EML 4551 Senior Design Project

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PREPARED IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE DEGREE OF
BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

BICYCLE POWERED WATER FILTRATION SYSTEM

25% Senior Design Report

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This B.S. thesis is written in partial fulfillment of the requirements in EML 4905. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Betzabe Gonzalez, Sandra Alzate, Justin Cromartie, and Kenneth Hernandez and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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1. Abstract

Water is the most basic necessity for life yet nearly one billion people in the world lack access to it. In many developing countries, people walk many miles to reach a source of water that is not necessarily potable. Not only is distance and potability an issue, but the average water collecting container in Africa, the jerry can, weighs over 40 pounds when full. This project proposes to take on challenges associated with the accesibility and cleanliness of water in developing countries by designing and building a filtration system and sidecar that are portable, durable, and cost-effective.

A peristaltic pump will be used to pull unsafe water out of one holding tank, pass through a filtration system, and onward into a clean tank while the rider pedals the bicycle. Both the holding tanks and the filtration system will be incorporated into the design of the side car as to provide an entire system that is portable and can be easily retrofitted to most standard bicycles.

Given that our design must target a demographic that includes some of the poorest regions in the world, reliability is one of the primary factors incorporated into the design. The functionality of the pump and filter system needs to require as little maintenance as possible. The design must also be user-friendly as the assumption will be made that users will have no experience with any vehicle of this type. Once the design is optimized, materials within the build will be considered to find the most cost-effective method of manufactoring.

2. Introduction

2.1 Problem Statement

Developing countries around the world face debilitating challenges accessing safe and clean drinking water. Alarming statistic led us to the idea that that we could use a simple mechanism of transportation that is common in these areas, such as the bicycle, to help aid their water and sanitation struggles. Our goal is to design a bicycle attachment to purify and transport water from contaminated sources that is activated while the rider is pedaling. This attachment, though not a permanent solution, would be a contribution to the improvement of their quality of life.

2.2 Motivation

The objective of providing pure drinking water throughout the world is one that has been an ongoing process for the past decades. Although we fully support the work done by charities such as The Water Project and Water.org, we believe that it will be a very long time until water can be provided as a clean source located locally throughout all developing countries. Therefore, our motivation was stemmed from the idea of aiding those less fortunate areas, as well as providing a backup should those regions run into contamination problems within their local wells. In addition our solution will exponentially reduce the time taken to retrieve the water, and allow time for more beneficial tasks to be accomplished in their native area. With our model we will be able to provide a working solution that mends the problem until a permanent clean water well can be produced within that community.

2.3 Literature Survey

2.3.1 Water Crisis

Water is the prerequisite for all human and economic development. Safe, clean drinking water is scarce. Nearly 1 billion people in the developing world don’t have access to it [15]. Water scarcity is either the lack of enough water or lack of access to safe water, but the problem goes beyond just water. In the developing world the availability of clean water is often consuming and expensive. In some areas on the Sub-Saharan African area women and girls specially, are given the task of walking miles at a time to a water source such as ponds or streams to collect water for their families. More often than not the water being collected is unsafe and full of diseases. Having access to clean water has the capability of improving four of the major problems in the developing world, these are education, hunger, health and poverty. When children are freed from gathering water they can return to class and especially young girls, who are commonly responsible for the task, are able to stay in school through their teenage years [10]. The United Nations estimates that Sub-Saharan Africa alone loses 40 billion hours per year collecting water; the same as an entire year's labor in all of France!. A study conducted in 2010 by UNICEF as a progress report on their Millennium Development Goals shown in Figure 1 shows that more than a quarter of the population in Africa takes longer than 30 minutes to make one water collection round trip. Water leads to food security, with continued access to it less crop loss occurs and hunger is reduced. As

