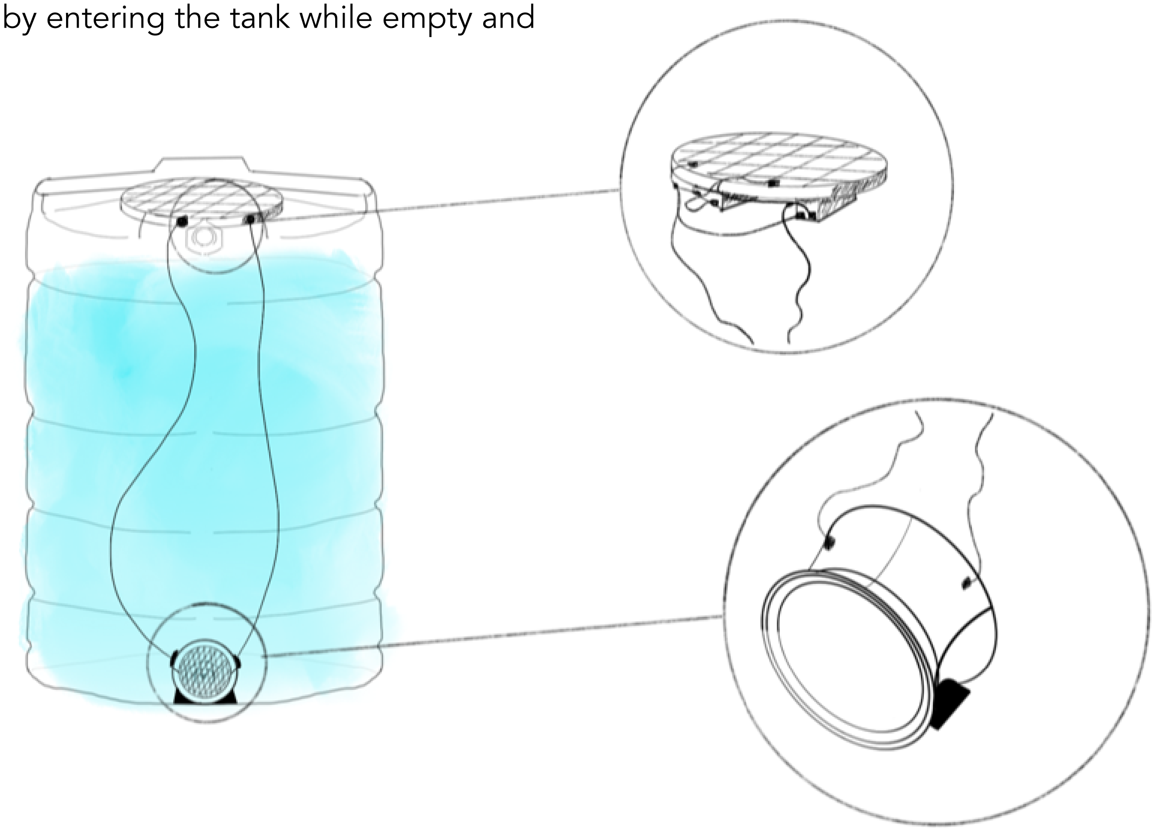
	1	2	3	4	5
POWER					
LOCATION					
SHAPE					
INSTALLATION					

Concept 1 : Overview

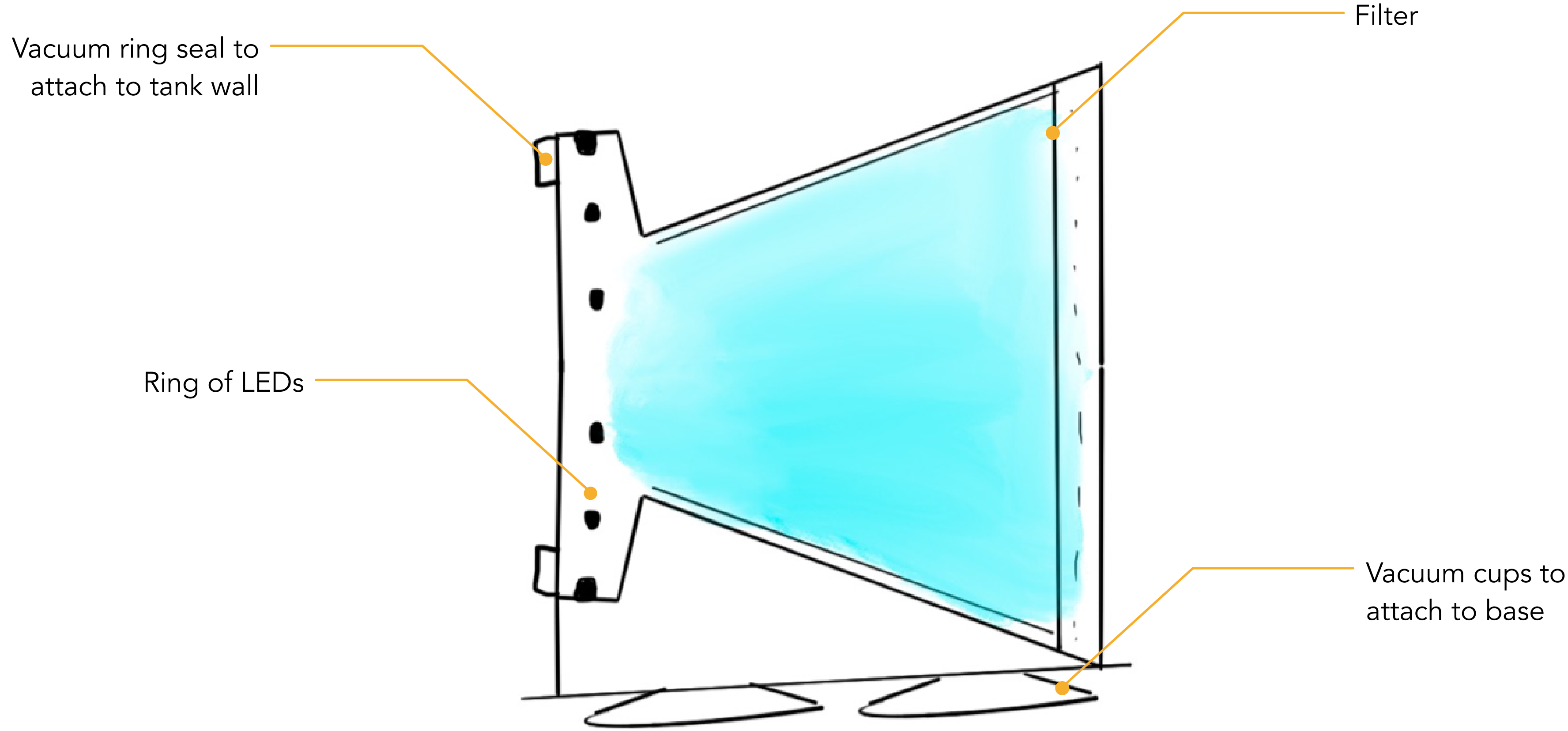
Concept 1 is attached to the inside of the tank, located at the water exit point. This device combines a filter and LEDs for water sanitation. The filter is necessary in this concept because sediment accumulates at the bottom of the tank.

The main body of the device is rounded to fit the curvature of the tank. Vacuum cups are used to attach to the base and a vacuum ring seal is used to attach to the wall.

Solar panels and a battery are located at the top of the tank and are connected to the device via cables. This device would be installed by entering the tank while empty and locking the vacuum cups and seal into place.



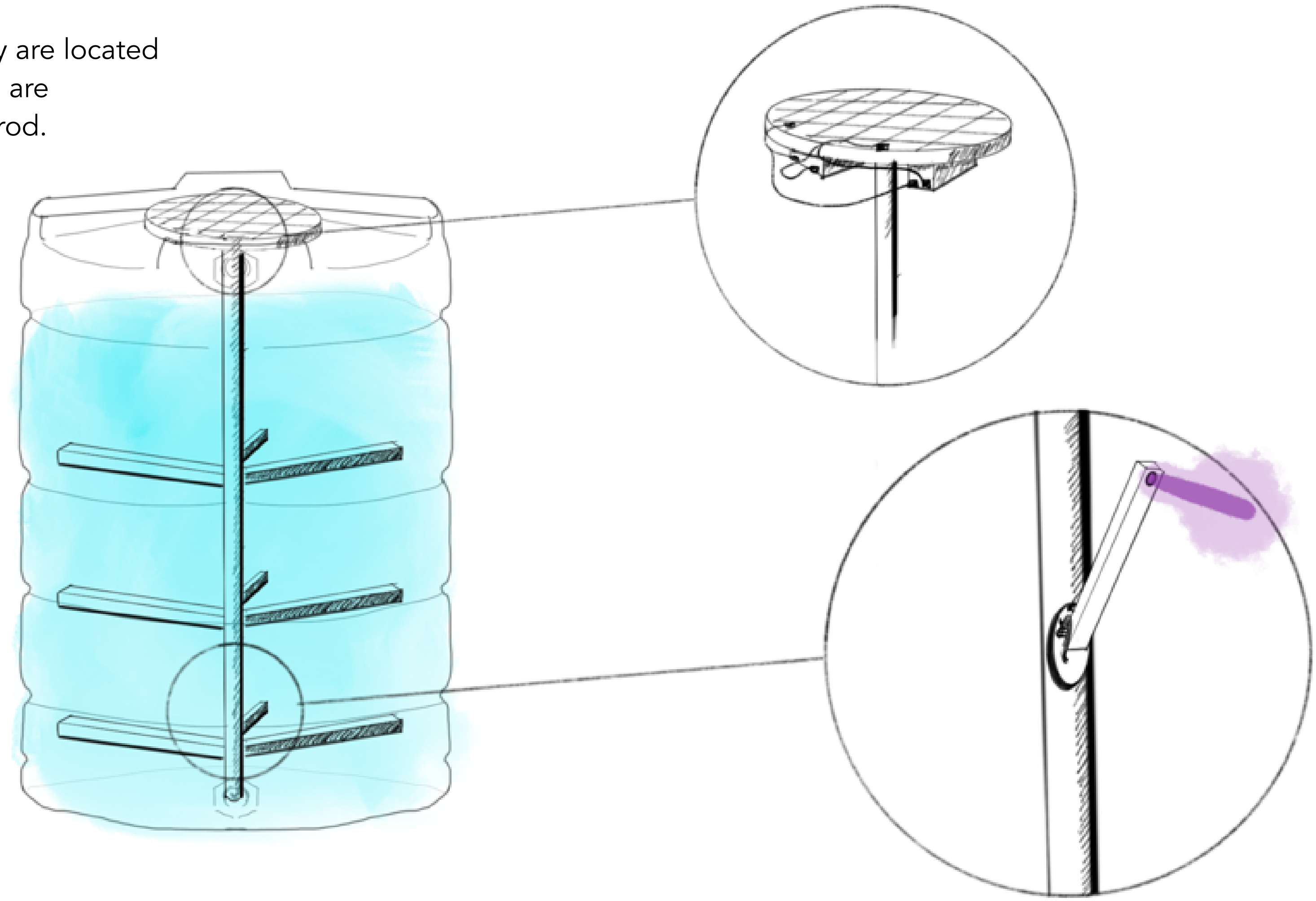
Concept 1 : Section View



Concept 2 : Overview

Concept 2 consists of branches attached to a central rod. Each brand has LEDs attached to it.

