Stacked Rapid Sand Filter Weir Model, Spring 2015

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Abstract

The team's task is to test, troubleshoot, and complete the scale model of the weir system developed by last semester's team. By the end of the semester, the team will create a set-up and video that accurately portrays the behavior of the water through the full scale weir system. The Fabrication Team aims to create a plant that is easier to operate, troubleshoot, and build.

Table of Contents

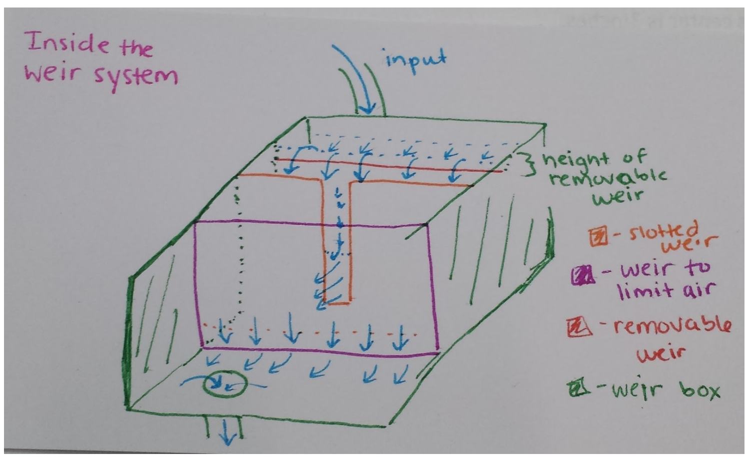
- Abstract
- Table of Contents
- Introduction
- Literature Review
- Methods
- Analysis
- Conclusions
- Future Work

Introduction

Low water supply, as from a drought, makes backwashing parallel filters challenging. The weir system solves this problem by controlling the flow going to each filter. Plant operators can easily remove a weir, diverting the flow rate necessary to backwash to one filter at a time. While one filter is backwashing, less water goes to the other filters. However this does not have a negative effect on the filtration because the less water running through a filter, the better the filter works. With the weir system, backwashing can be done for each filter one at a time. Backwashing each filter separately makes parallel filters feasible even when water supply is low. The Fabrication team created a scale model last semester that is being tested this semester to demonstrate how it works to students, partners, and plant operators. The team is currently assembling the weir system model and will create a video demonstrating the division of flow rate once assembly is complete.

Literature Review

The weir system is a tool to control and direct flow. When all of the filters are in forward filtration, 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 results in an equal split to each filter. To backwash one of the filters, the removable weir for that filter can be extracted. This diverts a specific flow despite plant flow rate to the backwashing filter and 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. 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.



<u>Figure 1</u>: How water flows through each chamber of the weir system. The water flow in the input, over the first removable weir, through the slotted weir, and then under the final weir, and out the system.

<u>Figure 2:</u> Front view of the weir system in operation.

Last semester the Fabrication Team reviewed the weir system for the Aguaclara Stacked Rapid Sand Filter (SRSF) and created a ⅛ scale model.[1] The ⅛ length scale was chosen so that hydraulic similarity could be maintained without the need for an excessively large flow rate. The scaling of the flow in the model is done so as to match the Froude Number of the plant scale.The Froude Number is the nondimensional ratio of the fluid's inertial forces to its weight. The number is calculated with the following formula:

$$Fr = v/\sqrt{g * L}$$

where *v* is the flow velocity, *g* is the acceleration due to gravity, and *L* is the length scale. The nondimensional number is used to determine similar fluid behavior in systems where the major contributing forces are gravity and inertia, which is the case for the weir system. Gravity is the sole force moving the water over or through the weir. At a ⅛ scale, the required flow rate was determined by last year's fabrication team to be 0.28 L/s, which is low enough that a centrifugal pump in combination with a valve for fine control is adequate. The team then determined that for their system the pump would need about 80% of that flow rate to

[1] Talsma, Carl; Cobo, Adrian; and Sanz, Sara; "Final Report;" Fabrication Team, Fall 2014; accessed at: https://confluence.cornell.edu/display/AGUACLARA/Fabrication

backwash. This number in the plant varies based on the filters used, but .224 L/s of the total flow rate in this system is a reasonable approximation for potential backwashing.

