StaRS FInE, Spring 2015

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Abstract

This semester's team picked up where last semester's team left off, testing inlet and outlet piping designs in a 10-cm by 10-cm test filter. Rather than an inverted U-shaped tube, a double winged inlet and outlet system with orifices in both pipes was tested in a small scale filter. Then, the inlet slanted wings were replaced with one set of vertical wings to make fabrication easier and to try to solve fluidization issues. After numerous trials, the team decided to run tests with only holes for the inlet pipes and no wings. In order to validate this holes-only design, a new 86 cm-long test apparatus was built, and slotted pipes were used for the outlets to maintain a control. This testing was largely successful, and there has been no indication that using holes in the inlet pipes would cause problems in the filter. The EStaRs team has already fabricated the new inlet module for full-size enclosed sand filter and the first test run was conducted. The optimal design for the outlet pipes has not yet been finalized, and the team has built a set of wings with a triangular cap on top that must be tested before a recommendation can be given.

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Introduction

The current design of the AguaClara StaRS filter, which has been used for several existing filters in Honduras and India, uses sets of slotted pipes to inject dirty water into and extract clean water out of the filter bed. The size of these slots is a width of 0.2 mm, which is smaller than the sand particles and prevents sand from entering the pipes; however, as dirty water is injected into the filter, these slots can become clogged with dirt particles, and this has been a source of problems for filters used in the field. Because of this issue, a new design must be developed for the injection and extraction piping for the filter, preferably one that does not rely on slotted pipes and size exclusion as a means of preventing sand from infiltrating.

This semester’s team will experiment with a new piping design that uses larger orifices to avoid clogging, and which is based on a gravity exclusion principle for keeping sand out of the piping during backwash. The design will use a system of wings along the piping in order to create a gravity sand exclusion zone around the orifices that will theoretically contain only water and create an appropriate area for the sand-water interface.

Literature Review

AguaClara has been working with two different kinds of filters: enclosed stacked rapid sand filters and opened stacked rapid sand filters. Currently, there are problems in both India and Honduras with the slotted pipes within these filters, because the slots are so small that they become clogged with particles when dirty water runs through them. Previous teams have looked to modify these pipes, eliminating the slots and creating larger orifices for flow that will not clog, but the biggest problem that has been encountered thus far is that sand can enter these pipes when it becomes fluidized during backwash.

Figure 1: Slotted Pipes are currently used for sand filter. The slots shown in this figure are prone to be clogged with sludge and other particles.

In order to solve the clogging problem, several previous teams in AguaClara and the CEE 4540 theory class have proposed that future AguaClara filters should be designed to include the injection and extraction of water through inverted channels or pipes. The inverted channel idea was proposed on the premise of gravity sand exclusion theory. This theory asserts that exclusion zones can be maintained in the filter, which would exist below the inlet and outlet pipe orifices and contain only water, and that sand would be prevented from entering these zones during backwash due to the downward pull of gravity and the fact that no water is actually flowing out of these pipes during backwash. Because the velocity in all pipes other than the backwash inlet is essentially zero during backwash, there would be no flow of water into these zones to carry sand up into the pipes. Professor Weber-Shirk and Professor Lion submitted a Fall 2014 EPA P3 proposal delineating the design of a gravity sand exclusion inlet and outlet system to reduce the cost of operation by replacing prone-to-clog slotted pipes and eliminating the need of backwash pumps.

Figure 2: Clean sand exclusion zone from fifth trial by Fall 2014 team

Last fall semester's team delved into the fluid mechanics of the sand filter, and they experimented with several different designs. The team showed that the use of gravity sand exclusion zones could successfully prevent sand from entering an inverted U-shaped channel during backwash. The exclusion zone remained sand-free during the backwash of the small scale sand filter despite successful fluidization of the sand bed. However, this team did have a problem with sand from the filter bed being fluidized and flowing out through the outlet pipe during filtration. In order to deal with this, the team proposed a more sophisticated "winged" design, which is intended to create a large enough sand-water interface at the exclusion zones to prevent the fluidization of sand in those areas during filtration. The previous team did not develop dimensions or a shape for these wings, and it is to be further designed, implemented, and experimented with this semester.

Therefore, our main priority is making sure the exclusion zones can successfully keep sand out of the pipes and that the inlet and outlet pipes are not prone to clogging. The Fall 2014 team also used a bucket with a pump as a way to keep their inlet and outlet water recycling in the system. However, when a test produced sandy outlet water, the pump would get clogged. Since this is just as likely to happen throughout our testing, as we are still figuring out what does and does not work, we are trying to use water directly from the sink for our influent water so that it is always clean. Then, we are collecting the outlet water in a bucket if it is sandy to prevent the sink drain from clogging.

However, at this point not much is known about our design in particular. It has not been tested at all before this semester, so our team goal is to determine the validity of gravity sand exclusion theory using this design, determine whether backwash can be successfully performed with this winged system, and hopefully optimize the dimensions of the design and the running of the filter. Since the previous group tested some different designs and they all had some problems, the group came up with the winged design at the end of their research. We hope to continue this and optimize the design and geometry of the pipe system. This includes wing angle and length, as well as hole size and placement.

