Low Power Ultrafiltration

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Submitted to—
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Executive Summary

Access to clean drinking water is extremely limited in some parts of the world. This is especially true in developing countries where much of their drinking water comes from potentially contaminated surface water sources and sanitation education is inadequate. Ingestion of contaminated waters can cause serious illness and even death, most of which occurs in children under five years of age. Limited availability to clean water sources has even lead to a number of conflicts over who should have access to this water. Providing education and clean drinking water for the people of these nations is of great importance to improve quality of life and socio-economic stability.

UltraTech Solutions' objective was to assess and improve a water filtration device designed by our client that is capable of removing soil colloids and bacteria from various water sources to produce a safe, clean product using ultrafiltration membranes and National Sanitation Foundation approved materials that is cheap to produce, easy to assemble and maintain with low power requirements for use in developing nations.

Statement of Problem

Clean drinking water is a necessity to healthy human life. In many areas of the world, this necessity is lurking just out of reach. According to a recent United Nations news article, at least 11 percent of the world's population, or 783 million people, still do not have access to safe drinking water, and billions live without sanitation facilities. (United Nations, 2012). Without proper sanitation facilities, fecal matter and other contaminants can easily end up in a community's drinking water source. Drinking water that has been contaminated with fecal matter can contain bacteria, viruses, and parasites. These organisms can cause severe sickness and even death to those who ingest them. Contaminated water is the major cause of diarrheal illness in developing nations, causing unnecessary suffering and malnutrition to much of the population (Braghetta, 2006). Two million deaths each year are attributed to diarrheal diseases caused by ingesting contaminated water. 90 percent of these deaths are children under the age of 5 (World Health Organization, 2012). This suffering and death is preventable through water purification technology and sanitation education. The Water4 foundation has even reported that improvements in sanitation and drinking-water could reduce the number of children who die each year by 2.2 million (Water4). These developing nations are in desperate need of a water filtration system that is easy to ship, construct, and maintain, that requires no or limited amounts of power, and removes the viruses, bacteria, and parasites that cause diarrheal diseases. Such a filter would not only improve the quality of life for the community, but would allow more children to see their fifth birthday.

Impacts

The development of a low-cost, low-energy water filtration device has the potential to make significant environmental, societal, and even global impacts.

Environmentally, this filtration device has the potential to decrease the spread of pathogenic bacteria and parasites, by containing them in the filtration units. There will be minimal environmental effects from constructing such a filter, and the low to no power requirement could reduce the carbon footprint of clean water production. The materials are all FDA approved and pose no threat of leaching chemicals into the environment, so the only impacts from construction would come from parts manufacturing. This filter also has the potential to be used for other purposes, such as separating algae from water in attempts to make biofuels. These other uses could cause even more environmental impacts.

Societally, clean water availability has many socio-economic impacts. One of the biggest impacts is on children. Children are the most susceptible to the illnesses caused by ingesting contaminated water, and are more likely to die as a result of this illness. Clean drinking water has the potential to save many children's lives. If children are sick less often from the pathogenic bacteria found in many water sources, then their education will be less interrupted and better. Currently many women and young girls have to walk hours a day to collect water that may or may not be safe to drink. Moving a well or filtration system closer to their village will allow many girls to stay in school and allow women to have more time to do other jobs as well. Improving education and making women available to work allows for the local economy to improve. Another major societal impact would be fewer wars over control of clean water as well as less corruption in selling water for prices higher than the general population can afford.

Globally, one of the biggest differences between developing and developed nations is the availability of clean, affordable drinking water and sanitation. This filter could aid in bridging this gap by increasing access to safe drinking water. Relations between these nations could also be improved if people in developed nations helped spread the filtration technology, and fewer wars would be fought over water rights.

Project Objectives

This document presents the results of UltraTech's assessment and testing of Pumps of Oklahoma's ultrafiltration filter modules. Some specific objectives for this project include:

(1) Identify a potting technique for the module's resin,

(2) Ensure filtered water is free of microorganisms and safe for human consumption, and

(3) Compare flow rates and backwashing needs of given and larger modules.

UltraTech Solutions' project, water filtration using ultrafiltration membranes, is to assess and improve upon a filtration system designed by Pumps of Oklahoma. Ultra Tech also designed a filtration module and corresponding system that will remove contaminants from a variety of water sources ranging from bacteria infested pond water to potentially contaminated shallow groundwater (see Appendix III). The specifications for the system as a whole are to remove sediment, parasites, bacteria, and viruses from water, rendering it safe for human consumption. The system will need to vary in size to satisfy the needs of a family or a community. The system should also be easy and relatively inexpensive to construct, preferably from readily available National Sanitation Foundation approved materials. Electrical power is often widely unavailable and extremely unreliable in the areas where these filters are designed to be installed, thus the need for the system to require little or no electrical power. If a power supply becomes necessary, UltraTech Solutions will power the system with solar or wind energy. The design will need to be structurally stable to prevent accidental tipping, especially in areas where children my try to climb the system.

Project Management

UltraTech Solutions has created a plan in order to accomplish our goals and objectives. We will follow the engineering design cycle as a guideline while we progress through our project (Figure 1). Our management objective was to complete the cycle through the step of choosing a design during the Fall 2012 semester. The Spring 2013 was set aside for construction and testing before completing our final design. After our change in project direction, the Spring 2013 semester was used for testing and assessing the modules provided by Pumps of Oklahoma. To stay on task and complete all company deliverables, UltraTech Solutions is utilizing Microsoft Project as a planning and organizational tool. Tasks, project deadlines and schedules are organized in this software to increase human resources efficiency and productivity.

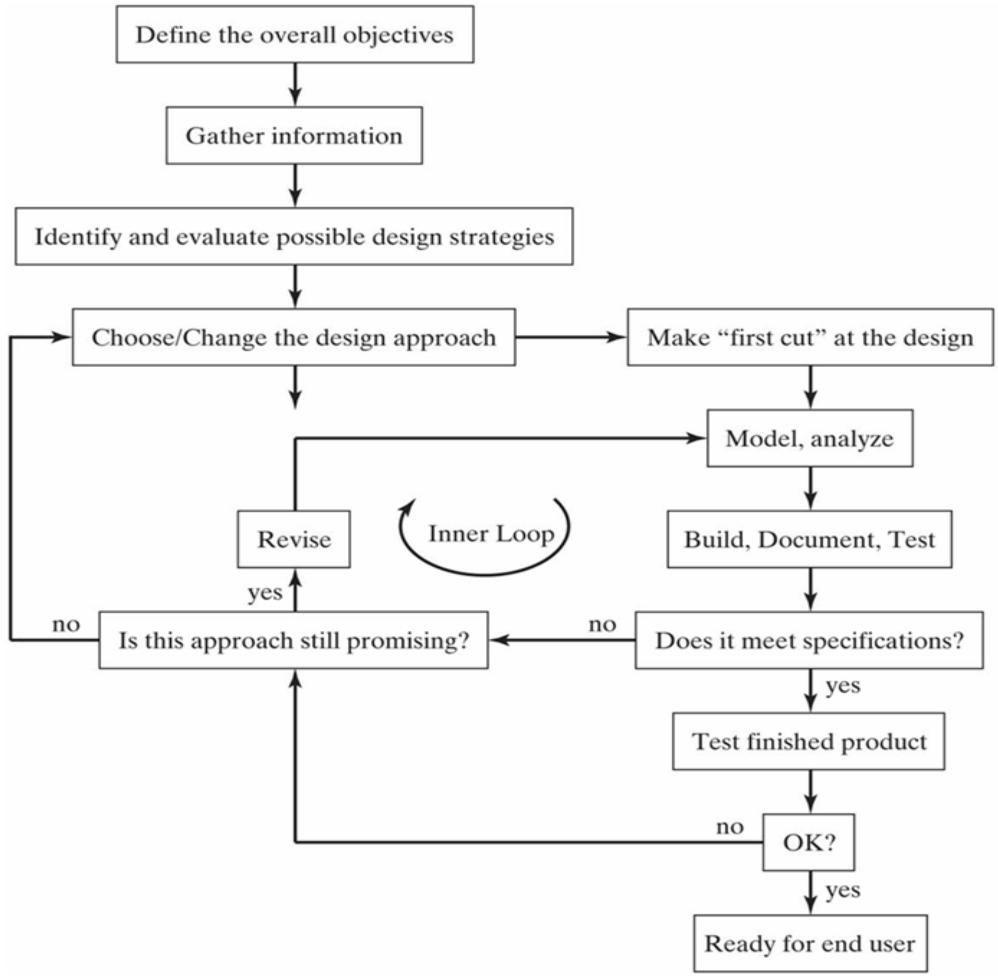


Figure 1- The Engineering Design Cycle, Horenstein Figure 2.7, page 39

Figure 2 is a condensed task list for Spring 2013, with scheduling for material orders, testing apparatus construction, and testing evaluations. UltraTech Solutions had a meeting with our client on-site at Water4, an affiliate organization on January 3, 2013. At the conclusion of this meeting, new project objectives were agreed upon by both UltraTech Solutions and Pumps of Oklahoma. Additional testing will be conducted in the spring including physical testing of gravity fed flux rate through the system, potting resin techniques, and various areas of design effectiveness. Our team will be administering tests to ensure our system completely removes all bacteria as well as upscale the current design to a larger scale.

Task Name	Duration	Start	Finish
Company Visit	1 day	Thu 1/3/13	Thu 1/3/13
Order Materials	6 days	Mon 1/7/13	Sun 1/13/13
Long Term Testing Apparatus Construction	19 days	Mon 1/7/13	Thu 1/31/13
Long Term Flow Rate Testing	23 days	Fri 2/1/13	Tue 3/5/13
Resing Potting Technique Testing	10 days	Fri 2/15/13	Thu 2/28/13
Large Module Construction & Testing	11 days	Fri 3/1/13	Fri 3/15/13
Bachwashing Testing	24 days	Wed 3/6/13	Mon 4/8/13
Final Presentation	15 days	Mon 4/1/13	Fri 4/19/13
Final Report	35 days	Mon 3/4/13	Fri 4/19/13

Figure 2: List of specific tasks for Spring 2013 with their corresponding deadlines

A major goal will be determination of the most effective maintenance and field cleaning methodologies to prevent and correct failure or fouling specifically backwashing requirements. Working with Pumps of Oklahoma's affiliate organization, Water4, our team will research potential avenues to incorporate our design with new and existing Water4 drinking wells.

Deliverables

The deliverables of this project have been broken up into several subsections for the quantification of tasks and designation of team roles. Details are provided in the following paragraphs.

Special Requirements

Ultrafiltration membranes incorporated in the final design must be polyvinylidene difluoride hollow fiber ultrafiltration membranes provided by Pumps of Oklahoma.

Ideally, the design will be compatible for use with a Water4 well in set our design apart from existing filtration systems. Another distinguishable feature will be the gravity-fed/ low power design for use in developing nations where power supplies are limited.

Technical Approach

Development of a water filtration system for our customer, Pumps of Oklahoma, required an extensive patent review and examination of existing design pros and cons. Ultrafiltration is not a “new” technology but the intended use of our product to purify bacteria, virus and sediment contaminated water is new, and several key design features set our product apart from the current industry.

Customer Needs

Our customers’ needs are very straightforward. The overall system must remove all particulate, bacterial and viral contaminants utilizing hollow fiber ultrafiltration membranes. Pumps of Oklahoma also specified the unit must be gravity fed or low power with three different sizes for individual, family and community use. However, the primary needs of our customer for the spring term are analytical data concerning flow rates, bacterial removal and backwashing requirements for the modules. Inclusive in these testing procedures is the evaluation of optimal designs based on module performance, taking into account the effectiveness of parallel and series module configurations. Additionally size and scaling of the modules will be taken into account with the overarching goal set by our sponsors being to provide them with analytical test data sufficient to begin construction of a full scale prototype.

Current Technology

Prior to development of design concepts, an extensive patent review was conducted to avoid patent infringement and evaluate industry competitors. There are numerous patents related to water purification, most of which are less than 20 years old. However, none of the reviewed patents utilize gravity fed systems or hollow fiber polyvinylidene difluoride (PVDF) tubes so there are no expected patent infringement issues. US Patent 7484626 issued February 3, 2009 is for a "Porous Water Filter" with pore sizes from 2 to 5 microns. Although this product is similar, our PVDF tubes have 0.1 to 0.2 micron pores. While it is not low power, US Patent 2006/0219613 issued April 1, 2005 describes a nanofiltration system that is incorporated into a home plumbing system. Our system will not be coupled with a plumbing system but could be utilized with a hand pump to filter water as needed. A more in depth review of similar patents may be necessary if a combination filter and pump setup is pursued. A filter straw-personal filter patent was also discovered which may be a useful reference for a filter pump design using our PVDF tubes. Issued on February 26, 1991 US Patent 4995976 filters water using a series of filter sizes as a person drinks through it. Other patents were examined that are not detailed here. For a complete list of comparable patents see Appendix I.

An examination of market competitors was conducted to determine the amount of competition in our market niche. There are several major companies including Koch, Dow Industries, Toray and Pall Corporation who manufacture or market ultra, nano and microfiltration systems. Koch Industries alone has 20 different technologies in this field.

However, the filters are marketed primarily for food separation and wastewater treatment in high power systems. Water filtration for drinking is a relatively open field although the Paul Corporation does market a fully NSF approved purification system. Our design will be much simpler, and gravity fed so there should be no infringement issues.

Ultratech Solutions also researched technologies currently being used in developing nations to purify drinking water. Comparisons were made based on the purification capabilities, flux rates, and economics of each filter which were later compared to our design in each area. These technologies include ozone filtration, chlorination, activated carbon filters, reverse osmosis, bio-sand filters, and water distillation systems. Ozone filtration systems are effective at removing contaminants, and requires little to no maintenance, however this type of filtration is expensive and can cost around $1 million for a 1 million gallon per day system. It also requires the use of a water softener and is specific towards the temperature of the water that can be cleaned.

Chlorination is utilized frequently in developing nations, but this system requires a specified contact time to be effective, must be continuously tested and causes the water to have a poor smell and taste. More significantly, the continual ingesting of chemicals could have negative impacts on human health. Activated carbon filters are also highly effective in treatment of contaminated water, but would not meet a villages water needs. These systems have extremely low flux rates, need to be replaced often, and are expensive to ship and maintain. This type of filter could also serve as a breeding ground for microorganisms, which feed on the organic materials and chemicals filtered out of the water. Reverse osmosis systems require a pre-treatment system to be effective. They also are not appropriate for treating water contaminated with coliform bacteria, which is often found in water sources of developing nations, whose sewage systems may be dumped untreated directly back into the drinking water source. Reverse osmosis is expensive, requires regular maintenance, utilizes high amounts of energy, and only about 5-15% of the water entering the system is recovered as drinkable water.

Slow sand filtration systems such as a biosand filter are good for removing soil colloids and most bacteria, but frequently these systems are not sufficient for virus removal. They require careful maintenance to prevent disturbance of the biological layer that utilizes the bacterial contaminants in water as food. Water flux through these systems is slow (0.26-2.6 GPM) and a large system is required for a family. Sand filtration would not be efficient for a village-sized system. Water distillation is effective for removing dissolved materials, bacteria, and even heavy metals, however this method requires large amounts of energy, and bacteria can recolonize quickly once the heating coils cool.

Cost Analysis

Developed countries have the infrastructure, piping systems, man-power and quality control standards to provide clean water in quantities well beyond basic need. Third world countries do not have these resources so the successful implementation of our design as a commercial product hinges on its cost. The scope of our project was significantly reduced for the spring semester, but the estimated cost of a full scale system can be seen in Appendix V.

Our sponsor, Pumps of Oklahoma, provided several small filtration modules 1 ¼ X 6 inches in size with roughly 125 feet of membrane tubing length at no cost. To begin testing, several items were necessary to set up the scaled prototype. These can be seen in the table below.

Table 1-Cost of construction materials for scaled prototype testing.

Item	Quantity	Cost per Item	Total Cost
100 gal. Stock Tanks	2	$118.16	$236.32
1-1/4 X 1/2 Bushing	12	$1.06	$12.72
1/2 X 1/4 Barb	12	$0.78	$9.36
1/2 to 1/4 Bulkhead Fitting	1	$8.78	$8.78

These items were used to set up three of the provided modules in a parallel configuration and to make a larger filtration module. The materials for the larger module were purchased the previous semester and can be seen in Appendix V.

Our proposed budget was much higher ($2200) prior to reevaluation of design objects. However, our project is on target to remain under our proposed budget.

Fabrication, Validation, and Testing

Fabrication Details

UltraTech solutions tried various methods of potting ultrafiltration tubes inside the PVC modules with FDA approved resin. Most methods were unsuccessful, but one method worked well. A half-inch hole was drilled into the inside of a 90 degree PVC elbow. Two foot lengths of ultrafiltration tubes were looped and inserted into PVC elbow and then placed in a one foot length of PVC pipe. Resin was mixed and poured into the hole in the PVC as shown in figure #. Resin was added until no more would enter the drilled hole. This was allowed to dry and cure for 48 hours before any testing was performed. This potting method requires a large amount of resin which would cause an increase in cost of production. The benefits of being able to pot the resin locally instead of ordering one size of pre-potted modules may outweigh this increase in cost.

Validation and Testing

UltraTech solutions performed a number of validity tests on various modules to ensure their effectiveness.

The first tests that were conducted were to determine whether the teams design of a completely gravity fed system would actually allow water to flow through the ultrafiltration filters. In this test, the team set up a 100 gallon stock tank at approximately 7 feet above ground. We felt this was a reasonable height for most houses and buildings where the filter would be in use. The filter was then attached to the drain on the tank using flexible hose (Figure 3). Water flowed through the filter at a rate around 1 gallon per hour, verifying that water will flow with gravity as the driving force and no pump required.

Figure 3 - Small modules filtering with gravity as driving force.

Tests were then conducted on the larger module that was potted by the team. Water was pumped through the system to ensure tubes had not been closed off by the resin. The water flowed through successfully so the team set it up to do flow testing with gravity as the driving force. These tests also were successful, and water flowed through the module. In order to ensure there were no holes in the resin, and the water was in fact flowing through the filter the team mixed some clay in with the water being pumped into the filter, to see if it would pass through to the other side. This test revealed that the filter was successful at filtering out sediment, as the water exiting the filter was clear of any sediment.

Bacteria removal tests were also conducted to ensure the filters would perform as expected and remove the bacteria from the water (Figure 4). Liquid swine manure was injected into the filter (Figure 5) and the outflow was tested for coliform bacteria (Figure 6). Full bacteria testing specifications can be found in Appendix IV.

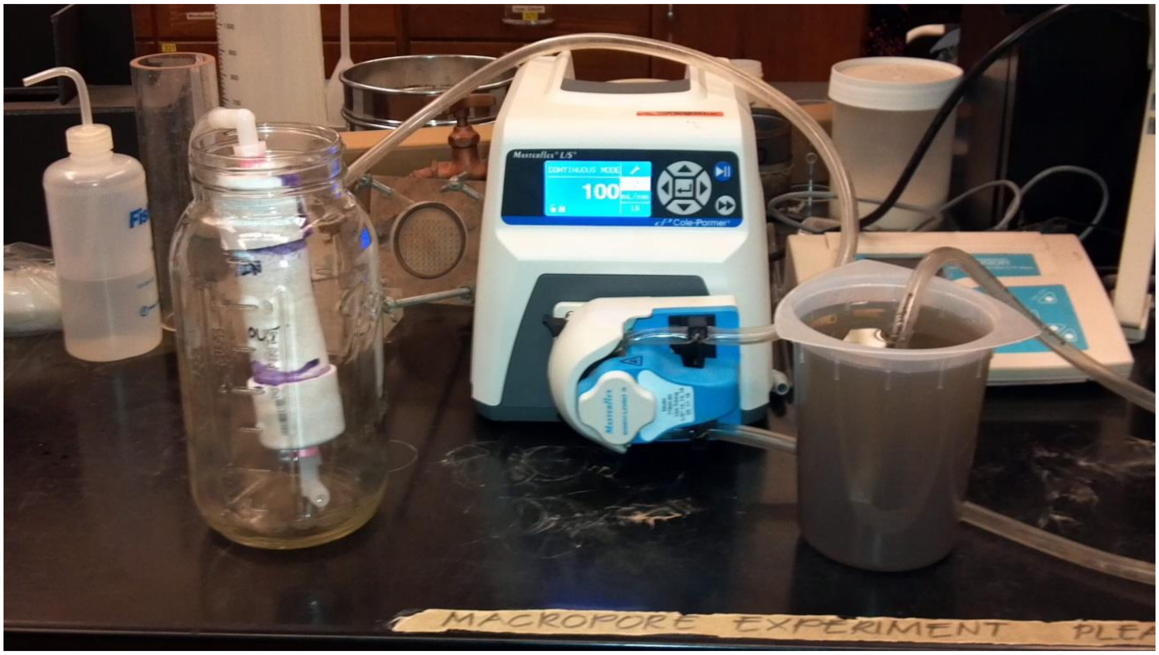


Figure 4 - Test setup for bacteria removal analysis.

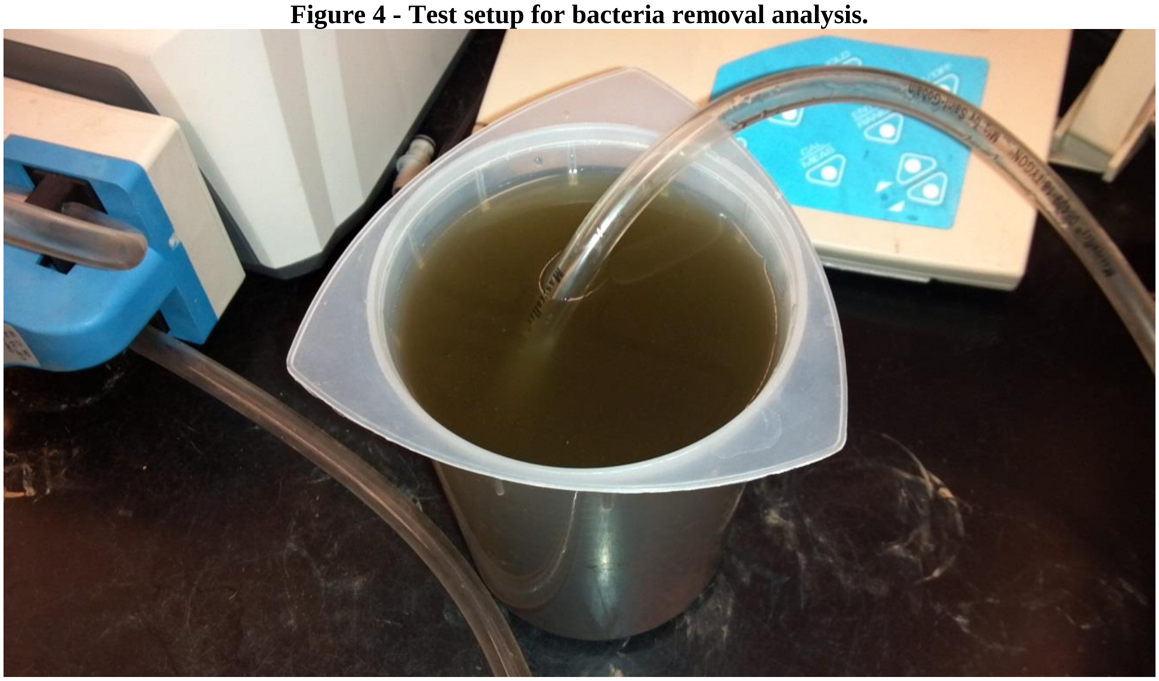


Figure 5 - Liquid swine manure solution used as inflow.

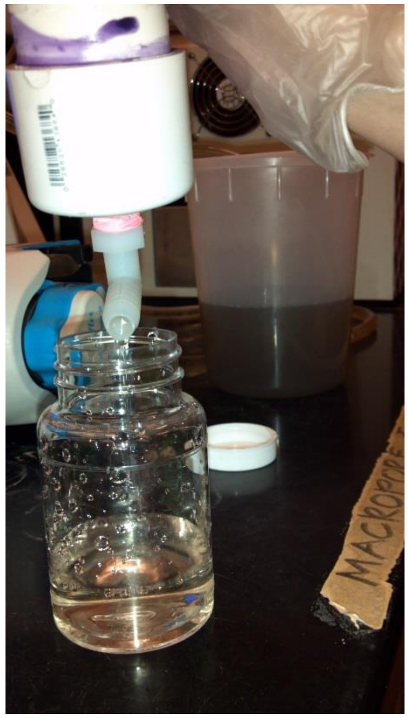


Figure 6 - outflow sample being collected.

One of the major unknowns in our project was the backwashing requirements for the filters and their life expectancy. It is important to know these requirements to determine if the project is feasible and cost effective. To test this water containing an average of 56.5 g/L suspended solids was allowed to flow through the filters. This experiment was set up as close as possible to what would be expected in their actual use, although the sediment loading used is expected to be a worst case scenario. The sediment infused water was mixed twice daily to simulate morning and evening use and the addition of more water to be filtered. Filter flow rates were then recorded at each mixing time, and the filters were backwashed every 24 hours. A flow reading was taken before and after backwashing and the volume of water used to backwash the system was recorded.

Overall, this experiment was very subjective with few values that could be quantified, especially the backwashing portion. To backwash the filters, a small amount of clean water was added to the outflow side and then the filter was shaken to dislodge sediment. This was done three times and then a small electric pump was used to backwash the larger module at 500 ml/min and the smaller filters at 150 ml/min. Both steps were important to remove loose sediment and the coating over the membranes (Figure 7).