Another scaling concern addressed in last year's final report was the constraint on the flow due to the scaled down size of the slotted weir. The team used the Kindsvater-Carter equation to calculate the maximum flow rate through the model's slotted weir.[2] The maximum flow rate found with this method was over 4 L/s, more than the 0.224 L/s maximum (80% of total) intended to flow through each weir during backwash conditions. This large flow rate through the slotted weir is too great, as it causes 100% of the flow rate to go through the filter being backwashed. If 100% of the flow rate goes to one filter it has the potential to wash the sand out of the filter rather than backwashing it. This problem was addressed by this semester's team by creating a new slotted weir. Like the slotted weir, the exit and entrance pipe diameters were chosen to accommodate more than enough of the maximum flow rate. However, these dimensions do not affect the weir system under normal conditions and will only add flexibility to the weir system. For the exit pipes, which are open to atmospheric pressure, the maximum flow rate will be controlled by the gate valves used to control backwash and the force of gravity. While a minimum diameter of less than ½ inch was calculated by mathcad, 1 inch PVC pipes were chosen due to their abundance in the lab and to allow for a factor of safety to prevent overflow problems during calibration or testing. Two gate valves, one on each exit pipe, were included in the model to control the exit flow from each half of the weir system. These gate valves can also be used to accumulate head at this point of the plant if necessary. However, as the flow over each weir is designed to be supercritical, or unaffected by the conditions of flow downstream, restricting the exit flow out of the model is not necessary for the functionality of the weir system.

Methods

The Weir System requires testing to validate the theory of how it affects and controls the flow rate of water. In order to provide such data, the team will attach a pump to the ⅛ scale model, and evaluate the division of flow due to the weirs. To calculate the flow rate through the weir system, the team times how long it takes to fill a 1 liter container from each output. Each output represents the path to a different filter. The sum of the flow rates from each output results in the total flow rate through the system.

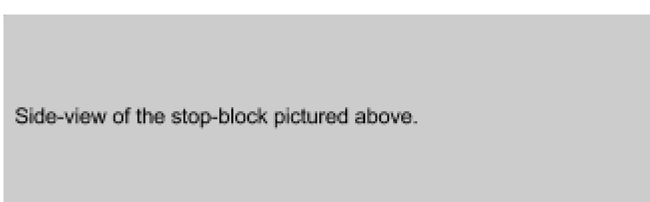
The first task was to put together an efficient and durable set-up. In order to achieve a reliable flow rate of 0.28 L/s entering the weir system, a robust pump was found. Two possible pumps were evaluated for use with the weir system. The first was a submersible pump with an outflow pipe diameter of ¼'' size pipe, while the second was a much larger centrifugal pump with a pipe outflow diameter of 1'' size pipe. Only the larger pump was capable of delivering the scaled flow rate of .28 L/s, so it was chosen. The rest of the set-up includes 1'' size

[2] LMNO Engineering, Research, Software, Ltd., "Rectangular Weir Calculator," accessed at http://www.lmnoeng.com/Weirs/RectangularWeir.php

flexible tubing that circulates water from a large bucket with a bulkhead connection through the pump, then the model, and back into the bucket.

With the weir system running at the desired flow rate, diversion of flow to the open weir completely cut off the flow to the closed weir. This problem was caused by the sizing of the slotted weir, as upon revisiting the previous team's calculations, the slotted weir was made too large. When the current dimensions of the slotted weir were scaled back up to plant size, they did not match the dimensions in the plant design. The incorrect dimensions, which were approximately twice as large as necessary could have been due to a conversion error, a miscommunication during fabrication, or a failure to realize that the water level would be at the higher level of the unmoved weir and not the lower portion of the first weir. To correct this problem, a new slotted weir was fabricated using accurately scaled dimensions. Although the slotted weir was correct, the placement of the inlet pipe on the left side of the model favored pumping water over the left weir due to the momentum of the entering water in that direction. In order to correct for the momentum and turbulence, a PVC panel was placed at an angle in front of an inlet to direct the momentum of the jet toward the center of the two weirs.

