Foam Filtration, Fall 2014 Final Report

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Abstract

The primary goal of foam filtration is to design a low cost, locally sourced, easy to operate water filtration system. During the summer of 2014, the backwash system was redesigned to improve cleaning efficiency. The new backwashing method plunges the foam through water, creating high pore velocities that shear flocs free from the foam. The Fall 2014 Foam Filtration team has focused its efforts in exploring the new backwashing method with the design and construction of a new apparatus: the 4” Pipe Small Scale Filter. Experiments performed on this filter, designed to hydraulically model the full scale filter, will be used to determine an empirical relationship between backwash pore velocity and the percent mass removal of the particles from the foam during the cleaning cycle.

The Chemical Dose Controller was redesigned with (1) an altered constant head tank constructed from Nalgene bottles or a 3” pipe, (2) the float situated inside the LFOM, eliminating the need for an entrance tank, and (3) major headloss elements that run vertically to reduce overall size.

Tests through mass spectrometry have confirmed that chemicals are leaching from the foam, however more testing must be done to determine the composition of the leachate. Designs for the on-the-ground implementation of the foam filter pilot project have been drawn up by AguaClara Engineer, Walker Grimshaw in Honduras. This design includes the set-up for the chemical stock tanks, designs for managing backwash and finished water, and the possible addition of a grit chamber.

The lever arm used for plunging the foam was redesigned with a rigid connection to the base of the filter support. This rigid connection eliminates large movement in the z-direction and the need for guidance by the barrel lid on the 55-gallon drum. The open-top design allows for integration of the new CDC/LFOM design: influent raw water pours out of the LFOM and directly into the filter body.

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Introduction

AguaClara won an EPA P3 award in 2012 and again in 2014 for its foam filtration research. The foam filtration team works to produce a feasible design that can be replicated in the field. The following bullet points are characteristics of the population the filter is designed for, the features the filter will have, and the way the water flows through the filter.

Target Demographic

- **Medium-size villages** of up to 1,000 people
- When **municipal plants are impractical** in terms of cost
- **Emergency situations** when traditional municipal systems have failed
- **Temporary situations** such as refugee camps

Features

- **Flow** rate: 1 L/S or serves roughly 1000 people at 86 L/person/day
- Low **cost**: less than $1000 USD initial cost
- Locally sourced: all **materials** can be found locally except the foam
- Easy to **build**: requires a small number of readily available tools, and is simple and transparent in design
- Easy to **operate**: little operation time is needed and operation is relatively simple
- **Gravity-powered**: only gravity powers the filter; there are no electrical components

How The Water Flows

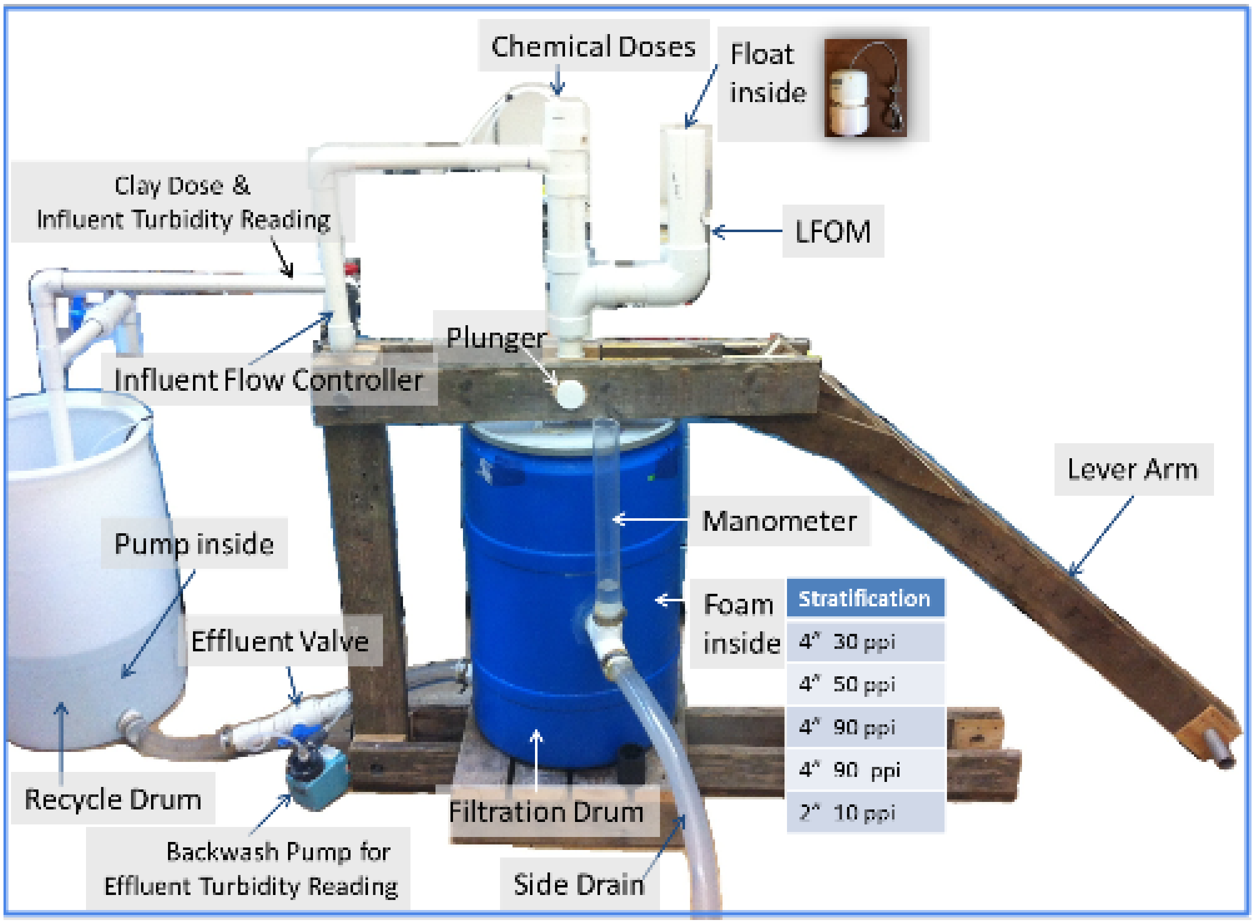

Figure 1: *This is an illustration of the current lab setup. The water enters through the influent flow controller, is dosed by coagulant, and enters the foam layers held in the barrel. The water percolates through the foam and the flocs, via the coagulant on the colloidal and pore surfaces, gets stuck in the foam, leaving much cleaner effluent. Effluent is dosed with chlorine before delivery to communities.*

Entrance

The filter is gravity powered, so the entrance must be above the rest of the filter. The filter is designed to receive a flow rate of up to 1 L/S. Due to the filter's ability to handle extremely high turbidity water (+500 NTU), the filter can have an influent of surface water such as streams, ponds, and lakes. The water is carried from the source in a pipe that is brought to the entrance LFOM in the filter.

Linear Flow Orifice Meter (LFOM) and Chemical Dose Controller System (CDC)

The LFOM and CDC work in tandem to dose the water with coagulant before the water enters the foam and chlorine after at a user-specified rate. The dose controller automatically adjusts the chemical flow to account for varied influent flow rates to maintain a constant dose.

Foam

The water then enters the foam layers from the top and percolates through the foam, starting in the coarsest foam and working towards the finer foam at the bottom. It is theorized (according to the Adhesive Nanoglobs Coagulation hypothesis) that the main mechanism of filtration is the attraction of the precipitated coagulant to the cell walls of the foam. The foam provides an immense area for the coagulant to “stick to,” and the colloids in the influent are attracted and “stick to” the coagulant. The last layer of foam is extremely coarse in order to provide the clean water a cavity to flow through out of the single outlet at the bottom edge of the filter.

Effluent

The effluent is then dosed with chlorine by the CDC to ensure disinfection both at the filter and through the distribution system.

Literature Review

Chemical Leaching and Potential Risks

The current foam filter design uses ether and ester based reticulated polyurethane foam. Various literature was reviewed during the summer of 2014 to address concerns that chemicals could leach from the foam into the effluent water. While polyurethane foam is a common material for a variety of filtration systems, its safety has not been well investigated. The chemical structure of urethane decomposes easily when in contact with urea; however, according to Ravey and Pearce, polyurethane decomposition by urea does not have a noticeable effect on the foam. Thermal decomposition of polyurethane is also possible, but is not a concern as it occurs at temperatures of over 110 ºC.

Another potential risk in chemical leaching is from the flame retardant added by manufacturers. Since polyurethane foam releases toxic yellow smoke when it burns, many foam companies apply flame retardants. While the retardant reduces fire hazards, its brominated hydrocarbon composition poses a threat to consumer health. Polybrominated Diphenyl Ethers (PBDE) and Polybrominated Biphenyls (PBB), two of the brominated hydrocarbons found in flame retardants, may act as endocrine disruptors in humans and animals. In 1973, PBB was banned from the US after one study showed that flame retardants’ presence in mice may lead to behavioral dysfunction caused by the neurotoxic bioaccumulation of PBDE and PBB. In 2009, the U.S. Environmental Protection Agency

(EPA) identified PBDE and PBB as emerging contaminants. According to the EPA's report "An Exposure Assessment of Polybrominated Diphenyl Ethers," PBDE's have low solubility in water temperatures between 20ºC and 25ºC. However, the risk of the reaction between PACl and the flame retardant is unknown.

The foam manufacturer, Crest Foam Industries, a subsidiary of INOAC USA, Inc., was contacted during the summer of 2014 to inquire about the foam's safety in drinking water treatment. According to a representative, the foams have been used for various wastewater filtration technologies, and no history of chemical leaching from water contact has been reported. The company did, however, recommend using foams made within the last 6 months, as older products contain carcinogenic tin. In addition, the company insisted that flame retardant is not a risk because it is only applied on the surface of the foam and can be removed by washing before use. When questioned on the absence of FDA approval for the foam, the representative replied that its safety had not yet been confirmed by a third-party.

Other Research

Foam Filtration is an emerging technology that has not yet been well-documented by other investigators throughout the country. Previous Foam Filtration teams reports were reviewed, and their findings are documented in the Previous Work section of this report.