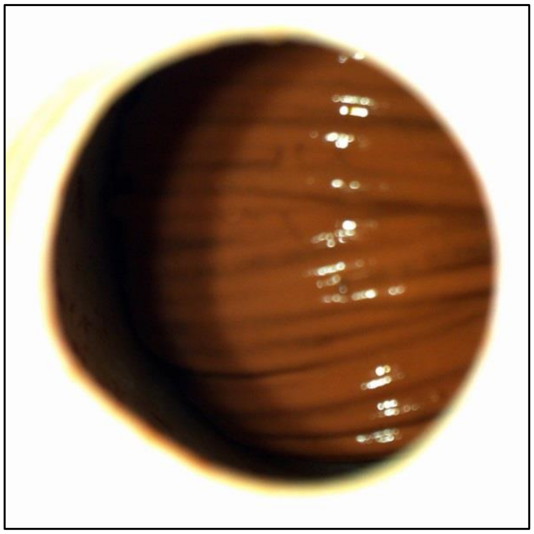


Figure 7 - Sediment coating on the PVDF membranes prior to backwashing.

Sediment/ Backwashing testing information…Appendix IV

Testing Results

Bacterial Removal Data:

Testing on February 20-21, 2013

Microbial tests from February 20th were unsuccessful.

Attempted running inflow at 100 ml/min, too much pressure built up causing the hose to come off of the filter. Only one sample was obtained, and this sample showed contamination. The most likely cause of this contamination is the hose coming off and getting inflow bacteria into the outflow.

Testing on March 4-5, 2013

Microbial tests were run on March 4. These tests ran smoothly and the results were favorable.

Inflow of liquid swine manure was started and two minutes were allowed before the first sample was taken. Four samples of 100ml outflow were taken between the times of 2-14 minutes. Samples were incubated following above procedure and results are outlined in Table 2 below. These results were obtained using the Idexx Quanti-trays below in Figures 9-12.

Table 2 - Results from bacterial testing.

	Coliform			E. coli		
	Large Cells	Small Cells	MPN (100ml)	Large Cells	Small Cells	MPN (100ml)
Inflow	49	45	173290	49	43	141360
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	1	0	1	1	0	1

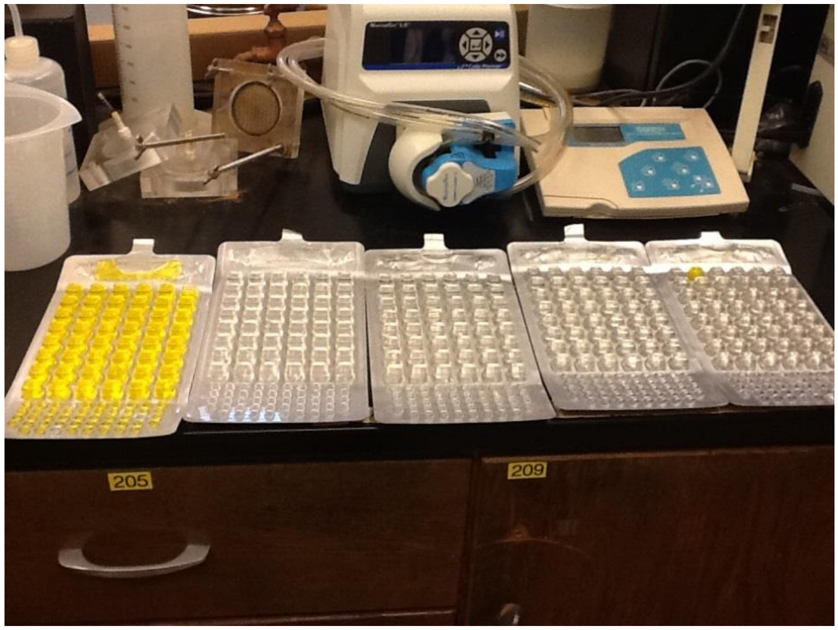


Figure 8 - Bacterial sample after incubation.

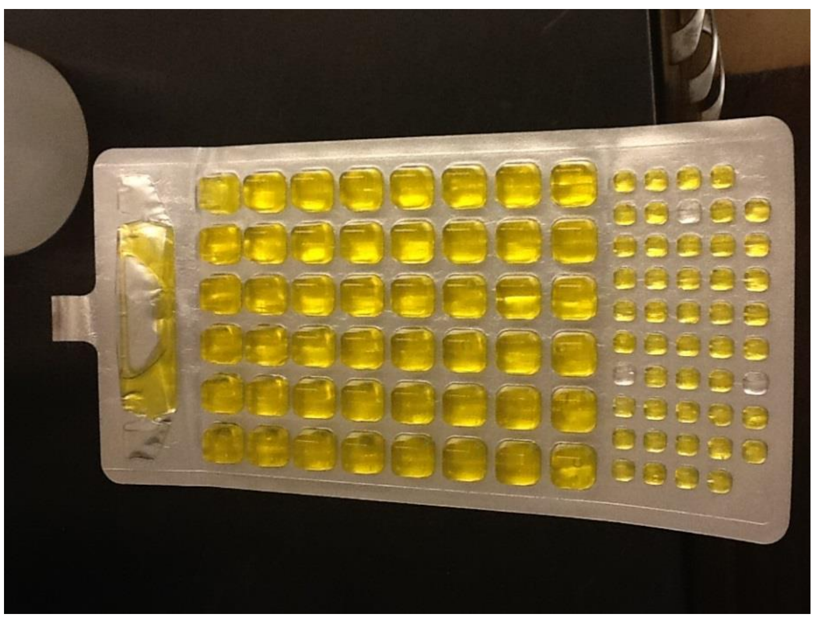


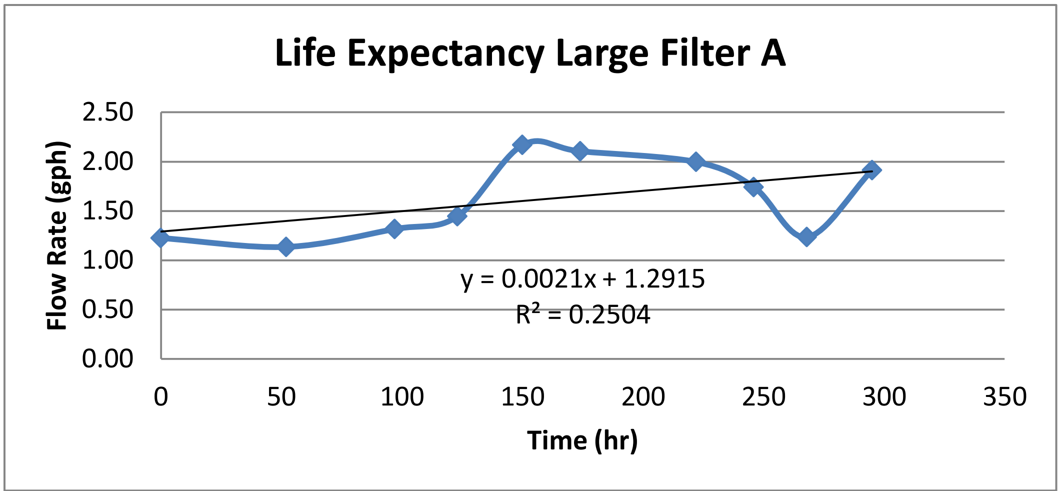
Figure 9 - Inflow bacterial sample.

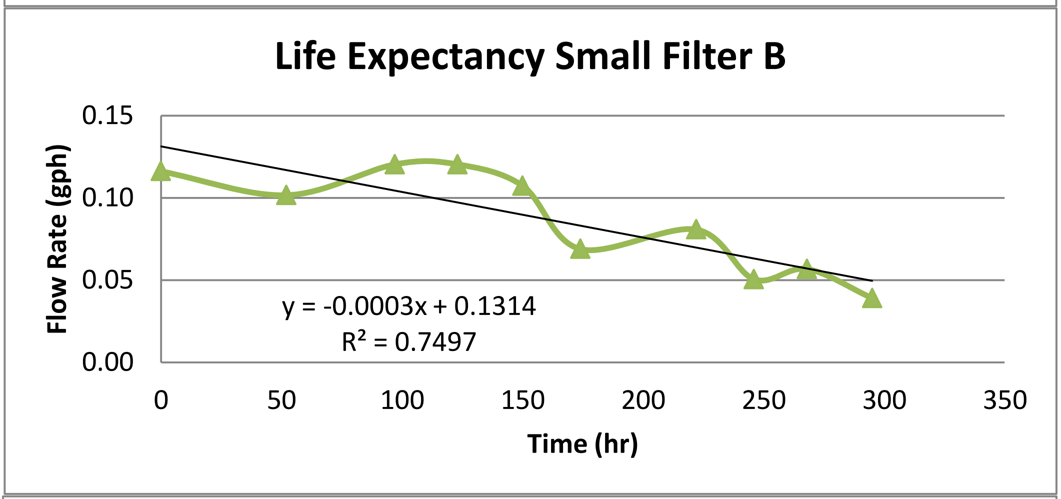
Figure 10 -Outflow samples one and two. No Bacterial Content.

Figure 11 - Outflow samples three and four. One contaminated cell representing one bacterium per 100 mL sample.

Backwashing Data:

The mechanical agitation (shaking) seemed to work the best to remove sediment. Backwashing with the electric pump removed a considerable amount but subsequent agitation would dislodge more sediment.





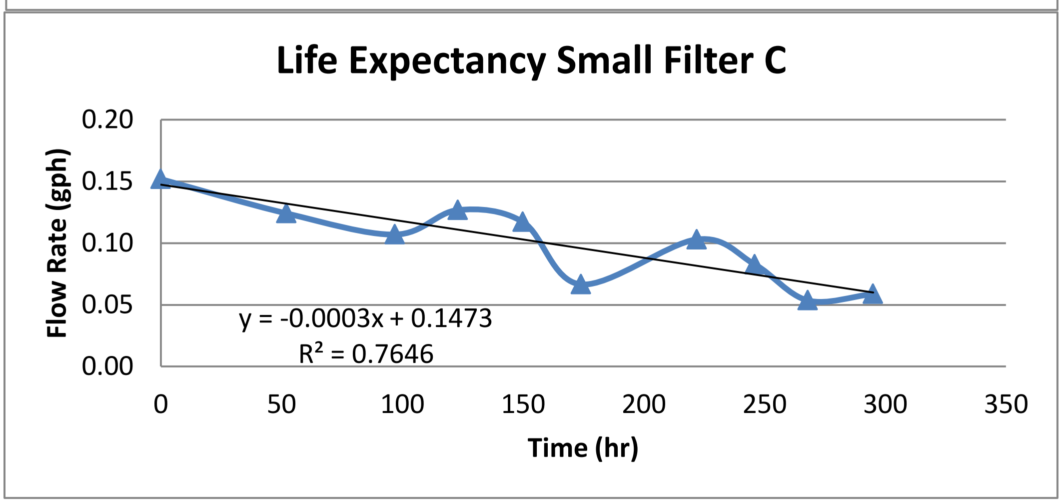


Figure 12 - Results of backwash testing. The filters were backwashed roughly every 24 hours and the flow rate after backwashing was recorded. This gave an estimation of the "recharge" ability of the filters to return to their normal flow rate. The sediment loading in the system was very high, 56.5 g/L.

For the small filters, a steady downward trend can be seen. This was expected, however, Ultratech solutions believes that this trend will eventually stabilize at a certain flow rate. Based on the trend line it will take 7 days before the filter reaches a flow rate of 0.075 gallons per hour. A longer testing run needs to be done to see if there is a limit to the flow rate reduction. The large filter was quite different and did not conform to expectations. We believe this is because the PVDF membranes are not packed as densely within the PVC pipe. As mentioned earlier, the backwashing technique employed used mechanical agitation to dislodge particulate and allow it to be removed in the wash water. A lower packing density allows the agitation to be more effective; the impact force is not absorbed by the PVDF membranes. The inconsistencies of the module flow rates are most likely a result of UltraTech Solutions' backwashing technique which was varied for each team member. Since shaking was used for mechanical agitation, the amount of dislodged sediment and therefore the increase in the flow rate are proportional to the strength of the team member responsible for that day's backwashing.

Conclusions and Recommendations

Our team met each of our three objectives:

(1) Identify a potting technique for the module's resin,

(2) Ensure filtered water is free of microorganisms and safe for human consumption, and

(3) Compare flow rates and backwashing needs of given and larger modules.

The potting method that we discovered is effective at removing soil particles, removing *E. coli*, increasing longevity, and increasing flow rates. The increased longevity and flow rates come from the comparison between the given modules and our team-potted larger module.

Our tests indicated that the water through the small modules experienced a five-log reduction in bacterial content between the inflow and outflow. This makes the water much safer for drinking than if it were to be ingested directly from the source. The inflow that was used was extremely concentrated liquid swine manure; a stream used for drinking water should have a much lower initial concentration of bacteria, making it possible for the outflow bacteria to be immeasurably low. The water was also visibly cleared of sediment. This water is much safer for human consumption than untreated water; however the pores are small enough to allow the transport of viruses. To ensure the water is safe for human consumption, a secondary filter is recommended.

Recommendations

- Include a secondary virus treatment to ensure safe drinking water.
- Gravity is sufficient to push the water through the filtration modules.
- To extend the life expectancy of the filters, a settling tank or sediment filter is recommended.
- Decreased packing density of filters allows for sediment to better be removed during backwashing.
- Utilize mechanical agitation as a primary method of cleaning the filters, as it is more effective and uses less water.
- Some type of brush or agitator would help remove filtered sediment, extending the longevity of the filter.

Sponsor Communication

UltraTech Solutions corresponds with Pumps of Oklahoma representative Micah Goodspeed via weekly email. Emails include updates on design changes, deliverables, and testing results as well as project progress. If the project requires site visits, Ultra Tech Solutions will commute to Pumps of Oklahoma in Oklahoma City. Phone calls and in person meetings are also scheduled as needed.

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Appendix I

Appendix I contains a list of patents relevant to our project. This is not a comprehensive list and there are numerous other patents with similar design features and purposes as our project.

United States Patent [19]
Vermes et al.

[11] **Patent Number: 4,995,976**
[45] **Date of Patent: Feb. 26, 1991**

[54] **WATER PURIFICATION STRAW**

[75] Inventors: **Sheldon A. Vermes**, Shoreview; **David M. Botts**, Spring Park; **Charles A. Peterson**, Hopkins, all of Minn.

[73] Assignee: **Water Technologies Corporation**, Plymouth, Minn.

[21] Appl. No.: **531,125**

[22] Filed: **May 31, 1990**

[51] **Int. Cl.**[5] **B01D 24/08**
[52] **U.S. Cl.** **210/266**; 210/282; 210/283; 210/289; 210/501; 210/502.1
[58] **Field of Search** 210/202, 266, 501, 282, 210/283, 287, 290, 289, 502; 424/179, 150

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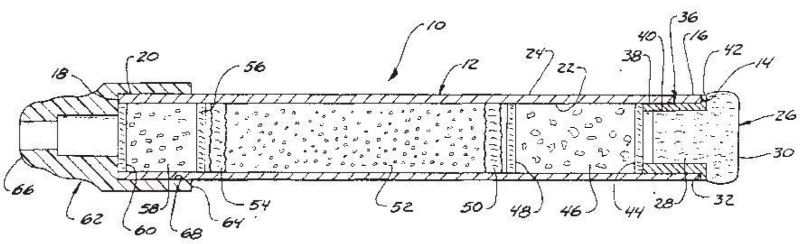
Primary Examiner—Stanley Silverman
Assistant Examiner—Cynthia L. Nessler
Attorney, Agent, or Firm—Kinney & Lange

[57] **ABSTRACT**

An orally usable filter straw for the purification of water by forced movement of the water through the straw. The straw includes an elongated tubular conduit having an inlet for reception of the water at a distal end of the conduit and having an outlet at a proximal end of the conduit for expulsion of the treated water. Beginning at the inlet of the straw, the straw includes the following materials retained within the conduit: a removably mounted filter, a purification resin, activated carbon granules, and a bactericide resin. A mouthpiece is mounted at the outlet of the conduit to allow the device to be suitably received by a human user. The straw includes a series of porous spacers positioned within the conduit to segregate the materials retained within the straw.

16 Claims, 1 Drawing Sheet



US005536395A

United States Patent [19]

Kuennen et al.

[11] **Patent Number: 5,536,395**

[45] **Date of Patent: Jul. 16, 1996**

[54] **HOME WATER PURIFICATION SYSTEM WITH AUTOMATIC DISCONNECTING OF RADIANT ENERGY SOURCE**

[75] Inventors: **Roy W. Kuennen**, Kentwood; **Robin M. Dykhouse**, Grand Rapids; **Dennis J. Kool**; **Ronald C. Markham**, both of Kentwood; **Bradley J. Pippel**, Grandville; **Dennis E. Kidd**, Rockford; **Merlin G. Tiede**, Ada, all of Mich.

[73] Assignee: **Amway Corporation**, Ada, Mich.

[21] Appl. No.: **35,011**

[22] Filed: **Mar. 22, 1993**

[51] **Int. Cl.**[6] **B01D 35/143**; B01J 19/10

[52] **U.S. Cl.** .... **210/87**; 210/97; 210/143; 210/192; 210/232; 210/282; 250/432 R; 422/186.3

[58] **Field of Search** .... 210/85, 87, 97, 210/110, 136, 192, 232, 282, 295, 501, 503, 504, 748, 143, 103, 137, 259; 422/186.3; 250/432 R, 435, 436, 455.11

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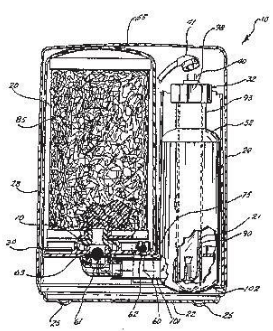
Primary Examiner—Joseph W. Drodge
Attorney, Agent, or Firm—Amway Corporation

[57] **ABSTRACT**

A point of use water purification system for home use is provided comprising a carbon block filter housed in a self-contained disposable pressure vessel for removing particulates and organic contaminants from water. The filter is provided with a pore-size distribution, a binder and a flow path which optimizes filtration performance and enhances microbiological kill rates obtained in a source of radiant energy which is used to kill microorganisms in the filtered water. The source of radiant energy comprises an ultraviolet discharge lamp having an elongate central axis and a diverter for providing a spiral plug flow of water about the discharge lamp. A flow regulator adjusts flow through the system for varying line pressure conditions to ensure adequate exposure of microorganisms to ultraviolet energy. A lamp control circuit conserves power and optimizes ultraviolet output. A diagnostic system includes a filter monitor which provides an automatic indication to the user when the filter has reached its end of life. The diagnostic system includes a radiation source monitor which provides an automatic indication to the user when the UV discharge bulb has malfunctioned. A filter quick-disconnect, a radiation source quick-disconnect and associated power safety interlocks protect the user and facilitate the safe and easy replacement of the disposable filter cartridge and ultraviolet discharge bulb.

26 Claims, 9 Drawing Sheets



US007390343B2

(12) **United States Patent**
Tepper et al.

(10) **Patent No.: US 7,390,343 B2**
(45) **Date of Patent: *Jun. 24, 2008**

(54) **DRINKING WATER FILTRATION DEVICE**

(75) Inventors: **Frederick Tepper**, Sanford, FL (US); **Leonid A. Kaledin**, Port Orange, FL (US)

(73) Assignee: **Argonide Corporation**, Sanford, FL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **11/680,840**

(22) Filed: **Mar. 1, 2007**

(65) **Prior Publication Data**

US 2007/0175196 A1 Aug. 2, 2007

Related U.S. Application Data

(63) Continuation-in-part of application No. 11/677,705, filed on Feb. 22, 2007, which is a continuation-in-part of application No. 11/531,107, filed on Sep. 12, 2006, now Pat. No. 7,311,752.

(60) Provisional application No. 60/744,043, filed on Mar. 31, 2006, provisional application No. 60/716,218, filed on Sep. 12, 2005.

(51) **Int. Cl.**
C02F 1/00 (2006.01)

(52) **U.S. Cl.** **55/527**; 55/523; 55/528; 55/DIG. 39; 95/273; 95/285; 210/660; 210/500.1; 210/505; 210/510.1; 423/627; 423/629; 436/177

(58) **Field of Classification Search** .... 55/527, 55/528, 523, DIG. 39; 95/273, 285; 210/660, 210/500.1, 505, 510.1; 423/627, 629; 436/177
See application file for complete search history.

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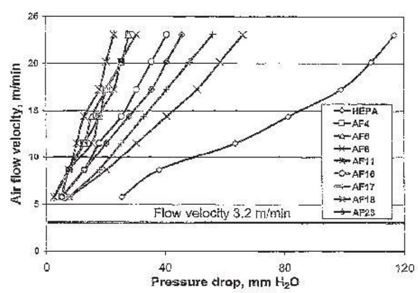
Primary Examiner—Duane Smith
Assistant Examiner—Minh-Chau T. Pham
(74) *Attorney, Agent, or Firm*—Alicia M. Passerin, Esq.; Cohen & Grisby, P.C.

(57) **ABSTRACT**

The invention is a device for purifying drinking water that has at least one fibrous structure. Preferably, there is an upstream and downstream fibrous structure. Each fibrous structure is a mixture of nano alumina fibers and second fibers arranged in a matrix to create asymmetric pores and to which fine, ultrafine, or nanosize particles are attached. Preferably, the device has an upstream antimicrobial for sterilization of retained microbes. The device is substantially more efficient at removing soluble contaminants such as halogens from a fluid stream than those previously available and is also able to retain turbidity, bacteria, and virus.

30 Claims, 20 Drawing Sheets



US007484626B2

(12) **United States Patent**
Judkins

(10) **Patent No.:** **US 7,484,626 B2**
(45) **Date of Patent:** **Feb. 3, 2009**

(54) **WATER NANO-FILTRATION DEVICE**

(75) Inventor: **Roddie R. Judkins**, Knoxville, TN (US)

(73) Assignee: **UT-Battelle, LLC**, Oak Ridge, TN (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 492 days.

(21) Appl. No.: **11/277,246**

(22) Filed: **Mar. 23, 2006**

(65) **Prior Publication Data**

US 2007/0221564 A1 Sep. 27, 2007

(51) **Int. Cl.**
B01D 29/44 (2006.01)
B01D 63/00 (2006.01)
C01F 1/00 (2006.01)

(52) **U.S. Cl.** **210/490**; 210/323.2; 210/321.6; 210/777; 210/650

(58) **Field of Classification Search** 210/490, 210/500.25, 650, 321.6, 323.2, 777; 96/11; 502/180, 416–417; 95/114; 55/523; 427/244
See application file for complete search history.

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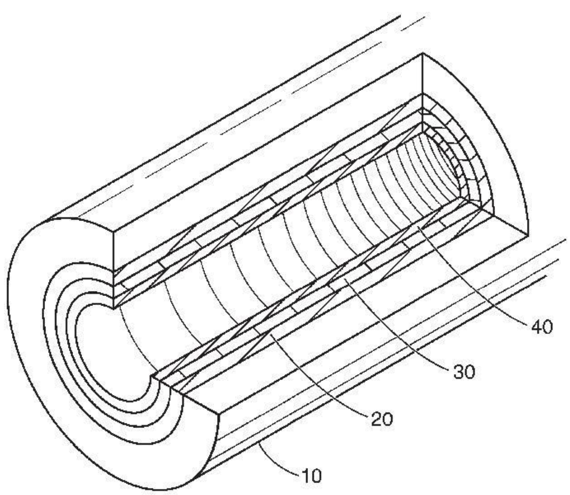
Primary Examiner—Ana M Fortuna
(74) *Attorney, Agent, or Firm*—Joseph A. Marasco; Marc T. Filigenzi

(57) **ABSTRACT**

A water filter includes a porous support characterized by a mean porosity in the range of 20 to 50% and a mean pore size of 2 to 5 μm; and a carbon filter medium membrane disposed thereon which is characterized by a mean particle size of no more than 50 μm and a mean pore size of no more than 7.2 μm.

4 Claims, 9 Drawing Sheets



US 20060219613A1

(19) **United States**
(12) **Patent Application Publication**
Scheu et al.

