UNIVERSITY OF HARTFORD

COLLEGE OF ENGINEERING, TECHNOLOGY, AND ARCHITECTURE

REPORT ON

LOW-COST WATER PURIFICATION SYSTEM

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ABSTRACT

Various water purification methods are studied to find the best in terms of cost and portability without compromising the quality of water. Various purification concepts are reviewed and compared carefully. The concepts are developed, and the best concept is chosen using the Pugh matrix. It is determined that a revolutionary technology called "Solar Bag" meets the requirements for a low-cost purification system criterion and therefore the approach towards it is identified. Two concepts based on this bag were developed and the project is in the development stage of making this concept working prototype. The stand was designed using SolidWorks software and the Stress analysis were performed using the COMSOL software. A stand model for the prototype was built based on the model using plywood material.

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INTRODUCTION

In the world, more than 2.2 billion people do not have safe drinking water and proper sanitation. It is one of the UNDP (United Nations Development Program) Goals, by 2030, every people in the world should have access to clean drinking water and sanitation. As per our basic human rights, it is essential to get contaminant-free water to all people around the world. "It is shocking that more than 5 million people around the world die annually because of not having safe drinking water". Mostly, the rural areas are those who are in poverty and cannot afford a water purifier to get drinkable water. So, there is a high demand for the requirement of the low-cost water treatment plant. It is essential to consider bringing a cheaper way of purification method for the water to make their lives better.

BACKGROUND

Nowadays, water that people get from their locality is being polluted by contaminants such as lead, bacteria, virus, pesticides, and other chemicals because of not having proper treatment of water from the industries that use these sources and again release them into the water body. This water will contain a higher amount of TDS (Total Dissolved solids) which might go up to 2000 mg/liter which is an alarming issue for human health as it will lead to harmful diseases.

The preferred level suggested by WHO (World Health Organization) is to have a TDS below 300 mg/liter, So, it is essential to reduce these TDS levels in the water to below 300 making it perfect for people to drink the water without any worries. The main purpose of the purifiers is to reduce the TDS level, contaminant particles, bad taste, odor and maintaining its acid levels. There are different water purification methods which include traditional methods such as Filtration, sedimentation, coagulation. Most of the process in the world are developed by mimicking the nature, Filtration is the process that people learned from the nature where when a water from river, lake, pond flows into a stream during that flow, they pass on to various pebbles, sand which removes the solid particles in the liquid, similarly, a set of filters are added to a tank and allowed the water to pass through it to clean the water. Sedimentation is the process in which the particles are allowed to settle down at the bottom of the tank with the help of gravitational force. Coagulation is the process where chemicals are used in the water by adding it such that the larger particles or flocs get deposited at the bottom at a faster rate. As science is known for its uncertainty, there are a lot of innovative technologies discovered to make the purification of water at the level of best like ozonation, reverse osmosis, UV, and Carbon Filtration. But this is not the only solution as these methods are used on a large scale and expensive to implement. As the world keeps on moving to the next level to bring a sustainable balance, it is necessary to find a source that is renewable, sustainable, feasible and cost-effective.

LITERATURE REVIEW

This project involves the study of various purification methods and finding out the pros and cons of each of the purification methods. We have taken 5 methods of purification into consideration, and they are as follows.

1. SEDIMENTATION AND COAGULATION
2. CARBON FILTERATION
3. OZONATION
4. SOLAR DESALINATION
5. SOLAR BAG

Each of the topics and the concept based on the respective purification method is discussed in detail below.

Sedimentation and coagulation

The data from waterborne outbreaks of giardiasis in the United States indicate that simple disinfection as the only treatment for surface water sources is ineffective in preventing waterborne transmission of this infection and that to protect against transmission, all surface water should receive pretreatment, preferably with sedimentation, and filtration in addition to chlorination. In Rome, the absence of filtration and treatment of surface water by simple chlorination only left the residents unprotected against waterborne giardiasis. In Camas and Berlin, outbreaks occurred even though the water supplies were filtered. In these outbreaks, deficiencies in both the operation and installation of the treatment facilities allowed the passage of cysts into the water system and subsequent illness. Lack of proper chemical pretreatment in these situations emphasizes the importance of chemical conditioning infiltration. The use of pressure filters in both systems illustrates the operational problems and the unreliability of pressure filter systems used for microbiological treatment of drinking water. While pressure filters are routinely used for iron and manganese removal, they are not recommended for microbiological treatment. Faulty construction of a new conventional treatment plant in Berlin allowed untreated water to bypass the rapid sand filters and illustrates the importance of superior design and construction inspection.

Waterborne outbreak data, engineering experience, and filtration theory indicate that well operated and properly functioning, conventional treatment plants employing coagulation/flocculation, settling, and filtration should be successful in preventing waterborne outbreaks of giardiasis. The giardiasis outbreaks that have occurred in filtered water supplies do not contradict this reasoning since numerous deficiencies have been found in the design, installation, and operation of these filtration systems. Water filtration theory indicates that organisms the size of Giardia cysts should be removed by conventional sand filters if effective pretreatment of the water is accomplished prior to

filtration. Conventional treatment of surface water includes coagulation /flocculation and settling prior to filtration, or if the settling process is not used, the addition of appropriate chemicals for conditioning of the water or the filter media. New State drinking water regulations adopted by Colorado in 1977 now require surface water supplies to be filtered, as well as disinfected, to remove Giardia cysts

Carbon Filtration

DeSilva, F. J. (2000, January). Exploring the Multifunctional Nature of Activated Carbon Filtration. The author in this article discusses the multiple nature of activated carbon filtration. Activated carbon filtration also known as granular activated carbon filtration (GAC), is used to eliminate the organic matter and residual disinfectants in the water. This paper also gets information about what kind of materials are used to make this filter, different properties of activated carbon and design parameters of its system. This article contains the design parameters required for it and amount of organic and residual disinfectants removed as per the suggested design process is discussed. This article supports this project by giving information for developing the design concept of the carbon filtration system by providing the required dimensions, getting knowledge about the number of contaminants removed, its properties and different constituents involved in the carbon filter.

S.G.J. Heijman, R. Hopman (1999), Activated carbon filtration in drinking water production: model prediction and new concepts, Colloids and Surfaces A: Physicochemical and Engineering Aspects. The author of this book did research on how far the GAC purifies water by removing the pesticides in it. He also makes an analysis of the lifetime of a GAC and its loss of purifying the water over a period. He used fast laboratory experiments instead of full-scale experiments on GAC as it will be a time-consuming process. These results are converted into full-scale experiments. The author explains about different combinations of treatments and new adsorbents as the fast lab experiments are quicker. This research is useful to know the different testing processes and the combination for the GAC and can be implemented into this report if this model is used for the future modelling of GAC.

OZONATION

The construction of electric discharge ozone generators developed from the apparatus originally designed by Werner von Siemens in 1857 in Germany. Brodie (England) and Berthelot (France) also designed early ozone generators. Siemens ' first ozonize essentially consisted of two coaxial glass tubes, the outer coated externally, and the inner coated internally with tin foil, air feed gas being passed through the annular space. (*Ozone For Industrial Water and Wastewater Treatment A ...*, https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=20006FGE.TXT.) Brodie substituted water as the electrode material in place of tin foil, and Bartholet used sulfuric acid.

The Siemens type of ozone generator has been developed commercially into a form suitable for industrial production of ozone, and today most of the ozone generating systems installed in water and wastewater treatment plants are of this type. Glass tubes are coated internally with a metal dielectric and the individual tubes are cooled by means of water.