Methods

Pipe Design

Initial New Pipe Design

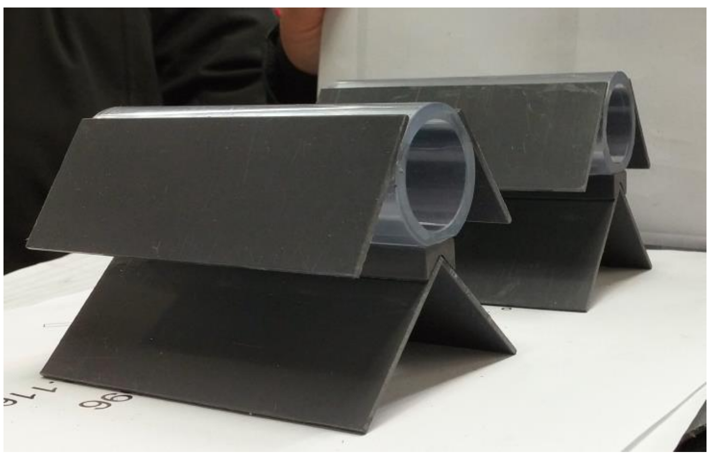

Figure 3: Initial newly designed and fabricated inlet and outlet pipes

A new set of pipes was designed with orifices replacing the slots as a means of injection and extraction of water and with wings used to create a sand exclusion zone below these orifices, as shown in Figure 3.

We initially chose to have three sets of orifices in each pipe within our filter. For each set of orifices along a pipe, there is one orifice on the bottom and two orifices higher up on the sides. In order to distribute flow relatively equally, we determined that the combined amount of flow through the two side orifices should equal the flow through the bottom orifice, and we determined that this should be achieved by having the two total areas be relatively equal (that is, the area of one side orifice should be one half of that of a bottom orifice). These rows of holes can be viewed inside of the piping in Figure 4.

In order to get decent flow distribution through the filter, we theorized that the total combined area of the orifices along a pipe should be less than or equal to the cross-sectional inner area of the pipe itself. The inlet and outlet piping has a nominal inner diameter of 1 inch; assuming a true inner diameter of 1.049 inches gives a cross-sectional area of approximately 0.864 square inches.

The model filter is essentially designed to be a one-tenth section of a full scale filter, with ten centimeter long pipe sections within a ten centimeter by ten centimeter filter area (full scale being a one square meter filter), so the total orifice area in our pipe section should be one tenth of that in the full pipe. However, in the first construction of these new pipes, the factor of ten was not considered. The initial hole sizes were a diameter of 0.303 inches for side orifices and a diameter of 0.428 inches for bottom orifices. A second design improved upon this by including the scaling factor, and the diameters in the second pipe design were 0.096 inches for side orifices and 0.135 inches for bottom orifices.

For the wing design, our goal is to create a large enough sand-water interface to prevent fluidization of the sand beneath the outlet, but also to block as little of the filter as possible so as to not interfere with fluidization required for backwash.

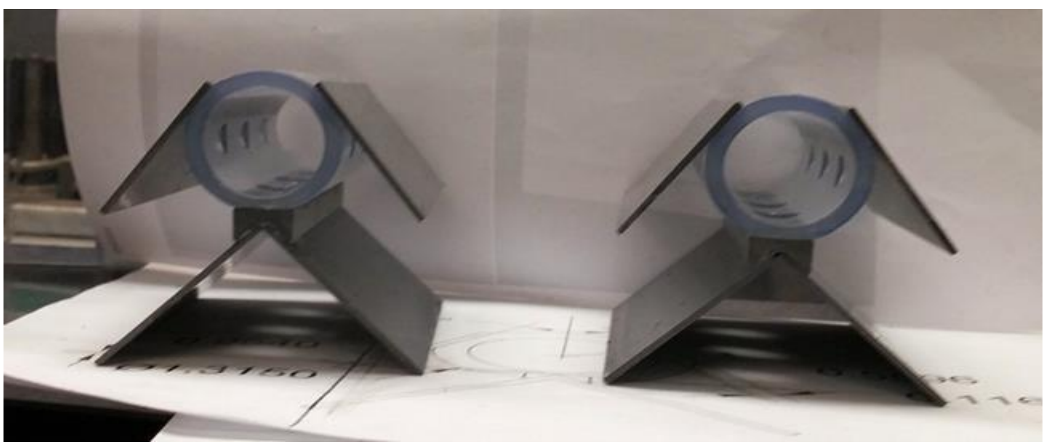

Figure 4: Inside view of initial new pipes

The angle of the wings along the side of the pipe was determined based on the method of construction that was used by Tim Brock in the shop. For the side wings, Tim shaved down the pipe wall slightly to create a flat surface onto which he attached the wings. Given this design constraint, the team determined a length for these wings that would result in the sand-water interface being located at the point where the pipe in the middle is narrowest. The bottom wings were designed such that the full width of the sand-water interface at the bottom would line up with the exclusion zones around the side orifices. The angle for these wings was also determined by the construction method. For these, Tim used a small piece of PVC with a flat top and a 90 degree angle indent on the bottom; he shaved down the bottom of the pipe to create a flat surface on which he attached this piece, and he attached the two bottom wings to the sides of the 90 degree angle on the bottom. The final design of these wings can also be seen in Figure 4.