(10) **Pub. No.: US 2006/0219613 A1**
(43) **Pub. Date: Oct. 5, 2006**

(54) **WATER PURIFICATION SYSTEM AND METHOD**

(76) Inventors: **Richard W. Scheu**, Rainier, OR (US); **Nathan Jacobson**, Rainier, OR (US)

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(21) Appl. No.: **11/097,567**

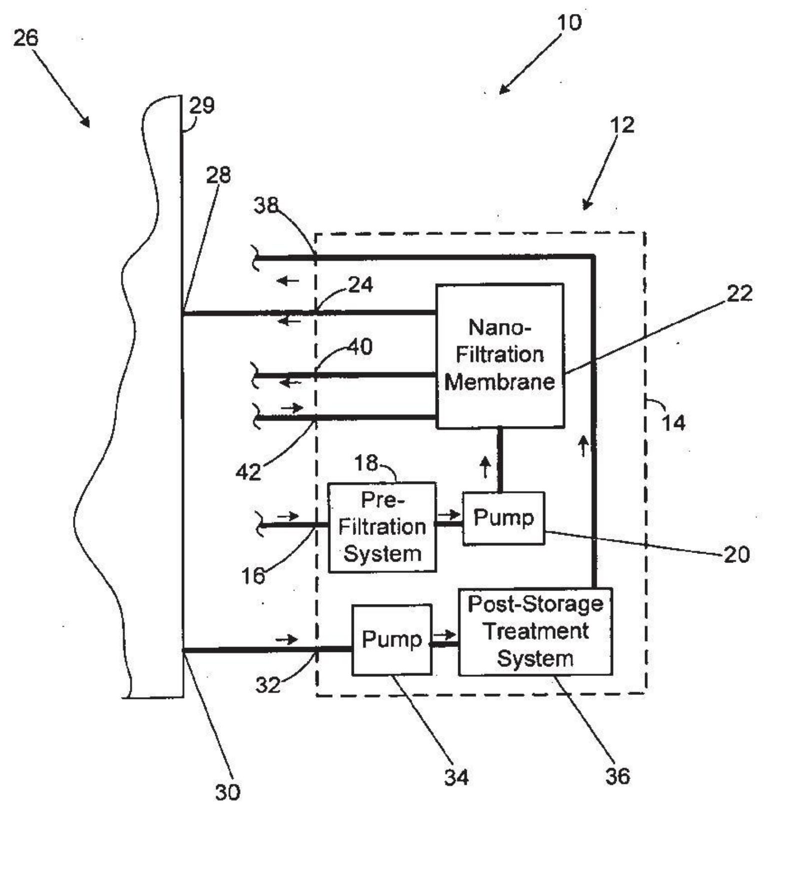
(22) Filed: **Apr. 1, 2005**

Publication Classification

(51) **Int. Cl.**
B01D 35/14 (2006.01)
(52) **U.S. Cl.** **210/108**; 210/130; 210/134; 210/192; 210/257.2; 210/258; 210/259; 210/195.2

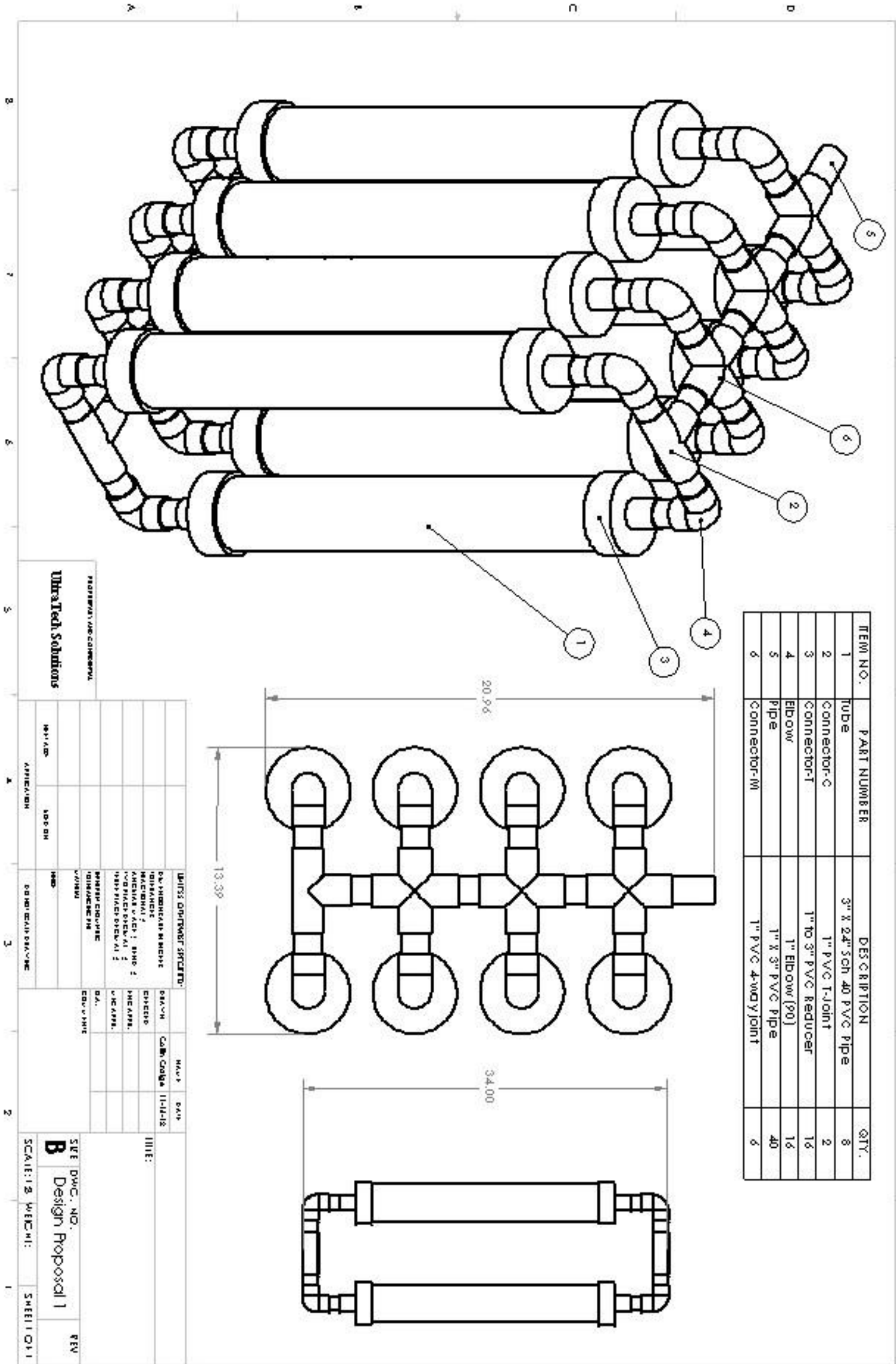
(57) **ABSTRACT**

A water purification system is provided that includes a pre-filtration system for pre-filtering water, a first pump, a nano-filtration membrane configured to separate pre-filtered water into nano-filtered water and effluent, a holding tank, and a second pump. The first pump is operable for pumping pre-filtered water through the nano-filtration membrane, and the second pump is operable for pumping nano-filtered water from the holding tank into the plumbing of a building.

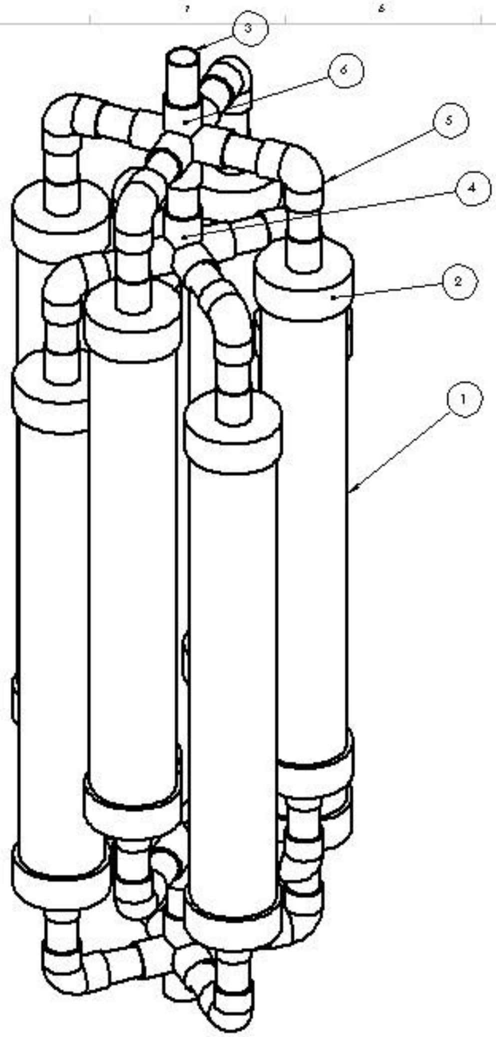


Appendix II

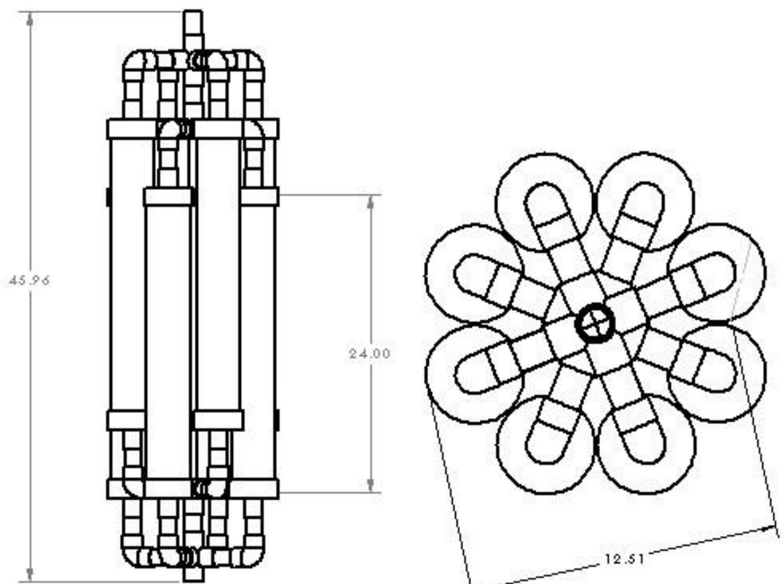
Appendix II contains drawings of proposed designs with dimensions for easier comparison of design features.



ITEM NO.
PART NUMBER
DESCRIPTION
QTY.
1
Tube
3" X 24" Sch 40 PVC Pipe
8
2
Connector-C
1" PVC T-Joint
2
3
Connector-T
1" to 3" PVC Reducer
16
4
Elbow
1" Elbow (90)
16
5
Pipe
1" X 3" PVC Pipe
40
6
Connector-M
1" PVC 4-way joint
6
20.96
13.39
34.00
1
2
3
4
5
6
UltraTech Solutions
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
11-6-12
TITLE:
SIZE
B
DWG. NO.
Design Proposal 1
REV
SCALE: 1:8
WEIGHT:
SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Tube	2" X 24" Sch 40 PVC	8
2	Connector-T	1" to 2" Reducer	16
3	Pipe1	1" X 3.5" Sch 40 PVC Pipe	35
4	Connector-M1	1" 5-way connector	2
5	Elbow	1" Elbow (90)	16
6	Connector-M3	1" 6-way connector	2



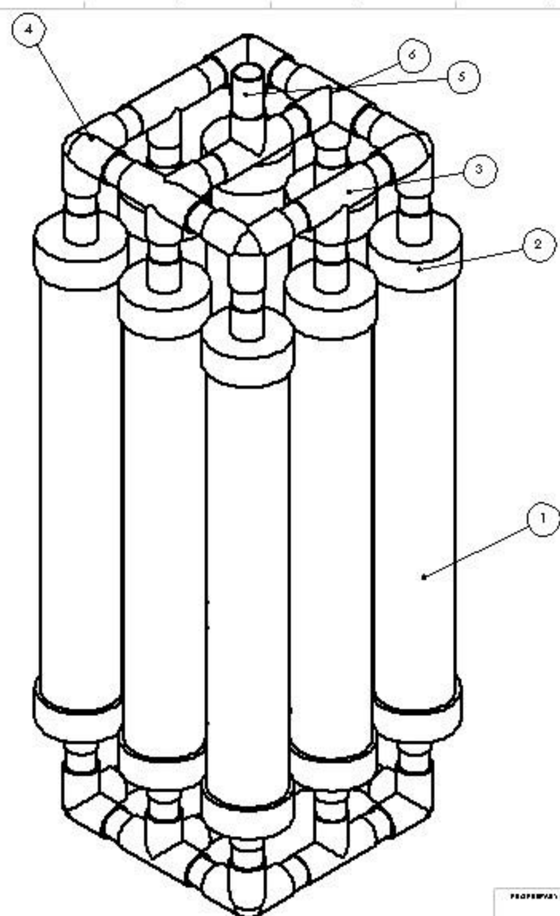
Ultra Tech Solutions

DRAWN: Colin Craige 11-16-12

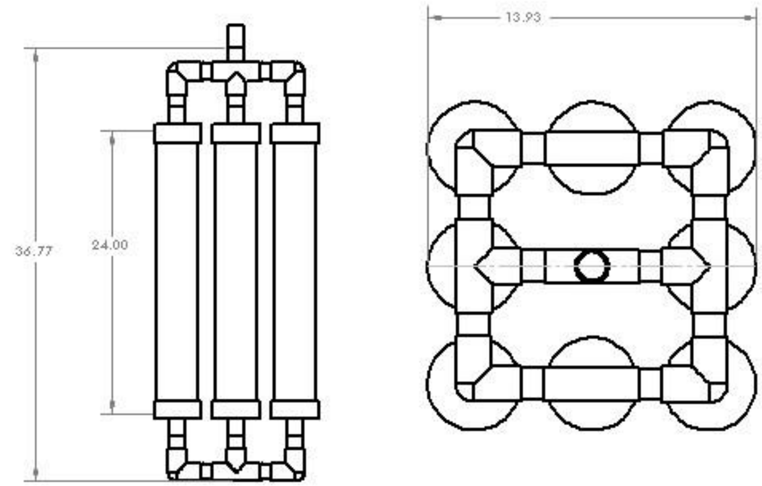
TITLE:

SIZE B DWG. NO. Design Proposal2 REV

SCALE: 1:12 WEIGHT: SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Tube	3" X 24" Sch 40 PVC Pipe	8
2	Connector-T	1" to 3" PVC Reducer	16
3	Connector-C	1" PVC T Joint	6
4	Connector C1	1" 3-way corner PVC joint	8
5	Pipe	1" X 3" PVC Pipe	37
6	Connector-M2	1" 4-way corner PVC joint	4



UltraTech Solution,

DRAWN Colin Craige 11-18-12

TITLE:

SIZE B DWG. NO. Design Proposal 3 REV

SCALE: 1:12 WEIGHT: SHEET 1 OF 1

Appendix III

Appendix III contains proposed design concepts that could be implemented at a later date.

Design Generation

Ultrafiltration Design

Each stage of the system was designed around the primary PVDF filter unit for maximum efficiency, cost reduction and simplicity. This methodology was selected so that any unforeseen concerns in the primary filter unit could be compensated for in the pretreatment and secondary systems. Additionally, the PVDF filter was the most complex component with the greatest potential for cost reduction. Literature review indicated that the most effective and simplest filter containment system was a tube rack module. A sheet or curtain setup is the most compact, with the highest PVDF filter density but the added complexity increases cost. An example of a curtain and tube rack systems from two competitors, Dow Industries and Zenon, are shown in Figure 13. Simplicity, cost and compact design were the key focus areas in the hollow fiber filtration module. After reviewing current systems and an extensive patent search, out three goals were broken down into more specific components to identify solutions (Table 3).

A compact setup reduces the required housing space and increases product transportability. Our system will be maintained with a limited number of tools and equipment so simplicity is paramount to a successful product. Achieving our goal in simplicity and space utilization will help us reduce costs, our greatest hurdle.

Figure 13 - On the left is a tube rack setup by Dow Industries while on the right is a curtain setup by Zenon. Although the tube system is not as filter dense it is much simpler.

Table 3 - After identifying three major goals, each goal was broken down into more specific elements to improve project management.

Specific Goal	Logic
Simplicity	
Exchangeable modules	Reduce cost, eliminate need for multiple designs
Hand assembly	Reduce cost, no power needed for construction
Small number of individual parts	Reduce cost, less chance for failure, easier to maintain/fix
Compact	
High filter density	Less material for frame support, low space requirements
Transportability	Reduce cost associated with transportation
Cost Reduction	
Material minimization	Lowers cost, simpler design
Common Materials	Reduce repair time, lower cost

From the criterion outlined in Table 3, three systems were developed, each featuring a single filter unit that can stand alone or be linked to increase filtration flux (Figure 14). Full specifications can be seen in Appendix II.

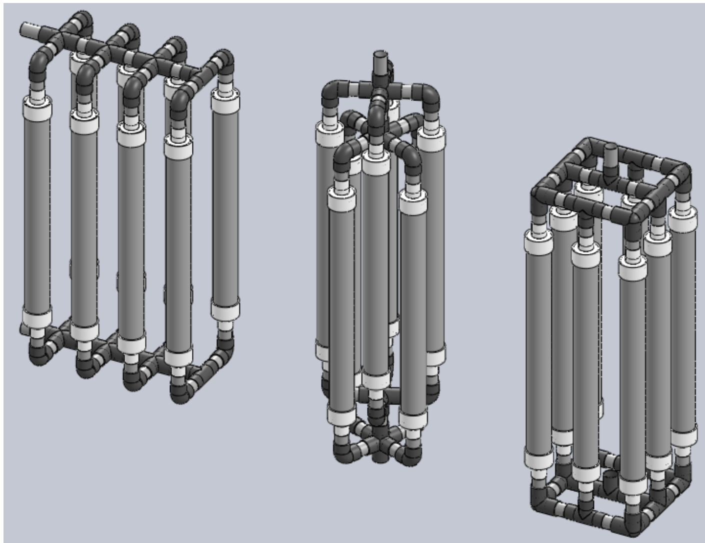


Figure 14 - Three different concepts were developed each with advantages and disadvantages. Left to right is design 1, design 2 and design 3.

Table 4 - Benefits and disadvantages of each design proposal.

Benefits		
Design 1	***Design 2***	***Design 3***
Self-Supporting	Compact	Compact
Simple		Self-Supporting
Low Cost		
Disadvantages		
Design 1	***Design 2***	***Design 3***
Not Compact	Extra Supports	Cost
	Custom Parts	

Each design proposal uses eight components, including the PVDF filtration tubes and sections can be added to increase overall system size. The entire system can be hand assembled from common PVC pipe, a common and easily obtainable product. Utilizing PVC pipe as the membrane housing greatly reduced costs while providing adequate protection for the hollow fiber membranes. To cut costs further, the PVDF tubes will be “looped” within the PVC and potted on only one end. This will cut potting costs in half.

The design concepts were developed around cost, simplicity and size. Design one is the least expensive design while design three is slightly more expensive, but is more membrane dense. Design two is the most compact design but would require a custom fabricated part which could reduce its cost advantage over design three. Consideration of these designs led UltraTech Solutions to select design concept three as the overall best design. The benefits and disadvantages of each design can be seen in Table 4.

Sediment Filter Design

The sediment filter will remove particulate matter and turbidity, to reduce backwashing frequency and clogging of ultrafiltration membranes. UltraTech Solutions discussed various methods to achieve soil particulate removal, selecting a quick infiltration sand filter. This filter will contain a small layer of gravel at the bottom, covered with a thicker layer of moderately course sand packed to a wet bulk density between 1.6 and 1.8 grams per cubic centimeter.

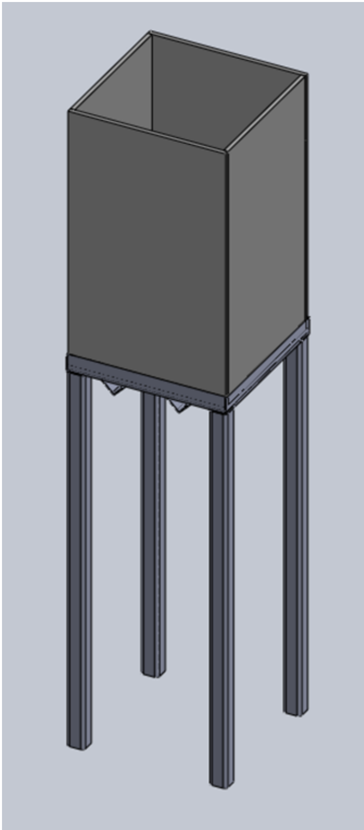


Figure 15 - Box design for primary sediment filter.

There are two design concepts for the soil pre-filter, a cartridge and a box design. In the cartridge design, sand would be contained in three inch PVC and would be incorporated as part of each ultrafiltration module. The upper cartridge could be unscrewed for removal routine maintenance. The box design would be a stand-alone sediment filter, filled partially with moderately course sand with a gravel base (Figure 15). This design would provide a holding area for water to add head to speed water flow through the filter. This design would also be easier to maintain, as the top layer would need to be scraped occasionally when the flow rate through the soil slows to an unacceptable rate. The box design is UltraTech's final selection because it is simple and more cost effective.

Ultraviolet Purification Design

The pores of our specific ultrafiltration membranes are large enough that free floating viruses can pass through and be ingested. To address this issue, UltraTech Solutions has incorporated a tertiary purification system. Several technologies were considered including chlorination, silver impregnated filters, and Ultraviolet purification. Chlorination was discarded as it requires a contact period to be completely effective and involves the unnecessary ingestion of chemicals. Silver impregnation was not economically feasible, and was removed from consideration. This left ultraviolet purification which provided a non-chemical, low-cost virus elimination system. The disadvantage of ultraviolet purification is the need for a power sources. Areas that have a reliable power supply most likely have relatively clean water so our team selected monocrystalline solar panels to power the unit. These panels are high efficiency (18%) providing steady power in sunny climates such as Africa. Other areas may require alternate power options.

Ultratech Solutions has developed a number of different design options that will be presented to Pumps of Oklahoma (Figure 16). These concepts include two different designs for the sediment filter, the three ultrafiltration module designs, the post membrane treatment, as well as pump types.

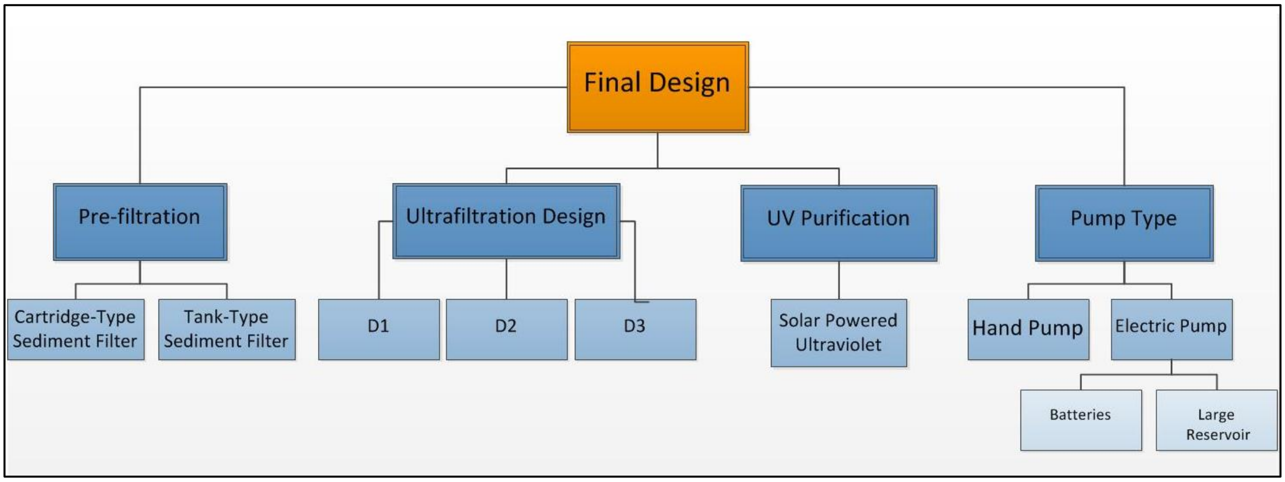


Figure 16 - Potential design combinations for each segment of the water treatment system.

Design Calculations

Basic calculations were done to verify concepts and develop proposals. The majority of these centered on sizing the PVDF membranes and solar panels for water flux and electric output respectively. More calculations are needed to finalize sizing requirements, such as trans-membrane pressure and required feed pressure but UltraTech believes that our current calculations have validated our design sufficiently to continue design work. In our flux calculations only one assumption was made. Unable to conduct flux testing this Fall, our team estimated the flux in a gravity fed system by linearly interpolating the flux corresponding to the minimum and maximum pressures outlined in the product manual to a gauge pressure of zero. Testing will be done in the Spring to determine the actual flux rate but, with this estimate we could begin sizing our system. First the total membrane length in each module was determined based on specifications given in the product manual and using the inside diameter of 3 inch schedule 40 PVC pipe. A packing density of 0.9 was used and 0.25 inches of space was allowed around the membrane bundle. These calculations indicated that each ultrafiltration module would filter 11 gallons per hour or 88 gallons for the base system.

We expected the ultrafiltration stage to be the filtration limiting step but the box soil filter was sized using Darcy's law to determine the smallest allowable sediment size (Equation 1). Using medium coarse sand and an area of 0.18 cubic meters a flow of 100 gallons per hour is achieved, greater than the ultrafiltration stage.

Equation 1 - Darcy's Law

$$Q = -KA\left(\frac{dh}{dl}\right) = 100 \text{ gal/hr}$$

$Q = Volumetric\ flow$

$K = Hydraulic\ conductivity$

$A = Area$

$\frac{dh}{dl} = \frac{Change\ in\ head}{Change\ in\ Length}$

Knowing our expected flow rate the ultraviolet filter was then sized to treat three gallons per minute. A direct current unit was used to reduce amperage draw from the solar panels. The nature of solar panels is that they work well on days with high insolation but not well on days when the earth's surface receives low insolation. Because of this, the panels were oversized to accommodate fluctuations in incoming insolation. Insolation also varies with location so a system may need to be larger for certain regions. Using data for South Africa, an average of 5280 watts/m^2 are received during 6.8 hours of sunlight. Our selected ultraviolet light requires 14 watts of power, and was assumed to operate for seven hours (Equation 2). Equation 3 shows that the selected solar panel kit is more than twice the size it needs to be, however, the extra size will be necessary on low insolation days and could be used to power a light or small pump.

Equation 2 - Panel area calculation.

$$Panel\ Area = \frac{Need}{Available} = \frac{7 * 14}{5280 * 0.15\%} = 0.125m^2$$

Equation 3 - Oversizing calculation.

$$\%\ over\ sized = \frac{available}{required} = \frac{231}{7 * 14} * 100 = 235\%$$

Appendix IV

Appendix IV contains testing specifications for bacteria removal effectiveness of the filter, as well as backwashing testing procedures.