Modifications to the original Siemens generator have been made, primarily dealing with the method of cooling, and today many diverse types of generators are available. ("*Ozone For Industrial Water and Wastewater Treatment A ...*, https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=20006FGE.TXT.") All operate on the same general principle, corona discharge, which requires high voltages and/or high frequencies, thus creating considerable heat. In turn, this requires that the generators be cooled to maximize ozone production yields and minimize power consumed. Cooling is usually accomplished by means of water (Siemens and Otto genera tors), air (Lowther plate type generator) or water and oil (cooling of both electrodes, one with water, the other with oil).

Solar Desalination

In the world seawater has a spread-out of over 97% and only less than 3% of the water is freshwater. The amount of freshwater that people obtain is much less than it produces. It is important to find a technology that can convert saltwater into freshwater as the water resources are getting depleted. The most effective way of converting seawater into consumable water is by solar desalination process.

Chandler, D. L. (2020, February 6). *Simple, solar-powered water desalination*. MIT News | Massachusetts Institute of Technology. The paper discussed about solar desalination was conducted by researchers at MIT and in China. It is a passive solar desalination system that can make out 5.67812 liters of freshwater. The system is manufactured in such a way it has many flat solar evaporators and conductors which are placed in order in a vertical arrangement. The system transparent aerogel insulation. one of the main objectives of the project is to get a low-cost solar desalination system with an efficiency higher than the previous models. The main research was focused on how to increase the efficiency of the system and achieved it by enabling each stage to desalinate the salt water by utilizing the heat generated by the previous stage instead of dissipating the energy. This method helped the researchers to reach an efficiency of 385 percent in converting the light from the sun into water evaporation process. This paper helped to gain knowledge about the process of solar desalination, more specifically being a topic that focuses on the low-cost purification system that co-relates to this paper gives a ton of details on developing the concept for this project.

Solar Bag

The basis of solar-based disinfection is not a new method as it was used by olden days people mostly by the native of Nepal, Ethiopia, Indonesia where they utilized the Sun's UV to purify water that they fetch nearby water resources. But the time for this type of purification takes a longer time to complete the process, though it is long, it inactivates bacteria and viruses. The drawback of this process is that it does not purify chemicals, the color of the water is not made clear.

Dessie, A., Alemayehu, E., Makonnen, S. et al. Solar disinfection: an approach for low-cost household water treatment technology in Southwestern Ethiopia. J Environ Health Sci Engineer 12, 25 (2014). In this research paper, the author has done research on basis of the household solar disinfection method (SODIS). Makonnen studied the process of how people of southern Ethiopia effectively purify their contaminated liquid by taking various temperature and concluded that further study must be taken to improve the method used. This literature will be helpful to know the basics of the solar disinfection method and to know which location this kind of disinfection can be employed and temperature requirements for it.

Katherine Lawrie, Andrew Mills, Manuel Figueredo-Fernández, Sergio Gutiérrez-Alfaro, Manuel Manzano, Matthias Saladin. ("*Selected Papers from EUROPTRODE 2014 - Article Selections ...*, https://www.journals.elsevier.com/sensors-and-actuators-b-chemical/article-selections/selected-papers-from-europtrode-2014.") UV dosimetry for solar water disinfection (SODIS) carried out in different plastic bottles and bags, Sensors and Actuators B: Chemical, Volume 208, (2015). The author of this research paper has done various research on different plastic bottles and bags to achieve a bacteria concentration level lower than the limit for Escherichia coli, Enterococcus. and Clostridium perfringens, using PET bottles, PE, and PE/EVA bags. As the result, it was revealed that PE was effective to disinfect the contaminants at solar UV of 290-385 nm with a dose of 385 kJ m–2. This paper will help get the knowledge of what type of material can be used to make the process more effective in this experiment.

Mark D. Owen. - Paralytics Technical Report (2015). The author has done in-depth research on light-activated nanotechnology for the purification of water. He has made a strong comparison between the methods of purification already in the field to that of his product (Solar bag). The solar bag is also known to be a photochemical water purifier that has five different processes which effectively removes the contaminants in the water. In this research, Owen has the sunlight to activate the nanotechnology coated fibrous to activate the processes. This paper shows that anatase Titanium Dioxide (TiO_2) is a highly effective catalyst for the conversion from light into hydroxyl radicals. This research will be useful to get information about how the solar bag works and what type of nanotechnology material is used, and the type of material used for the solar bag.

OBJECTIVES

The goal of the project is to provide a cost-efficient water purification system to give clean water for 30 to 50 people of capacity. The prototype system made must be portable, affordable, and has a sustainable design. The main challenges to this project are storage for holding water up to 120 liters, analyzing for a material which is cost efficient, of quality which does not contaminate the water and withstand for a lifetime of 2 years, the prototype model should be portable in such a way it can transported to the required location, research study on reducing the bacteria in the water during filtration and to find appropriate water purification method that would fit for the purifier. And based on the study, it is important to make a prototype that is portable, cost efficient, sustainable design.

CODES AND STANDARDS

WHO produces international norms on water quality and human health in the form of guidelines that are used as the basis for regulation and standard setting world-wide.

The Guidelines for drinking-water quality (GDWQ) promote the protection of public health by advocating for the development of locally relevant standards and regulations (health-based targets). According to the WHO the limit for each substance is given below.

- Arsenic 10µg/l
- Barium 10µg/l
- Boron 2400µg/l
- Chromium 50µg/l
- Fluoride 1500µg/l
- Selenium 40µg/l
- Uranium 30µg/l

For organic species, the following amounts are considered tolerable: -

- Benzene 10µg/l
- Carbon tetrachloride 4µg/l
- 1,2-Dichlorobenzene 1000µg/l
- 1,4-Dichlorobenzene 300µg/l
- 1,2-Dichloroethane 30µg/l
- 1,2-Dichloroethene 50µg/l
- Dichloromethane 20µg/l
- Di(2-ethylhexyl) phthalate 8 µg/l
- 1,4-Dioxane 50µg/l
- Edetic acid 600µg/l
- Ethylbenzene 300 µg/l
- Hexachlorobutadiene 0.6 µg/l
- Nitrilotriacetic acid 200µg/l
- Pentachlorophenol 9µg/l
- Styrene 20µg/l

Any water source that has the above limits is considered safe for drinking and does not affect human health in the long run.

METHODOLOGY

Based on the study of the various water purification systems, the best methods were selected. On implementing these methods in a concept, one design concept for every method was designed. These Design concepts were carefully rated based on ten criteria. The criteria are capacity, cost, location applicability, portability, ability to assemble, ability to recycle, durability, Power requirements and eco friendliness. Each criterion was given a weightage and the score for each concept was calculated. The concept that scored the highest in this comparison was chosen and a working prototype will be developed in the future.

DESIGN CONCEPTS

CONCEPT-1

Adding iron or aluminum salts, like aluminum sulphate, ferric sulphate, ferric chloride, or polymers, to the water is coagulation. These chemicals are referred to as coagulants and have a positive charge. The positive charge of the agent neutralizes the negative charge of dissolved and suspended particles within the water. Once this reaction happens, the particles bind along, or coagulate. The larger particles, or floc, are significant and quickly settle to the bottom of the facility. This subsidence method is termed sedimentation. The subsequent diagram illustrates the fundamental reactions and processes that occur during coagulation.