The team considered trying to implement stop blocks to adjust the flow rate as is a possibility in the plant, but decided to exclude them at the moment. The stop blocks would be small blocks that could be slid into grooves in the sides of the slotted weir. By adding in blocks, the weir's dimensions would change and the flow rate allowed through the slotted weir would decrease. This allows for finer control of the flow rate and an easy way to change the max flow rate for different filters and circumstances. In the ⅛ scale model, grooves would need to be made in the stop blocks themselves, as a groove in the weir would be too narrow to accurately fabricate. The stop blocks, as drawn below, could then be slid over the existing slotted weir to close off the slot area available for water to flow.



<u>Figure 3:</u> **Conceptual drawing of the model stop blocks viewed from above and from the side. The grooves in the side of the block would be made to fit right into the slot in the weir system, effectively blocking off flow at the bottom of the slot and adjusting the maximum flow rate through that side of the weir.**

However, this method of adjusting the flow through the slotted weir can only change the height of the slot, which can greatly increase the potential for error in the system and was not pursued further this semester. The theory behind the error has to do with the change in water level during backwash in the weir system, and will be explained in the analysis section.

With the properly sized slotted weir and the inlet correction panel in place, a video was made of the model's performance to be presented at the AguaClara Symposium at the end of this semester. Included below is a link to a video on the AguaClara Google Drive which shows the weir system under both normal and backwashing conditions. The video begins with both weirs closed, then the weir on the right is temporarily opened and more water can be seen leaving the slotted weir.

Link to the Weir System Demonstration Video:
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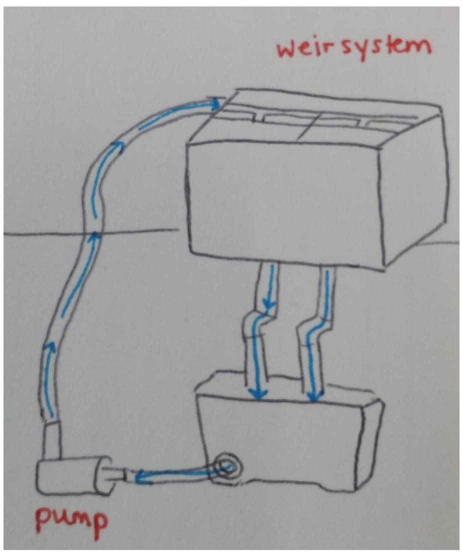

Figure 4: Current setup of the weir system with centrifugal pump and 1" tubing

Analysis

In order to evaluate the ability of the submersible, centrifugal pump available in the AguaClara basement lab to provide the required 0.28 L/s flow rate, the following test and sample calculation were performed. The test used a 1 L plastic container as the measure of volume and a digital stopwatch to measure time. The recorded times to fill the 1 L container using the provided submersible pump ranged from a high of 16 seconds to a low of 13 seconds. The fastest flow rate measured was 0.077 liters per second, far less than the design flow rate of 0.28 L/s. A submersible pump with larger head was ordered, and despite its increase in head, it also failed to deliver the specified flow rate, reaching a maximum of only 0.1 L/s.

Both submersible pumps had ¼ size tube connections, while the weir system was built with size 1 pipe inlets and outlets. In order to determine how the difference in pipe size impacted the system head loss, the minor loss of expanding the flow from ¼ size pipe to size 1 pipe of was calculated. The coefficient for minor loss due to expansion was calculated using the relationship in area for a 90 degree expansion, which is assumed the typical for a simple pipe expansion. The calculations were as follows:

$$h_L = K_L(V^2/2g)$$

where h_L is the head loss

K_L is the minor loss coefficient

V is the water velocity

g is acceleration due to gravity

The head loss coefficient was calculated using the approximation based on the difference in joined pipe area[3]:

$$K_L = (1 - A_1/A_2)^2 = (1 - 1/16)^2 = 0.8789$$

Where A_1 and A_2 are the respective areas of the pipes to be joined

$h_L = 0.2943$ meters

In order to compare this head loss to the overall pressure head provided by the pump tested, the energy equation of fluid flows was used to calculate the kinetic and potential energy head required to raise water at the speed and elevation necessary to enter the weir model with the specified flow rate and diameter. The model was assumed to be 1 foot above the level of the pump, as was set up in the test performed with the pump. Using the equation:

$$E_{pump}/\rho g = (KE + PE)/\rho g = (v^2/2g) + h_L$$

where E is the energy output by the pump

ρ is the density of water

KE and PE are kinetic and potential energy of the water

The resulting pumping head required was 0.349 meters (plus the height of the model above ground), which will need to be taken into account if a pump of ¼ diameter pipe size is to be used with this model in the future. At the current moment the only pump with adequate power to operate the model has size 1 pipe connections, and thus there is no expansion of pipe flow necessary.

[3] University of Waterloo, Canada; Course file from ENVE 214; accessed at http://www.civil.uwaterloo.ca/enve214/Files/Expansions_Pumps.pdf

When in operation at the desired flow rate of 0.28 L/s (+/- 0.03 L/s), the original weir system did not operate as intended. The flow was entirely redirected into the filter with the raised weir, and the remaining filter only received an inconsistent trickle of flow due to turbulence caused by the momentum of the jet hitting the base of the closed weir. This problem stemmed from the size of the slotted weir in the model. When the weir system was scaled down, the slotted weir was not fabricated with the correct dimensions, and as a result the slotted weir no longer provided a secondary control on the flow rate through the open weir. Using the Kindsvater-Carter Equation for flow through a rectangular weir[4]:

$$Q = C_e(\tfrac{2}{3})\sqrt{(2 * g)}(b + K_b)(h + K_h)^{\frac{3}{2}}$$

Where: Q is flow rate in L/s

Ce is the drag coefficient of the weir

b is the width of the slot in meters

h is the height of the water above the slot in meters

Kb and Kh are constants

$$= 0.59(\tfrac{2}{3})\sqrt{(2 * 9.8)}(0.0222 + 0.0024)(0.1016 + 0.001)^{\frac{3}{2}} = 1.41 \text{ L/s}$$

the current maximum flow rate through the slotted weir was approximately 1.4 L/s, far higher than 0.224 L/s (the desired maximum flow rate through the open weir). This calculation is only an approximate value, as the height of the water above the slotted weir is assumed to be the same as the height of the closed weir above the slotted weir, which is not always true.

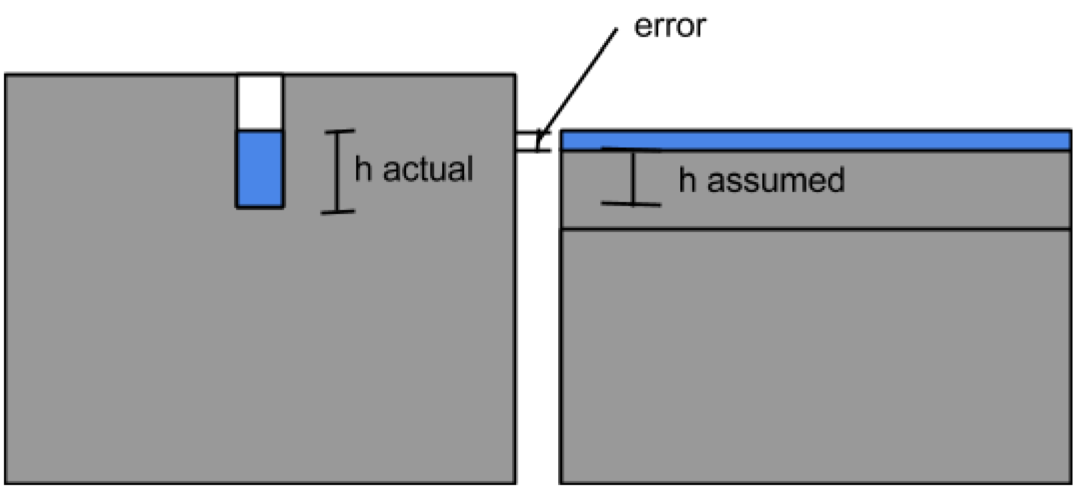

Figure 5: The left depicts the head of the water over the slotted weir. The right depicts the water level over the closed weir with the removable portion still in place.

