Foam Filtration Summer 2014

Abby Brown, Ethan Keller, Skyler Erickson, Ji Young Kim

August 1st, 2014

Abstract

The Summer 2014 Foam Filtration team will continue to improve the water treatment system, aiming to send a complete filter design to Honduras in July 2014. The goal of the summer is to verify the safety of the foam filter itself and to improve the design of the filtration system for better performance, easy fabrication and transportation. The foam filter will be additionally tested in Honduras.

Detailed Task List

1 Foam Leaching - Ji Young Kim

Review literature concerning harmful plastics leaching from the foam into the effluent.

2 Chemical Dose Controller -Skyler Erickson

2.1 Build and add the Linear Flow Orifice Meter (LFOM)

2.1.1 Ask Casey how to build the LFOM.

2.1.2 Integrate automated chemical dose controlled by the flow rate.

1. Make calculations to design LFOM 2. Find or purchase materials to build LFOM
3. Construct LFOM

2.2 Determine flow rates for the chemical dose controller based on turbidity and influent flow rate. By: 7/10/14

2.2.1 Determine flow rate to use to calculate head loss.

Consult into the MathCAD file from Fall 2013

2.2.2 Find head loss through the CDC system.

Expecting to find minimum 10 cm based on the calculations from previous semester.

2.2.3 Compare the MathCAD formula and real measurement.

2.3 Integrate the LFOM into the filter structure with a concise design.

New lever arm (single-armed) length of 20 in will be installed Mixed influent should be dripped into the LFOM directly

Float connected to CDC should be heavy enough to keep tension in the line. Look for past report for CDC on depth of submergence.

2.4 Evaluate required PACl dosing for successful filter operation based on varied influent turbidity.

3 Compression System - Ethan Keller

3.1 Verify Clean Out Cycle (COC) efficiency.

3.1.1 Install and test siphon

3.2 Propose alternative compression methods.

3.2.1 Considering light, compact, easy to use, alternative systems.

3.3 Designing final compression system for the straight drum.

3.3.1 Consult Paul and Tim about design and potential alternative compression methods (hydraulic compression methods).

3.3.2 Decide on materials and compile final materials list

3.3.3 Evaluate theoretical load strength of the designed system...(this would be good to do before you start thinking about alternatives so you'll have an idea of what is required to compress the foam) confirm this is adequate for sufficient compression

4 Experiment - Abby Brown

4.1 Understand the relationship between turbidity and head loss.

4.1.1 Measure head loss at 500 NTU raw water & head loss at breakthrough effluent turbidity

Consult to MathCAD file from spring 2014 (under spring 2014 MathCAD files folder) & ppt's from CEE 4540 website (under summer 2014 reference folder)

4.2 Optimize the system in terms of head loss

4.2.1 Reduce the head-loss in the system or extend the length of the filter. (addressed in the Challenges document)

4.3 Test for foam thickness and no-compression clean-out system using 4" pipe filter

Literature Review

Previous Semesters

When the Foam Filtration team brought the first filter design to Honduras during January 2014, assembling the filter presented a challenge. The foam from Cornell was too large to fit into the drum bought in Honduras. Additionally, the compression/decompression process was labor intensive due to the over-designed winch system. Another issue that arose was that the expected amount of coagulant was insufficient to clean the water. There were also difficulties in removing the water on top of the compression disk during compression. The team used a unfixed siphon system to solve the issue. This solution proved to be problematic though because it was inefficient and difficult to start and maintain a siphon.

With feedback from the engineers in Honduras, SP14 Foam Filtration team devised a new filtration system with a faster compression system and 80/20 structure to support a fully operational flow controller/LFOM system. Several designs were proposed including a simple pulley design, compound pulley system, screw system, lever/compound lever and pulley system. Considering the two most important constraints – the speed and the transportability, the team chose a simple pulley system with an 80/20 mast for the compression system. A plunging plate was attached to the bottom of the mast that moved down via the pulley system and compressed the foam. On top of the plunging disk, the team made and tested the 80/20 support system. 80/20 was chosen for its rust-free quality and transportability.

The team conducted experiments to find out exact specifications for efficient running of the filter. The team estimated 226.8 kg (500 lb) to compress the foam stack to 1/3 of its volume. For the efficient cleaning of the filter, compression velocity/cleaning efficiency testing was simulated using a 4-inch diameter foam filter column. Comparing the percentage cleaned over a range of compression velocities, the team concluded that a velocity greater than or equal to 181 mm/s will completely clean out the foam after one plunge.