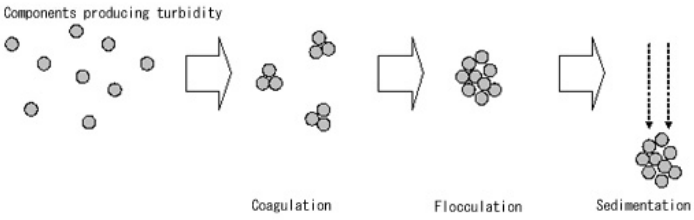


FIG-1 Sedimentation and Coagulation

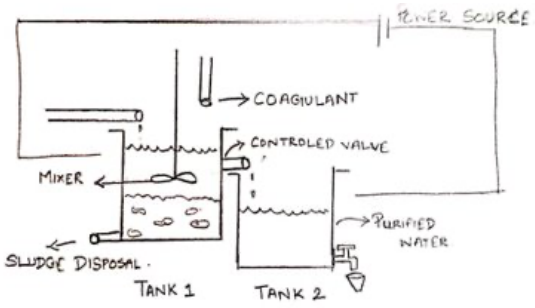


Fig-2 Sedimentation and coagulation Model

The concept involves the process of Coagulation, Flocculation and Sedimentation. The water initially entire the tank 1, where the coagulant is mixed with the water. The impurities settle down and the pure water that is separated is transferred to tank 2. The tank material would be polyethylene as it is lightweight and cost effective. Each tank would hold up to 135 gallons of water. The dimension of the tank is taken into consideration based on the sedimentation process. The tank should have a larger surface area to accompany the waste sludge. So, the dimension of each tank will be 60”x 18”x30”. We have chosen that the model would have a flow of 6 gallons/ min, so that the freshly added water does not disturb the settled down sludge. The entire system will be connected to a power

source(solar). The coagulants added would be ferric sulfate (a flocculant) and calcium hypochlorite (a disinfectant). The benefit of the system is that it speeds up the sedimentation and eases the process of separation. But at the same time, it is an additive process which involves chemicals. The byproducts can be hazardous if not treated properly.

CONCEPT-2

Carbon filters remove contaminants through adsorption. means that contaminants are attracted to the surface of the activated carbon and held to it, much the same way a magnet attracts and holds iron filings. Granular activated carbon (otherwise known as GAC) filters have extremely high adsorption capabilities and can remove a wide variety of contaminants. The lifespan of a carbon filter can vary based on how dirty or contaminated the water is. Carbon quality, humidity and usage can also factor into how long a carbon filter can last.it removes some organic chemicals, nauseating odors and taste in the water. For this concept, the dimension of the filter is 9.75" by 2.5." Each filter can filter up to 5000 gallons. This model does not require electricity and the pressure of water determines the flow rate. It can have flow rates up to 1 GPM. This is less expensive compared to systems using electricity. It needs to be used regularly to avoid the formation of bacteria.

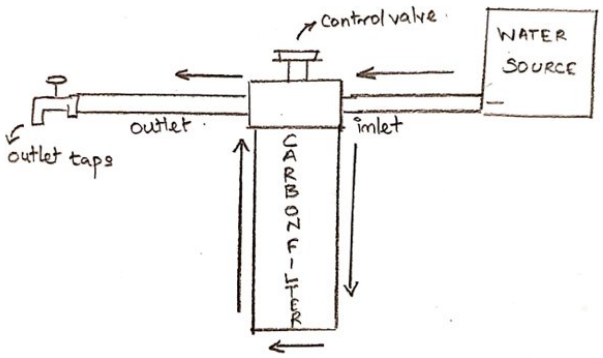


FIG-3 Carbon Filter

FIG-4 Carbon Filter Model

CONCEPT-3

Ozone is a powerful oxidant, stronger than chlorine. It is used to disinfect, deodorize, decolorize, and decompose organic matter in water. This system is exceptionally reliable and efficient. This concept is a modification based on the earlier concepts. At the point where the ozone mixes with the water, turbulence and bubbles are created; these ensure that the ozone contacts as much of the untreated water as possible. The greater the water flow rate, the greater the pressure differential and turbulence, and the more effective the treatment. It includes the process of ozonation with the other

purification methods. This system requires 4 tanks in total. Each tank dimension will be based on the size considered in concept 1. This concept requires a bigger electricity supple as an ozone generator is involved. As the ozonation process require the generator, the overall cost for this system is also high. However, the cost of maintaining is significantly low.

Initial cost about $1200 + overhead

Costs about 0.07 $/kWh in maintenance

Power consumption-4.5 kWh/lb. Ozone (generator)

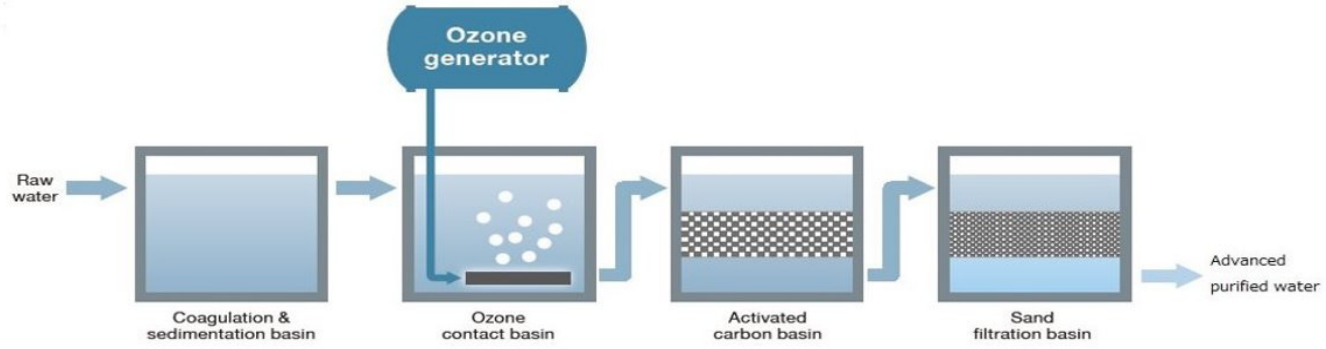


FIG-5 Ozonation

Ozone treatment can produce harmful by-products in drinking water. For example, if bromide is present in the raw water, ozone reacts with it to form bromate, shown to cause cancer in rats. Ozone equipment is one of the most expensive water treatment technologies and it conflicts with our constraints.

CONCEPT-4

Solar desalination is based on the process of evaporation and condensation. Using the direct heat from the sun or using electricity generated by solar cells to power a membrane process. It produces water with a low salt concentration from seawater or brine using solar energy. In this concept the total number of tanks used is 4. As the source of energy is solar, it could even be used to power this concept.

At the purification rate of 5.78 liters per square meter, it would require at least 20 square meters of panel.

