Foam Filtration Fall 2013

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1 Literature Review

1.1 Article Review

The inaccessibility of safe and cost effective drinking water that meets World Health Organization's standards is a growing concern worldwide. AguaClara research teams have determined that reticulated foam can function as a successful filter media to purify water and also produce higher filtration rates with lower head loss as compared to other technologies. University of Akron researchers Neepa Biswas, William Brian Arbuckle, and Malay Ghose Hajra have also concluded that foam filtration can be very resourceful although it may take a longer time to reach "steady-state turbidity" (2003). They implemented 15, 30, and 45 ppi "flexible polyurethane foam" in the form of packed cubes to minimize "wall effects" with 0, 9, and 29% compression, in columns with depths of 8 ft and diameters of 1 inch. It should be noted, however, that using a packed bed of foam cubes reduces the particle capture efficiency because the water can pass through the large pores created by the cubes. In their experiment, influent water of 10 NTU with a velocity of 4.2 mm/s was mixed with very high PACl concentrations of 500 mg/L and 1200 mg/L. Note that these PACl concentrations are 100 to 1000 times higher than would be expected to be used for low turbidity water. The turbidity broke through the foam after 20 hours. Optimization, in terms of purification efficiency, can be achieved according to their work if multiple columns of foam are used, compression is increased, and pore sizes of foam are increased. Besides the effects of cleaning the foam filters, it is likely that compression increased filtration because it decreased the pore space between the foam cubes therefore decreasing the preferential flow pathways that avoided filtration. Their system of 6 columns with two columns of each foam porosity type reached a breakthrough of 3 to 5.5 NTU after 19 to 22.5 hours depending on compression and ppi. Their conclusion that filter performance, measured by time of breakthrough, deteriorated after 20 hours confirms previous AguaClara teams experiments that filter performance decreases significantly as the filter becomes dirtied. However, this was simply a rough estimate done by Biswas and her colleagues; providing exact data for the lifetime performance of the foam is hard to do when not in the field because of variables that can't be accounted for like biological growth. Ultimately providing an accurate lifetime estimate for the foam will still be a goal of this project. Because the team at the University of Akron used different pore sizes and foam cubes that differ greatly from the AguaClara team, we can't take her data exactly and use it for our field estimates.

AguaClara's Spring 2013 Foam Filtration Team designed a structure to be used in disaster relief and recovery situations. They chose to design a structure made with PVC pipes, two filter columns, and a rapid mixer. However stability and a lack of an optimal design in terms of the PVC structure and the placement of the 90 ppi column were discovered during preliminary operational use. The Fall 2013 Foam Filtration team will create a new foam filtration design incorporating the lessons learned from previous teams.

1.2 Previous Semesters

The Foam Filtration Team came about as a response to growing pressure for the AguaClara plants to add a filtration stage at the end of plants. At the time, foam and sand filters were seen as possible ways of further cleaning the water prior to chlorination. Upon testing, foam was found as an extremely effective means of removing turbidity, even meeting EPA standards of under 0.3 NTU given a raw water turbidity of over 100NTU (Fall 2011 Team). This high efficiency made foam an ideal candidate for Point-Of-Use (POU) filtration. Instead of simply attaching a foam column to the end of an AguaClara plant, it could be used as its own "treatment facility" for communities or even families without access to municipal scale water plants because of their location or economic status (Spring 2011). As time continued, foam of different porosities, or the number of pores per linear inch (ppi), were tested to find optimal usage. 30 ppi was determined to be a better "roughing" filter to remove larger particles, with 90 ppi as a "finishing" filter to remove finer particles (Fall 2011). When the foam is run for an extended period of time, the pores begin to clog, eventually causing "breakthrough" or an inability of the foam to continue to clean the water. A cleaning process was developed to combat buildup of particles by plunging the foam, once the plunger fully compresses the foam it is expanded back to its original height by pulling on strings that are threaded through the foam. Next, the amount of time until failure was tested for various turbidities (Summer 2012). Last semester, a stand was developed to begin simulating potential permanent structures, complete with a linear flow orifice meter (LFOM) to begin the process of dosing the dirty influent water with a coagulant. This is where the Fall 2013 team began testing the stability of the stand and the lifetime of the foam.

2 Introduction

Affordable water treatment systems are needed in communities smaller than 1000 people that cannot support the costs of a flocculation/sedimentation/filtration AguaClara plant. Our challenge for this Fall 2013 semester is to build a cost effective reticulated foam filtration (RFF) system that can treat surface water at flow rates of 1 L/s or less. As a filter media, the high porosity of reticulated foam gives it a high solids loading rate and the capacity to handle a higher filtration velocity over sand. With the expectations of the low flow stacked rapid sand filter (LFSRSF) system being limited to treating water with a turbidity of 5-10 NTUs, a reticulated foam filtration system could be a solution to treating very turbid water that is common during the rainy season in Honduras.

In previous semesters, teams have worked to determine the capacity of the foam. This includes testing foam of different porosity for overall effectiveness of reducing turbidity, amount of time until breakthrough for different influent turbidities, and the idea of foam filtration being an independent point-of-use (POU) system as an emergency backup water filtration system for families. To increase the lifetime of the foam, a method of cleaning involving plunging followed by re-extending the foam was implemented. A recent development of the structure to house the foam and possibly act as a permanent facility was built to determine the overall feasibility of foam filtration. These methods, while effective, require significant troubleshooting and improvement.

