Foam Filtration

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December 6, 2012

Abstract

For large municipal communities, full scale AguaClara plants are necessary to treat the large demands. For smaller communities made up of 20 families or even fewer, such a treatment plant does not make economic sense. In such cases, a small scale treatment option such as foam filtration is more feasible. The foam filtration device that students at Cornell University have developed can significantly reduce influent turbidity below even EPA standards. This paper outlines additional contributions that we have made to the workings of this system. These include establishing a way of delivering water to the system without the use of electricity, creating a Chemical Dose Controller (CDC) for coagulant and chlorine that operators can easily manage, and exploring methods of detecting breakthrough from the roughing filter.

1 Introduction

For our portion of the AguaClara project, we have been assigned to improve on the previous design of the foam filtration system. Our tasks build off the previous system. We added a CDC for coagulant and chlorine to the system, developed an operator friendly method of determining when to clean the filter, and developed a way to run the filters without electricity. Finally, we designed a Secchi Disk to measure the turbidity of the roughing filter so operators can easily determine when to plunge the roughing filter. We also wrote an easy-to-use operations manual in Spanish.

2 Literature Review

2.1 Previous Filter Experiments

Originally, the foam filtration system consisted of a single 90 ppi (pores per inch) filter alone, but that caused too much headloss [1]. As a result, a 30 ppi filter was added so high turbidity water (up to 100 NTU) could be filtered without overwhelming the 90 ppi filter [2]. Having the roughing filter before the finishing filter also extended the life of the finishing filter and the performance of the filtration system [3]. The roughing filter has the ability to treat turbid influent up to 100 NTU without overwhelming the finishing filter. One design that was tested consisted of two roughing filters in parallel so one could be cleaned while water is being filtered through the other [3]. This design was scrapped because the second filter was not necessary since the cleaning process is simple and quick.

Cleaning both filters requires a plunging method that flushes the particles through a release valve located towards the bottom of the filter. The "plunger" consists of a 1.2m PVC pipe with a disk attached to the end. Originally, it was proposed that the filters were to be cleaned once every eight hours, but was reduced to once every four hours. This was found to be the longest period of time that the filter could run at varying turbidity without needing to be plunged [3]. Compressing and decompressing the filter can affect the performance of the foam, but plunging at this interval did not appear to have a profound effect on the filters performance. The lifespan of the filter appears to be 1 month with regular use at a range of turbidity. Water cannot be filtered through the system while it is being cleaned. Cleaning the filter uses approximately 3.79 liters of rinse water [3].

At this time, headloss is not a viable indicator of when the filter should be cleaned as shown in Table 1 [4]. Terminal headloss depends on both influent turbidity and the condition of the foam over the course of its life cycle. Even with both the roughing and finishing filter, it has been determined that coagulant is needed for the foam filtration unit to be effective [4].

Researchers unaffiliated with AguaClara have also focused their efforts on determining optimum filtration. Biswas et al. determined a relationship between breakthrough time and the degree of media compression and pores per linear inch [5]. They found that the breakthrough time increased as the foam was decompressed, with a compression of 0% giving the longest breakthrough time. Additionally, they found that the more porous the foam was, the longer the breakthrough time. Furthermore, Biswas noticed that foam filters have a ripening time leading up to optimum filtration. Filters require a certain amount of influent to pass through the medium before they reach optimum removal efficiency; this is defined as the ripening time. Past AguaClara students have made similar observations, recommending that the filters be left saturated in water until the foam needs to be changed [4].

2.2 Chemical Dose Controller Design

AguaClara researchers have developed a constant head dosing system for delivering coagulant or chlorine to a system. The doser consists of a float valve that creates a constant elevation of fluid at the inlet to the flow control system. The chemical flow is varied by varying the elevation of the end of the flexible tube coming out of the doser, creating a change in head [6].