Chemical Leaching and Potential Risks

Chemical leaching from the foam is a viable concern if the foam is to be used to provide drinking water. Ether and ester based reticulated polyurethane foam is currently being used in the foam filter.

Polyurethane foam is a common material for a variety of filtration systems, but its safety has not been well investigated for the purpose of drinking water treatment. The chemical structure of urethane itself decomposes easily when in contact with urea. But in a real life situation, polyurethane decomposition by urea does not have a noticeable effect on the foam. Thermal decomposition of polyurethane is also well-known, but is not a concern because it requires a minimum of 110 ^{o}C which we do not expect to reach in our system.[?]

Another potential risk in chemical leaching is from the flame retardant added by manufacturers. Since polyurethane foam lets out toxic yellow smoke when it burns, many foam companies apply flame retardants. It reduces fire hazards, but the chemical poses a different threat to the consumers. Flame retardants made of brominated hydrocarbons such as Polybrominated Diphenyl Ethers (PBDE) and Polybrominated Biphenyls (PBB) may act as endocrine disruptors in humans and animals. Exposures in rats and mice caused neurotoxic bioaccumulation of PBDE and PBB causing retardation and behavioral dysfunction. [?] Thus, PBB was banned in United States from 1973 for the reason. In 2009, the U.S. Environmental Protection Agency (EPA) stated PBDE and PBB are emerging contaminants. According to the EPA's report "An Exposure Assessment of Polybrominated Diphenyl Ethers" [?], solubility of PBDE's are low in general in temperatures ranging 20^{o}C to 25^{o}C. However, we are concerned about the effect of PACl and Chlorine's effect on the foam when they react with a certain flame retardant.

We have contacted our manufacturer, Crest Foam Industries, a subsidiary of INOAC USA, Inc. The company informed us that its foams have been used for various waste water filtration, and never got any histories of chemical leaching from contact of water. The company recommended using foams made within last 6 months because older products contained tin which is known to be carcinogenic. The caller also advised us to look for tin and amine through spectroscopy to ensure the safety of using the foam. Also, the company also informed us that flame retardant is not a risk because it is only applied on the surface of the foam and can be removed by washing it before use. We also contacted Clark Foam, and got answer that the foam is not FDA approved. We also asked for any reports or specific reasons for absence of FDA approval, but the company just told us that the foam just has to be tested by third party not by the manufacturer.

At this point are waiting for third party confirmation and testing that our foam is safe to use in drinking water applications. We will continue to explore options to have this testing done at Cornell.

Introduction

The Foam filter will benefit villages with less than 1000 people who are less likely to be provided with large scale water treatment facilities nearby. The team is aiming to provide villages with a small, user-friendly, cost-effective, and easy-to-build filtration system. Since AguaClara has won an EPA P3 award in 2012 and

now again in 2014 we have been working to produce a feasible design that can be replicated in the field. This summer our main goal is to send the best model of the foam filter to Honduras with the field engineers. This would entail making a filter that provides realistic filtration run time lengths and an effective and easy to operate clean out system. To do this we must create a working chemical dosing system and LFOM that are compact and accessible. Additionally, our goal is to get the clean out cycle as efficient as it can possibly be by adding an upgraded siphon that allows us to remove dirty water off any height of foam and is not difficult to prime. As safe, clean water is our priority, this summer we are looking into the safety of using foam as our filtering medium as outlined in the literature review. This is to make sure that there are no chemicals leaching into the water from the foam.

Methods

Building New Linear Flow Orifice Meter (LFOM)

Using the calculations found in S:\RESEARCH\Foam Filtration\Summer 2014\References\LFOM for Foam.xcmd, we made a U shaped LFOM out of 3 inch PVC. One vertical side of the LFOM contains the float connected to the dosing system. The parallel side holds the orifice meter a two inch PVC pipe with holes in specific locations to allow linear flow. The two sides are connected on the bottom so that the heights in both vertical sides correspond. The water flows in the side with the orifice meter through a T fitting and enters the filter through the two inch pipe. Below are pictures of the LFOM the first shows the interior of the LFOM and the second shows what is visible to the user.

Improving the Chemical Dose Controller (CDC)

To make the CDC system more compact and able to effectively work with the LFOM we raised and mounted the stock tank and constant head tank directly flush with the mast. This way, the lever arm which connects the CDC system to the LFOM could be attached underneath the constant head tank, making the whole system narrower. We ran tests to make sure that the CDC dosed appropriate amounts of PACl. Our goal in the next model is to add the same CDC system on the opposite side of the tank to additionally dose chlorine. After switching our pulley-compression design to lever arm-backwash design, we are planning to revise our CDC system structure. Along this change, the design of LFOM will be modified accordingly.