Modified Inlet and Outlet Orifice Sizes

Following initial experimentation, the team determined that the hole sizes in the fabricated pipes needed to be reduced in order to create greater head loss and direct the flow of water through the filter, particularly during backwash. To do this, the team returned to the initial constraint of having the total orifice area be equal to one-tenth of the cross-sectional area of the pipe. We also concluded that only one set of holes instead of three is needed, and good flow distribution through the sand bed can still be achieved. The new hole sizes are a diameter of 7/32 of an inch for the bottom hole and a diameter of 5/32 of an inch for the two side holes. In order to create this new set of holes, Tim's design was to insert a slightly smaller PVC pipe into the existing pipe, and in this new pipe were drilled only the three holes that we newly required. The two pipes are lined up such that the excess area is blocked, and the new and smaller holes allow flow to escape out of both layers of pipe. An epoxy was used along the edges of the piping in order to hold the inner pipe in place, and this allows for easier removal of the inner pipe in the future.

To design these new holes, we had initially used the constraint that sand should not be fluidized at the sand-water interface beneath the outlet piping. Assuming a sand-water interface area of 66 square centimeters (based on a width of 6.6 cm and a length of 10 cm), we determined that 26.4 mL/s could pass through the sand-water interface without achieving a velocity greater than 4 mm/s and therefore without fluidizing the sand. This would mean that the remaining 83.6 mL/s would flow through the sand bed along the side of the filter, through the remaining 34 square centimeters. To determine the head loss experienced during this flow through the sand bed, we used the Karman-Kozeny equation (Figure 5) for sand bed head loss. The height of this section of the sand bed was assumed to be 3.3 cm (H_{FiSand}), because the bottom wings are at a 90 degree angle. We calculated a head loss value of 16 cm (h_l) through this section.

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

Figure 5: Karman-Kozeny Equation

$\varepsilon_{FiSand} = porosity\ of\ sand\ =\ 0.4$

$k\ = Karman - Kozeny\ constant\ =\ 5$

$V_{Fi} = upward\ velocity\ = \dfrac{83.6\ mL/s}{34\ cm^2}$

$D_{60} = sand\ diameter\ approximation\ =\ 0.72\ mm$

$\nu = kinematic\ viscosity\ of\ water\ =\ 10^{-6} m^2/s$

$g = gravitational\ constant\ =\ 9.8\ m/s^2$

$H_{FiSand} = sand\ bed\ depth\ =\ 3.3\ cm$

$h_l = head\ loss\ = 16\ cm$

The holes sizes were then designed, based on the equation for head loss through an orifice, to achieve this same value of head loss when the full flow through the pipe passed through the bottom hole and then split to flow evenly out of the two side holes. The total head loss was set equal to the sum of the losses through the two holes through which the water would pass. To calculate head loss through the bottom orifice, the full flow rate of 26.4 mL/s was used, and to calculate head loss through a side orifice, one half of this flow rate value was used.

Based on these calculations, the team determined that the hole sizes would need to be reduced by a factor of approximately one-eighth. Given that conclusion, the team decided instead to return to our initial hole size constraint based on the pipe's cross-sectional area, which would have led to a hole size reduction by a factor of one-tenth.

