

Filter and Treatment Train Flow Control, Spring 2017

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Abstract

The objective for the Filter and Treatment Train Flow Control team (FTTFC team) this semester was to design and construct a weir module that would allow the plant operator to easily redirect sufficient flow for filter backwash without shutting off other filters' flow. The goal of the design was to be easily constructible, easy to operate, strong enough to withstand water pressure and require no calculations for plant use. The team designed several removable weir options and ultimately chose a hinged design. The design is similar to a dog door that will be shut during normal flow and open during backwash. The model was fabricated and tested under conditions simulating a 20 L/s plant. The weir module was strong enough to withstand the flow, was easy to construct and was simple to open and close even with the water pressure against it and therefore was a success. There was some significant leakage around the weir flap. Therefore, construction and design should focus on recommendations for watertightness of the flap if this design is to be used in an AguaClara plant in the future.

Introduction

During normal filtration flow, the filter systems in the plant run as separate systems in parallel with each other. The filter bed consists of sand. As the sand filters the water, the pores between the sand particles fill up with sediment removed from the water. When a large portion of these pores have filled, the filter bed can no longer function and needs to be cleaned. The cleaning process is done by backwashing the bed. Backwashing is providing a high enough flow rate from the bottom of the bed upwards, so that the solid particles separate from each other and act as a movable fluid. When this occurs, the water washes the particles and the filter media is cleaned.

During low water supply, low flow makes backwashing filters in parallel difficult. Backwashing requires a higher flow rate than normal filtration because it takes more flow to fluidize the particles. If the majority of the water from the total filter system could be diverted to the one filter, then there would be enough flow to backwash during low flow conditions. The team has been working on a module that will allow the operator to control the quantity of water entering each filter and divert the flow necessary for backwash to one of the filters. During this backwash period, the flow would be lower in the other filters, which does not impact their performance.

The chosen mechanism to fulfill this requirement is a module with a movable weir. A weir is a barrier across the width of a channel to alter the height of water. It may or may not have an open slot in the middle to allow passage of flow. When used between equal-sized channels in a parallel system such as three AguaClara filters, weirs can be used to create unequal division of flow. The FTTFC team has designed a system of two concrete weirs separated by a concrete slab at each filter entrance. The first weir has a large opening and the second has a narrower one. A movable flap is placed over the opening of the first weir. For backwash during low flow periods, the movable flap is lifted to uncover the opening in the first weir, thus increasing flow to the selected filter while the remaining water flows to directly to the other filter(s).

A weir module directs a specific maximum flow rate to the filter being backwashed. A flow rate too low will be insufficient to fluidize the sand, while a flow rate too high could cause sand to flow out of the filter. In order to eliminate the need for the plant operator to perform the calculations necessary to avoid either of the scenarios, the weir should be able to passively limit the backwash flow rate.

To summarize, the successful design of such a weir would allow the plant operator to conduct backwash even in low flow conditions without completely shutting off flow to the other filters and without having to make any calculations and move heavy parts. The team has considered designs that would be low maintenance for the plant operator and would also be easy to operate. These designs are discussed in

greater detail below. The material and designs also have to be strong enough to withstand the water pressure in the filter box and not exceed desired maximum leakage. The hinge design that was chosen achieved all of these goals when tested, except there was some leakage present around the flap. If there is too much leakage present, the weir is not able to control the height of the water going over the weir. The team modeled the leakage rate as a function of gap size between the weir and the flap, which can be used as a maximum leakage guideline. These results can be seen in the Manual. Overall the hinge design was a success, but efforts discussed in greater detail below should be taken to reduce the amount of leakage if the design is used in an AguaClara plant.

Literature Review

The preliminary weir design that the FTTFC began with was based off the work of the Stacked Rapid Sand Filter sub-team which was a part of the fabrication team of Spring 2015 (Mottl and Galdi, 2015). This team worked on a similar project with a rectangular weir, i.e. a weir with a rectangular notch at the top. This past design had a much deeper gap between the two weirs, and the first weir was entirely removable instead of having a closable flap. A large frame was used to hold the removable weir in place. The design worked but it had a lot of bulky components and it was difficult to insert and remove the weir. The design chosen by the FTTFC team has fewer parts and should be easier for plant operators to use.

The SRSF team began their research with this model and found that the the Kinsvater-Carter equation can be used to model flow through the weir (LMNO, 2014).

$$Q = C_e(232)g(b + k_b)(h + k_h)(3/2) \quad (1)$$

Where;

Q= discharge,

Ce= drag coefficient based on h/P (notch height/weir height)

b/B= notch width/ weir width

g =acceleration due to gravity

b= notch width

h= notch height

Kh=0.001m

Kb=constant based on the ratio b/B

The SRSF team used this equation for their calculation, based on the scale model fabricated. Based on backwash theory, the desired flow rate for this scale should be 0.224 L/s. The use of such an equation for construction of the slot in a concrete weir is sub-ideal since some imperfections are to be expected in concrete work. For this reason, the FTTFC team came up with a stop-log design to alter the depth of the smaller weir after construction, but before operation of the plant begins.

The concrete slab between the two weirs in the current design is a modification from the past design, in which there was a very deep separation between the two weirs. To calculate height of this concrete slab, the team modeled the slab as two open channels with rectangular cross-section, each starting at either side of the entrance tank and ending at the slot in the middle. Assuming a flat bottomed channel and critical flow, the critical depth can be found using the following equations.

$$y_c = \frac{2E}{3} \quad (2)$$

$$\frac{E}{3} = \frac{v^2}{2g} \quad (3)$$

Where;

y_c = the critical depth

E =specific energy

v =velocity

g =acceleration due to gravity

Based on this equation, it was found that for a 20 L/s plant, the required height difference between the concrete slab and the slotted weir should be 13 cm to avoid flow over the sides of the slotted weir.

This analysis was tested physically in a 20 L/s flow and was verified. For different flow rates, a MathCad file available in the AguaClara drive may be used to calculate height for the second weir.