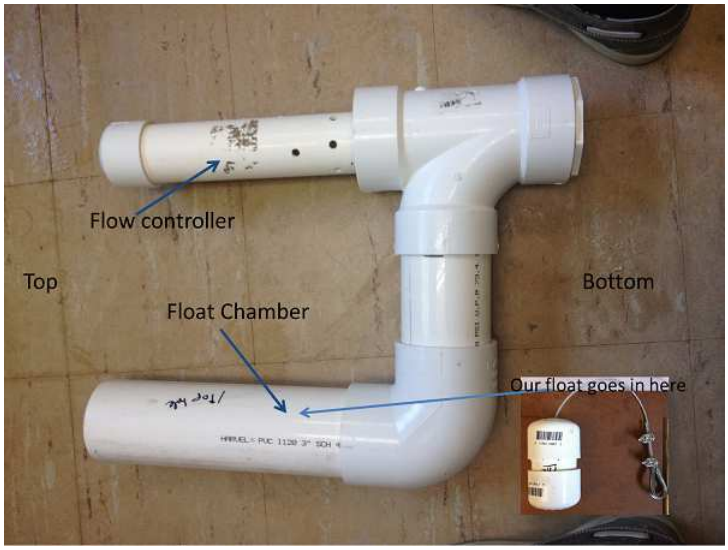

Figure 1: Inner LFOM

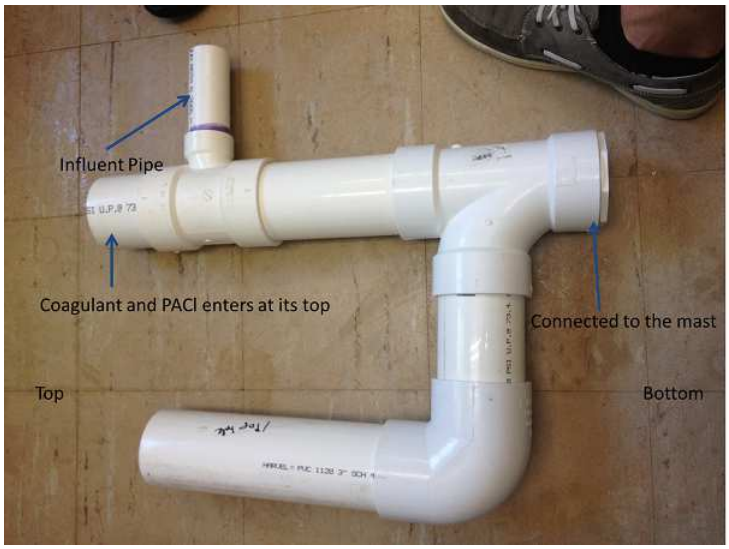

Figure 2: Outer LFOM

Remodeling the Clean Out System

Build the siphon for clean out cycle

The side valve proved ineffective in draining all the dirty water because it is limited to draining dirty water only at a certain height. We developed a flexible siphon to allow us to drain dirty water from any height. The portion of the pipe inside the filter drum is made of flexible tubing and is attached to the top of the compression disc. The outside portion was initially made of 1 inch PVC piping and a valve to regulate flow. This model is different from previous siphons used on the foam filter team because it does not require the operator to touch the dirty water. This was achieved by spin welding a fastening system for the siphon near the top of the filter as opposed to having the siphon drape over the top lip of the filter. As head loss in the system increases, the closed valve siphon fills up until it is completely full when the head loss in the filter equals the height of the top of the siphon. We had to eventually alter this system slightly so that the outside pipe was 1.5 inches in diameter to allow for a higher exit flow rate. We did not have a 1.5 inch valve, so instead we created a water trap similar to the system on the back of a toilet.

However, after switching into lever arm design, we went back to side valve because we no longer had to worry about varying water level.

Testing effectiveness of compression disk system

To achieve sufficient cleaning of the foam, it must be compressed with a high force at a high velocity, previously calculated by Foam Team Fall 2013. It was possible, but very difficult to compress the foam with enough force. Due to the pulley system that was in place we, all four of us, couldn't achieve a high enough compression velocity and concluded that an average person probably cannot reach the required velocity. In an attempt to create higher compression velocity, we added a winch system to the current pulley system on the opposite side of the filter to allow for simultaneous compression. We also made the mast of the compression system taller to compress the foam an adequate amount (compressing 20 inches of foam to 6 inches- 70% compression). Still, it required more than one person to compress the foam.