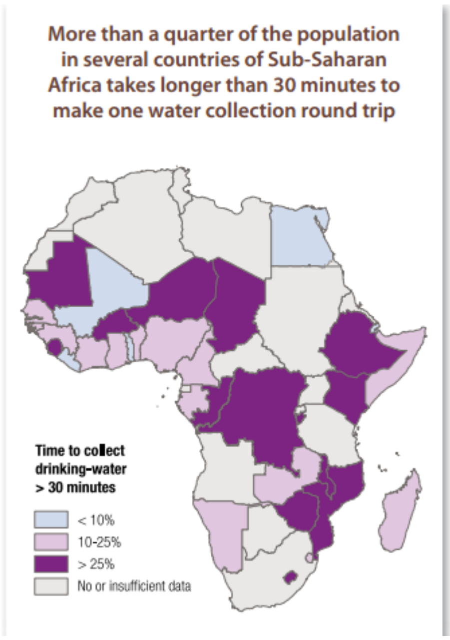

Figure 1: Time to Collect Drinking Water in Sub-Saharan Africa [08]

of today many non-profit organization have surfaced, all with one goal in common help fix the water crisis worldwide. Some of these organization are The Water Project who began their work in 2006, they mostly focus their work in Sub-Saharan Africa. Water.org was founded in 1990, with the experience they have gathered over the years the organization is able to help in a more worldwide scale currently having active projects in the Asian countries of Bangladesh and India as well as the Caribbean country of Haiti. Charity Water is another big non-profit organization founded in 2004 by Scott Harrison. Over the years this organization has become one of the most important in the battle for safe water, having brought their projects to 20 countries around the globe in Africa, Asia, Central and South America.

2.3.2 Current Products

Currently two products consisting on bicycle powered filtration system exist. These are the Japanese based Cycloclean and the winner of the Innovate or Die competition The Aquaduct.

2.3.2.1 Cycloclean

The only company that fabricates a bicycle powered water filtration system to sell in the market is Nippon Basic Co, Ltd. Nippon was developed after two major Japanese earthquakes the Hanshin Earthquake in 1995 (magnitude of 7.2) and the Chuetsu Earthquake in 2004 (magnitude of 6.8) [07]. The product is essentially made for emergency use, it consists on having a purifying case attached on a rear seat of the bicycle and because of its design the user can ride it to any destination where it is difficult for other types of transportation to access. The bike is capable of purifying almost any type of water source i.e.

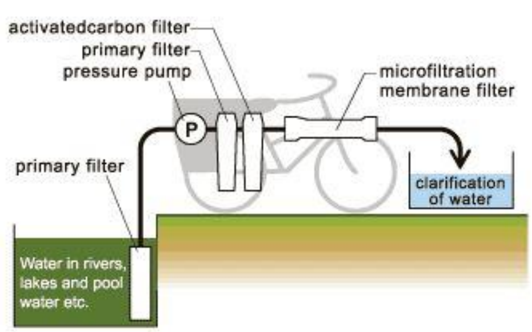

Figure 2: Schematic of Cycloclean [07]

ponds, rivers, lakes, bathtub and pools [07]. The device is powerful enough to siphon water from a depth of five meters [18]. The purifying system consists of three filters, a pressure pump, two water hoses and one manual fitting as illustrated in figure 2. Table 1 is an overview of the Cycloclean provided by Nippon. It should be emphasize that the system is capable of producing 5 liters of clean water every minute. However, the bike does have its disadvantages starting with its market prize of $6,600 that makes it impossible for people from developing countries to purchase it. Furthermore, the bike only works in a stationary position and does not contain a form of storage.

Table 1: Overview of the Cycloclean [07]

Cycloclean	
Parts for filtering	1 microfiltration membrane filter, 1 hybrid carbon filter, 1 primary filter
Filtration	Dirt, bacteria, smell
Applicable water resource	Water from natural environments and pooled water in tanks.
Processing capacity	With fresh water 5.0 liter/min
Outline measure	W 580 x L1,780 x H1,100 mm
Outline weight	About 50 kg
Fitting	1 intake water hose, 1 permeated water hose, 1 manual

2.3.2.2 The Aquaduct

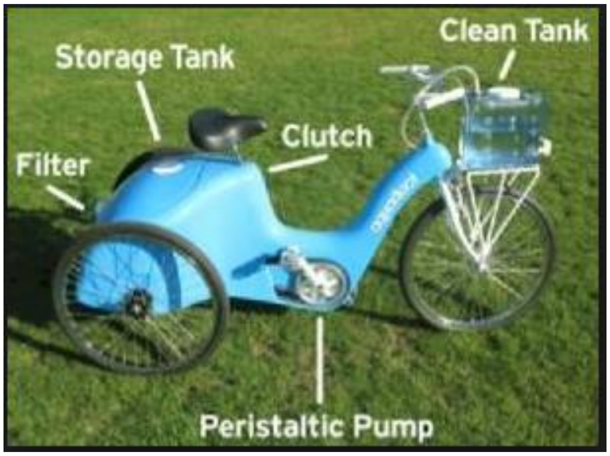

Figure 3: The Aquaduct [03]