Bacteria Removal Effectiveness Testing Procedure

Required Materials:

- Liquid Swine Manure
- IDEXX Quanti-Trays
- IDEXX Tray Sealer
- Fluorescence Viewer
- 100 mL clear plastic bottles
- Colilert reagent packets
- Positive displacement Pump
- Inflow container
- Outflow container
- Ultrafiltration Tube
- 2- 1 ¼ inch end caps fit with hose adapters

Procedure:

- Set pump to desired flow rate through the filter (this could be set to simulate a certain elevation of inflow). Small filters were tested at about 50ml/min. Large filters were tested at about 200ml/min.
- Take an initial sample of liquid swine manure to test initial bacterial concentration in inflow (this can be diluted or concentrated to adjust this value). Liquid swine manure was diluted to 40% manure 60% RO water. This was diluted to 1ml/100ml sample bottle to quantify the bacteria content.
- Begin test by pumping liquid swine manure mixture into filter. Pump is a positive displacement pump.
- Collect outflow for a predetermined amount of time in 100mL sample bottles (approximately 2 minutes).
- Pour Colilert reagent packets into each 100mL sample and shake sample until well mixed.
- Pour sample containing reagent into IDEXX Quanti-trays.
- Seal trays using the Tray Sealer.
- Put trays into incubator set to 35 +- 0.5 degrees Celsius for 24 hours.
- At exactly 24hours after incubation count the numbers of cells that are yellow (positive for coliform) and cells fluorescing and yellow (positive for *E. coli*). Fluorescence is seen when tray is placed in a black-light viewer. (Hopefully these numbers will be zero for our filtered samples)
- Compare this number of cells to the MPN chart included with the IDEXX trays to determine MPN of *E.coli* and total coliform bacteria found in the 100mL sample. The number obtained for the inflow must be multiplied by 100 to obtain the initial bacterial count.

Backwashing Testing Procedure

Materials:

6 – Ultrafiltration modules

2 – 100 gallon tanks

10ft – plastic tubing, ¼ inch

7ft – Stand

6 – Buckets

1 – Scale

6 – Ball valves

1 – Syringe

Operating Procedure:

Installation:

1. Hook three ultrafiltration modules together in parallel, one set for each tank placed on the 7 and 10 feet stands.

2. Place a bucket beneath each individual ultrafiltration module to collect filtered water. *Keep module filtrate separate.*

3. Fill the holding tanks with water from Lake Carl Blackwell.

Sample Collection and Testing:

1. Allow the water to settle for 10 minutes and collect three 100 ml samples of the dirty water to test for Total Suspended Solids (TSS), Microbial Plate Counts (MPC), Chemical analysis and protozoa. *See additional SOP's for instructions to conduct each test.*

2. Turn the valves on to begin filtration

3. After one hour, turn off the valves and weight the water to determine the flux rate of the ultrafiltration modules. *Determine the flux rate of each individual module.*

4. Collect three 100 ml samples of the filtered water for analysis of TSS, MPC, protozoa and chemical analysis.

5. Disconnect each ultrafiltration module and backwash the units: See backwashing procedure below. Record the amount of water used and collect a homogenized sample of 100 ml to test for TSS.

   Backwashing Procedure:
   - Empty unfiltered water from input end of filter.
   - Fill input end approximately ¾ full of water, with finger over opening shake vigorously for one minute. Empty contents into beaker for later examination. Repeat three times.
   - Connect pump to output end of filter, and run clean water through the filter in the opposite direction of water being filtered. Continue until output is clear, collecting the flow in the same beaker as in the previous step.

6. Reconnect the modules and begin at step two (2). If it is necessary to add water to the holding tank begin at step one (1).

7. Record the results of TSS, MPC, chemical analysis and protozoa counts in a datasheet. Also record the time between backwashing, the amount of water used the TSS of the backwash and the individual modules flux rate.

8. If it appears to be unnecessary to backwash the system every hour, increase the time span in one hour increments until a satisfactory equilibrium is established.

Total Suspended Solids

1. Perform the following procedure for three samples. Weight the crucible and filter, recording this number.

2. Using a pipette, collect a homogenized 10 ml water sample from the 100 ml beaker.

3. Filter this water through the crucible. Use de-ionized water to rinse the pipette and remove any residue. A suction flask should be used to pull the water through the crucible filter.

4. Place the three crucibles in a drying oven at 105 degrees Celsius for at least one hour.

5. Remove the crucibles and allow them to cool in a desiccator then weight the crucibles recording the number.

6. Calculate TSS using this equation: TSS (mg/L) = (End Weight-Initial Weight)*1000/Filtered volume.

Figure 17: Experimental Setup

Appendix V

Appendix V contains estimated cost values for a complete, working prototype that is ready for implementation.

Low Power Ultrafiltration

Collin Craige – Team Leader
Mikayla Marvin
Qualla Parman

UltraTech Solutions

Mission Statement: Providing low cost filtration systems capable of producing safe drinking water for community improvement.

Company Background

- Pumps of Oklahoma, Inc. is a wholesale supplier of industrial, municipal, agricultural and environmental pumps. They supply submersible and above ground pump equipment to the international community.

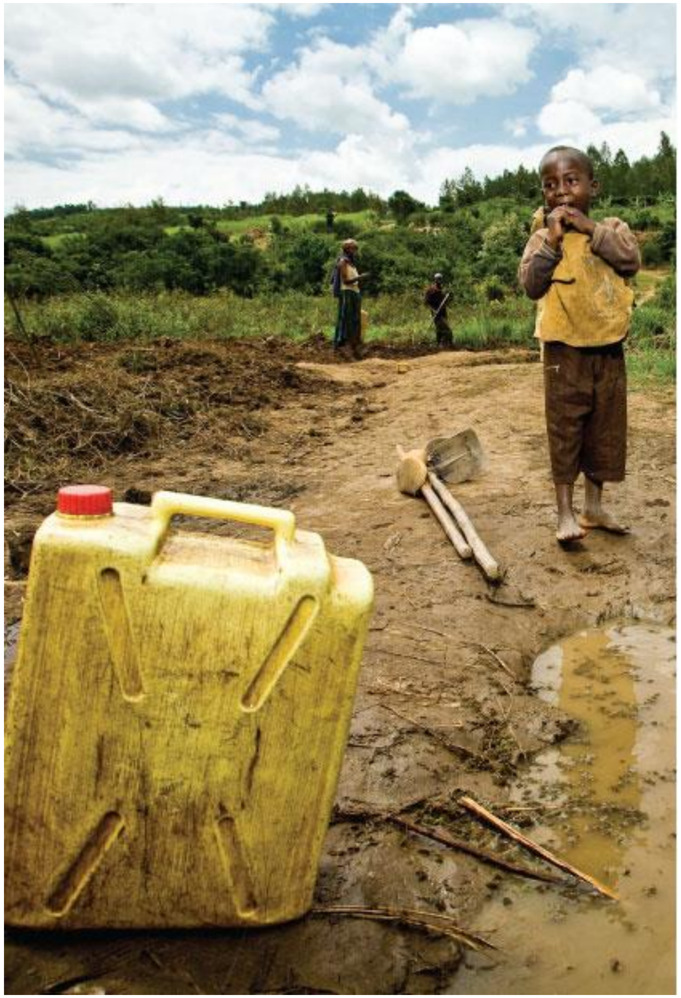
- Company has strong ethical standards and has close ties to the non-profit organization Water4.

Spring Requirements

- Problem
- Design
- Fabrication
  - Potting
- Testing
  - Bacteria
  - Flow
- Analysis
  - Economic feasibility
  - Backwashing schedule
  - Replacement schedule
- Results, Recommendations

A Basic Need Unmet

- 783 million people lack access to safe drinking water.
- Over two million deaths each year are attributed to diarrheal diseases caused by ingesting contaminated water.
- 90 percent of these deaths are children under the age of 5.



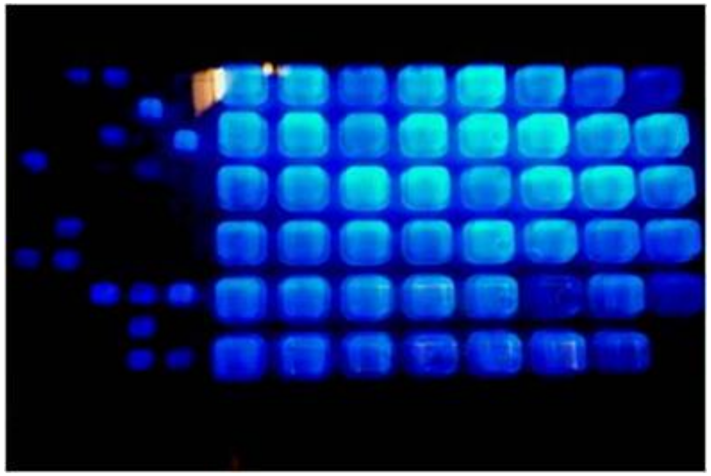
A Simple Solution

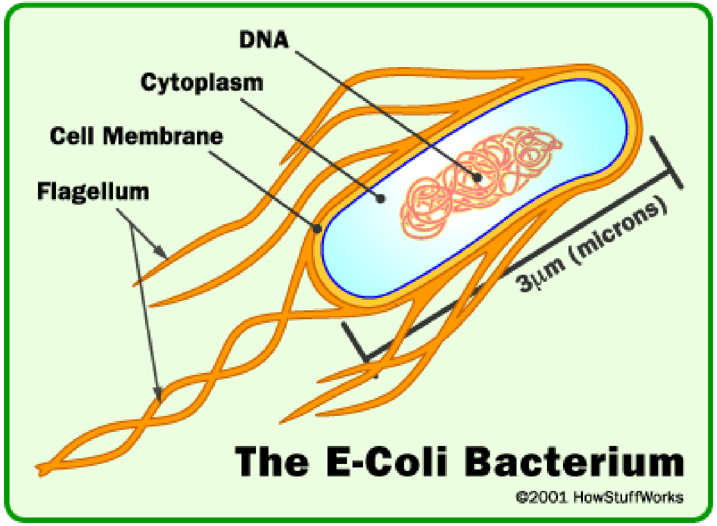
- Improvements in sanitation and drinking-water could reduce the number of children who die each year by 2.2 million.

- Suffering and death from diarrheal diseases is 100% preventable with access to safe drinking water.

Common Water Quality Contaminants

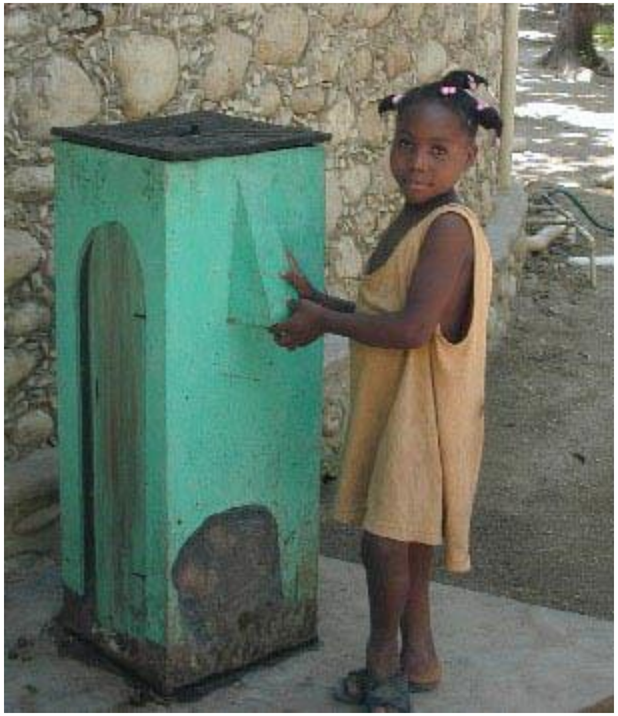
- Organic and Inorganic Salts
- Metals
- Dirt and Other Particles
- Infectious Species
  - Bacteria
  - Parasites
  - Viruses





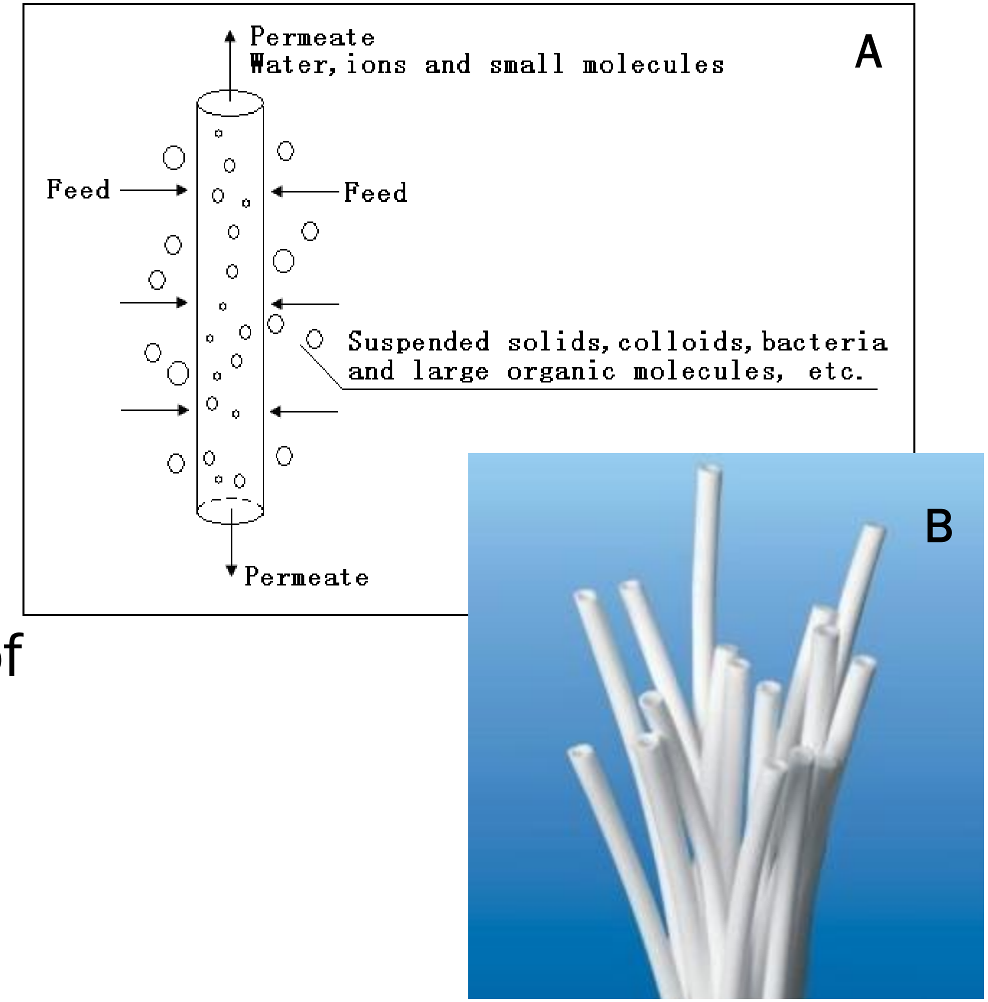
Competitors Response

- Ozone
- Chlorination
- Activated Carbon
- Reverse Osmosis
- Slow Sand Filtration (Biosand Filters)
- Water Distillation



General Requirements

- Utilize polyvinylidene difluoride (PVDF) hollow fiber membranes.
- Require very little or no power.
- Provide water that is free of microorganisms and safe for human consumption.



Ultrafiltration Capabilities

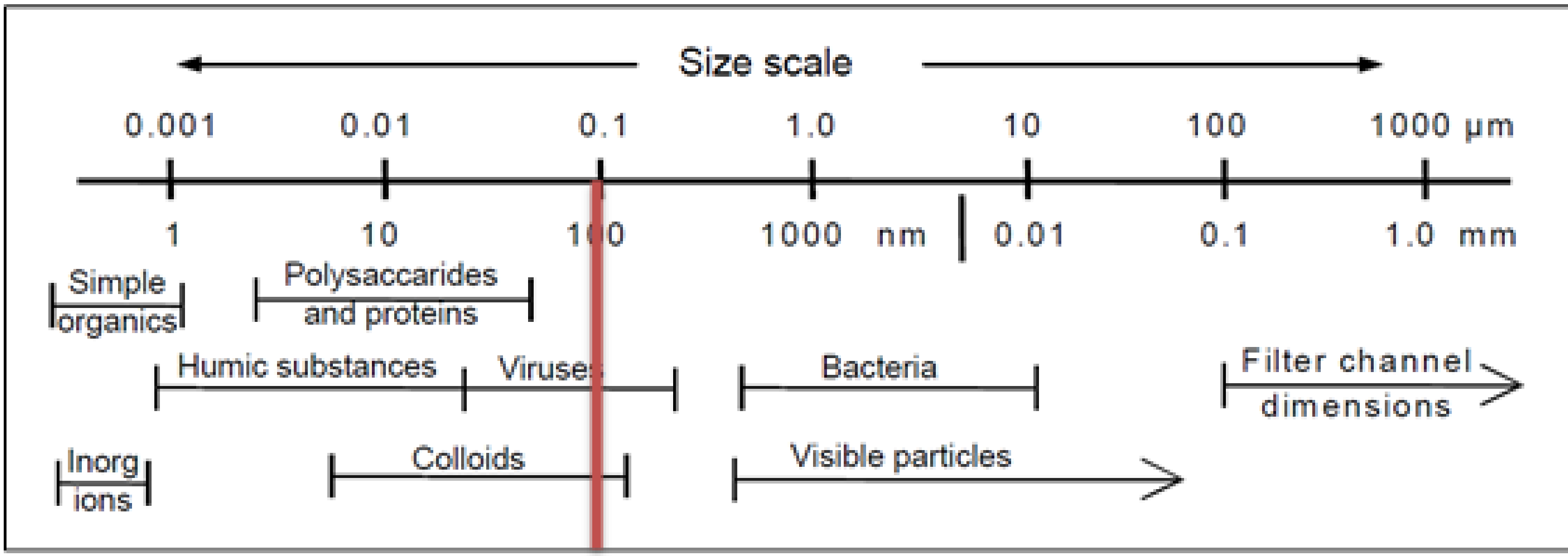
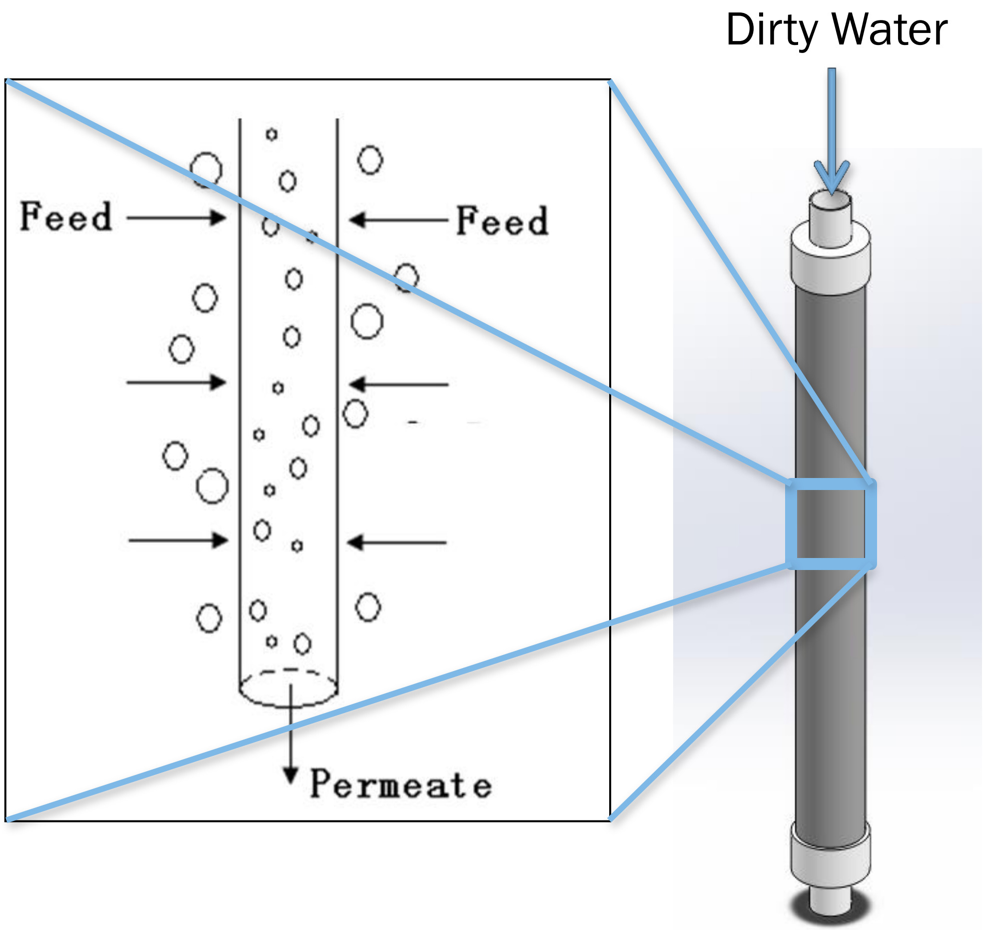


Figure 1 - Sizes of potential contaminants that will need to be filtered from contaminated water. Ultrafiltration membranes will remove bacteria and visible particles but not viruses. Obtained from *Nanotechnology in Drinking Water Filtration, a Literature Review*

Ultrafiltration Module

- "Dead End" Filter
- Gravity Fed
  - Reduce power need
- Loop PVDF Tubes
  - Less Resin

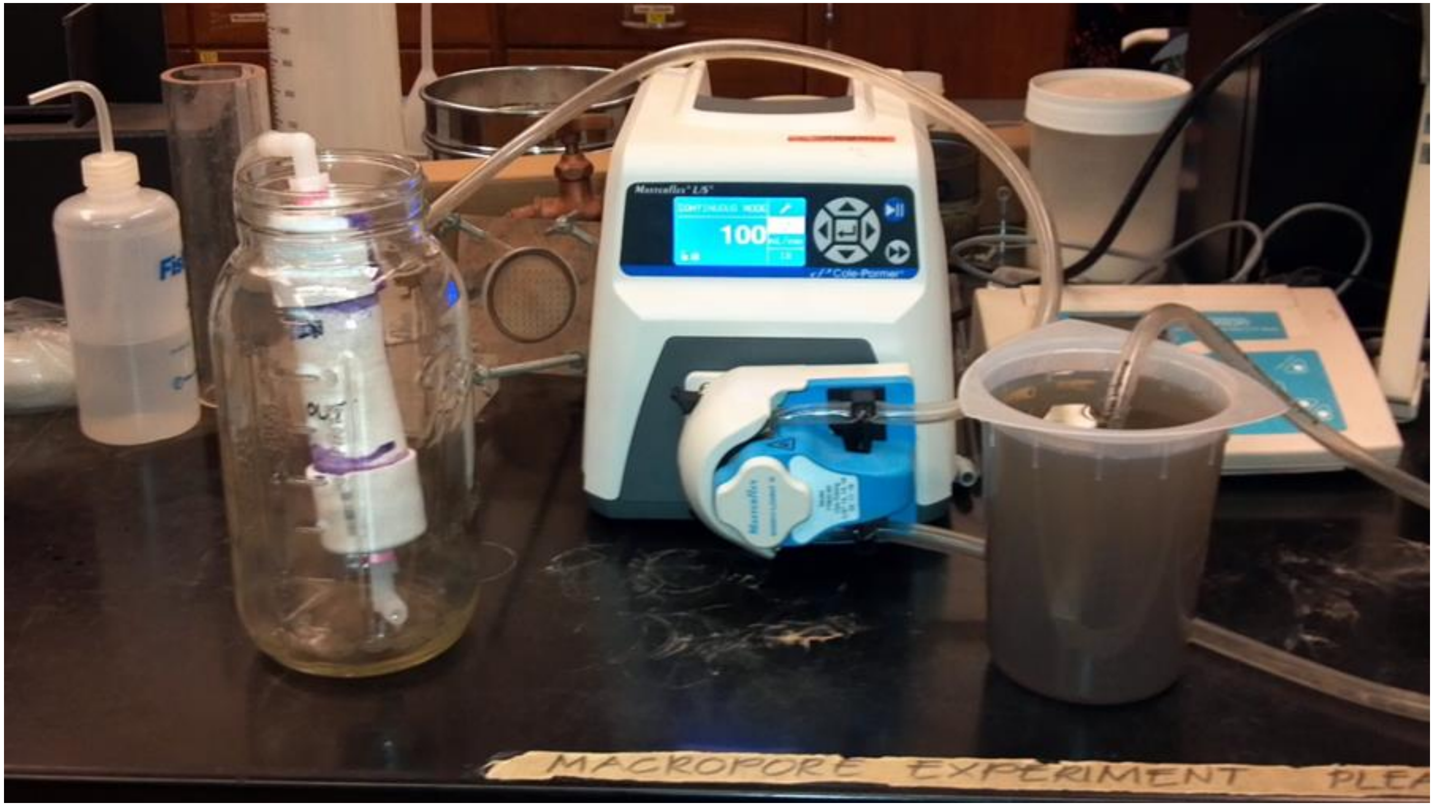


Potting Success

Initial try, holes in PVC cap to thread PVDF tubes.

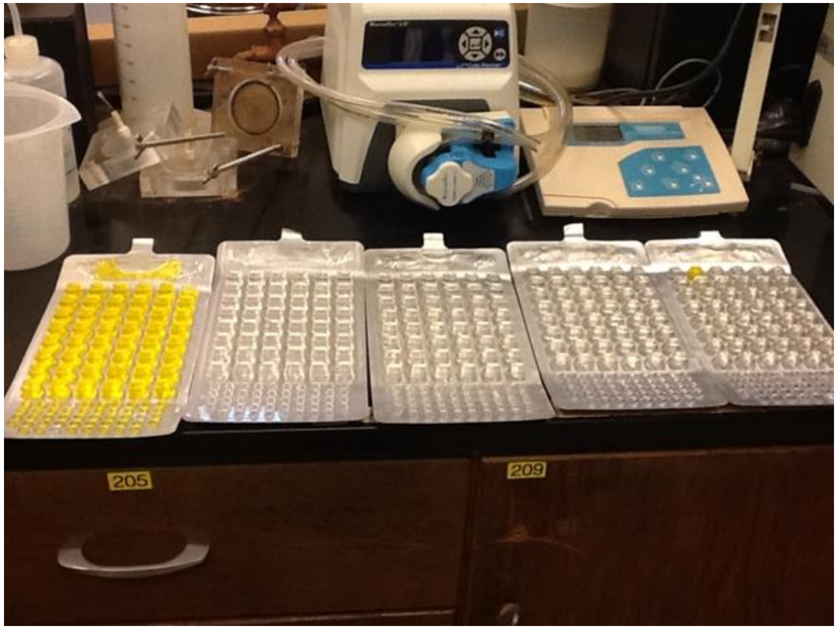
Successful attempt, filled 90 bend with resin.