Building a New System Centered Around Effective Compression

After implementing all the changes above, we could not achieve simultaneous compression velocity and force with the pulley system at a level that would provide adequate cleaning of the system. This led us to consider new designs focused on making compression as effective as possible. As a result, we went back to the drawing board and came up with two systems. The first is a similar set up to the pulley system, but uses a lever arm instead of pulleys. So that we can achieve large enough force and velocity, we would scale down the system to a 12 inch pipe that does not require as much force as the 55 gallon drum.

Multiple filters in series would be used to achieve sufficient flow rates. The second idea is a 55 gallon drum that is lined with foam along the vertical sides in which water would filter from the inside of the drum to the outside and the clean out system would consist of two rollers squeezing the foam.

Experiment

We performed testing on a 4" piece of foam to compare compression cleaning efficiency with backwash cleaning efficiency. In order to backwash the foam we aimed to shove the foam through water equal to the foams height without compressing it.

4" pipe simulation (only with 60 ppi)

We conducted experiments similar to last semester's experiment, but ran water through until break through-as defined by spike in effluent turbidity: 7 NTU to 25 NTU. We used video analysis for data collection. We tried to look at :

1. Performance of 60 ppi foam alone
2. Backwash vs. Compression performance
3. Keep track of volume of water passed through foam, and volume of dirty surface water
4. Check effect of PACl

We set up the experiment in 27" long 4" PVC pipe filled with 11" long 4" diameter 60 ppi foam.

4" Pipe Testing Procedure (Compression/Plunge):

1. Mix clay, tap water, and coagulant in raw water tank. Keep tack of both influent and effluent turbidity with Process Controller.
2. Pour clay water manually, keeping track of volume poured.
3. When effluent water NTU spikes about 7 to 25 NTU or 24L of clay water is poured, prepare to backwash foam. Fill up the pipe with tap water and pull out the foam to the top before plunging.
4. Manually plunge/compress the foam with a plunger (a plastic mast with circular disk with holes) to a constant level with another team member timing the plunging/compressing stroke with a video.
5. As soon as the plunging/compressing is done, pour out the wash water in the pipe into a container
6. Calculate velocity= displacement/time through video analysis.
7. Dilute 1:19 for accurate measurement and measure average turbidity of wash water.

Description	Velocity (m/s)	**Percent Cleaned**
1. Backwash through 15" of water	0.15	0.59
2. Backwash through 15" of water	0.08	0.54
3. Compression	0.15	0.53
4. Backwash through 7" of water	0.15	0.69
5. Backwash through 7" of water	0.15	0.77

Table 1: 4" Pipe Experiment Results after pouring 24L of clay water

8. Calculate the total NTU-Liters of total influent poured and effluent came out.
9. Calculate NTU-Liters of wash water that saturated the filter.
10. Calculate the ratio of washed NTU-Liters to filtered NTU-Liters as a measure of cleaning efficiency.
11. Repeat steps 1-5 for each data point

Results:

Remarks:

1. We found that our backwash method is more efficient than compressing the foam. From four backwash tests and one compression test with identical set ups, back-washing had a greater cleaning efficiency every time (sometimes marginally better and sometimes significantly better) than compression.
2. Pouring consistently: when we were pouring the clay water, effluent turbidity spiked whenever the head-loss in the filter exceeded a certain point. Flocs seems to be pushed through the foam.

Evaluation of Clean-out Performance with Influent water We still want to assess the clean-out cycle efficiency when the foam is plunged through influent water. The procedure is the same with above, but for step 3 replace tap water with clay water.

Finding out Required Height for Plunging We reduced the height of the water that we back-washed the foam through from 15" to 7" in order to simulate having less height in the 55 gallon drum. Back-washing an 11" piece of foam through 7" of clean water (2/3 ratio of backwash water to foam height) we still found a 73% clean out efficiency.

Figure 3: Homemade Spring Scale

Force Measurement

We made our own spring scale

- 1.4cm : 50lbs
- 2.9cm : 100lbs
- 3.5cm : 150lbs

We plunged 22"diameter foam in a 16" stack into 10" of water in the 55 gallon drum. We made our rectangular base with 80/20 in order to fix the foam to the mast firmly with minimal deformation. We used rope to connect the base and our plunging disk with the stack of foam in between. We used the pulley system to raise the foam to the water surface and to plunge to the bottom of the drum. The spring scale was installed on the one end of the pulley in order to measure the force required to plunge the foam through the water.