Price per square meter @ $120

Total cost= (20*120) + overhead

= $3000 (expensive)

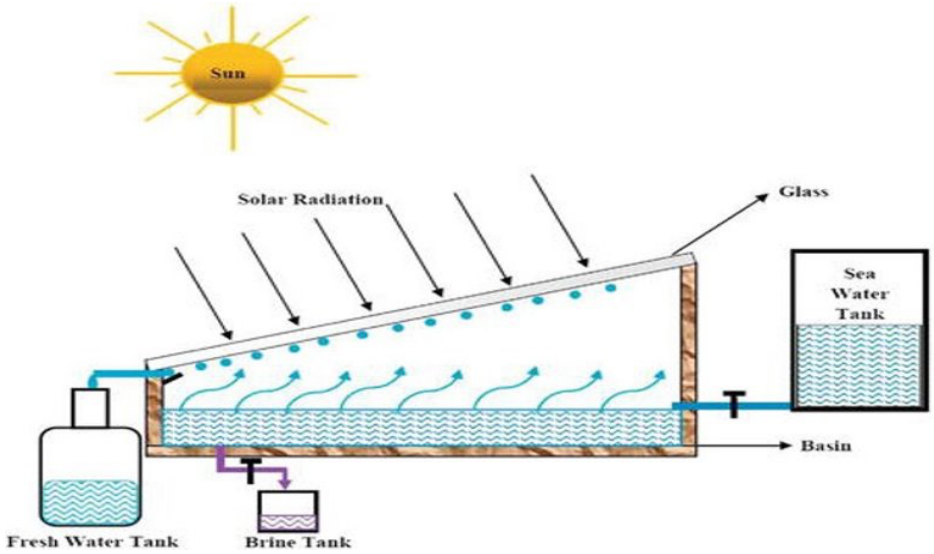


Fig-6 Solar Desalination

But one advantage of this system is that it is very cheap to maintain. This method can be highly effective in rural areas along the coast, where the only source of water is the sea. Although it is easier to maintain such a system, it requires an extremely high initial cost. This concept is also exceedingly difficult to transport and requires a large space for setup.

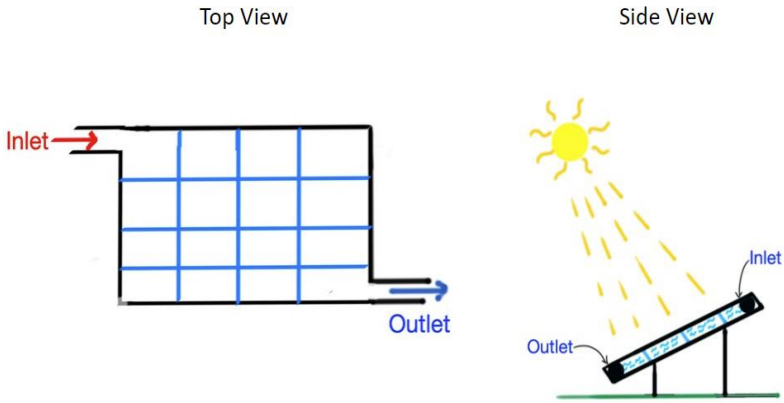
CONCEPT-5

This concept is based on a small water purification bag. The Solar Bag is a sunlight-activated reusable water purifier that destroys or reduces the broadest range of contaminants without pumping, electricity, chemicals, or replaceable components. Simply place the Solar Bag in the sun for a few hours and enjoy purified water. Through solar-activated nanotechnology, the Solar Bag offers the broadest contaminant treatment of any portable water purifier. The water is purified in 2-3 hours on a sunny day or 4-6 hours on a cloudy day or if the source water is tea colored. A Pure-Blue process timer indicates that the purification process is complete. It will not clog like a filter and no pumping

or backwashing is needed. It can be used for 100s of times. It uses no chemicals, so the water tastes great.

FIG-7 SolarBag

It involves five processes of intense cleaning of the water, they are photolysis, photocatalytic oxidation, photocatalytic. reduction, photo disinfection, and photo adsorption. Fig 9 shows the upscaled version of the solar bag. The main benefit of this concept is that it requires no electricity or battery. There are no chemicals involved for its purification process.According to Puralytics, 1 Solar bag can purify 10.5 liters/day and can be used for over 100 times. One of the most notable features is that it requires no technical knowledge and can be used by anyone. the Weight per bag is around 105g and the total weight comes around 10kg. The bag dimensions are as follows



- 1x1.5x0.4 (m) with a capacity of 120. Fig-9 describes the second design concept developed based on the technology of the

Fig-8 Solarbag Model-1

SolarBag. In this model, it is a replica of a solar panel where the PV cells are interlinked together, similarly, the multiple SolarBags are interlinked together to and framed into a panel and fixed at an angle where the panel can directly receive sunlight.

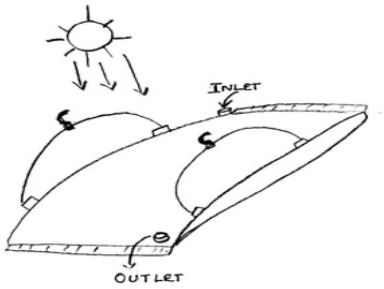


Fig-9 SolarBag Scaled-up version Model-2

The cost estimation for Model-1 as follows: -

MATERIAL	**COST**
plywood	$32
bag	$135
Polyethylene connectors	$10
Miscellaneous cost	$50
Total material cost	**$980**

Table – 1 Cost estimation for Solarbag model-1

DESIGN METHOLOGY

PUGH MATRIX

The Pugh Matrix is a criteria-based decision matrix which uses criteria scoring to determine which of several potential solutions or alternatives should be selected. Using this method, we were able to evaluate different concepts based on various criteria. On evaluation, it was found that concept -5 scored the most points with 33.2, followed by concept-4 with the score of 28.2. The other concepts scored below 25 in the decision matrix. As concept-5 scored most of the points, then it was brought to the conclusion to develop the prototype based on concept-**5**.

Low Cost Water Purification System:							
S.NO		IMPORTANCE	CONCEPT 1	CONCEPT 2	CONCEPT 3	CONCEPT 4	CONCEPT 5
	CRITERIA	WEIGHTAGE	SEDIMENTATION-COAGULATION	FILTRATION-CARBON	FILTRATION-OZONATION	SOLAR DESALINATION	SOLAR BAG
1	Capacity	1	4	2	4	4	3
2	Cost	1	5	2	4	2	5
3	Power Requirements	1	3	4	3	5	5
4	Location Applicability	0.8	3	4	3	4	5
5	Portability	0.75	3	4	3	3	5
6	Assembility	0.75	3	3	3	3	5
7	Durabilty	0.7	3	3	2	4	4
8	Eco-Friendly	0.6	2	2	2	5	4
9	Recycle	0.5	3	3	3	5	4
10	Maintenance	0.3	4	2	3	4	5
			24.9	21.85	22.9	28.2	33.2

Rating scale from 5 (max) to 1 (min)

Excellent	
Very Good	
Good	
Average	
Poor	

Table – 2 Pugh Matrix

SOLARBAG

When the capstone-2 project term started, the team decided to opt for the Model-2 (Fig-9), "The scaled-up version of the Solarbag". Based on calculations made for amount of water required for a small group of people (approximately 40 people), a 30-gallon bag was required to satisfy the need of the project. When considering other specifications of the bag such as a bag that would withstand wear and tear, should have a large valve for the easy replacement of the mesh, material that should allow UV-A rays between the range of 300 – 400 nm, it is important to find a supplier who can modify the bag as per the requirements mentioned above. EZ-pack were selected by the team as they have already worked with Puralytics for their bag manufacturing. When EZ-pack was contacted, they had different standard size bags from which the closest size bag of 25 gallon of dimensions 33.5 x 37.5 x 8 inch was selected and the bag would look as shown in the below figure,

Fig 10. Solarbag scaled-up Model

Some of the modifications are to be made to the bag as the above bag is manufactured for different purposes. So, some of the specifications were listed and provided to the EZ-pack in such a way that they can figure out a bag that would fit the project's requirements. As Blue dye is an important indicator in the project as it indicates the user whether the bag is filtered or not, transparent color along with rest of the specifications listed above was requested to EZ-pack.