Previous Work

Summer 2014

Building New Linear Flow Orifice Meter (LFOM)

During the summer of 2014, a new, U-shaped LFOM was constructed out of 3" PVC piping. One vertical side of the LFOM contained the float connected to the dosing system. The other, parallel side, held the orifice meter, a 2" PVC pipe with holes in specific locations to allow for linear flow. The two sides were connected such that the water heights on both sides would be equal (as if it were one continuous entrance tank in the full-scale AguaClara plants). The raw water entered in the side with the LFOM and continued to the filter through the LFOM orifices. Figure 2 below consists of images of the LFOM; the first shows the interior of the LFOM and the second shows what is visible to the user.

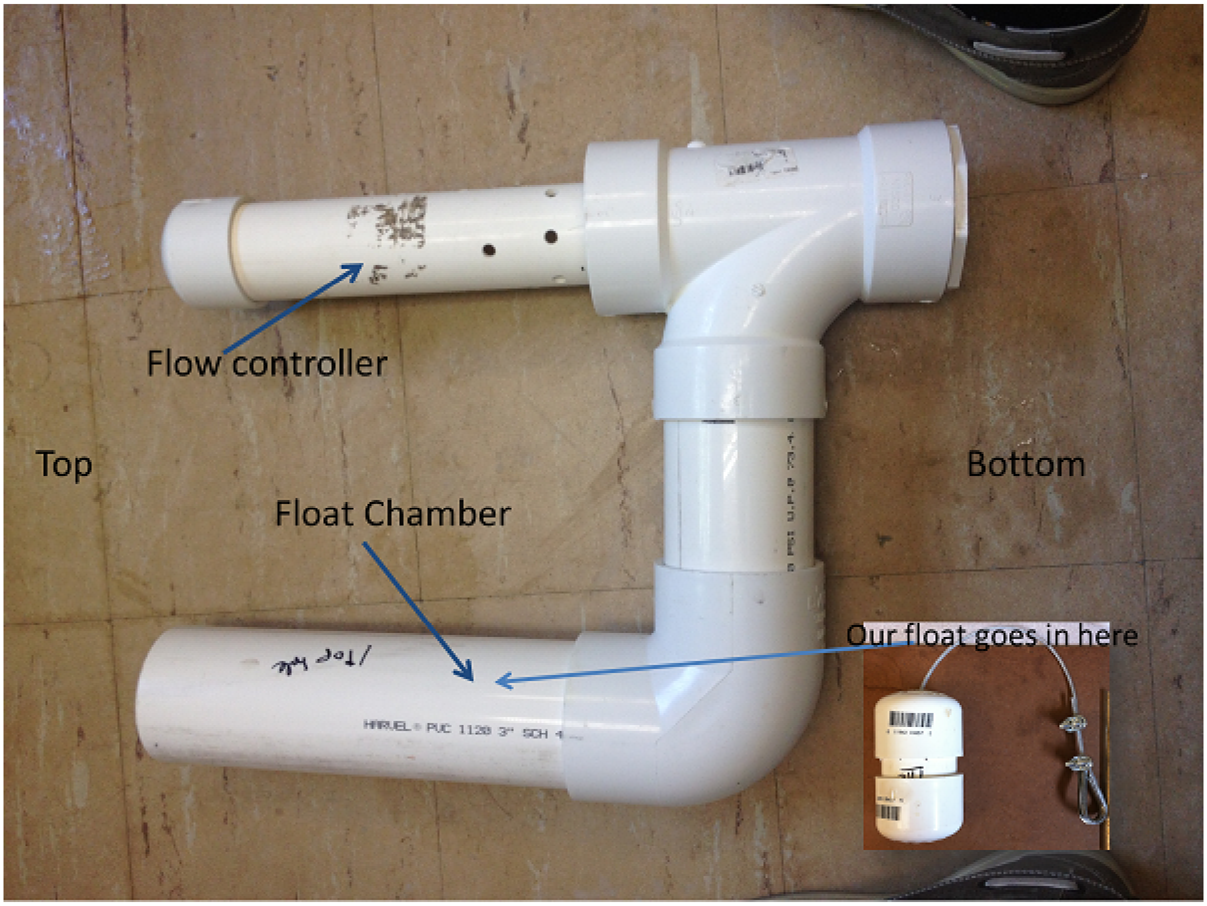

Figure 2: *View of the inside of the float chamber (left branch) and the flow controller (LFOM) in the right branch.*

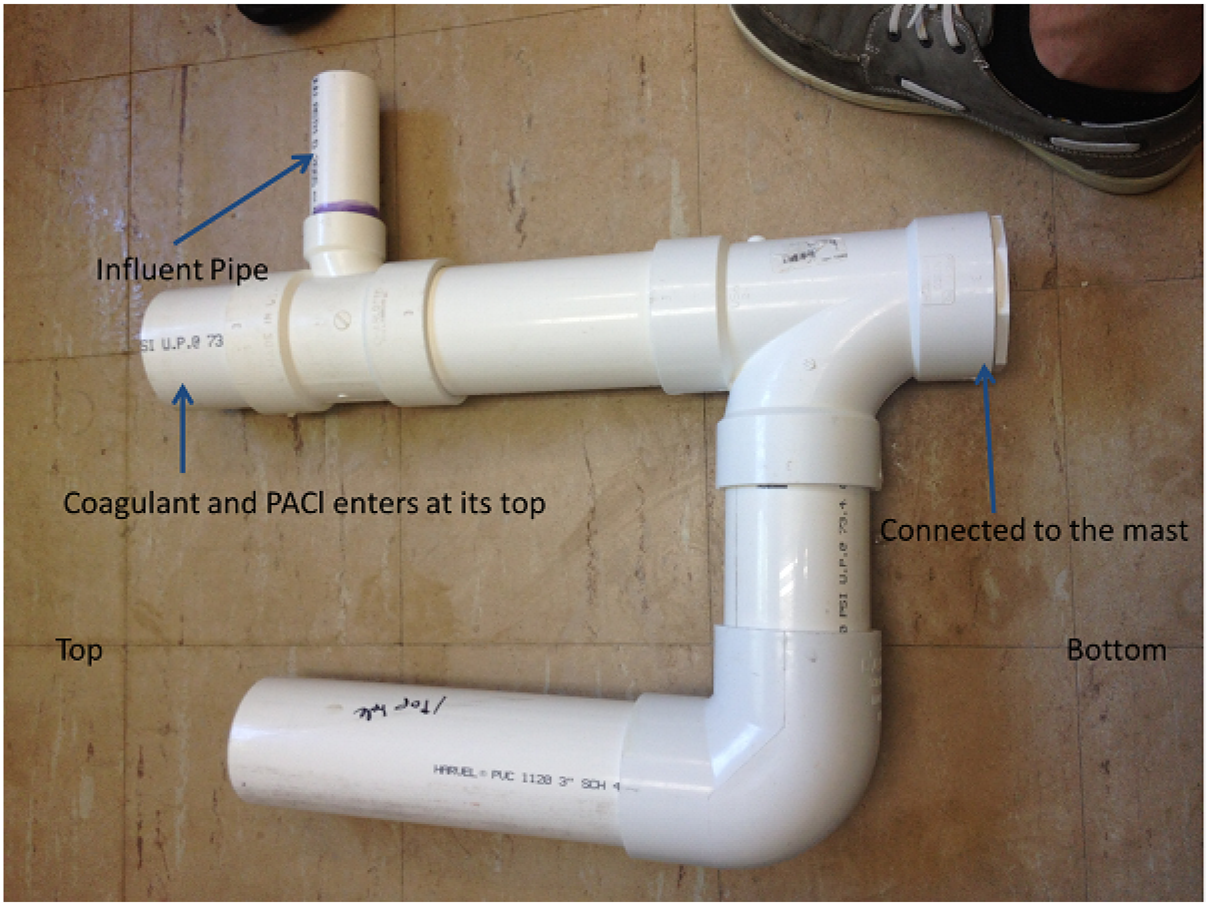

Figure 3: *Operator's view of the float chamber (left branch) and the flow controller (LFOM) in the right branch with the influent pipe. The water level in the left and right branches will be equal, as they are both exposed to atmospheric pressure.*

Improving the Chemical Dose Controller (CDC)

In order to make the CDC system more compact and still work in conjunction with the LFOM, the PACl stock tank and the constant head tank were both raised and mounted flush with the mast leading down into the filter. The lever arm connecting the dosing system to the float in the U-shaped LFOM piping eliminated the need for a traditional entrance tank. Tests were run to confirm that the CDC dosed appropriate amounts of PACl. In the summer 2014 report, the foam team mentioned that their goal for the next model would be to add the same CDC system on the opposite side of the tank to dose chlorine.

Remodeling the Clean Out System (Backwash Cleaning Design)

A backwash system is being used to clean the foam rather than a compression disk system, as it was determined that the compression system could not be operated by only one person. Over the summer, research was done that showed the backwash system has a much higher cleaning efficiency than compression, and requires much less force (~300 lbs) so is operable by one person. The wooden lever system uses a 4:1 force ratio, and was chosen as wood because PVC was determined to have deflected much of the force applied by the operator. The wooden lever has a slanted handle to allow the plunger to sit at the bottom of the barrel when the lever arm is resting on the ground.

Figure 4: *New stainless steel piping*

The push and pull marionette system used to plunge the foam through the water is currently a simple cross shown above, and was initially made of ¾-inch PVC pipes. It was determined that too much stress was being put on the PVC pipes where they meet at the cross, as one end of the cross broke after only 3 uses. Stainless steel ¾-inch threaded piping has been used as a solution to strengthen this design, through the same PVC mast, as shown in Figure 4.

A side valve system is being used to drain dirty backwash water from the system. The lever arm system allows for a side valve to be used, as varying water level is not a concern with this design. The side drain system is connected to the drum using spin welding. However, this method is not particularly compatible with the materials we are using, and the system was accidentally broken off from the drum during lab clean-up. A new spin weld has been ordered to re-attach the drain so that lab testing with the large filter may resume. Determining a better solution for the attachment of the side drain system is not a priority as a superior solution using PVC is currently available in Honduras and no research is necessary. However, we do not have a PVC specialist in Ithaca and therefore spin welding is a sufficient solution for the lab apparatus.