The Aquaduct is another example of a pedal-powered vehicle that filters water; unlike the Cycloclean it is capable of storing water. The prototype was designed and constructed for the Innovate or Die contest by a group of five Bay Area designers from IDEO. The device is designed to enable the user to filter and transport water simultaneously. As the user pedals, a pump attached to the pedal cranks water from the holding tank, through a carbon filter, to a clean tank. A clutch is used to engage and disengage the drive belt from the pedal crank, which allows the user to filter water while traveling or while stationary. The device is capable of storing up to five gallons of water every trip, which is amount of water a family of four needs every day. The problem with the prototype is the fact that mass production of the current design would be too expensive to manufacture for many parts of the world. The filtration technology used, although not specified, is not in the low cost range and the inventors are currently working on developing a more appropriate locally sourced filtration technology. Figure 2 shows the design and points where each of the parts are located.

2.3.3 Water Filters

Water filtration systems have changed the way we have been able to consume our water on a daily basis. A water filter generally removes any impurities by flowing the water through a series of screens and filters. The types of filters have progressively advanced since the 19th century. There are methods out there that don't require such an advanced process. For instance, a water filter can be made from a sequence of layers of natural resources: rock or sand. Nowadays, almost every refrigerator in the world has a built-in water filtration system. However, there are other various processes used depending on what contaminants are going to be removed.

Three-step water purification is a common filtration system made up of three stages: Sediment filter, Kinetic Degradation Fluxion (KDF) Filter, and an activated carbon filter. The first layer is the sediment filter, which removes any large matter from the water. These filters are generally made of pleated cellulose: a collection of natural fibers that are densely compacted. The KDF filter is the stage where the excess chlorine is removed and converted to chloride. The last step in this procedure flows through an activated carbon filter. The charged carbon particles attract other charged contaminants such as heavy metals lead and copper. There are profoundly other complex water filtrations systems that can eliminate almost any contaminants, including radioactive particles. One example is reverse osmosis, a high pressure driven filtering system that uses a quality of filters and membranes to eradicate most contaminates. Although, removing the essential minerals does not mean the water

Figure 4: Pleated Cellulose Filter (Sediment Filter) [01]

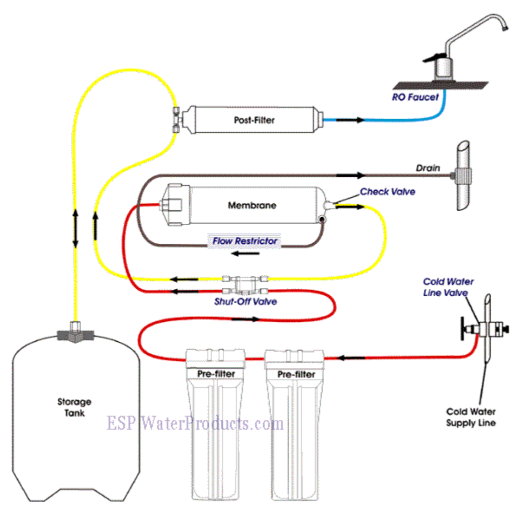

Figure 5: Reverse Osmosis Filtration System [09]

is safe to drink. Also, this approach can be generally expensive since there are a variety of filters required to flow the water through.

TYPICAL REJECTION CHARACTERISTICS OF R.O. MEMBRANES
Elements and the Percent R.O. Membranes will remove

Sodium	85 - 94%
Sulfate	96 - 98%
Calcium	94 - 98%
Potassium	85 - 95%
Nitrate	60 –75%
Iron	94 – 98%
Zinc	95 – 98%
Mercury	95 – 98%
Selenium	94 – 96%
Phosphate	96 – 98%
Lead	95 – 98%
Arsenic	92 – 96%
Magnesium	94 – 98%
Nickel	96 – 98%
Fluoride	85 - 92%
Manganese	94 – 98%
Cadmium	95 – 98%
Barium	95 – 98%
Cyanide	84 – 92%
Chloride	85 – 92%

% may vary based on membrane type water pressure, temperature & TDS

Figure 6: Typical Rejections using Reverse Osmosis [09]