The mesh that must be implemented into the bag was a recent nanotechnology mesh which is made of ceramic that is 2 times faster than the previous mesh that has been utilized in the traditional Solarbag. The mesh is made up of Nanotechnology photocatalytic coating that uses the AOP Plus process known as Advanced Oxidation Process that is used to purify the water with help of the hydroxyl particles. As the bag is scaled up, the size of the mesh should be proportional to the size of

the bag and multiple layers of mesh can be added for better results in the purification process by pleating the mesh together. Thus, a scaled-up model of the Solarbag with the ceramic mesh can be constructed after the supply from the manufacturers.

STAND

The next important part of the project is to construct a stand for the bag as it would be helpful in protecting the bag from wear and tear during placement in any areas of the world, also the angle of the stand plays a significant role as to get the maximum amount of sunlight to get exposed by the bag. There are different models that were developed for the bag which are hanging model, Pin slot folding stand and 3-piece stand model. Considering easy manufacturing, the 3-piece stand was selected.

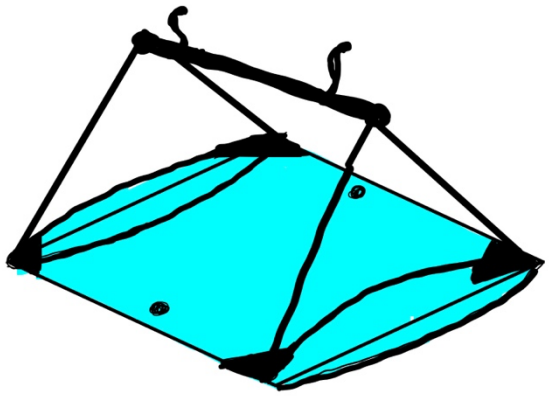


Fig-11 Hanging bag model

The 3-piece stand contains 1 rectangular plate with 2-stand for support. The specifications of the stand are as follows,

Dimensions of the rectangular plate – 47 x 28 x 0.625 in.

Material – Plywood

Angle of the stand - 45° degrees.

Software used to model that stand – SOLIDWORKS

Stress Analysis Software – COMSOL

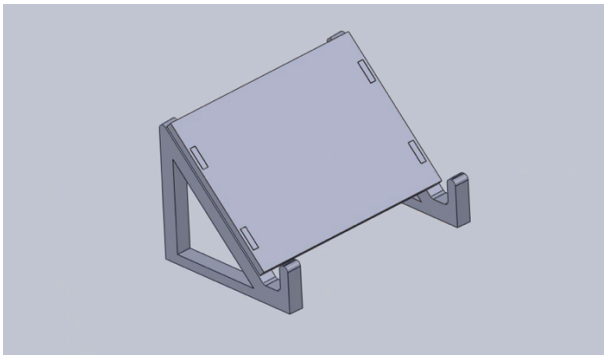


Fig-12 Stand model-1

The angle of the stand depends on the place and month of the year it is being used, typically, 45° is optimal for the spring season. If it is to be applied to different seasons, then different angles may apply to the stand for getting a good exposure of the sunlight.

To know whether material can withstand the load of the 25-gallon bag, maximum stress and defection calculation were calculated. To keep it simple, a uniform load was considered for the calculation purpose. The formulas used for the calculation are listed below,

$$\sigma_{max} = \frac{-\beta q b^2}{t^2}$$, Flat Rectangular plate Uniform loading stress equation, (lbf/in^2)

$$y_{max} = \frac{-\alpha q b^4}{E t^3}$$, Maximum Deflection, (Inches)

(Conversion factor from N/m^2 into lbf/in^2 is 1 N/m^2 = 1/6895 lbf/in^2)

Maximum Stress on the Rectangular plate = **269.23 lbf/in^2**.

Maximum deflection = **0.196 inches**.

Also, Stress distribution was found using the COMSOL software for the stand for better understanding. Physics applied to the model is Solid Mechanics with a stationary study. A load F of 1178.8 N (265 lbf) is given as parameter. The stand selected to be a fixed constraint and load is applied on the rectangular plate. A finer mesh is given to the model as it has small edges and faces. After computation, the results are plotted in the software. For stress, first principal stress theory is selected, and a contour plot is plotted for that respective theory, and the results as images are shown below,

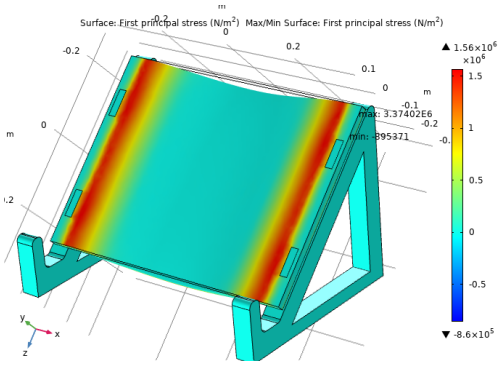


Fig-13 COMSOL Stress analysis on stand-1

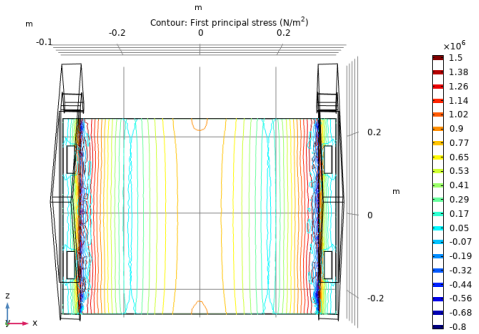


Fig-14 Contour plot

For the COMSOL analysis, the model differed with the thickness, the remaining size remained same as per the dimensions mentioned above. The thickness used during the analysis is 0.75 inches plate. The maximum stress values from the analysis are listed below,

Maximum Stress value (COMSOL Software) = **226 lbf**/in^2

Maximum Stress value (Hand Calculation) = **186 lbf**/in^2

The calculation varies a bit as the COMSOL takes multiple points of stress values that may result in even higher stress values at certain points on the plate whereas the in the hand calculation, uniform load for the center part is calculated.

To have a better stress distribution earlier version of the stand model was updated with holes in the plate and extra support. This model is a 4-piece model that contains 1 rectangular plate with holes and 3- stands for support. The specification for the stand is listed below,

Dimensions of the rectangular plate – 47 x 28 x 0.625 inches.

Hole Diameter – 6 inches

Material – Plywood

Angle of the stand - 30° degrees.

Software used to model that stand – SOLIDWORKS

Stress Analysis Software – COMSOL

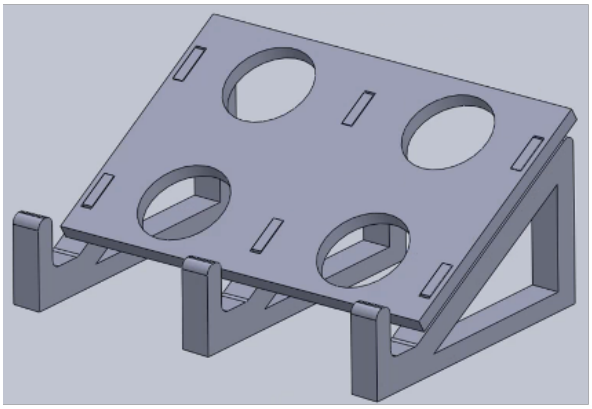


Fig-15 Updated version of stand

For this stand the angle changed from the earlier version from 45° to 30° for better placement of bag and better exposure to the solar energy, Still the angle depends on the place where that is utilized.

The stress calculations were performed for this stand, the calculations were like that of the earlier model, but as there were holes in the stress concentration factor were found for this stand.