Solar panels and a battery are located at the top of the tank and are connected to the central rod.



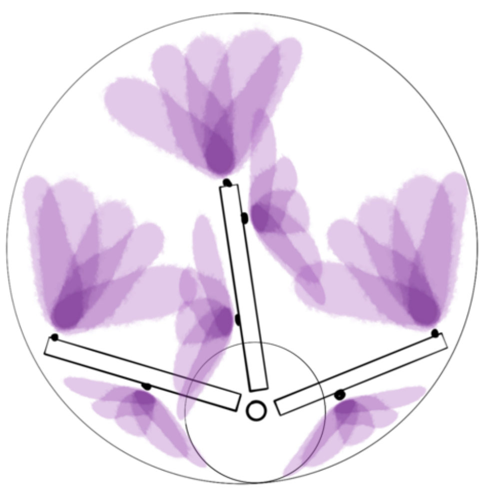
Concept 2 : Details

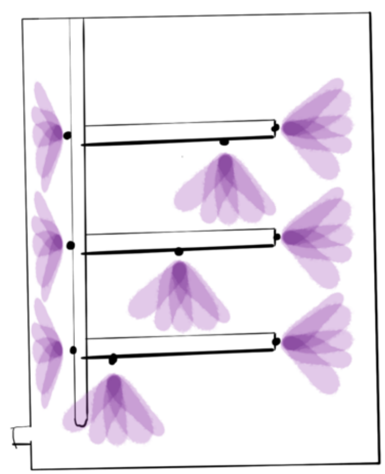
LED EXPOSURE

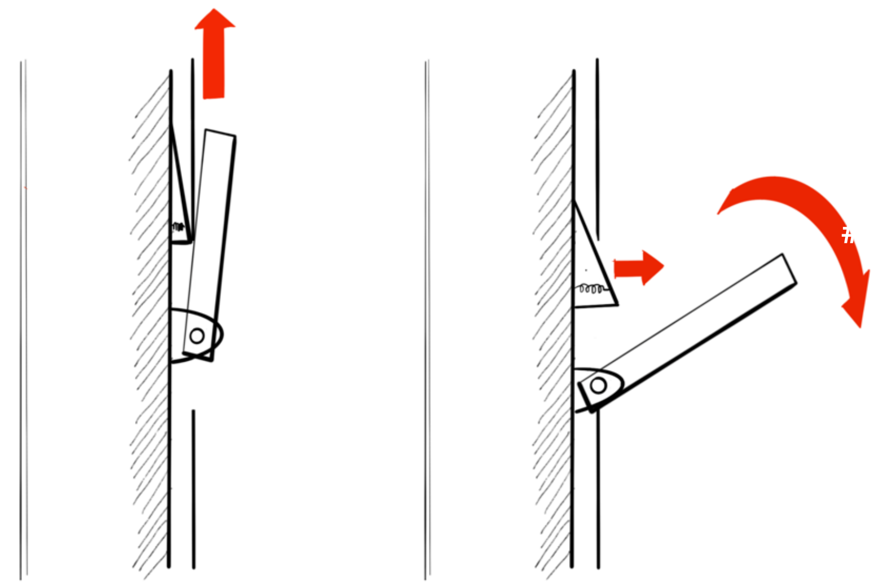
LEDs are located at strategically placed locations on the branches and central rod of the device. As seen in the image below, The LEDs are positioned to expose as much water as possible to them.

OPENING MECHANISM

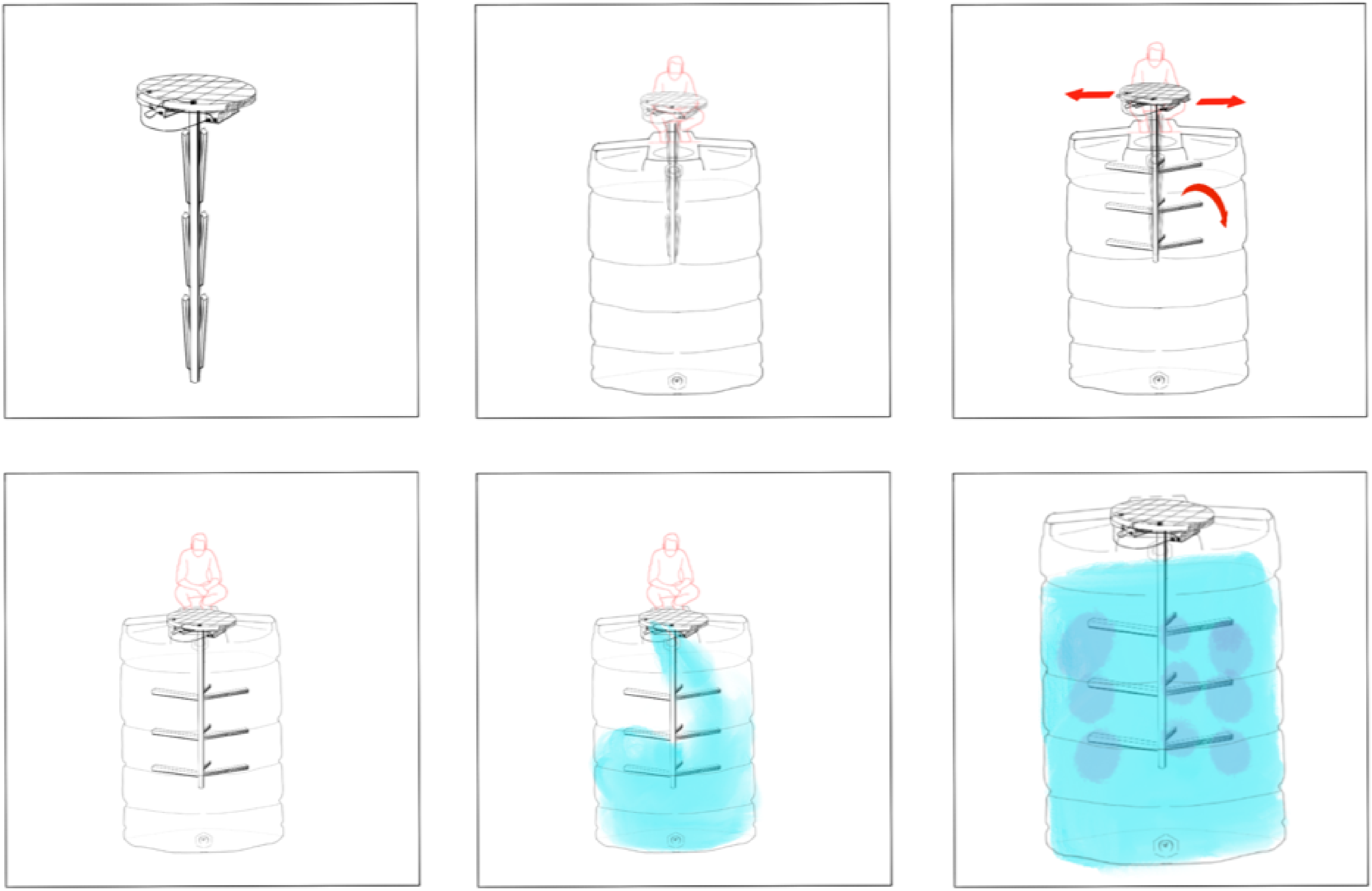
While installing the device, the branches are compacted upward so that the device can fit through the top opening of the tank. After the device has be lowered into the tank, the installer will open up the branches by pulling on tabs located under the solar panel. This causes the branches to be pushed outward into their opened position. This can be seen in the image below.