- First trial: 100lbs
- Second trial: 300 lbs
- Th rid trial: 200lbs
- Fourth trial: 100 ~ 150lbs
- Fifth trial: 200 lbs

Remarks:

1. Tons of frictions(foam is too big -> wall friction, 80/20 mast) in the system, but it took only 300 lbs of force to plunge the foam to the bottom of the drum. A more precise foam fit and a lever system with much less friction should help to get this number even lower.
2. Our spring scale is homemade and not 100% accurate.
3. Rope issues: rope holding the foam in between the base and our plunging disk is stretching and one of the four knots is broken.
4. Then, we bought a spring scale for better force measurement. Also, the stretching rope was replaced with non-stretching climbing rope.

Barrel Testing

To maintain consistent experimental methods, we developed this checklist of things to check before testing the filter

Check Lists

- Gate valve- black lines aligned for 1 L/s flow (2 turns from fully closed, will pass black line twice before achieving 1 L/s flow)
- Water Level- foam fully submerged without significant head loss above foam
- Tight pipe/tube fittings, specifically turbidity pipes/tubes
- Calibrate turbiditimeters (check whether turbidity of tapwater is reasonable!)
- Check PACl pump connection to the stamp box

55-Gallon Filter Run Procedure With Recycle System

1. Open the effluent valve connecting the recycle drum and the filtration drum.
2. Fill both containers with tap water to the bottom spin-weld on the filtration drum. Close the effluent valve.
3. Finish filling the recycle drum. (55 gallons total)
4. Open the gate valve to 1 L/s. From fully closed, unscrew till the black line crosses 3 times and stop on the third (That will be roughly 2.25 turns)
5. Insert the PACl line and influent turbidity return line into the top of the LFOM.
6. Insert the effluent turbidity return line into the recycle drum.

7. Add sufficient clay and PACl for the given runtime.
8. Turn on Process Controller.
9. Run filter in normal operation until effluent turbidity rises suddenly.
10. Immediately close effluent valve and wait for water level to reach top of the filter drum. turn Process Controller to "OFF" state.
11. Proceed to the 55-Gallon Backwash Procedure and Evaluation section.

55-Gallon Backwash Procedure and Evaluation

1. After completing the 55-Gallon Filter Run Procedure, immediate
2. Stop the process controller and close the connection valve to the recycle drum as the water level reaches the top of the mark on the manometer.
3. Slowly lift the lever arm. Get videos ready.
4. Plunge the foam through the water.
5. After a plunge (or multiple plunges), close the valve connected to the recycle drum and immediately empty the filtration drum with the side-valve.
6. Analyze the velocity of the plunge with the video.
7. Sample of the clean-out water, dilute the sample 1:19 with tap water to measure average turbidity. Try to get multiple sample data for accurate calculation.
8. Calculate the total NTU-Liters of total influent poured and effluent came out based on the average turbidity of the sample obtained in step 7.
9. Calculate NTU-Liters of wash water that saturated the filter.
10. Calculate the ratio of washed NTU-Liters to filtered NTU-Liters as a measure of cleaning efficiency.

Results

Run Time	Raw Water NTU	Effluent Water NTU	NTU-Liters through filter	NTU-Liters Removed b
45 Minutes	100	1.35	270,000	266,355
75	100	1.35	450,000	443,925

Backwash Cleaning Design

The clean out system has been redesigned because back-washing the foam proved to have a much higher cleaning efficiency and requires significantly less force. A