One specific water filtration product that is out on the market now is a combination of many filtering systems. Sawyer is a company that makes water filtration devices that are made up of a hollow fiber membrane that filters hurtful bacteria such as “bacteria, protozoa, or cysts like E. coli, Giardia, Vibrio cholerae and Salmonella typhi (which cause Cholera and Typhoid) to pass through”. According to Sawyer.com, their product is considered “small, portable, easy-to-use, reliable, inexpensive, and can last a decade without needing to be replaced”. This product includes the whole package where the filtration is inexpensive and removes any harmful bacteria than can be found in ponds, lakes, rivers, canals, etc.

Figure 7: 3-Way Inline Water Filter [11]

2.3.4 Pump

A water pump is an essential device used to move the fluid by a mechanical system. There are various types of pumps utilized on a wide range of applications such as pumping waters from wells, water-cooling in a car, aquarium filtration systems, etc. A reciprocating or rotary type of mechanism is usually found in a water pump. One special type of pump out in the industry now is the peristaltic pump. The mechanism draws in the fluid content by applying alternating compression and relation motion (rotary).

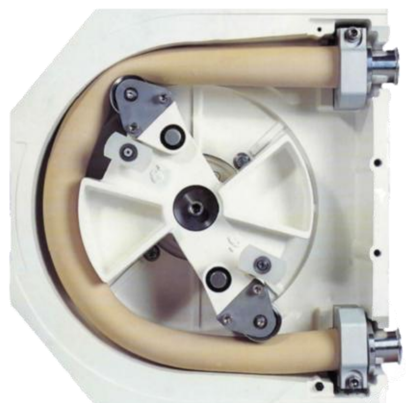

Figure 8: Peristaltic Pump [06]

The specialty of this pump is the applied rolling force, or restitution, on the tube creates a compression that seals and acts as suction; therefore, discharge the fluid forward. The advantages of the peristaltic pump are the strong vacuum created to propel the fluid and

Figure 9: Peristaltic Pump Motion [06]

the no-slip effect. This pump is typically operated in the medical industry to pump intravenous fluids, blood during a by-pass surgery and other viscous fluids. This ideal pump is considered to provide life-long tube efficiency and a free flow fluid rate.

3. Design Alternatives

For the project several designs were implemented in order to assess which fit properly for the group goals. Two of the major factors were durability and cost. There are three design aspects that will be presented with both positives and negatives also represented.

3.1 Design Alternate 1

The first design consisted of an all incumbent tricycle or quadcycle with the built in filtering system. The picture displayed below is the initial prototype created by and independent company called the Aquaduct. Our goal was to be inspired by this design and improve upon it in

Figure 10: Aquaduct Tricycle Influence Example [03]

areas in which it was lacking. The design shown consists of a peristaltic pump that uses the rider's kinetic energy to filter impure water (placed in the rear tank) to the front tank. Our tricycle will be more durable for more rural areas, and will have filters that can be self-cleaned and long lasting. Although this model is very well built, it is extremely expensive and only in the prototype stage. Once analyzing price comparisons, we also came to the conclusion that building a whole tricycle would be far too costly for the budget we are trying to achieve. Therefore, we chose to move to further alternatives.

3.2 Design Alternate 2

Figure 11: Bicycle Trailer Caboose Influence [05]

Given the problems presented above the group decided to take the discussion into another direction. This included the idea of creating a caboose cart that could be dragged along behind an already existing bicycle. The same idea of filtering the water by the energy presented to the pedals would be used. But now this attachment along with the pump could be dismantled and attached to any other bicycle at the rear. This seems like an excellent method to consider, where the tanks and pumps could be placed on a rear platform and the seat would be removed. Some concern though does exist in weight distribution, as well as the sloshing of water when moving. Balancing could become an issue and create hauling problems, which would not be ideal for the given conditions.

3.3 Design Alternate 3

The third and final option is somewhat similar to the design above except for it is versatility and location on the bicycle frame. This option acts like a sidecar that can be folded in and out when carrying loads or just needing the bicycle to get to another location.