In order to quantify leakage in the system as a function of size of the gap between the first weir and flap (see 15), the orifice equation was used. This was done assuming that the bottom of the flap and the wall of first weir formed a slot-like orifice. The leakage was calculated as a percentage of total flow through the module (20 L/s). The team arbitrarily chose an acceptable leakage rate of five percent of the total flow. For a flow of 20 L/s this would result in a gap of 3.5 mm. The maximum allowable leakage percentage can be decided on during plant design and construction.

$$Q = \Pi_V * A * \sqrt{2 * g * h} \tag{4}$$

Where;

Π_V = the vena-contracta coefficient for an orifice (0.63)

A = area of the rectangular gap based on gap width and flap width

g = acceleration due to gravity

h = height of the flap relative to the bottom of the flap (i.e head)

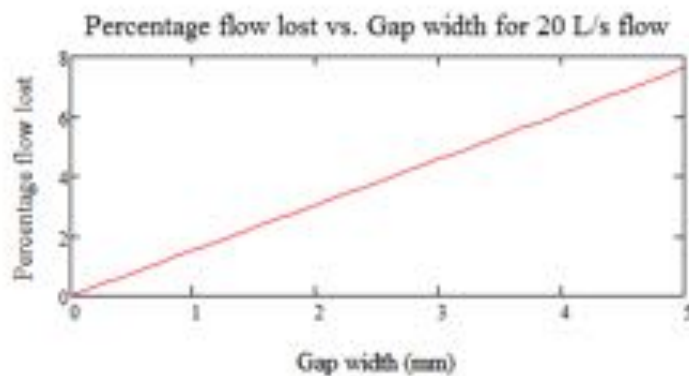


Figure 1: Leakage vs Gap size

There is little literature available on removable weirs in a drinking water treatment setting. Removable weirs, however, are frequently used for upstream flood control and flood alleviation as shown in figure 2 (ACE, 2012). These weirs can either be manually operated or machine operated. These weirs are typically larger scale and are made out of Stainless Steel which is more than an AguaClara plant needs.



Figure 2: Tilting Weir Example

Figure 3 shows two weirs in parallel (ACE, 2012). This is similar to the AguaClara filtration system where there will be several filtration tanks in parallel and the weir can be removed on one of them to induce backwash.



Figure 3: Parallel Weir System

Previous Work

The FTTF team is a new team this semester so there is no previous work from this team. In the Spring of 2015, the Stacked Rapid Sand Filter team, SRSF team, tested and troubleshooted a weir design that would allow the plant operator to adjust the quantity of water entering into the filters for backwash (Mottl and Galdi, 2015). Their model can be seen in figure 4. During the normal forward filtration flow, water enters the first tank, passes over closed weirs of equal height, through a slotted weir, under a last weir, and finally through the outlet pipes. This process results in an equal split to each filter. To backwash one of the filters, the removable weir for that filter can be removed. This removal diverts a specific flow to the backwashing filter regardless of if the plant is at low flow conditions. The rest is evenly divided between the other filters. While the first weir has the capability of diverting a large fraction of the flow to one weir, the second weir sets a maximum flow rate necessary for backwash for each path in the system which prevents sediment loss in the filter. The last weir prevents unwanted air from entering the water. This weir system is proposed for use in AguaClara plants with more than one filter and utilizes only gravity as its driving force.

One issue that the SRSF team ran into was that the slotted weir was so large, that the filter being backwashed would receive all the water while the other would receive a trickle. When the weir size was reduced, the backwashed filter received 75 percent of the flow instead of the target 80 percent. This difference was caused by leaks and possible inaccuracies in dimensions. The SRSF team designed and constructed the model with the intention of it being one eighth the intended size. In reality it was not one eighth and so some of the dimensions were not proportional to what they would be in the plant. The SRSF team also placed a removable weir along the entire entrance tank rather than just the slot where the water enters the filtration system. This design results in a very large weir that is difficult to remove because it is so big and because it has so much water pressure against it. In response to these issues, the FTTF team this semester has been using the AguaClara plant dimensions in AutoCAD to ensure that the dimensions and calculations are accurate. The FTTF team has also proposed a smaller weir that only covers the water entrance slot which will require less materials and will be easier to remove.

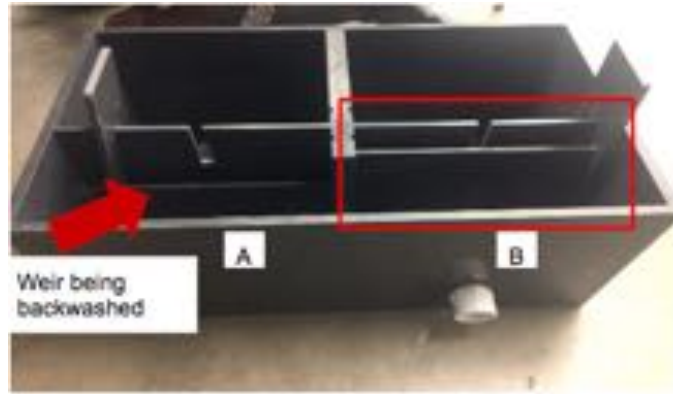


Figure 4: Removable weir model built by SRSF Spring 2015

The AguaClara plant in Las Vegas, Honduras features a removable weir system based off of SRSF Spring 2015's design in their filtration tank. Their system includes a vertically sliding weir made out of acrylic plastic and welded aluminum, as seen in figure 5. This system design has resulted in several problems. The Las Vegas plant receives a high flow rate of 20 L/s. This high flow rate results in a lot of water pressure on the weir and as seen in figure 6, the weir is actually warping from the water pressure. Based on this information, the FTTC team has decided to make their weir out of PVC plastic which is stronger than acrylic plastic and aluminum. PVC sheets were not available at the time of construction of the Las Vegas plant but they will soon be available in Honduras because they are required for the 1 L/s plant. Another problem with the Las Vegas design is that the weir is very difficult to remove when a high flow rate is flowing as shown in figure 6 (Erickson, 2017). The FTTC team is adding a removal mechanism to the weir such as a handle or a pulley so that this issue is resolved. The system is also currently leaking because it is not watertight and is resulting in a lot of losses, especially during low flow conditions. The FTTC team is also focusing on making their design watertight so this issue is resolved.