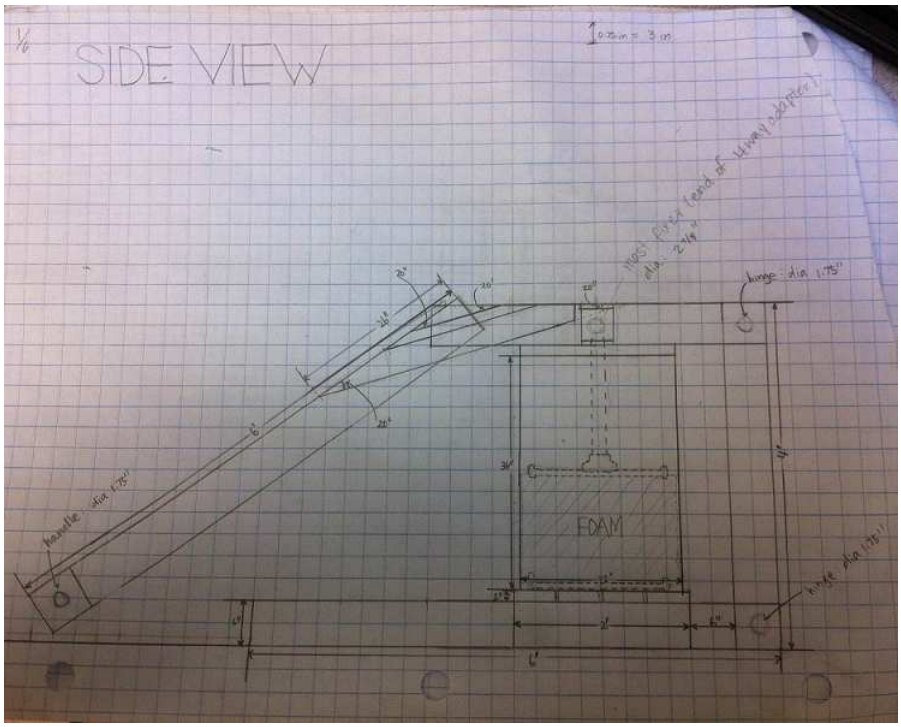

Figure 4: A to-scale drawing of the new, wooden lever arm system.

newly designed lever system which uses a 4:1 force ratio to backwash the foam has been implemented. The lever system will operate like a garlic press and was initially drawn up to be made out of PVC. We have found that PVC and the required fittings to build this system are significantly cheaper and also more accessible world wide than 80/20. In addition, the LFOM has been redesigned again to be an inline system connected to the fulcrum of our lever arm.

Then, it was discovered that PVC structures and plastic spin-welds were deflecting too much and unable to deliver the full force from the operator to the plunger. The frame was changed to a wooden structure. The wooden design still operated like a garlic press, but also had a slanted handle to optimize the geometry. The slant enables the top of the plunger to be at the top of the drum while the end of the lever arm is at ground level.

We also updated our plunger. First, we tried to make a better disk improved from the punctured PVC plate from last semester. So, we built 19" wide octagon push-and-pull plates out of 1/2" PVC pipes. We made a top with a 2"-to-3" adapter in the center of the plate so that we can connect it to the mast. The bottom one was placed under the foam. Then, two plates were connected with non-stretching ropes and carabiners.

While testing our new plunger, we broke our cross piece of the top and

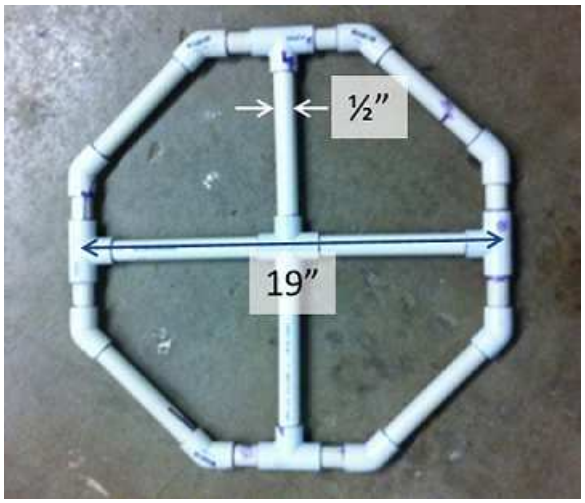

Figure 5: Push and pull prototype

realized that our octagon design actually inhibits the durability of our plunger. So, we replaced our 1/2” pipes to 3/4” pipes and changed design to a 22” wide simple cross.

Then, we concentrated on testing the cleaning system. In order to observe how the head builds up while the water is filtered, we replaced our side-valve on the blue drum with a Tee. On the top of the Tee, we put a clear plastic tubing thrusting upward. On the side of the Tee, we placed the side drain. Also, a pressure sensor was added to the filtration drum so that we can automate our Process Controller to turn the process off as the water level reaches the top of the barrel.