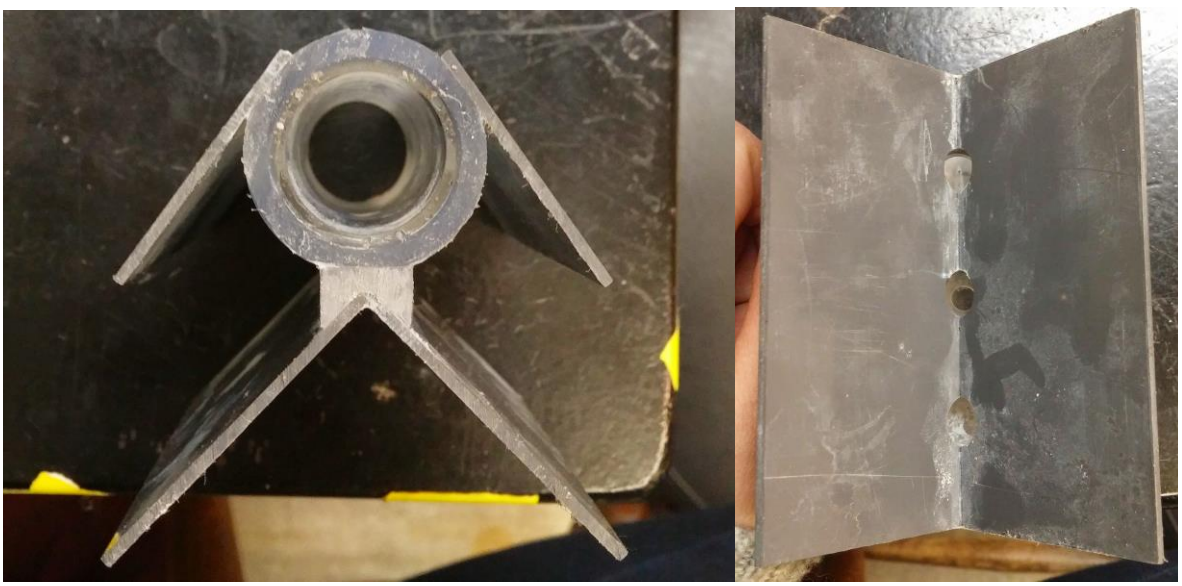

Figure 6: The newly designed piping with the smaller PVC inserted inside of the original pipe, and with the smaller hole in the center shown on the right

Running the Filter

Once the new piping was fabricated, we began to experiment with how best to fill the filter with sand and initiate flow in order to establish the necessary sand exclusion zones. The initially designed filter containing pipes and no sand is shown below in Figure 7.

Figure 7: Filter with pipes inserted, before sand has been added to fill the filter bed

We decided to fill the filter with water before adding the sand, but we concluded that the flow of water into the filter must be very low while sand is being added, otherwise it will fluidize the sand and make it very difficult to get only water in the gravity exclusion zones.

Once the filter was properly filled, initial experimentation showed that water was able to flow from inlet to outlet without disturbing the sand bed and that the established exclusion zones could be maintained as long as the flow rate was not high enough to fluidize the sand.

In order to prevent sand from entering the piping, the flow velocity must be kept below the fluidization velocity at all times except when the outlet is blocked and there is no flow through that piping, as is the case in backwash.

The theoretical filtration velocity is 1.8 mm/s, which is what we will try to run through the filter when it is in filtration mode. For a filter area of 100 cm x 100 cm, this would require a flow rate of 18 mL/s for one layer. One challenge posed by this design, is that the backwash inlet serves only one layer, while the outlet above it should theoretically be pulling water from two layers. Thus, the backwash inlet will need to be able to properly distribute a flow rate of 18 mL/s, while the outlet will need to be able to pull in 36 mL/s without failure.

The theoretical fluidization velocity is 5.5 mm/s, and the velocity through the sand-water interface must be kept below this value during filtration to prevent sand from rising into the exclusion zones. The theoretical backwash velocity is 11 mm/s, and this is what we will try to run through the filter during backwash, although further testing will need to be done to determine how this value is affected by the presence of the wings blocking a significant portion of the filter. For a 10 cm x 10 cm filter area, the theoretical backwash velocity is achieved with a flow rate of 110 mL/s.

Figure 8 below shows the filter setup after it has been filled with sand, and the sand is appropriately distributed to create the proper exclusion zones. The filter should always go through backwash before being run in filtration, because this will cause the sand to settle out in the proper way, reflecting what would occur in a real filter.

Figure 8: Filter after the bed was filled with sand, and with exclusion zones visible below the inlet and outlet piping

Modified Inlet Pipe Wing Design

The team has concluded that the multiple-inlet wing design is unnecessary for the inlet pipes, and due to these wings potentially interfering with backwash effectiveness, we have decided to remove them from the inlets. The primary purpose of the wings (vertical or angled) on the inlet is still to create a pronounced gravity sand exclusion zone during backwash. The gravity sand exclusion zone will prevent the sand from being fluidized around the orifices on the inlet pipes above the backwash inlet.. The newly designed inlet pipe has only one orifice along the 10 cm length, which is on the bottom of the pipe in the center, and it has a diameter of ⅜ inch. This size was chosen so that the area of the orifice is approximately one-tenth of the cross-sectional area of the inlet pipe. The team’s initially modified design included one set of vertical wings on the inlet pipe to replace the angular wings, which are shown in Figures 9 and 10 below. However, we later determined that even these wings could be removed from the inlet.