The Fall 2013 semester goal is to design, build, and test a cost effective, gravity powered water treatment system plant that integrates a single foam filtration column, a chemical dose controller, a linear flow orifice meter, a rapid mixer, and an easy to use (user friendly) cleaning method to be used in a pilot project in Honduras for January 2014. One critical issue being investigated is whether the reticulated foam filter system can be designed in such a way so that the monthly costs are affordable and economically sustainable. These monthly costs would pay for the chemicals, replacement foam, operator/plumber salary, and maintenance. It was stated by Drew Hart of Agua Para Pueblo (APP) that a monthly cost of $70 Lempiras ($3.42 USD) is unsustainable and that under $40 Lempiras ($1.96 USD) should be the goal. A monthly cost that is affordable is vital to adoption and implementation.

The first task is testing the mechanical failure of 30 ppi and 90 ppi foam to determine lifetime use under different turbidity conditions. The lifetime of the foam will determine how often new foam will be purchased. Once the lifetime is determined to be economically feasible, a more stable and permanent structure will be designed to ensure the greatest efficiency for the filtration system. This system would include a fully functional coagulant doser and chlorination for different flow rates depending on the size of the community the plant would provide for.

3 Methods

3.1 Mechanical Failure Point Testing

The lifetime of the foam was tested by simulating the cleaning cycle of compression and expansion. Testing was performed using the Spring 2013 Foam Filtration team's emergency filtration system that used one 30 ppi and one 90 ppi column with a diameter of 4 inches. Water with an influent turbidity of

200 NTU was created by mixing 0.141kg of clay with water and then added to the 30 ppi roughing column to simulate the breakthrough time at which the 30 ppi foam needs to be cleaned by compression. This simulates when the effluent turbidity of the roughing filter overwhelms the finishing filter. The amount of clay (0.141kg) at failure for a 200 NTU system was calculated

$$\mathrm{C_{con}} * \mathrm{NTU_{Target}} * \mathrm{Q_{Plant}} * \mathrm{Time_{Failure}} = 0.525\frac{\mathrm{mg/L}}{\mathrm{NTU}} * 200\mathrm{NTU} * 0.049\mathrm{L/s} * 2.775\mathrm{hr} = 0.051$$

kg where C is the clay concentration constant that converts clay mass to a target turbidity as derived by fall 2012 foam research to be $0.525mg/L$. Our plant flow rate $Q = 0.049L/s$ came from the derivation $Q = VA$ where our velocity is $6mm/s$ and our cross sectional area of the 23" diameter filter is $12.56in^2$ or $8.107 * 10^{-3}m^2$. The average time to failure at which the system no longer produced clean water for an influent turbidity of 200 NTU was $2.775hours$ as determined by previous teams (Table 1).

1. Once the water and clay were in the system, the 30 ppi column of foam was plunged using a hard plastic circular plunger all the way down to the bottom of the column, then decompressed back to its original shape by pulling up on the foam with string. The 30 ppi column was not plugged, so water moved into the 90 ppi column and out of the system upon plunging. We maintained this clay in the system by catching all of the water the system produced because of sponging, and then adding this clay-water back as necessary to the 30 ppi column. This procedure was repeated 197 times.

2. After 197 cycles, we attempted to plunge the 90 ppi foam column to keep the clay moving through the system. At this point, the column bottom cap came off because it had not been glued and all of the water and clay from the system was lost. This marked the end of the test.

3.2 Minimum Diameter for Expansion

One of the proposed ideas for post-cleaning restoration of foam was natural expansion. This means that after the foam is compressed, at a large enough diameter, it will be able to expand back upwards to its full height. To calculate this diameter we cut$1in^3$ squares of 30 and 90ppi foam and placed them on a scale to find the force required to compress the foam. Results of this downwards force approximation can be found in Table 2 of the Appendix: Foam Compression Tests.

Afterward, upon reflection, the downwards force itself was not so important as the height and Poisson ratio derived in Appendix: Minimum Diameter. These equations yielded a minimum diameter of approximately 36 in, an additional foot wider than the proposed diameter. Later, after deriving these equations we determined that pressure was a varying function with depth because of pore compression. This means that our initial assumption of pressure as a constant was incorrect and if reevaluated, would need to be integrated across depth. However, full re-expansion through upwards force will no longer be the main concern as the foam may perform better when slightly compressed as this decreases the pore size. Additionally, new designs plan on natural re-expansion of the foam, as opposed to the current arbitrary pulling on strings.

3.3 Elasticity and compression forces

A compression test was performed on various dimensions of foam in order to determine its elasticity and resistance to compression. The test was performed by using an electronic balance to measure the amount of force required to reach 20%, 25%, 50%, and 66% reductions in height. 66% reflects the maximum reduction in height possible for our foam material. The 30 and 90 ppi circular foam of 14.75” height x 4” diameter were tested as well as 30 and 90 ppi rectangular pieces of 4” x 2.75” x 1.375”. Measurements of force in kg were converted to units of pressure or stress in N/m^2 by the equation $Strain = Force/Cross\,sectional\,area$. Stress was measured in m/m and defined by $Stress = dH/H_0 = Change\,in\,height/Original\,height$. The stiffness or rigidity of the foam was calculated using the Young’s modulus equation $E = Stress/Strain$ that has units N/m^2.

4 Analysis

4.1 Economic Analysis (Update with exact costs of new foam from Clark Foam Products after obtaining receipt from Casey)

Determining the economic sustainability of a foam filtration plant is critical to the future and implementation of this project. If it is too expensive in terms of monthly costs, communities will avoid adopting and using the technology. The level of initial construction cost defined as affordable has not yet been identified. UNICEF has expressed interest in funding the initial construction cost of a pilot project and possible future projects. The sustainable monthly cost per household target is defined as 40 Lempiras/month and below, courtesy of Drew Hart our Agua Para Pueblo contact. The monthly cost per household is defined as the total monthly costs divided by the number of households. The total monthly costs pays for chemicals, replacement foam, general maintenance, and the operator/plumber salary. Presented in the tables below is an example of the calculations for the monthly cost with 120 households.