Clean Out System Analysis

Compression System Redesign

Using a lever was never seriously pursued because of the much higher force required to compress the foam. Because back-washing (method of plunging the foam into the water) requires significantly less force (~300lbs), we can now operate a leaver arm effectively. We have been considering the weight required to lift the foam and the water on top of the foam, and we believe that our 4:1 ratio operated by the lever arm will be enough to do this comfortably. If lifting the foam does become a problem, we have come up with two solutions. The first is to back feed influent water at the bottom of the drum to help us raise the foam while simultaneously draining water off the top of the foam with a spin welded side valve. The second is to filter in the up position which would require us to be able to raise the head without spilling over the drum. Doing this would allow us to plunge the foam through clean water and then allow the

Using mostly PVC and wood, the pulley system with lever arm design which would plunge through the water, not compress the foam

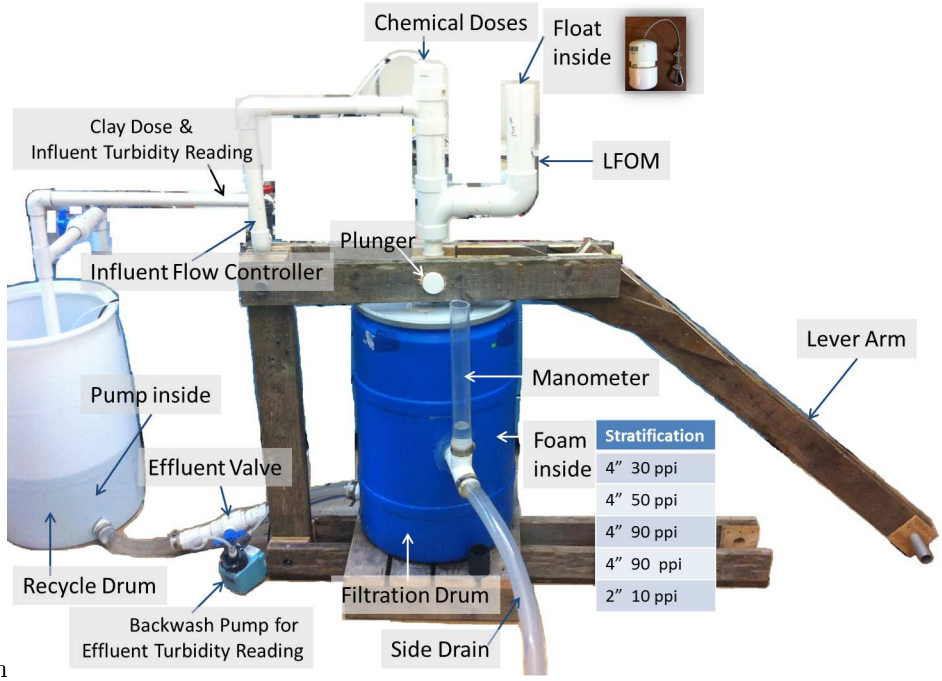

Figure 6: Final overview

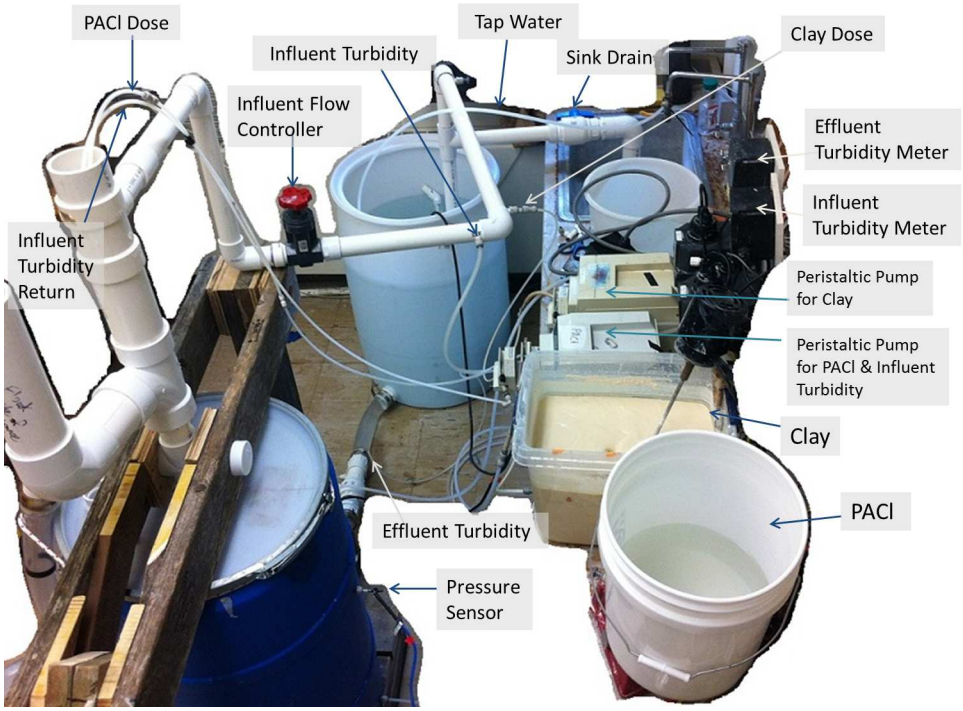
PACl Dose
Tap Water
Clay Dose
Influent Turbidity
Sink Drain
Influent Flow Controller
Effluent Turbidity Meter
Influent Turbidity Meter
Influent Turbidity Return
Peristaltic Pump for Clay
Peristaltic Pump for PACl & Influent Turbidity
Clay
PACl
Effluent Turbidity
Pressure Sensor