For Thickness, t = 0.625 inches,

Maximum Stress on the Rectangular plate = **247.19 lbf/in^2**.

Maximum deflection = **0.180 inches**.

Stress concentration factor, Kt = 2.3

Stress concentration and related formulas are listed below,

$k_t = \frac{\sigma_{max}}{\sigma_{nom}}$, Stress concentration factor (K_t)

$\sigma_{nom} = \frac{F}{(w-a)\times t}$, Nominal Stress (N/m^2)

$\sigma_{\max} = \frac{-\beta q b^2}{t^2}$, Maximum Stress (N/m^2)

$y_{\max} = \frac{-\alpha q b^4}{E t^3}$, Maximum Deflection (Inches)

(Conversion factor from N/m^2 into lbf/in^2 is 1 N/m^2 = 1/6895 lbf/in^2)

Also, COMSOL software was used to see the stress distribution through the rectangular plate with holes, the conditions applied for this COMSOL model were same as the earlier model, the results are shown below,

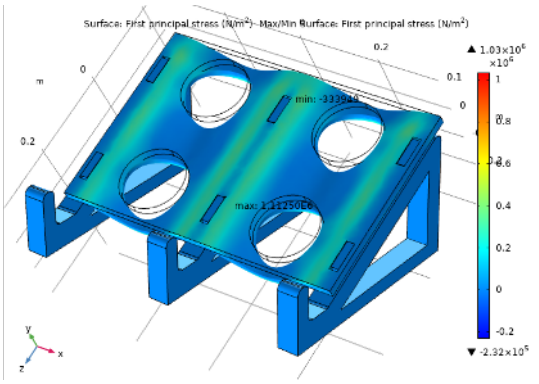


Fig- 16 COMSOL Stress analysis on Updated model

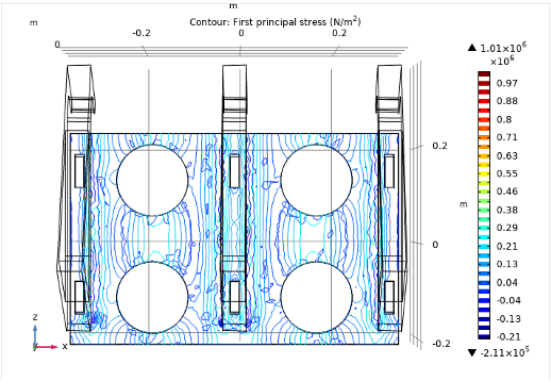


Fig-17 Contour plot of updated model

The COMSOL model's dimensions are the same as mentioned but it changes by the thickness by 0.75 inches, the maximum stress calculated in COMSOL, and hand calculations are shown as below,

Maximum Stress value (COMSOL Software) = **163 lbf/in^2**

Maximum Stress value (Hand Calculation) = **172 lbf/in^2**

Stress concentration factor, Kt = **1.95**

The plate with holes with different angles of 45° and 30° were 3-d printed with a scaling of 0.4 from the original model, the specification of 3-D printer and the model picture is displayed below,

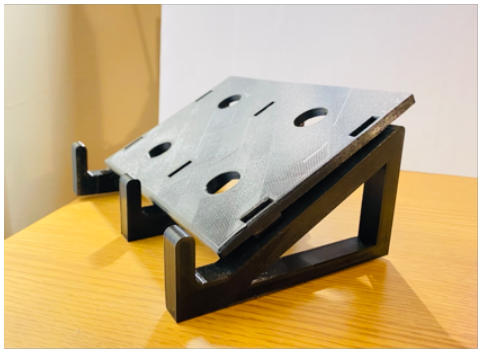


Fig-18 3-D model Stand with 30° angle

Fig-19 3-D model Stand with 45°angle

The 3-D printer that was used was the Ender-3 Pro 3D Pinter by Creality. The parameters of the printer are as follows:

Molding Technology	FDM (Fused Deposition Molding)
Printing Size	220*220*250mm
Printing Speed	≤180mm/s, normal 30-60mm/s
Printing Precision	±0.1mm
Nozzle Diameter	Standard 0.4mm, can be in 0.3 or 0.2mm
Hotbed Temperature	≤100°C
File Transfer	Online or SD card offline
File Format	STL, OBJ, AMF
Slicing Software	Cura/Repetier-Host/Simplify3D
Power Supply	Input: AC 100-120V/6.8A 200-240V/3.4A 50/60Hz output: DC24V 270W
Filament	PLA, ABS, TPU, copper, gradient, etc.
N.W.	6.98kg
Machine size	440*420*465mm

Table-3 3-D Printer Specifications

COST ESTIMATION

MATERIAL	**COST**
plywood	$100
25 Gallon bag	$135
Mesh cost (1 sq. meter)	$50
Overhead cost (Approximately)	$40
Total material cost	**$325**

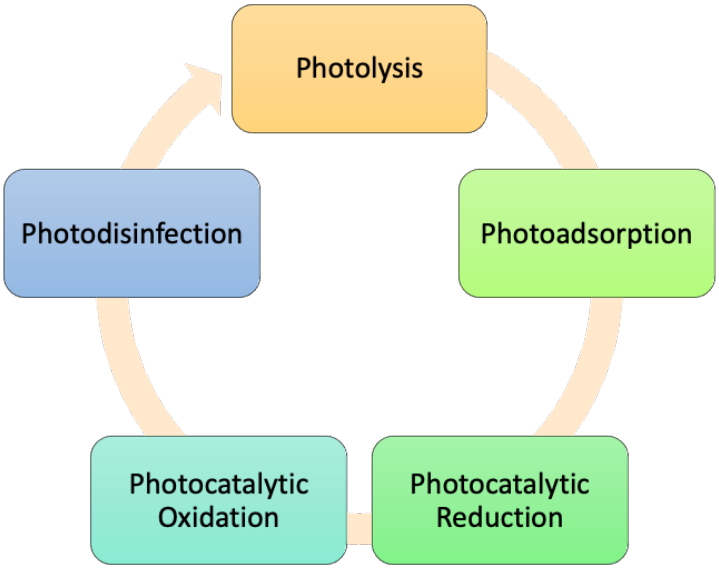
Table-4 Cost Estimation for Prototype Model

25 Gallon bag is used instead of 30 gallon as it is the standard size and closest size to this project's objective that is available in the market.

TESTING METHODOLOGY

The major testing element that was used in this project was the blue dye by Puralytics, when a drop is added to the bag the water in the bag turns a blue color. When the blue dye in the water dissipates and the water becomes transparent, this signifies the purification process has been completed. During the exposure time, the water inside the bag is undergoing the five processes by which the mesh uses to purify the water, during which the blue dye is also treated. These five processes can be seen below. The blue dye acts as a benchmark to aid in visualizing if the five processes have been completed. This is due to the difficulty filtering blue dye from liquids poses. These processes require ultraviolet light to activate. This light is normally provided by the Sun, yet these UV rays can be

provided by other sources. Part of the testing process was exploring the treatment time of the Solarbag outdoors under the Sun as well as under electronic ultraviolet light.