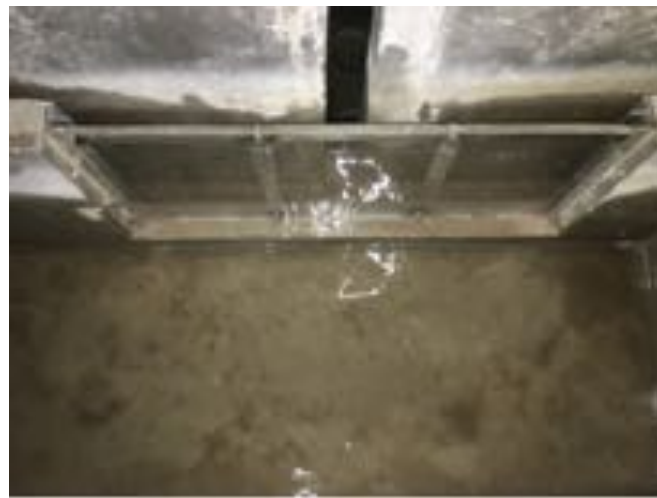


Figure 5: Las Vegas Removable Weir System



Figure 6: Las Vegas weir system is warping from water pressure

Methods

Before the weir designs were developed, a base design was created to model the tank that the weirs would be built onto. This base was planned using equations and parameters that can be adjusted for different plant sizes. These equations are explained further in Base Designs and the Methods Sections below. The full scale rendering of the base that the FTTFC team used, is based on the dimensions for AguaClara's 20 L/s plant. Design components such as wall thickness, space in between weirs, and height of weirs were pulled directly from measurements of the real plant using the AutoCad design tool. After the base design was completed, stop-logs were designed to fill the second weir slot. These stop-logs would allow the plant operator to control the flow rate without changing the width of the slot or using any calculations. These stop-logs are beneficial because the weir slot is made out of concrete and therefore it is very hard to adjust the flow rate once the structure is completed without the use of stop-logs.

After the stop-logs were designed, the FTTFC team began designing the removable cover for the first weir, depicted in green in figures 7 and 8. The first step was to draft and brainstorm preliminary designs. The beginning design was based off of the vertical sliding design done by the SRSF team. From there, the team developed other systems such as a horizontal and vertical sliding system and a hinge design. After brainstorming, the next step was to draw the designs in a computer system to get a better understanding of how they would look and perform. The original hand drawn sketches were transformed into 3D CAD models, specifically Fusion 360 models. Ultimately the team decided on using a hinge design because it has few components, can be made water tight, has durability and is easy for the plant operator to use. A more thorough explanation and a list of pros and cons of the other designs can be seen in the Manual.

Base Design

In order to properly test the weir gate designs, the team needed to start with a base design. The base would provide a platform to model all of the other designs. Calculations, shown in the manual in the appendix, were done to obtain the appropriate sizes and dimensions of the walls and channels. The dimensions are integral to the success of the base because the flow rate going into these entrance tanks needs to be monitored by the physical components of the base.

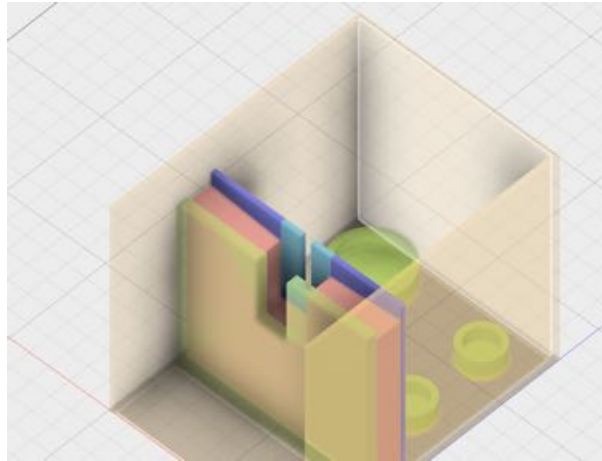


Figure 7: Model of Base

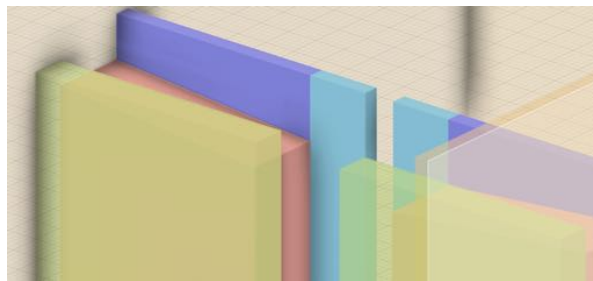


Figure 8: Closeup of Middle Section

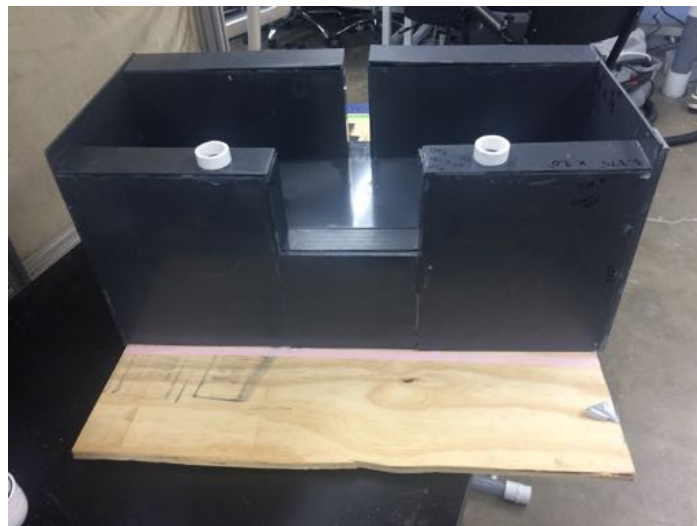


Figure 9: Constructed Base

Larger Weir Design

Regarding the first weir with a large opening (represented in green in figures 7 and 8), the precision and accuracy of the concrete work will have some effect on the watertightness of the system when the movable section is in closed position. If implementing the hinged design described in later sections, the movable flap would be flush to the concrete and imperfections in the smoothness of the concrete would result in small gaps between the PVC flap and concrete. These gaps will result in leakages and therefore should be minimized. The team came up with two ideas to limit this leakage that could be further explored.

The first idea is to have a thin rubber gasket attached to the PVC flap at its place of contact with the first concrete weir. When the pressure from water in the tank pushes against the flap in closed position, the rubber would compress and create a seal between the PVC flap and the concrete weir. The team tested this concept using slit rubber tubing fit around the edges of the flap (see Figure 18).