Table 1: Comparison of Summer 2012 Experiments [4]

Experiment	Influent Turbidity	Time to Breakthrough	Roughing Head Loss (cm)	Finishing Head Loss (cm)	Average Overall pC*
1	100NTU	7h 5m	44.03	20.64	3.71
2	100NTU	8h 9m	49.03	11.96	3.75
3	100NTU	8h 4m	44.58	13.87	3.32
4	200NTU	2h 3m	20.05	22.027	2.83
5	200NTU	3h 31m	30.68	29.49	3.62
6	450NTU	2h 6m	33.96	23.37	4.01
7	450NTU	1h 23m	25.60	11.13	4.02
8	450NTU	1h 25m	27.15	10.46	4.02
9	1000NTU	50m	20.74	10.90	4.05

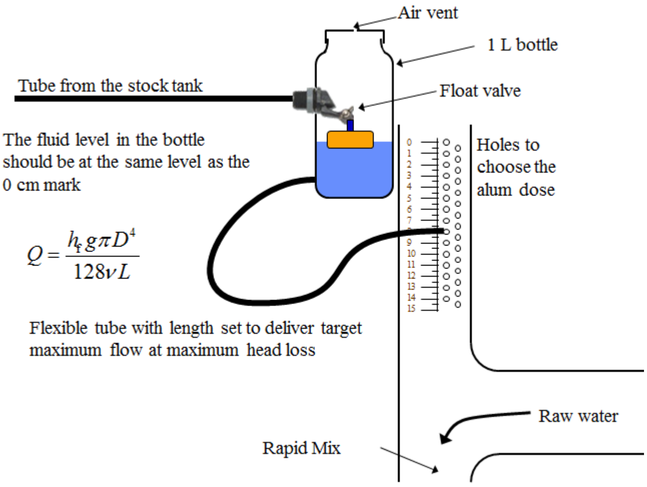


Figure 1: Chemical dose controller schematic [6].

2.3 Secchi Disk

A Secchi disk is a black and white disk mounted on a pole or line and slowly lowered down into the water until the pattern on the disk is no longer visible. The depth at which visibility is lost can be taken as a measure of turbidity and is known as the Secchi depth [7]. Secchi disks are easy to fabricate and to use; thus, they are ideal in situations where an expensive or electricity intensive turbidity meter cannot be readily installed.

3 Methods/ Analysis

3.1 Coagulant Doser

The system was originally designed for experiments around a computer that controls the coagulant dose delivered to the mixing tank. One of our tasks for this semester was to create a coagulant doser that works without electricity. We used the AguaClara design for our system (Figure 2).

This dosing system has been used by other members of the AguaClara team. To set up this system, we used Mathcad to calculate the necessary height of the stock tank, coagulant tank, and dosing tubes.

To solve for the neccessary height of the dosing tube at various NTUs, we first found the empirical ratio of influent turbidity to PAC (Equation 1).

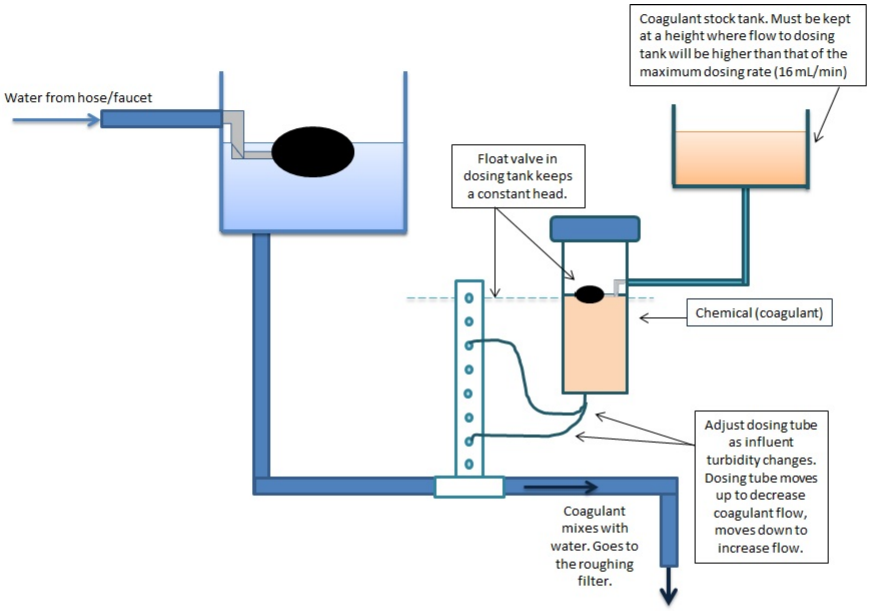
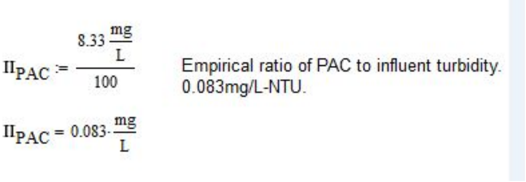


Figure 2 : Constant head tank and coagulant dosing system.

