Foam Filtration Spring 2014

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Abstract

The Spring 2014 foam filtration team will focus on improving the water treatment system designed in Fall 2013 and incorporating the knowledge learned on the trip to Honduras in January, 2014. This includes: redesigning the cleaning techniques to improve efficiency in removing dirty water off of the top of the foam, investigating foam re-expansion in a drum with vertical sides, designing the LFOM, and implementing a coagulant doser. The goal for this semester is to design, build, and test a compact system that can be easily transported and eventually implemented in small communities. In order to achieve this long-term goal, the Foam Filtration team will need to investigate multiple design options and create an operational system in the AguaClara lab. The foam filter will then be tested in Honduras.

Detailed Task List

1 Design New Apparatus for Lab

1.0.1 Flow Rate– Melissa

Figuring out how to recycle 1 $\mathrm{L/s}$ of water in the lab to simulate real world conditions.

1.0.2 Redesign (De)Compression Technique– Skyler

Working to design a compression technique that can rapidly compress the foam, is light weight, and is also corrosion resistant.

1.0.3 Siphon Technique– Bari

In Honduras, the siphon was slow at draining the dirty water off the top of the compressed foam. We aim to have either an improved siphon design or a completely different drainage system.

1.0.4 LFOM and Doser– Jeff

Based on our MathCAD files made last semester, the LFOM and doser designs should be improved. This includes the amount of coagulant dosed and attachment to the apparatus.

2 Life of Foam

2.0.5 Durability of Foam– Kristin

Foam lifetime and durability is suspected to vary significantly based on the turbidity and organic constituents in the influent water. In Honduras where surface water is the primary source of drinking water, the quality and composition of the influent water can vary significantly in both time and space. Thus, the durability and lifetime of the foam can only be determined on-site at a community and may only be accurate for that specific community.

2.0.6 Compact Complete System– End of semester goal to keep in mind by all

This overall goal we have throughout the semester is to create our entire apparatus so that it is easy to ship, construct, and maintain. This also keeps in mind the potential of foam filtration for disaster relief and getting to small communities.

3 Role Assignment

3.0.7 Kadambari Suri- Wash water drain Design & Team Organizer

Bari excels at keeping us on track. She sends us most of our reminders via text and emails and will continue to do so. Also, as a freshman her main task is to learn and continue the team in future semesters.

Bari is currently in charge of the side valve design.

3.0.8 Jeff Suen- Pulley System Design & Data Coordinator

Jeff did the majority of the LyX training and MathCAD last semester. Therefore, he is the most knowledgeable and willing to get work done.

Jeff is currently working with Skyler on the pulley design and the compression/decompression techniques.

3.0.9 Skyler Erickson- Pulley System Design & Materials Coordinator

Skyler gets along best with Paul and Tim, he also was the main team member last semester who contacted the foam distributor. He will continue to keep in touch with these providers to help us redesign our system.

Skyler and Jeff are also going to work with Paul and Tim in order to design the most efficient pulley system.

3.0.10 Melissa Shinbein- Plunger Materials & Team Leader

Melissa has been on foam filtration the longest. She will continue to use her M.Eng and undergraduate experience to guide the team towards their short and long term goals.

Melissa is currently working on researching materials for the plunger.

3.0.11 Kristin Chu- Displacement Velocity vs. Turbidity Testing & Proofreader

Kristin, as the newest member of the team, will be in charge of proof reading. This will assure she becomes well acquainted with our goals and past research. She will use her novice status to make sure that the writing is clear and concise.

Kristin is currently working on setting up a foam filtration model to conduct velocity and turbidity tests.

Literature Review: Previous Semesters

The foam filtration team had the opportunity to bring a foam filter to Honduras this past January and present it to officials there. The process of assembling the filter in Honduras proved to be quite the challenge as the foam transported from Cornell did not optimally fit the drum bought in Honduras. As we were pressed for time, we had to use the next best drum that we could find, which turned out to be too small and resulted in a very tight fit for the foam. Even though the decompressibility of the foam was time consuming (as a result of the tight fit), the foam eventually re-expanded after it was removed from the drum and allowed to expand openly. This suggests that the foam can decompress with a more exact fit in the drum. Also, the compression system was heavy and tedious to assemble; it was made for a particular sized drum and could only be expanded by the use of washers, but could not be made smaller in case the drum in use was smaller. Furthermore, using the winch was too labor intensive because it had to be unwound by manually raising/releasing the compression disk. During testing, we ran into two big hurdles: the amount of coagulant being used and the mechanism used to remove wash water, or water that collects on top of the foam during compression. Due to the presence of biological organisms and natural organic matter (NOM) in the water, the amount of coagulant that we used proved to be insufficient, showcasing that there is a gap in our knowledge in regards to how the foam performs in lab under ideal situations and in the field. However, this is a task that will be addressed by plant operators in the field through trial and error. For the time being, we will have to simulate field conditions as best we can. When it came time to clean the filter, we realized that the siphon pipe was difficult to prime and took a long time to completely drain the dirty water. There is a need for a more permanent structure installed such as a side valve that allows water to exit off the top of the compressed foam. We realized that if the foam filter is to be released into the “market” then it is imperative that there is standardization in the materials used and the compression system needs to be user-friendly not only during set-up, but also during usage.

Introduction

The challenges for the Spring 2014 team will include expanding our knowledge and engineering solutions to problems encountered during the Honduras trip in order to iterate an improved water filtration system. Specific challenges include making the system lightweight and easy to assemble, improving the ability to remove dirty wash water above the foam via side valve, using pulleys to quickly compress the foam, and having an appropriately fitting drum to enable foam decompression after compression. The figure below represents the design at the end of the Fall 2013 semester that was presented in Honduras. While the design met the World Health Organization’s standard of effluent water below 3 NTU, the compression system was over-designed, making it difficult to operate. Additionally, siphon cleaning was slow and required the operator to put his or her hand in the dirty influent water, something that should be avoided in the future. Therefore, the primary tasks of the Foam Filtration team are to improve cleaning techniques by inserting a side valve and using pulleys for speed, using 80/20 aluminum extrusions in the cleaning technique to prevent rusting, and adding a fully operational flow controller/LFOM system.