Experiments

Compression Cleaning vs. Backwash Cleaning with 60 ppi, 4” pipe foam filter

An experiment was conducted to determine the more efficient cleaning method: backwash versus compression. Clay water was poured manually into the 60 ppi, 4” pipe foam filter until it yielded an effluent turbidity spike. The spike was an indicator to begin the cleaning cycle. For cleaning, tap water was run through the filter, allowing the foam to be plunged through a specific water height (15” and 7” were used for backwashing in this particular experiment). While one team member plunged the foam with a porous disk, another recorded the plunging stroke on video, allowing for a displacement versus time analysis. A mass balance was done between the NTU-liters of the influent raw water, of the filtered water, of the wash water, and of the effluent. The ratio of the NTU-liters of the wash water to the NTU-liters filtered yields the cleaning efficiency of the foam. Mass balance over whole filter:

NTUliters.in = (NTU.removed + NTU.effluent)Vol.filtered

After the NTU.backwash and Vol.backwashed are measured:

(NTUliters.backwashed)/(NTUliters.removed)=Cleaning efficiency

The results showed the backwash method through 7” of water to have the highest cleaning efficiency (higher than that of both compression and backwashing through 15” of water).

Force Measurement

After developing its own spring scale, the Summer 2014 Foam Filtration team ran an experiment to determine the force required to plunge the 16” thick stratified foam through 10” of water for backwash cleaning. Five trials were completed; however, the results varied from 100 lbs. to 300 lbs.

Barrel Testing

An experiment was conducted to determine the cleaning efficiency of the backwash method in the full-scale 55-gallon drum filter for two different run-times: 45 minutes and 75 minutes. The cleaning cycle was initiated after the first turbidity spike was shown in the effluent turbidity meter. The foam was lifted with the lever-arm system and plunged through tap water. This process was video recorded to facilitate a displacement versus time analysis. The wash-water was then drained from the drum and its turbidity was measured. Using the same mass balance approach was in the experiment with the 4” pipe filter, the cleaning efficiency for both run-times was calculated. Both efficiencies were calculated to be around 71%.

Conclusions

- Backwashing the foam is more efficient than compression both in cleaning efficiency and force required by the plant operator.
- A much higher pore velocity can be applied with less force through the lever-arm design for backwashing.
- The apparatus was able to filter 100 NTU water down to 1.35 NTU for about 75 minutes, with a resulting cleaning efficiency of 71 percent.
- The filter was able to achieve nearly the same run times for similar experiments performed days apart. This indicates that the foam was adequately cleaned via the backwashing method between experiments.

Connections to work in Honduras

The lever-arm design specifications and 23” foam (4” 30 ppi and 4” 90 ppi) were sent to Honduras on July 27, 2014 with AguaClara Field Engineers Walker and Jon in hopes that the filter can be implemented in the field by the end of the Fall 2014 semester.

Additional Notes

Additional information about previous work can be found in the Summer 2014 Final Research Report (see references section).

Methods

Research Approach

The foam research approach is a two-pronged style that addresses both the implementation using a full scale model as well as the governing equations and design parameters for foam filtration using a smaller and easier to operate model. The small scale model provides information on cleaning efficiency, filtration efficiency, clean out force required, pore size effects, etc…, which can be scaled up for any design. The large prototype filter provides information on the ease of use of the filter, the design challenges due to scale, and provides a much closer representation of the filter to be constructed in Honduras. The larger filter also enables the team to test the filter-sized LFOM and CDC system.

Large Filter and Recycle System

The following figures provide a more in-depth view to the overall experimental setup outlined in Figure 1. Figure 5 is a rendering of the large filter design completed in SketchUp over the summer. This provides a more clear understanding of the components of the backwash system inside the drum. The two crosses are to be connected with string with the foam in between. However, as previously shown in Figure 4, the upper PVC cross was broken during testing and has since been replaced with stainless steel piping. The list of methods used to operate the large filter can be found in the Summer 2014 Research Report.

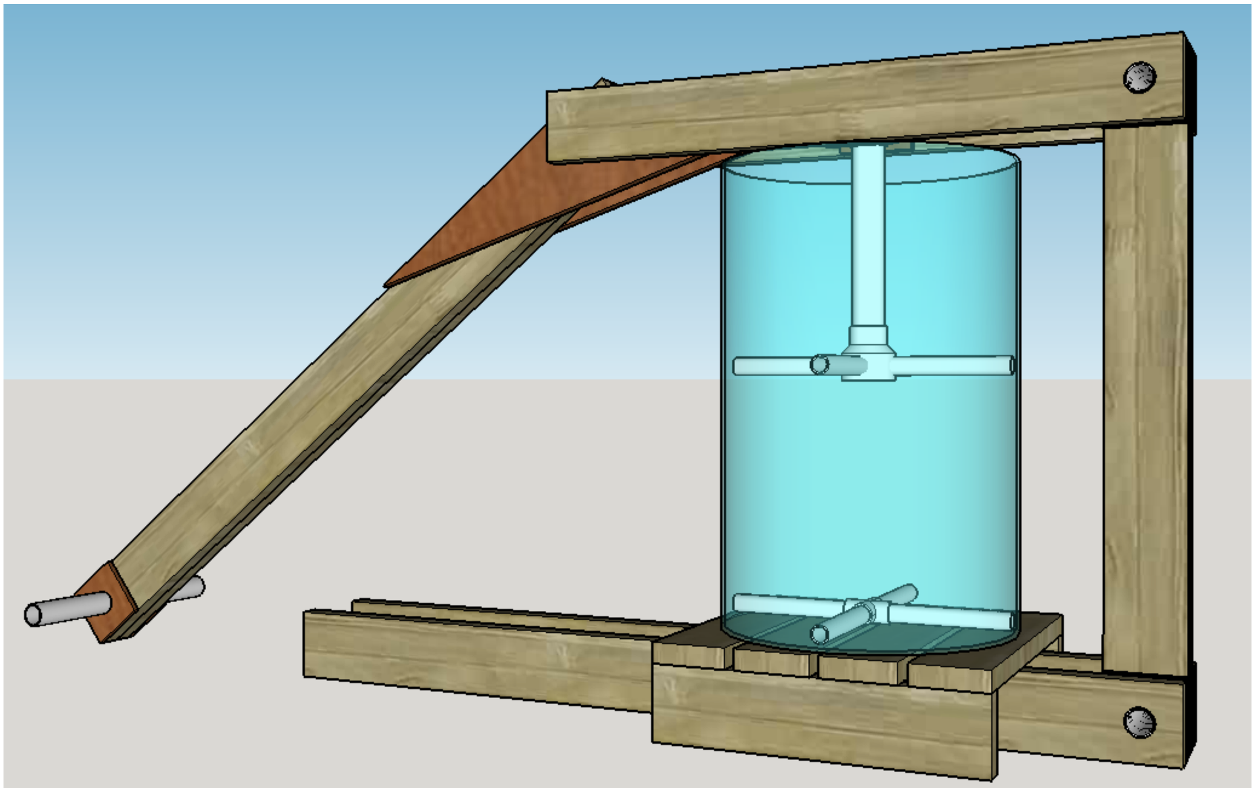

Figure 5*: Large filter design*

Figure 6 describes the flow of the influents and effluents of the system, where they enter, and where they are measured. This includes the recycle system, displaying the two peristaltic pumps that control the coagulant flow rate and the clay stock flow rate. This again illustrates the side valve system which is currently disconnected from the drum. Once the system is reconnected, we can begin fabrication of the proposed CDC system (described in the Designs section below). Meanwhile, the equipment setup has since been altered to prevent spillage from the clay tank onto the turbidimeters, as well as to accommodate for the use of the small filter.