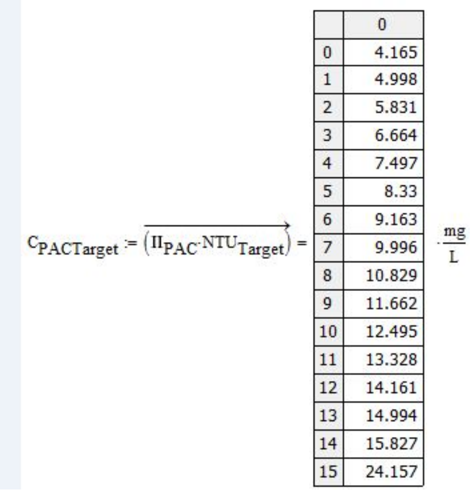


$$\Pi_{PAC} := \frac{8.33 \frac{mg}{L}}{100}$$

Empirical ratio of PAC to influent turbidity. 0.083mg/L-NTU.

$$\Pi_{PAC} = 0.083 \cdot \frac{mg}{L}$$

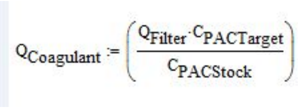
Equation 1: Empirical ratio of PAC to influent turbidity.



$$C_{PACTarget} := \overrightarrow{\left(\Pi_{PAC} \cdot NTU_{Target}\right)} = \cdot \frac{mg}{L}$$

	0
0	4.165
1	4.998
2	5.831
3	6.664
4	7.497
5	8.33
6	9.163
7	9.996
8	10.829
9	11.662
10	12.495
11	13.328
12	14.161
13	14.994
14	15.827
15	24.157

Equation 2: Range of PAC concentrations given a range of turbidity from 0-200 NTU and 400 NTU.



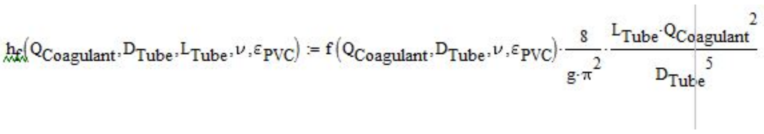
$$Q_{Coagulant} := \left(\frac{Q_{Filter} \cdot C_{PACTarget}}{C_{PACStock}}\right)$$

Equation 3: Coagulant flow given filter flow, range of PAC concentrations, and the concentration of the PAC stock.

Using the empirical ratio, we next used a range of NTU values to solve for a range of PAC concentrations (Equation 2). We chose to use a range of 0 to 200 NTU since these values seemed reasonable for normal operating conditions in Honduras. We also included an estimate for 400 NTU to demonstrate the scaling of the chemical doser.

Finally, we solved for coagulant flow (Equation 3). From this, we found a range of coagulant flow rates ranging from 0 to ~30 mL/min. An earlier Foam Filtration team had found that the foam filter could work effectively without coagulant at an NTU of <5, so we calibrated the CDC to reflect this.

Once we obtained the flow of the coagulant, we chose a diameter of 1/16th inch for the dosing tube. We picked a diameter that we felt was reasonable given the flow of coagulant.



$$h_f(Q_{Coagulant}, D_{Tube}, L_{Tube}, \nu, \varepsilon_{PVC}) := f(Q_{Coagulant}, D_{Tube}, \nu, \varepsilon_{PVC}) \cdot \frac{8}{g \cdot \pi^2} \cdot \frac{L_{Tube} \cdot Q_{Coagulant}^2}{D_{Tube}^5}$$

Equation 4: Dosing tube heights for varying flow rates.