Test Results – Coliform Removal



Test Results – Coliform Removal

	Coliform			E. coli		
	Large Cells	Small Cells	MPN (100ml)	Large Cells	Small Cells	MPN (100ml)
Inflow	49	45	173290	49	43	141360
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	1	0	1	1	0	1



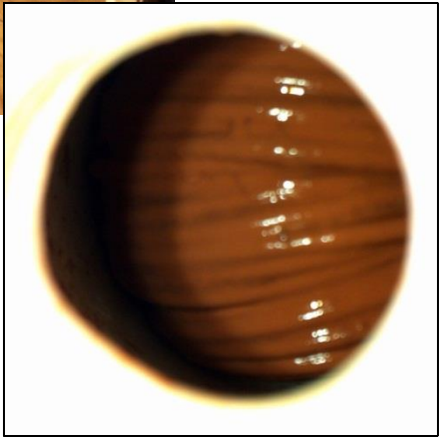
Testing Setup

Tubing was used to connect the modules.

For backwash testing a second port was drilled for the large module. (Right)

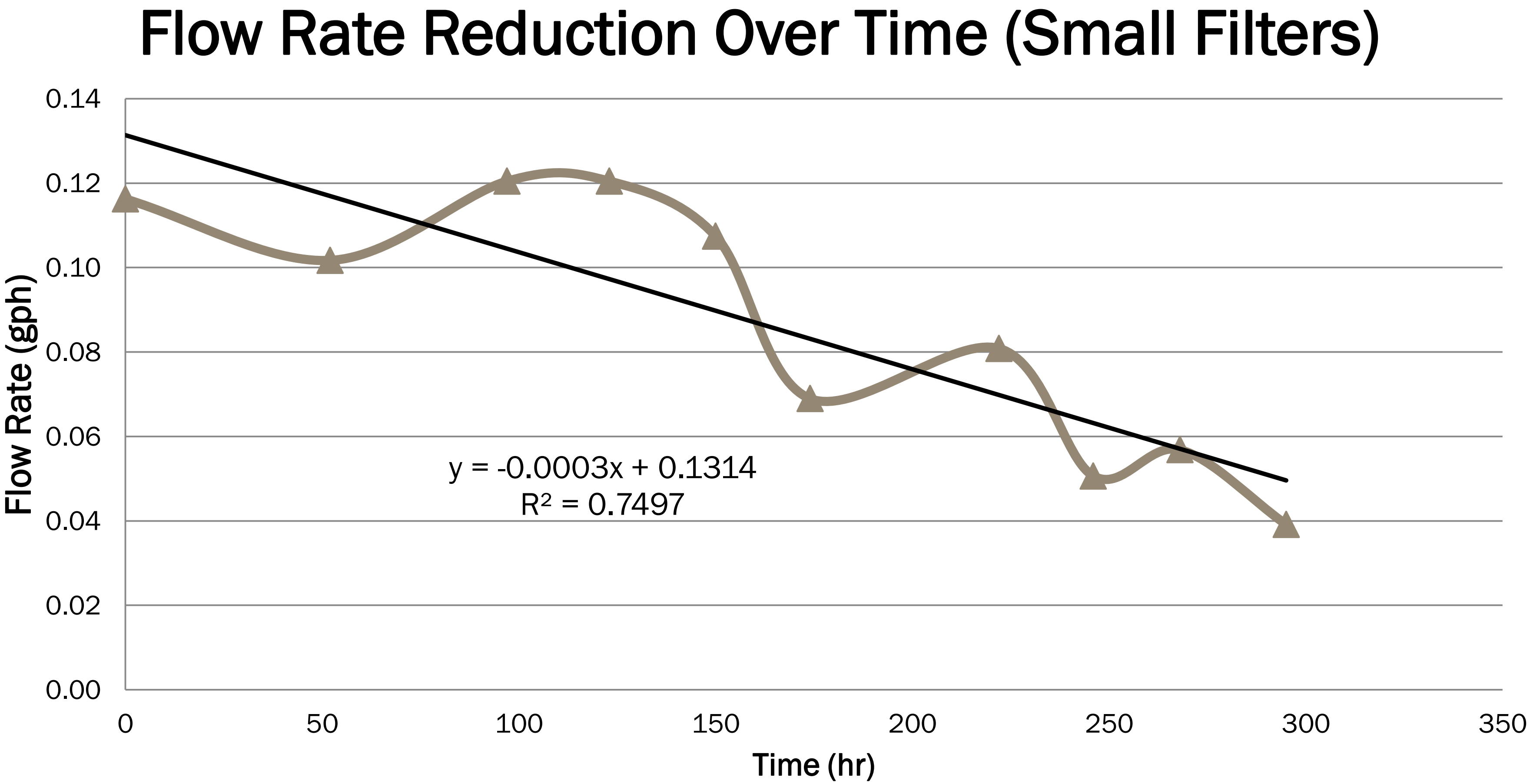
Testing Results – Backwashing

- Similar results for each module tested
- Backwashed with small electric pump
  - Hand pump would work as well
- Worst Case Scenario – 56.5 g/L suspended sediment
  - Mixed twice daily to simulate typical use
- Last 1 week before reaching 0.075 gph
  - May follow decreasing exponential form

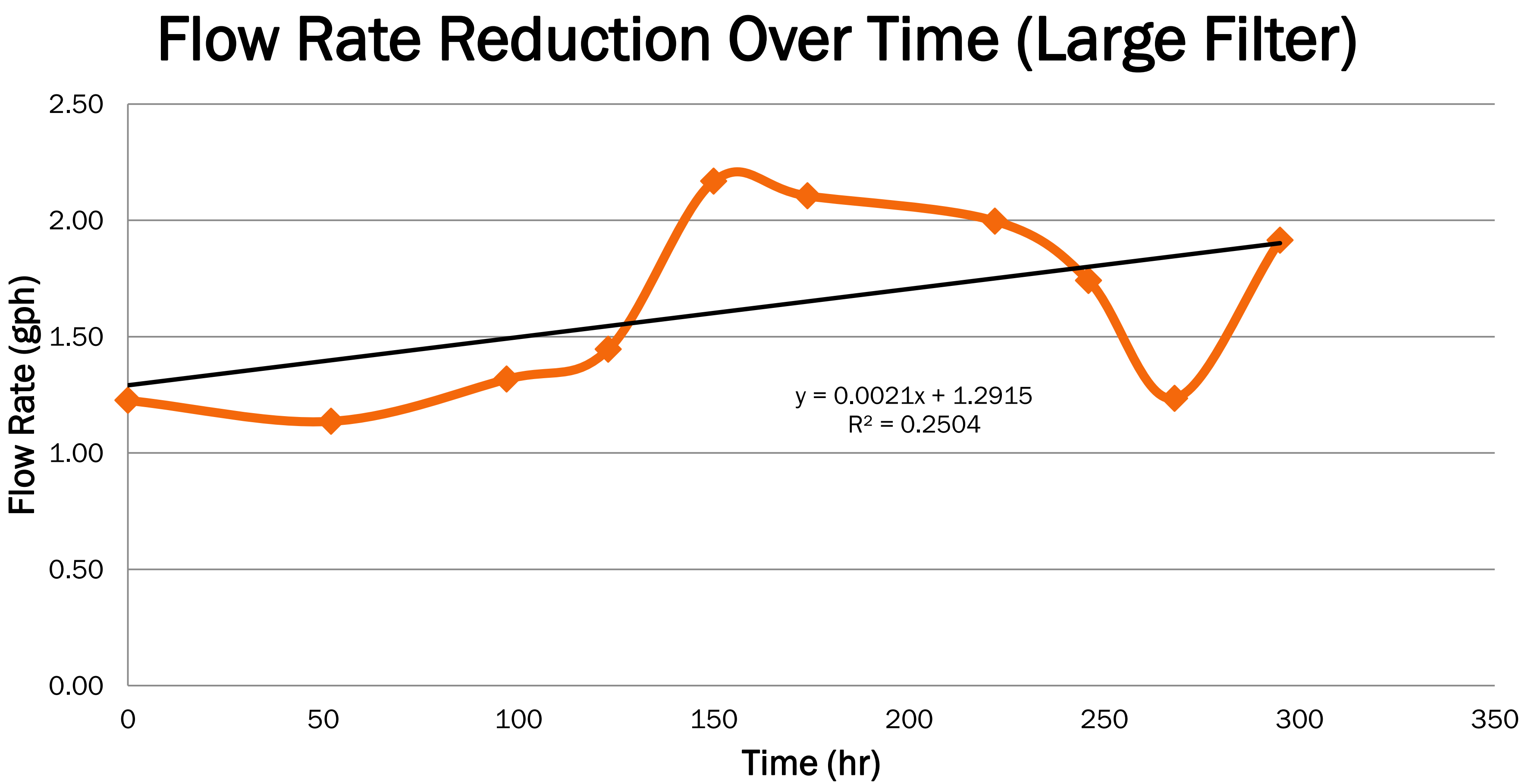


Testing Results – Backwashing

Testing Results – Backwashing



Testing Results – Backwashing



Financing

Item	Quantity	Cost per Item	Total Cost
100 gal. Stock Tanks	2	$118.16	$236.32
1-1/4 X 1/2 Bushing	12	$1.06	$12.72
1/2 X 1/4 Barb	12	$0.78	$9.36
1/2 to 1/4 Bulkhead Fitting	1	$8.78	$8.78
Total			$267.18

Large Module Filter
-Dimensions 2” X 12” PVC

Material

-Resin	$10.66
-Pipe	$0.68
- Fittings	$4.66
- PVDF membranes	$29.52
Total	**$45.52**

Filters an average of 1.6 GPH

4 gallons per person per day

Supplies 9 people per filter

One Year Investment
$5.06/person

Recommendations

- Filter Modules
  - Reduce PVDF membrane packing density
  - Mechanical agitation
- Pretreatment
  - Sediment/particulate filter (sand column)
- Tertiary Treatment
  - Virus Treatment
  - UV or similar system

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  - Mr. Greenly
  - Mr. Goodspeed
  - Mr. Johnson

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  - Dr. Weckler
  - Dr. Fox
  - Dr. Frasier
  - Wayne Kiner

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Image References

- Slide 5 – Image From: https://water4.org/how-to-help/
- Slide 6 – Image From: https://water4.org/contact-us/
- Slide 7a – Image From: Technical Specifications Sheet
- Slide 7b – Image From: http://www.made-in-china.com/showroom /220215451/product-detailpqdJfUTOgKVG/China-PVDF-Hollow-Fiber-Ultra-Filtration-Membrane.html
- Slide 10 – Image From: http://www.worldneighborhoodfund.org/q5/ haiti.html

Low Power Ultrafiltration

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Submitted to—
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Table of Contents

Executive Summary

Access to clean drinking water is extremely limited in some parts of the world. This is especially true in developing countries where much of their drinking water comes from potentially contaminated surface water sources and sanitation education is inadequate. Ingestion of contaminated waters can cause serious illness and even death, most of which occurs in children under five years of age. Limited availability to clean water sources has even lead to a number of conflicts over who should have access to this water. Providing education and clean drinking water for the people of these nations is of great importance to improve quality of life and socio-economic stability.

UltraTech Solutions' objective is to design, create and test a water filtration device that is capable of removing soil colloids, bacteria, and viruses from various water sources to produce a safe, clean product using ultrafiltration membranes and National Sanitation Foundation approved materials that is cheap to produce, easy to assemble and maintain with low power requirements for use in developing nations.

Statement of Problem

Clean drinking water is a necessity to healthy human life. In many areas of the world, this necessity is lurking just out of reach. According to a recent United Nations news article, at least 11 percent of the world's population, or 783 million people, still do not have access to safe drinking water, and billions live without sanitation facilities. (United Nations, 2012). Without proper sanitation facilities, fecal matter and other contaminants can easily end up in a community's drinking water source. Drinking water that has been contaminated with fecal matter can contain bacteria, viruses, and parasites. These organisms can cause severe sickness and even death to those who ingest them. Contaminated water is the major cause of diarrheal illness in developing nations, causing unnecessary suffering and malnutrition to much of the population (Braghetta, 2006). Two million deaths each year are attributed to diarrheal diseases caused by ingesting contaminated water. 90 percent of these deaths are children under the age of 5 (World Health Organization, 2012). This suffering and death is preventable through water purification technology and sanitation education. The Water4 foundation has even reported that improvements in sanitation and drinking-water could reduce the number of children who die each year by 2.2 million (Water4). These developing nations are in desperate need of a water filtration system that is easy to ship, construct, and maintain, that requires no or limited amounts of power, and removes the viruses, bacteria, and parasites that cause diarrheal diseases. Such a filter would not only improve the quality of life for the community, but would allow more children to see their fifth birthday.

Design Objectives

This document proposes the design of a low power ultrafiltration system for removal of contaminants from surface water sources. Some specific objectives for this project include:

(1)Utilize polyvinylidene difluoride hollow fiber ultrafiltration membranes,

(2) Require very little or no power, and

(3) Provide water that is free of microorganisms and safe for human consumption.

UltraTech Solutions' project, water filtration using ultrafiltration membranes, is to design a filtration module and corresponding system that will remove contaminants from a variety of water sources ranging from bacteria infested pond water to potentially contaminated shallow groundwater. The specifications for the system as a whole are to remove sediment, parasites, bacteria, and viruses from water, rendering it safe for human consumption. The system will need to vary in size to satisfy the needs of a family or a community. The system should also be easy and relatively inexpensive to construct, preferably from readily available National Sanitation Foundation approved materials. Electrical power is often widely unavailable and extremely unreliable in the areas where these filters are designed to be installed, thus the need for the system to require little or no electrical power. If a power supply becomes necessary, UltraTech Solutions will power the system with solar or wind energy. The design will need to be structurally stable to prevent accidental tipping, especially in areas where children my try to climb the system.

Technical Approach

Development of a water filtration system for our customer, Pumps of Oklahoma, required an extensive patent review and examination of existing design pros and cons. Ultrafiltration is not a "new" technology but the intended use of our product to purify bacteria, virus and sediment contaminated water is new, and several key design features set our product apart from the current industry.

Customer Needs

Our customers' needs are very straightforward. The system must remove all particulate, bacterial and viral contaminants utilizing hollow fiber ultrafiltration membranes. Pumps of Oklahoma also specified the unit must be gravity fed or low power with three different sizes for individual, family and community use. To be practical in third world countries, the system must be inexpensive so UltraTech Solutions has set a target cost of $2000 for the community size module.

Current Technology

Prior to development of design concepts, an extensive patent review was conducted to avoid patent infringement and evaluate industry competitors. There are numerous patents related to water purification, most of which are less than 20 years old. However, none of the reviewed patents utilize gravity fed systems or hollow fiber polyvinylidene fluoride (PVDF) tubes so there are no expected patent infringement issues. US Patent 7484626 issued February 3, 2009 is for a "Porous Water Filter" with pore sizes from 2 to 5 microns. Although this product is similar, our PVDF tubes have 0.1 to 0.2 micron pores. While it is not low power, US Patent 2006/0219613 issued April 1, 2005 describes a nanofiltration system that is incorporated into a home plumbing system. Our system will not be coupled with a plumbing system but could be utilized with a hand pump to filter water as needed. A more in depth review of similar patents may be necessary if a combination filter and pump setup is pursued. A filter straw-personal filter patent was also discovered which may be a useful reference for a filter pump design using our PVDF tubes. Issued on February 26, 1991 US Patent 4995976 filters water using a series of filter sizes as a person drinks through it. Other patents were examined that are not detailed here. For a complete list of comparable patents see Appendix I.

An examination of market competitors was conducted to determine the amount of competition in our market niche. There are several major companies including Koch, Dow Industries, Toray and Pall Corporation who manufacture or market ultra, nano and microfiltration systems. Koch Industries alone has 20 different technologies in this field. However, the filters are marketed primarily for food separation and wastewater treatment in high power systems. Water filtration for drinking is a relatively open field although the Paul Corporation does market a fully NSF approved purification system. Our design will be much simpler, and gravity fed so there should be no infringement issues.

Ultratech Solutions also researched technologies currently being used in developing nations to purify drinking water. Comparisons were made based on the purification capabilities, flux rates, and economics of each filter which were later compared to our design in each area. These technologies include ozone filtration, chlorination, activated carbon filters, reverse osmosis, bio-sand filters, and water distillation systems. Ozone filtration systems are effective at removing contaminants, and requires little to no maintenance, however this type of filtration is expensive and can cost around $1 million for a 1 million gallon per day system. It also requires the use of a water softener and is specific towards the temperature of the water that can be cleaned.

Chlorination is utilized frequently in developing nations, but this system requires a specified contact time to be effective, must be continuously tested and causes the water to have a poor smell and taste. More significantly, the continual ingesting of chemicals could have negative impacts on human health. Activated carbon filters are also highly effective in treatment of contaminated water, but would not meet a villages water needs. These systems have extremely low flux rates, need to be replaced often, and are expensive to ship and maintain. This type of filter could also serve as a breeding ground for microorganisms, which feed on the organic materials and chemicals filtered out of the water. Reverse osmosis systems require a pre-treatment system to be effective. They also are not appropriate for treating water contaminated with coliform bacteria, which is often found in water sources of developing nations, whose sewage systems may be dumped untreated directly back into the drinking water source. Reverse osmosis is expensive, requires regular maintenance, utilizes high amounts of energy, and only about 5-15% of the water entering the system is recovered as drinkable water.

Slow sand filtration systems such as a biosand filter are good for removing soil colloids and most bacteria, but frequently these systems are not sufficient for virus removal. They require careful maintenance to prevent disturbance of the biological layer that utilizes the bacterial contaminants in water as food. Water flux through these systems is slow (0.26-2.6 GPM) and a large system is required for a family. Sand filtration would not be efficient for a village-sized system. Water distillation is effective for removing dissolved materials, bacteria, and even heavy metals, however this method requires large amounts of energy, and bacteria can recolonize quickly once the heating coils cool.

Target Specifications

Removal of bacterial, viral and particulate contamination to produce potable water is our primary focus. Hollow fiber ultrafiltration tubes with 0.1 micron pore sizes will be used to remove bacterial and particulate contamination. However, the ultrafiltration membranes are unable to remove viruses (Figure 1). Nano filters are available but are more expensive and would greatly reduce or eliminate water flux in a gravity fed system. To work properly nanofiltration tubes typically require a minimum of 145 psi pressure so Ultratech Solutions opted to add an extra purification stage after the membrane unit to minimize cost and power requirements.

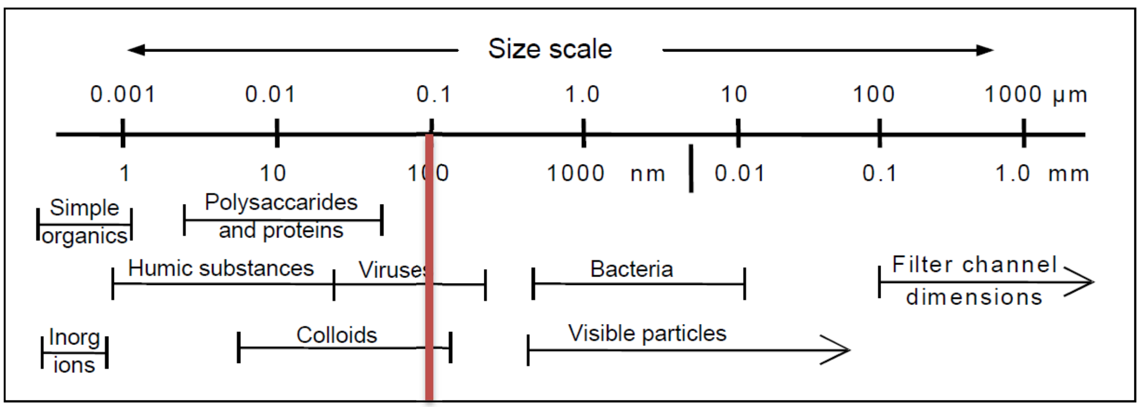


Figure 1 - Sizes of potential contaminants that will need to be filtered from contaminated water. Ultrafiltration membranes will remove bacteria and visible particles but not viruses. Obtained from *Nanotechnology in Drinking Water Filtration, a Literature Review*

To meet design criteria, UltraTech Solutions has selected ultraviolet light as the tertiary treatment stage. A small ultraviolet light will kill viruses without the addition of chemicals all while meeting low power requirements. The UV stage could be powered by a car battery or small solar panel to provide adequate power for continual operation of the filtration module. While this step increases installment costs it will ultimately reduce maintenance costs compared to utilizing nanofiltration tubes which would require more cleaning. UltraTech Solutions designed an interchangeable and additive filtration module to meet requirements for individual, family and community size systems. This design ensures that any given system will not be under or oversized.

Overall system cost is a concern, especially for implementing the design in third world countries. The primary treatment stage containing the hollow fiber ultrafiltration tubes will incur the most expense for both installation and maintenance. Common PVC pipe components that are NSF approved are the most cost effective solution to maximize value in this stage. Reducing maintenance of the ultrafiltration tubes, including backwashing and replacement is a key objective to cut costs. To prevent membrane fouling, a sediment trap has been proposed as a water pretreatment stage to remove particles greater than 0.5 millimeters. Although installment cost is increased, this is a necessary addition to increase the working life and effectiveness of the ultrafiltration tubes.

Design Concepts

Ultrafiltration Design

Each stage of the system was designed around the primary PVDF filter unit for maximum efficiency, cost reduction and simplicity. This methodology was selected so that any unforeseen concerns in the primary filter unit could be compensated for in the pretreatment and secondary systems. Additionally, the PVDF filter was the most complex component with the greatest potential for cost reduction. Literature review indicated that the most effective and simplest filter containment system was a tube rack module. A sheet or curtain setup is the most compact, with the highest PVDF filter density but the added complexity increases cost. An example of a curtain and tube rack systems from two competitors, Dow Industries and Zenon, are shown in Figure 2. Simplicity, cost and compact design were the key focus areas in the hollow fiber filtration module. After reviewing current systems and an extensive patent search, out three goals were broken down into more specific components to identify solutions (Table 1).

A compact setup reduces the required housing space and increases product transportability. Our system will be maintained with a limited number of tools and equipment so simplicity is paramount to a successful product. Achieving our goal in simplicity and space utilization will help us reduce costs, our greatest hurdle.

Figure 2 - On the left is a tube rack setup by Dow Industries while on the right is a curtain setup by Zenon. Although the tube system is not as filter dense it is much simpler.

Table 1 - After identifying three major goals, each goal was broken down into more specific elements to improve project management.

Specific Goal	Logic
Simplicity	
Exchangeable modules	Reduce cost, eliminate need for multiple designs
Hand assembly	Reduce cost, no power needed for construction
Small number of individual parts	Reduce cost, less chance for failure, easier to maintain/fix
Compact	
High filter density	Less material for frame support, low space requirements
Transportability	Reduce cost associated with transportation
Cost Reduction	
Material minimization	Lowers cost, simpler design
Common Materials	Reduce repair time, lower cost

From the criterion outlined in Table 1, three systems were developed, each featuring a single filter unit that can stand alone or be linked to increase filtration flux (Figure 3). Full specifications can be seen in Appendix II.

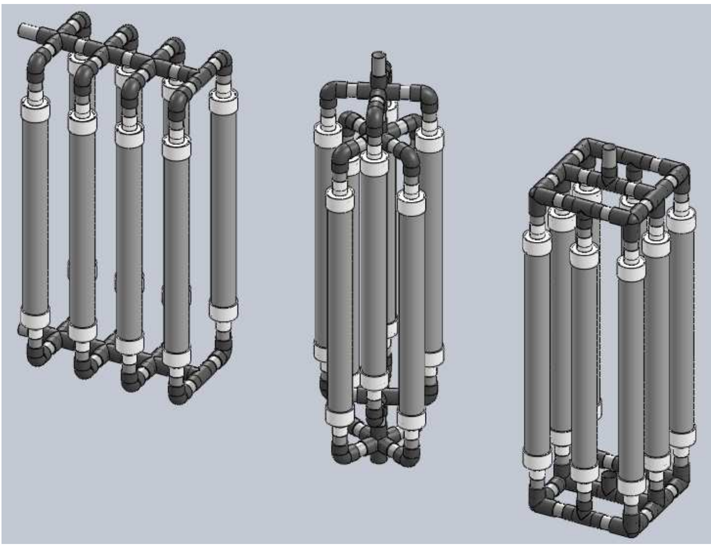


Figure 3 - Three different concepts were developed each with advantages and disadvantages. Left to right is design 1, design 2 and design 3.

Table 2 - Benefits and disadvantages of each design proposal.

