Alternative Backwash without Slotted Pipes, Fall 2014

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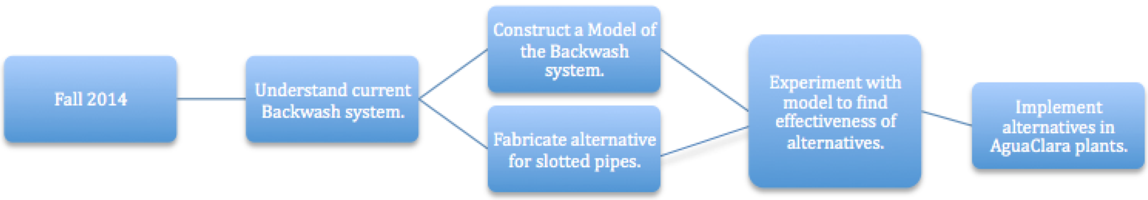
Abstract

The current slotted pipes being used in the backwash system of the AguaClara filtration plants have been clogging up with sand, thus posing a problem for the backwash system since the slotted pipes's purpose is not being fulfilled. Given this issue, the Alternative Backwash without Slotted Pipes subteam will work to find an alternative pipe for the backwash system that will not clog up with sand at any point of backwash or filtration and will be easy to manufacture on site in Honduras and India given the resources available in each respective country. The team has successfully built a STaRS scale model to be used to accurately experiment with alternative pipes for both an inlet and an outlet valve. Through experimentation, it was found that the alternative tubes in the shape of a hollow rectangular prism cut in half lengthwise and placed with the interior facing down did not fill up with sand during the processes of filtration or backwash.Once the pump was turned off, however, the sand would settle underneath the outlet pipe. This led the team to two possible courses of action: the first being that the team could leave the pump running the water at a low flow rate and the second being that the team build a second alternative for the outlet pipe. Both actions would solve the issue of the sand clogging up, but the team pursued the second alternative. The new shape for the alternative was a hollow cylinder with wings that extended out tangentially from the top of the cylinder with a hole in the middle of the cylinder's bottom. In experimentation, the new alternative outlet pipe worked well for the first trial, but filled up with sand in the subsequent trials. Through more experimentation with the current alternatives, or perhaps new alternatives, future subteams will work to find a solution that will consistently work without filling up with sand.

Task List

Task Map



Task Details

1. **Understanding the Current Backwash System** - *Jorge, Ainhoa, and Alberto*

<u>To be completed by:</u> *September 24*

In order to further this semester's endeavors with the main goal of finding an alternative to the slotted pipes in the backwash system, the sub-team must all have a mutual and strong understanding of how the backwash system actually works, either through a lab demonstration or a meet up with our research advisor or perhaps a meet up with Professor Monroe. Also, by understanding the backwash system the members of the sub-team strive to determine the aftereffects of removing the slotted pipes from the system as a whole, the paths which the sand and water take within the backwash system can be further understood and thus lead to new thoughts on alternative ideas to the slotted pipes.

2. Build a model of a Backwash System without Slotted Pipes -Led by Alberto, with help from Jorge and Ainhoa

To be completed by**:** November 12

Once research has been complete regarding a new design for the slotted pipes, the sub-team hopes to build a small-scale model of the filter to visually see how the water flows in the system, especially near the inlet pipe. All research regarding materials to be used for the model, along with model specifications, will be collected and organized by Alberto and each of the sub-team members, with the help of the Shop in the basement of Hollister Hall, will construct a small-scale model. Based on the findings of the small-scale model, the sub-team will be able to determine how to scale it up if the findings provide feedback that supports the new design as an alternative to the current design. The sub-team will need to evaluate failure modes and determine whether a solution exists that eliminates the need for slots.

2.1 Determine how to close the outlets during backwash.

To be completed by**:** *October 23**

After gaining knowledge and determining the shape of the first alternative pipe, the sub-team noted that the inverted "U" design will have a large opening along one of its sides. To better visualize this shape, think of cutting off the bottom half of a circular pipe. The sub-team needs to develop a system to close the outlets during backwash, so that the sand does not leave the filter.

2.2 Determine how to design pipes and holes in the filter box so that they can be changed.

To be completed by**:** *October 23**

Constructing the model so that the pipes for inlet and outlet can be changed is a difficult challenge. To experiment as much as possible the sub-team needs to be able to remove the pipes to use different shapes and in order to improve the model.