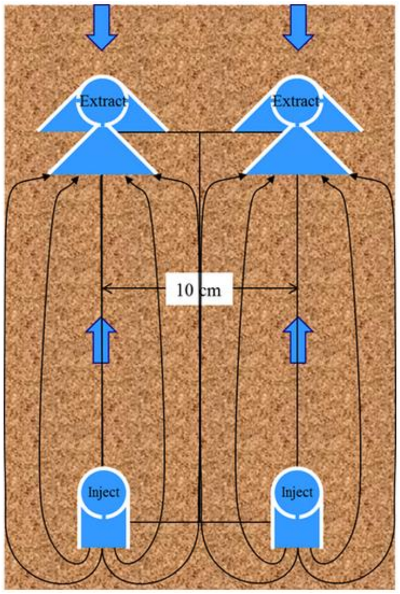

Figure 9: Revised inlet pipe design with vertical wings by Monroe Weber-Shirk

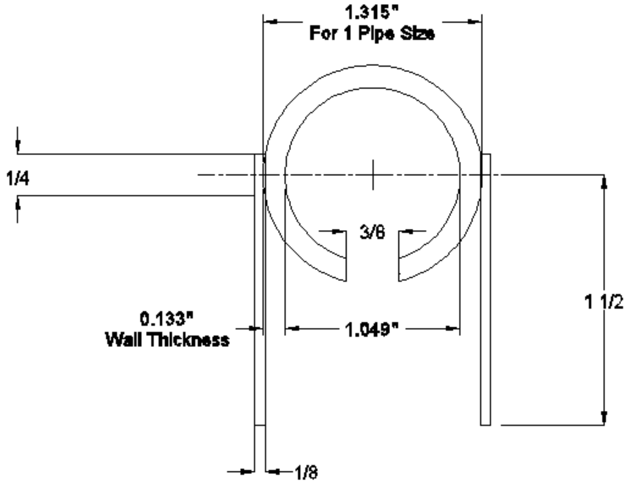

Figure 10: AutoCAD drawing of inlet pipe with dimensions (wall size noted above is the original wall size of 1" pipe)

Design of 10 cm x 86 cm Larger-scale Filter Simulation Setup

In order to find out whether inlet pipes solely with orifices or pipes with wings work on a larger scale, the team has now designed and fabricated a larger filter system, which is longer and has two inlet pipes, one above and one below the outlet. The new filter has a width of 10 cm and a length of 86 cm. The filter includes two layers, each of which has a height of 20 cm, matching the existing filter design.

The setup of the new filter is shown in Figure 11.

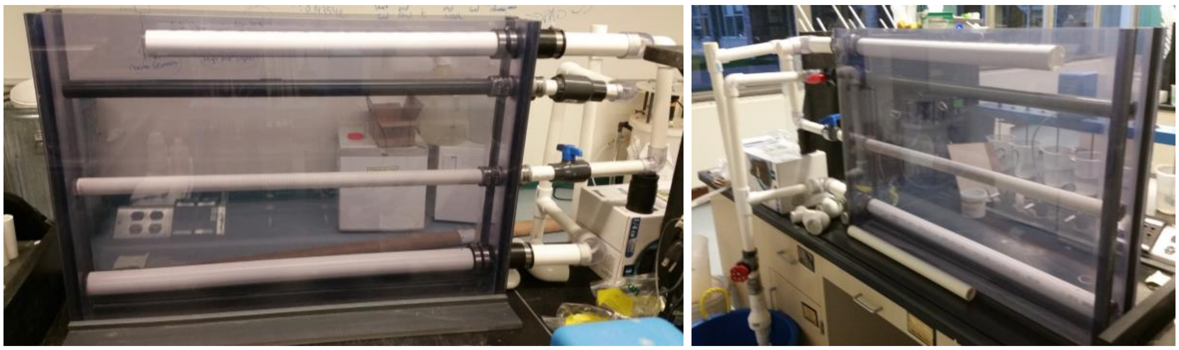

Figure 11: The new 10 cm x 86 cm filter, with two inlet pipes that have orifices on bottom, one outlet pipe that is slotted, and a backwash inlet with orifices on top

The backwash inlet is a 1.5 inch diameter pipe, with 10 orifices on the bottom of the pipe that are ⅜” in diameter. The orifices are spaced 10.5 cm apart and are centered along the length of the filter. The top inlet is a 1 inch diameter pipe, which also has 10 orifices on the bottom of the pipe. These orifices are also ⅜” in diameter and spaced 10.5 cm apart, centered along the filter. The hole size for these orifices is the same as what was previously used, and since there are 10 holes along each pipe, it meets the constraint of having total orifice area be less than or equal to pipe cross-sectional area for both the 1” and 1.5” pipes.

The outlet pipe for this filter is a slotted pipe with 0.2 mm slots, which is the same as those currently used in StaRS filters. Although we determined that the winged system as an outlet would work based on the experiments we ran, this isn’t a necessary change due to the fact that the outlet slotted pipes aren’t the ones that are clogging. Rather, the inlet slotted pipes are clogging due to dirty water entering the filter. By the time it filters through to the outlet, the water is much cleaner and the outlet pipes don’t clog. Therefore, we decided to isolate our testing to be just on whether holes with orifices work as inlets, and keep what is currently used as the outlet which is the slotted pipe. Later on, however, we will test the winged system also as an outlet simply because it can be fabricated on location rather than the slotted pipes which need to be shipped from the US.

The backwash outlet for the filter is another 1.5 inch diameter pipe located at the top of the filter. This pipe is located less than 10 cm above the top inlet pipe, which does not leave room for 30% bed expansion during fluidization. However, this is also limited by the total height of the filter, which is restricted by the fact that one must be able to reach an arm to the backwash inlet. Because significant bed expansion was not seen in previous experimentation, this might not be an issue; however, it is unclear what will happen due to the fact that all wings have been eliminated, even on the outlet pipes.

