Stacked Rapid Sand Filtration Summer 2010 Reflection Report 3

Stacked Filtration Reflection Report

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Abstract

The objective of the Stacked Filtration team is to design and build a vertically stacked filtration system that meets the AguaClara project constrains.

In the previous semester, the Stacked Filtration Team conducted research on stacked filtration and rapid sand systems, completed a literature review of past research and technology, and developed a robust laboratory filtration system. Most recently, we were able to successfully back wash the system by sequentially fluidizing individual sand layers. Our main challenge for the future is to test whether pipe “troughs”, solid pipes with 1/3 of the pipe wall circumference removed, can replace the slotted pipe in the filtration unit. In addition, we hope to construct a clear PVC pipe experimental apparatus to visually confirm flow patterns and fluidization levels within the filter.

Introduction

The task of the Filtration Team is to design a filtration system for the AguaClara water treatment plants already operating. The filtration system must be able reduce the turbidity of current AguaClara effluent water ranging from 5-10 NTU to a turbidity that meets the U.S. EPA standards of less than 0.3 NTU. The system must not require electricity, while avoiding specialized components that would be difficult to obtain in remote areas, and should be easy and economically efficient to construct and maintain.

The work of the previous semester consisted on creating an appropriate stacked filtration experiment design and researching past sand filtration methods and technology. They designed a filtration system where the sand layers are stacked on top of one another. This way the same water would be used to back wash all of the filters. The design entails four filters stacked on top of each other, thus four layers of sand with 20 cm of depth each (Figure 1).

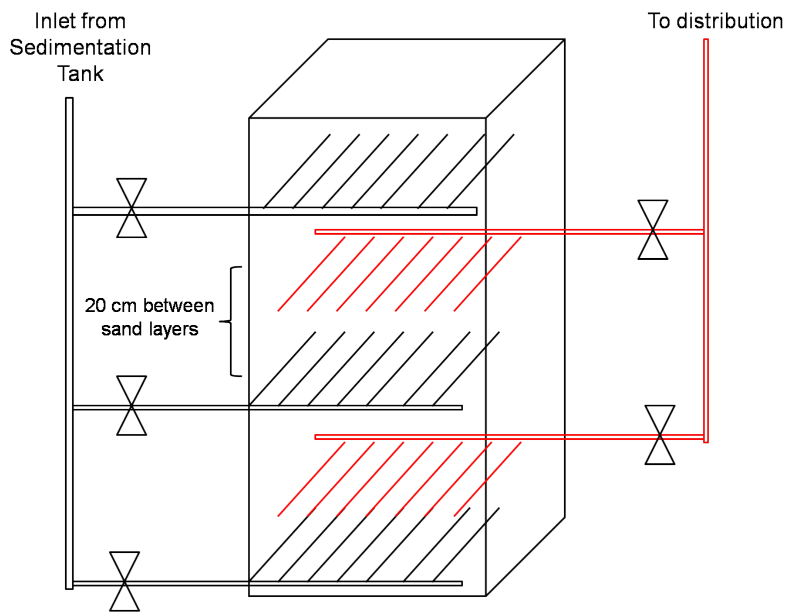

Figure 1 : Illustration of filter design with 3 inlet pipes and 2 outlet pipes, creating 4 filter layers

Our bench scale model of this design consists of three slotted influent pipes and two slotted effluent pipes will be placed in 4” inner diameter PVC pipe (Materials and Methods).

We have begun conducting experiments on this apparatus, and in the last 2 weeks have managed to successfully control the influent raw water turbidity, as detailed in the Materials and Methods section.

Materials and Methods

Control of Parameters

Conditions of constant turbidity were created by introducing a concentrated kaolin clay (R.T. Vanderbilt Company, Inc., CT) suspension (Figure 2) into a direct line of tap water using a computer controlled digital peristaltic pump (Masterflex, Cole-Parmer, USA). Water directly from the tap was used in this experiment, as opposed to a raw water source, due to the high flow rates required for both the filtration and backwash cycles of the experiments (2.7 L/min and 4.8 L/min). These flow rates could not be feasibly achieved using peristaltic pumps. The turbidity was controlled using process control software which compared turbidity readings to the specified target turbidity level. If the turbidity dropped below the target level, the process controller increased the concentrated clay suspension flow rate. If the turbidity went above the target turbidity level, the process controller decreased the concentrated clay suspension flow rate. The most recent successfully conducted experimental trial had a relative standard error of 12.6% in the influent turbidity.