Benefits		
Design 1	***Design 2***	***Design 3***
Self-Supporting	Compact	Compact
Simple		Self-Supporting
Low Cost		
Disadvantages		
Design 1	***Design 2***	***Design 3***
Not Compact	Extra Supports	Cost
	Custom Parts	

Each design proposal uses eight components, including the PVDF filtration tubes and sections can be added to increase overall system size. The entire system can be hand assembled from common PVC pipe, a common and easily obtainable product. Utilizing PVC pipe as the membrane housing greatly reduced costs while providing adequate protection for the hollow fiber membranes. To cut costs further, the PVDF tubes will be "looped" within the PVC and potted on only one end. This will cut potting costs in half.

The design concepts were developed around cost, simplicity and size. Design one is the least expensive design while design three is slightly more expensive, but is more membrane dense. Design two is the most compact design but would require a custom fabricated part which could reduce its cost advantage over design three. Consideration of these designs led UltraTech Solutions to select design concept three as the overall best design. The benefits and disadvantages of each design can be seen in Table 2.

Sediment Filter Design

The sediment filter will remove particulate matter and turbidity, to reduce backwashing frequency and clogging of ultrafiltration membranes. UltraTech Solutions discussed various methods to achieve soil particulate removal, selecting a quick infiltration sand filter. This filter will contain a small layer of gravel at the bottom, covered with a thicker layer of moderately course sand packed to a wet bulk density between 1.6 and 1.8 grams per cubic centimeter.

There are two design concepts for the soil pre-filter, a cartridge and a box design. In the cartridge design, sand would be contained in three inch PVC and would be incorporated as part of each ultrafiltration module. The upper cartridge could be unscrewed for removal routine maintenance. The box design would be a stand-alone sediment filter, filled partially with moderately course sand with a gravel base (Figure 4). This design would provide a holding area for water to add head to speed water flow through the filter. This design would also be easier to maintain, as the top layer would need to be scraped occasionally when the flow rate through the soil slows to an unacceptable rate. The box design is UltraTech's final selection because it is simple and more cost effective.

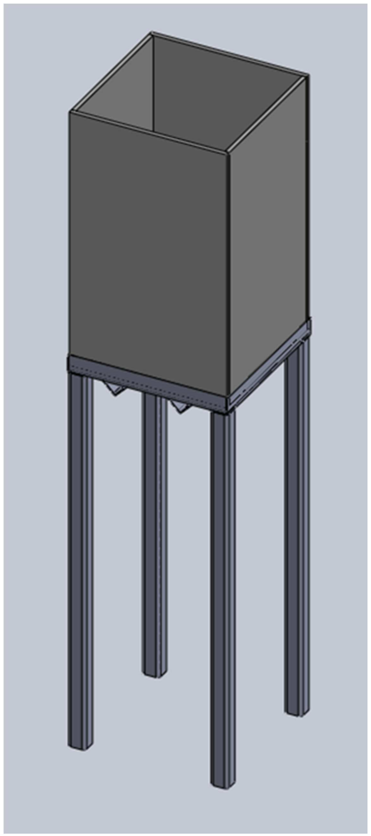


Figure 4 - Box design for primary sediment filter.

Ultraviolet Purification Design

The pores of our specific ultrafiltration membranes are large enough that free floating viruses can pass through and be ingested. To address this issue, UltraTech Solutions has incorporated a tertiary purification system. Several technologies were considered including chlorination, silver impregnated filters, and Ultraviolet purification. Chlorination was discarded as it requires a contact period to be completely effective and involves the unnecessary ingestion of chemicals. Silver impregnation was not economically feasible, and was removed from consideration. This left ultraviolet purification which provided a non-chemical, low-cost virus elimination system. The disadvantage of ultraviolet purification is the need for a power sources. Areas that have a reliable power supply most likely have relatively clean water so our team selected monocrystalline solar panels to power the unit. These panels are high efficiency (18%) providing steady power in sunny climates such as Africa. Other areas may require alternate power options.

Ultratech Solutions has developed a number of different design options that will be presented to Pumps of Oklahoma (Figure 5). These concepts include two different designs for the sediment filter, the three ultrafiltration module designs, the post membrane treatment, as well as pump types.

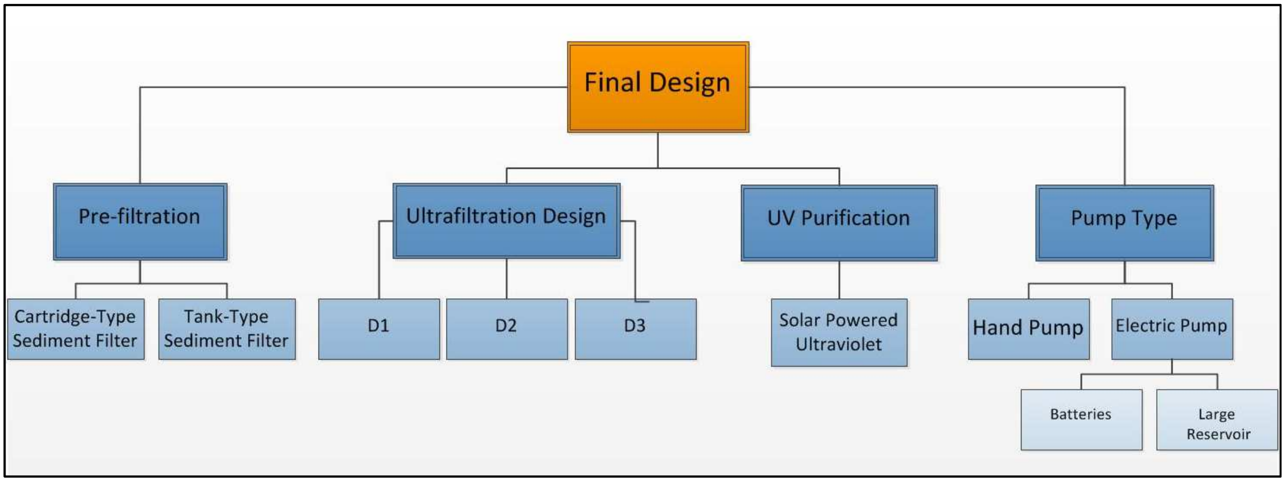


Figure 5 - Potential design combinations for each segment of the water treatment system.

Design Calculations

Basic calculations were done to verify concepts and develop proposals. The majority of these centered on sizing the PVDF membranes and solar panels for water flux and electric output respectively. More calculations are needed to finalize sizing requirements, such as trans-membrane pressure and required feed pressure but UltraTech believes that our current calculations have validated our design sufficiently to continue design work. In our flux calculations only one assumption was made. Unable to conduct flux testing this Fall, our team estimated the flux in a gravity fed system by linearly interpolating the flux corresponding to the minimum and maximum pressures outlined in the product manual to a gauge pressure of zero. Testing will be done in the Spring to determine the actual flux rate but, with this estimate we could begin sizing our system. First the total membrane length in each module was determined based on specifications given in the product manual and using the inside diameter of 3 inch schedule 40 PVC pipe. A packing density of 0.9 was used and 0.25 inches of space was allowed around the membrane bundle. These calculations indicated that each ultrafiltration module would filter 11 gallons per hour or 88 gallons for the base system.

We expected the ultrafiltration stage to be the filtration limiting step but the box soil filter was sized using Darcy's law to determine the smallest allowable sediment size (Equation 1). Using medium coarse sand and an area of 0.18 cubic meters a flow of 100 gallons per hour is achieved, greater than the ultrafiltration stage.

Equation 1 - Darcy's Law

$$Q = -KA\left(\frac{dh}{dl}\right) = 100 \text{ gal/hr}$$

$Q = Volumetric\ flow$

$K = Hydraulic\ conductivity$

$A = Area$

$$\frac{dh}{dl} = \frac{Change\ in\ head}{Change\ in\ Length}$$

Knowing our expected flow rate the ultraviolet filter was then sized to treat three gallons per minute. A direct current unit was used to reduce amperage draw from the solar panels. The nature of solar panels is that they work well on days with high insolation but not well on days when the earth's surface receives low insolation. Because of this, the panels were oversized to accommodate fluctuations in incoming insolation. Insolation also varies with location so a system may need to be larger for certain regions. Using data for South Africa, an average of 5280 watts/m^2 are received during 6.8 hours of sunlight. Our selected ultraviolet light requires 14 watts of power, and was assumed to operate for seven hours (Equation 2). Equation 3 shows that the selected solar panel kit is more than twice the size it needs to be, however, the extra size will be necessary on low insolation days and could be used to power a light or small pump.

Equation 2 - Panel area calculation.

$$Panel\ Area = \frac{Need}{Available} = \frac{7 * 14}{5280 * 0.15\%} = 0.125m^2$$

Equation 3 - Oversizing calculation.

$$\%\ over\ sized = \frac{available}{required} = \frac{231}{7 * 14} * 100 = 235\%$$

Project Management

UltraTech Solutions has created a plan in order to accomplish our goals and objectives. We will follow the engineering design cycle as a guideline while we progress through our project (Figure 6). Currently, we are identifying and evaluating different design strategies. Our management objective was to complete the cycle through the step of choosing a design during the Fall 2012 semester. The Spring 2013 has been set aside for construction and testing before completing our final design. To stay on task and complete all company deliverables, UltraTech Solutions is utilizing Microsoft Project as a planning and organizational tool. Tasks, project deadlines and schedules are organized in this software to increase human resources efficiency and productivity.

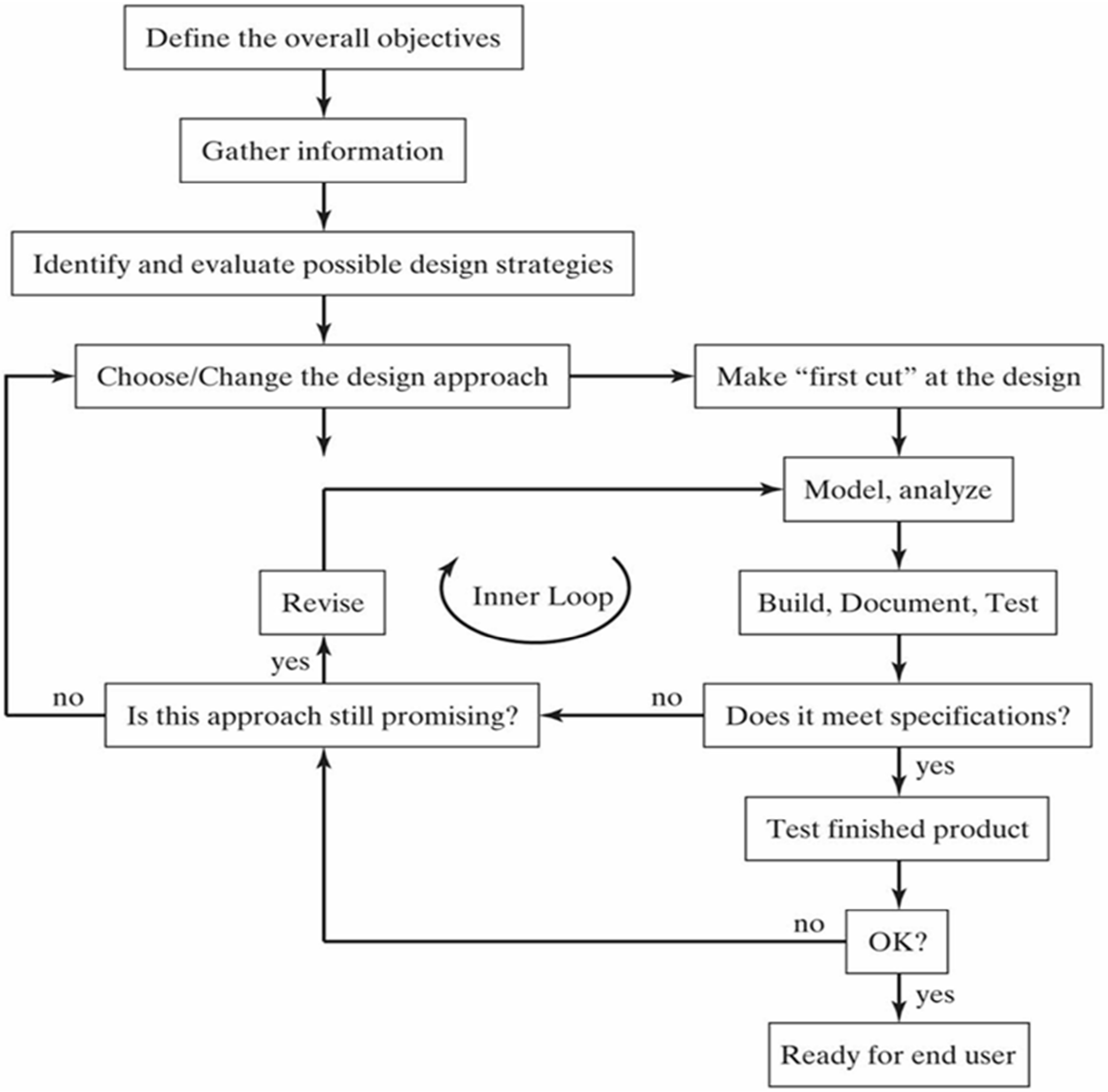


Figure 6 - The Engineering Design Cycle, Horenstein Figure 2.7, page 39

Figure 7 is a condensed task list for Spring 2013, with scheduling for prototype construction, design evaluation, and final design completion. UltraTech Solutions will be meeting with our client on-site at Water4, an affiliate organization on January 3, 2013. At the conclusion of this meeting, design options will be agreed upon by both UltraTech Solutions and Pumps of Oklahoma. Additional testing will be conducted in the spring including physical testing of gravity fed flux rate through the system, testing of design's life expectancy, and various areas of design effectiveness. Testing the actual gravity fed flux rate of our membranes will be a priority task. Our team will be administering tests to ensure our system completely removes all possible contaminants, including viruses.

Task Name	Duration	Start	Finish
Company Visit	1 day	Thu 1/3/13	Thu 1/3/13
Choose Final Design	21 days	Mon 12/10/12	Mon 1/7/13
Order Materials	6 days	Mon 1/7/13	Sun 1/13/13
Additional Testing	19 days	Mon 1/7/13	Thu 1/31/13
Prototype Construction	11 days	Fri 2/1/13	Fri 2/15/13
Testing & Evaluation	10 days	Fri 2/15/13	Thu 2/28/13
Final Construction	11 days	Fri 3/1/13	Fri 3/15/13
Final Testing & Evaluatio	12 days	Fri 3/15/13	Mon 4/1/13
Final Presentation	15 days	Mon 4/1/13	Fri 4/19/13

Figure 7 – Task list for spring 2013, containing a rough schedule of construction and evaluation.

A major goal will be determination of the most effective maintenance and field cleaning methodologies to prevent and correct failure or fouling. Working with Pumps of Oklahoma's affiliate organization, Water4, our team will research potential avenues to incorporate our design with new and existing Water4 drinking wells.

Deliverables

The deliverables of this project have been broken up into several subsections for the quantification of tasks and designation of team roles. Details are provided in the following paragraphs.

Delivery Requirements

The 0.1 to 0.2 micron ultrafiltration membrane tubing is sufficient for removal of particulate matter, parasites, and bacteria. However, it cannot filter viruses and will be rapidly clogged by sediments. To satisfy customer needs, the final design will incorporate three separate treatment modules; a sediment trap, ultrafiltration membrane and an ultraviolet or chemical virus deterrent. The sediment trap should remove particles greater than 0.05 millimeters (fine sand) to reduce fowling of the ultrafiltration membrane. The membrane will remove the remaining flocculent material except viruses which will need to be destroyed by the final ultraviolet or chemical treatment module. The system as a whole will be modified according to village populations, but will be designed with the requirement of 4 gallons of water per person in mind.

Acceptance Criteria

UltraTech Solutions' goal is to exceed customer expectations by cleaning water to United States potable water standards using materials approved by the National Sanitation Foundation. Pumps of Oklahoma will accept the design of UltraTech Solutions when the filtration system removes soil colloids, microbial colony forming units, and virus plaque forming units from a contaminated water source.

Special Requirements

Ultrafiltration membranes incorporated in the final design must be polyvinylidene difluoride hollow fiber ultrafiltration membranes provided by Pumps of Oklahoma. Ideally, the design will be compatible for use with a Water4 well in set our design apart from existing filtration systems. Another distinguishable feature will be the gravity-fed/ low power design for use in developing nations where power supplies are limited.

Cost Analysis

Developed countries have the infrastructure, piping systems, man-power and quality control standards to provide clean water in quantities well beyond basic need. Third world countries do not have these resources so the successful implementation of our design as a commercial product hinges on its cost. To reduce product costs, UltraTech Solutions will focus on materials, maintenance and manpower to make our design a viable option. The estimated budget includes all components except structural supports for the sediment filter and holding tanks. These are items are not expected to be as expensive as the other components and will be dependent on the final system sizing. The budge outlined in Table 3 is for a base design that uses the least amount of electrical power possible. A more complete cost analysis will be done in the Spring and will include maintenance costs, structural supports and estimated man hours associated with the project.

Table 3 - Total budget for "base" filtration system design.

Item	Supplier	Quantity	Item #	Unit Price	Total
3” X 24” Sch 40 PVC Pipe	Grainger	8	5AFJ9	$3.19	**$25.52**
1” PVC T-Joint	Lowe’s Hardware	6	23876	$0.70	**$4.20**
1” to 3” PVC Reducer	Pex Supply	16	429-335	$9.35	**$149.60**
1” Side Outlet Elbow	Lowe’s Hardware	8	315499	$2.05	**$16.40**
1” X 3” PVC Pipe	Lowe’s Hardware	37	23976	$0.08	**$2.98**
1” PVC cross Tee	Lowe’s Hardware	4	22702	$2.22	**$8.88**
PVDF Tubing	Jofur	6672 feet		$0.09	**$631.82**
SterAlloy Resin	Hapco	1 Quart	2463	$53.28	**$53.28**
Solar Panel	Northern Tool & Equipment	1	45 W Wel-Bilt	$249.99	**$249.99**
Power Cable	Missouri Wind and Solar	15	345	$0.80	**$12.00**
Battery	Wholesale Batteries	1	D5722	$75.95	**$75.95**
UV Filter	Atlantic Ultraviolet	1	MIN-3 12v/DC 3 GPM	$514.00	**$514.00**
Clean Water Tank	Plastic-Mart	2	N-43870	$189.95	**$379.90**
Hand Pump	Northern Industrial	1	108982	$99.99	**$99.99**
				Total	**$2,224.51**

The overall system cost, from Table 3, is very high. However, each component is expected to last many years with proper care. The PVDF tubes are estimated by the EPA to have a useable lifespan of 5 to 10 years (EPA, 2005). Using a 5 year replacement period results in a yearly cost of $207. This includes total replacement of the PVDF membranes and yearly replacement of the ultraviolet purifier lamp. The base system is capable of providing 4 gallons of water per person for 155 people. The design would essentially cost 0.25 cents per person for a day’s worth of water. The goal of this project is not to profit, but to provide address a global concern by providing clean water for people. However, to assist the program recipients might “pay” for the water to provide money to install another unit in a neighboring village.

Sponsor Communication

UltraTech Solutions will correspond with Pumps of Oklahoma representative Micah Goodspeed via weekly email. Emails will include updates on design changes, deliverables, and testing results as well as project progress. If the project requires site visits, Ultra Tech Solutions will commute to Pumps of Oklahoma in Oklahoma City. Phone calls and in person meetings will also be scheduled as needed.

References

1. Braghetta, A. 2006. Drawing the connection between Malnutrition and lack of safe drinking water in Guatemala. American Water Works Assn. J. 98(5): 97-107.
2. United Nations, "World meets goal of boosting access to clean water but lags on better sanitation," http://www.un.org/apps/news/story.asp?NewsID=41465&Cr=MDGs&Cr1#.UKaH6ofAfX4/ (Blue Ridge Summit, PA: UN News Centre, 06 March 2012).
3. Water4 Foundation, "The Complex Need," https://water4.org/complex-need/ (Oklahoma City, OK: Water4 Foundation, 23 October 2012).
4. World Health Organization, "Facts and Figures on Water Quality and Health," http://www.who.int/water_sanitation_health/facts_figures/en/index.html (Geneva, Switzerland: World Health Organization, 20 October 2012).
5. Techneau, 2006. Nanofiltration in Drinking Water Treatment: A Literature Review. Techneau, D5.3.4B.
6. EPA, 2005. Membrane Filtration Guidance Manual, Environmental Protection Agency 815-R-06-009.

Appendix I

Appendix I contains a list of patents relevant to our project. This is not a comprehensive list and there are numerous other patents with similar design features and purposes as our project.

Appendix II

Appendix II contains drawings of proposed designs with dimensions for easier comparison of design features.

Low Power Ultrafiltration

Collin Craige – Team Leader
Mikayla Marvin
Qualla Parman

Our Team

Mikayla Marvin

Collin Craige

Qualla Parman

UltraTech Solutions

Mission Statement: Providing low cost filtration systems capable of producing safe drinking water for community improvement.

Company Background

- Pumps of Oklahoma, Inc. is a wholesale supplier of industrial, municipal, agricultural and environmental pumps. They supply submersible and above ground pump equipment to the international community.

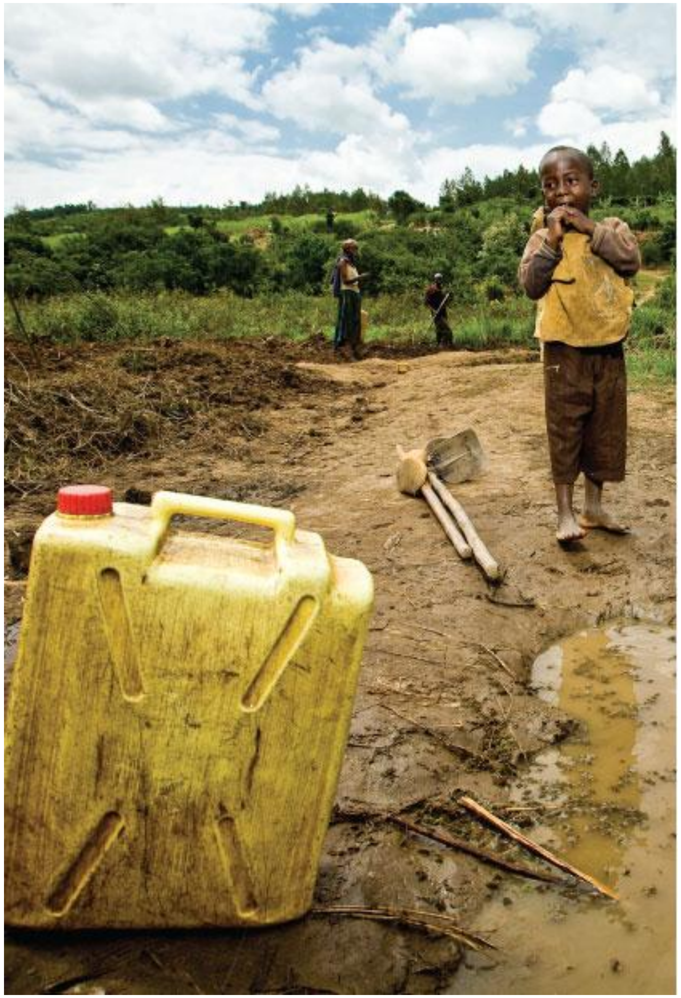
- Company has strong ethical standards and has close ties to the non-profit organization Water4.

Pumps of Oklahoma

water4 foundation
Empowering Communities One Well At A Time

A Basic Need Unmet

- 783 million people lack access to safe drinking water.
- Over two million deaths each year are attributed to diarrheal diseases caused by ingesting contaminated water.
- 90 percent of these deaths are children under the age of 5.



A Simple Solution

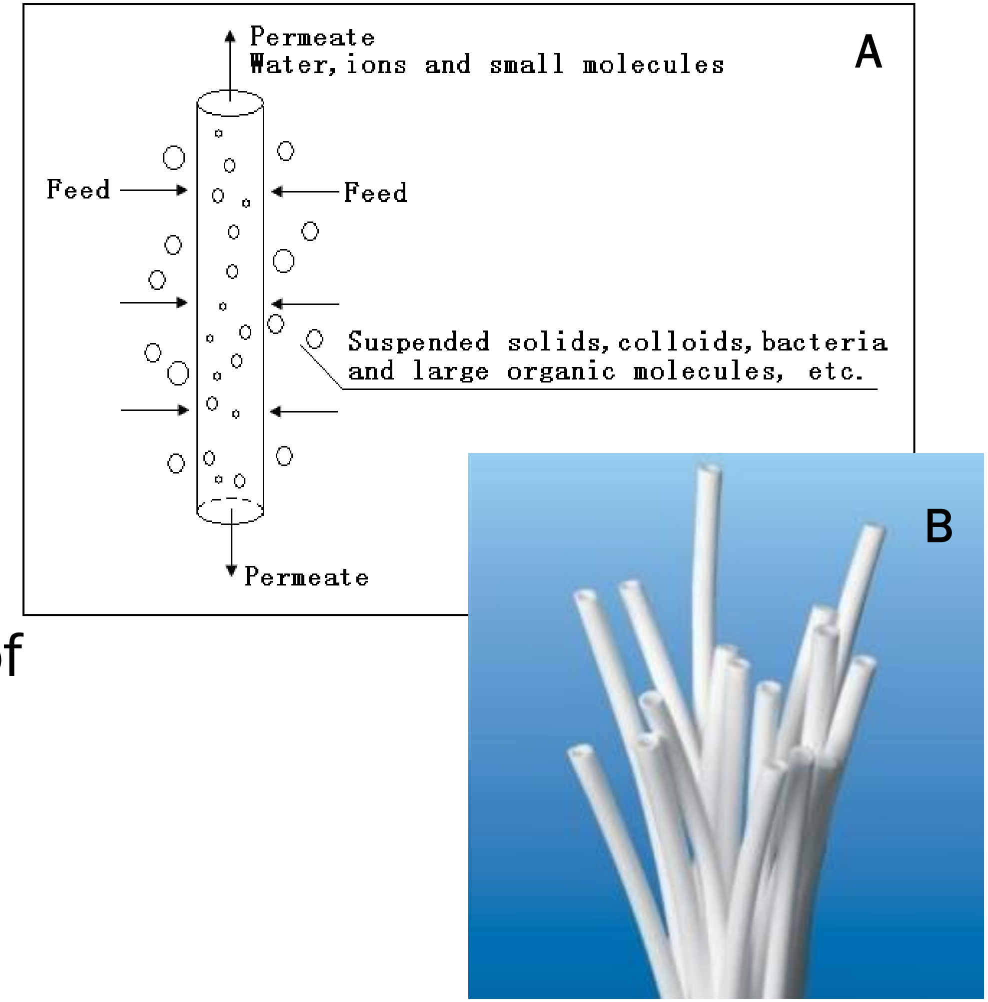
- Improvements in sanitation and drinking-water could reduce the number of children who die each year by 2.2 million.
- Suffering and death from diarrheal diseases is 100% preventable with access to safe drinking water.