2.3 Format prospective expenses for model construction

To be completed by: *October 28*

As the materials are finalized an estimate for the expenses related to the project should be created. The materials will be ordered from the McMaster-Carr website and once the expenses have all been listed in a professional format, a sub team member will send a copy of the list to Monroe and William.

2.4 Determining the effects of changing the shape of the pipe - *Alberto*

To be completed by**:** *Ongoing*

Perhaps the problem may be that the current shape of the pipe is more prone to clogs than others. For example, instead of using the full, cylindrical shape with slots for the pipes, the sub-team could try to incorporate a pipe that has the same cylindrical shape but with no slots and that has a relative "U" shape instead of the usual "O" shape. The sub-team hopes to find a way to keep the sand from flowing with the water into the pipes, thus clogging the pipes. Though the "U" shaped pipe was a suggestion made by Professor Monroe, the sub-team hopes to look at different shapes for pipes that may also prevent sand from leaving the filter.

The sub-team will test these different shapes by building models of the pipes and implementing them into the model to be built in the future.

2.5 Experimentation based on Fluids Mechanics and Geotechnics- Ainhoa

To be completed by: *November 1**

Since the construction of the scale up model is going to take more or less 2 months, a spreadsheet with different values of velocities, diameters and sand densities will be written so that as rapidly as the model is finished, the sub-team can begin to experiment with it.

2.6 Construction of Model *-Alberto, Ainhoa, Jorge*

To be completed by: *October 31**

With the help of Paul in the shop of Hollister Hall, the sub-team hopes to construct the model fully in order to begin experimentation.

3. Scale up model and implement design- *New Subteam*

To be completed by: *Spring 2015*

Once a successful alternative for the slotted pipes has been found, the sub-team hopes to scale up the small-scale model and create a design to be implemented in the water treatment plants in Honduras and India. The sub-team will determine which materials need to be changed, along with how to have these designs constructed easily with current resources in each country.

4. Redesign the arrangement of the model - Alberto, Ainhoa, Jorge

To be completed by: November 19

The first attempt in using the recently constructed model was a disaster; all the water has overflowed the bucket. The main reason for the failure was that the we bucket had to be lifted the bucket so that the pump would receive waterworks, but put lower than the outlet pipe in order to the filtered water goes out. That is why the sub-team needs to, we have to think about a better arrangement of the elements that form part in the model.

5. Outlet and inlet tubings

To be completed by: November 26

During the first attempt, the tubing that connects the outlet rectangular pipe and the bucket, was clogged by the sand, so the sub-team needs to determine whether it is a problem related to the previous point (redesign the distribution of the model) or if it is a problem that has to be solved. Furthermore, the inlet tubing, the one that connects the inlet pipe with the pump, was also clogged.

6. Backwash Velocity

To be completed by: November 18

The water that comes from the pump has to be regulated manually with a valve. The method used in order to know which is the velocity of the fluid consists in counting the number of turns of we have made to the valve that have been made. The sub-team has determined obtained that the filtration velocity is obtained when we turn 2.5 times the valve is turned 2.5 times. However, the backwash velocity proved impossible to reach even though when the valve is completely opened. Thus, the sub-team will test this again to determine if this conclusion was mistaken or there is a need to need to try again in case we made a mistake or find another alternative.

* Dates are tentative and are subject change.

Team Roles

Jorge Guevara: *Team Coordinator*

- Keep track of the progress the sub team has made with their tasks.
- Arrange meetings to be held outside of designated time weekly.
- Maintain communication with team members and our research advisor.
- Edit any reports that will be submitted.

Ainhoa Arribas Llona: *Head of Research*

- Ensure the validity of resources used for research.
- Organize research found by other team members and create a Word Document containing the research, the name of the team member who found it, the date when the team member found, and a detailed summary of findings that can be used from the found research.

Alberto Arnedo: *Head of Design*

- Lead the construction of any models required for the sub team by finalizing the materials needed for the model, the sketch of the model, and a tentative construction schedule.

