Stacked Rapid Sand Filtration

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Abstract

Stacked filters have been demonstrated as a novel alternative to traditional rapid-sand filtration, and their efficiency makes them an appropriate part of sustainable municipal-scale drinking water facilities. In this study, a pilot-scale apparatus was set up as a model of the hydraulic controls for the stacked filter system. This pilot-scale system was used to develop and provide experimental justification stacked filter design equations. In addition, a bench-scale apparatus was developed with a single-layer rapid-sand filter to study fundamental questions such as removal efficiency in upflow and downflow filtration.

Literature Review

O'Connor, J.T. and O'Connor, T.L. (2002). "Rapid Sand Filtration." In Control of Microorganisms in Drinking Water. Reston, VA: American Society of Civil Engineers, p. 127-148. This article discusses the prevalence of rapid sand filtration as a means of removing microbial pathogens from drinking water. It discusses the role of rapid sand filtration, following flocculation and sedimentation, as the last barrier between suspended particles and the public drinking water source. The article also discusses the importance of using coarse grain filter media for meeting drinking water turbidity standards.

Lin, P.-H. (2010). "Filter media modification in rapid sand filtration." Thesis (Ph.D.)–Cornell University, May 2010. This thesis focuses on developing improved operating methods for rapid sand filtration. It discusses several different coagulants like alum, ferric chloride and polyaluminum chloride which are applied to modifiy the sand filter medium, concerning to their dosage and pretreatment. Moreover, it introduces a novel fludized-bed pretreatment process which enhances the efficiency of trubidity removal. In addition, the thesis discusses and explains the mechanism related to the improvement of the filter performance.

Methods

At this point in the semester, three experiments are either complete or underway.

First, the pilot-scale control system was utilized to test the siphon. This appratus included a bucket representing the filtration inlet channel with four pipe stubs connected to hoses through the bottom of the bucket. Each of the four hoses runs from the bottom of the inlet bucket to one of the four filtration column inlet manifolds. The hose connected to the bottom inlet manifold is connected to the shortest pipe stub, and the hose connected to the top inlet manifold is connected to the second shortest pipe stub. The two hoses connected to the middle inlet manifolds are connected to the tallest pipe stubs. This configuration allows the water level in the inlet bucket to fall below the top of the higher pipe stubs during backwash initiation, thereby cutting off flow to the middle inlet manifolds. The siphon is configured to hold an air trap during filtration mode, and then backwash mode can be initiated by releasing the air trap and allowing the siphon to transport the total system flow to the backwash outlet. The control system was run in cycles beginning with filtration mode, followed by initiating backwashing by breaking the air trap, followed by stead-state backwashing, followed by initiating filtration by forming the air trap, and so on and so forth. Partcular attention was paid to the water level in the inlet bucket and flow of air and water through the siphon during these cycles. A diagram of this apparatus is found below.

Second, the pilot-scale apparatus is undergoing an overhaul to set up for the upcoming flow distribution studies. The inlet bucket has been replaced by a clear 4" pipe with the same configuration of stubs and hoses. The goal of the new clear 4"

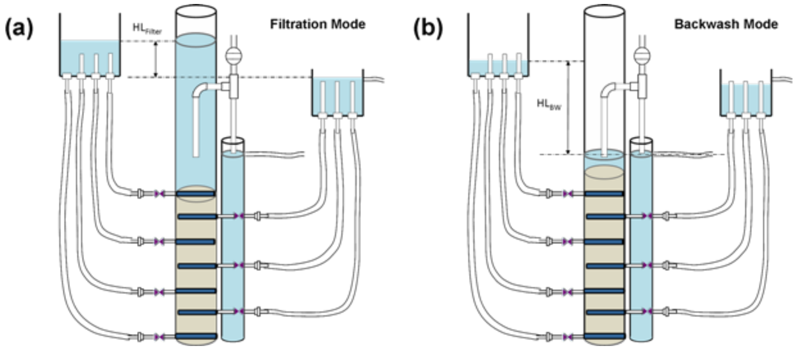

Figure 1: Diagram of the pilot-scale apparatus for the control system study, showing the water levels during (a) the filtration cycle and (b) the backwash cycle along with important head losses.

pipe is twofold: first, it will allow for visual monitoring of water level in the inlet channel and second, it provides a reduced diameter of wetted perimeter in the inlet channel and reduces the volume of water that sits in the inlet channel during filtration mode. Pressure sensors are being installed in the side of the filtration column, evenly spaced 10 cm apart in the middle of each of the six layers. Monitoring the loss of piezometric head over the given length of filtration media in each of the six layers will allow for the calculation of the true flow rate through each of the six filtration layers. The expectation is to find that the total system flow divides evenly between each of the six layers.

It is worth mentioning that the bottom of the backwash siphon-capture pipe has been replaced with clear PVC to allow for the visual monitoring of flow through the siphon. The goal is to visually identify whether air is completely trapped in the siphon or if some bubbles flow out through the bottom of the siphon as the water level in the filtration column rises.

Third, the bench scale filter has been rigged to test turbidity removal performance of upflow versus downflow. This has involved rigging a series of tubes and valves to pump water, dose alum, dose clay, and monitor influent and effluent turbidity. Each dose and sampling system has a pump which requires calibration, and solenoid valves are controlled by the process controller software to control the system in upflow and downflow.