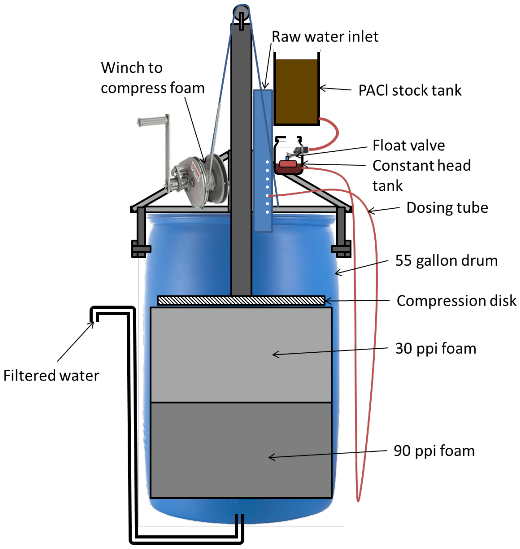

Figure 1: System Diagram Fall 2013 (Designed by Dr. Monroe Weber-Shirk, AguaClara 2013)

Methods

Ordering New Foam and Drum

During Fall 2013, the idea of foam being capable of natural or automatic re-expansion over time was considered an alternative to manual re-expansion of the foam by the operator. However, due to the tight fit of the drum in Honduras where the 21" diameter foam was too large for the 20" diameter of the tank, the foam was unable to completely re-expand in the field. To continue to improve the system, a new straight-sided 22" diameter drum was ordered from EBK Containers. Unfortunately, our 23" diameter foam that we have on hand from last semester is about 1" too large for the new drum. We plan to use this foam in our laboratory unit even though it is not a perfect fit, and order new foam to be a perfect fit for the new straight sided drum. Once the foam fits adequately into the drum without being too large, or as close as possible to a "perfect fit", it will be possible to view the full potential of foam to decompress without manual input. If the foam is able to re-expand on its own, this will make cleaning simpler. If it is unable to decompress fully, a new method which requires manually pulling each section of foam will be devised.

Designing New Compression Techniques

One aspect of foam cleaning being explored is the possibility that rapid compression of foam during the cleaning process will have a significant effect on the removal or displacement of materials captured by the foam. How fast the foam is compressed can be viewed as to how fast the structure of the pores will collapse. The velocity at which water is forced from the pores is important because it provides a shear or drag force that pushes the captured solid particles out of the foam's pores. The velocity gradient between the fluid and an attached particle is proportional to the maximum velocity of the fluid relative to the pore. Shear is proportional to the velocity gradient and thus the force available to detach the particles from the reticulated foam is expected to increase with the compression velocity (details on the experiment testing this hypothesis are provided later in the document). In rapid sand filters the backwash approach velocity is approximately 11 mm/s. The average velocity of the water in the expanded filter bed can be obtained by first calculating the expanded bed porosity.

$$\varepsilon_{FiSandBw} = \frac{\varepsilon_{FiSand} - 1}{\mathit{\Pi}_{FiBw}} + 1 \tag{1}$$

where $\varepsilon_{FiSandBw}$is the expanded bed porosity, $\varepsilon_{FiSand}$is the filter bed porosity at 0.4, and $\mathit{\Pi}_{FiBw}$ is the ratio of expanded bed height to filter bed height. The pore water velocity can be calculated from the approach velocity as

$$V_{PoreBw} = \frac{V_{Bw}}{\varepsilon_{FiSandBw}} \tag{2}$$

where $V_{Bw}$is the approach velocity during backwash and $V_{PoreBw}$is the resulting average fluid velocity in the fluidized bed. For a rapid sand filter that is backwashed at $11\,{}^{\mathrm{mm}}\!/\mathrm{s}$ and that is expanded by 30% the expanded bed porosity (1) is 0.54 and the pore water velocity is $20.4\,{}^{\mathrm{mm}}\!/\mathrm{s}$. This provides an initial estimate for a target pore water velocity. Given that the foam we are using from New England Foam ranges from 95-98% http://www.newenglandfoam.com/filter.html and the literature reports reticulated foam porosity ranges from 0.85 to 0.97

(Moe & Irvine, 2000; Liu et al., 2006; Studart et al., 2006; Xu et al., 2008) there is little difference between pore water velocity and compression velocity even when the foam has been significantly compressed. An accurate measurement of porosity can be done by using specialized equipment such as a gas pycnometer or through direct methods such as using bulk density and the density of the strut material to solve the equation: $porosity = 1 - (bulk\,density/strut\,density)$ or by knowing the strut thickness and strut length to calculate for relative density to solve the equation: $porosity = 1 - relative\,density/strut\,density$ with $relative\,density = C^p(strut\,thickness/strut\,length)^2$ where C^p is a constant that depends on the foam's microscopic geometrical properties (Dourtres & Atalla, 2012). See the picture below for an example cell structure displaying the pore faces and struts.

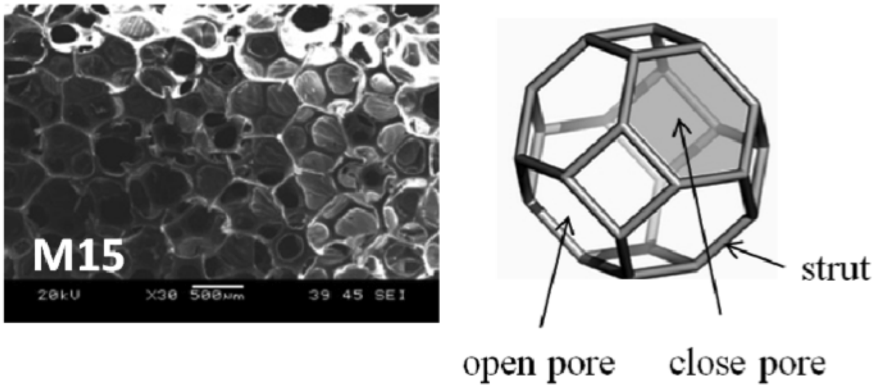

Figure 2: Cell Structure Diagram (Dourtres & Atalla, 2012)

The compression velocity could be further refined by calculating the velocity gradient at the surface of the sand grains and the required velocity in the reticulated foam to obtain a similar velocity gradient. However, the flow geometry is sufficiently complex in both the fluidized sand bed and in the reticulated foam to make calculating the velocity gradient difficult. The velocity gradient will decrease as the pore diameter increases and thus cleaning the 30 ppi foam may be more difficult than cleaning 90 ppi foam. TheGiven our desire for a high compression velocity, we have proposed four different compression techniques:

1. Simple Pulley Design

Use a system of traveling and fixed pulleys connected by one continuous piece of rope to apply downwards force to the plunger and compress the foam. This system would decrease the amount of force required to compress the foam but also increase the amount of rope required to pull the plunger down rapidly. For example, in a pulley system with an ideal mechanical advantage of 5:1, applying 5 newtons on the pulley system would result in 25 newtons being applied to compress the foam. In addition, for each 10 cm of rope pulled, the compression device would move 2 cm. Each pulley added to the system would increase the ideal mechanical advantage by 1 so a system of 5 pulleys would have an ideal mechanical advantage of 5:1. For the actual mechanical advantage, the friction of the rope and pulleys as well as the angles of forces in the systems must be taken into account. Presently, this is our first choice for compressing the foam because it is thought to offer the greatest compression speed as the operator can pull the rope connected to the pulleys in a single run. We are in the process of experimenting with pulleys to determine how we would position them around the drum to provide balance, how many of them we would use, and what would be the best pulley and rope/wire combination.