Chemicals	
Price of PACl (units?) per kg	L. 18.50
Price of Chlorine (units) per kg	L. 62.50
Transportation cost (for what?) of chemicals per month	L. 100
Average Dose of PACl	12 mg/L
Average Dose of Chlorine	1 mg/L
Monthly Cost of PACL	L. 1,024
Monthly Cost of Chlorine	L. 288
Total Monthly Cost	L. 1,413

Filter Material	
24” diameter x 15” length, 30 ppi	L. 4,476.36
24” diameter x 15” length, 90 ppi	L. 4,599.00
Foam Lifetime Required	6 months
Monthly 30 ppi costs	L. 1,492.12
Monthly 90 ppi costs	L. 766.50
Total Monthly foam costs	L. 2,258.62

Plumber/Operator wage	L. 500
General Maintenance Costs	L. 500
Total Cost	L. 4,671
Monthly Cost/Home (120)	L. 38.93

For an example of chemical calculations $MonthlyCostPAC = AverageDosePACl * PriceofPACl * DesignFlow$. The monthly costs of chlorine and PACL were then summed together to get the Total Monthly Cost. For an example of the filter material calculations, the Monthly 30 ppi Costs of foam (L. 1,492.12) were calculated by taking the total cost of two pieces of 30 ppi foam (L. 8,952.72) and dividing it by the foam lifetime required (6 months). If the 30 ppi foam is going to last at least 6 months, the costs will be spread out over those 6 months. The foam life was calculated by $FoamLifetimeRequired = 663 * (#ofhouseholds)^{-1}$. This equation was formed on the basis of limiting foam costs to no more than 20 Lempiras/month or half of the max sustainable monthly cost. The rest of the costs (chemicals, maintenance and operator wage) make up the other half or 20 Lempiras/month of the monthly cost/home of 40 Lempiras/month. The equation describes how long it will take a specified number of households to pay for a complete set of new foam if each household contributes 20 Lempiras/Month. This in effect translates to the minimum lifetime of the foam because a community does not want to be paying for more than 1 set of foam at a time. The costs described for the Plumber/Operator wage and General Maintenance Costs are not currently known so the estimates in the tables above are hypothetical. However, it does demonstrate that any combined maintenance and operator wage above 1,000 Lempiras is likely to be greater than 40 Lempiras/month. leaving the monthly Cost/Home with a degree of variability. As a reference point, the average salary of a typical full scale AguaClara plant operator is 4,000 Lempiras/Month which is unsustainable for this project. One observation about the economic model used is that it does not use the true lifetime of the foam. One set of foam may very well last for more than 1 year which will result in savings and thus lower monthly costs. The opposite may also be true and that the foam may last less then the required lifetime due to human or natural events which will result in increased monthly costs. Adding both a risk and savings element to the economic model may help produce a more realistic cost. The largest uncertainty in costs remains to be the true lifetime of the foam where it can no longer be effective as a filter for drinking water as well as the variables that cause this decrease in effectiveness.

4.2 Mechanical Failure Analysis

Mechanical failure can be defined on both a macro and micro scale. On the macro scale, the ripping or tearing of the foam can create a preferential flow path that can decrease the filtration efficiency on the system and render it unusable. On the micro scale, the collapse of a pore's cellular structure through a combination of cell wall buckling, breaking, and the formation of a plastic hinge in the cell wall will result in reduced void space and decreased expansion after compression (Gibson & Ashby, 1999). The two 30 ppi foam in series reached 197 cycles of compression and decompression before testing ended due to unglued pipes separating and partially flooding the lab. The breakthrough point of mechanical failure was unable to be determined but it gave insight into what defines a structurally sound system. For example, the PVC columns containing the foam need to be adequately supported to handle the downwards force used for compressing the foam. An interesting observation after testing was the discovery of PVC particles embedded in the sides of the foam that is likely due to the friction created with the PVC interior walls during compression. During testing, the method of plunging was not only tedious and hard to examine for the degree of compression, but it failed to work on the 90 ppi foam because the plunger could not fit into the 90 ppi column due to interference with the pipe that releases water from the 30 ppi column to the 90 ppi column. Furthermore, when the 30 ppi foam is plunged, the turbid water accumulates on top of the foam, suggesting that a valve on top of the foam should be implemented for cleaning purposes. However, even after 197 pumps the foam was intact and doing its job, thus the mechanical durability of the foam can be concluded as independent from the efficiency of the foam. In addition, the system would be greatly simplified if both the roughing and the finishing filter were put in the same column, stacked to give 45" of foam filtration. This would allow us to use just one column and clean every filter via the plunging method in one effort.

4.3 Structural Analysis/Compressive Strength of Foam

A 23" diameter filter column will require a large force in order to compress the foam. In order to calculate this force, we compressed the foam to varying heights on an electronic scale. The results (Table 3) indicate that for every square inch of foam, approximately 1kg of weight is needed to compress it 66%. When applied to the new system with a 22in diameter and 35in height this surpasses the amount of force a plant operator would be able to apply, approximately 840 kg. Therefore a lever arm is proposed as a possible idea to add the additional force to make compression possible for one person . Another major consideration in designing a new filter is to have foam large enough in diameter to be capable of decompressing itself after cleaning. If the foam could decompress without manual labor, this would significantly cut down on the maintenance. The thought process behind this was as follows:

- There is a downwards force pushing on the foam from the plunger with an equal and opposite force coming from the foam once it reaches compression.
- The compression of the foam causes slight side expansion where the foam pushes on the walls of the filter column.

When this was tested on a 4-inch diameter filter, the foam only re-expanded to about a quarter of its previous size. More analysis will be done to calculate the minimum diameter needed for 100% re-expansion of foam. After discussing these findings with a PhD candidate in the Fracture Group at Cornell University, the findings seem valid enough to suggest that a larger diameter foam filter would in fact be able to re-expand itself.