The second idea is to embed a large ceramic tiles over the opening and the front face of the first concrete weir. The tiles would then be cut to uncover the opening, resulting in a weir with a smooth tiled section in area of contact with the PVC flap. The smoothness of this contact area will reduce the incidences of gaps and hence reduce leakage. The fabrication for this method would be simple since it is easy to embed tiles in concrete. Since the model designed by the FTTFCT team used PVC instead of concrete, this concept was tested by using the flap without the rubber tubing gasket.

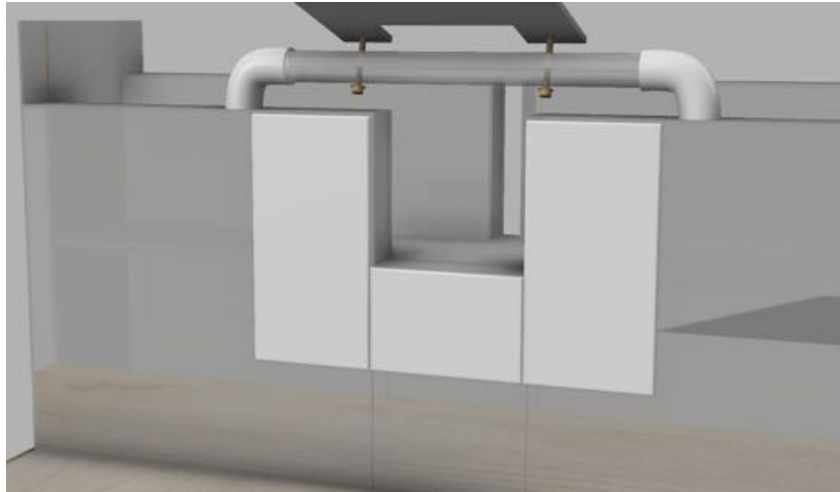


Figure 10: Tile Design

Smaller Weir and Stop Log Assembly Design

The FTTFCT team has designed a modular stop log design that can be used to finely tune the flow rate through the smaller weir. As seen in Figure 11, small one cm tall pieces would slide into the notch and allow the height of the hole to change. The stop logs would have an H design and could be easily added or removed to offer more modularity. The idea of embedding a PVC section into the concrete weir was conceived as a way to minimize the specificity required in concrete work. However, based on feedback from the engineers in Honduras it was decided that constructing the slotted weir fully in concrete is not a significant problem and embedding PVC in concrete would be an additional inconvenience. Tile could be embedded into the concrete as was suggested for the larger weir to create a smoother contact point between the stop logs and the weir. The modular stop logs with the H-design will still be used to adjust for slot size.

The height of the larger weir relative to the concrete slab was calculated using equations (2) and (3) as described under the Literature Review section.

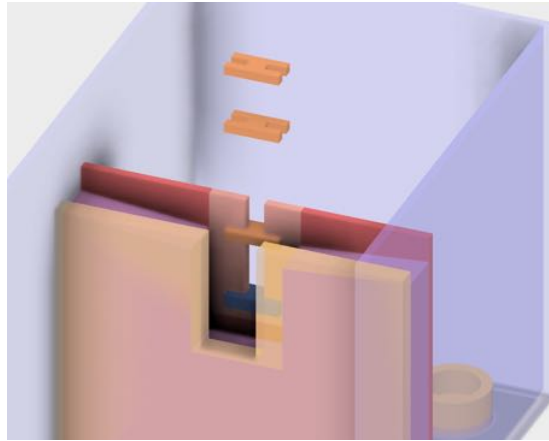


Figure 11: Stoplog Assembly

Selection of Hinge Design

After the base was designed, the adjustable weir designs could be fitted to that specific model. There were three proposed designs: a hinge, a horizontal slide, and a vertical slide.

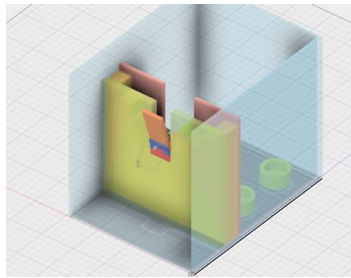


Figure 12: Hinge Design

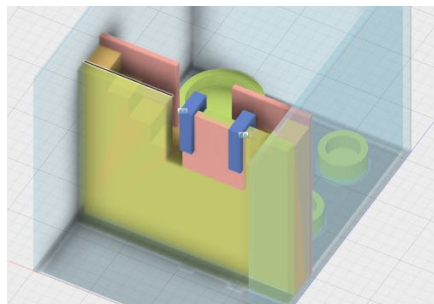


Figure 13: Horizontal Slide Design

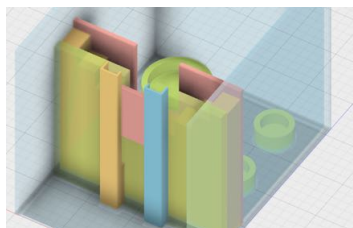


Figure 14: Vertical Slide Design

These models were continually iterated and modified. The weir designs themselves were also improved to become easier to use, cheaper to fabricate, and more water tight. Additionally, motion studies for these mechanisms were made to fully understand the movement of the wall along its path. A more comprehensive list of pros and cons for each of these designs can be found in the manual.

When considering a final design, several criteria were considered including: ease of constructibility, ease of use, cost and availability of parts, structural stability, water tightness, professional aesthetic, and longevity. The final design that the FTTFC team decided was the top sided hinge design for its simplicity and ease of use. One of the main reasons for picking hinge design over the horizontal and vertical sliding designs was that it eliminates all sliding surfaces. The vertical and horizontal designs consist of PVC sliding along the concrete surface of the weir. These two surfaces sliding against each other would create friction, making it harder to use. This friction also reduces the life of the weir since it will wear away the material. It is also difficult to create a watertight seal between two surfaces that have to slide across each other, so the hinge design will be more watertight than the other two designs. The hinge design is also very easy to construct and requires very few components compared to the sliding designs. The gap between the two weirs can also be increased by a few inches, reducing adjacent walkway size by the same magnitude, in order to improve ease of access for constructibility for masons.