In addition to the responsibilities assigned with each role, each member of the ABSP sub-team must follow the subsequent set of responsibilities:

- Maintain communication through the use of email and the phone app “WhatsApp”
- Submit research summaries and information to the Head of Research
- Update each other with findings that will have an impact on the project

Literature Review

The backwash system in the filtration plants made by AguaClara relies upon many of the principles of fluid mechanics. It is known that as a fluid flows through a pipe, there are two associated head losses that accompany it: the major head loss and the minor head loss. What these head losses measure are the amount of energy lost due to friction and the energy loss due to flow expansion, respectively. In the major head loss calculations, the formula seen below is used:

hf =fLDv2 2g (Weber-Shirk,2014),

where the cause of the head loss is friction on the pipe wall, itself. In the formula above, f is the friction factor, L is the length of the pipe, D is the diameter of the pipe, v is the flow velocity, and g is the standard acceleration due to gravity. When looking at the minor head loss calculations, the following formula is used:

he =Ke v22g (Weber-Shirk, 2014),

where the cause of the energy loss is flow expansions at different edges and turns in the pipe. In the formula above for minor head loss, K is the loss factor, v is the velocity of the flow of water, and g is the standard acceleration due to gravity.

These calculations are of significance when looking for alternative pipes to replace the slotted pipes, because the flow rate has to be maintained at a rate that is as consistent as possible to ensure that the sand bed does not undergo unintentional fluidization. The relationship between head loss and flow rate are direct, meaning that if the flow rate increases, the head loss will increase. Head loss increases proportionally to the square of the flow.

Fluidization is an important factor to consider when attempting to find an alternative to the current slotted pipes used in the current backwash system in the filtration plants. According to an article written by Mohammad Asif, a recognized chemical engineer, the value of the minimum fluidization velocity varies depending on the variation of sizes of the constituent species (Asif, 2012). As the sizes of the species are more varied, the value for the minimum fluidization velocity decreases, because the concomitant volume change (smaller particles fitting into voids left by larger particles) leads to a lower porosity, causing a higher pressure drop in the mixed bed (Asif, 2012). If one were to investigate the situation at a microscopic level, one could use the following equation to calculate the minimum fluidization velocity for a single sand particle,

$$V_{MinFluidization} = \frac{{\varepsilon_{FiSand}}^3 g D_{60}^2}{36k\nu\left(1-\varepsilon_{FiSand}\right)}\left(\frac{\rho_{Sand}}{\rho_{Water}}-1\right),$$

where ε_{FiSand} is the porosity of the particulate material, g is the gravitational constant, D is the sand diameter, k is the Kozeny constant which typically has a value of 5 for most filtration conditions, v is the kinematic viscosity, ρ_{sand} is the density of the sand, and ρ_{water} is the density of the water. When using the above equation, it is vital to note that it is meant to be used with laminar flows (Weber-Shirk). By using the above equation, the minimum fluidization velocity of a specific particle size can be found. This fluidization velocity is an important parameter to take note of when working with the backwash system.

Introduction

The Alternative Backwash with Slotted Pipes sub team has began its first semester with the AguaClara project team in response to multiple problems arising from the use of slotted pipes in the backwash system.

The AguaClara StaRS filter design uses slotted pipes to inject water into and extract water out of a sand bed. The slots must be designed to be smaller than the smallest sand grains. The slots in the OStaRS (Open Stacked Rapid Sand Filters) in Honduras and in the EStaRS (Enclosed) in India are currently using 0.2 mm wide slots in PVC pipes. With the technologies currently available to the AguaClara Filtration sites in India and Honduras, problems have arisen regarding the fabrication of the tiny slots on the pipes.

In addition to manufacturing issues, these slots can gradually clog, especially if the water from the sedimentation tanks (in the case of OStaRS filters) or from the source (in the case of EStaRS filters) is not very clean. Some of the filtration plants, both those using OStaRS filters and those using EStaRS filters, have attempted to remove the clogs. This, however, is not an ideal situation because the sand must be removed from the pipes to get inside it. In India, one of the water treatment plants with EStaRS had trouble, because the well pump was pumping mud from the bottom of the well into the filter. The inlet manifold piping and slotted pipes clogged with the mud, and then the filters couldn't be backwashed. In Honduras, workers added purge valves on all of the inlet and outlet pipes so that the slots could be partially hydraulically cleaned.

