EStaRS, Fall 2015

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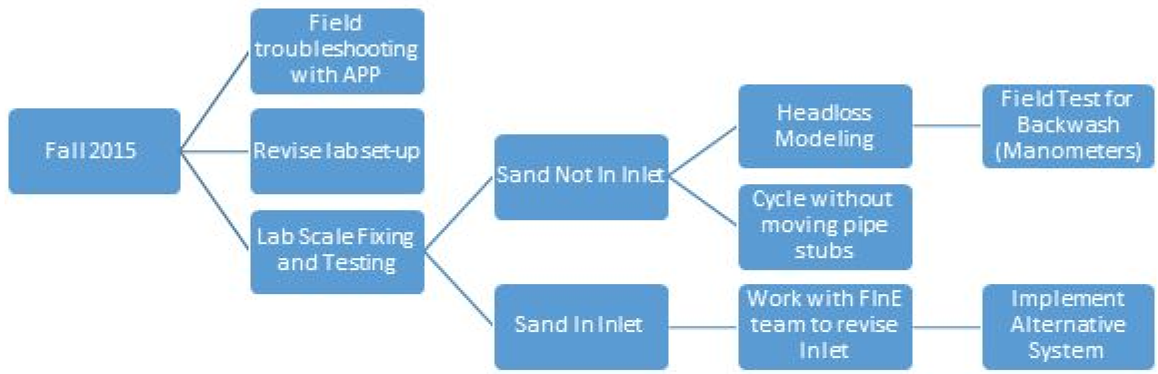
Abstract

The Fall 2015 EStaRS team reworked the lab scale setup of the EStaRS filter to work without a large pool to preserve lab space. The team then finished the orifice inlet implementation that was begun in Spring 2015, and provided an operating procedure for both filtration and backwash to avoid trapping sand in the inlets during the transition. The biggest takeaway from the operating procedure is that orifices can be operated successfully as long as the backwash transition does not create a drastic pressure change. Slowly closing the gate valve on the backwash siphon provides a gradual change and does not trap sand in the inlets. This procedure was the result of numerous inlet cloggings, and thus the team also devised a method for unclogging inlets without disassembling the filter. The team also implemented a pressure sensor to track headloss accumulation through the filter bed in the entrance tank. This pressure sensor was used to measure a clean bed headloss which is very close to the design clean bed headloss.

Table of Contents

Task List

Task Map



Task Details

1. Revise lab set-up
    a. Minimize lab space: September 16, Natalie
        i. Smaller alternative for backwash
            1. Replace kiddie pool with buckets/drain system
        ii. Organize new pump system
    b. Manometer set-up November 20, Natalie
        i. Create field test apparatus to evaluate the fluidization of the bed
    c. Set-up Process Controller: October 30, Skyler
        i. Configuring inlet/outlet
        ii. peristaltic pumps
        iii. turbidimeters
        iv. pressure sensors
2. Lab Scale Fixing
    a. Filter operates with minimal leaking: October 2, Lilly
        i. checking connections & compile/order supplies
        ii. deconstruct and fix connections
        iii. reassemble filter
3. Lab Scale Initial Testing
    a. Run preliminary tests and observe sand in inlet tubing/pipes: October 9, Lishan
    b. Sand Not in Inlet Plan: December 4
        i. Test with several turbidites (Lishan)
        ii. Head loss Modeling (Natalie)
        iii. Cycle without moving pipe stubs (Lilly)
        iv. Field Test for Backwash (Skyler)

    c. Sand in Inlet Plan: December 4
        i. Work with FInE team to revise Inlet (Lilly, Lishan)
        ii. Implement alternative system (Natalie, Skyler)
4. Collaborate with FInE on new extraction system
    a. Communicate with FIne: October 30 (Natalie)
    b. Dependent on timeline, possibility of fabrication and implementation this semester (Lilly)
5. Field Troubleshooting with APP: Continuous (All)

Team Roles:

<u>Team Coordinator</u>: Skyler
The Team Coordinator will maintain sight of the team's goal and work to keep everyone up to date and focused on that goal. He will also be the main point of contact between the team and the rest of AguaClara, whether it be an advisor or another subteam.