- With 2 Block & Tackles (17 Pulleys) [15:1 Ideal MA]
  - The simple pulley design represented below in Figure 2 uses two block & tackles, each containing 8 pulleys, plus one single pulley on top of the plunger. Only 15 of the 17 pulleys mentioned contribute to the system, providing an ideal mechanical advantage of 15:1. The lone pulley attached to the side of the drum only changes the direction of the pulling force and does not contribute any mechanical advantage to the pulley system itself. Total foam height is based on 3 roughing and 4 finishing filter foam that each have a height of 4". The compression distance of 18.67" is based on the 28" of foam being compressed by two-thirds the amount to 9.33". The total amount of rope needed for the pulley system is roughly estimated to be 44.2 ft (13.5 m) based on the vertical rope length of 30.7" between the block and tackles and multiplied by 16 (number of pulleys), the horizontal rope length of 2" that wraps around 14 of the block and tackle pulleys, and

an estimated 12" of rope that wraps around the middle single pulley and connects the block and tackle systems on either side of the drum. The operator needs to pull 26.4 ft (8.1 m) of rope to compress the foam to one-third of its original volume. An undetermined length of rope will be added to the 44.2 ft (13.5 m) to compensate for the margin of error and make the system easy to operate for two or more people.With a 15:1 ideal mechanical advantage, pulling the rope of the pulley system with 33.3 lb. of force will result in 500 lb. of force being applied to the foam.

- Materials & Assembly

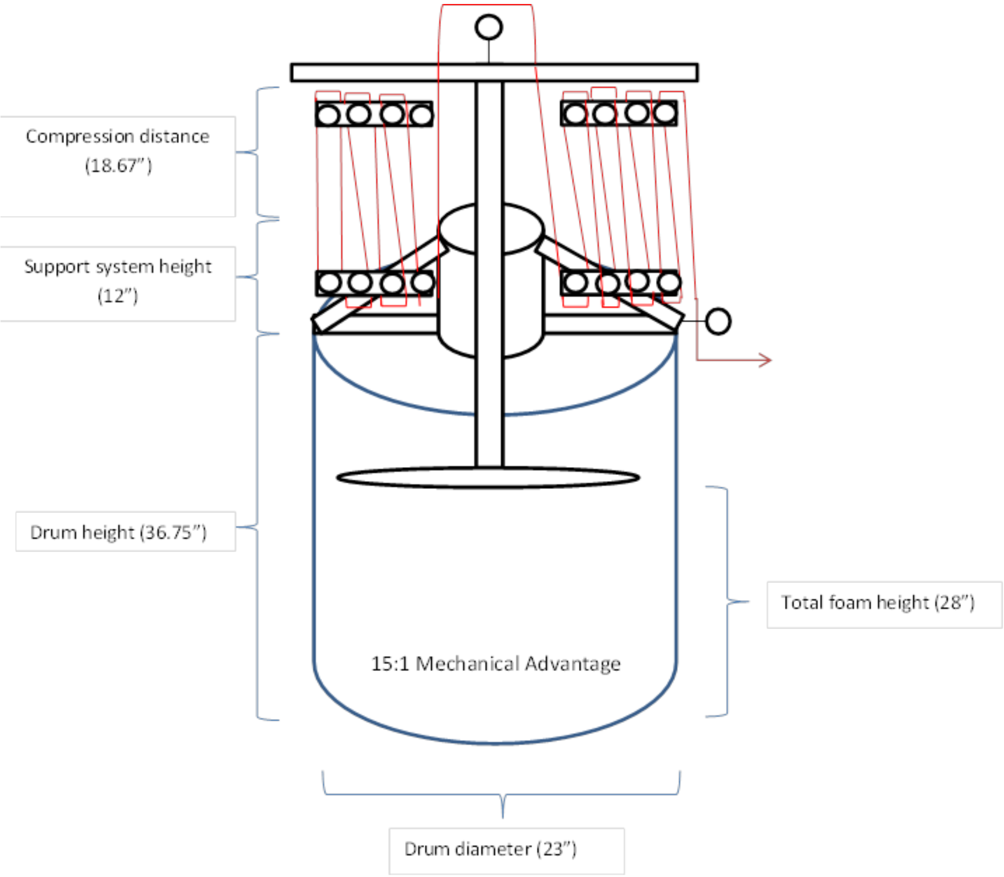

Figure 3: Simple Pulley System - Block & Tackle Arrangement

2. Compound Pulley System:

- With 7 Pulleys and 3 Prusik Hitches [54:1 Ideal MA]

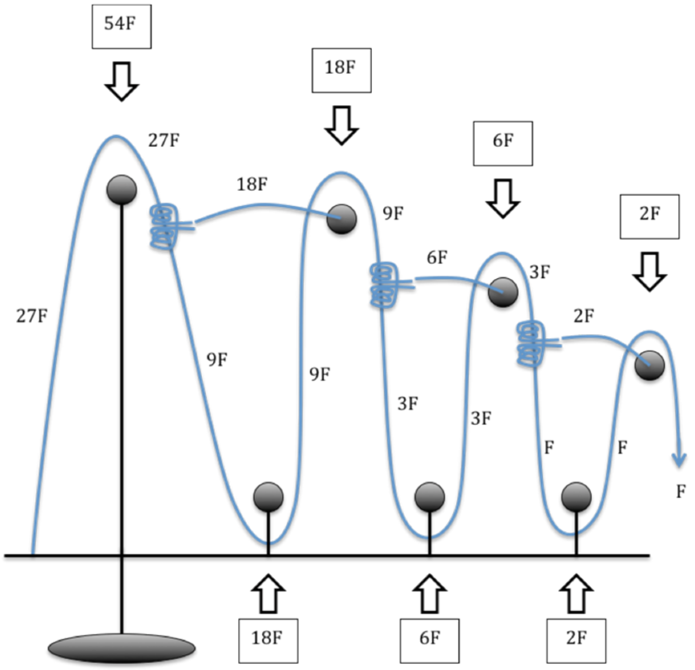

Figure 4: Compound Pulley System with 7 Pulleys and 2 Prusik Hitches (54:1 Ideal MA)

- With 1 Block & Tackle (9 Pulleys) [14:1 Ideal MA]
  - This compound pulley design uses one block and tackle containing 8 pulleys plus a single pulley on the plunger to achieve an ideal mechanical advantage (IMA) of 14:1 with 9 pulleys. The block and tackle represents a simple pulley system with a 7:1 IMA that is acting on another simple pulley system that has a

2:1 IMA. The length of rope that needs to be pulled to move the plunger and compress the foam can be calculated by looking at the IMAs of the two simple pulley systems being used. The rope that applies tension to the plunger will be labelled the “plunger rope” and the rope the operator pulls will be labelled the “block and tackle rope”. With the IMAs of 7:2:1 that make up the entire pulley system, 2.54 cm of foam compression requires pulling 5.08 cm of plunger rope and pulling 2.54 cm of plunger rope requires pulling 17.78 cm of block and tackle rope. As a result, 2.54 cm of foam compression requires pulling 35.56 cm of block and tackle rope. Testing of the pulley system supported these calculations with one exception in which the initial 2.54 cm of compression required 11.43 cm of plunger rope instead of 5.08 cm, which in turn required 80.01 cm of block and tackle rope instead of 17.78 cm. This initial increase for the required length of rope pulled for 2.54 cm of foam compression could be the result of the plunger rope stretching and decreasing the amount of slack present. Pulling with 35.7 lb. of force will result in 500 lb. of force being applied to the foam.