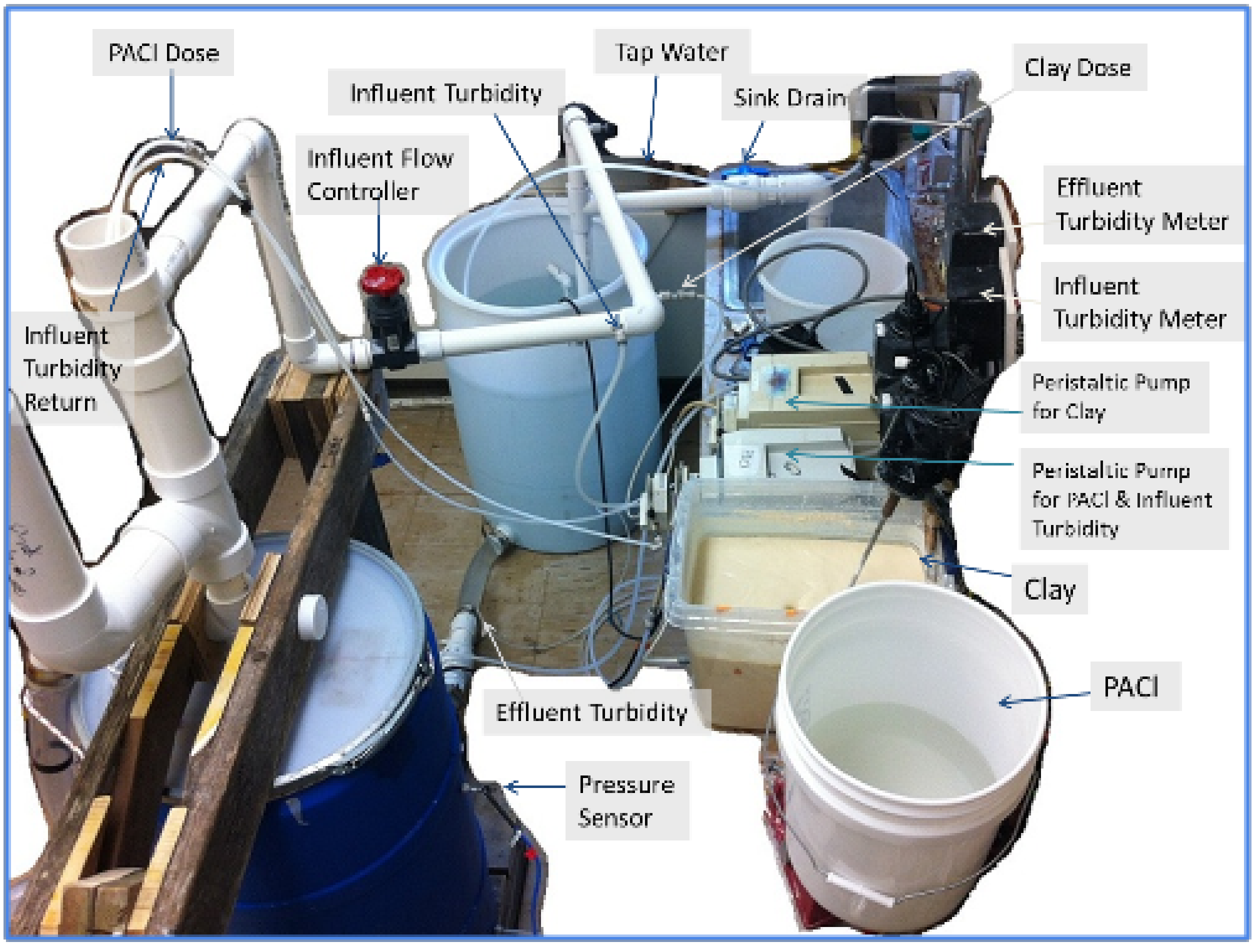

Figure 6: *Large filter experimental setup*

Small Filter Test Unit

The small filter has been designed and is under construction. The basis of this design is a simple approach to backwash. Manually pushing the foam through the water for backwash yields many variables, especially with regard to an inconsistent force used to plunge the foam. In the case of a large 55 gallon drum, this manual force is necessary to achieve the velocity needed for cleaning. However, for the 4” small pipe filter, such a force is not needed. The backwash method for this design, pumping the water through the foam layers rather than plunging the foam itself, will allow for the isolation of important variables. The first variable to be isolated and analyzed will be the pore velocity through the pores of the foam and its effect on performance. Figure 7 below is a schematic of the design to be implemented, and Figure 8 is a photograph of the current implementation. Figure 9 lays out the dimensions and the exact heights at which the entrances and exits are placed.

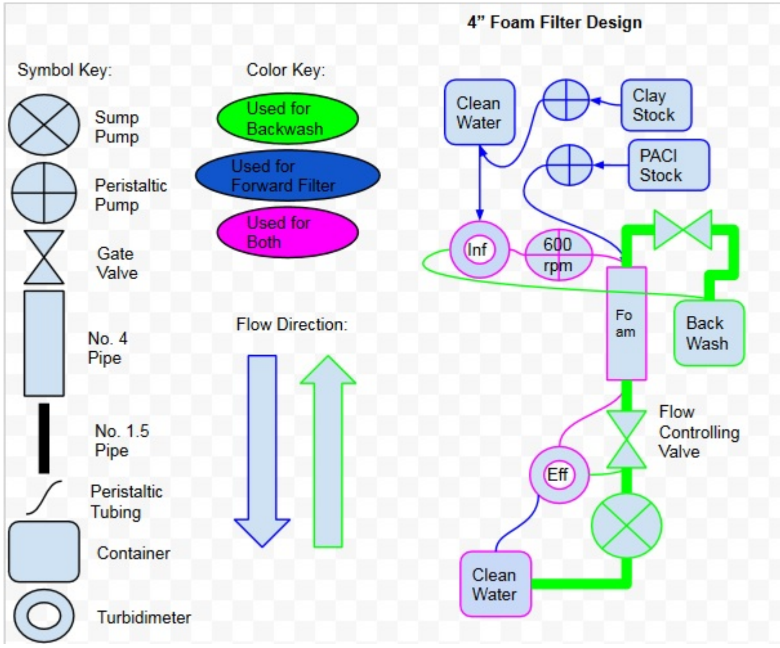

***Figure 7**: Schematic of Small 4” Pipe Filter*

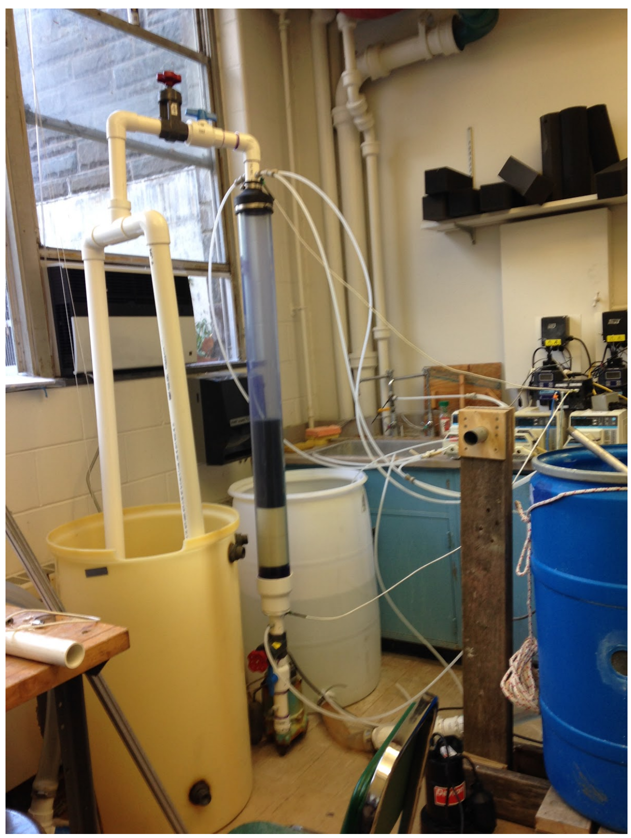

***Figure 8:** Current implementation of the Small 4” Pipe Filter*

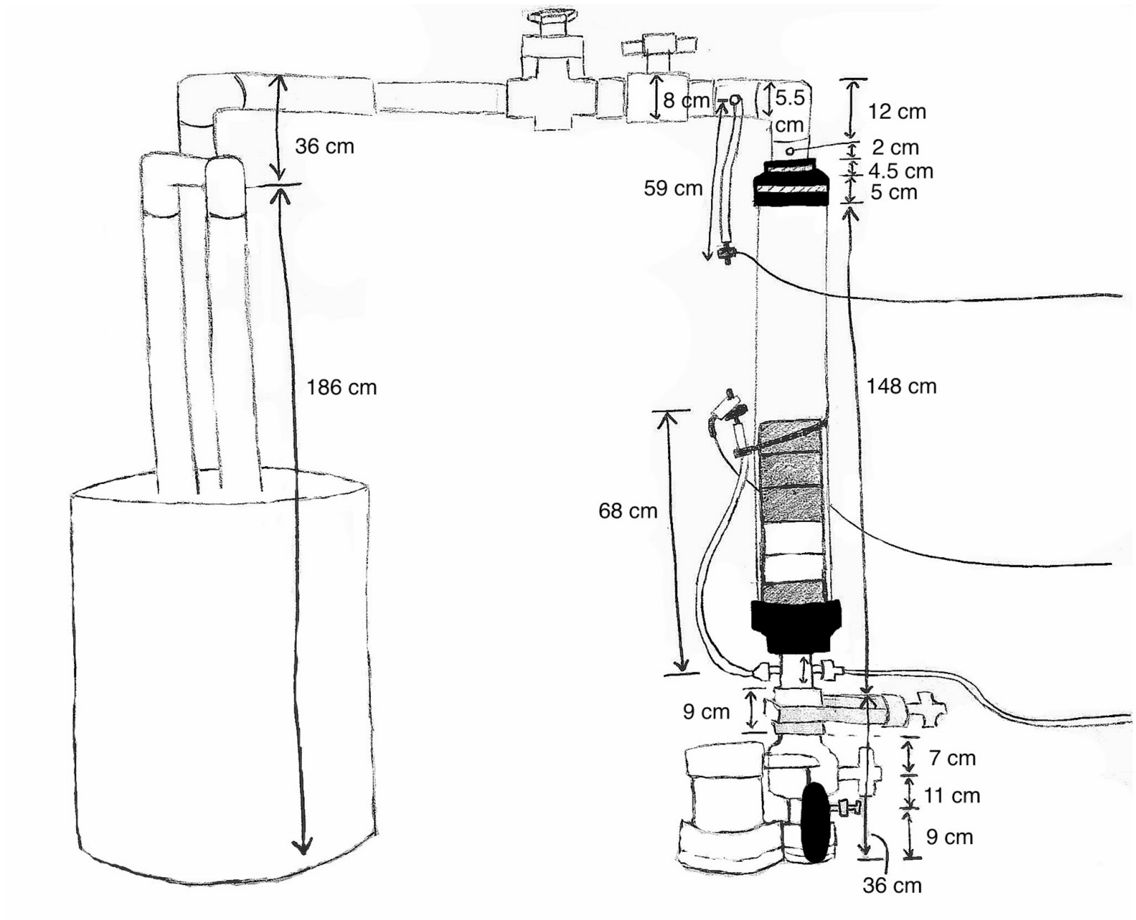

Figure 9*: Drawing of the Small 4" Pipe Filter with Heights*

Design Characteristics

The filter was designed keeping the following characteristics in mind:

- Easy to operate: setting up an experiment takes little time and the filter is not prone to flooding. The small filter will be connected to a sump pump located in a drum, sharing the existing experimental setup (including turbidimeters, peristaltic pumps, and water source).
- Accurate results: the filter was designed in such a way that it will produce useful results for the large filter. The two filters are hydrologically very similar.
- Transparent: the filter body that houses the foam is clear to enable easy viewing of the foam both in backwash and normal operation. This can be seen in Figures 8 and 9.
- Highly measured and controlled: all aspects of the filter's operation will be carefully measured, including the pressures between each foam layer, the influent and effluent turbidity, the backwash waste turbidity, the backwash force required, the filter flow rate, the coagulant dose and more. Creating an air-tight system allows us to more easily manipulate the system and track the changes during testing. As shown in Figure

9, a pressure sensor will be attached to a tube running the length of the filter and used to determine the headloss through the foam.