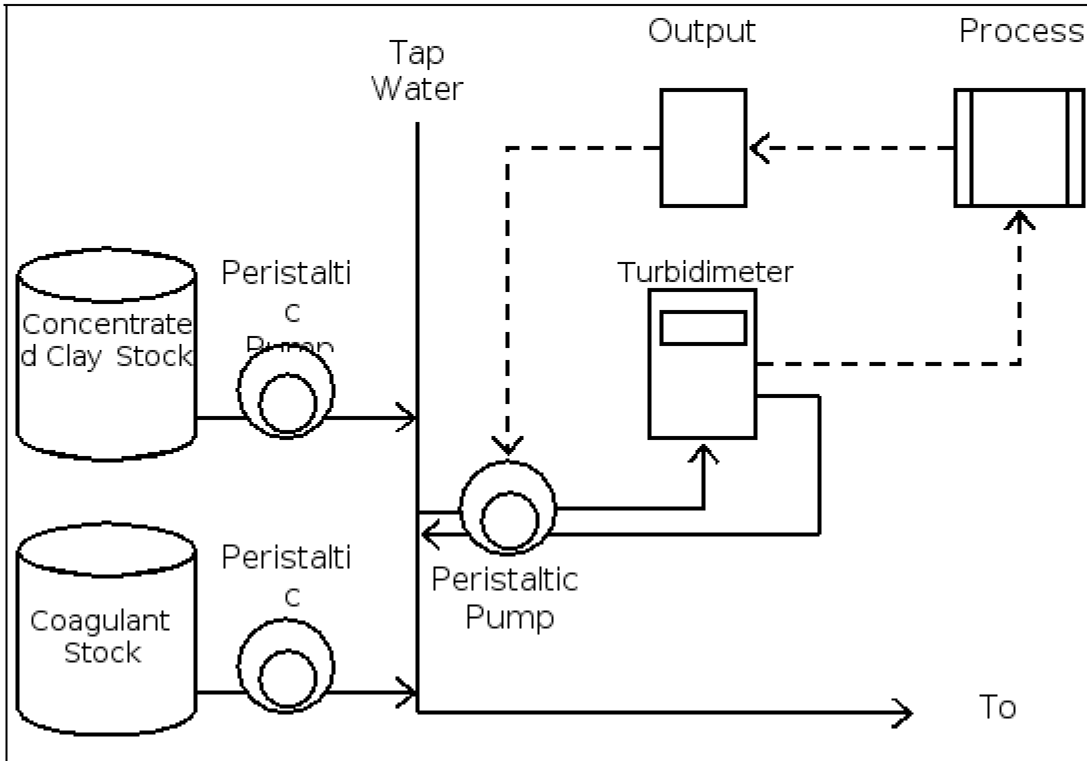

Figure 2. Schematic showing how influent turbidity is controlled using process control

The alum coagulant was prepared and refilled daily for the duration of the experiment to avoid ageing (Rossini et al., 1999). The desired amount of alum was added to the raw water line using a constant flow rate peristaltic pump (Masterflex, Cole-Parmer, USA). Rapid mix is assumed to occur of the 120 cm length of 6.35 mm I.D. (inner diameter) tubing.

A constant flow rate into the filter was achieved using a control board, (Figure 3) which consisted of a flow director which switched between filtration and backwash cycles, a flow reducing gate valve, and a calibrated flow gauge for each filtration and backwash cycles.