Two methods of attaching the hinge to the concrete were also designed. These designs can be seen in figures 15,16, and 17. The first attachment method, Hinge Design One, consists of a strip of PVC and a hinge (15). Cheap aluminum hinges are relatively easy to acquire in Honduras. If a specific plant location was unable to acquire aluminum hinges, it is possible to make simple PVC hinges, Hinge Design Two (16 & 17). This design simply requires two PVC elbows and a loose fitting PVC tube to connect them. Two bolts can be drilled through the tube and act as a rigid connector between the wall and tube. This design is also very adjustable because the bolts can hold spacers that ensure the wall is always flush to the weir.

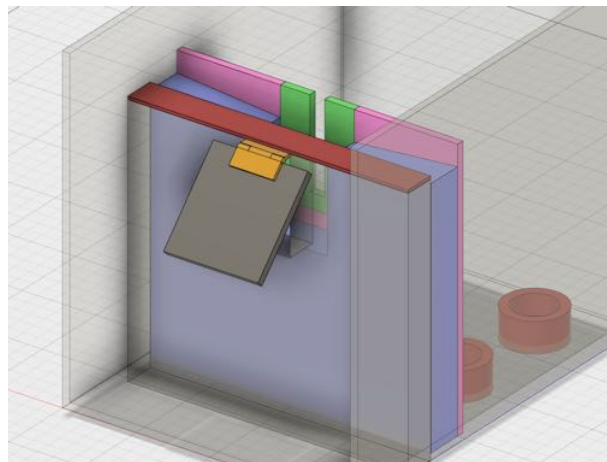


Figure 15: Hinge Design 1

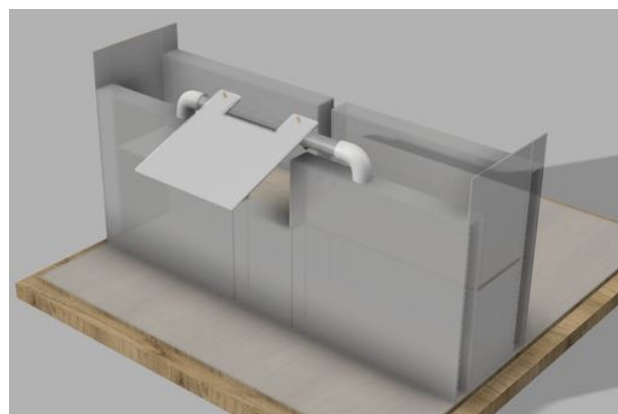


Figure 16: Hinge Design 2

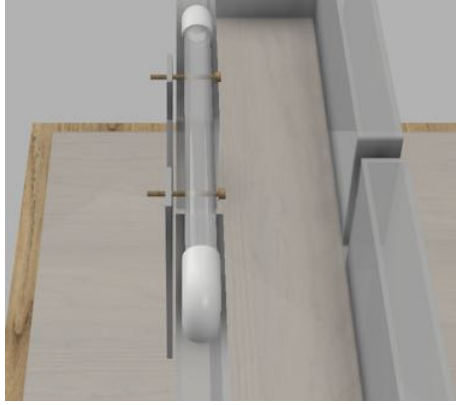


Figure 17: Hinge Design 2

There are several possible issues with the two hinge designs that should be considered. In Hinge Design One pictured in 15, water might be able to squeeze underneath the PVC strip and alter the effective height of the weir. A possible solution to this issue is using the same gasket or tile ideas recommended for the base design. Additionally finding a hinge strong enough to support the adjustable flap against the water pressure could be problematic. Aluminum hinges also have the problem of tarnishing over time and thus taking away from the professional aesthetic of the plant. Hinge Design Two solves the problem of tarnishing by using PVC elbows and a loose fitting PVC tube to connect them. It is unclear, however, how the PVC elbows will be attached to the concrete underneath. PVC tubes could be embedded and attached to the elbows but this takes up valuable space and may interfere with rebar in the concrete. This design is also less polished overall and not as visually appealing as the aluminum hinge design.

Procedure

The FTTCF team tested the weir in the DeFrees hydraulics lab using one of the flumes. The intention of this trial was to test the ease of opening and closing the model during 20 L/s and to see the amount of leaking that occurred.

Before testing, the model was constructed. The fabrication process consisted of building three sections, the front weir with the slot, the middle flat section, and the last notched weir. These sections consisted of a wooden 2x4 base and then layers of either 1/8" or 1/4" thick PVC. The wood was meant to give the module enough strength to withstand the design flow rate of 20 L/s and the PVC covering was to ensure that the surface was watertight and was a similar smoothness to finished concrete.

First, the wooden 2x4 frame was constructed and was attached to the plywood sheet base. The base was necessary so that the module would be able to stand up once placed inside of the flume. Then, the PVC sheet sections were attached to the frame using PVC glue. By using PVC glue, the seams of the PVC would remain watertight and strongly held together. The system was built to fit the width of the flume. There were some irregularities in the wood which resulted in some gaps in the module. These gaps meant that the module was not watertight, however this was not too much of a concern since the module was intended to be used just once for testing.

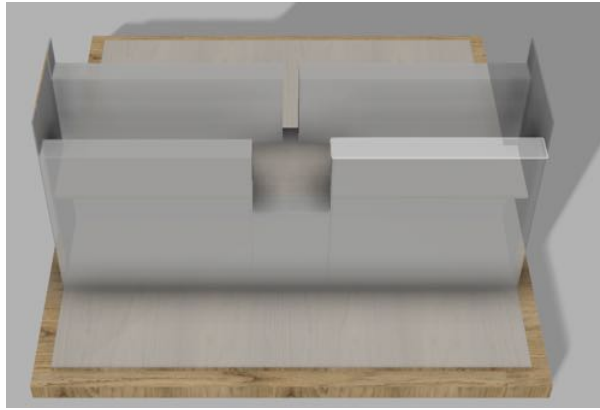


Figure 18: PVC and Wood Base

In addition to the weir module, the team constructed three different gates/coverings for the weir opening: 1/4 thickness PVC, 1/8 inch thickness PVC, and 1/8 thickness PVC with reinforcement. This can be seen in figures 19, 20, and 21 respectively.