<u>Data Coordinator</u>: Lishan
The Data Coordinator will make sure the sets of data that the team obtains is organized and stored properly and safely. Her knowledge of the data will be beneficial in the explanation and support of ideas and conclusions that the team has.

<u>Materials Coordinator</u>: Lilly
The Materials Coordinator will be in charge of ordering materials for the team as well as for keeping track of the materials that are being used up in the lab.

<u>Abroad Coordinator:</u> Natalie
The Abroad Coordinator will maintain contact with India, thus supporting a feedback loop system where needs in the field can be addressed in the lab. This way the work done in lab remains relevant to the goal of implementation in India.

Introduction

Traditional sand filtration is a commonly used technology that can be implemented at multiple stages of the water treatment process. The AguaClara water treatment system is designed to use sand filtration as the last stage of treatment. To improve on current sand filtration techniques, AguaClara has developed a Stacked Rapid Sand Filter that requires less space than traditional models. These filters use sand more effectively than conventional sand filters by decreasing the depth of the sand bed needed to treat the same flow rate. Additionally, it is designed so during backwash, water only flows through the lowest layer of piping. It creates the same effect as backwashing in traditional sand filters, but without requiring electricity. During backwash, only the bottom inlet is open and only the backwash pipe at the top of the tank allows water to exit. This causes the filter to fill with water and pressure to build up. This pressure, combined with gravity, creates a siphon through the backwash outlet. This siphon causes the fluidization of the bed during backwash. The process is much more condensed than traditional sand filters. This makes AguaClara Stacked Rapid Sand Filters simpler to construct, operate, and maintain in the field.

More recently, AguaClara has been working to build a stand alone sand filtration system that can operate at much lower flow rates called Enclosed Stacked Rapid Sand (EStaRS) filters. The goal of these smaller scale filters is to provide water treatment in places where is it not practical to implement a full-scale AguaClara treatment plant, such as in the rural villages of India. So far, the filters that have been implemented in India to treat water drawn from wells at a design flow rate of 0.8 L/s per filter, and provide water to villages of around 600 people.

Smaller communities in the developing world without easy access to a clean water supply are the main reason for continued EStaRS filter research. For such communities requiring water treatment plants, it is most important to emphasize the ideas of cost effectiveness, accessible materials, and simple construction and operation. To achieve these goals, the EStaRS filters aim to be efficient and adaptable to communities of all sizes. The EStaRS team is currently conducting research to improve the filter system to bring AguaClara closer to their commitment of long-term environmental, social, and economic sustainability for any community.

Literature Review and Previous Work

Sand Filters are a very common water treatment technology and are used in a variety of forms for different purposes. Traditional sand filters have only one “layer” of sand that is much deeper than an EStaRS filter. These sand filters require vast land area and significant energy inputs in order to fluidize the sand bed and clean the filter. The AguaClara EStaRS filter uses multiple “stacked” sand layers in order to create a system that can be easily backwashed. Inlet manifolds are embedded into these layers. They feature very thin slots that allow water through but not sand. The sand captures the dirt particles from the influent water in the filtering process, thus the filter efficiency slowly decreases as the products build up in the sand. When the filter is no longer producing adequate effluent water, the EStaRS filter can be backwashed by cleverly manipulating the entire system flow rate through only one layer of sand. The system is designed to create an upwards velocity during backwash that is sufficient to fluidize the very bottom layer of sand, and thus every layer above it.

The Spring 2015 team focused on a variety of different filter improvements. The team investigated the Fernco fitting system that is used to cap both the top and bottom of the filter, and also connect the two filter columns. When the filter body was under pressure, the filter column cap would pop off. To fix this situation, the previous semester’s team determined the best fabrication technique for applying the Fernco fittings was to get rid of the underlying metal sheet because it was deforming under the force of the hose clamps. Once the metal sheet was removed, two hose clamps were placed over the Fernco fitting to ensure a water-tight seal. These hose clamps were clamped to their maximum capacity of 40 foot pounds with a torque wrench.