In order to prevent sand from entering the backwash outlet pipe, holes have been drilled on the top of it, through which the water will enter, and which will allow it to function like a weir. There are 15 total holes, which are ⅝" in diameter and spaced evenly along the pipe. The size of these holes was chosen so that the weir could accommodate the full backwash flow rate with less than 2 cm of head above it, which is the height of the filter remaining above that pipe and thus the maximum acceptable height of the water.

A pump will be used to send water to the filter, and a gate valve will be used to set the appropriate flow rate for either filtration or backwash. Valves will be used to block flow through both the outlet pipe and the top inlet pipe during backwash. Given the area of our filter, the flow rate required for filtration will be 317 mL/s, and the flow rate required for backwash will be 950 mL/s, which is three times the filtration flow rate due to the fact that we have only two layers.

Modified Outlet Pipe Design

The team created a new design for outlet piping that uses orifices instead of slots. To achieve better ease of fabrication, this design includes only one set of wings, at the top of the piping, and holes are located only on the sides of the piping, not on the bottom.

Because there is only one set of wings, the length of the sand-water interface must be wider in order to prevent fluidization at that location. Assuming a filtration velocity of 3.7 mm/s, because it pulls from two layers, and a fluidization velocity of 5 mm/s, the team determined that the bottom width of the wings should be 7.4 cm, given that the total width of the filter is 10 cm.

The orifice area was determined to achieve the same total hole area along the outlet pipe as what is currently installed along the inlet pipes. Because there are holes on either side of this piping, and thus twice as many total holes as there are on the inlet piping, the area of one hole on the outlet pipe is one-half of the area of one hole on the inlet pipe. The necessary diameter of the holes was determined to be 0.264", so the holes will most likely be drilled with a ¼" drill.

The spacing of the holes along the piping will also be the same as is currently installed for the inlet pipes, with 8 total holes along the 86 cm length of the filter, and with 10.5 cm center-to-center spacing between the holes.

Figure 12 below shows the new design for the outlet piping.

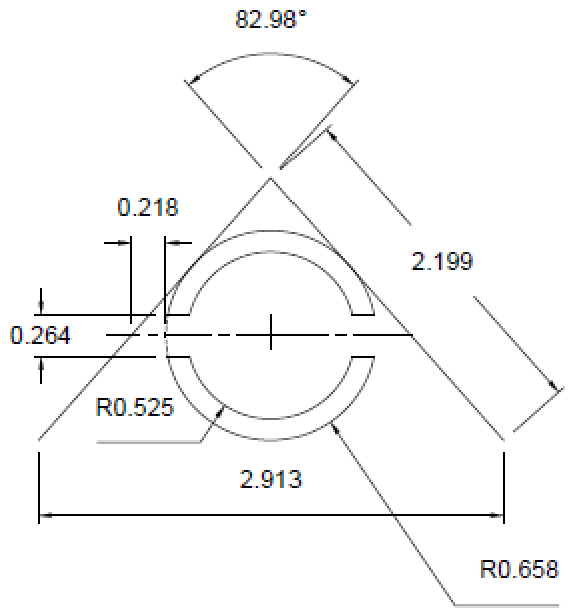

Figure 12: The design for new outlet pipe with one set of wings and holes on either side

Analysis

Filtration in 10 cm by 10 cm Filter

Initial trials of running the filter in filtration mode seem to have been successful. The team was able to get the velocity up to 2.2 mm/s in filtration mode before the apparatus began to show signs of failure at the inlet, which is higher than the 1.8 mm/s that corresponds to the standard upward velocity for filtration in AguaClara filters. At no point during this filtration, prior to failure at the inlet, did sand fluidize up into the exclusion zones or enter the outlet piping itself. Failure at the inlet means visible fluidization around the inlet pipe orifices because such fluidization of sand may result in long term clogging in the inlets.. Because the area of the sand-water interface is quite large (its width being greater than 6 centimeters), it meets our expectations that the velocity at this interface is low enough to prevent any fluidization of the sand at this location. The signs of failure that came at the higher flow rate were that fluidization began to occur in the sand that was situated just below and along the sides of the wings on the inlet pipe. This created small eddies around the wings themselves that were persistent and would likely have been problematic for the overall direction of flow as water passed through the filter.

To test the full effectiveness of the outlet pipe and the sand-water interface below those orifices, we need to run a total flow rate of 36 mL/s through the filter and through that outlet, because this pipe is actually meant to serve two layers of the filter. However, experimentation has clearly shown that 36 mL/s cannot be sent through the backwash inlet without causing significant fluidization at that inlet and resulting in problems during filtration. This is not an issue in and of itself, because the backwash inlet would never need to handle that high of a flow rate during filtration due to the fact that it only serves one layer, but it means that the team will need to include another source of influent water in order to test the backwash outlet at the appropriate flow rate. To deal with this, the team intends to add a second inlet at the top of the filter, which could send water down through a layer of sand above the inlet. During filtration, the flow would be divided such that one half would go through the backwash inlet, and one half would go through the top inlet.