[4] LMNO Engineering, Research, Software, Ltd., "Rectangular Weir Calculator," accessed at http://www.lmnoeng.com/Weirs/RectangularWeir.php

If the water level drops below or backs up above the height of the closed weir during backwashing, the assumed height is incorrect and the calculated flow rate is no longer accurate. If the weir system operates correctly and divides the flow to both weirs, the water level should not change noticeably. However, the original system showed a significant drop in water level during backwash, which makes the 1.4 L/s calculation only an approximation of the actual maximum flow rate through the slotted weir. Regardless of the increased error, it was clear that the slot needed to be made smaller.

Experimentally, the team generated new dimensions for the slotted weir, with a width of 1/16th inch and a height of 2.12 inches. The team simulated smaller slot sizes by blocking off the existing weir with scrap PVC. These dimensions were later found to be incorrect because the team did not anticipate the large influence of leaks around the unsealed slotted weir.

Upon consulting Monroe and the AutoCAD drawing of the fully sized weir, it was discovered that both the width and the height of the slot were not at ⅛ scale as stated in the previous report. The properly scaled weir slot should be 1.16 cm wide by 3 cm tall. The 3 cm height is not the full height of the weir, but the depth to which the slot should reach under the water. As the water level is approximately equal to the full height of the closed weir, the new slotted weir' height is the sum of the height of the weir above the water level and 3 cm. Using the Kindsvater-Carter Equation to check check the maximum flow rate through this weir yields:

$$Q = 0.59(\tfrac{2}{3})\sqrt{(2 * 9.8)}(0.0116 + 0.0024)(0.03 + 0.001)^{\frac{3}{2}} = 0.133 \text{ L/s}$$

Although this flow rate is below the desired flow rate of 0.224 L/s, experiments with the correctly sized weir show a maximum flow rate of 0.21 L/s, close enough to the designed flow rate to provide a proper demonstration (0.21 L/s through slotted weir ~ 75% of total flow through the open weir). The difference between the calculated and experimental results can likely be explained by the assumed water level error inherent in the calculations, as well as the small scale of the system relative to those for which the Kindsvater-Carter Equation is generally used. Multiple trials were run, showing that the weir system divides the flow rate as predicted at the ⅛ scale.

Trial 3	.22L/s	.063L/s	0.283
Percentage	78	22	100
Trial 4	.21L/s	.06L/s	0.27
Percentage	78	22	100
Trial 5	0.21L/s	.07L/s	0.28
Percentage	75	25	100

Table 1: The results of three trials that validate that the weir splits the flow between filters.

Conclusions

The weir system model has a complete set-up and accurately depicts the phenomenon in the full-scale weir system. The AguaClara research teams will use the model to demonstrate the difficult theory behind the weir system to plant operators, new students, and partners. The weir system can divert the whole flow rate consistently to each filter easily with the removal of one weir. The trials conducted show the division of flow. The backwashing filter received 75% of the flow instead of the target 80%, which can be explained by leaks in the system and possible inaccuracies of the dimensions in the fabrication of the weirs. This error could be addressed in the full plant by using stop blocks to add finer control of the flow rate through the slotted weir. The scale model exhibits the division of flow rate and provides support for the use of the weir system in full-size AguaClara plants to supplement the use of parallel filters.

Future Work

While there is a complete set-up for a functioning scale weir model, there are more possibilities for enhancements. In the full-sized plant, stop blocks will likely be used to adjust the slotted weir's size to control the flow rate at the necessary rate for backwashing, as resizing the entire slotted weirs will be impractical. This semester the team did not leave time to create a scaled demonstration of this concept, but future teams could fabricate stop blocks as shown in the report and evaluate their effect on the water level and corresponding deviation from the design flow rate of the slotted weir. In addition, more complex and in depth visuals can be produced using this model. Ultimately this model and all the accompanying media will be shared with AguaClara research teams and partners to show the functionality of the weir system.