Figure 19: 1/4"



Figure 20: 1/8"



Figure 21: 1/8" with reinforcements

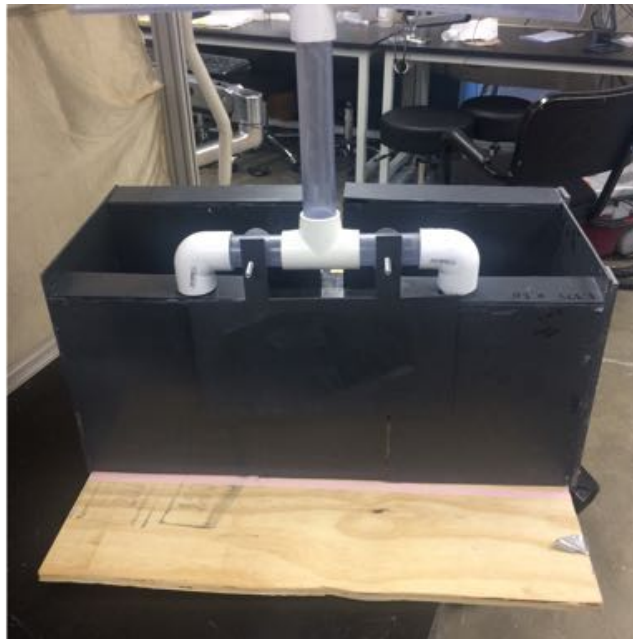


Figure 22: Constructed Module with hinge weir

The team also decided to use the PVC hinge system (Hinge Design 2 shown above in 16) to attach the weir covering to the module. This design was chosen because it was easy to construct and the materials were readily available in the lab. A PVC handle was also attached so that the covering could be opened and closed easily. The finished product is shown in figure 22.

Results and Analysis

Once the FTTFC team finished the fabrication, they tested the model to see if it held up to expectations. To reiterate, a successful weir would be watertight, be easy to open and close and would not warp under the pressure of a lot of water.

The performance of the weir, with regards to the goals mentioned above, were as follows:

1. Test that the module does not break when subjected to a 20 L/s flow rate

When the weir model was placed within the flume at a 20 L/s flow rate, the structure stayed intact. This means that the same model and/or fabrication technique could be used by future teams wishing to test flow control. Moreover, the PVC hinge system used to connect the gate to the main module did not break or warp when subject to a 20 L/s flow rate. This means that such a system could be used in the real plants especially if aluminum hinges cannot be obtained. The

model was not damaged at all, meaning that it could also handle a flow greater than 20 L/s and therefore could be scaled up for larger plants.

2. Physically observe if the system would redirect flow

When the module was in 'closed' position, a majority of the flow went over the top of the first weir, as desired. There was some leakage through the gaps between the flap and the first weir, which will be elaborated on under 'Acceptable Gap Size Between Flap and Weir' in the Manual. When the weir was in 'open' position, the water level was retained at the height of the first weir while water flowed through the exposed opening. This observation combined with the analysis conducted by the SRSF Weir Model team in 2015, indicates that the module designed by the FTTFc 2017 team would result in desired redirection of flow (Mottl and Galdi, 2015).

3. Verify that the calculated height for the slotted weir would result in zero flow over the top of the second weir

The height of the slotted weir (weir two) in relation to the height of the gap between the two weirs was calculated assuming open-channel flow from the each side of the gap towards the slot at the center. The height of the second weir relative to the gap was set as the maximum height in the open channel so that no water would flow over the top of the second weir. During testing, no water flowed over the top of the second weir and a decreasing depth was observed from the sides of the gap towards the center. This verifies that the calculated height was appropriate.

4. Check for warping of the different PVC flaps while opening and closing the module

Due to the high moment involved, the flaps are most likely to break while being opened against incoming flow. While opening the 1/4 inch thickness flap, no visible warping was observed. The 1/8 inch flap had slight warping along the narrower strips used to connect the flap to the hinge. The 1/8 inch reinforced flap did not display any visible warping. This suggests that 1/8 thickness inch PVC with reinforcement could be used in the plants to reduce the cost since 1/4 thickness PVC is more expensive.

5. Qualitatively test ease of operation (i.e. force required to open and close the weir module)

The system was very easy to operate, and very little physical effort was required to open and close the flap against a 20 L/s flow rate. This indicates that the system is appropriate for a single plant operator to use without any mechanical aid. Since the bulk of the force against the flap comes from hydrostatic pressure rather than the deceleration of moving water, the water velocity does not play a significant role in the force required to move the flap. Thus, for similarly sized flaps, the force required to open the weir module would be similar, and thus would still be easy to open and close during higher flow rates. This means that this design could be used in AguaClara plants larger than 20 L/s

6. Observe leakage in the system

The system had some leakage when the weir was in closed position. This could be minimized through more precise fabrication, or through use of a more effective gasket (see subsequent point on 'Observe the effects of the rubber-tubing gasket'). The flow lost to leakage was also modeled theoretically by assuming that the gap between the flap and the first weir behaves as an orifice. Minimizing this gap results in a lower percentage of flow lost.

7. Observe the effects of the rubber-tubing gasket at reducing leakage.

For testing purposes, a gasket was fabricated using rubber tubing (peristaltic pump tubing) with lateral slits to fit the PVC flap. The effects of this gasket were inconclusive, although qualitatively, it appeared mildly successful at reducing leakage when the flap-with-gasket design was compared to the flap-without-gasket design. The team recommends using the chart for gap vs. leakage, 23 in the Manual, as a primary indicator for leakage in the system, with a gasket serving as a secondary measure to reduce leakage.

Conclusions

The FTTFc team has completed the semester objective of designing and constructing a weir module that successfully diverts the flow from one weir to another. The hinge design chosen by the FTTFc

team was easy to construct and easy to operate but did have minor issues with watertightness. Leakage around the flap can be reduced by adding a rubber gasket around the flap to compress the connection between the the weir and flap to a seal. The FTTFC team used slit rubber tubing as a gasket, however the use of a smooth, flat rubber gasket could be expected to work better. The walls of the weir should also be as planar as possible so that the flap lies as flush against the walls as possible. This weir module design has been successfully tested in realistic flow conditions and can be used in AguaClara plants to redirect flow during backwash during low flow conditions. The design is also easily scalable for plants larger or smaller than 20 L/s.