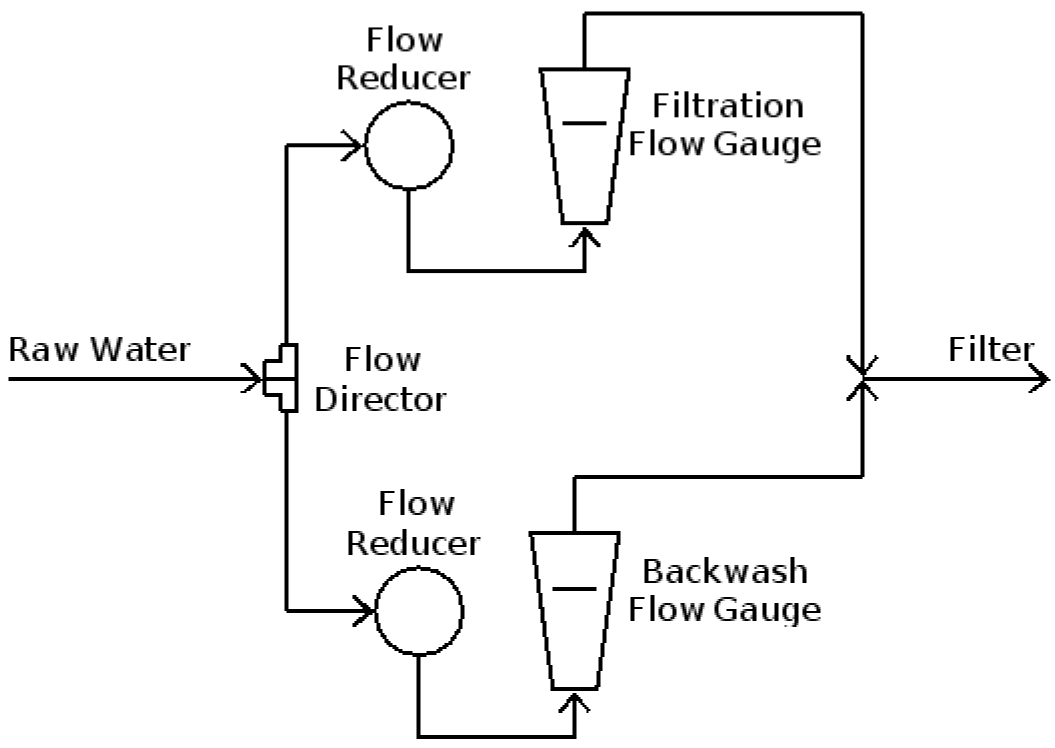

Figure 3. Schematic of control board for filter flow rate regulation

Experimental Setup

The filter arrangement in this experimental setup consisted of 4 individual sand layers, each with 20 cm of depth, that were each stacked on another (Figure 4). This arrangement resulted in a total sand depth of 80 cm. Influent raw water was delivered to each filter layer through a slotted pipe embedded between sand layers. Clean effluent water was extracted from the filter through a set of effluent slotted pipes, displaced 20 cm from the influent slotted pipe. This arrangement forces water to travel, in either direction, through a minimum of 20 cm sand depth before it can be delivered as clean effluent from the filter.