Concept 2 : Installation

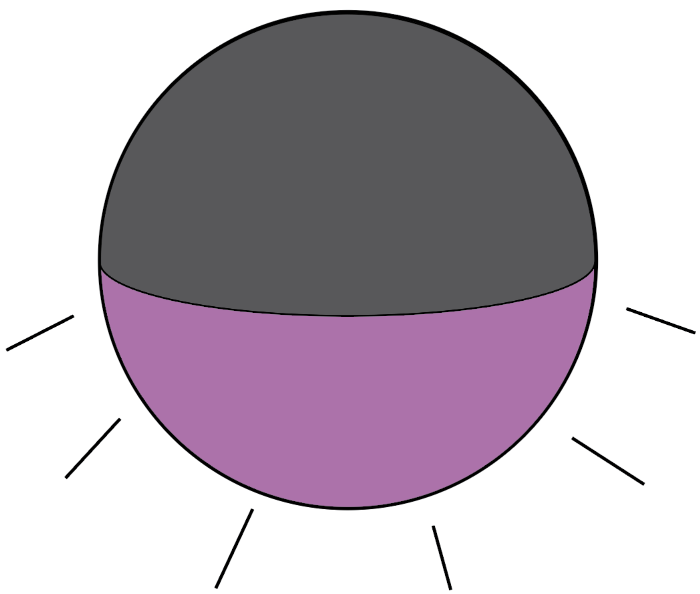


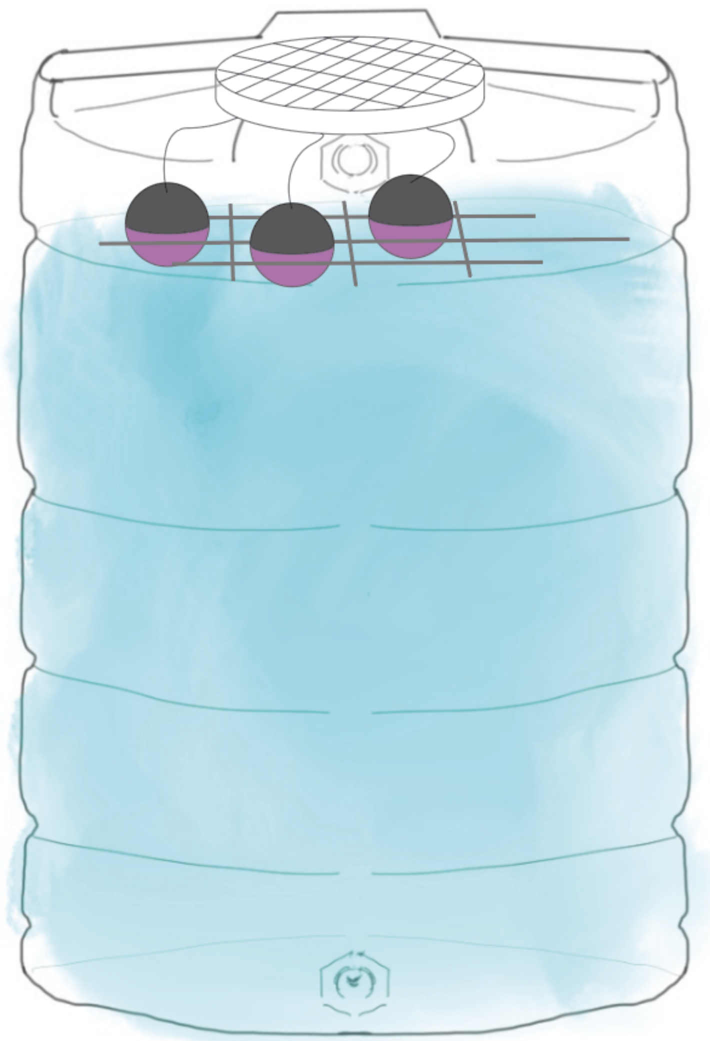
Concept 3 : Overview

Concept 3 is a system of floating spheres weighted so LEDs always face into the water for sanitation. Multiple spheres are used per tank. The spheres are placed in an expandable floating grid system to prevent them from congregating together.

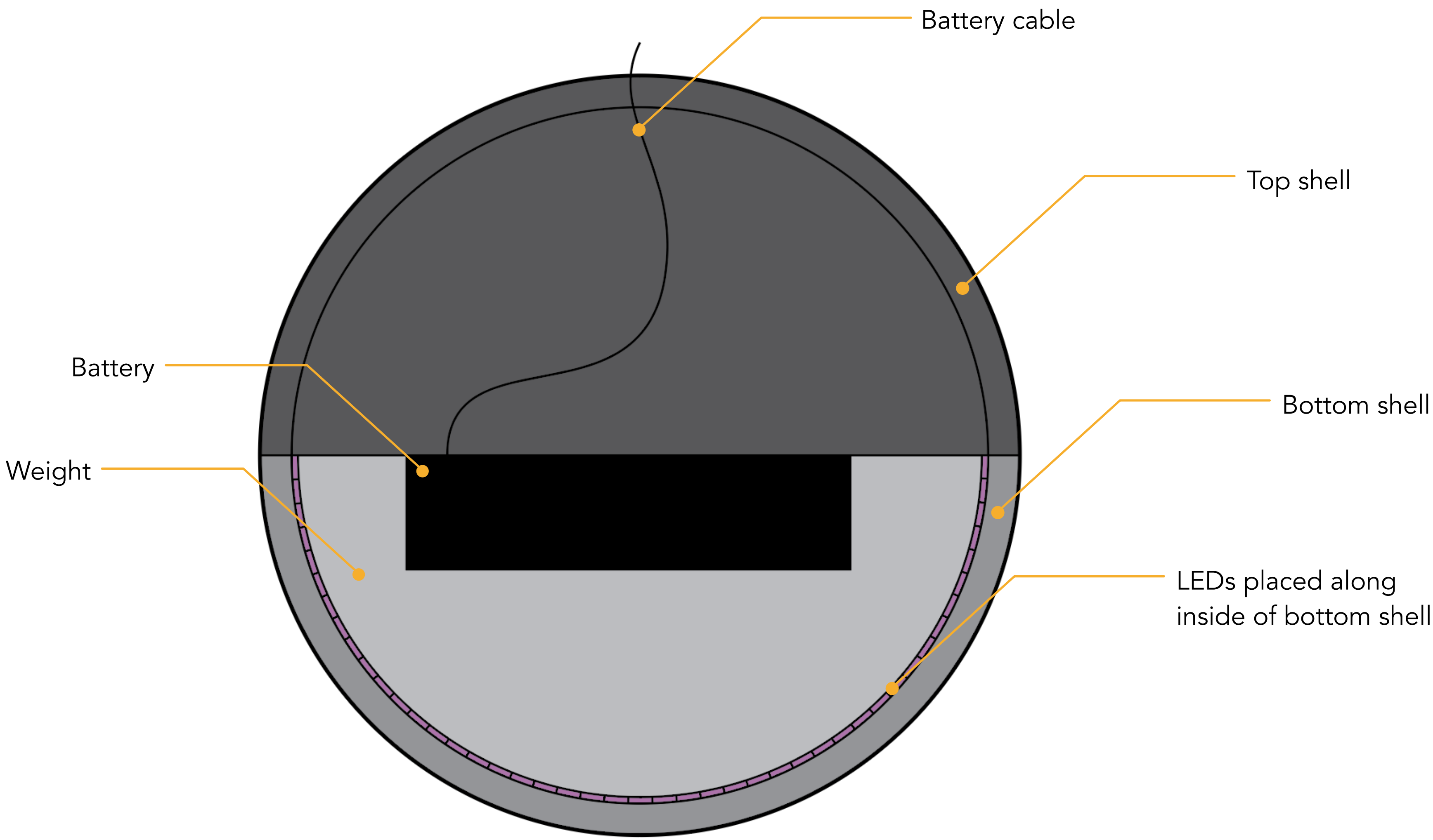
A battery is located within each sphere. Each sphere is connected to a solar panel via cables. The solar panel is attached to the top of the tank.

Each sphere is approximately 6 inches in diameter.