The results of the foam compression and elasticity test are represented in the two tables below.

90 ppi 4” Diameter x 14.75” Height

Height Reduction %	**Force (kg)**	**Stress (N/m^2)**	**Strain (m/m)**	**Young’s modulus (10^6 N/m^2)**
20% (11.8”)	**1.9, 2, 2**	**2,419**	**0.00399**	**0.606**
25% (11.06”)	**2.3, 2.25, 2.3**	**2,782**	**0.00533**	**0.522**
50% (7.375”)	**3.3, 3**	**3,810**	**0.0120**	**0.317**
66% (5.00”)	**4.7**	**5,685**	**0.0163**	**0.348**

Required output force for 90 ppi 24” diameter foam

Height Reduction %	**Force (kg)**	**Force (lbs)**
20%	**2 x 36 = 72**	**158.7**
25%	**2.3 x 36 = 82.8**	**182.5**
50%	**3.15 x 36 = 113.4**	**250**
66%	**4.7 x 36 = 169.2**	**373**

30 ppi 4” Diameter x 14.75” Height

Height Reduction %	**Force (kg)**	**Stress (N/m^2)**	**Strain (m/m)**	**Young’s modulus (10^6 N/m^2)**
20% (11.8”)	**2.25, 2.4 2.25**	**2,782**	**0.00399**	**0.697**
25% (11.06”)	**2.5, 2.44**	**2,988**	**0.00533**	**0.560**
50% (7.375”)	**3.9, 3.5, 3.7**	**4,476**	**0.0120**	**0.372**
66% (5.00”)	**5.6**	**6,774**	**0.0163**	**0.415**

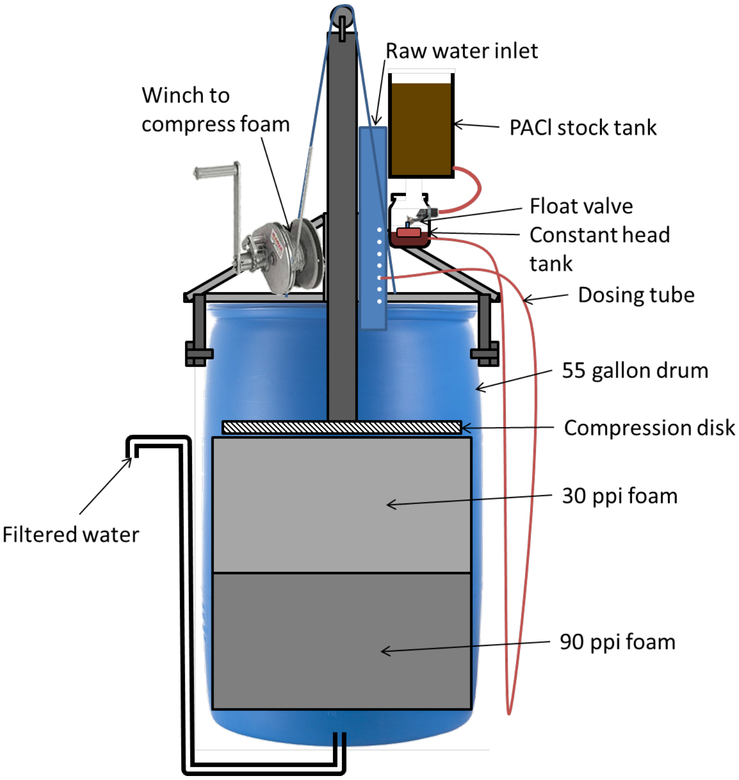
Required output force for 30 ppi 24" diameter foam

Height Reduction %	**Force (kg)**	**Force (lbs)**
20%	**2.3 x 36 = 82.8**	**182.5**
25%	**2.47 x 36 = 88.92**	**196**
50%	**3.7 x 36 = 133.2**	**293.6**
66%	**5.6 x 36 = 201.6**	**444.3**

5 New Designs for a Foam Cleaning System

Five new designs with a focus on simplicity and ease of use have been considered for creating the next iteration of the AguaClara Foam Filtration System. The first design is the use of a mechanical pulley system (exact device needs confirmation) and a cylindrical concrete weight for compression. The pulley system would allow the operator to safely control the descent and compression of the foam with the concrete weight. The concrete would have a few holes to allow the flow of water to the top of the drum container. The second design would use a winch and pulley system that wraps around the drum and connect to a PVC disk that would compress the foam. Winding the winch in one direction would tighten the cable wrapped around the drum and apply pressure to the PVC disk to compress the foam. The third design option involves a lever and threaded screw system attached to the PVC disk. The operator would rotate the screw head (potentially having spokes coming out of it) and be able to thread the screw downwards to apply a force to compress the foam. A support structure would be attached to the drum to hold the screw system and PVC disk in place. The fourth design option is a compound lever system similar to the mechanics of a fingernail clipper. A system of two levers with a support system would allow a downwards force to be applied to the PVC disk, allowing the operator to pull down and use their weight/gravity to their advantage. The fifth design, and the design we have ultimately decided on for Honduras 2014, is a modification of design No. 2 and uses a ratchet lever hoist ("come-along") and pulley system to apply a downward force on a steel disc. A support structure consisting of a vertical outer (telescoping) steel pipe is attached by flat steel bars on 4 equidistant sides at both 45 and 90 degrees to the inner wall or rim of the drum. A long steel pipe with threads on one end would then go through the outer steel pipe and then connect to a steel disk. The insertion of a small pin through both pipes would elevate the disk above the foam when not in use. Finally, the ratchet lever hoist and set of pulleys would be able to pull the inner rod through the outer rod and compress the foam.