By finding a successful alternative to the slotted pipes, both the processes undertaken for the construction and for the maintenance of the AguaClara filtration plants will be made more efficient by allowing for a potentially easier fabrication process and by reducing the amount of time and effort spent cleaning up the clogged slotted pipes.

The goal for this research was to explore and invent alternatives to slotted pipes that would be less prone to clogging. To accomplish that, the goal was to design a water inlet system that can inject water into a sand bed using a large opening size that is not prone to clogging. The main challenge is to design the inlet so that it does not fill with sand during backwash.

Methods

Once the first AutoCAD model was constructed, members of the subteam went to consult with Paul in the shop in order to get an idea of how the construction of the model would proceed. After the consultation, it was decided that the model would be made mostly from PVC sheets. Also, Paul expressed some concern with regards to trying to make the model able to be adapted to multiple shapes and sizes for the inlet and outlet pipes. The subteam took this concern into consideration, and began to think of a method to deal with this issue. The subteam came up with the idea of making the holes where the inlet and outlet pipes enter as large as the largest pipe which the team would experiment with, which would likely to have a diameter of two inches.

When most of the fabrication ideas and materials were beginning to be finalized, the sub team, along with their research advisor, met with Professor Monroe to both consult with Monroe on the progress of the model. During the consultation with Monroe, many aspects of the design and project as a whole were discussed. From this discussion, the team decided to alter the prior design for the model and create a new one with some slight modifications, as seen in the figure below. The main changes to take note of are that the pipe closest to the base of the backwash model should be closer to the base in order to save material and make the box lower so that it could be more compact. Also, the diameter of that pipe was chosen to be 3.81 cm (one and a half inches), while the other two pipes were given diameters of 2.54 cm (one inch). In addition, a pump and a bucket for recycle of water were added into the design. The reason for the pump lies in the fact that water must move throughout the system with enough velocity to produce sand fluidization during backwash. The bucket was added as a place for the backwash water to go. The water used in the model was recycled as a means to achieve sufficient flow in the column and to avoid the waste of clean water. A great feature of the bucket is that the subteam can know if the effluent pipe in the model has failed or not dependent on whether there is sand accumulation at the bottom of the bucket.

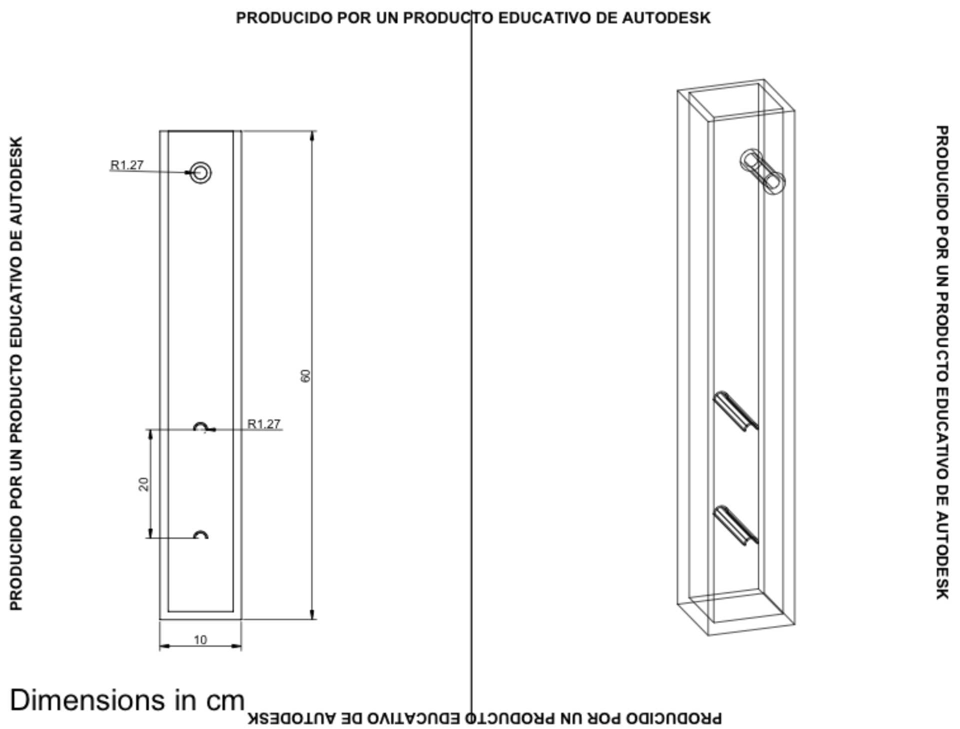


Figure 1: Initial AutoCAD Drawing of Backwash Model with Alternative Pipe with Dimensions in cm

All in all, the main elements of the stacked rapid sand filtration backwash model are the following:

1. Water bucket 1: The model has a bucket full of water, from which the pump propels the water. This bucket was also initially used to recycle water, as the flow required for these experiments is more than can be sustained by the tap, however issues were found with sand entering the bucket, and thus entering the pipe.