- Materials & Assembly

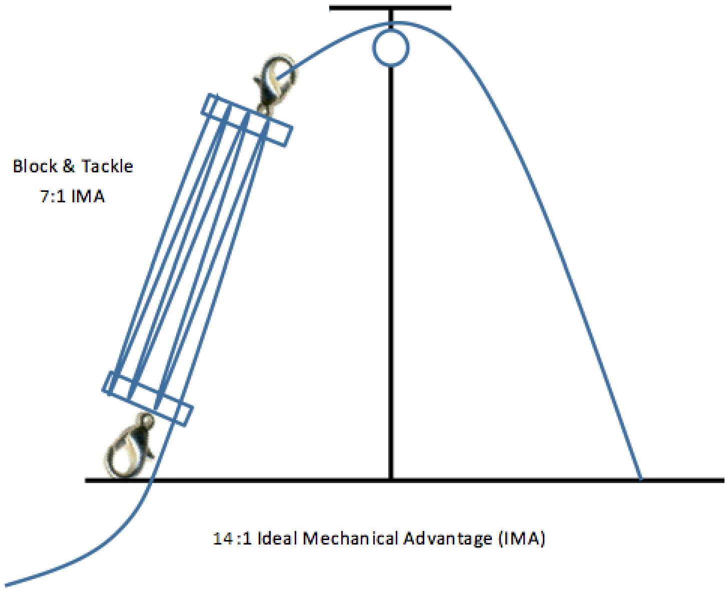

Figure 5: Complex Pulley System with 1 Block & Tackle (6:1 Ideal MA

- ∗ The block and tackle comes with its own rope and includes 8 pulleys. The whole unit comes as one package.
- ∗ Material type and length for the plunger rope have not been finalized yet.

3. **Screw System:** Use a threaded screw to push a plunger down and compress the foam. This alternative would allow the operator to spin a screw that drives the plunger down to compress the foam. How fast the operator could compress the foam using this met hod is unknown.
4. **Lever/Compound Lever and Pulley System**: Use a block and tackle pulley system in combination with a lever or compound lever to apply direct force to the plunger. One foreseeable obstacle to this system's implementation is designing it to be compact.

Determining the Best Compression Technique - Objectives and Constraints

There are two important constraints to keep in mind when determining the best compression technique. The first and most important is speed. Our hypothesis is that the faster the foam is compressed, the greater the cleaning efficiency will be. We will test this hypothesis in our compression velocity testing. Given our desire for speed, we suspect the simple pulley system gives us the quickest compression; it is only effected by the amount of rope that needs to be pulled through the pulley system, and this length is about 12 feet-depending on how many pulleys are actually used. The drawback to this implementation is that it is difficult to pull the plunger down in a balanced and even way. We have created this balance by adding triangle supports that connect to a “box” of four 80/20 pieces that the main plunger slides within. Because of our initial difficulties in applying a balanced force, we used a compound pulley system in our first implementation in the lab which seemed to provide a better balance of downwards force on the plunger. As we expected, however, we were limited by the distance between the traveling and the fixed pulleys. Instead of using an autoblocking pulley/prusik friction hitch to maintain the tension in the rope to reset the traveling pulleys, we have instead opted to use a taller plunger (62”) which will give us enough distance between the fixed and traveling pulleys to compress the foam a total of 16”.

The second constraint is that the system be light and easily transportable. We know that our materials need to be resistant to corrosion as well. We have decided to prototype with 80/20 anodized aluminum because it is light weight, very strong (minimum yield strength is 35,000 lb./in^2) and corrosion resistant. We will also use stainless steel for the screws and slide-in t-nuts to maintain structural integrity and minimize pitting of the aluminum extrusions In addition we have verified that Cornell’s 80/20 distributor (Ralph E. Wearl Company, Ralph E. Wearl Company) will be able to ship to Honduras as well. 80/20 also provides us an advantage in that it requires no welding and it is easy to manipulate with different connecting pieces and fasteners for rapid prototyping. This allows us to easily experiment on different designs, giving us the flexibility to manipulate the structure in any way we need to in order to distribute our force evenly.

Plunger Materials and Attachment

In the drum, the foam is compressed to approximately 50% of its original height by a compression system. This system involves a plunger that in previous semesters was made of PVC with holes drilled into it. The holes enabled dirty water to come out of the top of the compressed foam towards the surface of the water, where it was removed by a siphon (or, in the future, a side valve). For the demonstration in Honduras, the plunger plate was approximately 20" in diameter to allow space on either side for easy insertion or removal in the drum. The plate had many small holes drilled into it manually. After consulting with Paul Charles in the CEE lab on different feasible materials, he believes that for the aims and cost constraints of foam filtration, hard plastic with manual drilling is still the best option. Even though there are other materials available such as McMaster-Carr extra-rigid type 304 stainless steel wire cloth, the amount of labor that would be required to cut the square pieces into a circular plunger render it less optimal than hard plastic.

This semester our plunging plate was created from a piece of hard plastic found in the lab. It is 18" in diameter and has 3/16" diameter holes spaced 1" apart across the entire plate. It is bolted to an 80/20 piece that distributes the downwards force of our pulley system evenly across the whole plate. Instead of using spacers to create a water channel between the 80/20 piece and the disk, we believe that the natural channels in the 80/20 aluminum framing will be adequate enough to carry the water from the holes in the the plate and out the side valve. Drilling holes across the entire plate was a tedious process, and should these holes prove inadequate to remove dirty surface water from the foam, an alternative method of creating PVC channels at the bottom of the plate was suggested. The channels would involve gluing PVC pieces the length of the plate with different widths and depths to the bottom of the plate. These channels would create a path for the water to flow out of the compressed foam. Should we later use this method, some experimentation would need to be executed to find the ideal widths and depths of the channels.