Attaining this Solution

- Research
  - Membranes
  - Competitors
  - Contaminants
- Design
  - Pretreatment
  - Ultrafiltration
  - Secondary Treatment
  - Sizing – **<u>Meet basic human needs</u>**

Our Solution

- Utilize polyvinylidene difluoride (PVDF) hollow fiber membranes.
- Require very little or no power.
- Provide water that is free of microorganisms and safe for human consumption.

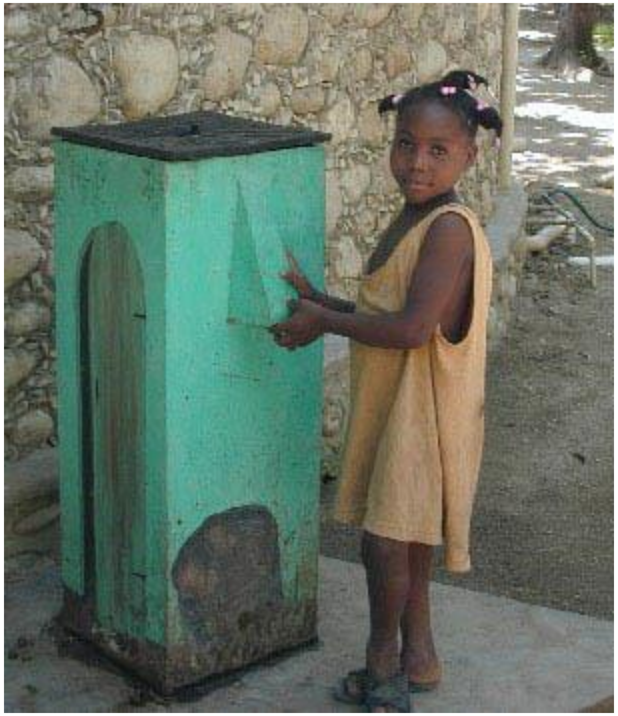


Membrane Filter Requirements

- Requirements
  - Gravity fed, low-power
  - Viral, infectious species, and bacterial removal
  - High quality water
  - Easily shipped, built, and maintained
- Added goals
  - Exchangeable modules
  - Unobtrusive
  - Inexpensive material
  - FDA/NSF approved materials

Competitors Response

- Ozone
- Chlorination
- Activated Carbon
- Reverse Osmosis
- Slow Sand Filtration (Biosand Filters)
- Water Distillation



Filter Tube Competitors

- Micro, ultra and nano filtration is well explored
  - Food and beverage
  - Wastewater treatment

- Primary competitors
  - Koch Industries
  - Dow Industries
  - Paul Corporation
  - Toray

A

B

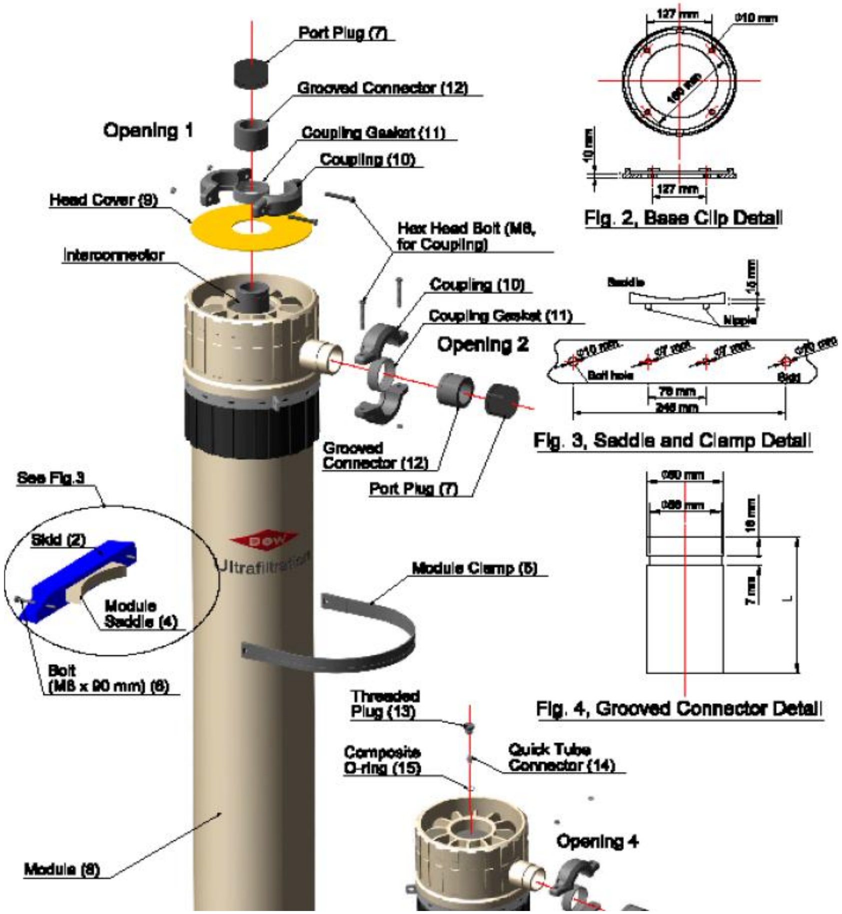
Filter Tube Patents

- European Patent 2125171 – Artificial Organ
  - Potential replacement for kidneys

- US Patent 0219613 – Home Plumbing Filter
  - Nanofiltration incorporated in plumbing

- US Patent 7484626 – Porous Water Filter
  - 2 to 5 microns
  - Carbon filter medium

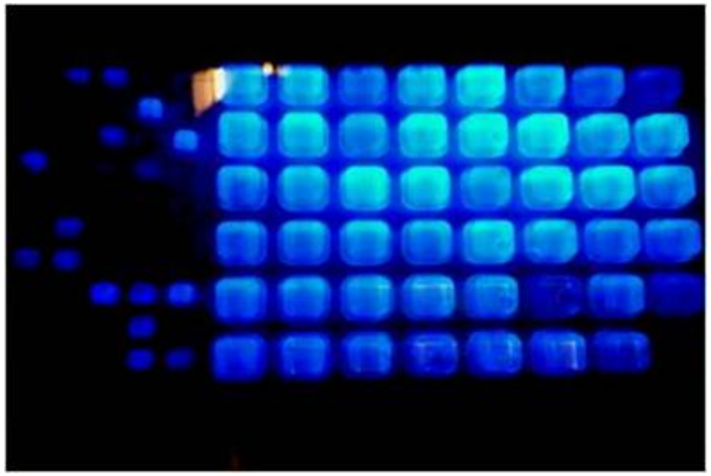
Filter Tube Competitors

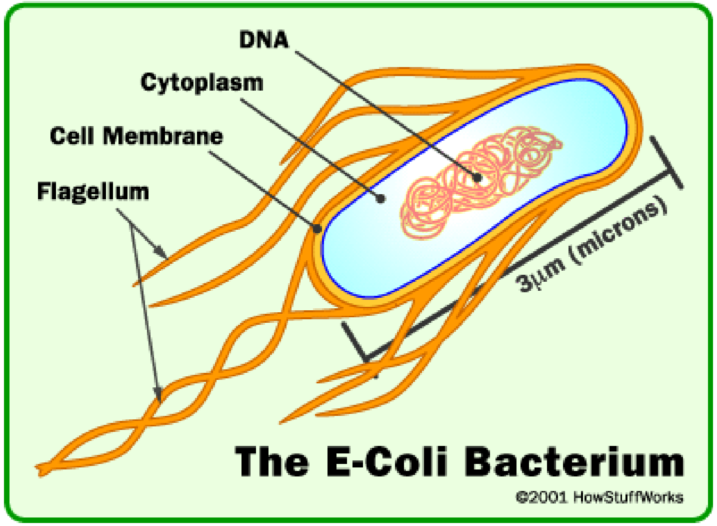


- Key objective was to minimize components
  - Less material = less cost
  - Easier to maintain

Common Water Quality Contaminants

- Organic and Inorganic Salts
- Metals
- Dirt and Other Particles
- Infectious Species
  - Bacteria
  - Parasites
  - Viruses





Ultrafiltration Capabilities

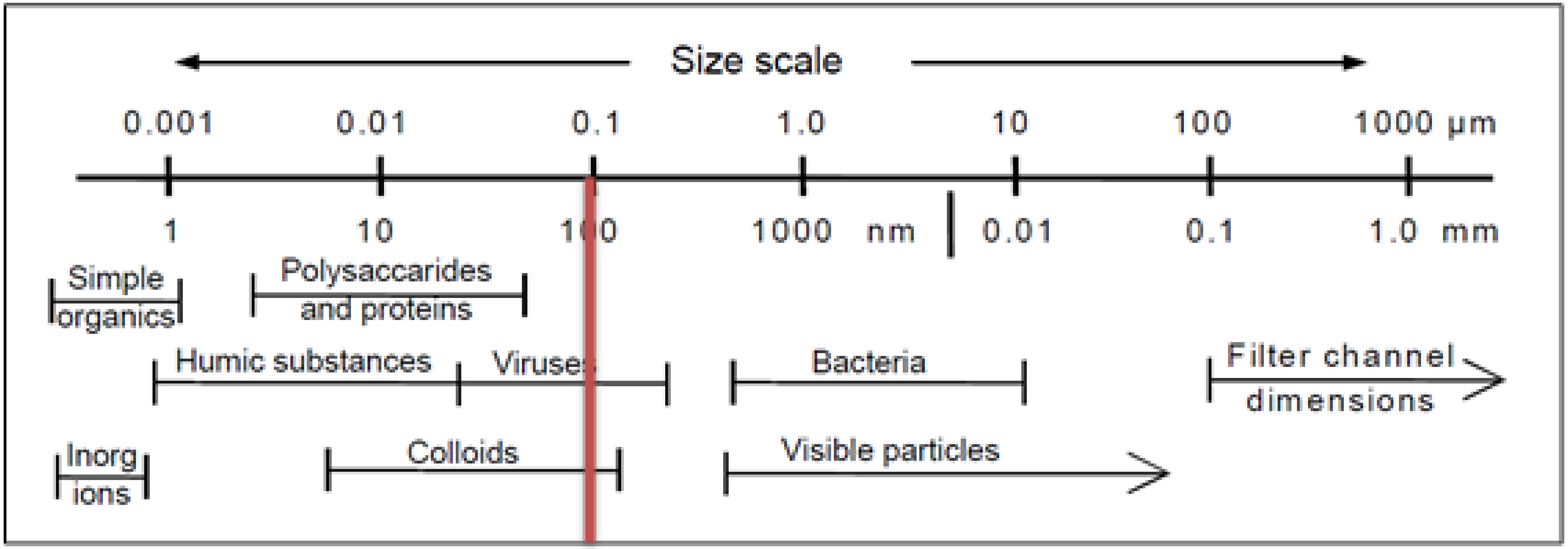
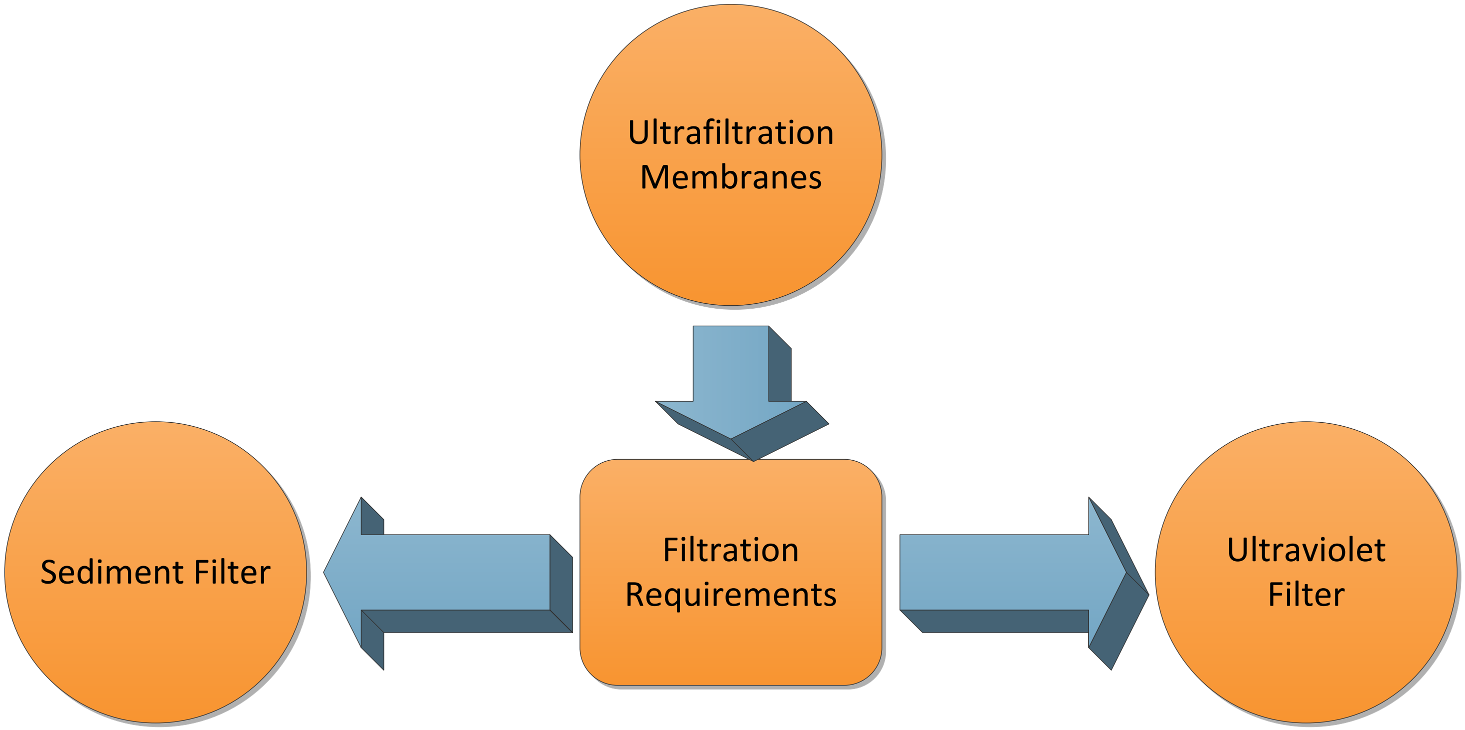


Figure 1 - Sizes of potential contaminants that will need to be filtered from contaminated water. Ultrafiltration membranes will remove bacteria and visible particles but not viruses. Obtained from *Nanotechnology in Drinking Water Filtration, a Literature Review*

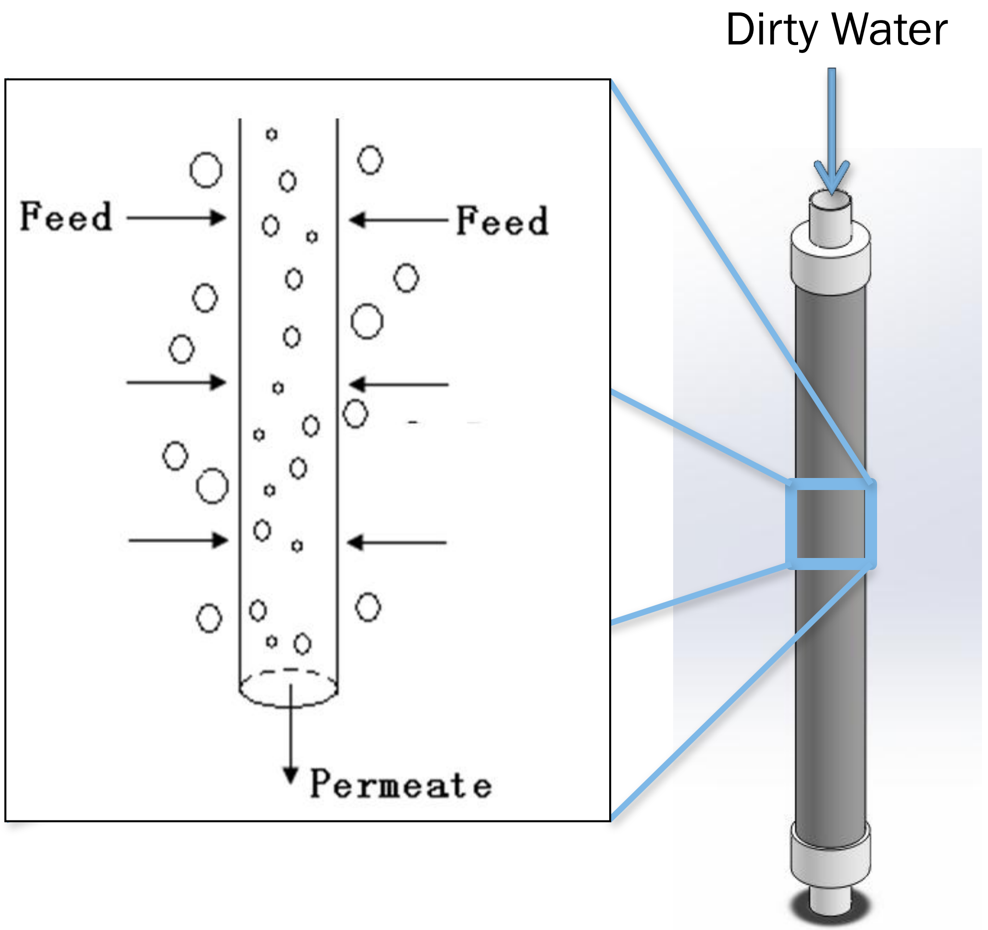
Design Process



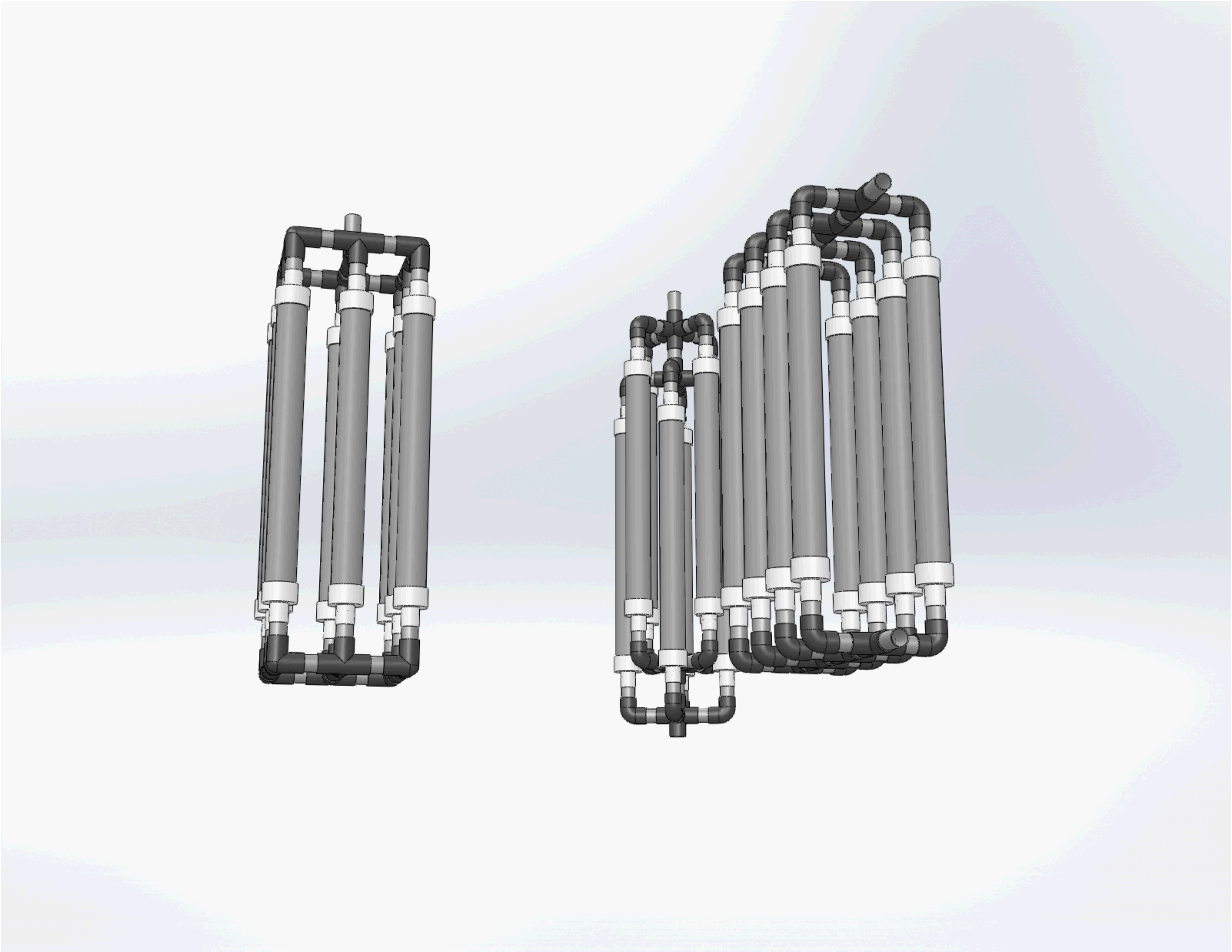
- Began with primary filter
- Developed pre filter and secondary filter from research

Ultrafiltration Module

- Gravity Fed
  - Reduce power need
- Clear PVC
  - Safety
  - Visual inspection
- Loop PVDF Tubes
  - Less Resin



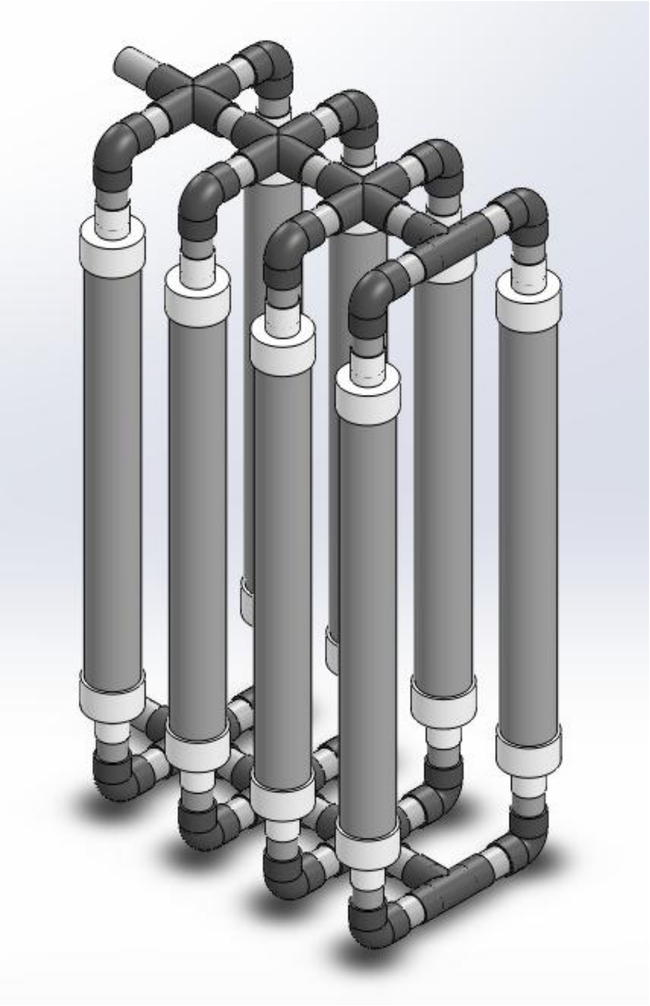
Preliminary Design Concepts



Design Concept One

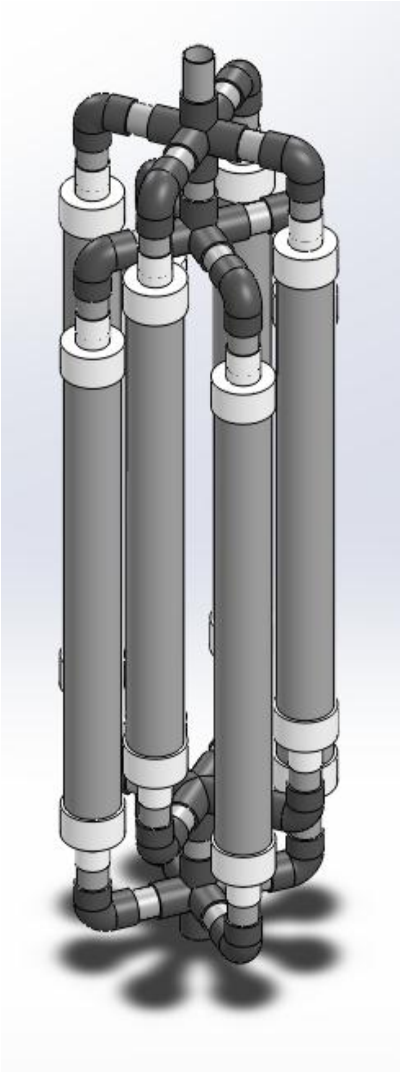
- Advantages
  - Simplest
  - Easiest to add modules
  - Self Supporting
  - Cheapest