2. Water bucket 2: This bucket stores the water that comes from the outlet and backwash pipes. Once the experiment finished, the subteam would move the water from bucket two to water bucket one. If any sand came out, it was put back into the sand column.

3. Pump: A centrifugal pump was used to circulate the water. Because the water was not dirty (like in real filters), the water was recycled in the system. In order to solve the problems with sand flowing into the pump that happened in the first experiments, the pump was placed at a higher position than the water in the sandbox so that when the pump is turned off, the sand does not get into the pump.

4. Box: A clear PVC rectangular 65 cm height box has been built, so that the behaviour of the sand can be seen through the box walls. A removable lid may be added in case overflow problems occur. According to the dimensions, the height has to be much larger than the cross sectional area, because during backwash the height of the sand bed expanded by 1.3 (for the scale model, the subteam used a coefficient of 1.5, in order to have more security against overflow). In regard to the cross sectional measurements, the only requirement was to be big enough to handle and change the pipes.

5. Inlet pipe (first pipe in the figure, beginning from the bottom): The inlet pipe is the one from which water enters into the box. There were no concerns about clogging this element, because it is impossible since water without sand circulates through it constantly. Tubing of 1.91 cm (3/4'') diameter was used.

6. Outlet pipe: This pipe allowed the water to exit the box during filtration. While backwash was taking place, the outlet pipe had to be lifted at a higher height than the water in the box so that water couldn't flow through it. The most important concern about this element was that it might clog during filtration. (second pipe in the figure). The tubing used was the same as in the inlet, 1.91 cm (3/4'') diameter. These tubing is flexible and allows a better arrangement of all the elements in the system. However, special care must be taken near the connections with the box and pump so that the tubing does not bend and impede the flow water or result in leaks.

7. Backwash pipe: The backwash pipe is the one that is located near the top of the box. The diameter of it is 2.54 cm diameter (1''). Moreover, it was connected to another pipe that drained into the bucket.

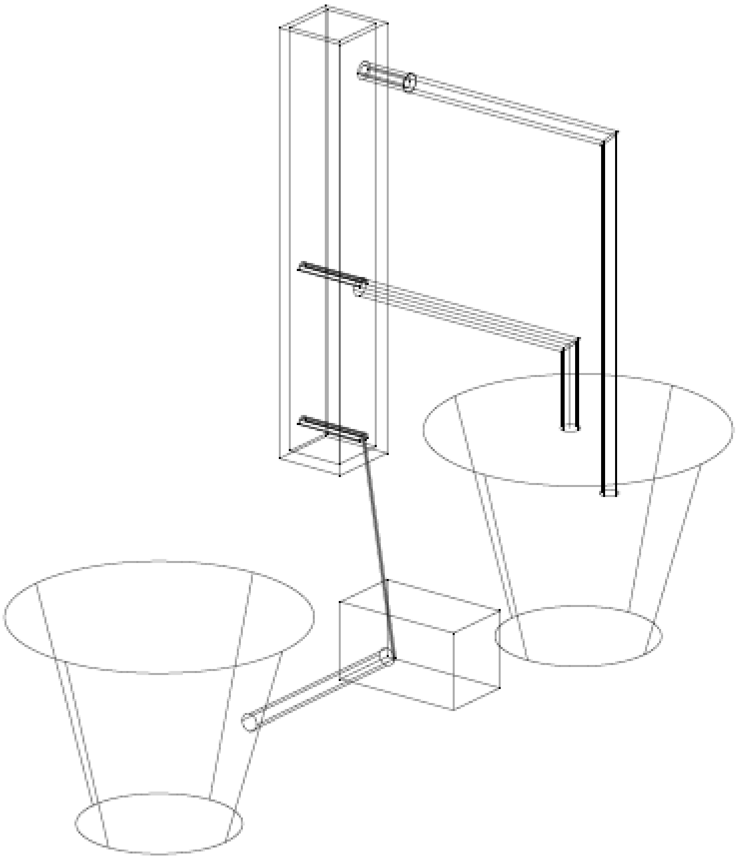


Figure 2: AutoCAD Drawing of New Backwash Model with Alternative Pipe with Dimensions in cm