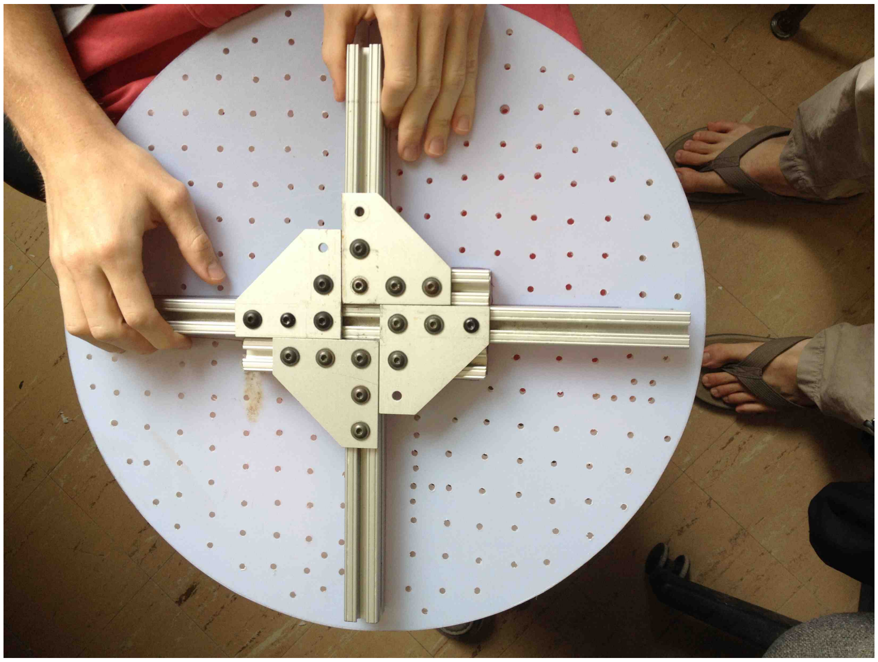

Figure 6: HDPE Disk Attached to Aluminum Extrusions

Support System Design

- Test support System made out of 80/20 aluminum extrusions
  - The primary system that supports the pulley system during compression has two pairs of aluminum extensions inserted through the drum wall with one pair laid vertically and the other pair laid horizontally underneath the first pair. Support and stability are provided by both the drum and single continuous 80/20 pieces.
  - We have added more stability by creating a "box" from four vertical 80/20 pieces that are supported by 45 degree angle pieces and 90 degree connectors. The main plunger slides within this "box". A locking mechanism on the "box" holds the plunger and disk above the foam and water level when not in use.

- At the point of contact between the plunger piece and the plastic compression disk, in-between is a system of 80/20 pieces that helps spreads the force from a single point, provides stability, and prevents damage to the plastic disk. In the absence of the support system laid above the disk, the 80/20 piece that acts as the plunger would wobble and easily slide so the force applied on the foam would be at an angle.

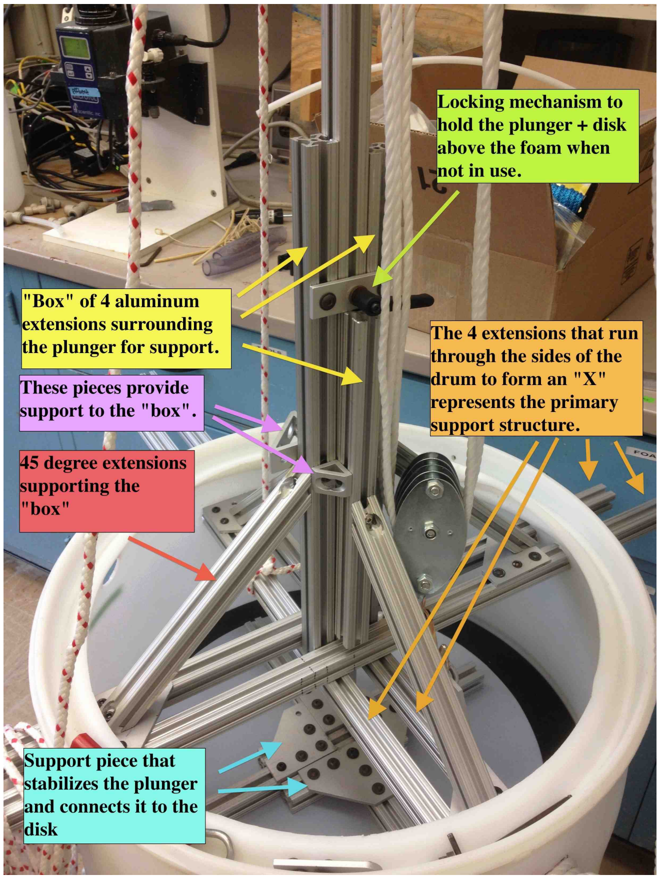

Figure 7: Support System Diagram

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- Issues to resolve:

  * The rope through the pulley on top of the plunger has visible

fraying caused by the rope being in close contact with some of the screw pieces attached to the aluminum extensions. Duct tape was applied over the screws as a temporary measure to reduce friction but even the duct tape was worn out after a couple days of compression testing.

- List of Materials for the Support System

Quantity	Material	Vendor/URL
8	3/4” length stainless steel button head cap screws	McMaster
62	1/4” length stainless steel button head cap screws	McMaster
70	80/20 (10 series) stainless steel slide-in economy t-nut, 1/4-20	Amazon
1	80/20 (10 series) 57” aluminum extrusion - main plunging piece	
4	80/20 (10 series) 20” aluminum extrusion - for the “box” surrounding the plunger	
4	80/20 (10 series) 45º angle 12” aluminum extrusion - supports the “box”	
4	80/20 (10 series) 26” aluminum extrusion - cross drum beams	
1	80/20 (10 series) 16” aluminum extrusion - going across the disk	
2	80/20 (10 series) 7” aluminum extrusion - going across the disk	
4	90º plates for 1” extrusions - 5 holes	
8	1” elbow braces	
2	Extended plate for 1” extrusions - 6 holes (3x2)	
1	Tee for 1” extrusions - 5 holes	
1	stainless steel spring link with ??? thickness - attaches block and tackle to the support system	
1	Plate for 1” extrusions - 3 holes - for locking mechanism	
1	L-Handle linear bearing brake - for locking mechanism	Amazon

Table 1: Support System Materials

Experimental Set-Up for Compression Velocity/Cleaning Efficiency Testing

The foam team worked with Casey to set up an apparatus to simulate the function of the foam filter using a 4-inch diameter column. Figures 6 and 7 below are an image of the schematic and an actual photograph of our set-up.