- Disadvantages
  - Not compact



Design Concept Two

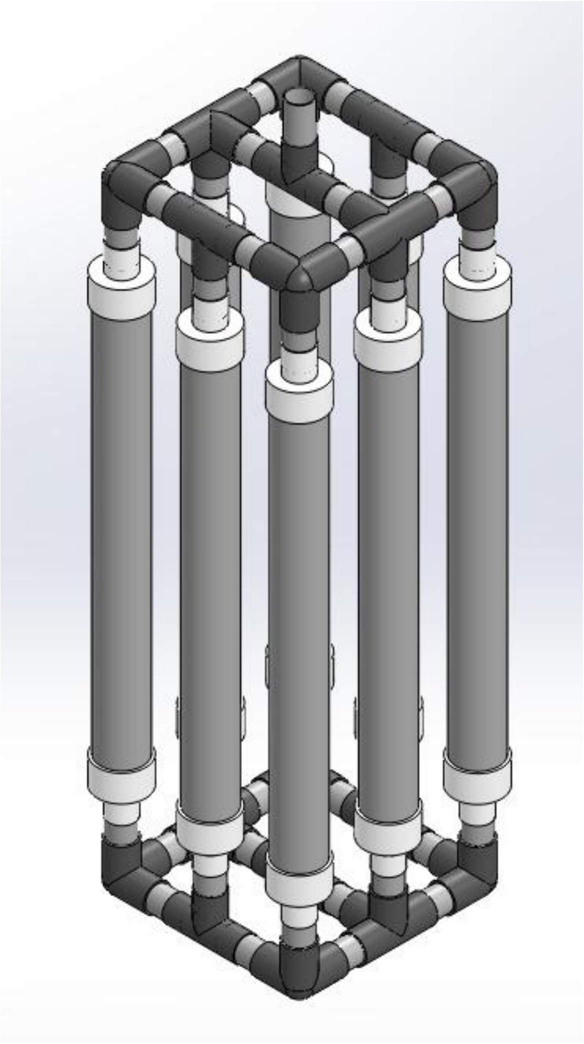
- Advantages
  - Compact
- Disadvantages
  - Extra supports
  - Custom part



Design Concept Three

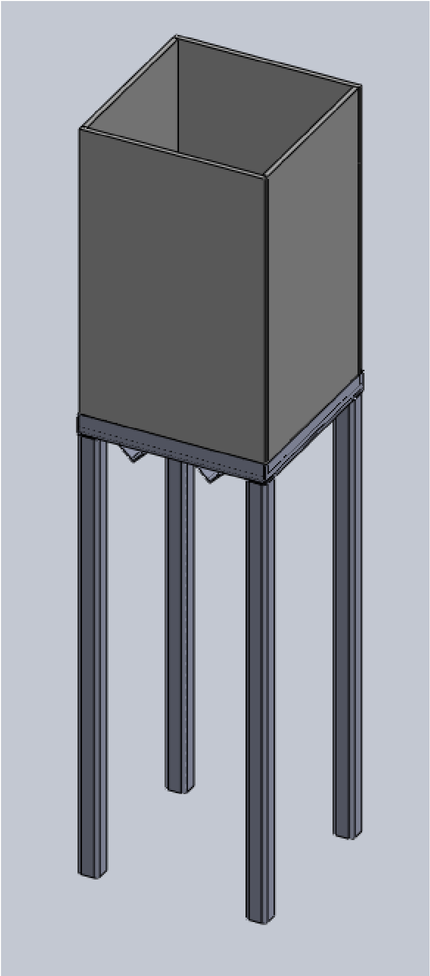
- Advantages
  - Compact
  - Self Supporting

- Disadvantages
  - More Expensive



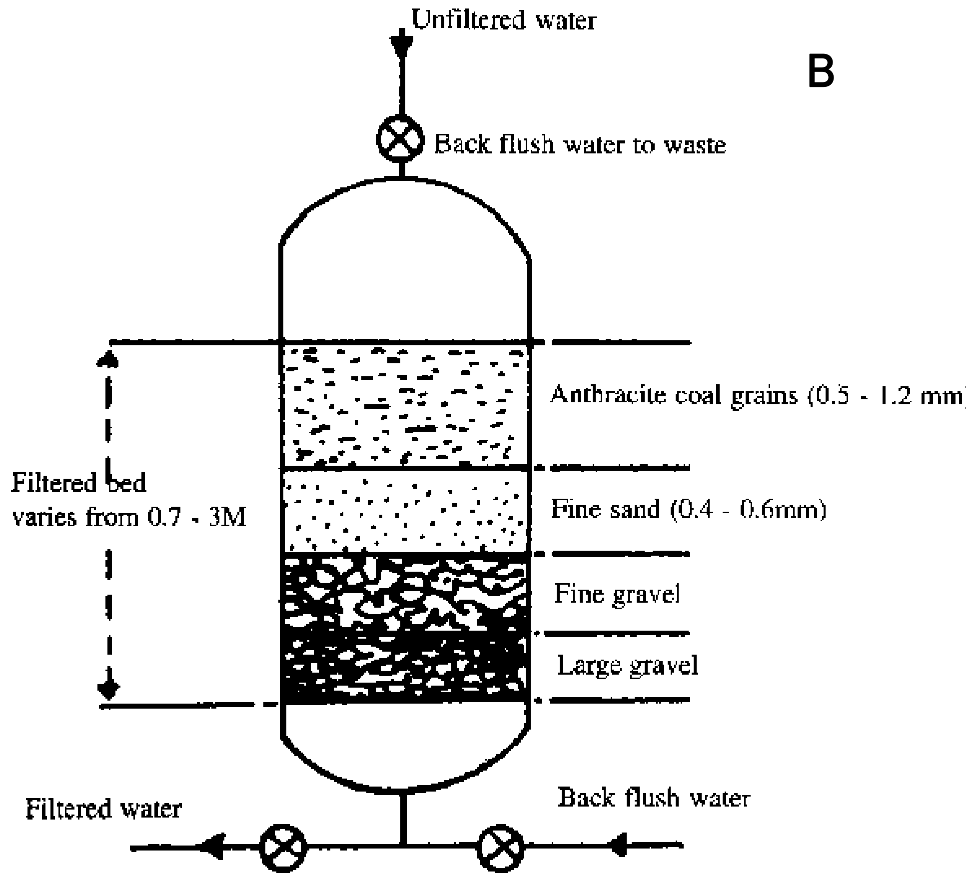
Primary Sediment Filter

- Quick Infiltration Sand Filter
- Cartridge or Box design
- Moderately coarse sand
- Wet Bulk Density between 1.6 and 1.8 g/cm^3
- Removal of particulate matter and turbidity



Primary Sediment Filter

A

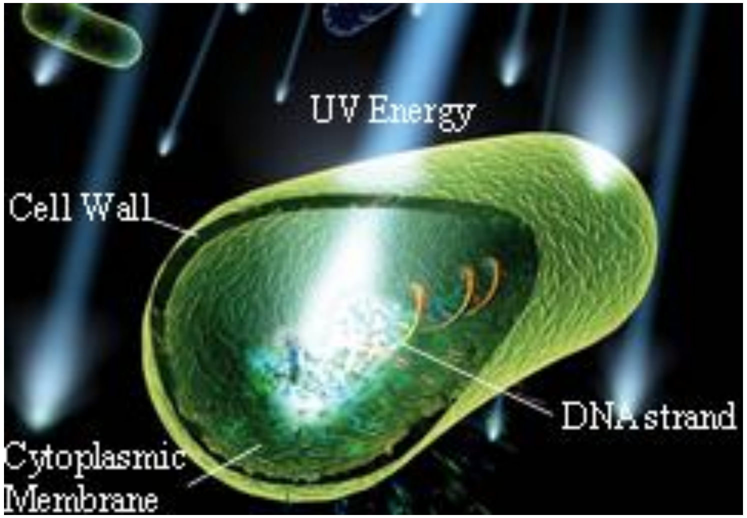


B

Post Membrane Treatment

- Joint project with freshmen class
  - Andrew Slavens and Jake Burdine

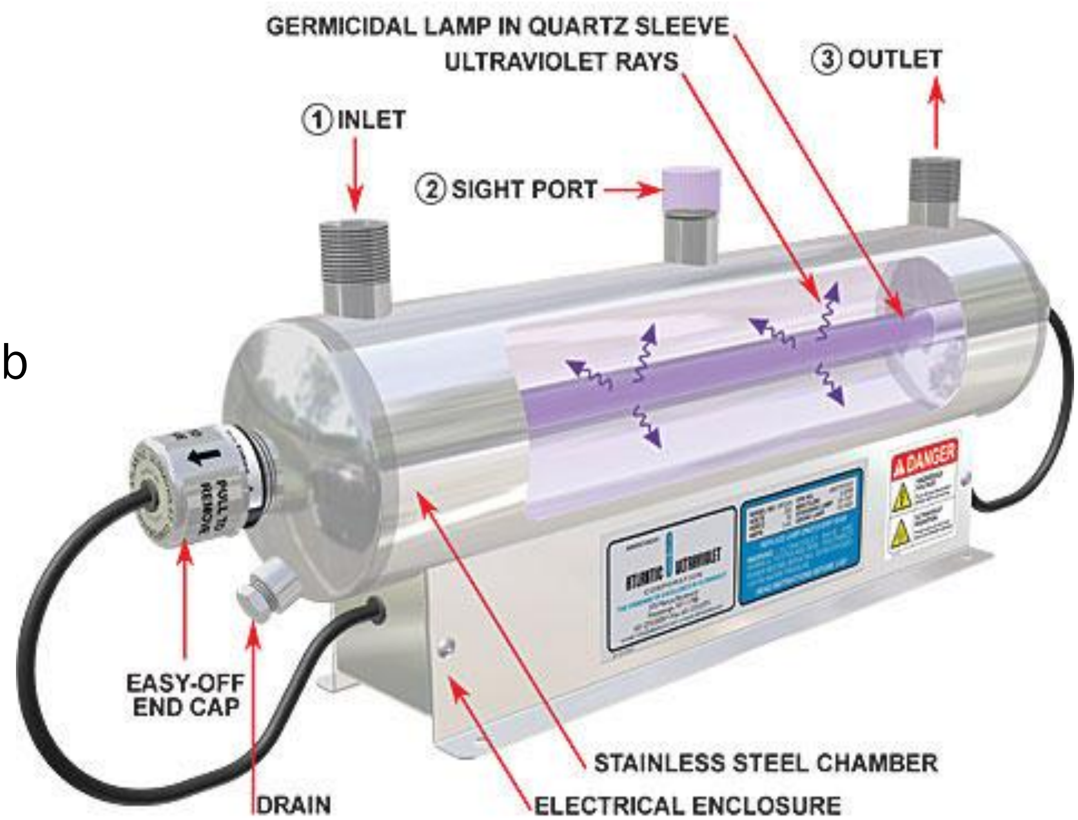
- Key Objectives
  - Non chemical (UV light)
  - Low cost
  - Viral decontamination



Post Membrane Treatment

- Requires electric power
  - Solar panels
  - Car battery

- Power Requirements
  - Less than a 60 watt bulb
  - 1.44 Kwh ~ $0.12

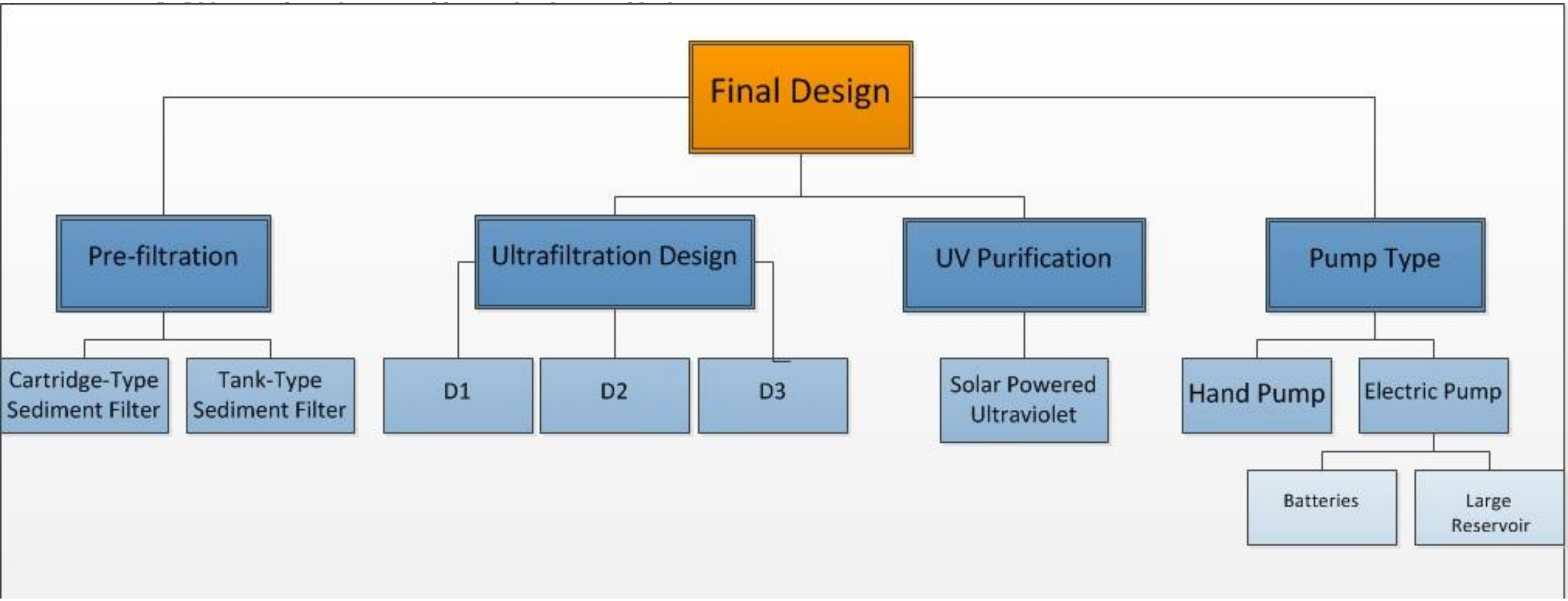


Water Tanks

- Clean Tank
  - Serve as a reservoir ~ 2500 gal.
  - Store "back up" water

- Dirty Tank
  - Large tank to minimize solar panels
  - Place above columnar sediment filter
  - Gain head by elevating tank

Design Options Summary



Sizing

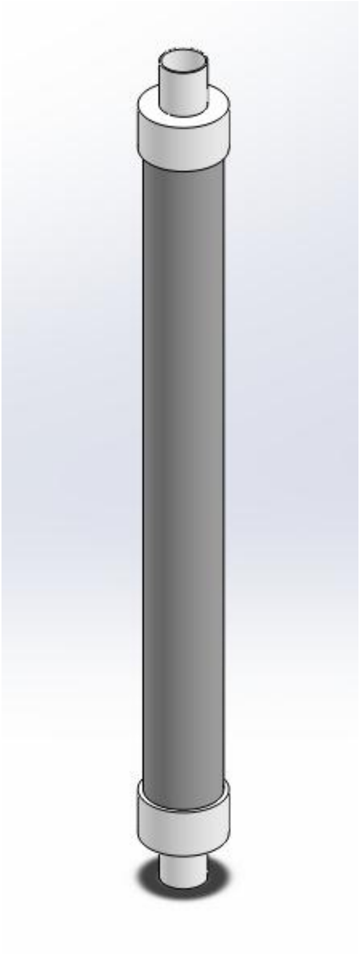
- From the beginning
  - Module cleans 11 gallons per hour
  - 88 gallons per hour for “base” system
  - Ideally modules are operated 24/7

- Tank sizing

$$Storage = 88\ gph\ * 24\ hrs$$

  - ~2150 gallons
  - Selected 2500 gallon tank

Flux (Gal/ft^2 Hr)	Gal/Person
0.215	4



Flow Calculations

- Sediment filter

$$Q = -KA\left(\frac{dh}{dl}\right) = 100 \text{ gal/hr}$$

- PVDF filter

$$Q = Tube\ SA * Flux * Modules = 88 \text{ gal/hr}$$

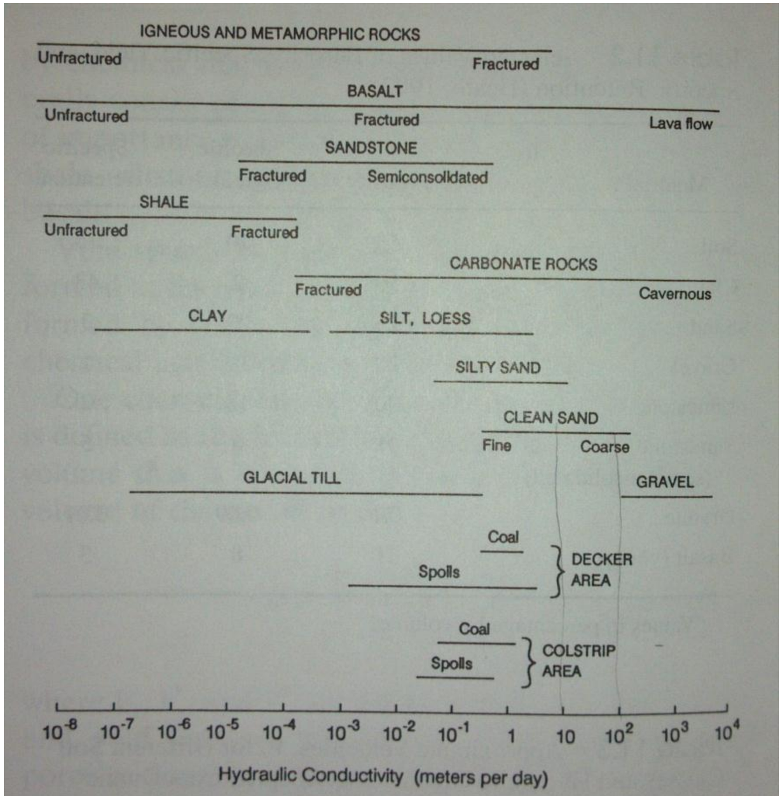


Figure 11.6 Typical values of hydraulic conductivity (adapted from Heath (1982) and Van Voast and Reiten (1988).

Sizing

- Power Needs
  - Elevating water tank provides filtration head
  - How do we get it up there?
  - 5280 Watts/M^2/day
  - 21 Watt UV light, 120 Watt pump

$$Watt\ hrs = (21\text{ W} * 6\text{ hrs}) + (120\text{ W} * 6\text{ hrs})$$

670 Watt hrs/day

$$Panel\ Area = \frac{Need}{Available} = \frac{670}{5280 * 0.18\%}$$

0.7 m^2

Pump will only run 4.1 hrs. So 62% larger than needed.

Intro to the Economics

Driving down costs is imperative. The less a system costs the more likely it can be implemented sustainably and successfully.

Materials Maintenance Manpower

Economics

- Ultrafiltration

Item	Supplier	Quantity	Item #	Unit Price	Total
3" X 24" Sch 40 PVC Pipe	Grainger	8	5AFJ9	$3.19	**$25.52**
1" PVC T-Joint	Lowe's Hardware	6	23876	$0.70	**$4.20**
1" to 3" PVC Reducer	Pex Supply	16	429-335	$9.35	**$149.60**
1" Side Outlet Elbow	Lowe's Hardware	8	315499	$2.05	**$16.40**
1" X 3" PVC Pipe	Lowe's Hardware	37	23976	$0.08	**$2.98**
1" PVC cross Tee	Lowe's Hardware	4	22702	$2.22	**$8.88**
PVDF Tubing	Jofur	6672		$0.09	**$631.82**
SterAlloy Resin	Hapco	1 Quart	2463	$53.28	**$53.28**
				Total	**$892.68**

Major cost is PVDF tubing

Economics

- Solar Panel and UV filter

Item	Supplier	Quantity	Item #	Unit Price	Total
Solar Panel	Home Depot	2	GS-S-100-Fab36	$199.00	**$398.00**
Controller	Missouri Wind and Solar	1	PWMSCC	$59.98	**$59.98**
Power Cable	Missouri Wind and Solar	10	345	$0.80	**$8.00**
Mounting Rack	Missouri Wind and Solar	1	SPRK4FT	$79.98	**$79.98**
				Total	**$545.96**

Item	Supplier	Quantity	Item #	Unit Price	Total
UV Filter	Atlantic Ultraviolet	1	MIN-9 24v/DC 9 GPM	$674.00	**$674.00**

Item	Supplier	Quantity	Item #	Unit Price	Total
Clean Water Tank	Plastic-Mart	2	N-40631	$911.95	**$1,823.90**
24-volt Pump	Pump Agents	1	18670-0943	$271.83	**$271.83**
				Total	**$2,095.73**

Economics

Cost breakdown for total system

Item	Startup 1 Electric Pump	Startup 2 Hand Pump	Maintenance/yr
Sediment filter	$ 0.00	$0.00	$ 0.00
Ultrafiltration system	$ 892.68	$ 892.68	$ 137.00
MIN-9 24v/DC 9 GPM	$ 674.00	$ 514.00	$ 71.97
Solar panel setup	$ 545.96	$ 337.94	$ 0.00
Water tanks	$ 2095.73	$ 479.89	$ 0.00
Total	**$ 4208.37**	**$ 2224.51**	**$ 208.97**

Economics

- Initial startup cost is high
- Overall maintenance cost is low
- Simplified cost over 5 years – $925 / $207
  - 2100 / 620 gallons per day
  - 528 / 155 people @ 4 gallons per day
  - $2.85 / $1.57 per day

$$\frac{\$2.85}{day} \div 2100\ gal = 0.0014\frac{\$}{gal}$$

Spring 2013 Task List

Task Name	Duration	Start	Finish
Choose Final Design	21 days	Mon 12/10/12	Mon 1/7/13
Order Materials	6 days	Mon 1/7/13	Sun 1/13/13
Additional Testing	19 days	Mon 1/7/13	Thu 1/31/13
Prototype Construction	11 days	Fri 2/1/13	Fri 2/15/13
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Final Testing & Evaluatio	12 days	Fri 3/15/13	Mon 4/1/13
Final Presentation	15 days	Mon 4/1/13	Fri 4/19/13

Spring Action Items

- Gravity head flux rate
  - Issues sealing modules with resin
- Effectiveness
  - Viral tests – indicator bacteria
  - Cleaning – backwashing, air scrub
  - Fixing broken PVDF tubes
- Test predictions on estimated life
- Water4 Applications

Patent Information

- US Patent 7390343, June 24, 2008 – A drinking water filter that rids water of bacteria and viruses
- US Patent 4995976, February 26, 1991 – A filter straw personal filter patent
- US Patent 5536395, July 16, 1996 – Filter attaches directly to a household sink
- EP Patent 2271382 A1, April 14, 2009 – Method for concentrating a protein with ultrafiltration

Acknowledgements

- Pumps of Oklahoma
  - Mr. Greenly
  - Mr. Goodspeed

- OSU Biosystems
  - Dr. Weckler
  - Dr. Fox
  - Dr. Frasier
  - Wayne Kiner

Questions?

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- qualla.parman@okstate.edu

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- Braghetta, A. 2006. Drawing the connection between Malnutrition and lack of safe drinking water in Guatemala. American Water Works Assn. J. 98(5): 97-107.

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- Water4 Foundation, "The Complex Need," https://water4.org/complex-need/ (Oklahoma City, OK: Water4 Foundation, 23 October 2012).

- World Health Organization, “Facts and Figures on Water Quality and Health,” http://www.who.int/water_sanitation_health/facts_figures/en/index.html (Geneva, Switzerland: World Health Organization, 20 October 2012).

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- EPA, 2005. Membrane Filtration Guidance Manual. Environmental Protection Agency: Office of Water 4601

Image References

- Slide 5 – Image From: https://water4.org/how-to-help/
- Slide 6 – Image From: https://water4.org/contact-us/
- Slide 7a – Image From: Technical Specifications Sheet
- Slide 7b – Image From: http://www.made-in-china.com/showroom /220215451/product-detailpqdJfUTOgKVG/China-PVDF-Hollow-Fiber-Ultra-Filtration-Membrane.html
- Slide 10 – Image From: http://www.worldneighborhoodfund.org/q5/ haiti.html
- Slide 11a – Image From: Toray Ultrafiltration Brochure
- Slide 11b – Image From: GE-Zenon Wastewater Treatment Overview
- Slide 13 – Image From: Dow Industries Ultrafiltration Manual
- Slide 14 – Image From: http://thoughtfulindia.com/2012/06/e-coli-outbreak-in-six-states-is-probed/
- Slide 15 – Image From: Techneau, D5.3.4B, December 2006, Nanofiltration in Drinking Water Treatment: A Literature Review
- Slide 17 – Image From: Technical Specification Sheet
- Slide 23a – Image From: http://www.soilmeasurement.com/tempe.html
- Slide 23b – Image From: http://www.fao.org/docrep/X5624E/x5624 e05.htm
- Slide 24 – Image From: http://www.waterfilter-usa.com/trojan-uv-max-d4-p-335.html?currency=USD&gclid=COzar4LijbQCFegWMgodgBAApg
- Slide 25 – http://www.freshwatersystems.com/p-4497-mighty-pure-mp36c-12-gpm-ultraviolet-water-purifier.aspx
- Slide 26 – Image From: http://www.plastic-mart.com/product/5856/305-gallon-water-tank-green-40863
- Slide 30 – Image From: Design Hydrology and Sedimentology for Small Catchments Page 430