Figure 3: Photograph taken on 07/11/2014

After the StaRS scale model was built, as seen in Figure 3 above, experimentation begun to test the effectiveness of the alternative entrance pipe. Three trials were completed, and they all shared the same basic setup: once the model was completely set up, the pump had to be plugged in to an electrical outlet, and then water would flow at the filtration or backwash velocity (depending on which one was being experimented).

The first type of pipes that were tested were inverted U-Shaped rectangular pipes order to know if they would be prone to clogging. As in the real systems circular pipes are used, the shape of the pipes was changed to circular with a hole one. Then, the same shape with wings was used and finally,half of the circular pipes with wings. In the figure below are all shown:

All of them were attach to the box by pressure, glue or screws were not used.

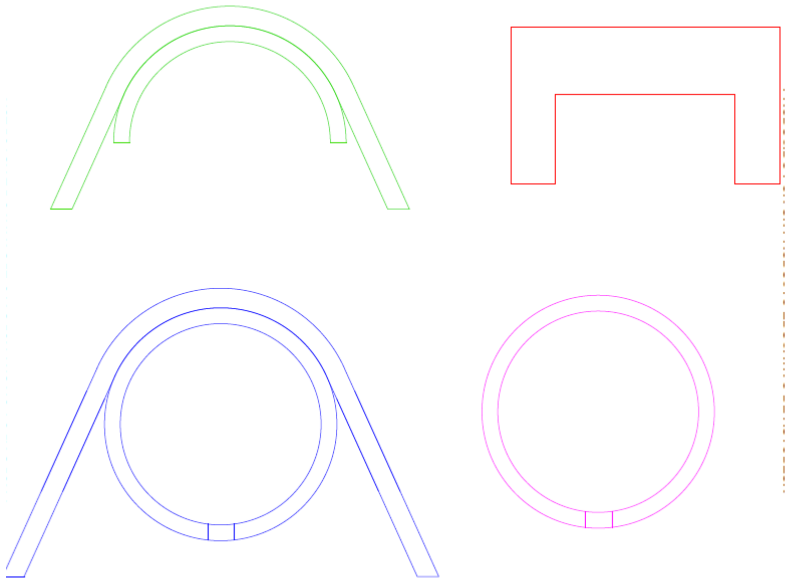


Figure 4: Different alternative pipe shapes created and used for the experiments

Results and Discussion

First Trial

The first trial was unsuccessful. One of the connectors ordered to join the tubing and the pump had not arrived yet, thus delaying experimentation. This was resolved through the use of a different connector that joined two pipes with different cross-sectional areas (a reducing coupler), which then substituted for the connector that had not arrived yet.

The next concern was the discharge provided by the tubing. Since smaller tubing had to be used due to the use of a different connector, the backwash velocity could not be reached, therefore the experiment was limited to testing the flow rate ranges of filtration.

During filtration, the sand was exiting the box through the outlet tubing to the bucket. This raised the concern that the pump could clog, since the water that was being recycled. For this reason, it was decided to switch off the pump. However, it was discovered that it was not the best decision. Due to elevation differences, the water from the box, together with the sand, started to move from the box down the inlet tube into the pump. Then, the tubes were disconnected from the pump before the water and sand could reach it, thus accidentally causing water to be sprayed throughout the lab space.

Second and Third Trials

For the second attempt, the focus was reaching the backwash velocity. Since the connector had arrived by this point, the intended dimensions of the tubing were used so that the model could potentially reach the backwash velocity. However, the experiment did not go well due to the fact that the valve and the pump got clogged with sand.