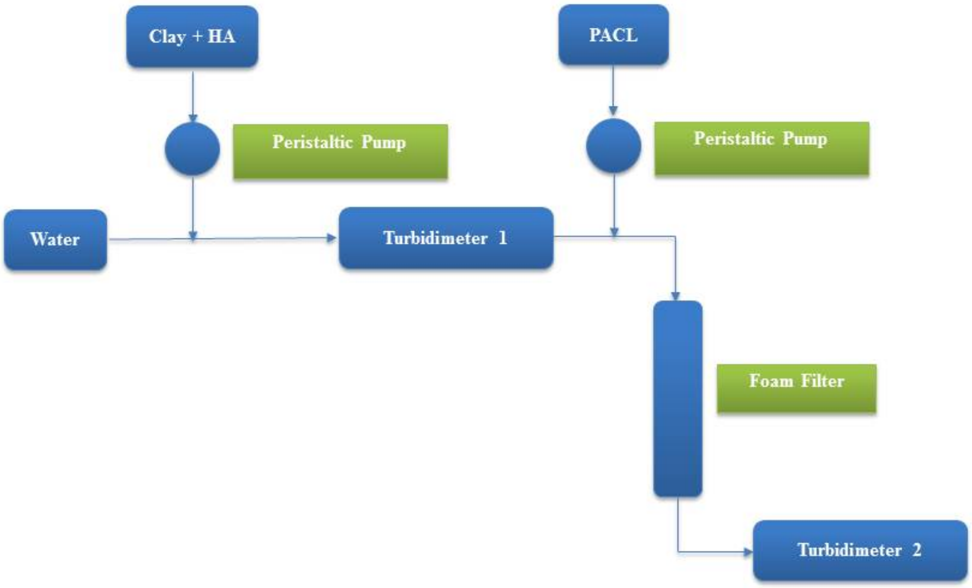

Figure 8: Experimental set-up schematic

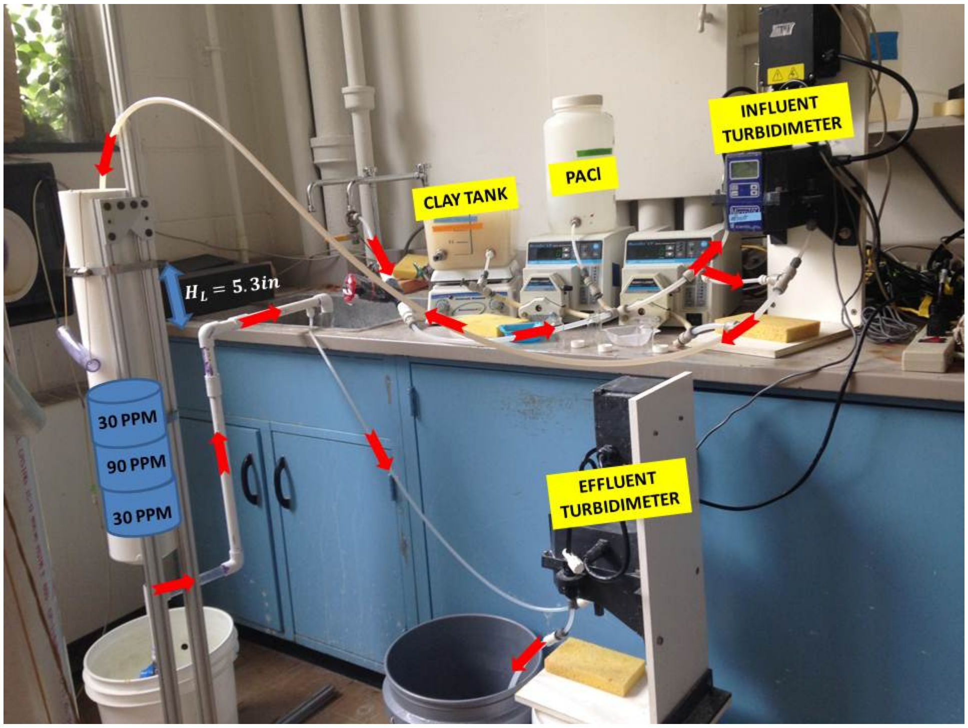

Figure 9: Photograph of experimental set-up in lab.

There was an unforeseen complication where the pipe used to control the water height in the column, allowing the water to exit into the sink, was too high. The water level in the column rose rapidly, meaning the distance between the top of the column and the top of the pipe was not large enough to account for the head loss in the system. The total head loss in the exit pipe (the head loss in the column is insignificant in comparison) was calculated using the following equations:

$$H_L = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

Where:
f = friction factor found using Moody diagram
L = length of pipe
D = diameter of pipe

V = average velocity in pipe

$$V = \frac{Velocity_{column} Area_{column}}{Area_{pipe}}$$

$$H_L = (0.05)\left(\frac{0.855m}{0.009525m}\right)\frac{(0.62\frac{m}{s})^2}{2(9.8\frac{m}{s^2})} = 0.135m = 5.3in$$

To be on the safe side, we had Paul Charles help us saw off part of the PVC pipe to a height just above the sink as there is no harm in leaving extra room (and the water level rises rapidly as the foam clogs). Once this issue was addressed, we were able to conduct a test. Another road block was encountered when the turbidity of the water above the foam was too high for the turbidimeter to read. As we continue testing, we are going to have to dilute this water sample in order to accumulate data points, and calculate the percentage of particles removed using that data. Because there were many constants in our experiment including the height of the foam, the distance the foam was compressed, the flow rate of the entire system, and the time the system was run during each test, the calculation for the percentage cleaned can be condensed into the following equation:

$$\%_{Cleaned} = \frac{(Turb_{comp} - Turb_{inf})\,Vol_{comp}}{(Turb_{inf} - Turb_{eff})\,Qt}$$

Where:
$Turb_{comp}$= Turbidity after Compression
$Turb_{inf}$= Turbidity of Influent
$Turb_{eff}$= Turbidity of Effluent
Vol_{comp}= Volume of the foam compressed = $\Pi(2in)^2(467mm) = 3.79L$
Q = flow rate = $3\frac{L}{min}$
t = experiment run time = 5.4min

The current hypothesis being tested is that higher velocities result in cleaner foam (higher NTU in the wash water sample). The procedure described below entails the manual compression of the foam at a constant velocity. It will be difficult to maintain a constant compression rate. We have not taken any steps to ensure a constant rate and so we anticipate some variability in the compression rate, but we will still be able to come to a general conclusion of the efficiency of the cleaning process as a function of the compression velocity. If we continue these tests next semester, we will certainly look into ways to better generate a constant velocity (we have though about using different weights on the plunger). We will test compression velocities ranging from 30 $^{\text{mm}}/_{\text{s}}$-300 $^{\text{mm}}/_{\text{s}}$.

Testing Procedure:

1. Mix clay and tap water in raw water tank to get a turbidity of approximately 200 NTU.
2. Feed raw water and 20 mg/L PACl to the 10 cm diameter foam filter at a 6 mm/s filtration velocity for approximately 5 minutes (flow rate of 50 mL/s).The volume of water filtered was 15 L.
3. Manually compress the foam with a plunger at a constant velocity with another team member timing the compression stroke with a stop watch.
4. Calculate velocity= $\frac{displacement}{time}$.
5. Mix the wash water and measure the volume of wash water.
6. Measure turbidity of the wash water sample in turbidimeter (diluting if necessary).
7. Calculate the total NTU-Liters that were recovered from the filter during washing and compare with the NTU-Liters filtered by the filter.
8. Calculate the ratio of washed NTU-Liters to filtered NTU-Liters as a measure of cleaning efficiency.
9. Repeat steps 1-6 for a wide range of velocities, beginning with a compression velocity that is slower than the expected velocity of the full scale plunger and a compression velocity that is perhaps 40 mm/s (much faster than rapid sand filter backwash velocity.
10. Repeat steps 1-5 to have triplicates for each data point.