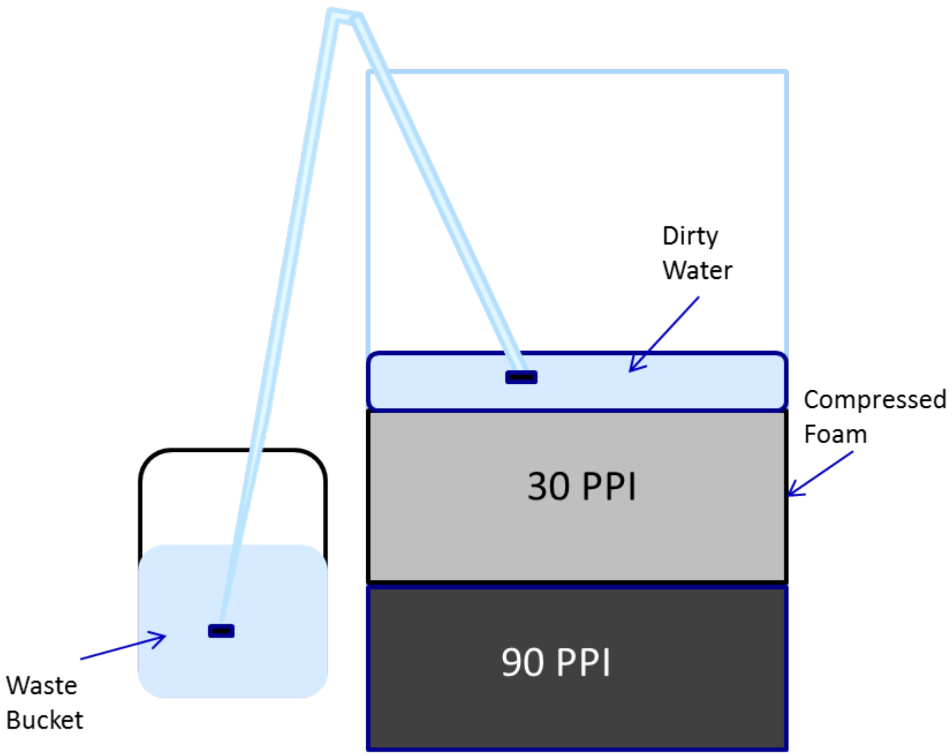
5.1 Ratchet lever hoist and pulley system (Design 5)



Source: Director of Agua Clara Monroe Weber-Shirk

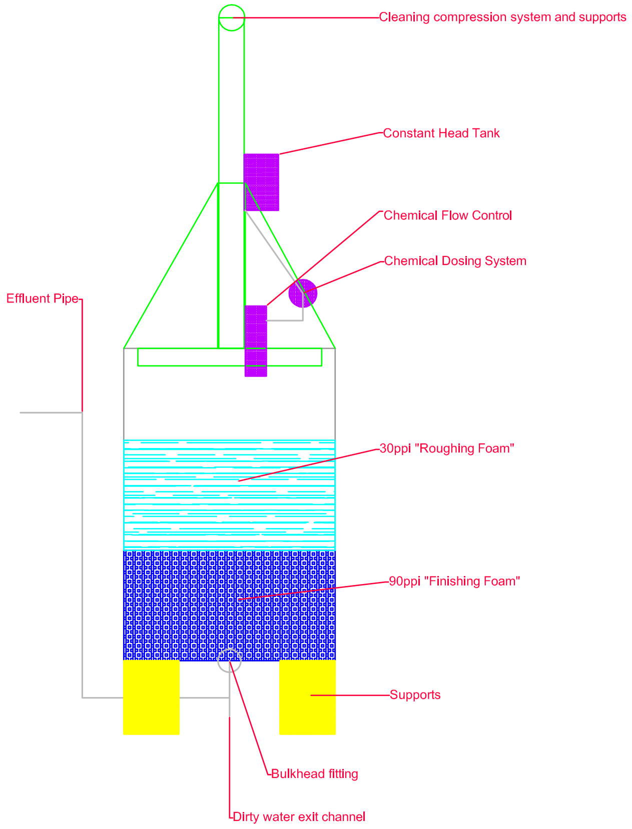
5.2 Siphon

In the act of compressing the foam from the past Foam Filtration team's filter, some of the dirty water displaced from the foam was not able to exit through the exit valve on the bottom. Instead, this water remains on top of the foam until it eventually flows back into the filter. Because of this, we have decided to include a 6-8 foot siphon made from flexible tubing in our new design. The siphon tube will come from the top of the drum and sit on the uppermost surface of the foam such that, when the foam is compressed, the "dirty" water that arises on top of the foam can be siphoned out. The siphon will have a valve on both sides so that it can be taken out at any time and remain primed. The thinking behind the siphon is to ensure that the foam is thoroughly cleaned of dirt and to potentially prolong the lifetime of the filter



6 New Design

In order to accommodate 1 L/s flow rates for a community with 100 families as requested by Drew Hart, the filter would need to be scaled to approximately 18" in diameter. This will require an entirely new design. The new design will consist of a single 55 gallon drum (approximately 23" in diameter and 40" in height) to house our foam because they are large enough in diameter and easily available in Honduras. This drum will house foam units 22" in diameter and 4" in height. Our tentative design is to have at least (3) 90 ppi units which will stack to 12" of 90 ppi finishing filter, and (4) 30 ppi units which will stack to 16" of 30 ppi roughing filter. Stacks of 4" foam also give our unit flexibility to accommodate head loss caused by varying conditions because we can easily add or remove roughing filter. Our system will also consist of a scaled down version of the AguaClara coagulant and chlorine dosing system.