If implemented in the AguaClara plants, this weir module will allow for smoother transfer of flow between filters during times of backwash in low flow. The system currently implemented in Las Vegas, Honduras, for this purpose has a number of problems including inconvenience of removal/ insertion, very high leakage, noticeable warping of the flap, and intricate concrete work. The module designed by the FTTFC team improves on all of these aspects compared to the previous system. If the filters can effectively backwash during low flow rates then the plants are less vulnerable to variations in flow rates and are therefore more effective in various conditions.

Future Work

The objective of the FTTFC team has been met and therefore a future team is not necessarily required. If a future team was created, they could focus on altering the design for tubular filter systems. They could also work on reducing the leaking around the hinge and brainstorming materials that would be available in Honduras. Otherwise, the next steps should be to send the design to Honduras and implement the concept in an AguaClara plant to see how it performs in real life conditions.

References

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Manual

For members of APP and other AguaClara engineers who intend on building a weir system, this manual contains important calculations and analysis of various designs. Although the FTTFC team has suggested that most plants use the hinge design, it is possible another design could be better suited.

Base Calculations

The base design consisting of two weirs with a concrete slab is a modification on previous filter entrance tank designs. The concrete slab is an addition that will improve ease of constructibility for masons since there will be no deep slot between the two weirs. The height of the slotted weir relative to the concrete slab is calculated using assumptions of open channel flow above the slab.

$$y_c = \frac{2E}{3} \quad (5)$$

$$\frac{E}{3} = \frac{v^2}{2g} \quad (6)$$

Where;

y_c = the critical depth

E = specific energy

v = velocity

g = acceleration due to gravity

Based on this equation, it was found that for a 20 L/s plant, the required height difference between the concrete slab and the slotted weir should be 13 cm. This height prevents flow from going over the sides of the slotted weir. These dimensions were tested physically in a 20 L/s flow and were verified. For plant sizes besides 20 L/s, a MathCad file available in the AguaClara drive calculate be used to calculate height for the second weir. All other dimensions besides the concrete slab width were scaled from the 2017 AutoCad files for AguaClara plants.

If ease of construction is a concern, the concrete weir can be widened by a few inches, while decreasing the adjacent walkway width by the same magnitude. This would allow masons to fit more easily into the space to construct the weir.

Acceptable Gap Size Between Flap and Weir

Due to error in construction/fabrication and irregularities in concrete, there is expected to be a small space between the PVC flap and the concrete of the first weir. The percentage of total flow lost to leakage is a function of the size of this gap. The flow lost due to leakage was calculated using the orifice equation (equation 7), which assumes that the gap formed by the bottom of the flap and the first weir forms a slot-like orifice. The graph in figure 23 below represents the relationship between percentage of flow lost to leakage and gap width for a 20 L/s flow. For different flow rates, the MathCad file located in the AguaClara Drive may be used to calculate required gap size to maintain a desired maximum leakage rate. The FTTFC arbitrarily chose an acceptable leakage rate of five percent of the total flow. For a 20 L/s plant this would be a gap of 3.5 mm. The maximum allowable leakage percentage can be decided during plant design and construction.

$$Q = \Pi_V * A * \sqrt{2 * g * h} \quad (7)$$

Where;

Π_V = vena-contracta coefficient for an orifice (0.63)

A = area of the rectangular gap based on gap width and flap width

g = acceleration due to gravity

h = height of the flap relative to the bottom of the flap (i.e head)

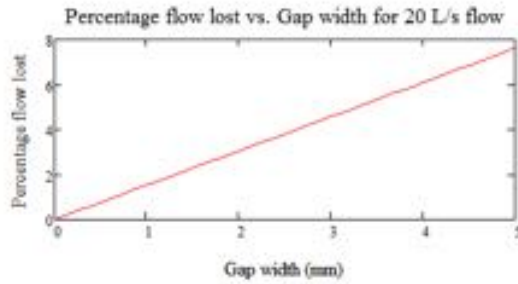


Figure 23: Leakage vs Gap size

Hinge Force Calculation

These forces were calculated from the hydrostatic pressures associated with holding the water in the tank.

$$\rho = 1000 \frac{\text{kg}}{\text{m}^3} \quad H_{\text{weir}} = 10 \text{ in} \quad L_{\text{weir}} = 10 \text{ in} \quad g = 9.807 \frac{\text{m}}{\text{s}^2}$$

$$F_{\text{total}} = 0.5 \cdot \rho \cdot g \cdot H_{\text{weir}} \cdot H_{\text{weir}} \cdot L_{\text{weir}} = 10.351 \text{ N}$$

$$F_{\text{resultant}} = F_{\text{total}} \left(\frac{2}{3} \right) H_{\text{weir}} = 13.606 \text{ J}$$

$$F_{\text{counter}} = \frac{F_{\text{resultant}}}{H_{\text{weir}}} = 53.567 \text{ N}$$

Figure 24: Force needed to open hinge

Figure 24 shows that it takes approximately 54 N or 12.5 pounds to open the hinge by pulling at the end of the wall. This amount of force is easily manageable by the operators.

Hinge Design Analysis

When considering a final design, many criteria were considered including ease of constructibility, ease of use, cost and availability of parts, structural stability, water tightness, professional aesthetic, and longevity. The final design that the FTTFC team decided was a top sided hinge for its simplicity and ease of use. One of the main reasons for picking the hinge design over the horizontal and vertical sliding designs was that it eliminates all sliding surfaces. The vertical and horizontal designs consist of PVC sliding along the concrete surface of the weir. These two surfaces sliding against each other would create friction, making it harder to open and close. This friction also reduces the life of the weir since it will wear away the material. It is also difficult to create a watertight seal between two surfaces that have to slide across each other, so the hinge design will be more watertight than the other two designs. The hinge design is also very easy to construct and requires few components compared to the sliding designs.

Two methods of attaching the hinge to the concrete were also designed. These designs can be seen in the figures 15,16 and 17. The first attachment method, Hinge Design One, consists of a strip of PVC and a hinge (15). Cheap aluminum hinges are relatively easy to acquire in Honduras. If a specific plant

location was unable to acquire aluminum hinges, it is possible to make simple PVC hinges, as shown in Hinge Design Two (16 & 17). This design simply requires two PVC elbows and a loose fitting PVC tube to connect them. Two bolts can be drilled through the tube and act as a rigid connector between the wall and tube. This design is also very adjustable because the bolts can hold spacers that make sure the wall is always flush to the weir.