Results

	Velocity	Influent Turbidity	Effluent Turbidity	Filtered water (L)	Turbidity after Compression	Wash water (L)	Percent Cleaned
Test 1	$\frac{18.4in}{1.5s} = 312\frac{mm}{s}$	180 NTU	0.7 NTU	15	978.2 NTU	1.321	104.1%
Test 2	$\frac{18.4in}{2.58s} = 181\frac{mm}{s}$	294 NTU	2.28 NTU	15	1530 NTU	1.321	99.1%
Test 3	$\frac{18.4in}{3.36s} = 128\frac{mm}{s}$	234 NTU	1.6 NTU	15	1029.4 NTU	1.321	80.0%
Test 4	$\frac{18.4in}{12s} = 39\frac{mm}{s}$	220 NTU	0.67 NTU	15	250 NTU	1.321	3.2%

Four tests were conducted at a range of velocities. Table 1 above outlines the data collected during each experiment. The primary column worth comparing is the Percent Cleaned. Based on these results, we can confirm our hypothesis that higher compression velocity does in fact clean foam more. We also discovered the approximate minimum velocity needed to completely clean the foam after one plunge as all velocities greater than 181 $\frac{mm}{s}$should clean the foam completely. Over 100% was likely reached in Test 1 due to some extra dirt left in the foam before testing.

Analysis

Feasibility of Pulleys

The amount of foam used in the current design requires an estimated 500 lb. to be compressed to 1/3 of its original volume. The pulleys can be mounted onto the drum in such a way to divide up the required force, which makes the pulleys a feasible and attractive option. The compound pulley system using a block and tackle seems to give us enough compression for now, however there are a number of different pulley combinations that may be tested and implemented to give us even greater compression in the future. For the time being, pulleys appear to be the simplest alternative to the over-designed winch system. A pulley that could handle up to 420 lb. cost less than $6.00 at Lowe's Home Improvement store in Ithaca, NY.

Foam Decompression (Re-expansion)

Ideally we would like to have our foam fit perfectly inside the drum to minimize friction with the drum walls and give us an optimum chance for natural decompression. We have yet to create this perfect fit because we have changed drum types, however foam with a diameter 2.5 cm larger than the drum diameter showed excellent decompression during testing in the drum with tapered sides. Decompression started immediately following the completion of compression with full decompression happening under 30 seconds . While decompression was successful, we are still uncertain about the exact relationship between decompression ability and foam diameter relative to the drum diameter and we look to further test this with new foam matching our straight sided drum diameter. Determining the exact behavior between excess foam diameter and decompression ability would help determine our design constraints and is a subject for future research. The coefficient of friction between the foam and drum wall appears to be much smaller for the plastic drums than for the steel drum used in Honduras.

Side Drain

The siphon proved to be difficult to start (and maintain) and so we searched for alternative methods of draining wash water from the compressed foam. One idea was attaching a bulkhead fitting onto the side of the drum. This would protrude into the space within the drum and provide a gap between the foam and the tank wall next to the bulkhead fitting (involving water passing around the foam rather than through it) . Another suggestion was to attach a Polypropylene Sink Drain to the side of the drum. Paul Charles recommended spin welding a fitting onto the side of the drum, over the use of a Polypropylene Sink Drain as a drain connection to ensure a water-tight fitting. This fitting would be attached by the process of spin welding, which entails cutting a hole the size of the inner diameter of the fitting into the side of the drum and then using a router to melt the fitting into the drum by rotational friction. Custom Plastics

(Custom Plastics), a company that specializes in spin welding, recommended several fittings of diameters 0.25” to 1”. Based on the suggested fittings, a fitting with a diameter of 1” was chosen to minimize the time it takes to drain the wash water. It was determined through “hole in the bucket” calculations (shown below) that draining the wash water from a 55 gallon drum with a diameter of 22” would take 3.1 minutes with a 1” diameter fitting placed 0.4m below the initial height of the water. After ordering in a 1" FPT Raised Heavy Duty Poly-Propylene Fitting from Custom Plastics, the fitting was attached to the side of the prototype/test drum at a height of 16” from the bottom (see pictures below). We hope to run a few trials of cleaning the filter to ensure that the side drain is water-tight.

Solving for time to drain using:

$$t = \left[\frac{D_{drain}}{\left(\frac{K_e * H_{tank}}{2*g} \right)^{1/4}} \right]^{-2} \left(\frac{8 * A_{tank}}{\Pi} \right)$$

Where:

K_e,the sum of minor losses= 2

D_{drain} ,the diameter of the drain= 0.025m

A_{tank}, the area of the drum above the foam= $0.234m^2$

H_{tank} , the initial height of the water above the drain = $0.4m$

We get $t = 3.1$min

Figure 10: Side drain

Flow Controller

In Honduras, one of the main troubleshooting problems was dosing the influent water at a high enough concentration to produce flocs that were able to get trapped in the foam. When the flow controller was first installed, the coagulant dose was too small, meaning even though there were flocs, they were still passing through the porous foam, marginally decreasing the turbidity of the effluent relative to the influent. This problem was remedied by cutting the dosing tube, allowing coagulant to flow faster into the influent water. This semester, we redesigned and fabricated the flow controller system including: the length of the dosing tube, distance between the stock tank, constant head tank, and flow controller in order to properly dose coagulant into the raw water. The flow controller is a PVC pipe with ten holes of equal spacing drilled in. The topmost hole marks where zero dosing is required; the bottommost hole is the maximum flow rate through the tube. Full calculations can be found in the "Flow Controller" Mathcad at N:\RESEARCH\Foam Filtration\Spring 2014\MathCad. As a basis, the design for the flow controller has a chemical stock tank, a constant head tank, and tubing that connects to a PVC pipe with 10 holes used to control the coagulant dosing amounts where the top most hole represents zero dosing flow and the bottommost is max flow, pictured below.

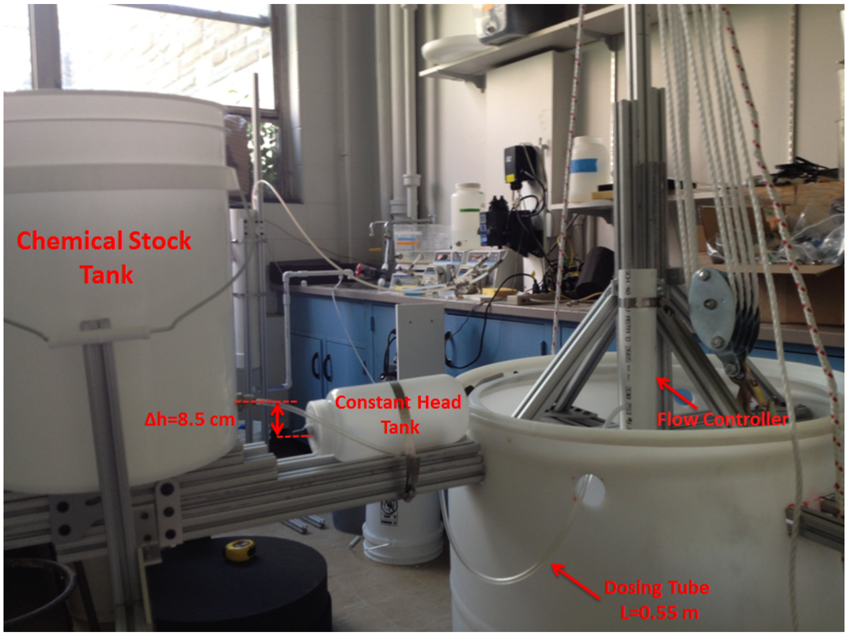

Figure 11: Flow Controller Design

Specifically, the length was found through:

Step 1: Calculate the maximum and minimum flow rate through the tube. This is the maximum flow rate through a dosing tube based on the requirement of minimizing minor losses.

$$Q_{StockMax} = \frac{\pi D^2}{4}\sqrt{\frac{2H_L g \Pi_{error}}{\sum K_e}} = 3.5\frac{mL}{s}$$

$$Q_{StockMin} = \frac{\pi D^2}{4}\sqrt{\frac{2H_L g \Pi_{error}}{\sum K_e}} = 1.1\frac{mL}{s}$$

Where

D is the inner diameter of the tubing at $\frac{1}{8}in$ to avoid clogging

H_L is the maximum doser head loss of $10cm$

g is acceleration due to gravity

K_e is the sum of minor losses in the dosing tubes at 2

Step 2: Calculate the chemical flow rate ($C_{StockMax}$), we predefined the maximum dosage ($C_{FilterMax}$) based on average doses used at other plants and the flow through the plant (Q_{plant}) from discussions with Monroe and Drew.

$C_{FilterMax} = 20\frac{mg}{L}$ used for influent water of 500 NTU
$C_{FilterMin} = 1\frac{mg}{L}$ used for influent water of 5 NTU
$Q_{Filter} = 1\frac{L}{s}$
Therefore,

$$C_{StockMax} = \frac{Q_{Filter}C_{FilterMax}}{Q_{StockMax}} = 5.7\frac{gm}{L}$$

$$C_{StockMin} = \frac{Q_{Filter}C_{FilterMin}}{Q_{StockMin}} = 0.92\frac{gm}{L}$$

This coagulant dose is necessary to calculate the size of the chemical stock tank. The size of the chemical stock tank determines how often coagulant needs to be replenished. A five gallon bucket should suffice for the amount of coagulant used over the period between cleanings.

Step 3: The final step, calculate the length of the dosing tube

$$L = \frac{gH_L\pi D^4}{128\nu Q_{StockMax}} - \frac{Q_{StockMax}}{16\pi\nu}\sum K_e = 0.55m$$

This calculation was compared to the AguaClara Source Code for CDC functions and found to be equivalent. Next, the minimum elevation difference between the float valve orifice and the outlet of the chemical storage tank (Δh) was determined to be 2.6 cm from a manipulation of the CEE 4540 formula:

$$Q_{max} = \Pi_{vc}A_{or}\sqrt{2g\Delta h} = 8.5cm$$

Where:
A_{or} is the area of the float valve 0.09 in
Π_{vc} is the vena contracta constant of 0.62

These design constraints impact how the chemical storage tank, the float valve, and the dosing holes are attached to the foam filtration unit. Because the elevation differences are so small, the components can be directly attached to the drum or a small additional structure that can be attached to the drum. As shown above, the current system utilizes extra 80/20 that comes off the side of the compression unit. While this may not be a permanent design, it was the easiest for this drum.

Conclusion

This semester we have designed a foam filtration unit building off our knowledge of the filters performance in Honduras. We have invested in a HDPE drum with straight sides we can now use as the standard for our system. The compression system has been completely redesigned and now uses 80/20 aluminum extensions for structural support and a complex pulley system to produce our desired compression force. The actual plunging plate contains small holes allowing dirty surface water to flow above the plate. We used spin welding to add a side valve to the unit replacing the siphon technique to remove this dirty water from the top of the plate. In addition, our initial observations of natural foam decompression in a situation where the foam diameter is too big for the drum have been very promising. Through a series of compression velocity tests, we can also confirm that a higher compression velocity does in fact result in cleaner foam. Once we run the current system, we will see the speed at which we can compress the foam, and make any adjustments necessary for the system to reach the target velocity we discovered of approximately 300 $\frac{mm}{s}$, which will theoretically result in a 100% cleaning of the foam. In addition, we have scaled a chemical dosing unit to complete our system. We are excited to have this unit tested in Honduras this summer.

Future Work

Before the new employees of AguaClara LLC leave for Honduras this summer with an operational foam filtration unit, we would like to:

1. Insert a side outlet hole for effluent water with a bulkhead fitting using spin welding on the straight-edged drum
2. Test the completed unit including filtering dirty water and compression cleaning!
3. Create an instruction manual for the assembly and operation of the foam filtration system. This would also include an inventory of materials and methods for tying the appropriate knots.

Now that the full system is complete, it remains to be tested. The unit in the lab should be tested initially, then based on any changes that are made to the system all of the new materials may be ordered to fabricate and send our straight sided drum for formal testing in Honduras.

For future semesters:

1. Continue testing and improving on the design, perhaps finding a substitute for 80/20
2. Determine the behavior of the relationship between excess foam diameter and decompression ability
3. Determine optimal hole size and design of the plunger
4. Design a manifold to direct effluent water out of the side outlet hole

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Inventory of Project Materials

Material	Item Code	Supplier	Price
Polypropylene Sink Drain with Recessed Strainer & Plug	2701K61	McMaster-Carr	$36.04
22"x36" 55 Gallon Drum - Straight Sided, HD polyethylene	135450B	BascoUSA	$168.85
Wall Mounted Pulley - zinc coated steel body, zinc sheave, 420 lb capacity, 3/8" max rope size	348562	Lowe's	$4.58
Single Rigid Eye Pulley - zinc coated steel, zinc sheave, 420 lb capacity, 3/8" max rope size	348597	Lowe's	$5.98
50 ft Braided Nylon Rope - weather resistant, 150 lb safe working load, 550 lb break strength, 1/8" diameter	340003	Lowe's	$8.98
50 ft Braided Polyester Rope - 230 lb safe working load, 5/16" diameter	349229	Lowe's	$5.18
30 ppi foam, 4" height and 22" diameter		New England Foam	
90 ppi foam, 4" height and 22" diameter		New England Foam	
1" fitting for side drain (spin welded)		Custom Plastics	
2" bulk head fitting for effluent		McMaster-Carr	
12" angled pieces for 45 degree brace		McMaster-Carr	
3x2" wide plate with six holes		Amazon	
1" elbow brace		Amazon	
3/4" length stainless steel screws (button head cap)		McMaster-Carr	
1/2" length stainless steel screws (button head cap)		McMaster-Carr	
80/20 (10 series) stainless steel slide-in economy t-nuts		Amazon	
Block and tackle, 7:1 ideal mechanical advantage		Amazon	
Stainless steel spring link, 160 lb working load limit		Lowes	