Previous experimentation shows that slotted pipes can cause problems. While preventing sand and flocs from flowing out of the filter column, some of the smaller flocs become trapped in the slots. This sludge and subsequent growth of algae results in clogged inlet manifolds that are impossible to clean without the labor intensive process of disassembling the filter column. Since the previous semester, the EStaRS filtration team has been working with the Filter Injection and Extraction team to modify the inlet system. The filter inlet system was changed from using slotted pipes to orifices aligned on the pipes. The current design uses a series of orifices drilled into a 0.5 in. pipe to replace the previous 0.5 in. slotted piping in the inlet manifolds as seen in the Figure 1. The orifices eliminate the clogging issues in the slots but introduce a threat for large scale flow of sand into the orifice. For sand to clog the inlets, there needs to be reverse flow through the system, which is avoided through careful operation of the filter. A problem unaccounted for includes the drastic pressure change in the filter column during the transition from backwash to forward filtration. The EStaRS team was able to account for the reverse flow caused by the pressure change this semester. The reliability and viability of the inlet manifold with orifices continues to be tested in the lab.

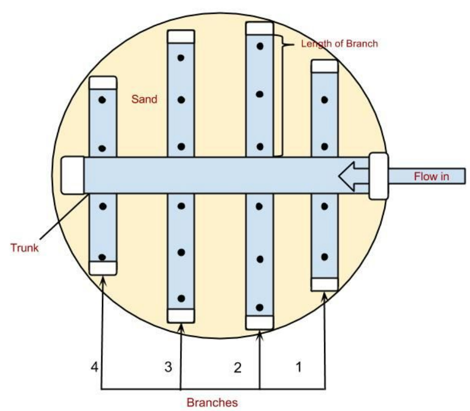


Figure 1: Bottom view of inlet manifold with orifices

Methods

The experimental focus of the Fall 2015 semester is testing the new inlet system. The EStaRS team will extensively run the filter in forward filtration and attempt to seamlessly transition to and from backwash. Through repetitive testing, the EStaRS team will isolate and address any issues with the inlet manifold.

Initial Testing

The first stage of testing includes mostly qualitative data concerning the amount of head loss and the maintenance of backwash. The team observed the flow rate through each inlet, sand movement into inlet manifolds and tubing, and the sustainability of the backwash siphon. The level of head loss, along with sand in the inlet system, indicates a clogged inlet. This is one of the greatest problems with the new orifice system. During testing, when a clogged inlet is discovered, the team attempts to unclog it by increasing flow to the inlet and cleaning out the inlet manually.

Once initial testing was completed and the main problems with the inlet system were identified, the EStaRS team disassembled the filter. First, the filter was drained of water and sand, separated into two halves, then cleaned and repaired. To clean the tubing, the team ran chlorine and water through each individual tube. Additionally, the team removed each inlet and outlet manifold, emptied them of sand, and replaced o-rings and teflon tape. The kiddie pool was eliminated from the lab-set. The team will replace this with a u-shaped bend to the backwash pipe to redirect flow from backwash to an additional bucket. The new experimental set-up, shown in Figure 2 below, includes a large drum that pumps water into the entrance tank. There is a smaller bucket that pumps backwashed water into the sinks or, if the backwash water is not very turbid, recycles it into the large drum. This set-up can be altered easily when the team clogs the filter with clay and coagulant during testing. Once the lab setup was complete, the filter was reassembled.

Figure 2: Revised Lab Set-Up

Filter Operating Procedure:

A conservative plant operating procedure was developed to ensure that sand does not clog the inlet pipes in systems with the orifice design but without protective wings. This procedure was developed by taking into consideration every occasion where there could be some degree of backflow from the filter into the inlet pipes. Backflow through the inlets would carry sand into the inlets if the velocity was high enough.