Headloss (cm)	NTU Range	#
0	**<5**	**1**
2	**5-30**	**2**
4	**30-50**	**3**
6	**50-70**	**4**
8	**70-100**	**5**
10	**100-120**	**6**
12	**120-150**	**7**
14	**150-170**	**8**
16	**170-200**	**9**
18	**200-220**	**10**
20	**220-250**	**11**
22	**250-280**	**12**
24	**280-300**	**13**
26	**300-330**	**14**
28	**330-350**	**15**
30	**350-380**	**16**
32	**380-400**	**17**
34	**400-430**	**18**
36	**430-450**	**19**

Table 2: Shows the relationship between headloss in centimeters and selected NTU ranges.

Since the numbers we found weren't round numbers, we created a range of NTUs for a coagulant dose. We assumed that when picking the coagulant for this range, it was better to pick the dosing height associated with the greater NTU. The height of the tube changes very little over a range of NTUs, so for example, if the NTU was between 5-30, so we chose the dosing tube height associated with 30 NTU. The headlosses we determined are shown in Table 1.

The headloss values correspond to the height the coagulant tube must be to get the desired flow rate.

3.2 Chlorine Doser

We developed a system similar to the coagulant doser. Thus, the equation for the flow of chlorine is based on the same formula for the flow of coagulant (Equations 1-3).

AguaClara uses a maximum concentration of chlorine of 2 mg/L, so we chose the same target value for our system. The chlorine doser works the same way the coagulant doser does by using gravity and the appropriate headloss to produce the flow desired. We chose a dosing tube with the same diameter and length as the dosing tube for the coagulant doser. The flows produced correspond to a chlorine concentration range from 0-2 mg/L. Ideally, the plant operator should have some leeway in choosing the chlorine dose, but as the flow is so low, the spacing between the dosing holes would be too close if we were to include a range similar to the coagulant doser.

3.3 Detection Methods

To create the Secchi Disk we cut a plastic disk 8.75 cm in diameter and painted it in black and white quadrants. We attached the disk to a metal pole about 0.45 m long, long enough to lower into the finishing tube.

As we were testing the effectiveness of the Secchi Disk at 5 NTU, we realized that this device would not be accurate enough to test low turbidity waters. It would only be useful in more turbid waters. We noticed in the roughing filter effluent when the disk was lowered until it just touched the filter at 20 NTUs, it was difficult to see the Secchi Disk. Thus, the Secchi Disk would be useful for measuring higher turbidity waters and is a good way to measure the finishing filter influent and possibly then determine the breakthrough time.

At low NTUs the Secchi Disk was ineffective, therefore it is not recommended.

We searched for other methods of determining the NTU before the finishing filter. We found that a previous AguaClara team researched different methods