Flow through the filter:

Forward-Filter Mode

In forward-filter mode, water is taken from the sink (the blue Clean Water box in the schematic above), where it is dosed with clay to simulate turbid raw water. A portion of that water is sent through the influent turbidimeter, then rejoined with the rest of the raw water to be filtered. The water is pumped up into the top of the filter using a 600 rpm pump (used to facilitate changes in flow rate), and is dosed with coagulant before entering the filter body. There is the option to implement pressure sensors before and after the filter body in order to empirically measure the head loss through the filter. After passing through the air-tight filter, a portion of the filtered effluent is sent through the effluent turbidimeter while the remaining effluent continues into the clean water tank (the purple Clean Water box in the figure). This water is later used during the backwash cycle.

Backwash Mode

Water is pumped using a sump pump in the Clean Water tank (in purple) into the bottom of the filter and up through the foam layers. The flow rate at which the water is pumped through the layers is controlled by a gate valve before the entrance to the filter. A portion of the dirty water that results from the backwash is sent through the turbidimeter, while the remaining portion will be collected in the Backwash tank (green in the schematic) and wasted.

Experiments

Foam Leaching Test

In order to answer the question about foam leaching, samples were provided for Professor Helbling for a mass spectrometer reading in Hollister Hall. Although this technology cannot immediately declare what chemicals exist in a sample or it’s quantity, it can provide an answer to the general question of whether chemicals are being released from the foam or not. The following is the procedure used for the initial foam leaching test:

1. Thoroughly clean 3 glass beakers with soap and water.
2. Fill each beaker with 150 mL of nanopure water.
3. Prepare 1.5 g of foam for two of the three beakers (the third beaker will be used as a control).
4. Cover the beakers with aluminum foil.

5. After a minimum of 24 hours, transfer 10 mL of each sample into a separate, clean glass vial (labeled correctly) for sampling.

The foam used in this experiment was 60-PPI black polyester foam. There was no method in selecting the foam as it was assumed that the amount of leaching did not vary depending on the type of foam. However, for the two foam samples we used foam purchased within the past year and foam purchased a couple years ago as there was a possibility that the age of the foam affected the amount of leaching.

The test concluded that there is a definite presence of leached chemicals in both foam beakers, though there was no significance between the new and old samples. As it is already concluded that there is a significant amount of leaching in the short time of the experiment, there is no need to conduct more tests over a longer period of time. At this point in time, only Professor Helbling has the ability to potentially identify exactly what is leaching and in what quantities. Although he has expressed great interest in this research, he will not be able to commit the time required to resolve these questions in the near future; therefore, it cannot be concluded at this point whether the leaching is harmful.

It can be assumed, however, that a significant amount of the leached chemicals are the esters which the foam consists of. Reactions of esters with water can result in the formation of acids, depending on the composition of the esters, which can be potentially harmful. Because the foam filter uses foam of high and low pore per inch (PPI), where high and low PPI foam (10, 20, 60, 80, 90 PPI) are ester-based and medium PPI foam (20, 30, 40, 50) are ether-based, it will be beneficial to test a sample with the ether-based foam as well. Though the greatest foreseeable danger would be the reaction of the ethers with halides, such as chlorine which is often used for the disinfection of drinking water, this information could be crucial to the development of the foam filter.

Small 4” Pipe Filter

Rules and states for the pumps, sensors, and turbidimeters have been set up in Process Controller, the software used to control the pumps, and record the turbidimeter and pressure sensor data. The steps for experimental set-up are saved in the Research folder in the Foam Filter Google Drive.

Air Tightness of the 4” Filter

After constructing the filter, a short experiment was conducted to determine if the system provided an air-tight seal. Air tightness is important because the planned Pore Velocity versus Cleaning Efficiency experiment will require that the filter column model the full-scale model as closely as possible. In the full-scale model, the foam is plunged through the water. In this scenario, there are no air bubbles present between the pores, as all the air is pushed out by the flow rate through the foam layers. Air bubbles in the foam could affect the capacity of the backwash cycle to effectively shear off particles from the pore walls. To assure the absence of air bubbles in the 4” filter system and precisely model the full-scale backwash, all air flows into the system must be prevented.

Set-up

The ball valves on either side of the filter column were closed to assure that air would not enter from above or below the filter. The tube running through the effluent turbidimeter, which would normally drain into the “Clean water clearwell,” was connected to a 3 liter bucket filled with water. The hypothesis was that if all the air were sucked out of the filter, the pump would eventually start sucking water from this effluent source. Upon the initiation of this phenomena and the subsequent filling of the filter with water, the water level in the 3 liter bucket would begin to drop.

Methods & Results

Trial 1

The 600 rpm pump was run in reverse, such that instead of providing an influent water source to the filter body, it would suck air out of the system. The pump would run until the hypothesis was proven true or false. The pump was run for about five minutes, and the air continued to flow out of the influent tube throughout the entire run. The water level in the 3 liter bucket never faltered from its original height. This result shows that the filter was not yet air-tight. It was assumed that this air leak could be largely due to a loose Fernco fitting on the top of the filter.

Trial 2

After tightening the hose clamps around the Fernco fitting, another trial was run, plugging all entrances and exits to the filter (the coagulant dosing tube, clay influent, tubing to the influent turbidimeter, etc) except for the influent water source and air exit tube to try to isolate the leak. After the pump had run for about three minutes, the water level began to rise in the filter and consequentially, drop in the bucket. The bucket would continue to be refilled until the water was sucked all the way through the system and into the sink. For further assurance of air-tightness, the water level was allowed to drop until a visible point on the filter body and marked with tape. 46 hours later, the water level was measured again, with a visible water level drop of 10.8 cm. This drop corresponds to a exit flow of $5.29 \times 10^{-3} \frac{mL}{s}$ from the filter body. As leak is very minimal, it can be concluded that the current small filter system is sufficiently air-tight for the experiments.

Pore Velocity versus Cleaning Efficiency

Experimental Set-Up Checklist

After confirming that the filter body was air-tight, the final step to be completed before running experiments was to check the function of each of the components of the experimental set-up.

Pumps

First, the flow rates of the pumps were checked to determine empirically the relationship between RPM’s and the flow rate in mL/s. The use of the 600 rpm pump was to provide a controlled influent velocity of 6 mm/s (corresponding to a flow rate of 50 mL/s in the 4" filter) to accurately model the conditions of the full-scale filter. When the maximum flow rate of the 600 rpm pump was measured by monitoring the flow into a graduated cylinder, however, it only measured 26 mL/s. This is nearly half of the needed flow rate. It was decided that instead of the 600 rpm pump, the experimental set-up should employ the centrifugal pump, which was able to supply a flow of 66.67 mL/s and thus, meet the desired flow rate.

The coagulant dosing pump was tested, producing a flow rate of 1.56 mL/s at 100 rpm, and the clay pump will need to be tested before the first experiment is run.

PID

It was originally assumed that PID would need to be employed for the clay dosing pump to maintain a constant turbidity influent. However, the pump was actually able to maintain an influent turbidity flow more constant than that achieved with PID. It was decided then, that this experiment will be performed with the clay dosing pump set at a target RPM to maintain an 800 NTU influent water reading in the turbidimeter.

Coagulant Stock Concentration

The turbidity of the coagulant stock concentration was measured by diluting the stock by 100 times and running it directly through the turbidimeter. The turbidimeter read a constant value of about 355 NTU, making the stock concentration equal to 35,500 NTU. This measurement is important for measuring the NTU-liters entering the filter, since the centrifugal pump used for the influent raw water in forward filter mode will not maintain a constant flow rate as headloss builds up in the filter. As such, summing up the influent turbidity measurements over time with respect to an inconsistent flow rate could provide erroneous data for the NTU-liters entering the filter. Instead, this stock concentration will be multiplied by the volume of water that is filtered. (The accumulated water height will be measured by a pressure installed at the bottom of a 55 gallon drum.)

Future Set-Up

The clay dosing pump flow rate will need to be tested to learn the empirical relationship between the pump RPM and the flow rate in mL/s. In addition, the pressure sensors will need to be zeroed and tested for accuracy.

Experiment Description

The first experiment to be run on the small filter will attempt to find an empirical relationship between the backwash pore velocity and the filter cleaning efficiency (percent of total clay mass removed). The experiment design is in its initial stages, but the ideal end result would be a graph of pore velocity versus percent clay mass sheared off by the filter.

The initial condition for the experiment would be a clogged filter. The filter mode would be changed into backwash mode, and the gate valve opened just slightly in order to allow a small flow for beginning backwash. By initiating the backwash, it is expected that a plume of turbid water will be created from the clay particles sheared free from the foam layers. The turbidity of the backwash effluent will be constantly measured. When the current flow rate no longer appears to be shearing any clay particles free of the foam, the gate valve will be opened larger to allow for a greater flow rate. The hypothesis is that each pore velocity will be capable of removing a certain mass percentage of the clay. This cycle will continue until the backwashing process does not show any signs further signs of clay particle removal. In other words, the flow rate will be increased until the filter visibly appears to be 100% clean.

The constant turbidity measurements will allow for a relationship to be developed between pore velocity and approximate percentage of clay particle mass sheared free from the foam. It will provide insight into the best pore velocities for backwash cleaning efficiency.