Careful observation coupled with the team's theoretical understanding of how water flows through the filter led to the conclusion that backflow only occurs during the transition from backwash to filtration. This backflow may occur under two circumstances: 1) the filter is immediately shut off during backwash and the siphon is left open or 2) The siphon is closed, but water is still being pumped in through the bottom inlet, which then flows into inlets 2, 3, and 4. If this happens, the water being pumped into the filter prefers to exit through the paths of least resistance. One of these paths is through the second inlet, which lies two layers of sand above the bottom inlet. The team has solved this transitional backflow problem with the installation of valves on every inlet. The procedure to operate the filter to prevent failure is as follows:

1. Run the filter in forward operation
2. Insert the pipe stub to block the exit, open the air valve on the top of the filter column, and raise the water level in the filter column
3. When the water overflows out of the air valve, open the siphon and close the air valve. Backwash is initiated.
4. Close inlet valves 2, 3, and 4.
5. Run backwash until effluent siphon water is no longer dirty.
6. Close siphon valve to end backwash.
7. Wait until it is clear that water is entering inlets 2, 3, and 4 from the entrance tank (either observed from entrance tank or from clear inlet tubes). Once water is flowing in, open valves 2, 3, and 4.
8. The filter is now in forward filtration mode, and can be stopped at any time.

Testing with ProCoDA and Manometers

In order to obtain accurate and consistent measurements, ProCoDa was set-up in the lab. The team installed a pressure sensor to measure head loss using the tap at the bottom of the entrance tank as shown in Figure 3 below. The head loss measurements are taken as the difference in water height between the entrance tank and the exit tank. The pressure sensor is zeroed when the filter is empty in order to get accurate readings. In addition the comparison to the exit tank water level because the water in the entrance tank is very close to the bottom of the entrance tank. Going forward, the team intends to clog the bed and record head loss during forward filtration and backwash.

The sensor precisely displays the height of water in the inlet tank without one of the team members having to look inside and measure using a ruler. The pressure measured by the sensor increases as the water level in the entrance tank increases. This measurement is then converted by ProCoDa into a height of water that corresponds with the measured pressure. This allows the team to easily measure the changes in head loss between forward filtration and backwash.

Figure 3: View of the bottom section of entrance tank with pressure sensor on the left.

In addition to ProCoDa, a manometer can be installed in future semesters through the bottom layer of sand in order to determine if fluidization occurs during backwash. Currently, the team is using the clear effluent tubing as manometers to see if the sand bed is fluidized during backwash. However, once tests are run, the team plans on attaching tubing to the manometers set up on the back side of the filter body to measure the differences in pressure. The differences in pressure can then be converted into a backwash bed expansion percentage..

Clean Bed Head Loss

The clean bed head loss through a sand filter can be calculated using the Karmen Kozeny equation as shown below:

$$h_l = 36k\frac{H_{FiSand}(1-\varepsilon_{FiSand})^2 \nu V_{Fi}}{\varepsilon_{FiSand}^3 g D_{60}^2}$$

$H_{FiSand} = 0.2\ m$

$\varepsilon_{FiSand} = 0.4$

$k = 5$

$\nu = 1\ E - 6\ m^2/s$

$D_{60} = 0.5\ mm$

$V_{Fi} = 1.72\ mm/s$

From this calculation, it was determined that head loss through the sand was 14.28 cm at the test flow rate of 0.74 L/s. In previous tests, the team ran water through the system without sand in the filter body. The empty filter head loss includes major losses and minor losses due to the pipe friction, inlet system geometry, and head loss through the orifices. During forward filtration, the empty filter head loss was measured to be 25.4 cm. According to these calculations, the total head loss through the system when filled with sand should be 39.68 cm. When the team ran the filter, the head loss through the system was measured to be 38.1 cm. This is very close to the predicted value, so there is good evidence that sand is not trapped in the inlet manifolds restricting flow paths and providing additional head loss.

Analysis

During the team's testing after the inlets had been unclogged and the conservative backwash procedure was established, the team was able to successfully transition the filter from forward filtration to backwash through only the siphon valve. A closed siphon valve indicates filtration, and an open siphon valve indicates backwash. Thus, a plant operator would only need to "prime" the system once by clogging the outlet to raise the initial height of water in the filter to be high enough to start the siphon.

The team has also evaluated the potential to switch from manual hand valves to check valves. Check valves would change the backwash procedure in that steps 4 and 7 would no longer be necessary. This would certainly make operation of the filter easier. A potential drawback to the check valves is that they require 30 cm. of head above them in order to open. Check valves also add more headloss in the entrance tank. Another design could feature both check valves and hand valves. The check valves would prevent against any possible backflow, and the hand valves could be used to fluidize individual layers of the sand filter during backwash without having to manipulate pipe stubs in the entrance tank. In the future semesters, the team will evaluate whether or not these valves are necessary, and whether or not the sand filters in the lab and Honduras even have sequential fluidization by layer of sand.