SUNLIGHT

The first step in exploring the Solarbag's activation time was to test the bag under direct sunlight. This is the environment the bag was designed to be used in. Multiple outdoor trials were conducted to better understand the rate of purification. The first trial was on October 21, 2021. During the month of October, the UV-index averaged around 2.4. The UV index is an indicator of the strength of solar ultraviolet radiation for that day at that location and is calculated by the U.S. National Weather Service. The UV index relates regional weather forecasts, elevation, and ozone concentration to the ground-level solar ultraviolet radiation. During the October test the water used in the Solarbag was unpolluted tap water with a drop of the blue indicator dye. The purification time for this test was approximately 4.5 hours. This time is similar to the advertised completion time of the Solarbag, four hours, yet when we add impurities to the water inside the bag, the completion time increases. The second trial done was in November which had a UV index of 1.3 this was lower than October's which caused the completion time of the test to dramatically increase. The purification time of contaminated water during this test was over 18 hours of exposure. These outdoor tests lead to the investigation on the differing ground level radiation received at different t locations and different times of year. The activation of the Solarbag's mesh technology has the same conditionals as solar energy. The figure below shows the results of the testing using natural direct sunlight. The top images show the purification of the tap water during the month of October, and the bottom images show polluted water and the before and after for the testing done in November.

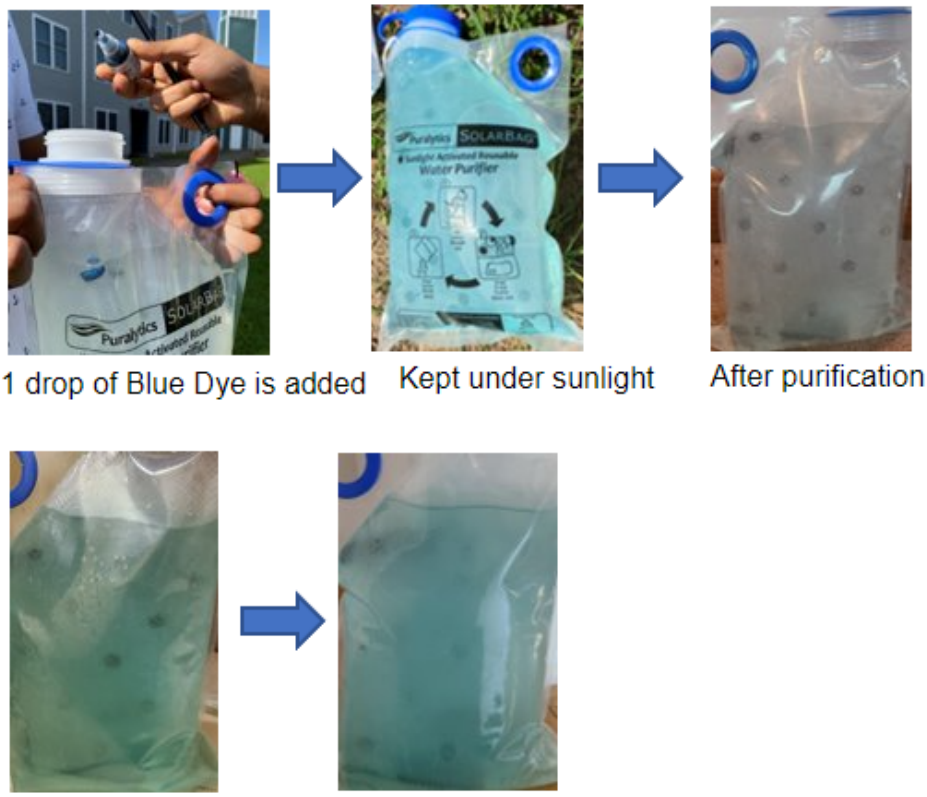


Fig-20 SolarBag Test under Sunlight

UV-LIGHT

The second series of tests were done in front of an electronic UV light. This light was 30W and emitted type A ultraviolet radiation at a range of 380-400nm. This energy output was lower than that of the sun on the days we tested the Solarbag outdoors. The first trial was done using clean water with only the blue dye, this test took 16 hours to complete. During the second trial, over 30 hours of continuous exposure to the electronic ultraviolet light was not sufficient to purify the water. This leads to the conclusion that in order to purify polluted water using the Solarbag under an electric ultraviolet light, one would need a powerful enough light source with enough energy output to activate the mesh. The figure below shows the results of the testing using the electronic UV light. The top images show the purification of the tap water during the process, and the bottom images show the polluted water and its process.

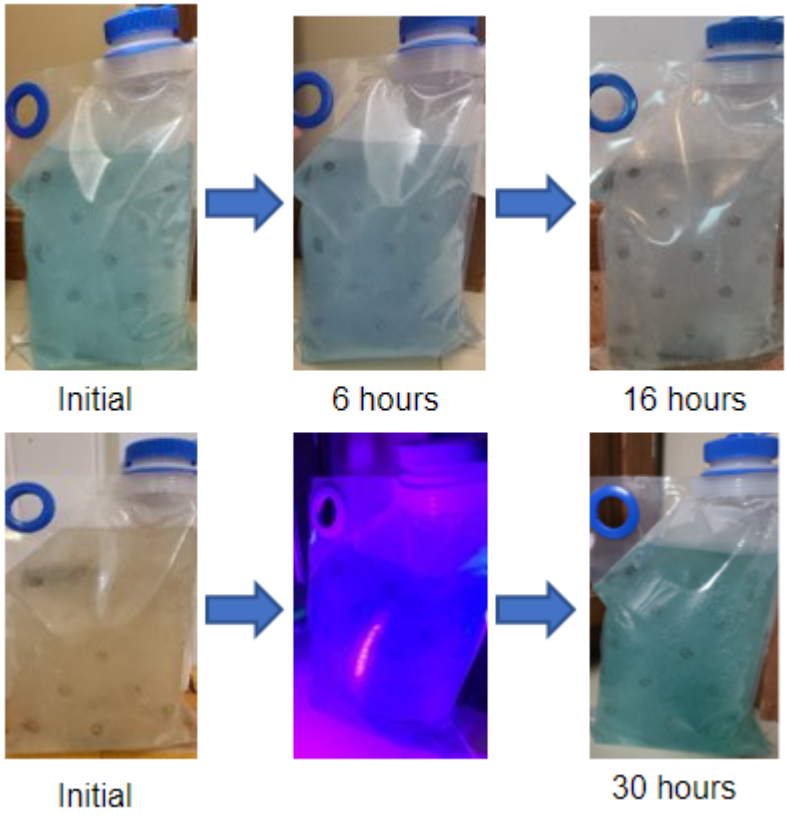


Fig-21 SolarBag Test under UV Light

DISCUSSION

Environmental Implications of Design

I. Bag design

The solar bag is made of polyurethanes, which is non-toxic to environment as they break down. polyurethane does not consist of any chemicals that affect endocrine and hormone systems, and it does not contribute to the PH change in soil or water. In other words, it has no negative impact on the environment. It does not leak and contaminate into water, nor does it corrode healthy soil. It can be recycled and used again. Oftentimes, polyurethane can be recycled into a remarkably similar product that it was originally made for.

II. Mesh

The filtering mesh is coated with titanium dioxide. Titanium dioxide is the naturally occurring UVA filter. It is also self-sterilizing, self-cleaning coated, and deodorizing when it is coated with the mesh.

III. Plywood Stand

Plywood is one of the eco-friendly materials. It is made from wood carved into sizable pieces and glued together using a solid formaldehyde adhesive. It is recyclable, sustainable, biodegradable which has zero adverse effects to impact on the environment.

In the world, more than 2.2 billion people do not have safe drinking water and proper sanitation. It is one of the UNDP (United Nations Development Program) Goals, by 2030, every person in the world should have access to clean drinking water and sanitation. As per our basic human rights, it is essential to get contaminant-free water to all people around the world. Mostly, the rural areas are those who are in poverty that cannot afford a water purifier to get drinkable water.' It is essential to have a low-cost water purification system in order to make these people's livelihood better.