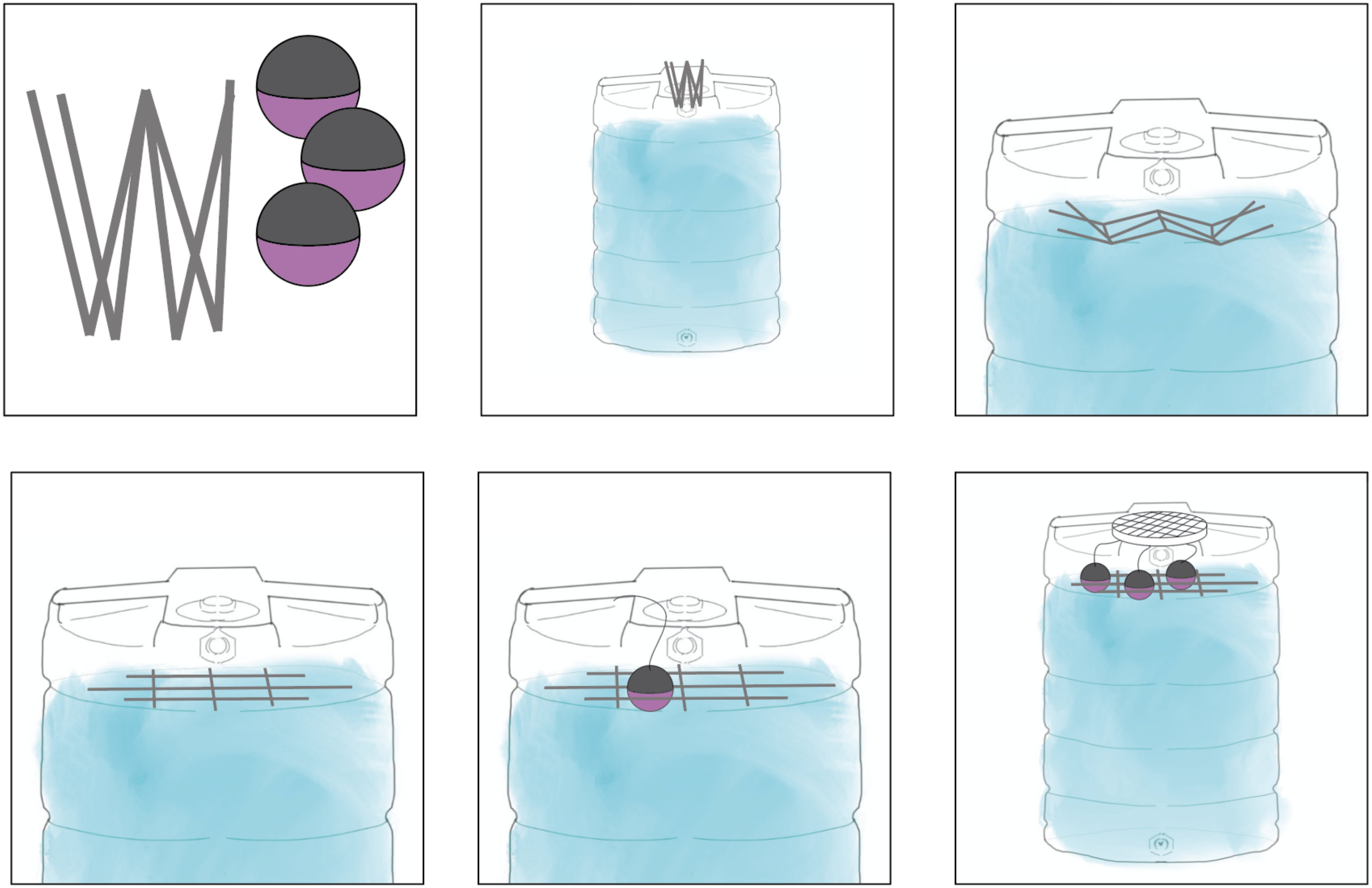




Concept 3 : Section View



Concept 3 : Installation

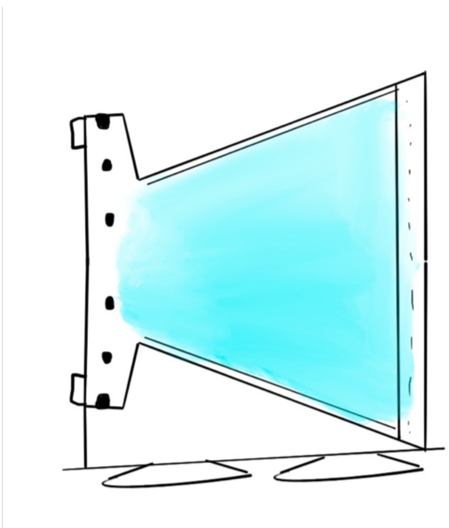


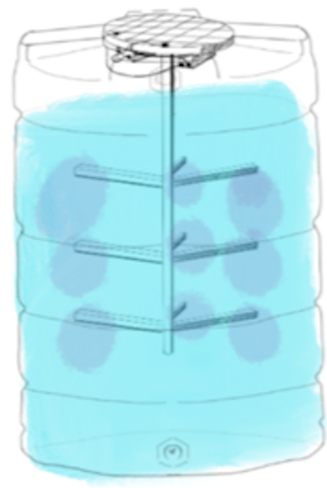
DEVELOP

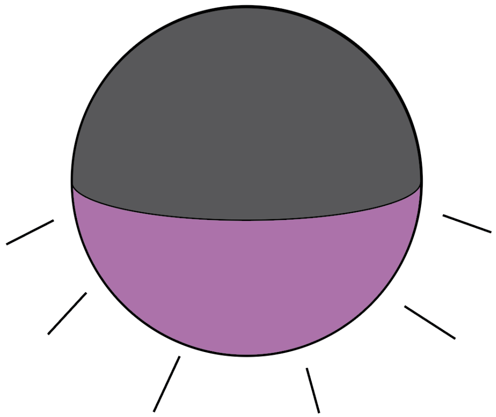
It's time to look at the details...

How do the parts connect?
If something needs to be fixed, is it easily accessible?
Is the enclosure waterproofed?
How much does the device cost?
Can this be easily prototyped?
Is this concept scalable?

Concept Selection







CONCEPT 1
Even with slightly difficult installation, we determined this design to have the most potential out of our 3 options for sanitization using least power. The next section of this book will focus on our exploration of Concept 1.

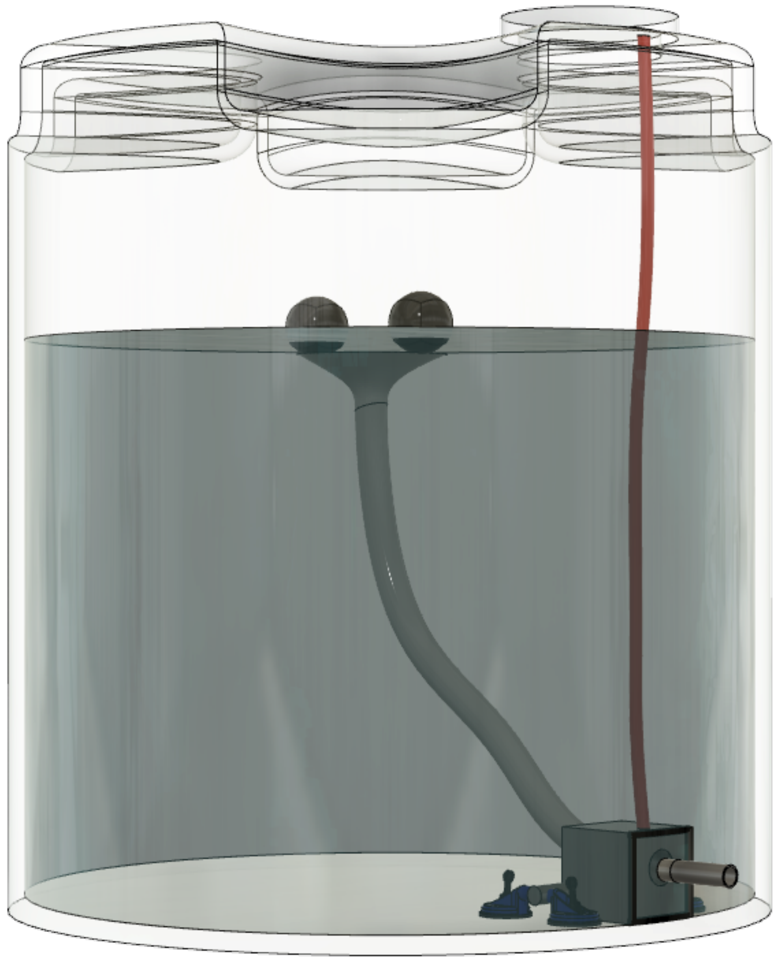
CONCEPT 2
Though this concept intrigued us with its ability to sanitize the entire tank at once, we determined it to be too complicated and complex for installation and maintenance purposes.

CONCEPT 3
After looking into this design more, we determined that this concept would only sanitize the water on the top of the tank. The tap is located at the bottom of the tank, and therefore would dispense unsanitized water.

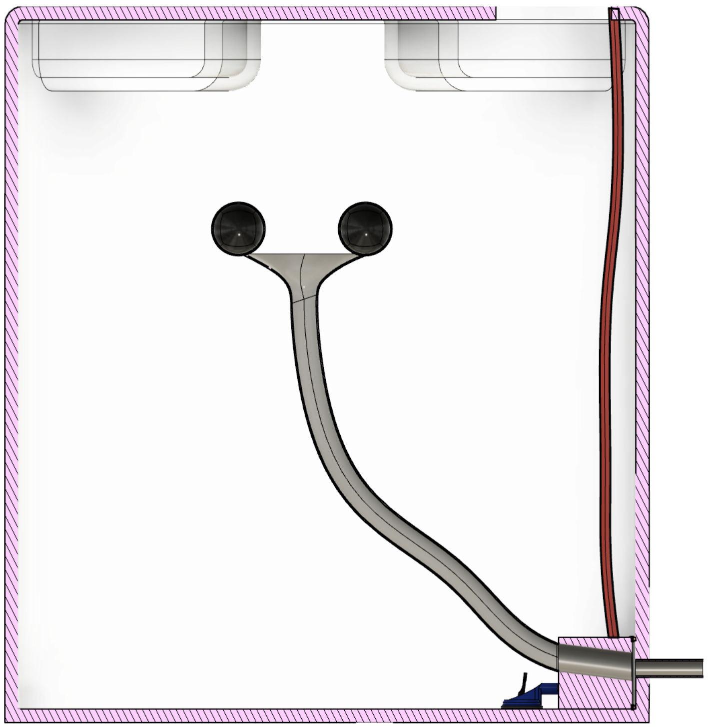
Refined Design

REMOVING THE FILTER
After looking into different types of filters used for water sanitation, we determined that we would not be able to use a membrane filter in the way we had originally planned. The filter was a necessity when sanitizing the water taken from the bottom of the tank. This is because sediments settle at the tank base. We redesigned Concept 1 by adding a pipe and funnel system to draw water from the top of the tank instead. The system would be held at the correct level by floating spheres.

SECURING TO THE TANK
Safely Securing the device to the tank was an initial concern of ours. The tanks used for water storage typically have an uneven surface on the inside. Because of this, we knew regular suction cups or adhesives would probably not hold securely. We looked into different attaching devices and found vacuum suctions cups used for heavy-duty glass lifting. The suction cups have a lever used for easy installation and releasing.



Overlooked Problems



INSIDE THE BOX

Though most of the concept had been thought out, we still needed to configure the insides of "the box" containing the LEDs. After this first design refinement, we determined that we needed to take a deeper look into the form. In our next refinement, we take a stab at designing a sleeker device that is easier to lift and install into the tank.

SECURITY AGAINST THEFT

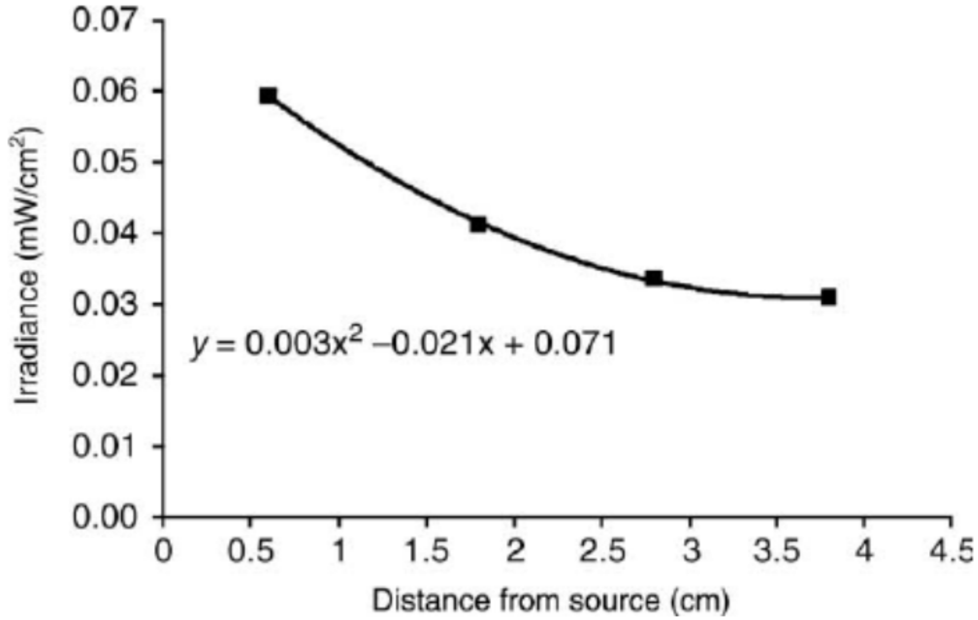
With this current design, the device is powered by a battery that is recharged by a solar panel. The battery and solar panel are located on the roof of the tank, and connected to the box via waterproof cables. After a lot of thought and additional research — we could not determine a way to secure the panel and battery to the tank without damaging the tank. Anti-theft security was a key feature that arose in our preliminary research. In our next refinement, we replaced the battery and solar panel with just one larger battery located inside the box. This allows for easier installation and a lesser chance of theft.