Analysis

Our main recent experiment has been putting the siphon through control system tests, which has shown siphon failure in the system. When the system is in filtration mode, the water that rises in the main tube and increases pressure on the air pocket that is in the siphon. What we have found, through simple observation, is that this pressure becomes too much and the water begins to flow into the siphon pipe. Our

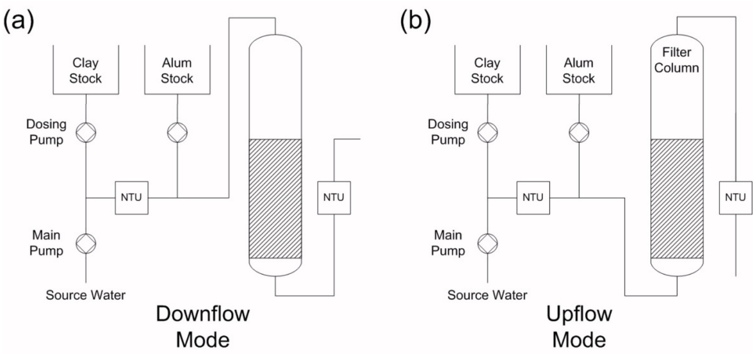

Figure 2: Diagram of the bench-scale apparatus for (a) upflow and (b) downflow filtration.

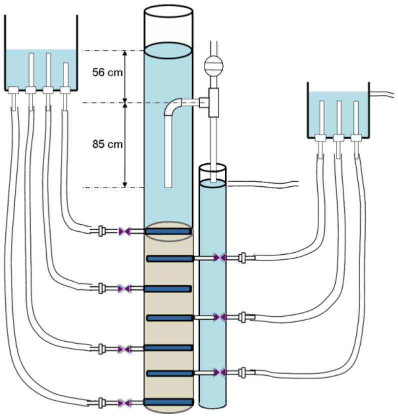

Figure 3: Diagram showing water levels observed at siphon failure, when water began leaking into the siphon.

experimentation consisted of putting the system through its normal filtration and backwash cycle, but carefully taking measurements of the height of the water in the inlet bucket as well as in the column when the siphon just began to leak.

All of our data in this part of the experiment was pretty consistent, but also coincides with the predictions from the design equations that tell us the water is supposed to go over the siphon only about 56 cm. That being said, we must still work on finding a way to prevent siphon leakage.

Conclusions

The placement of the siphon pipe through the walls of the filter is an important design constraint to make sure that the air trap will work correctly during the

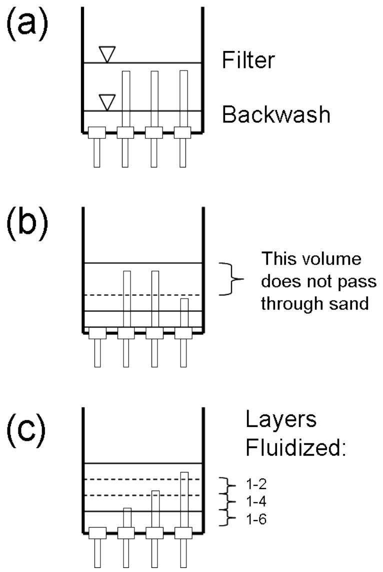

Figure 4: Configurations of pipe stubs to be tested, including (a) all of the same height, (b) smallest for top inlet, and (c) staggered sizes.

filtration cycle. The design equations used for the field-scale filter appear to be valid for the failure modes of concern.

Future work

In the following week, we would be working on solving the problems we encountered with during the backwash cycle. The phenomena of free surface within inlets connected to the two lowest pipe stubs and of poor fluidized sand may be a result of generated air trap somehow during the process. To verify this assumption, we will run several tests with the revamped apparatus. One part of our efforts would be devoted to optimize the configuration of pipe stubs. As several problems occur by using shorter inlet #1 style pipe stub, we would like to try other pipe stub configurations, like the all the same size pipe stubs which would drain the excess water out of the inlet box out the highest inlet, or we may use staggered inlet pipes so that the layers fluidize two at a time instead of all at once.

In order to determine whether there are significant differences in performance between upflow and downflow filtration, we have set up the rapid-sand filter column with the same sand that is currently used in the pilot-scale filter. Last week, we have spent several lab hours to make everything set, such as calibrating pumps, setting up turbidimeters, pressure sensor, clay stock tank and alum stock tank with dosing pumps and so on. On Thursday, we have connected all components to the computer, and set up a Process Controller with the computer.

As everything is set, our next step is to run the bench-scale rapid-sand filter column act in both upflow mode and downflow mode, and log data from turbidimeters and pressure sensor with the Process Controller. The objective for this part is to confirm that the filtration performance for these two modes is similar.

For the performance of reducing turbidity, we can plot the results of filter run as log removal pC*, which is calculated as:

$$pC* = -log\frac{EffluentTurbidity}{InfluentTurbidity}$$

We can also use the filter rate equation to compare the filtration performance of the two modes adopting the equation:

$$R = \frac{InfluentTurbidity - EffluentTurbidity}{InfluentTurbidity} * 100\%$$

For the performance of pressure, we assure that there is no significant difference between upflow mode and downflow mode.

Further more, we may also evaluate the possibility of using smaller sand grain size and determine if there would be advantages to making this change.