Figure 12: Bicycle Foldable Side Cart Influence [17]

This product seems to be another great method for transporting the water to and from the source as it is cleaned. In this case the pump could be hung or attached to a bag above the platform and the two water tanks (clean and dirty water) could be placed down. Another great characteristic of this option is that it could be used for hauling other loads if they needed to be moved from communities. Balance would also be another contributing factor, as now the weight would be distributed across three wheels, therefore helping to counteract any weight issues. When not in use the attachment is easily folded upwards and over the frame to allow the bicycle to move without any hindrances.

3.4 Proposed Design

The designs contemplated occurred in the order listed above. Due to the description of each design, it is easy to tell which design became the final influence. As the group began to weigh the advantages and disadvantages of each, it was easy to notice that the third design would provide the best overall benefit and versatility. It is important to note that pictured above is a model built by another company that will be a basis for our design, but not completely representative of ours. We will look to create a more heavy-duty side cart that could withstand a beating, as well as be able to handle larger weights acting on it. Choosing the right model was tough to distinguish considering the disadvantages to overcome with the given idea. But, with the side cart we feel very enthusiastic that this will satisfy our needs and goals.

4. Project Management

4.1 Organization of Work and Timeline

The project timeline shows the major milestones of the project starting in the beginning of spring 2014 semester and ending in fall 2014. This Gantt chart will be used to ensure that all of the important goals of the Project are competed in an efficient and timely manner.