Figure 7:

dirty water to exit through a side valve so we would not have to worry about lifting the foam and all the water on top of the foam.

Analysis of Siphon

The siphon had limited success. With the initial outside pipe system, the siphon worked, but there was a very low flow rate that made the system take an unproductively slow amount of time. When we expanded the outer pipe size to generate a larger flow rate we were unable to use a valve. Without the tight seal, the siphon was ineffective. The siphon was not used and instead a side valve was implemented.

Foam's Ability to Clean

Foam Leaching

Research on foam leaching is still underway, but so far we have not found any issues with using foam as a drinking water filter. There were no reports from New England Foam or Crest Foam, but it was suggested by Crest Foam that we test the foam for amines and tin, both of which are health hazards. We also contacted Clark Foam, and got answer that the foam is not FDA approved. We also asked for any reports or specific reason for absence of FDA approval, but the company just told us that the foam just has to be tested by third party not by the manufacturer.

Foam Geometry

Different configurations of foam may be more effective at cleaning the water. We are currently experimenting with different thicknesses of foam to determine just how much we need to have so that the filter is effective. Additionally, we are looking into more dramatic stratification by having an entire filter as approximately 10-30 ppi foam that feeds into a finer filter with 50-90 ppi foam. This would enable us to better tailor the clean out system to the varying shear force required to clean the filter (30 ppi foam requires approximately 1/3 the shear force needed by the 90 ppi foam). Our new design ideas are on track to answer these questions and generally give us a baseline for how the foam works as a filter.

Conclusions

The system completed by the Spring 2014 Foam Team was a great place to start especially with integrating an LFOM and the CDC system. Where there was room for improvement was in the clean out system. The major turning point for the team this summer was the discovery through small scale testing that backwashing the foam was comparable in cleaning efficiency to compressing the foam

and also required significantly less force. The construction of a lever-arm then yielded a significantly greater cleaning efficiency than compression because a much higher velocity could be applied with less force. Over several test runs, we were able to filter 100 NTU water down to 1.35 NTU for about 75 minutes, and our resulting clean out efficiency was 71 percent. The critical indicator of how our new lever-arm system was actually performing was the run times of successive filter trials. Because we were able to achieve similar run times for similar tests, we can conclude that we were able to adequately clean the foam between filter runs. This marks a major accomplishment for foam filtration on a 1 L/s 55-gallon drum scale.

In addition, we decided to send lever-arm design specifications and 23" foam (4" 30 ppi and 4" 90 ppi) to Honduras on 7/27 with AguaClara Field Engineers Walker and John. This will be a great test to see if our Field Engineers can manage to source a drum and the required materials to build a lever arm. The goal is to have a foam filter pilot project up and running in the near future.

Future Work

The next step for foam filtration is to get a pilot project up and running in the field. This will depend on Walker and John's ability to source a straight sided drum and the required materials to build a lever-arm in Honduras. Depending on what they are able to come up with on the ground, we may need to send them additional foam that fits their new drum. There is still a lot of research that needs to happen on our full-scale unit in the lab as well. Future teams should focus on coming up with a compact way to install the CDC lever arm in conjunction with the in-line LFOM. It will also be important to figure out the optimal foam configuration (in terms of filter depth and stratification of pore sizes) to extend run times in the filter. In addition, further research can be done to determine head loss relationships throughout the filter depending on turbidity and foam height variations. The foam team also needs to find a way to have a third party test our foam to validate that foam leaching is not an issue and confirm that our unit is a safe way to meet a community's water needs. The foam filter also needs to develop design code on the AguaClara design server. Finally, a new and improved lever-arm 2.0 should be designed to continue to improve the "pusher" and "puller" and also make the system lighter, and a system to somehow automate this process should be considered as well.

Bibliography

References