MINIMIZING PARTS

Another issue with this design is the complexity of the parts. In our next refinement, we removed the lifted pipe and funnel system. Instead, we move the water inlet to the top of the box device - this positioning helps avoid drawing water from the bottom and also allows for easier installation and removal because it lessens the total amount of parts.

Calculations

LED CHARACTERISTICS
After taking a deeper look into UV-C LED research, we learned that the irradiance of UV-C LEDs decreases the farther we go from the source. The graph to the right shows the irradiance of UV-C LEDs as a function of distance from the source. This is one of the sources we turned to when we decided which of our 3 concepts to pursue. We determined Concept 1 to be the best direction to move forward with because the concept gave us the most proximity of LEDs to dispensing water.

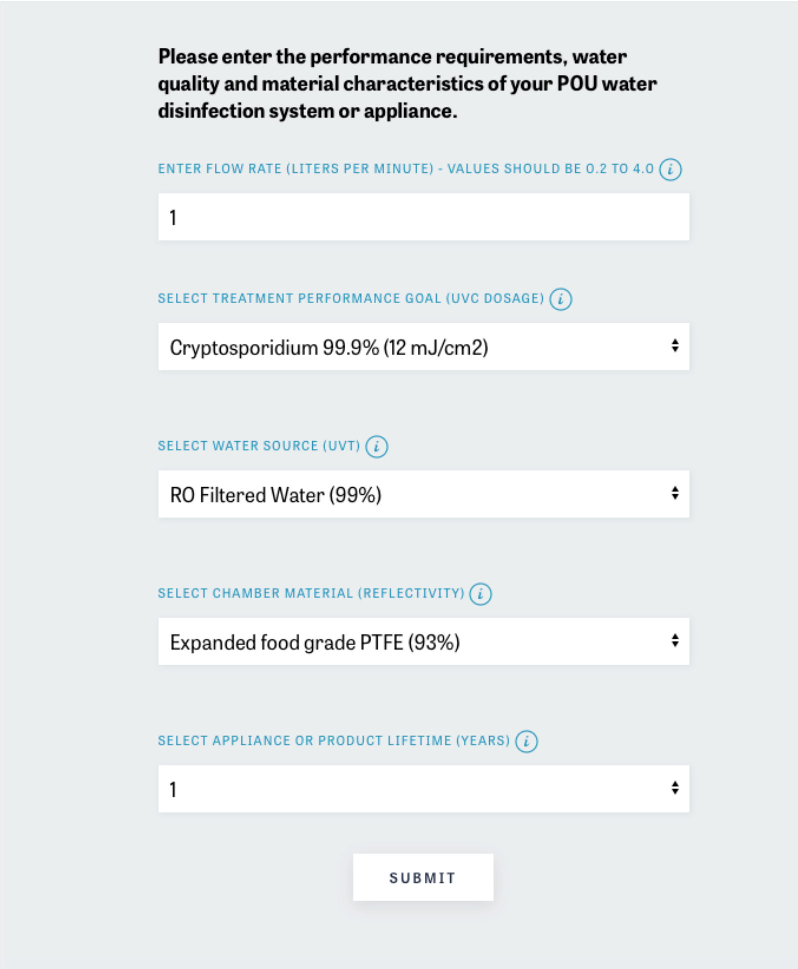


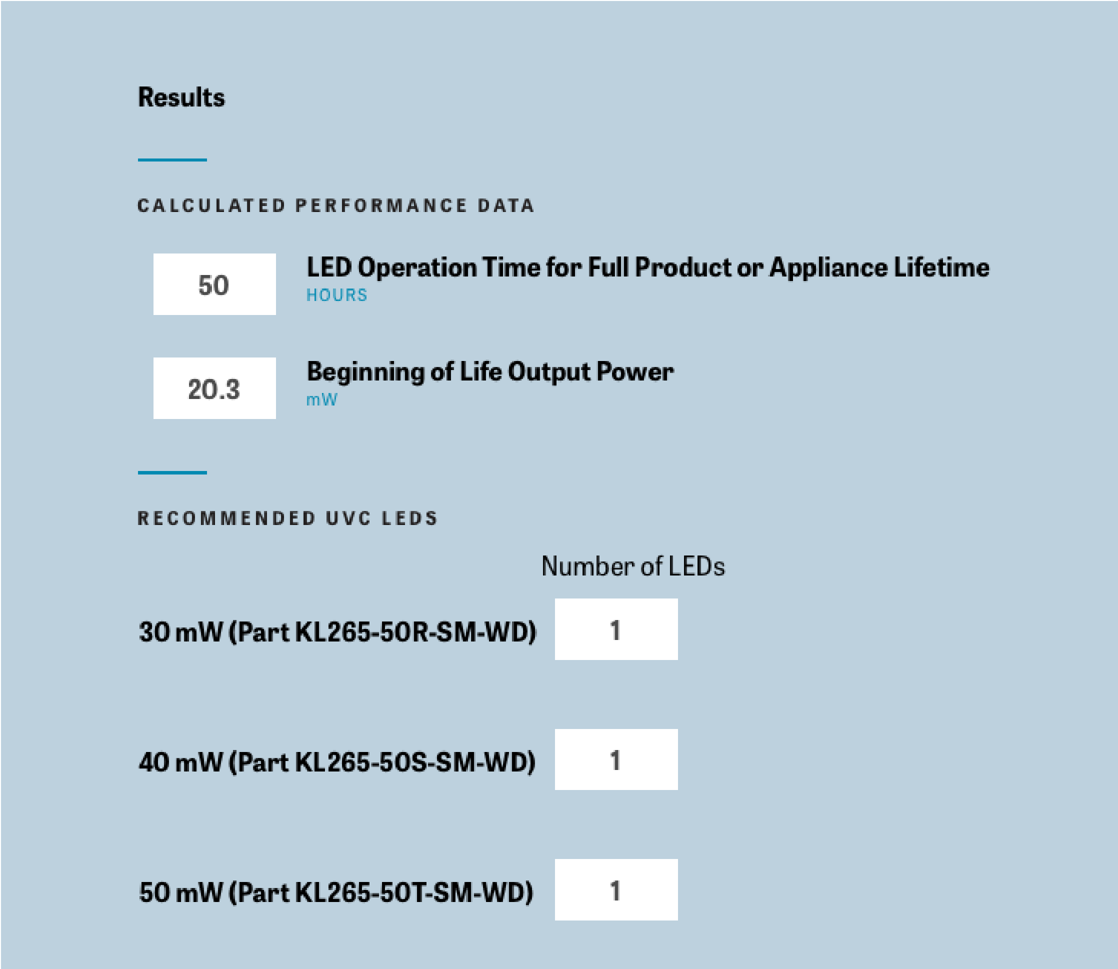
Considering the **effective height** of the water level above the entry of the device pipe (1120 mm) and the entry **pipe diameter** of 20 mm at the top of the device, we calculated the flowrate that the LED's have to disinfect in.

Tank Height (h) (mm)	Exit Velocity (v=√2gh) (mm/s)	Tank Exit Diameter (mm)	Flow rate (v*pi*R^2) (ml/min)
1120	148	20	776

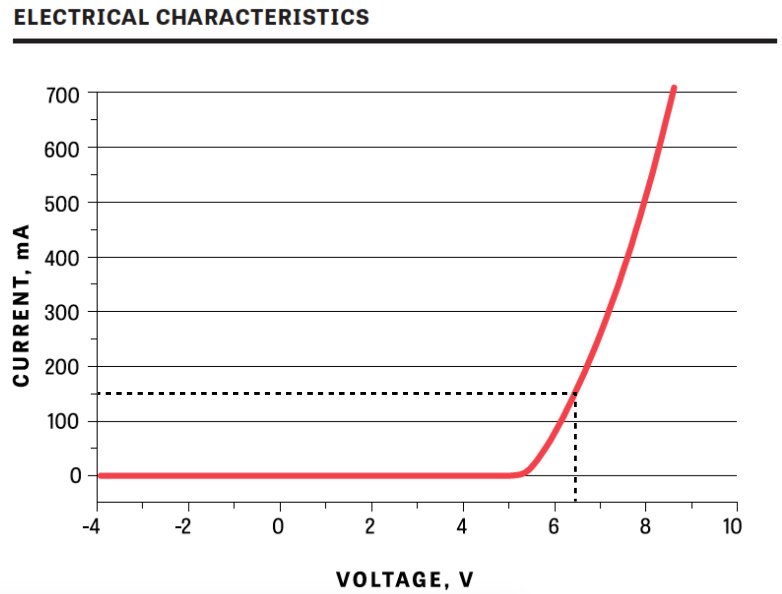
Calculations

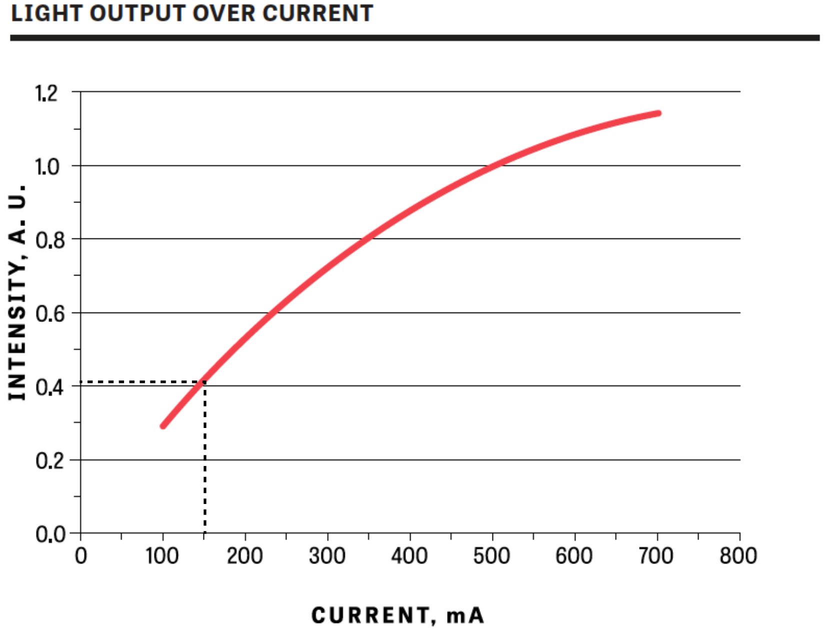
Klaran® is a company that develops UV filtration devices. They have a deep research based focus on developing their UV filtration systems. Apart from developing the filtration system they also manufacture UV LED's generally in the wavelength range of 260-270 nm. They provide a LED calculator that can be used to calculate the optical power output of LED required for a given **flowrate** and disinfection **dosage** requirement.