Initial runs with a total flow of 36 mL/s and two separate inlets indicated that the outlet pipe with two sets of wings is capable of taking in a total flow rate of approximately 36 mL/s, corresponding to a velocity of 1.8 mm/s from two layers, without having any signs of failure. During this test, however, due to leakage through the inlet piping system and buildup of water at the top of the filter, we measured that the actual flow rate leaving the filter through the outlet piping was closer to only 33 mL/s. During this trial, it was also clear that flow was not being evenly distributed between the two inlets, and the majority of water was flowing in from above the outlet pipe, due to the head loss being much higher for the water that flows in through the bottom inlet and up through the sand. The reason for this difference in head loss was that the water coming from the top was simply flowing in from a loose pipe above the outlet and not passing through a full 20 cm of sand.

Video 1: Initial run sending 36 mL/s through filter and splitting the flow:
(Video title: splitting the flow)
https://drive.google.com/open?id=0BwW0-ETy63v2bV85R2pOMjhyOWs&authuser=0

Backwash in 10 cm x 10 cm Filter

Greater problems arose when the team began to experiment with running the filter in backwash mode. One of the initial problems we encountered was that sand would flow up into the exclusion zone and enter the bottom holes of the outlet pipe, even though the pipe was blocked off and no water was flowing out of it. Further into backwash, even when exclusion zones were preserved and relatively free of sand, there were instances when sand was being forcefully lifted and essentially launched into these zones, although it often fell back down and did not actually enter the pipe. This became more of a problem as the flow rate was increased during experimentation. These problems were recorded and can be seen in Video 2 below.

Video 2: Backwash trial with initial piping and hole sizes
(Video title: backwash with extreme flow rate)
https://drive.google.com/open?id=0BwW0-ETy63v2bjV3YXVVdTJfMm8&authuser=0

After consulting with Monroe and viewing the video of this process, the team came to the conclusion that the flow was actually taking an unwanted shortcut through the pipe while the filter was being run in backwash. Water would flow up through the bottom orifices of the blocked off outlet pipe, and it would then flow back out through the side orifices and return to the filter bed. In order to prevent this from happening, the team determined that the hole sizes needed to be reduced, which would create much greater head loss through these orifices and cause the water to choose to flow through the sand bed along the side of the wings instead.

Another issue that we came across initially was that the entire sand bed would not be fluidized. At the outset of backwash, the water would preferentially flow out of the holes along only one side of the inlet pipe. A small section on that side of the pipe would then become fluidized, mostly along the side wall of the filter, and water would flow only through that fluidized section for the remainder of the run. The team is still unsure what would be the reason behind the initial creation of these preferential flow paths, but we actually determined that the flow rate we had initially used for backwash was much smaller than the one that was theoretically required, and therefore we were not actually sending enough flow into the filter to fully fluidize the bed in the first place. Further, given the reductions that we made in the size of the orifices, we have significantly increased the head loss as water flows through these holes, which has forced the flow to divide more evenly along both sides as it flows out of the backwash inlet pipe. Since reducing the total orifice area in the pipes, we have seen significant improvements in the ability to fluidize the sand bed.

Figure 13: The sand bed only partially fluidized during backwash

Video 3 below shows backwash after we had reduced the hole size, switched to the pipe with vertical wings on the bottom, and increased the height of sand above the outlet pipe. More sand was needed to increase head loss through the sand bed before water reaches the top of the filter, which would allow for better distribution of water throughout the width of the filter rather than choosing certain paths. It is also a better depiction of a real filter and allows us to see what would happen in another layer above the wings, rather than just one layer between bottom inlet and the first outlet. The video shows improved fluidization of the entirety of the sand bed, although the area directly above the winged outlet is pretty still due to obstruction by the wings.

This is the reason why we decided to add a pointed cap on top of the outlet to circulate sand better, and also ultimately we went back to using slotted pipes in our new system. Also notable is the fact that all of the sand initially in the inlet pipe was expelled, and the force from the water hitting the bottom of the filter was enough to raise the entire inlet pipe slightly within the filter. Video 4 shows backwash after the cap has been added to the outlet pipe, with a notable increase in circulation with sand moving more easily down the length of the wings.

Video 3: Backwash with modified inlet piping with vertical wings
(Video title: Backwash after lowering pipes 11 mm/s)
https://drive.google.com/open?id=0BwW0-ETy63v2Z2tvWkZhaFk3aDQ&authuser=0

Video 4: Backwash with modified outlet piping with capped top wings
(Video title: Capped Backwash 11.6mm/s)
https://drive.google.com/open?id=0BwW0-ETy63v2TXNrYnNaYmlvRGc&authuser=0

Removal of Wings from Inlet Pipe

The team removed the wings from the inlet altogether and ran the filter in both filtration mode and backwash. There did not seem to be a detrimental effect on filter performance, and the team decided to move forward with inlet pipes having only orifices and no wings. Since our initial testing included only a backwash inlet, it is not exactly clear what will happen at the other inlet pipes during backwash. Most likely, the fact that there is no flow through these pipes during backwash will prevent this from being an issue. This testing is shown in Video 5.