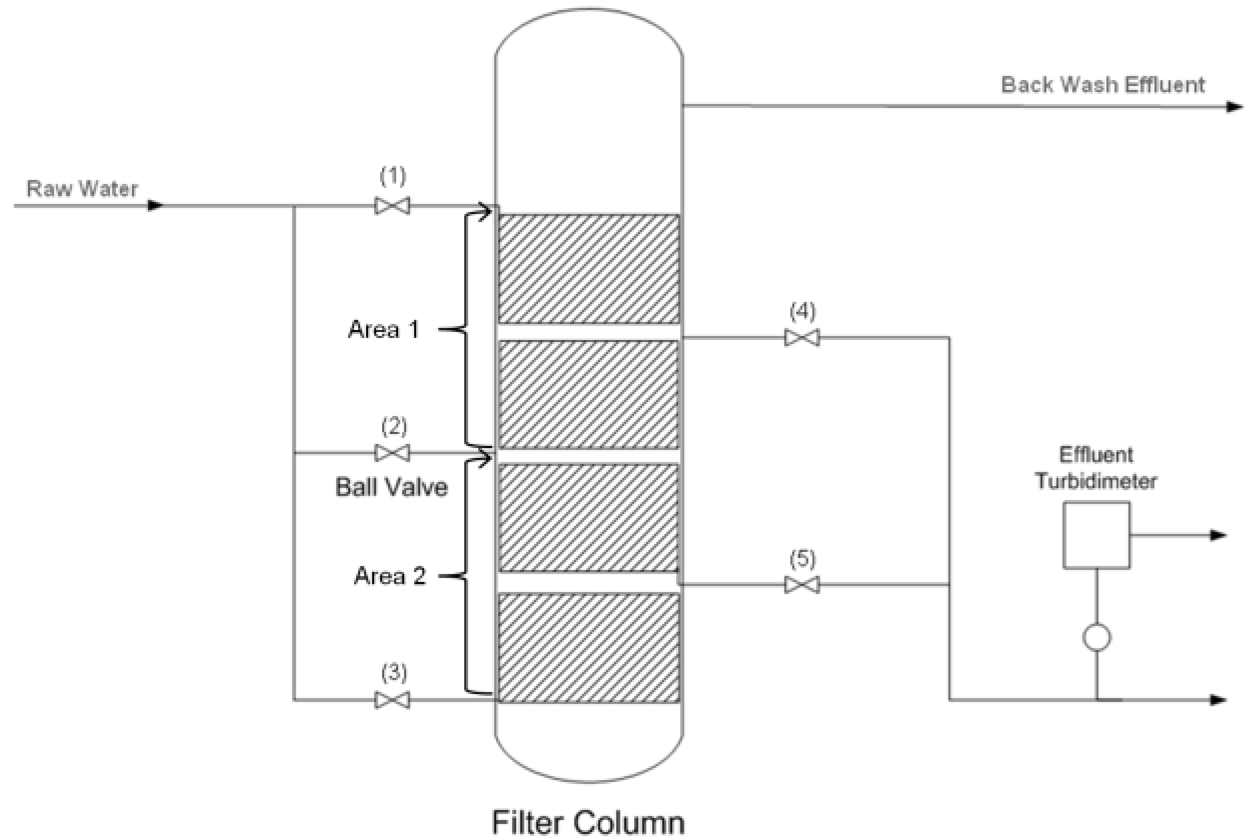

Figure 4. Schematic showing filter column arrangement

For this filter arrangement, back wash is achieved by closing all valves, except the middle influent (Valve 2), and increasing the flow rate to the backwash flow rate. Since all effluent valves are closed, the full filter flow is forced through the one open influent pipe. This full flow rate is enough to fluidize the sand bed layers that are above the open influent pipe, as a result, Area 1 of the sand filter is fluidized. Once fluidization of Area 1 occurs, Valve 2 is closed while Valve 3 is simultaneously opened. All flow is then forced through lowest pipe, into Area 2. Since the upper layers of the filter in Area 1 are already fluidized, the amount of extra energy required to support the sand is very minimal compared to the energy required to fluidize the total 80 cm sand depth. This results in the fluidization of the bottom 2 sand layers in Area 2, and thus the entire filter is fluidized. This process of fluidizing segments of the filter in sequence achieves 30% bed expansion, while requiring a significantly less volume of water to backwash, as compared to conventional rapid sand filtration backwash methods.

Data Acquisition and Sampling

Effluent turbidity was continuously sampled using a Micro TOL turbidimeter (HF Scientific Model 20053, Ft Myers, FL), and recorded every 5 seconds for the duration of each experimental trial. Each experimental trial was conducted until filter failure occurred. For this set up, filter failure is defined as either the build up of particles resulting in excessive head loss across the filter, or as a decrease in the level of filter performance as a result of turbidity breakthrough. Raw water turbidity was also recorded for comparison to the effluent data to determine the particle removal efficiency of the stacked rapid sand filter.

Performance Analysis

Data presented were taken for the duration of each experiment. In the graphical representation of the data, a smoothing function is employed, in which one graphical point represents the average of 10 data points.

In order to characterize and compare the performance of the stacked rapid sand filter, the negative logarithm of the fraction of residual particles, pC* (equation 1) was employed. Log reduction is typically used to characterize the removal of biological pathogens; however, it is sometimes used to characterize the log removal of turbidity (Carlson, 2001). In this study, pC* is used to indicate the log of the fraction of particles remaining after filtration.

$$pC^{*} = -\log\left(\frac{\text{Effluent Turbidity}}{\text{Influent Turbidity}}\right) \quad (1)$$

Also reported is the length of time for which experimental trials performed below the U.S. EPA surface water treatment standard of 0.3 nephelometric turbidity units (NTU).