Calculations





Based on the data provided by Klaran®, we decide to move ahead with a **60mW optical power LED**. From the graph we see that the LED works with **150 mA of current at 6.5V**. At 150mA the optical power output of the LED will be **0.4 times its full output**.
Thus for a 60 mW LED, the optical power output will be **60 X 0.4 = 24mW**.
This is higher than the required optical power output for 50 Hours of functioning.
The LED will only be on for 50 Hours in the span of one year.

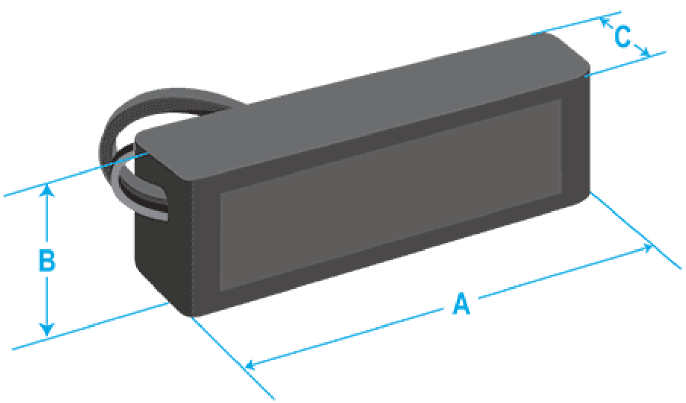
Voltage (V)	Current (mA)	Number of LEDs	Optical Power (mW)	Hours of Use	Battery Power required (mA-Hr)
6.5	150	1	24	50	7500

Battery Selection

BATTERY SIZE
Based on the battery power required as calculated on the previous page we decided to choose a 9V 7500 mAH, graphene based LiPo battery. LiPo batteries are known to have high power density and hence come in a compact form factor.

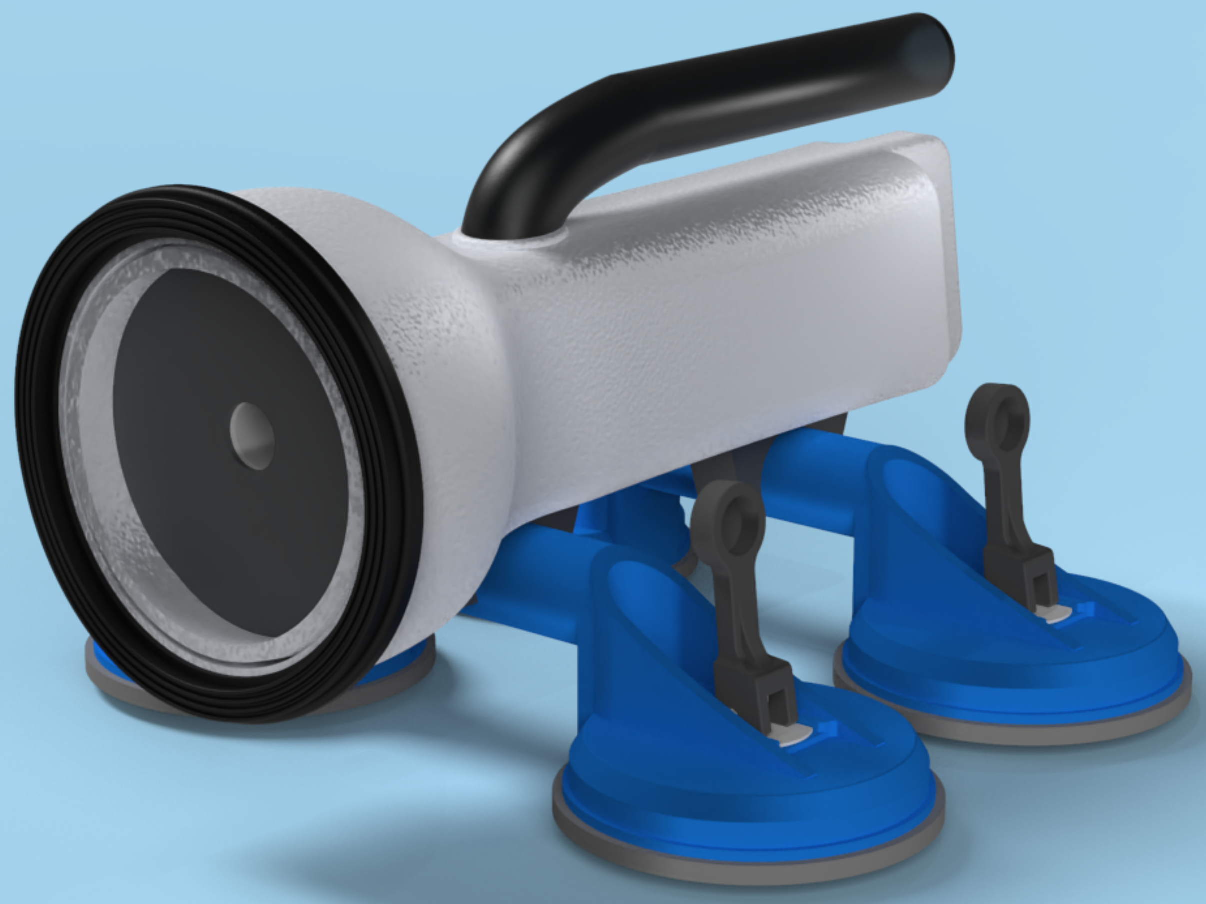
Voltage (V)	Current (mA)	Capacity (mA-Hr)
6.5	150 min	7500

Capacity (mAh)	7500.00	Discharge(c)	90.00
Max Charge Rate(C)	10.00	Length-A(mm)	130.00
Height-B(mm)	47.00	Width-C(mm)	26.00