Designs

Honduras Foam Filter Pilot Project Lay-Out

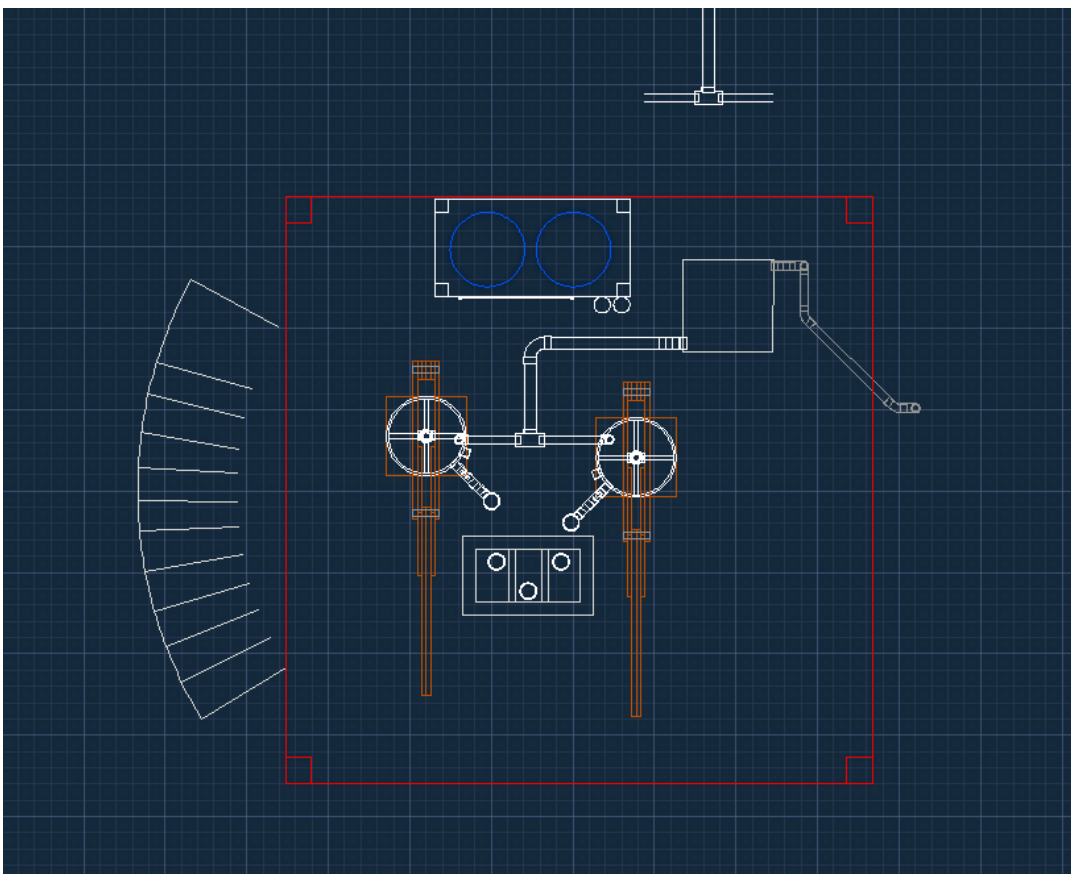

Figure 10: *First Comprehensive Model*

The design in Figure 9, created by Walker, is unlikely to be used. The filters are drawn on top of the distribution tank, and the two white circles shown are foam filters.

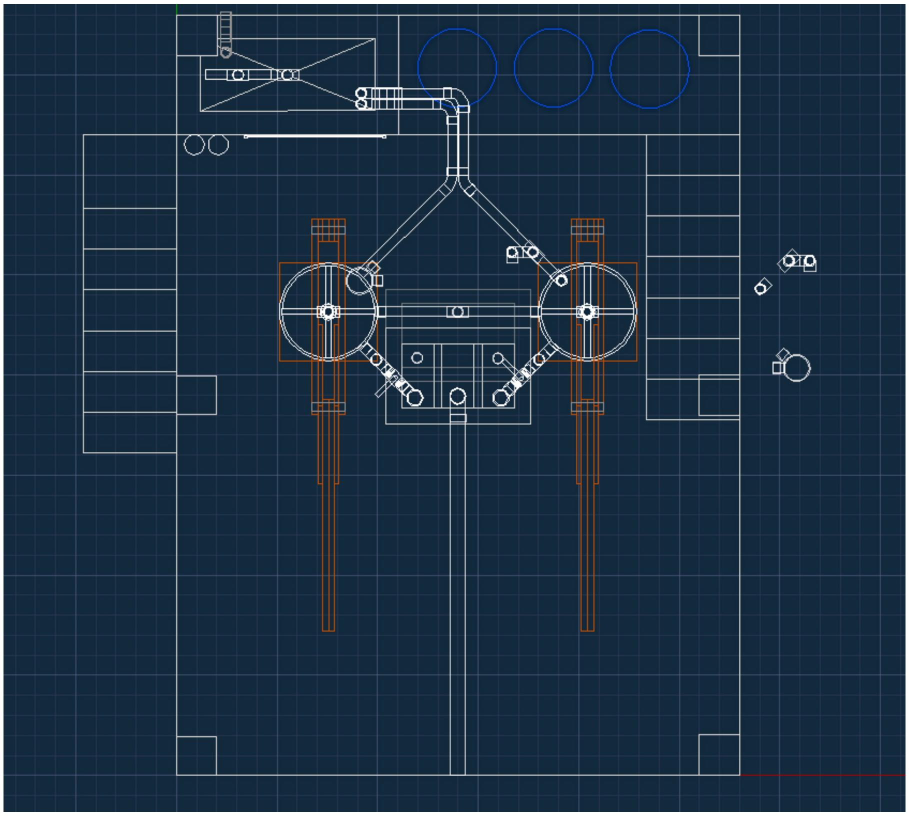

Figure 11: *Preferred Comprehensive Model*

This model in Figure 10 is the preferred of Walker's two AutoCad designs. Again, the two white circles are foam filters. The LFOM entrance tank is off to the side. Water flows from the top left corner through the 2-inch conduction line to the distribution tank, which is structured similarly to the hopper in AguaClara entrance tanks. The white pipe near the bottom is for overflow that will be diverted into the watershed area. The two parallel pipes will take water over to the LFOMs. The T's in these lines serve as a secondary overflow.

Backwash water and clean water enter the same tank, and the operator will decipher dirty water from clean, which will cut down the number of pipes. The distribution line would need to be bigger to reduce head loss.

Some possible edits to Walker's design would be to eliminate the grit chamber by using a colander-type design to separate the entrance flow and remove larger particles from the entrance flow. It would also need to be determined how long the filter can run for with a reasonable amount of sand input and also how much sand the filter can handle by taking samples from the filter at various times. Another thing to keep in mind is minimizing construction costs.

Chemical Dose Controller System

Purpose

To develop a Chemical Dose Controller that accurately maintains a constant dose throughout the plant's operation. The current system in the full scale plant has several characteristics that make it more difficult to apply to the foam filter. A quick summary of the challenges can be found below, but for more information on the current CDC system, please see AguaClara's latest CDC report.

Challenges of Implementing the Current CDC System to the Foam Filter:

- Requires an entrance tank to hold the float
- Hanging drop-tubes require a great deal of space to hang and move while unrestricted
- Heavy drop-tubes necessitates a large-cross-section float to mitigate error
- The current lever-arm and slider are expensive to manufacture

Proposed CDC System

- **Altered constant head tank (CHT)**
    - The proposed CHT is either constructed from Nalgene bottles (somewhat resistant to chlorine, or 2" PVC pipe, making it more resistant to chlorine and easier to design to the proper depth and geometry.
- **Place float into LFOM to eliminate need for entrance tank**
    - The water now flows out of the LFOM as viewed in the figure below. This means that it is now the level of the water in the LFOM 6" pipe that changes linearly with the flow rate, and therefore the float must measure the level of that water surface.
- **Run Major Headloss Elements (MHE) vertically to reduce overall size**
    - It was determined that the MHE is still necessary to maintain a linear flow rate response from the doser, however; the MHE orientation was changed to reduce the overall footprint of the filter. Changing the dosing tubes to run vertically actually assists the purging of air bubbles up and out of the tubes. Additionally, the drop tubes are attached to the lever arm with a slider as currently done so that PACl and Cl dose may be adjusted for a variety of influent water conditions.
- **Attach the float to the lever arm with a rigid dowel rather than a chain.**
    - For the smaller size and greater vulnerability of the foam filter, it was determined that the float will be attached to the lever arm with a stainless steel rod rather than a chain. This will reduce the chance of accidental overdoses due to the chain getting caught during operation.

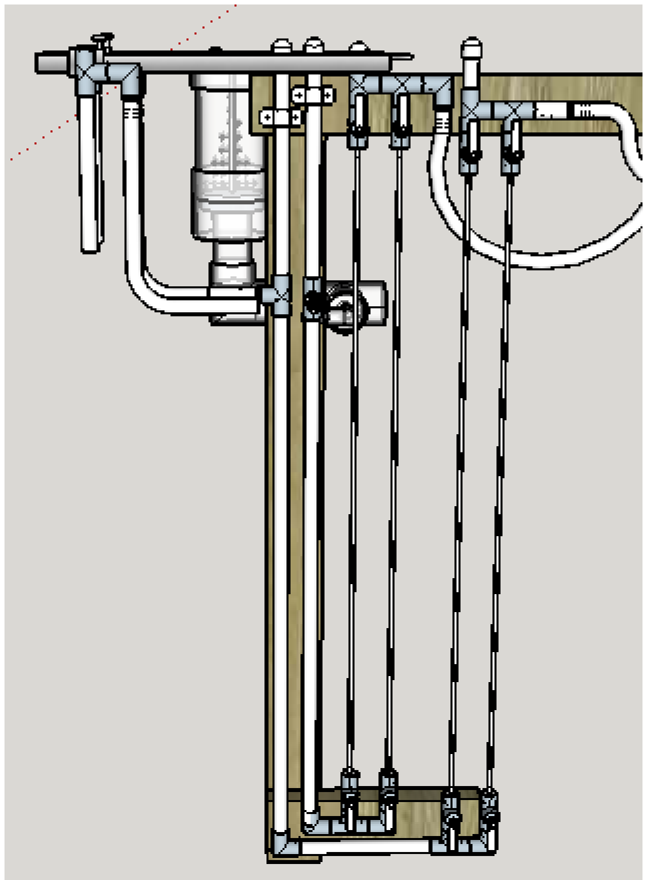

Figure 12: This is a side view of the newly designed CDC system. The MHE is vertically oriented, the LFOM is also the influent pipe, and the float is located inside the LFOM. The tubing running from the MHE to the drop tubes is flexible over all the positions the slide on the drop tube can go to. The two cut-off tubes come from the CHTs that are outside of the frame.

Grit Chamber

A grit chamber to remove large, fast settling particles such as sand was originally believed to be necessary to protect the foam. However, after further discussion with Monroe, it was found that instead of just employing a separate grit chamber, the top layer of the foam would act as one, thus simplifying the design for the time-being. The top layer may have to get cleaned periodically manually, or the regular backwashing process may be adequate to keep it cleaned. If it does need manual cleaning, than a disk of foam with a hole for the mast and a slit to that hole to make it easily removable should suffice.