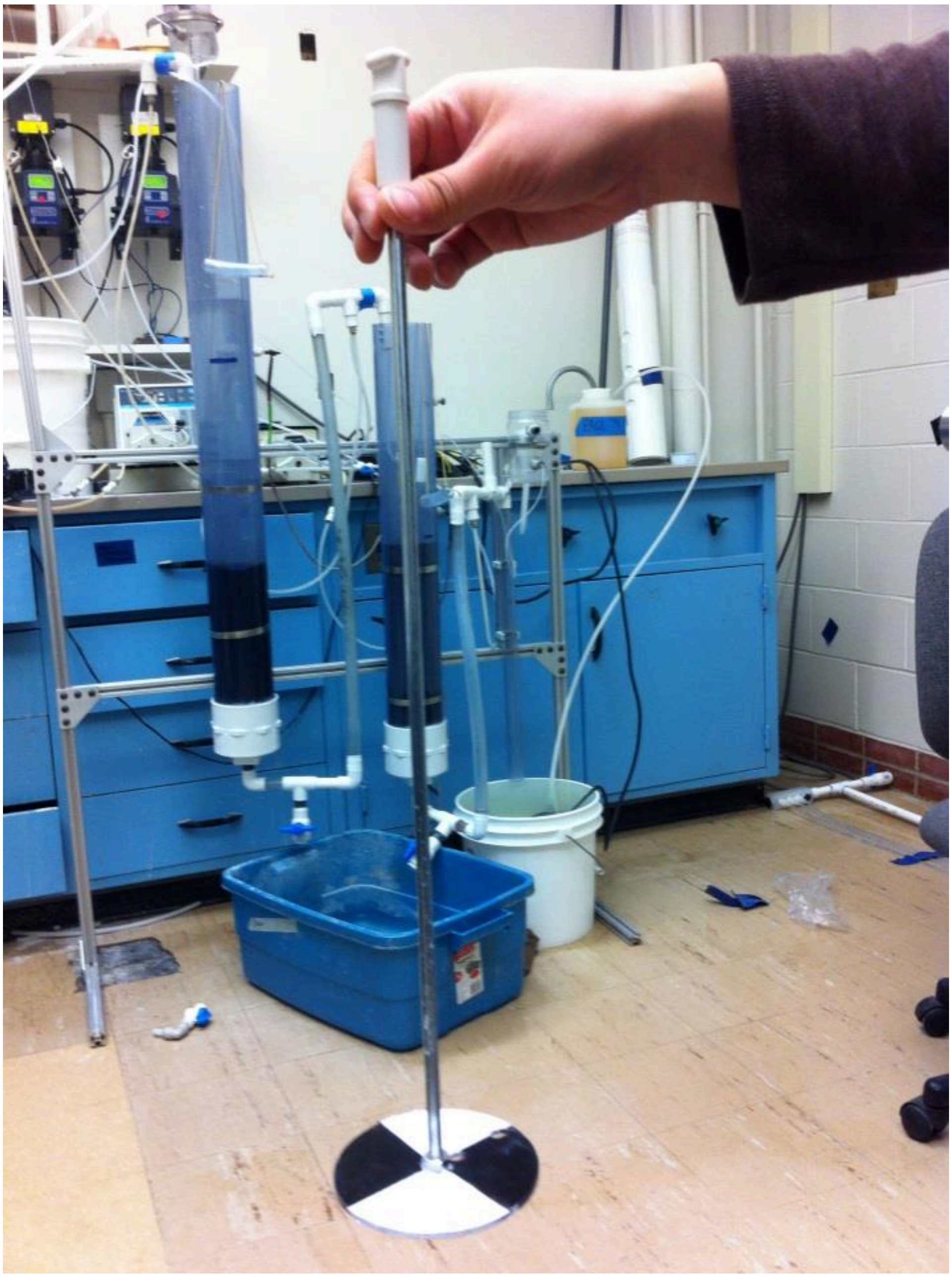


Figure 3: A complete view of the Secchi Disk. The quadrants were painted in Krylon.

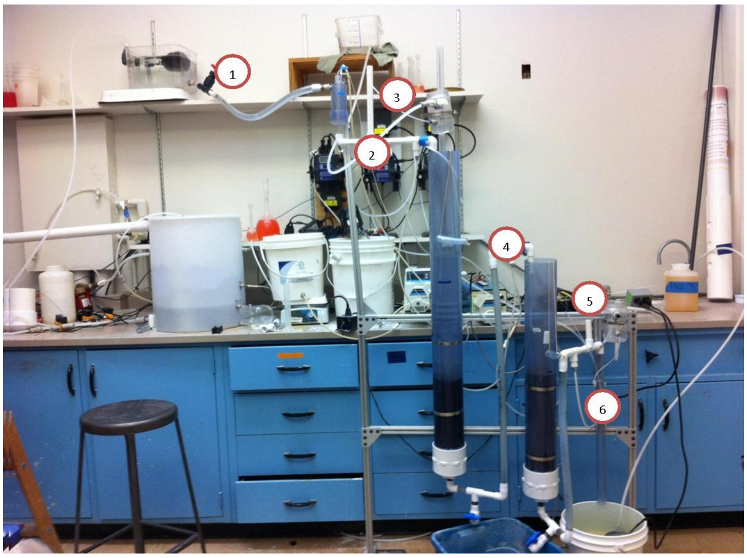


Figure 4 : Filtration system with elevated tank and CDC dose controllers for coagulant and chlorine. The different parts of the system are labeled: 1. Influent tube, 2. Rapid mix pipe, 3. CDC for coaguland, 4. Finishing filter influent tube, 4. CDC for chlorine, 6. Effluent pipe.

of calculating the turbidity. The Fall 2011 Turbidimeter Team created a turbidimeter design using a blue LED light and a HDPE block that may be able to read values all the way down to 7 NTU [8].