Empty bed head loss through the system is very close to the calculated value, as discussed previously. This is a good indicator that the inlet system and filter operation strategies are successfully preventing sand from entering the manifolds. Head loss increases through the system as the filter is run and the sand bed becomes clogged with more floc particles. This is especially important to keep track of during an experiment because head loss will increase as the filter bed clogs. The team wants to track how high head loss reaches when the filter reaches a breakthrough turbidity that is 100% of the original effluent turbidity.

Table 1. Head Loss Measurements

	Clean Bed (Measured)	Clean Bed (Theoretical)
Forward Filtration	38.1 cm	39.68 cm
Backwash	19 cm	20 cm

The forward filtration measured and theoretical head loss values are very close. This validates the fact that the Karmen-Kozeny equation still holds when inserting water in a non-uniform fashion throughout the sand bed using the orifices. The backwash headloss value is also very close, and this serves to validate that the orifice inlets were designed correctly to meet the entrance tank design geometry requirements.

Slow Backwash Transition

It was determined that check valves are not an adequate solution because they add too much head loss in the entrance tank. Rather than trying to mitigate the issue with check valves, the team has focused on understanding the conditions that cause reverse flow and sand in the inlets. Reverse flow seems to be caused by the drastic pressure change associated with closing the siphon valve rapidly. This pressure change sends water from the bottom inlet into inlets 2,3, and 4. We primarily observed sand in inlet 2. To solve this issue, the team has installed a gate valve on the siphon pipe to allow the team to slowly transition out of backwash. This slow transition has two phases. During the first phase, water does not seem to equilibrate in inlet tubes 2, 3, and 4, which means to reverse flow from the filter body to the filter entrance tank. Once the valve is about halfway closed, inlets 2, 3, and 4 suddenly start to equilibrate. As these tubes equilibrate, the water level in the entrance tank also rises so that water is now entering inlets 2, 3, and 4. Thus, as soon as water is flowing in through these inlets, the gate valve can be closed the rest of the way without worry about reverse flow caused by pressure change. Slowing down this equilibration by slowly closing the gate valve seems to be a working solution. Thus far, the team has not encountered sand in the inlets with this method.

Conclusion

During backwash, the sand bed is expanded and fluidized by the water coming from the bottom inlet. According to the gravity exclusion principle, sand will not enter the manifolds during backwash. When the filter is switched back to forward filtration, there is a transition stage when water is neither lifting the sand bed nor flowing through all the inlet manifolds. In theory, water would instantly be flowing through the inlet pipes into the filter as soon as backwash is stopped. However, that is not the case and is one of the main reasons the EStaRS team is having difficulties keeping sand from flowing back into the inlet piping. A slow transition from backwash to forward filtration is a solution to this problem but requires an additional gate valve on the backwash pipe.

The validity of the orifice inlet system has been supported by the by clean bed headloss during filtration and backwash. The bed appears to be fluidizing during backwash and there are ways to prevent sand from flowing in the inlets. This success should be explored further, but it indicates that the orifice system may be a good alternative in the filters.

Future Work

Future teams should evaluate the loading capacity of the filter. Trial runs at the end of this semester did not yield great results, and the team had a hard time getting the filter to produce clean water that would meet drinking water standards. EStaRS filters have been around for a while now, but a really sound characterization of their performance is still lacking. The filter seems to operate inconsistently, and it's hard to say how it will perform under a given circumstance. An experimentally validated loading capacity will be useful to determine the potential applications for these filters across a variety of conditions.

It would also be beneficial to establish an easy to use manometer metric for measuring backwash fluidization percentage. This would be some kind of visual that goes next to the filter manometer that the operator could check at a glance to determine whether or not backwash is operating efficiently.

References

Weber-Shirk, M. (2014, September 14). Flow Control and Measurement. Retrieved September 30, 2014, from https://confluence.cornell.edu/display/cee4540/Syllabus

Bolander, Sarah, et al. "Enclosed Stacked Rapid Sand Filtration (EStaRS), Spring 2015". 6 Mar. 2015.