PROJECT MANAGEMENT AND ORGANISATION

Number of team members – 4

I, Mrityunjaya Aadityaa Ravichandran Sai, my contribution for the project is the literature review, Stress calculations, COMSOL stress analysis, modelling of the stand in SOLIDWORKS.

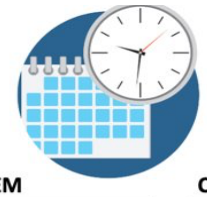
I, Shiva Shankar Ragupathy – my contribution to the project is field trails, literature review, supply chain management, stand designing, research developed on other concepts.

I, Praveen Mohan did graphical and data visualization, research on various purification techniques and standards, cost analysis of the various concepts and did a fair share in contributing technical support to other team members.

I, Nathan Duray tested the solar bag using direct sunlight(outdoors) as well as Electronic UV light(indoors). I also 3D printed models provided by Sai, to create a better visualization of our designs. I built a physical wood stand for our large Solarbag concept that would be utilized in the design expo. Throughout the semester I stayed connected with the group through consistent messages addressing my own progress and the progress of the other members of the group. I researched energy levels of ultraviolet light emitted by the sun and from electronic sources as well as investigated solar data from the United States.

PROJECT PLAN AND SCHEDULE

GANTT CHART



LOW COST WATER PURIFICATION SYSTEM	CAPSTONE - 1	2/10/2021	5/13/2021
PRPJECT NAME	SUBJECT	START DATE	END DATE

Task Name	Start Week	End Week	Resources	WK01	WK02	WK03	WK04	WK05	WK06	WK07	WK08	WK09	WK10	WK11	WK12	WK13	WK14	WK15	WK16	WK17
SELETION OF TOPIC	WK01	WK02		1	1															
RESEARCH OF PURIFICATION METHODS	WK02	WK04			1	1	1													
WATER CAPACITY CALCULATION	WK05	WK05						1												
CONCEPT 1	WK06	WK08							1	1	1									
CONCEPT 2	WK06	WK08							1	1	1									
CONCEPT 3	WK07	WK09								1	1	1								
CONCEPT 4	WK07	WK10								1	1	1	1							
CONCEPT 5	WK09	WK11										1	1	1						
PRESENTATION	WK12	WK12													1					
REPORT	WK10	WK13											1	1	1	1				

The table-5 Gantt Chart for Capstone-1, shows our progress through spring 2021.

GANTT CHART

LOW COST WATER PURIFICATION SYSTEM	CAPSTONE 2	09-06-2021	12-11-2021
PROJECT NAME	SUBJECT	START DATE	END DATE

Task Name	Start Week	End Week	Resources	WK01	WK02	WK03	WK04	WK05	WK06	WK07	WK08	WK09	WK10	WK11	WK12	WK13	WK14	WK15	WK16	WK17
DESIGN SELECTION	WK01	WK03		1	1	1														
DETAIL DESIGN	WK03	WK04				1	1													
DETAIL ANALYSIS	WK04	WK05					1	1												
ORDER MATERIALS	WK04	WK06					1	1	1											
3D PRINTING	WK07	WK08								1	1									
ASSEMBLE PROTOTYPE	WK07	WK09								1	1	1								
FINAL REPORT	WK09	WK10										1	1							
FINAL PRESENTATION	WK10	WK11											1	1						

The table-6 Gantt Chart for capstone-2, shows progress for fall 2021.

PROJECT RISK MANAGEMENT

The project will proceed into the prototype development stage based on the concepts. The concept designing stage has not faced any major problems. But it is believed that the project will face the following problems and will be managed by the protocols below.

If the project cost exceeds the $1000-dollar mark. Then the materials used previously would go under review and the methods to reduce the cost will be implemented. If the prototype has some leaks, then the model will be inspected for finding the source of leak and be corrected. If the prototype cannot be held by the straps, then other options for stronger strap will be reviewed. Other risks include not completing the project on time. To deliver the project on time, various time management techniques like Gantt charts are used. To reduce the damage in transit, various methods for packaging will be studied and compared.

The changes in design will undergo the following flow chart.

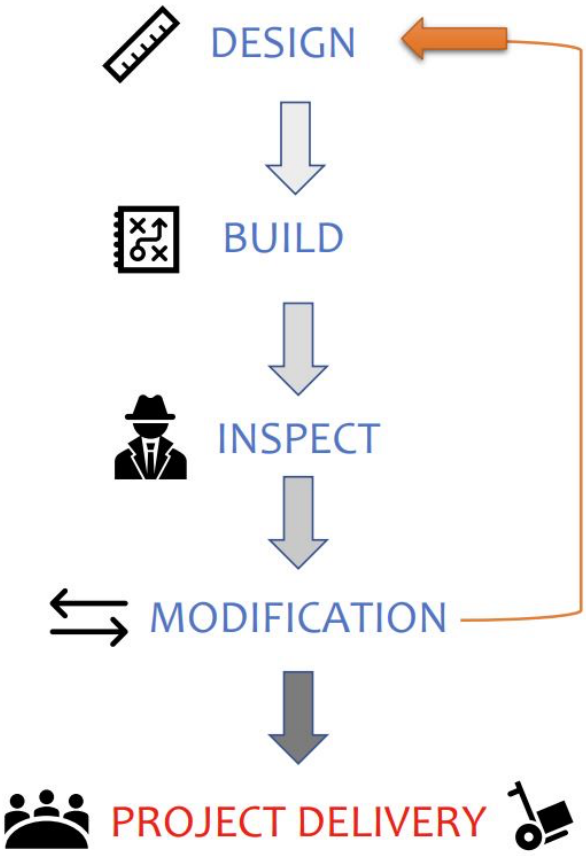


Fig-22 Risk Management

CONCLUSION

Based on the requirements of the project, different design concepts were developed based on the literature review carried out. Each of the design concepts projected in this report is implemented by thorough research on each purification system. Pugh matrix was developed to compare each concept's weightage and to get a good concept based on the requirements mentioned in the job ticket. Based on the comparison, based on the technology of SolarBag, it proves to be the better concept by fulfilling the criteria's such as portability, ease of assembly, low-cost which makes affordable for a small group of people in rural area. Based on this decision, the future scope of the project will involve selection of the material for SolarBag, studying on the nanotechnology mesh developed by Puralytics, requesting the manufacturer to manufacture a mesh based on the model developed analysis of the structure of the designs developed, developing a prototype model analysis for the efficiency of the SolarBag to purify the water. Therefore, the first phase of the project is successfully completed and making progress for the next step in the project.

Recommendation for Future Development

The project prototypes were not completed on time, due to poor time management and supply issues. If the project timeline were to be extended, the first thing to be done is to complete the model and test it for various parameters such as portability and purification rate. The project could be further developed by making a few design considerations for a better model. As the research suggests, the bag works under the activation of the UV light. Developing a UV source that can mimic the sun can make the project open for more possibilities. This includes the purification of water in places where there is no or less sunlight. Furthermore, the stand can go under more material research and more suitable "low-cost" materials can be used. This can reduce the weight of the stand and improve the overall design. Such material should not only be readily available but also easily recycled.

The Puralytics team are working on a new mesh that is based on the material ceramic. It is said to be twice as powerful as the old mesh. Implementation of this mesh in the stand model can reduce the overall purification time, thus improving its overall efficiency.

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