Lever Design

Motivation for Redesign

The new LFOM design required the lid to be removed so that water may pour directly onto the foam, and so that the operator may easily inspect the influent water quality and the headloss through the filter. But losing the lid meant there was nothing to hold the vertical component of the filter from flopping forward to back and keep the mast in line with the bucket. Therefore the following design change was suggested.

Proposal: Rigid Vertical Lever Arm

Making the vertical lever arm rigidly connected to the base will eliminate the need for the guidance such as the barrel lid provided. However, this adjustment means the top of the mast will trace an arc rather than a line during compression, necessitating about 5 degrees of rotation, creating preferential flow paths around the foam (where it is cockeyed and thus not fitting into the barrel exactly) during cleaning. However, this effect was deemed negligible. If this effect does become problematic, there are multiple ways to reduce this movement. For instance, the following design (Figure 14) extends the mast to reduce the effect:

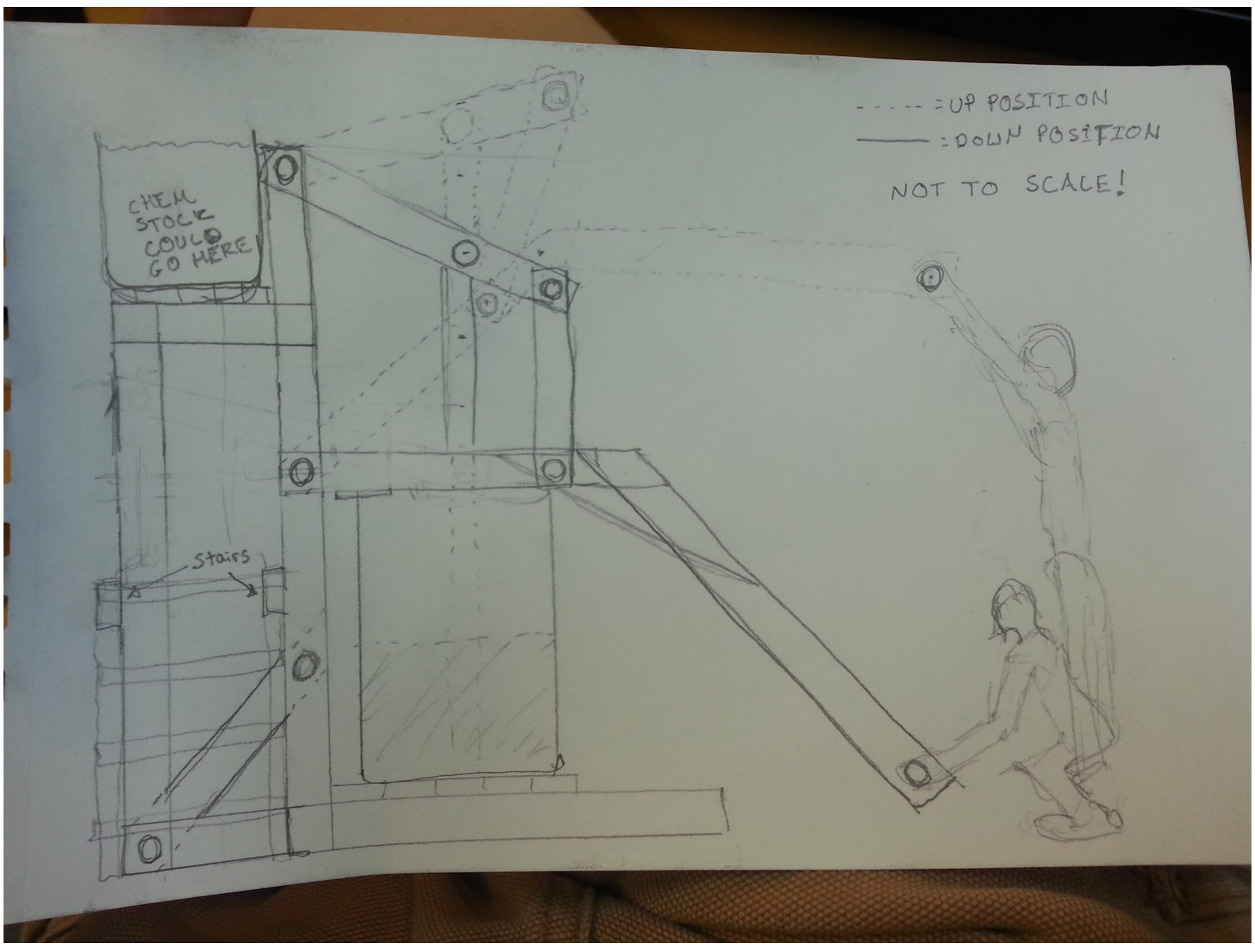

Figure 13: *New lever arm design*

Other ways to reduce this effect include:

- Making the mast taller by moving the lever pivot up
- Leaving the pivoted lever arm and adding a guide to the side to restrict the mast to only moving up/down

Honduras

Efficiency Data

AguaClara engineers in Honduras have encountered some difficulties procuring funding for the pilot project due to skepticism surrounding the efficacy of the filter and the newly designed backwash method. Data from the Foam Filtration Summer 2014 report was analyzed and shared with the engineers in Honduras as support for the efficacy of the filter. The data sent include the results of the compression and backwash experiments on the 4" pipe filter as well as the backwash experiment performed on the full-scale filter. The results are shown in the tables below:

4" Pipe Filter Compression Test

Water height = 4/3(Foam Height)

***Table 1:** 4" Pipe Filter Compression Test Data*

Trial	Vol. poured (Liters)	Influent with PACl (NTU)	Influent (NTU)	Effluent (NTU)	Effluent NTU-Liters	Influent NTU-Liters	NTU-Liters filtered:	NTU backwash water*	NTU-Liters backwash water*	Cleaning Efficiency
1	24	970	820	12	288	23280	22992	3200	10400	0.45233125
								4500	14625	0.63609081
2	24	980 --		14	336	23520	23184	3600	11700	0.50465839
								4120	13390	0.57755349
3	24	1040	960	4	96	24960	24864	4360	14170	0.56990026
								3800	12350	0.49670206

4" Pipe Filter Backwash Test

Water height = ⅔(Foam Height)

***Table 2:** 4" Pipe Filter Backwash Test Data*

Trial	Vol. poured (Liters)	Influent with PACl (NTU)	Influent (NTU)	Effluent (NTU)	Effluent NTU-Liters	Influent NTU-Liters	NTU-Liters filtered:	NTU backwash water*	NTU-Liters backwash	Cleaning Efficiency
1	24	887	900	4.5	108	21288	21180	6800	14796.8	0.6986213
								6800	14796.8	0.6986213
2**	24	1020	--	12	288	24480	24192	9100	19801.6	0.8185185
								8180	17799.68	0.7357672

***During Trial 2 the foam reached breakthrough because the effluent turbidity spiked with no head accumulation.*

Full Scale Backwash Test

Water height = ⅔(Foam Height)

***Table 3**: Full Scale Backwash Test Data*

Trial	Vol. poured (Liters)	Influent with PACl (NTU)	Influent (NTU)	Effluent (NTU)	Effluent NTU-Liters	Influent NTU-Liters	NTU-Liters filtered:	NTU backwash water*	NTU-Liters backwash water*	Cleaning Efficiency
1	2700	100	100	1.8	4860	270000	265140	2000	190000	0.71660255
								1400	133000	0.50162178
2	4380	100	100	1.8	7884	438000	430116	3500	315000	0.73236057

**The backwash water was diluted in a 19:1 mixture of clean water to backwash water to achieve an accurate turbidity reading for all three of the experiments.*

**Two samples were taken from the backwash water and measured for all three experiments.*

The cleaning efficiency was determined using the mass balance derived in the Compression vs. Backwash Cleaning experiment of the Previous Work section,

NTUliters.in = (NTU.filtered + NTU.effluent)Vol.filtered

After the NTU.backwash and Vol.backwashed are measured:

(NTUliters.backwashed)/(NTUliters.filtered)=Cleaning efficiency

In addition, data was shared on filter efficiency (influent vs. effluent data). Figure 15 below is a graph showing the resulting effluent over time with 100 NTU influent water.