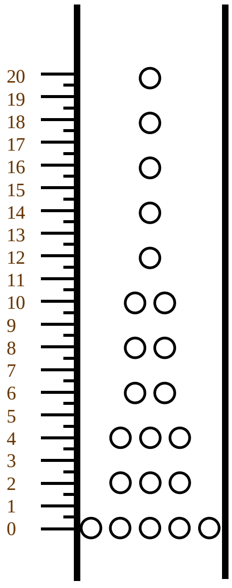


6.1 Frame

The frame for the new design must meet the constraint of getting the 55 gallon drum at least 6 in off of the ground in order to facilitate the bulkhead fitting, exit channel for dirty water, and the effluent water pipe. However, the supports can be constructed of any convenient material such as cinder blocks in Honduras.

6.2 LFOM

A linear flow orifice meter (LFOM) is an AguaClara technology to measure the flow into the system. This works by having a storage space for inflowing water that will make its way through a series of holes of varying amounts drilled into a pipe (pictured below). As the water level in the storage space rises, the amount of water flowing into the system is directly proportional to the height of the water.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Under the guidance of Casey Garland, a MathCAD file was created to generate potential LFOMs for low flow conditions. The end result for a 1L/s flow comprised of 10 rows with the 3/8th inch diameter holes numbered per row as such:

Row	Number of Holes
9	1
8	1
7	1
6	1
5	2
4	1
3	2
2	2
1	2
0	7

More specific details on the set up of the LFOM can be found at N:\RESEARCH\Foam Filtration\Fall 2013\MathCAD as LFOM Foam Filter.

6.3 Flow Controller

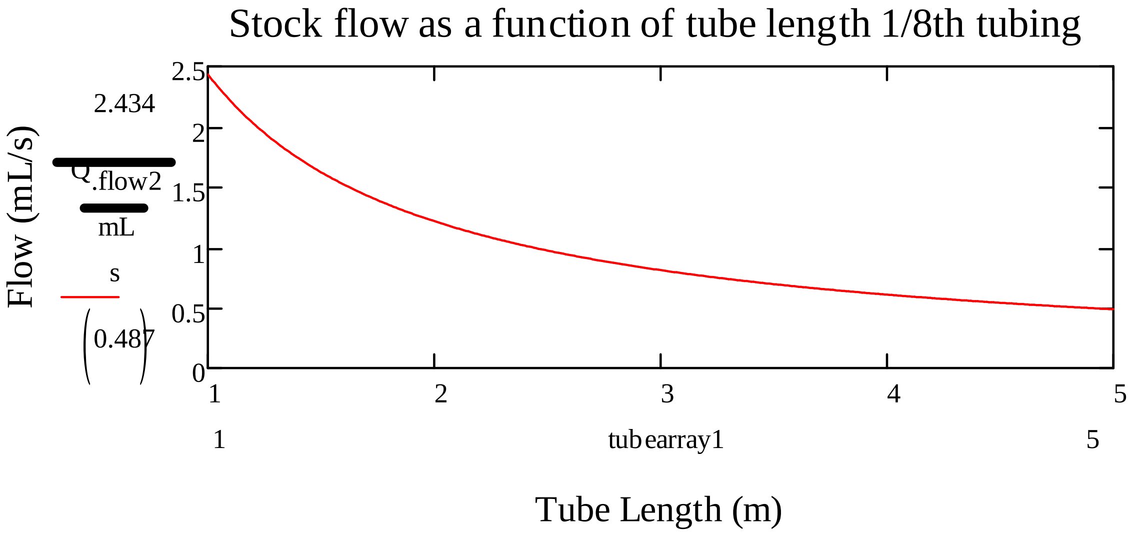
The flow controller controls the amount of coagulant entering the system. Operators adjust the amount of coagulant entering the plant by changing the location of tubing seen in the figure below. The topmost hole is at equilibrium, where no coagulant is entering the system. This is much simpler than a full chemical dose controller (CDC) because it will not require a full lever. Since the flow controller, it will be mounted directly on the system, making shipping easier.

Where optimal flow from the stock tank (Q_{flow}) was derived under the relationship:

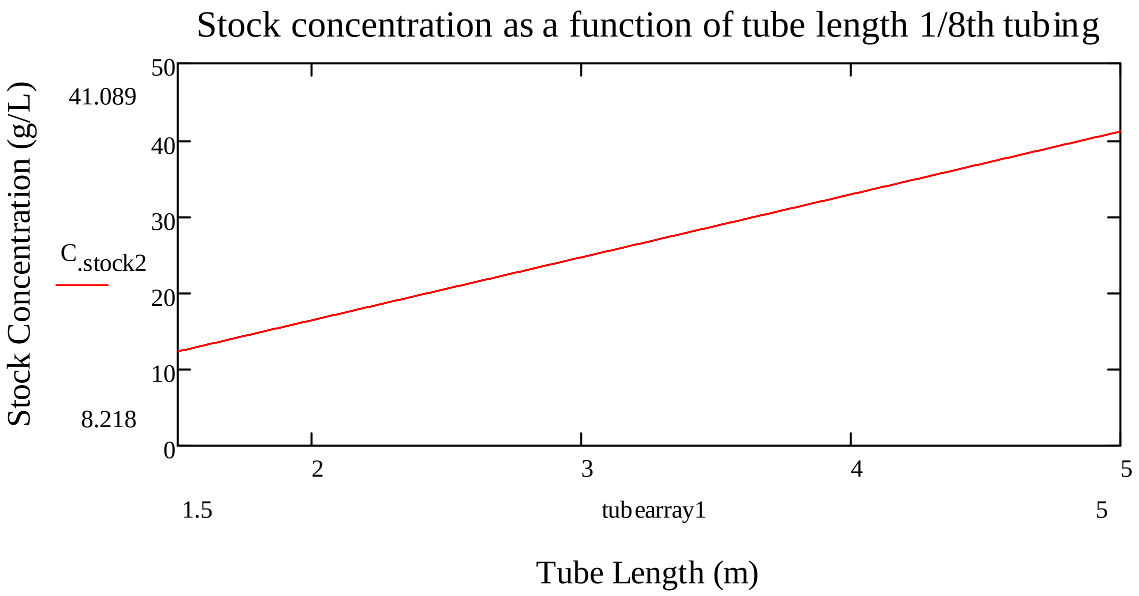
$$Q = \frac{h_f g \pi D^4}{128 \nu L}$$

with the constraints $Q_{plant} = 1^{\mathrm{L}}/_{\mathrm{s}}$,$Dose_{Max} = 20^{\mathrm{mg}}/_{\mathrm{L}}$,$C_{stock} \leq 200^{\mathrm{g}}/_{\mathrm{L}}$,$h_f =$ 10cm. A simulation was run in MathCAD at different possible lengths of the tubing to get a range of Q_{flow}. Since Q_{flow} had to be linear, this narrowed scope of potential tube lengths. From this scope, a range of possible concentrations in the stock tank (C_{stock}) was calculated which, from information gathered about other plants, could not be greater than 200 or 260mg/L.

For 1/8th inch tubing the results were as follows:

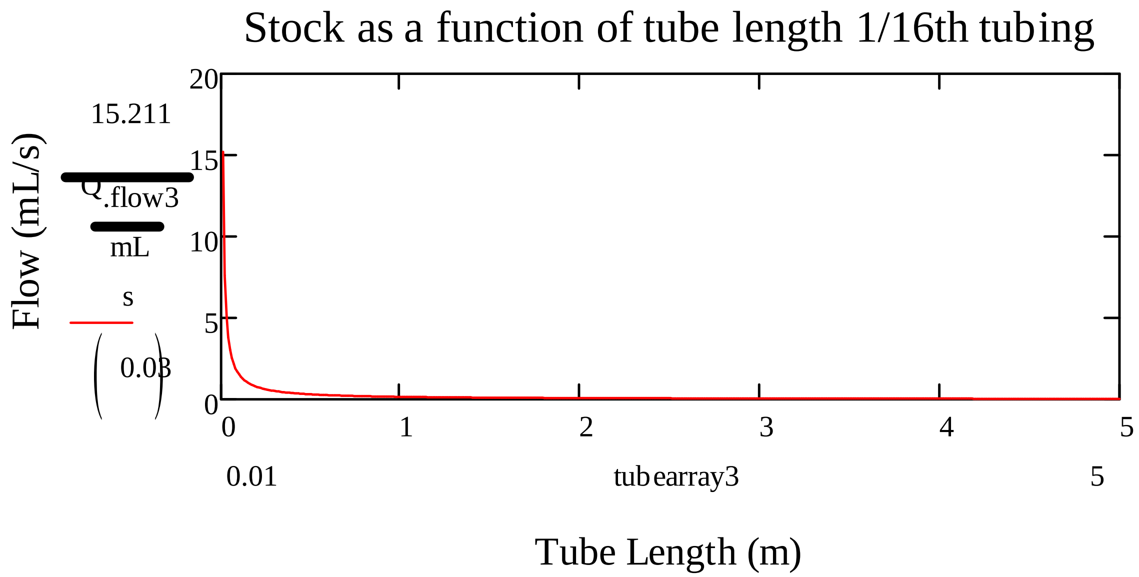


This means the range of flow had to be within 2.5 to 5m, resulting in stock concentrations of:

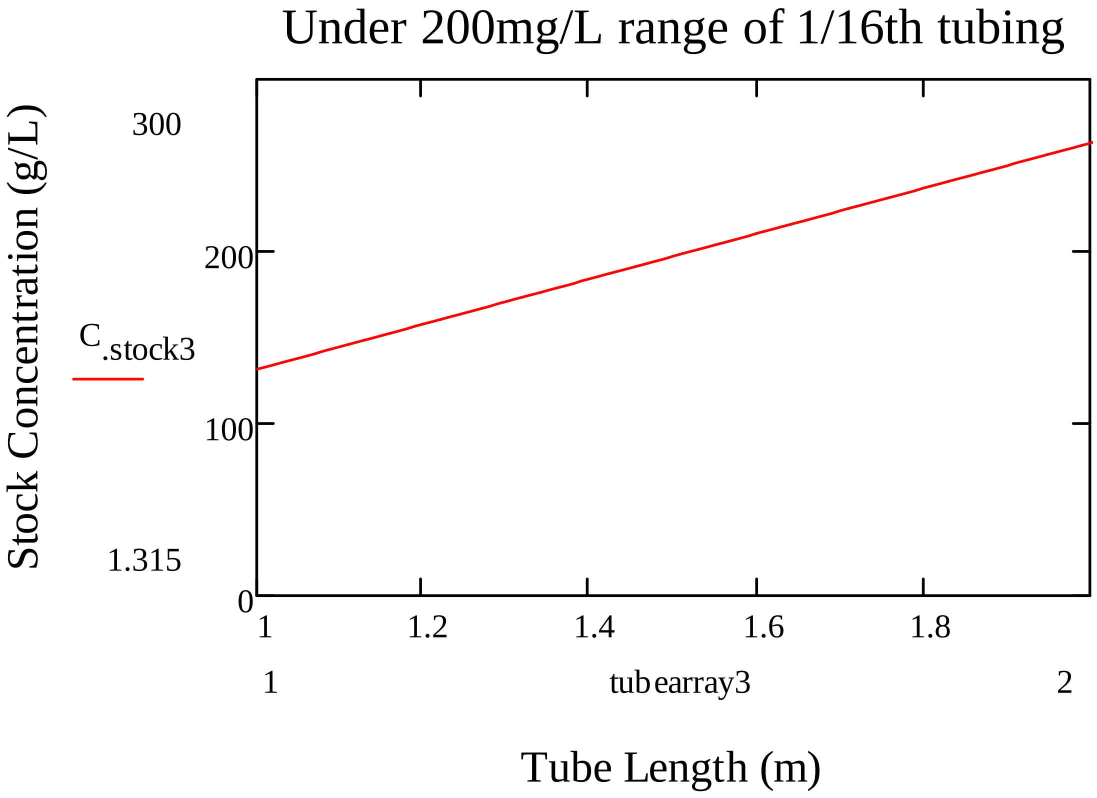


Narrowing the stock concentration from 20mg/L, the maximum dosing concentration, to 200g/L, the 1/8th inch diameter tubing can be from 2 to 5 meters long, having a stock concentration a max of 41g/L and a flow of approximately 0.5mL/s.