The video shows that there is initially sand in the pipe, which entered when the piping was disconnected from the sink and thus is an issue specific to this particular system; however, it is also clear that there is some sand at the end of the pipe that does not flow out immediately during filtration. If, on a larger scale, sand ends up in inlet pipes during backwash and remains there, it could pose a problem for this filter design with orifices.

Video 5: Filtration and Backwash in Filter after Removal of Wings on Inlet
(Video title: filtration to backwash)
https://drive.google.com/open?id=0BwW0-ETy63v2SkpXUTM3VmQxcXM&authuser=0

Running the 10 cm x 86 cm Larger-scale Filter

Testing with the longer filter has shown nothing to indicate that using inlet pipes with orifices instead of slots will cause problems in the filter.

Because we returned to a slotted pipe for the outlet, the primary concern during this testing was whether sand would enter the inlet piping through the orifices while it was fluidized during backwash. Throughout our experimentation, sand entry into the inlet piping did not ever result in a failure mode being reached; for our purposes, a failure would occur not if sand simply entered the orifices of the inlet pipes during backwash, but only if it also subsequently flowed into the piping beyond the filter, where it would be more likely to cause problems and could not necessarily be flushed out easily during filtration. It appeared that some sand and dirty water would enter the top inlet pipe during backwash, but this would be immediately flushed out again once the filter went back into filtration mode. In the current filters, it is already the case that dirty water enters this piping during backwash, so this finding indicates that the operator would need to continue the practice of wasting some of the initial water in order to flush out the pipes upon return to filtration. Sand was never seen in the transparent elbow of either the top or bottom inlet, which indicates that this sand is not actually entering the length of piping that runs outside of the filter, and therefore sand entry has not shown itself to be an issue.

Our experiments also showed that there was a good amount of fluidization happening when the filter was put into backwash. Initially there were issues with the filter overflowing before a fluidization flow rate could be achieved, because the backwash outlet piping would not drain quickly enough; however, after we removed one of the elbows and sent the piping more directly into the bucket, this was no longer an issue. There were also noticeable channels of flow that seemed to come directly out of the orifices in the backwash inlet, which indicated some formation of preferential flow paths, but there was enough circulation occurring throughout the entire filter that this did not seem to be much of an issue. One way to deal with that if necessary would be to make the holes in the backwash inlet smaller and more frequent, in order to increase the head loss through them and distribute flow more easily, but that would also increase the necessary height of the filter and should therefore be avoided unless it is actually necessary.

We have also seen some indication that flow is not being distributed entirely evenly throughout the filter during either backwash or filtration. One cause for this is that pressure recovery is high enough at the end of the piping that it seems to be causing more flow to exit the pipe through the last hole than through the first hole. Again, this issue could be solved by decreasing the hole sizes and increasing head loss, but increasing head loss through the filter would not be ideal. There also seems to be more flow at the back side of the filter, in the direction perpendicular to the pipes along the filter length. This is possibly due to the momentum that the water has flowing in that direction after it flows up from the pump.

Conclusions

Despite the issues that the team has experienced, the experimentation thus far has seemed to indicate that gravity-based sand exclusion zones are a viable option for keeping sand out of the piping while eliminating the existing slots and increasing orifice size. The wing system used on the outlet pipe in the smaller filter has been successful at keeping sand out of the main lines of piping during both backwash and filtration, even when the sand below the outlet was significantly fluidized.

Experimentation has also shown that the inlet and outlet piping designs will likely not be identical. Because fluidization during filtration is not an issue at the sand-water interface below the inlet pipes, these pipes do not need the same interface area as do the outlet pipes, and therefore they do not need the same set of wide-angled wings. Particularly on the inlet pipe, it has appeared to be the case that the dual-winged system that was widely angled and blocked much of the filter made it much more difficult to initiate fluidization of the sand bed. After the inlets were converted to have only orifices and no wings, fluidization was significantly improved, and flow during filtration was not negatively affected.

We have also seen that the inlet design with orifices and no wings does not cause a failure during backwash where sand is able to enter the piping as it is fluidized. Even though sand enters the piping within the filter, it does not flow up into the inlet piping outside of it, and it is flushed out during filtration. In the case of our filter, there is a valve that is responsible for keeping sand and water from flowing further into the pipe; in a regular StaRS filter, the head difference incorporated into the piping that currently prevents water from flowing up through it during backwash should have the same effect and prevent sand from flowing into areas where it will become a problem.

Future Work

Going forward, the first step is to fabricate and install the new outlet pipe with one set of wings that is capped on top. Once that is installed, further experimentation can be run on the larger-scale filter to determine if the system will be able to run properly, which includes the abilities to fluidize the bed for backwash, to keep sand from entering the piping through the orifices, and to avoid fluidization at the sand-water interface below the outlet pipe during backwash.

In the future, we would like to collaborate with the EStaRS team to have these new piping designs for both inlet and outlet be installed in the EStaRS lab filter.

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