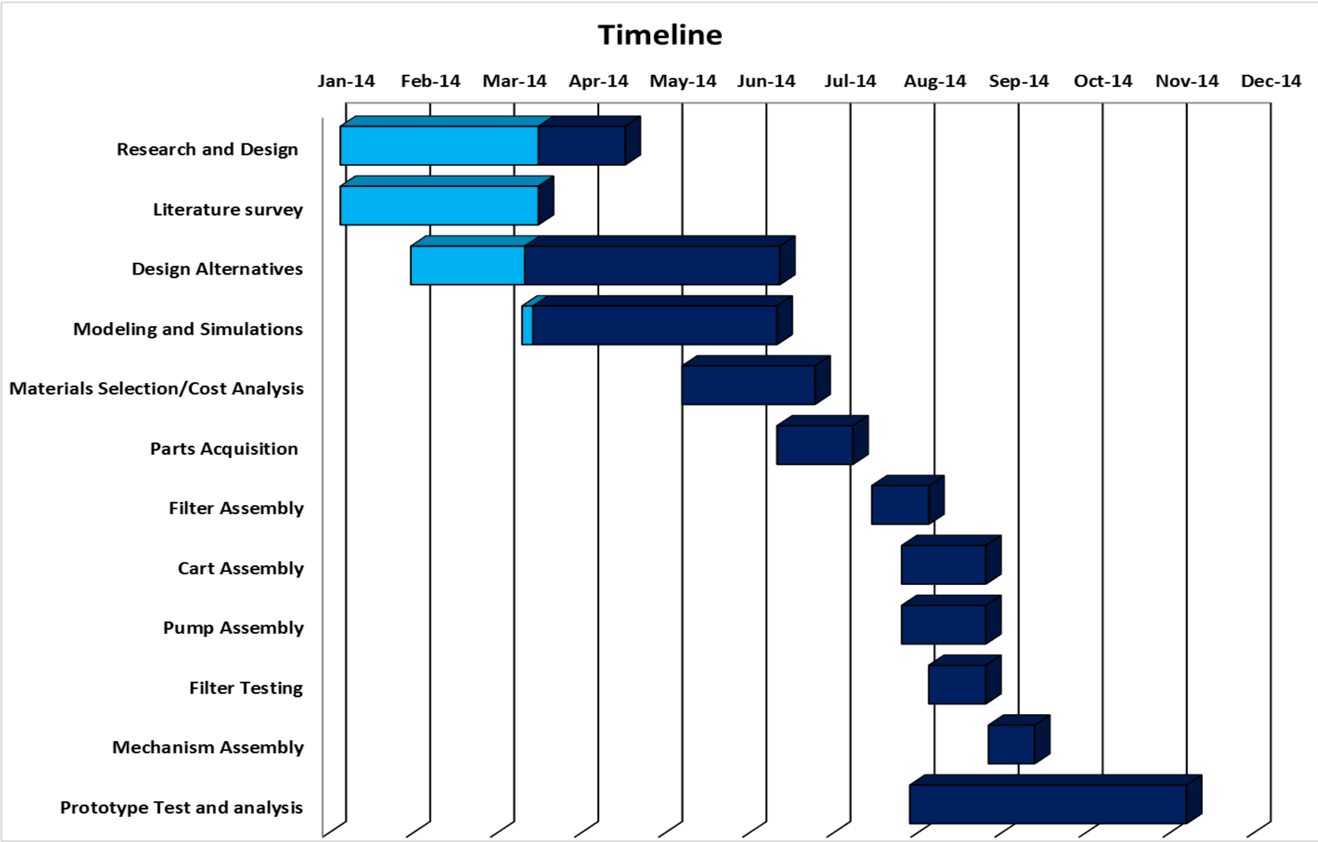

Figure 13: Gantt chart for Bicycle Powered Water Filtration System

4.2 Breakdown of Responsibilities among Team Members

The responsibilities of each team member is listed in table 2. Should be noted that each of the four members contributed equally to every report and presentation.

Table 2: Breakdown of Responsibilities

Breakdown of Responsibilities				
	Betzabe	**Sandra**	**Justin**	**Kenneth**
Filtering system				
Pump mechanism				
Attachment assembly				
Cost Analysis/Material selection				
Solidworks modeling				

5. Analytic Analysis

A pump is designed to move fluids by mechanical energy. Mechanical Energy takes three basic forms, Kinetic, potential and static.

The general equation for a pump comes from modifying the Bernoulli equation into:

$$\frac{(V_1)^2}{2} + gz_1 + \frac{P_1}{\rho} + w_{pump} = \frac{(V_2)^2}{2} + gz_2 + \frac{P_2}{\rho} + w_{loss}$$

Where:

V = velocity of the fluid

P = Pressure

z = Height

w = work done or lost

The principles of a peristaltic pump are mostly detected in its distinct tubing designed along with the mechanism produced by the rollers. The tubing is fixed between the tube-bed and the rotor and is continuously squeezed by the rollers pushing the liquid in the direction of the revolving rotor, and producing a "pillow" of liquid between the rollers as shown in figure 14 [06]. The pillow is the pump chamber and it is used to determine the volume per roller step and consequently the flow rate. The roller-step volume depends on the pump system, tubing, liquid properties and application conditions. The flow rate is then calculated by using the following formulas:

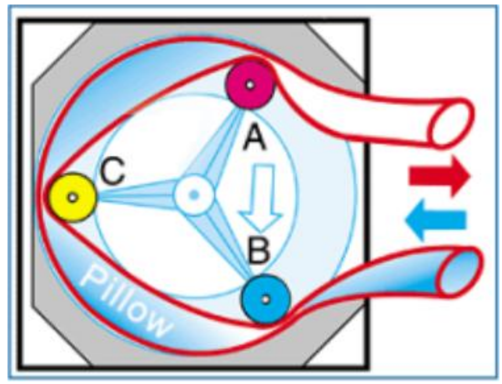

Figure 14: Peristaltic Pump Diagram [04]

Volume per roller step (pillow volume) x Number of rollers = Volume per revolution

Volume per revolution x rotation speed per minute = Flow rate per minute.

The flow rate is also affected by other components, such as tube diameter, number of rollers and the speed of the rollers [04]. Increasing the tube diameter will increase the flow rate, while adding more rollers will actually decrease amount of flow but will make it steadier at the exit.

Occlusion is an important parameter to increase the life of the pump and it is capable of defining the wall thickness required for the tubing. The occlusion percentage is typically between 10% and 20 % and it is given by the following equation:

$$\% \, Occlusion = \frac{2t - g}{2t} * 100$$

6. Major Components

6.1 Pump

The pump selected for this project is a peristaltic pump. This pump is a type of positive displacement pump. This type of pump will produce the same flow at a given speed no matter the discharge pressure, hence the reason they are called constant flow machines [14]. Peristaltic pumps are easy to clean, service and can provide low maintenance costs. It is also a simple system that can be repairable shall any failure occur. Another advantage is sludge can be pumped with a solid content of up to 60% [06].

We will be making our own peristaltic pump for budgeting reasons. Our design will have three rollers to steady the exit flow. We will be using clear PVC tubing that is non-toxic, FDA certified, and a thermoplastic elastomer. Elastomeric tubing is necessary to maintain the tubing's circular cross-section after extensive cycles of squeezing by the rollers [16]. In Table 3 are the properties of the PVC tubing we selected for our initial prototype.