Results and Discussion

During these two weeks we were able to run a few full length experimental trials. The experimental conditions used in all of the trials involved a filter flow rate of 2.7 L/min, which is equivalent to 5.6 mm/s total filtration velocity, with 1.4 mm/s per filter layer. In the first experiment we ran, the influent turbidity was much steadier than in our previous experiments since less clay was settling out in the tubes. One issue we did run into though, was that we ran out of alum. This is shown by the drop in performance in Figures 5 and 5. However, the results we achieved are still very promising. As can be seen in Figure 1, the first experiment consistently achieved a pC* of more than 1, until the alum stock ran out.

Figure 5. Experiment 1: pC* vs. Time. Filter flowrate: 2.7 L/min (5.6mm/s total, 1.4mm/s per filter layer). Note: Alum ran out at around 14 hours where performance drops.

As shown in Figure 6, the resulting effluent turbidity was less than 0.2 NTU for this time period, about 14 hours. Also illustrated by Figure 6, the influent turbidity remained very steady and had a mean of 6.3 NTU and standard deviation of 0.86. This translated into a relative standard error of just 13.5%, which is very good and acceptable for our trial.

Figure 6. Experiment 1: pC* vs. Time. Filter flowrate: 2.7 L/min (5.6mm/s total, 1.4mm/s per filter layer). Note: Alum ran out at around 14 hours where performance drops.

In the second experiment we ran, we made sure we had enough alum so that it would not run out over night. The experiment ran for 40 hours, and we achieved very good results! As shown in Figure 8, the pC* was between 1.5 and 1.75 for the entire duration, ignoring a random spike, which is very good.

Figure 7. Experiment 2: pC* vs. Time. Filter flowrate: 2.7 L/min (5.6mm/s total, 1.4mm/s per filter layer).

As illustrated by Figure 8, the effluent turbidity for this experimental trial was below 0.2 for the duration of the experiment, and even dipped down close to 0.1 at times. The influent turbidity was also a bit steadier than the first experiment and had a mean of 6.0 NTU and standard deviation of 0.76. This resulted in a relative standard error of 12.6%, which is great!

Figure 8: Experiment 2: Turbidity vs. Time. Filter flow rate: 1.4mm/s per filter layer

We also had pressure sensors installed at the inlets and outlets for this experiment. As can be seen from Figure 9, the pressure in the lower filtration bed rose gradually over time as flocculated particles clogged up the sand pores. There seems to have been an error with the sensors between the 30^{th} and 40^{th} hours of the experiment, we are unsure what this might be indicative of.

Figure9:Experiment 2: Head loss difference vs. Time. Filter flowrate: 1.4mm/s per filter layer

The most recent experimental trial was conducted at filtration velocity of 1.83 mm/s, with all other influent conditions the same. It was desired to test the filter at this higher filtration velocity, as it would enable a filter to be built at the Marcala plant that had a filtration velocity equal to the backwash velocity. It is important to note that in all of the following figures, the time scale should have about 7,200 seconds added to the start time. Data was not successfully recorded for this time period, however, the experiment was indeed running. As illustrated in Figure 10, this experimental trial achieved a very consistent pC* of 1.5, except when the influent turbidity dropped to 1.7 NTU (Figure 11).

Figure 10: Experiment 3: 1.83 mm/s, 5 NTU , and 1.5 mg/L alum dose. Note: time scale needs to have 7200 seconds added due to delayed data recording

It is unclear why this happened for this period of time, however, the tubing may have become clogged with clay particles. This clog may have removed itself, and which then allowed the influent turbidity to return to about 5 NTU, as illustrated in Figure 11.