At last, in the third trial, all pumps, valves, and tubes were clean and ready for experimentation, and the trial ran wonderfully. The sand did not clog up the pipes while the water was being pumped into the system, as seen in the video here:

https://www.youtube.com/watch?v=rS-wZVM_D8k&feature=youtu.be

For a better visual of how the model looked like with the alternative pipes set in the inlet and outlet valves, Figure 5, below, shows the absence of sand filling up underneath the pipes.

Figure 5: Photograph taken on 11/11/2014

Although the pipes worked well in the third trial, the team still wanted to experiment with other alternative pipes that would be easier to manufacture when the pipes are made and sent out to replace the current pipes in the field. In India and Honduras, the pipes that are being used are circular, PVC pipes, thus leading the subteam to work with circular shaped pipes, instead of experimenting with rectangular ones. Also, the team had more incentive due to the fact that the outlet valve would clog with the rectangular alternative when the pump was completely turned off.

Fourth Trial

Construction of the new alternative began with a 2.54 cm (1 inch) diameter PVC pipe. The pipe was built with a 7.6 mm (0.3 inch) diameter circular drilled into hole in its center, so that the water would go out from the outlet tubing without being filled out with sand. Once the experiments began with this new alternative pipe, it was found that the pipe filled up with sand almost immediately. In fact, once the filtration process began with the water being pumped into the box, the sand began to enter to the pipe, as depicted in the photo below.

Figure 6: Photograph taken on 11/25/2014

Working off this slight failure, the subteam consulted with Professor Monroe and came up with the idea of creating “wings” on the circular pipe used previously that would extend downward tangentially from two sides of the pipe. The way the subteam created such a tube was by ordering a thin, 1.6 mm (1/16 of an inch) sheet of PVC. The wings were created by heating the sheet with a heat gun while it was held around the pipe. Once the new alternative was built, it was placed in the outlet of the apparatus to prepare for experimentation.

The experiment worked well initially when the water was being pumped below the filtration velocity into the system. The sand did not enter the pipe at all for the first minute. As the velocity increased, however, small amounts of sand entered through the hole. Even though the sand was filling up in the pipe, the sand was not exiting the outlet valve. The first trial of this experiment can be seen in the attached YouTube link:

https://www.youtube.com/watch?v=IWFC0q9RoOQ&list=UU-cSaUFl5zPdi0k7cGLywSw,

An image of the new pipe’s implementation can be seen in Figure 8, below:

Figure 7: Photo taken on 12/3/2014

While the team was carrying out the experiment, it was realized that the sand had been going out through the outlet in the previous trials due to the positioning of the outlet tube, which was originally creating a siphon that would carry the sand out of the outlet valve. For this reason, the height of the outlet tubing was lowered and put in a vertical position. The change in positioning and elevation can be seen in Figure 8, below.

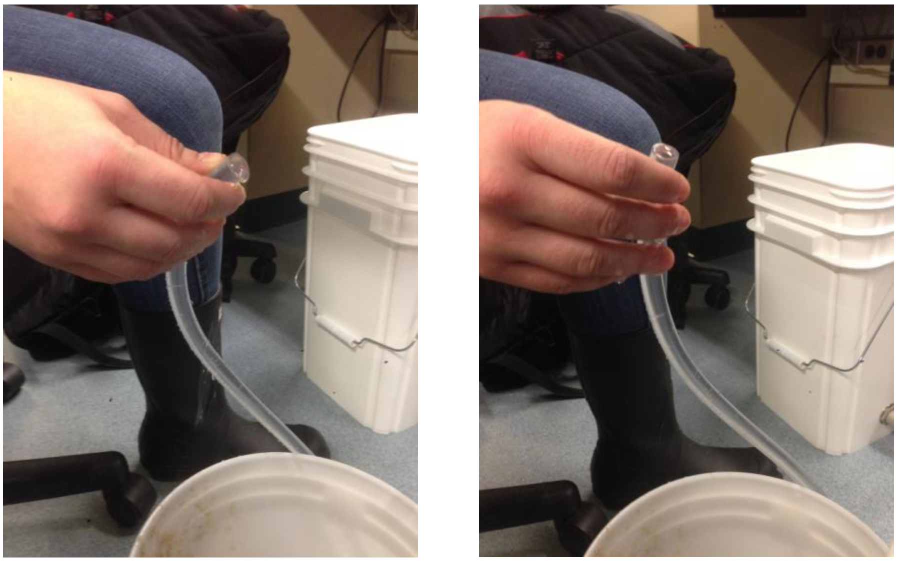


Figure 8: The left photo is the original positioning and the right photo is the new; photograph taken on 12/3/2014

No more sand came out of the outlet tube after this adjustment, but the flow rate of water coming out was lowered.