Table 3: PVC Tubing Properties

Properties	Units	Values
Outside Diameter	Inches	13/16
Inside Diameter	Inches	5/8
Thickness	Inches	3/32
Hardness	Shore A	68
Tensile Strength	Psi	2000
Elongation at Break	%	400
Brittle Temperature	℉	-41, 140
Specific Gravity		1.20

Since the pedaling speed will vary, determining an approximate actual flow rates will be rather difficult so we expect to build more than one pump prototype for testing and eventually acquire the ideal size of the pump.

6.2 Filter

The Sawyer 3-way inline filter satisfies our filtering needs and it comes in at a relatively low price point. This Sawyer filter employs a hollow fiber membrane technology with a guarantee that no pore size larger than 0.1 micron in size. This makes it impossible for harmful bacteria, protozoa, or cysts like E. coli, Giardia, Vibrio cholerae and Salmonella typhi (which cause Cholera and Typhoid) to pass through [11]. The specifications for the pump are listed in Table 4.

Table 4: Sawyer Filter Specifications

Filter Material	Units	Hollow Fiber Membranes
Output	Liters/min	1.7
Housing Material		ABS Plastic
Dimensions	Inches	1.75 x 3.5
Weight	Ounces	1.8
Cartridge Life	Gallons	1,000,000

6.3 Sidecar

A sidecar attachment will be the largest component implemented on the bike design. The goal of this type of model will achieve the convenience of retrofitting any filtration system onto any ordinary bicycle. The cart will contain an adjustable one-wheeled device capable of holding a source of load on a solid platform. The two large tanks of water: a clean and contaminated water tank, and the water filtration system will be the main components secured onto the bottom platform of the attachment.

In theory, the sidecar can be retrofitted at the back hub of the wheel and onto the actual frame of the bike. This type of design can maneuver a bicycle with suitable handling especially when traveling through corners. The amount of weight is a huge factor to be aware of when installing these types of attachments. This installment is mainly utilized to carry a heavy load enough to handle comfortably for the driver. In this design, the objective is to carry and store the largest amount of water during one round trip. However, the amount of water to transport is still in development but it will highly depend on the cost of types of materials and the manufacturing executed on the sidecar frame.

7. Structural Design

The sidecar will be the main housing of the water filtration system. As mentioned earlier, the sidecar will be attached at the back hub (center) of the wheel and to the actual bicycle frame. The one-wheeled device will hold a water filtration system that runs water through several stages until clean water is produced. The system is made up of interconnected water tubes linked to a peristaltic pump and a Sawyeer three-way filter. The initial step is using the pedaling mechanism to activate pumping the water from the contaminated container. While in motion, the water will flow through a set of tubes and enter the Sawyer filter. Therefore, the filter will remove all the harmful contaminants in order to produce fresh drinkable water. Eventually, all the water will be transferred to the clean water tank, which will have the option of easily removing the tank to be utilized around the home.

8. Cost Analysis

Table 5: Cost Analysis for Prototype

Cost Analysis for Prototype		
Part	**Per Unit**	**Total**

9 1/2" Light Tin Spring form Cake Pan		$ 2.69
2" Light Duty Caster (3)	$ 2.99	$ 8.97
Assorted screws, bolts, t-nuts and washers		$ 5.00
Sawyer 3-Way in line water filter		$ 60.00
10 Feet PVC Clear Tubing	0.82 ¢/ft.	$ 8.20
Side Car Materials		$ 150.00
Bike		Donated
	Total Cost	**$ 234.86**

9. Plan for Tests on Prototype

9.1 Pump

The peristaltic pump will be tested by first optimizing the size of the pump for an adequate flow rate at an average bicycle speed. The pump will be rotated for an unknown period of time at a constant speed to the point of failure, in order to determine its basic rating life and operating hours. The tubing will be tested alongside the pipe. The goal is to have the tubing last as long as possible to achieve the main objective of this project. Once an elapsed time has passed, the tubes will no longer return to their original shape after being squeezed by the pump rollers at which point the life expectancy will be determined. It should also be noted that at any point during the test the pipes could tear thus providing us with more data for a life expectancy.