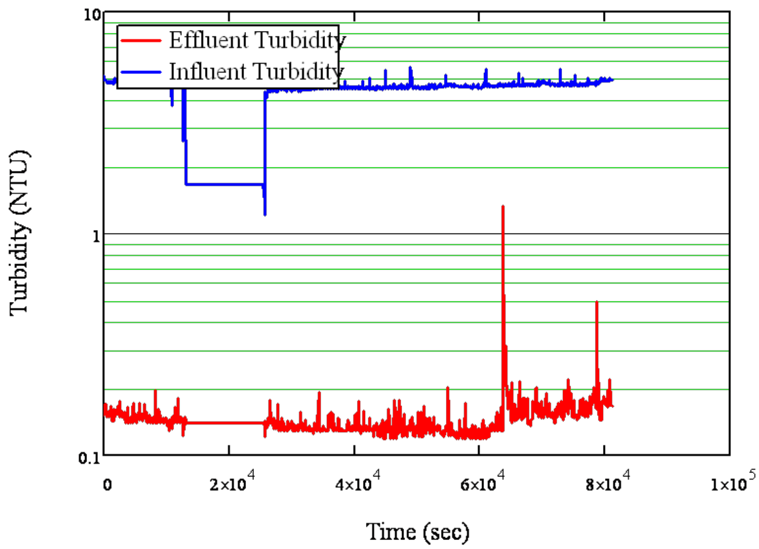

Figure 11: Experiment 3: 1.83 mm/s, 5 NTU , 1.5 mg/L. As seen in the graph, the influent turbidity dropped to 1.7NTU. Note: Time scale needs to have 7200 seconds added due to delayed data recording

These graphs clearly indicate that despite the increased filtration velocity, the filter is nonetheless able to achieve the same level of performance as experimental trials conducted at the lower 1.4 mm/s filtration velocity. However, as also indicated in Figure 11, filter failure seems to occur much faster than it occurred in the 1.4 mm/s experimental trials. We can see a spike in the effluent turbidityin the form of turbidity break through at about 62000 seconds on the graph, or at 69200 seconds (19 hours) on the actual time scale. As indicated in Figure 12, the head loss increased over time until the experiment was shut off when water flowed over the backwash weir of the setup.

Figure12:Head loss over the experimental trial with filtration velocity 1.83 mm/s and 5NTU and 1/5 mg/L alum dose influent. Note: Time scale needs to have 7200 seconds added due to delayed data recording

So far our rapid sand filter has been extremely efficient at removing turbidity from water. With influent water turbidity around 5-7 NTU, we have managed to reduce the turbidity to below US standards. Backwashing the filter has also gone smoothly and proven effective at removing clay from the filter. Typical required backwash time for this filter is about 7-10 minutes, after which the backwash water appears clear.

Through these experiments we have achieved a good level of consistency. The main goal for these experiments was to keep the influent water turbidity as constant as possible in order to better characterize filter performance and allow us to acquire more accurate results from our filter.

Future Work

We currently just finished adding pressure sensors to our apparatus, which will enable us to obtain head loss measurements over time, and provide a more complete comparison to a conventional single layer filter. It will also tell us when the particle build up in the filter is too great, thus determining the effective filter life, and how often backwash will be required. We plan to determine this in the next few experimental trials.

In addition, we aim to replace the 4” PVC pipe with a clear 4” PVC pipe, and add an additional 2 layers to our bench scale model in the following weeks. These additional filter layers will require additional flow rate beyond what is capable in the current lab, and thus, the apparatus will need to be moved to the new lab downstairs.

Team Reflections

Through these past two weeks the Stacked Filtration team has come across and overcome many obstacles that have hindered our progress. The first problem we had was the settling of the clay in the lines. We have continued to address this problem by increasing the flow rate of the clay, lowering the diameter of the tubing used for the clay, and lowering the concentration of the clay stock. Another problem we encountered was adding pressure sensors into our experimental setup. When we tried to add the pressure sensors into our experiment, the results from the pressure sensors were unexpected. After much brainstorming and discussion we finally decided to rearrange the pressure sensors in a simpler fashion. Installing the pressure sensors was also a very difficult because we needed to push the ends of the pressure sensor into leaking tubing without getting the bridge of the pressure sensor wet. Another experiment in the lab had malfunctioned and damaged equipment which interfered with our data collection. The last problem we encountered was adding new coding the MathCAD file that we used to analyze our data collected from the experiments. The goal of the new coding was the automatically changed -999 data readings, small glitches in the data collection, into the data before it. This small coding section took us a while to figure out and finally, with some help from Rami, we managed to write a working code that accomplished such tasks.