For 1/16th tubing



This plot illustrates that after 1m flow becomes relatively linear. The new constraint results in a stock concentration of:



Therefore ideal tube length is between 1 and 1.8m. Even though this is a shorter length and a closer to the dosing of full AguaClara plants, there is a high risk of the coagulant clogging such a small diameter of tube. After some consideration, it is probably more reliable to have a slightly longer and wider tube at a smaller concentration. More detail can be found in the MathCAD file N:\RESEARCH\Foam Filtration\Fall 2013 as FlowControllerDesign.

6.4 Effluent Pipe Sizing

The diameter of the effluent pipe size was calculated with the use of the total total pipe diameter equation $D_{PipeTotal}\left(Q_{plant}, h_{target}, L_{tube}, K_{tube}, \upsilon, \epsilon_{pvc}\right)$ with $Q_{plant} = 1\,L/s$, $h_{target} = 3\,cm$, $L_{tube} = 33in$, $K_{tube} = 2$, $\upsilon = 10^{-6}m^2/s, and\, \epsilon_{pvc} = 0.0015\,mm$. Acceptable head loss was chosen as 3 cm which yielded a pipe diameter of 2 in.

6.5 EPA P3 Competition

This semester, the Foam Filtration team also submitted an application to the EPA P3 competition. The design for the competition marketed the foam filtration unit as an emergency use system, with all components packaged into one

55gallon drum. The original draft can be found at: https://docs.google.com/a/cornell.edu/document/d/1cnz8nQ90_5c1I4QDN49FAJiADC Y9X39OJ6d9YqEZQCU/edit?usp=sharing.

7 Conclusions

Early experimentation highlighted the need for redesigning the original PVC structure housing the foam unit. This new design has all the foam components in one 55 gallon drum with a 23” diameter. While the original cleaning method depended on a manual plunger system, the force one adult can exert is not enough to compress the foam entirely. Therefore, a “come-along” will be used to exert a force between 500 and 1000 pounds to compress the foam. Dirty water that pools on top of the compressed foam will be removed by a siphon of flexible tubing. Additionally, an LFOM and linear CDC will work to control influent water conditions. These will be strapped and attached to the outer diameter (telescoping) pipe. Once the water exits the foam, it will leave the housing unit through a bulkhead fitting to a storage tank where it will be chlorinated. It has yet to be determined if the system will meet the criteria of being under 40 Lempiras/month per household but results from the foam mechanical failure test suggest that physical tearing of the foam from plunging will not be the reason system fails. The foam team also worked on submitting an EPA P3 proposal for grant funding.

8 Future Work

In order to maximize the efficiency and longevity of the system, a more stable and reliable system needs to be designed. The new system needs to address the same issues of how to compress the foam and best design a system that is both flexible and easily packable for potential disaster recovery applications. A key component will be determining a method that can compress the foam quickly and displace the water all at once so as to best clean the foam. The foam can be compressed a variety of ways, so modifying and optimizing our five designs to give us quick and reliable compression is the future of the project. Another problem that needs to be addressed is the decompression of the foam. The ideal system will be one that both compresses and decompresses the foam entirely. Additionally, a rapid mixer that can achieve mixing of the coagulant for a wide range of turbidities using LFOM technology and a chemical dose controller for both coagulant and chlorination needs to be integrated into the system. Once added, these components will make a complete water treatment system that is capable of providing water for communities smaller than what a full AguaClara plant can provide. While designing these parts, simplicity for a plant operator will be a key component.

After the trip to Honduras this January, changes to the new design are expected. Future work is subject to change based on suggestions and critiques received during our initial presentation. Tests should be run to develop operator guidance for when to clean the foam. The designs for community water treatment facilities and for emergency use should be allowed to evolve independently given the different constraints on the two target uses for this technology.

9 References

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Special thanks to Albert Cerrone, Ph.D candidate in the Fracture Group of Cornell University for his consultations about the compressive strength of foam.

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10 Appendix

Mechanical Failure Testing

Figure 1: 30 ppi foam after 197 cycles at 200 NTU, noticeable PVC debris

Figure 2: 30 ppi foam without handle after 197 cycles at 200 NTU

Figure 3: 30 ppi foam with handle after 197 cycles at 200 NTU

Figure 4: Structure leaking from multiple points throughout experiment

Foam Compression Tests

Table 2: Foam Compressibility for a $1 in^2$ of foam

	Weight of foam	Weight to Compress
30 ppi	0.98g	1.0kg
		1.1kg
		1.3kg
90 ppi	0.97g	1.2kg
		1.1kg
		1.3kg

of the water and clay from the system was lost. This marked the end of the test.

Minimum Diameter

$P = \frac{F}{A}$

$F_{upwards} = P * A = P * \frac{\pi * d^2}{4}$

$F_{downwards} = P * \pi * d * h * \mu_F$

$F_{upwards} = F_{downwards} \Rightarrow \frac{d}{4} = h * \mu_F$

$d_{min} = 4 * h * \mu_F = 4 * 45in * 0.2 = 36in$