9.2 Filter

The water will be tested before and after it is put through the chosen filter. The goal is to bring the contaminated water to a lab on campus for further testing. After the liquid is filtered using the Sawyer 3-way inline filter, the water will be tested again and compare the results of the previous experiment. The second option of testing the water is to buy a home water testing kit and perform a red dye test.

9.3 Sidecar

Using Solidworks, a prototype will be drawn and tested in order to select the materials with bigger load resistance. Once the materials are selected the sidecar will be built and attached to the bicycle for further testing. The second part of the test will consist of riding the bike under different terrains, such as unpaved roads, while the sidecar is loaded and assess how it will affect the bicycle balance and maneuvering.

10. Conclusion

Through extensive research we found cost effective parts that will meet our goal of building a portable filtration system that can be retrofitted to any standard bicycle and facilitate the transportation of water for the daily use of families in developing countries. In the coming months a prototype will be constructed which consists of a peristaltic pump, the filter and a sidecar. Each component will be thoroughly tested in order to provide the best product possible at the most reasonable price. In the future we hope to be able to partner with one of the many non-profit organizations dedicated to provide clean water around the globe such as, The Water Project, Water.org and Charity Water and reach the millions of people in need of a product like ours.

11. References

[01]. Assistant, Appliance. *How Water Filters Work*. 2013. 14 March 2014. <http://applianceassistant.com/Refrigerator-Repair/How-Water-Filters-Work.php>.

[02]. B.V, Verder International. *The Green Peristaltic Pump* . n.d. 16 March 2014. <http://www.verderflex.com/how-do-peristaltic-pumps-work/>.

[03]. Flahiff, Daniel. "Aquaduct Bike Purifies Water as you Pedal." 08 November 2008. *Inhabitat.com.* March 2014. <http://inhabitat.com/aquaduct-bike-purifies-water-as-you-pedal/>.

[04]. Folkner, David. "Peristaltic Pump." 20 March 2012. Powepoint Presentation. 6 April 2014. <http://mechatronics.ece.usu.edu/ece5320/Schedule/hw01-2012/folkner_david_late_136117_10860907_David_Folkner_a.pdf>.

[05]. Lipton, Josh. "Trailer for Adult Passengers." 4 July 2007. *BikeShopHub.com Blogs.* March 2014.

[06]. Michael Smith Engineers LTD. "How a peristaltic pump works." 22 July 2009. 6 April 2014. <http://www.michael-smith-engineers.co.uk/pdfs/howperistalticpumpworks.pdf>.

[07]. Nippon Basic Co. *Water Purification System*. 2006. 20 January 2014. <http://www.nipponbasic.ecnet.jp/eindex.html>.

[08]. Organization, World Health. *Progress on Sanitation And Drinking-Water (2010 Update)*. New York: UNICEF, 2010.

[09]. Products, E.S.P. Water. *How Do Reverse Osmosis Filter Systems Work & What Do They Do?* 2009. <http://espwaterproducts.com/about-reverse-osmosis.htm>.

[10]. Programme, United Nations Development. ""Resource Guide on Gender and Climate Change."." 2009. <http://www.undp.org/climatechange/library_gender.shtml>.

[11]. Sawyer. *Sawyer 3 Way Water Filter*. Safety Harbor, n.d. <http://sawyer.com/products/sawyer-3-way-water-filter/>.

[12]. —. *Water Filtration*. 5 April 2014. <http://sawyer.com/technology/water-filtration/>.

[13]. Staff, Heartspring. *Heartspring*. 21 December 2013. 14 March 2014. <http://www.heartspring.net/water_filters_guide.html>.

[14]. The Engineering Toolbox. *Positive Displacement Pumps*. n.d. 6 April 2014. <http://www.engineeringtoolbox.com/positive-displacement-pumps-d_414.html>.

[15]. The Water Project. *Why Water?* 2014. 25 January 2014. <http://thewaterproject.org/why-water.php>.

[16]. Wikipedia. *Peristaltic Pump*. n.d. 5 April 2014. <http://en.wikipedia.org/wiki/Peristaltic_pump>.

[17]. Xtracycle. "Xtracycle SideCar with Deck." Oakland, 2012. <http://www.xtracycle.com/sidecar.html>.

[18]. Zimmer, Lori. *Cycloclean Purifies Drinking Water Using Bicycle Pedal Power*. 17 February 2011. <http://inhabitat.com/cycloclean-uses-pedal-power-to-purify-water-for-drinking/>.