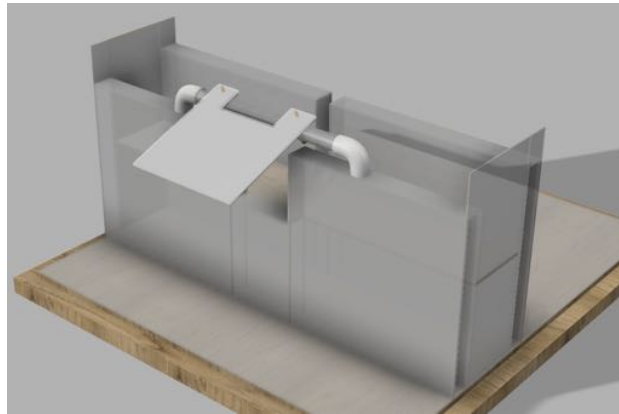


Figure 25: Hinge Design 1

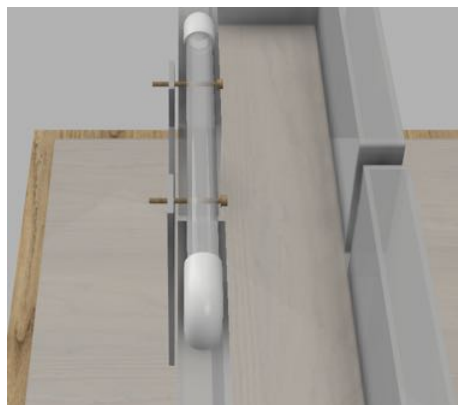


Figure 26: Hinge Design 1

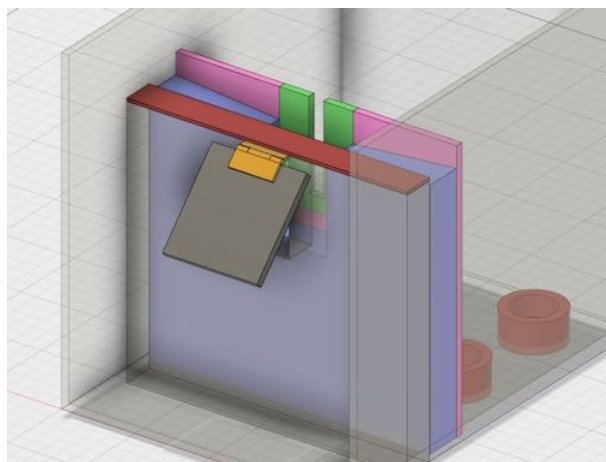


Figure 27: Hinge Design 2

There are several possible issues with the two hinge designs that should be considered. In Hinge Design One pictured in 15, water might be able to squeeze underneath the PVC strip and alter the effective

height of the weir. A possible solution to this issue is using the same gasket or tile ideas recommended for the base design. Additionally finding a hinge strong enough to support the adjustable flap against the water pressure could be problematic. Aluminum hinges also have the problem of tarnishing over time and thus taking away from the professional aesthetic of the plant. Hinge Design Two solves the problem of tarnishing by using PVC elbows and a loose fitting PVC tube to connect them. It is unclear, however, how the PVC elbows will be attached to the concrete underneath. PVC tubes could be embedded and attached to the elbows but this takes up valuable space and may interfere with rebar in the concrete. This design is also less polished overall and not as visually appealing as the aluminum hinge design.

Non-Hinge Design Analysis

1. Vertical Slide

- Description: Vertical sliding mechanism that would be held between two vertical tracks that would be bolted into the concrete. The design proposed by FTTFC Spring 2017 uses tracks that are flush to the front of the first weir extend all the way down to the floor of the tank (figure 14), as opposed to the design in the Las Vegas plant (figure 5), where the tracks are laid inside the weir opening. The proposed design is less reliant on accuracy of the concrete work to avoid leakage.
- Pros: very watertight due to pre-built tracks, low friction inside tracks, could attach a pulley system easily to top
- Cons: requires some system to hold it up, still some friction in between two surfaces, difficult to fabricate tracks

2. Horizontal Slide

- Description: A wall attached with two clamps slides along a strip of PVC placed on top of the first weir
- Pros: Very simple to use, would always stay in place (does not need a locking mechanism), easy to fabricate
- Cons: not watertight, lots of friction, could be hard to reach the center of the first weir, may not have enough room to the left or right of the notch to fit

3. Valve

- Description: A vertical column with vertical fins attached that when rotated 90 degrees opens or closes the slot
- Pros: Simple to use, easy to fabricate, does not require a lot of material
- Cons: Fins might be flimsy, not very watertight, fins would have to be very wide to cover the whole slot,

4. Plug

- Description: A solid piece of material that would simply slide into the slot to cover it (very similar to stop log design but on a larger scale)
- Pros: Sturdy, easy to fabricate, watertight
- Cons: Pieces would have to be very large, difficult to pick up on account of weight, would need to store them somewhere when not in use, operator would need to decide how many logs to use.

Scalability

The FTTFC team designed this weir for plants with flow rates of 20 L/s and has only tested the viability under this flow rate. It is possible issues may arise when scaling up; the main concerns would lie in the strength of the gate, ease of use, and leakages.

Despite these preliminary concerns, FTTFC is confident that the hinge design will work in other plants that have greater than 20 L/s. Many discoveries were made through the tests in the flume that

reassured this confidence. The ease of operation was far better than expected and posed no difficulties for the operator. The 1/4" gate and 1/8" reinforced gate experienced little to no flex from the stress of the water when opening. Lastly, water leakage was fairly minimal and was primarily caused by fabrication errors. Because these equations will hold true for any sized plant, this leakage analysis can be done for any location.

Many of the calculations used for this particular gate design should also apply to ones with greater flow rates. This is because in plants with larger flow rates, there is also a higher quantity of filter entrance tanks, so the flow rate per tank should be similar. The combination of this information and the results found by the FTTC team suggests that no matter the plant this hinge design will be strong, easy to use, easy to fabricate, and sufficiently waterproof.