Effluent Turbidity Data for 100 NTU Influent

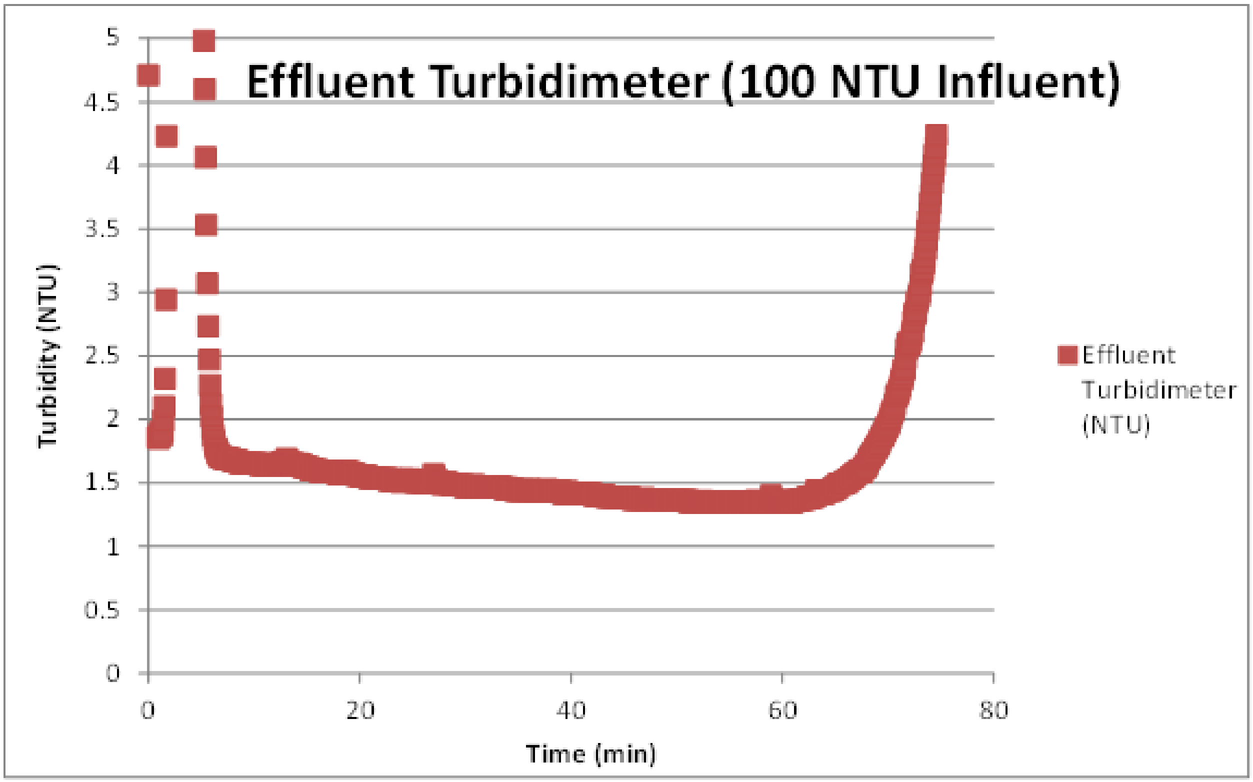

Figure 14: *Effluent data over 75 minutes in full-scale filter. This data shows that after about 10 minutes of filtering 100 NTU influent water, the filter consistently yields about 1.5 NTU water during about 65 minutes. As shown in the graph, after 75 minutes of run-time, the filter fails and yields an effluent turbidity spike.*

Future Work

EPA P3 Phase II Project Proposal

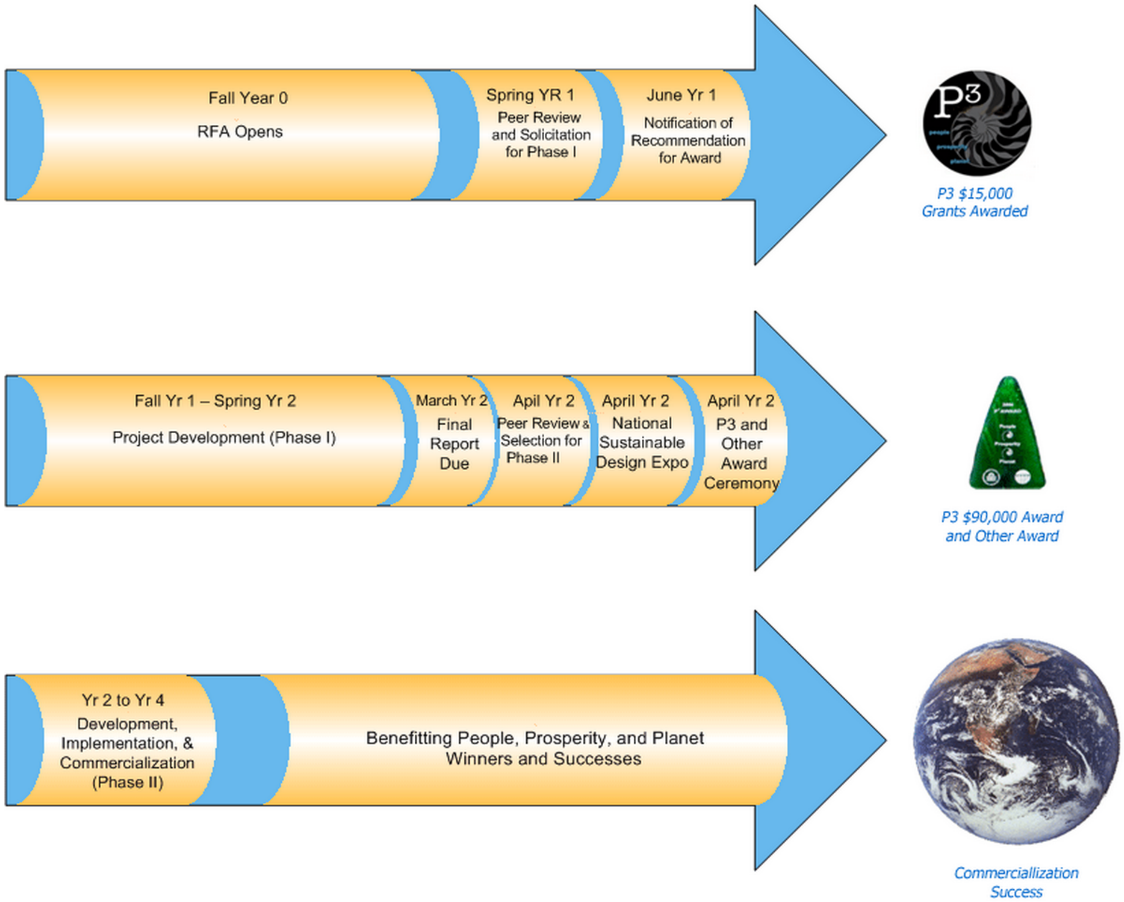

Figure 15: *EPA P3 Proposal Timeline*

The EPA P3 Phase II Grant is for $75,000 to take a project up to the next level, with a goal of implementation in the field. The EPA P3 Grant is valid for this foam filter project, as it is supported by the Safe Drinking Water and Clean Water Acts. Each project must propose a specific outcome, where our outcome would be producing a foam filter to be used in the field.

The EPA P3 Phase I Grant was received by the team last June, with Peer Review and Solicitation last spring. Currently, we are in the Project Development portion of the process (outlined in Figure 16), and the Final Report is due in March 2015. The Project Report should describe the project and the team's proposal for a Phase II Grant award. This report is going to be Kristin's primary responsibility next semester as she will have less time to be involved in research. Mandatory documents that should accompany this report are the Project Narrative Attachment Form, the EPA Key Contacts Form, and the Application for Federal Assistance.

The Project Narrative Attachment Form should include:

- Table of Contents (including page numbers)

- Abstract – clearly states goals, ensures that the project is understandable to broad audiences, and asserts why the research is important
- Research Plan and References
- Budget Justification that corresponds to the Budget Form but includes more detail
- Resumes – faculty advisor, co-advisors, members of the student team (2pg limit/resume)
- Current and Pending Support - http://epa.gov/ncer/rfa/forms; for faculty advisors, co-advisors and important co-workers (but not consultants or contractors)
- Letters of Intent & Letters of Support – one brief paragraph, letters submitted separately will not be accepted

The EPA Key Contacts Form (http://epa.gov/ncer/rfa/forms) should list four separate people for the following:

- Authorized Representative
- Payee
- Administrative Contact
- Project Manager

Kristin, Ethan, and Marlana will continue to be on the team next semester, with Kristin specifically organizing the EPA report papers.

Below are the remaining tasks from the Fall 2014 Task List to be completed next semester.

Next semester tasks

1. Make filter cohesive and easier to operate in the field
    a. Construct the full-scale filter
        i. The full-scale filter will need to be re-constructed
            1. Re-attach backwash drain using a spin-weld
    b. Design Lighter Lever Arm
        i. Designing a lighter lever arm is essential to the overall goal of fabricating a cohesive and operation-ready system which can be sent to Honduras or any other country.
        ii. A structures analysis of the current design and new design recommendations will be necessary to make the operation of filter easier.
        iii. Continue communication with John and Walker in Honduras to formulate a proposal for the design, taking into account the materials available in Honduras.
    c. Integrate CDC and LFOM
        i. The LFOM, float, and CDC lever-arm must be integrated seamlessly and effectively, and the system must accurately respond to flow

changes. Design should be robust, affordable, easily constructible and easy to understand.

ii. Fabricate LFOM and CDC

1. A plan for integrating the CDC and LFOM using a dual-lever system has been created, drawn in Sketchup, and communicated with the engineers in Honduras.
2. The next step will be to fabricate this system and attach it to the large filter in the lab in order to begin testing.

2. Foam Leaching
    a. One of the primary tasks to be completed is to be certain that there are no harmful chemicals being released into the water due to the use of foam for water treatment. The manufacturer has not expressed great concern of leaching, but to be certain, experiments will be run with the mass spectrometer with help from Professor Damien Helbling.
    b. The testing process is very extensive and time-consuming. Hopefully Professor Helbling will help the team come to a more conclusive result in the Spring 2015 semester.
3. EPA Phase 2 Project Proposal
    a. See EPA Phase II Project Proposal section
4. Lab Research
    a. Run the first experiment on the small-scale filter
        i. The small scale filter is the main priority. It will be used to determine an empirical relationship between pore velocity and cleaning efficiency through backwashing the foam.
    b. Perform Stress Tests and Durability Testing on Foam
        i. Research will need to be conducted on the degradation of foam over time.
        ii. A great deal of experiments will be performed with the smaller, 4 inch. foam filter, and this task is dependent on the fabrication of that filter.
        iii. Some questions to answer include:
            1. Does the foam break down? As it breaks down, does chemical leaching from the foam become more evident? Does the foam develop headloss more quickly?
            2. How fast does it clog, and under what conditions? Does the clean out cycle reach a reasonable steady state?
    c. Research Backwash Parameters and Efficiency
        i. Run several iterations of cleaning cycles changing a TBD variable (coagulant dosage, total foam width, backwash with turbid water, backwash with tap water, etc.) and analyze results. These tests will be performed on the small-scale filter.
        iv. Brainstorm ways to reduce water wastage in the cleaning and filter to waste states.

v. Implement and test these techniques to be sure they are effective.

Long-term Goals

The largest challenges that remain to be dealt with are:

- Determining the toxicity of the foam leaching
- Developing a set of governing equations to guide the foam filter design
    - For forward filter:
        - Determining effect of stratification and various foam pore sizes on cleaning efficiency
        - Determining constraints for filter approach velocities
        - Develop an equation that may predict filter clogging time/ pressure in filter after time T given water influent NTU, PACl dose, filter geometry, flow rate, etc.
    - For backwash:
        - Find relationship between force and pore water velocity for various foam pore sizes
        - Develop relationship between pore water velocity and percent of foam cleaned
        - Find out how many backwash cycles various foams can take before tearing/breaking/failing

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