Fifth Trial

Coming back to completely open pipes, a 2.54 cm (1 inch) diameter PVC pipe was sliced in half for a new alternative design. Wings were also included as an improvement for retaining sand at a lower height. Similar to the results of the first trial, it worked perfectly for backwash and all the sand settled after backwash stopped. However, during the first stages of filtration, water went through the outlet pipe very quickly, thus lifting the sand at the bottom of the pipe and taking it out through the outlet tubing. The shape of the pipe is the following:

Figure 9: U inverted shape half pipe with wings; photograph taken on 12//10/014

A video of the trial can be seen in the Youtube link below:

https://www.youtube.com/watch?v=Wy0J8CqHGv8

In order to correctly perform the filtration and backwash processes, the issues below needed to be taken into consideration:

1. The pump: The pump used was not submergible, therefore it was vital to make sure the pump did not get wet. Furthermore, when sand entered into its impeller, it clogged up the pump and thus made it stop working. In addition, it lacked a on/off switch, so a power strip was needed for safety.

2. Gate Valve: The valve was clogged easily if sand entered into it. Furthermore, it took too long to open and close it. Based on this issue, it could be of interest to buy another kind of valve. Nevertheless, with the current velocity regulator valve, the system works perfectly. Furthermore, the amount of turns necessary to get the backwash velocity have been determined. For this reason, it may be a good idea to install a ball valve in front of the current one.

3. Arrangement of the elements: When starting the system, the subteam ensured that the tubing carrying water from the bucket to the pump had no air in it. If it had some air, the pump would not work, since it was not self-priming. The pump needed to be at a higher elevation than the water in the sandbox so that when it was off, water did not reverse its flow and enter to the pump with sand. The subteam preferred the use flexible tubing, which was much better to achieve a proper arrangement of the objects. For this reason, the tubing was switched to lengthier and more flexible tubes. A new bucket was also purchased to avoid pumping sand-filled water into the system.

4. Water leakage: During the second experiment, many leaks appeared in the system. On the one hand, the inlet and outlet connections to the box were losing water when running the experiment. The problem was solved by taking out the connections and teflon-taping them. On the other hand, the valve had some strange leaks. After looking carefully, it was discovered that the sand that had entered the valve produced some small channels in the interior of the valve that led to a loss of water-tightness.
5. Outlet pipe: When the filtration process was experimented with, it was realized that the sand exited the box, thus posing a problem for the pump. For this reason, a second bucket was bought to store the water that came from the outlet and the backwash.

All in all, with a correct performance of the issues explained above the results obtained show that inverted U-shaped pipes worked better that round pipes with a hole since the sand got out once backwash finished.

Conclusions

The first experiments showed that the possibility of using inverted U tubes was feasible, although the shape could be improved, since the pipe used in that experiments has a very small branch height. Designing a channel with a higher branch height for the water to flow would prevent the sand from settling and plugging the inlet into the box.

From all the experiments completed with different alternative pipes, it was found that after backwash has finalized, the sand settles and the pipes have free space for water to flow. All the alternative pipe designs, except for the one used in the fourth trial with the hole at the bottom, are optimal alternatives for the slotted pipes during backwash.

Issues regarding the filtration portion of the project have not been solved. Once backwash has stopped and filtration begins, water flows through the outlet at a very high velocity, thus lifting the sand from the bottom and carrying out sand from the outlet at the same time. This happened until there was no more water at a higher point than the outlet pipe.

Future Work

Future subteams should focus on a few of items.

The main problem that future teams must solve is the problem of filtration. The sand still gets out when filtration starts because the water lifts the sand at the bottom of the box. The system for the outlet must be changed, using different outlet tubing diameters, changing the shape of the outlet pipe or using items like the wings to make more difficult to sand to get into the pipes.

Another area that could be worked on would the size and shape of the “wings” used on the second alternative pipe. Different angles of extension and sizes of the wings could be made to allow for a wider range of sand being settled underneath the pipe. More experiments should be run with the current pipe’s wings to determine what shape or angles would best work.

References

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