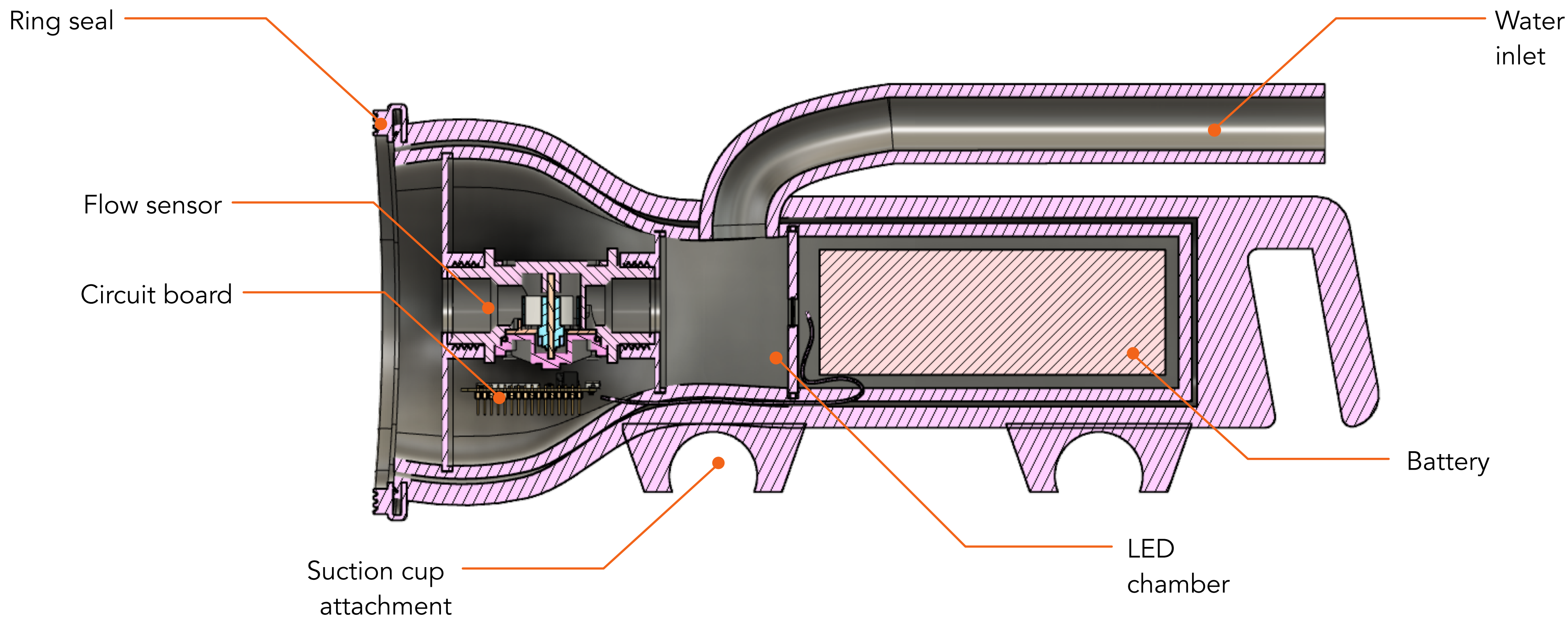


Final Design : The Torch

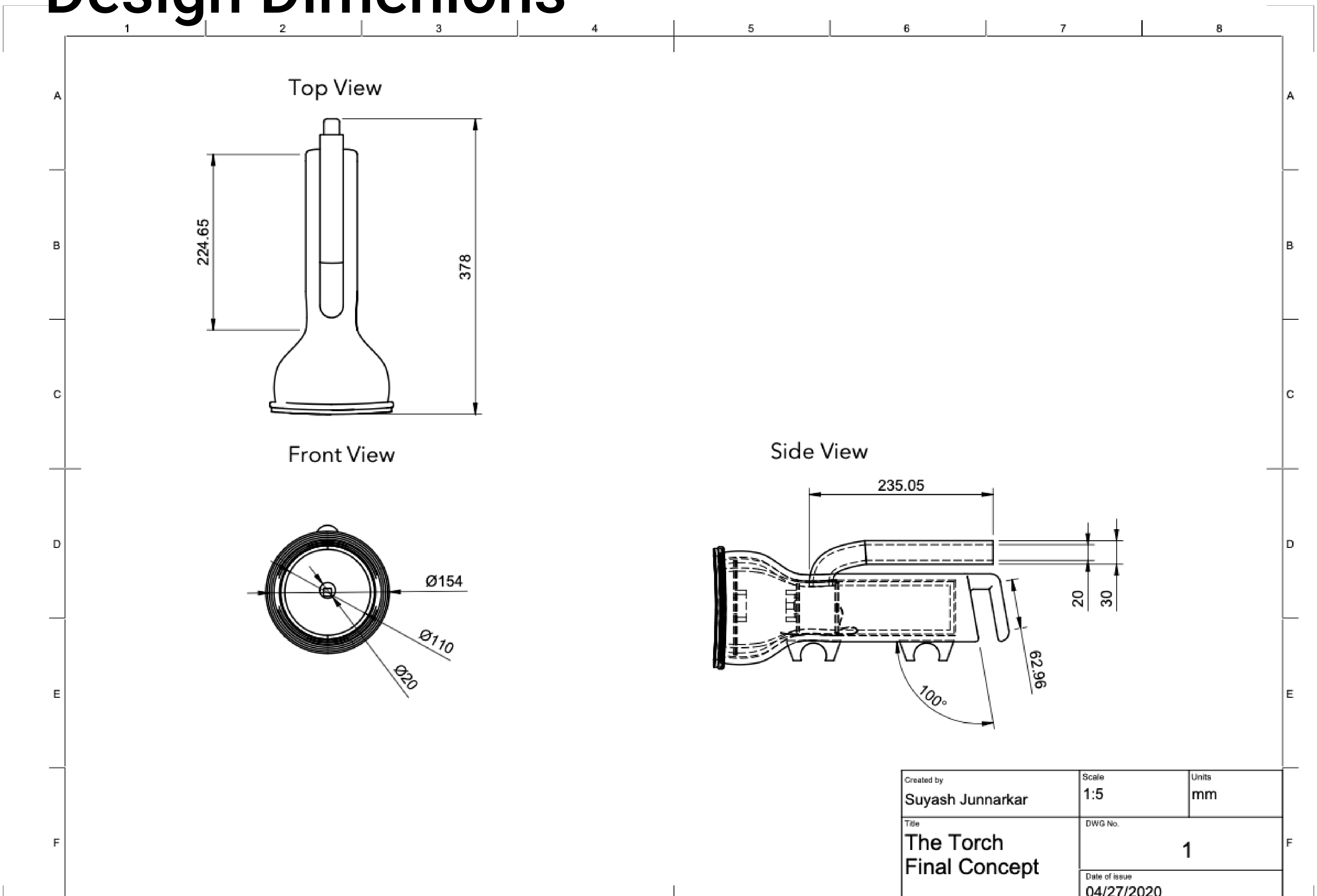
Our final design, dubbed "the Torch", is a UV-C LED water sanitation device meant to be used in community water tanks. The Torch attaches to the inside of the tank where the water is dispensed. This battery powered device intakes the tank's water through the top pipe, sanitizes the water inside the LED chamber, the clean water then passes through a flow rate sensor, and exits the tank through the tap.



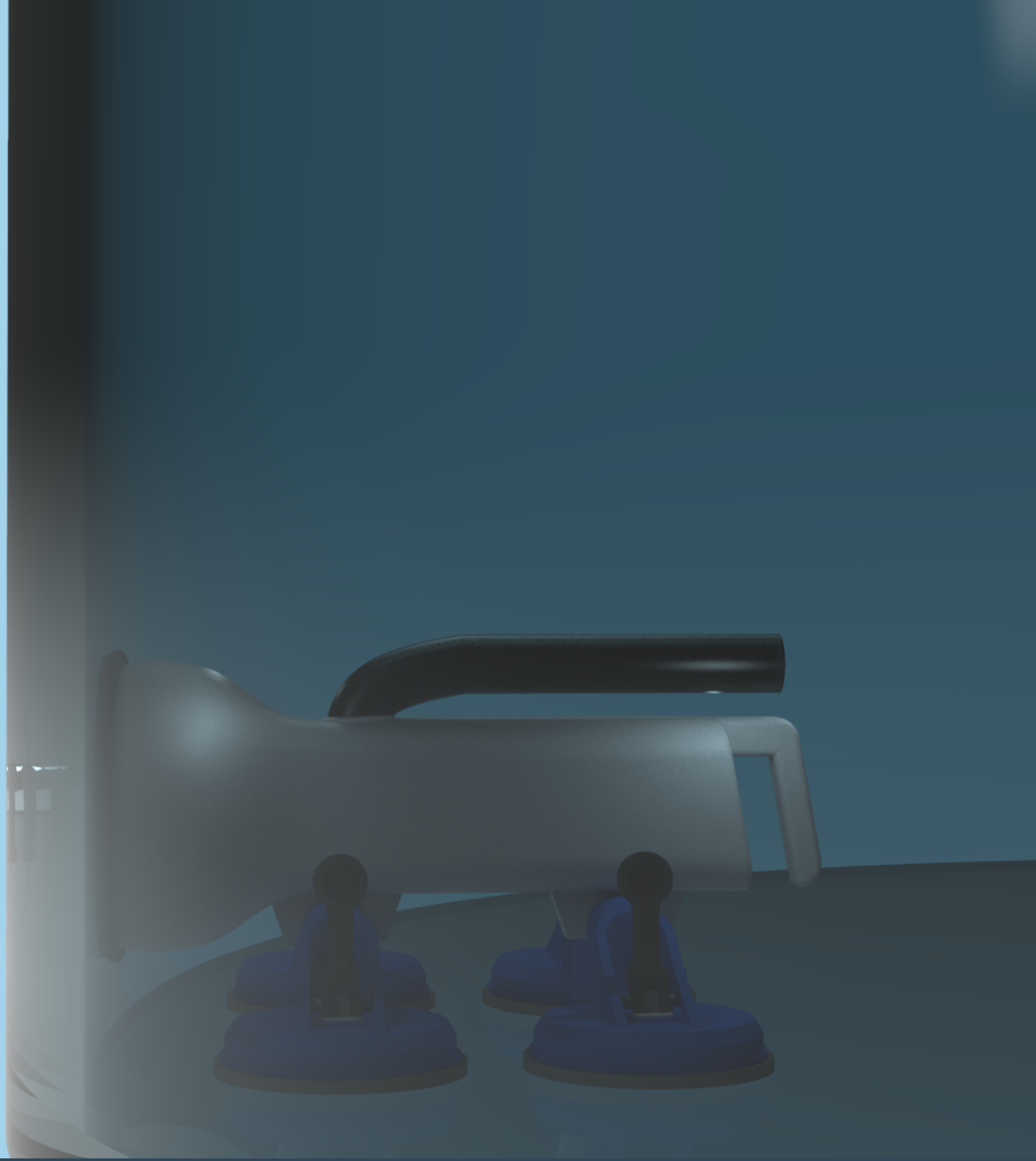
Design Components



Design Dimenions



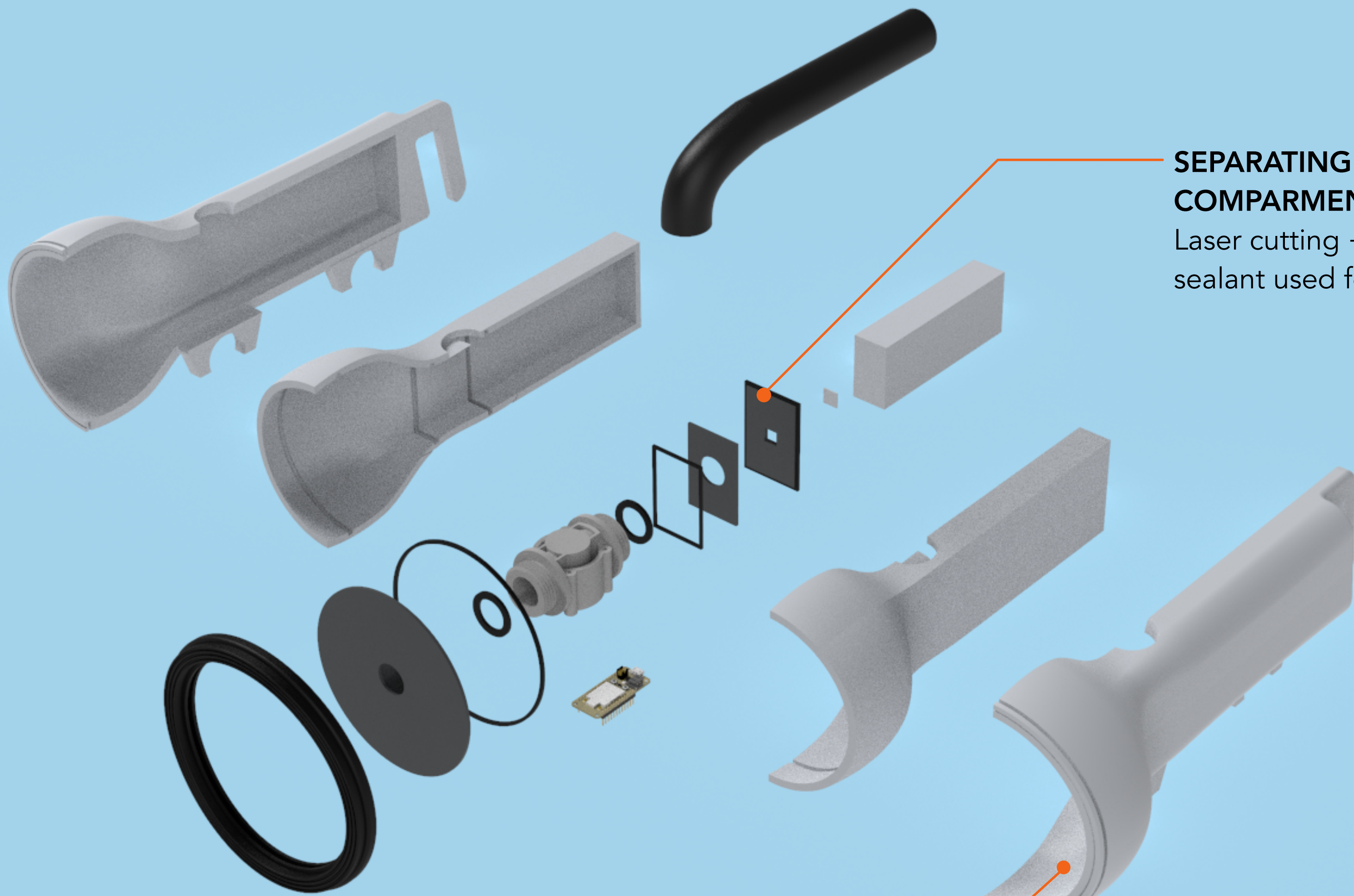
Location



Installation

The installer enters the empty tank and situates the device at the water exit. Using the handle, they can firmly push the device against the wall to create a seal. Then they can use the suction cup levers to secure the device to the tank floor.