3.4 Cleaning the System

Cleaning the system is a relatively simple process. All of the tubes (1,2, 4, and 6 in Figure 4) are easily detached. Clay and coagulant can settle in standing water and precipitate out, causing build up in the system. We noticed that in the rapid mix pipe (2) and in the roughing filter, when water is left in the system, clay can settle out. Once the system is run again, the clay is quickly re suspended. A similar problem exists with the coagulant in the tube leading to the finishing filter (4) and in the effluent tube (6). A pink scum forms in the tubes when water is left sitting; it does not go away after the system is run. This scum does not appear to affect effluent turbidity however.

To clean the system, we simply disconnected tubes 1, 2, 4, and 6 and threaded wire through a rag, dragging it through the tube. We were concerned with removing the residual coagulant as it is not removed by water. It removed most of the scum. After we finished, we returned the same tubes to the system. We noticed however, that the fittings were loose following the cleaning. This may be because an attachment was added to the existing tubes that stretched the tube. We fixed this by wrapping the attachments with Teflon tape to prevent leaks.

3.5 User Manual

We created an illustrated user manual in Spanish to concisely guide the operator through the task of operating the system. Below is the text of the operator's manual in English and Spanish. The illustrated version is available in a separate document.

1. Put new filters in system. *Poner filtros nuevos en el sistema.*
2. Turn on hose. Allow tank to fill; adjust flow control valve on tank tube until water level in Linear Flow Orifice Meter (LFOM) is at the marked level. *Encender la manguera. Permitiar que el tanque se llene; ajustar valvula de control de flujo en el tanque de tubo hasta que el nivel de agua en el medidor de orificio de flujo lineal llegue al nivel indicado.*
3. After the water level in the tubes have reached the marked water height, compress the filter to remove air bubbles. *Despues de que el nivel de agua en los tubos llegue al nivel indicado, comprimir el filtro para remover en burbujas de aire.*
4. Check the influent turbidity and accordingly adjust the CDC for the needed coagulant dose. *Revisar turbidez influente y ajustar el dosificador quimico para dosificar el coagulante requerido.*
5. Run system until break through at finishing filter exceeds 5 NTU. At that point, open the waste valve and compress filter to clean. Repeat from step 3. *Correr el sistema hasta que la turbidez en el filtro finalizador exceda 5 NTU. En ese punto, abra la valvula de desperdicio y limpie el filtro comprimiendolo. Repetir de acuerdo a paso numero tres.*
6. After roughly a month of running the system (based on 4 hours a day), change the filters. If after plunging, the finishing filter doesn't experience a decrease in turbidity, change the filter. *Cambiar los filtros despues de correr el sistema por aproximadamente un mes. Cambiar el filtro finalizador si despues de comprimir el filtro, el filtro no reduce la turbidez.*

4 Conclusions

The addition of the CDC for coagulant and chlorine give the operator the ability to regulate the amount of chemicals added to the system. We expect the operator to have knowledge of the influent turbidity so that he or she can dose the system appropriately. With the addition of the Secchi Disk, the operator will be able to determine the breakthrough point of the roughing filter, and clean the system accordingly. The point at which the operator should change the roughing filter is about 1 month; we have not yet determined if the finishing filter should be changed at the same time or at a later date. The user manual we compiled will simplify the process of maintaining the system.

5 Future Work

As tests were being run, we noticed that we could visually track the flocs getting trapped in the roughing filter. A continuous line on the outside of the first roughing filter forms as the system runs, but upon reaching the second roughing filter, this no longer happens. Based on this, we feel that stacking two foam pieces on top of one another may not be the most efficient method of filtration. Future experiments need to be designed and run to determine if stacking two foam pieces is ineffective and what makes this method ineffective.

Further experiments need to be done using the Secchi Disk. As they are ineffective in low turbidity waters, they could only be employed in waters with a higher turbidity. It is still not clear just what NTU the water would have to be. Additionally, it would be useful to know the best location to take readings from the Secchi Disk. One method would be to place the Secchi Disk just above the foam during operation. A consistent depth would also promote consistency among readings.

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