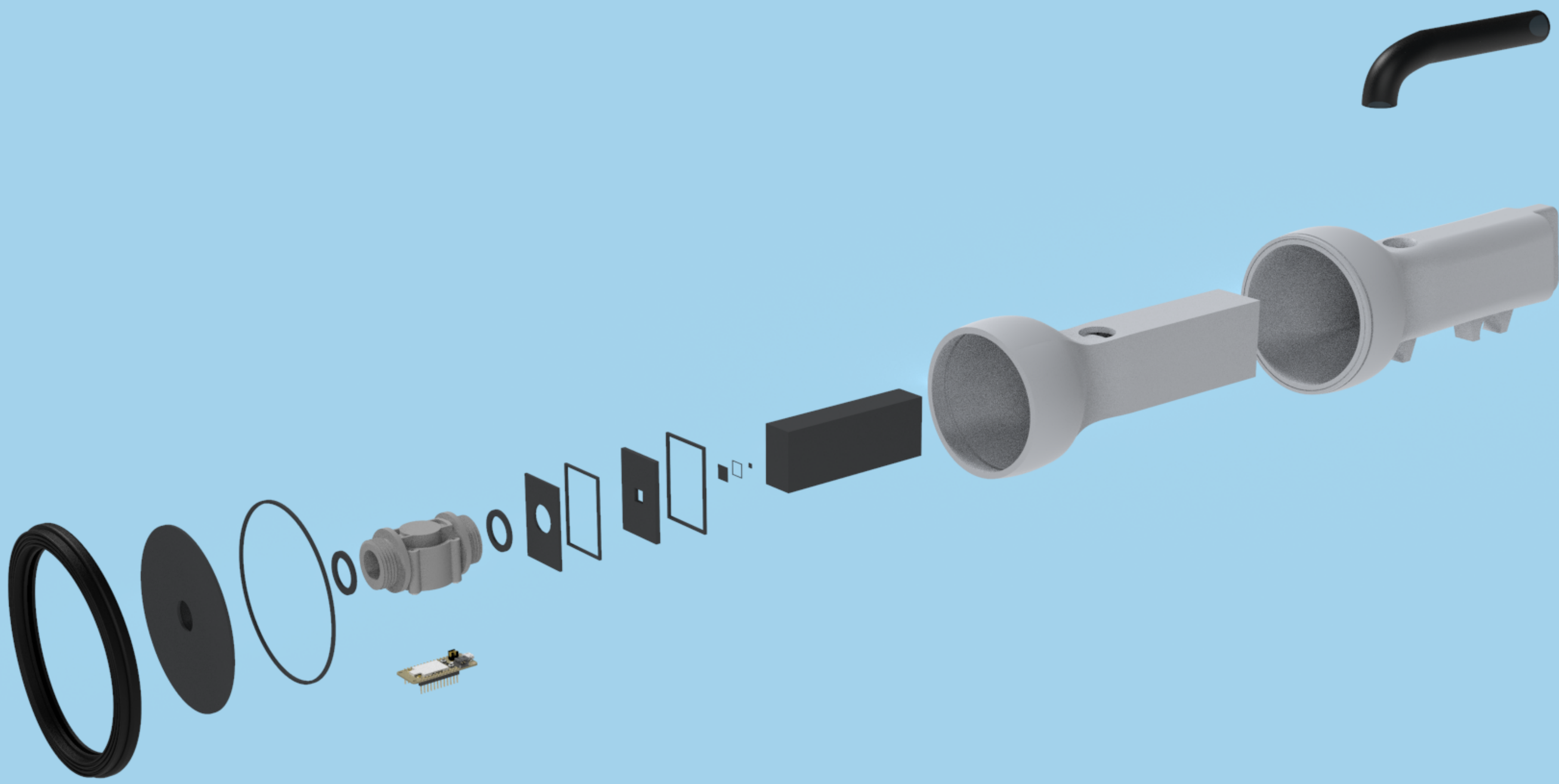
Manufacturing



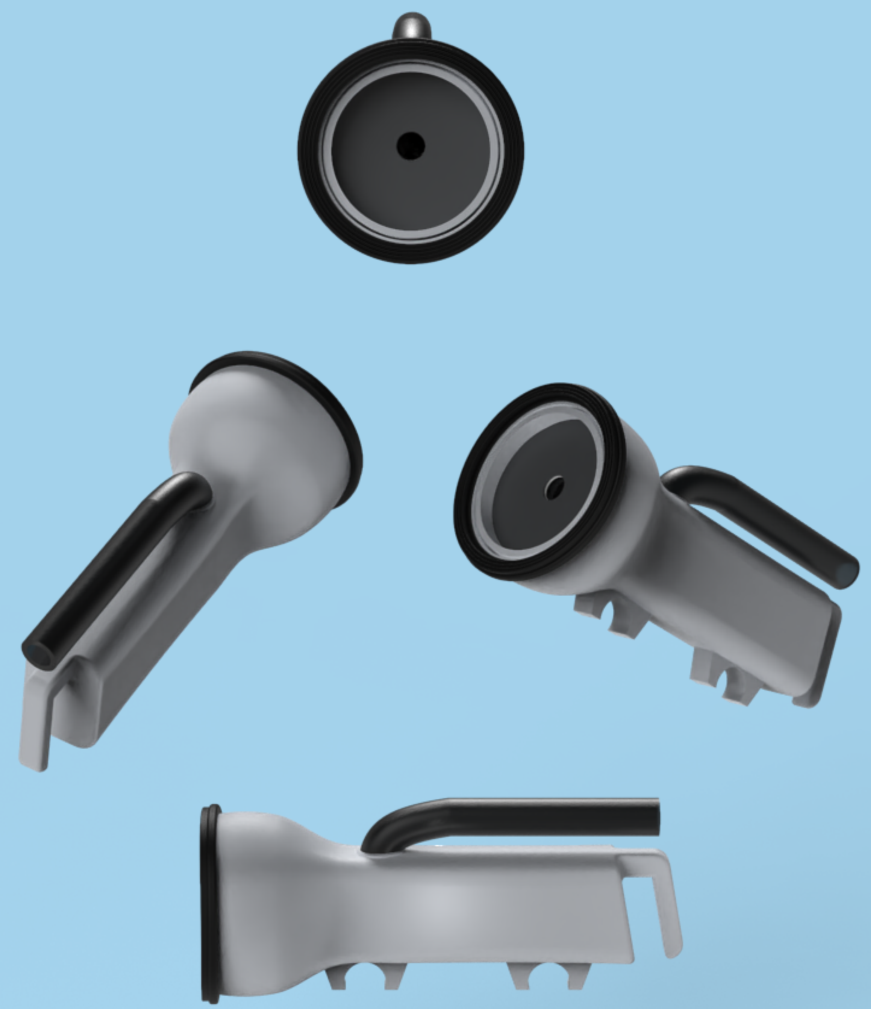
SEPARATING COMPARMENTS
Laser cutting + Silicone sealant used for waterproofing

SHELLS
Injection molding + Silicone sealant used for waterproofing

Assembly



The Torch



Future Scope

SCALABILITY

The challenge given to us in addition to The problem statement was on The scalability of The solution we develop. One of The advantages of our design is that it is not limited to a specific volume of water. The device sanitizes the water at the tank's outlet, therefore our device could work for a 5000 liter tank or a larger one.

POTENTIAL POWER SOURCES VS ANTI-THEFT SECURITY

Our current design is battery powered, however future work could be done to possibly use a renewable energy source. Though we spent time looking into solar cells, we could not determine how to mount a panel to the exterior of the tank to both prevent easy theft while also not permanently damaging the tank itself.

Acknowledgments

WENDELL WILSON + THE SCHOOL OF INDUSTRIAL DESIGN AT THE GEORGIA INSTITUTE OF TECHNOLOGY

We would like to thank our professor, Wendell Wilson, for his continued support, guidance, and encouragement throughout the entirety of this process. We are also appreciative of Georgia Tech and the School of Industrial Design for providing us the resources needed to complete our project.

GOUTHAMI RAO + CDC

A special thanks is in order for Gouthami Rao and the CDC for providing us with the opportunity to work on such an interesting project this semester. We are grateful for Gouthami's constant feedback during our presentations and for answering our many question-filled emails.

References

https://www.researchgate.net/publication/43073434_Demonstration_and_evaluation_of_germicidal_UV-LEDs_for_point-of-use_water_disinfection

https://www.rototank.co.za/wp-content/uploads/2015/11/Vertical-water-tanks.pdf

https://www.klaran.com/images/Products/CIS_Klaran_WD_DS_032020.pdf

https://hobbyking.com/en_us/graphene-7500-mah-2s2p-hardcase-w-5mm-female-bullet-connector.html?queryID=6e572d75c6d1681ba663fca935fbf467&objectID=45476&indexName=hbk_live_magento_en_us_products

https://infrastructurenews.co.za/2017/02/13/sa-company-to-provide-potable-water-to-zambian-village/

https://amthorinternational.com/tanks/water-tankers/

https://agrismartzambia.com/

https://todaysmodernhomes.com/the-essential-four-tools/

https://twitter.com/usembassyzambia/status/999651510496751616

https://www.who.int/news-room/fact-sheets/detail/cholera

https://www.familyhandyman.com/cleaning/mistakes-cleaning-with-bleach/

http://www.enviolet.com/en/uv-disinfection/microfloatr-uv-disinfection-of-closed-tanks.html

https://innovativeh2o.com/sunspring-hybrid-2/

https://www.cdc.gov/

https://www.aquamatetanks.com/water-tank-donations/aquamate-partners-with-world-vision-in-southern-zambia-africa/

https://www.samaritanspurse.org/article/2012-year-in-pictures/

https://www.aquisense.com/