StaRS Filter Theory

Stacked Rapid Sand Filtration Theory

The overarching goal of the Stacked Rapid Sand Filter Theory team is to develop a mathematical model for filter performance. A new apparatus will be designed to model a stacked rapid sand filter. Experiments with constant turbidity and varying coagulant dosages will be run and analyzed. From the analyzed data we hope to be able to create a model that will be able to predict the expected head loss of a given SRSF filter if the coagulant dosage and amount of solids already accumulated in the filter are known.

Spring 2013 (formerly called Depth vs. Surface Sand Filtration)

The big goal of this research is to understand the difference between surface and depth filtration and the parameters that determine which regime is operative. We suspect that subsurface injection of the water to be filtered shifts the regime to depth filtration. The head loss and effluent turbidity were measured and compared between a control filter, where water is added above the filter in a conventional downflow design, and a subsurface injection filter in which water is injected into the middle of sand bed through a smaller tube modelling a slotted pipe in the Stacked Rapid Sand Filter.

Depth filtration likely occurs when the fluid forces on the flocs that bridge across a pore in the filter bed exceed the strength of the flocs. Thus the dimensionless parameter that determines whether depth or surface filtration occurs must include both floc strength and pressure drop through a thin layer of flocs. Pressure drop through a thin layer of flocs is influenced by the porosity of the flocs which is a function of their fractal dimension. Small flocs are less porous than large flocs and thus small flocs are less likely to produce surface filtration.

In our research, we set up two filters in parallel that both received the same raw water but with one filter operating as a conventional rapid sand filter and the other filter having the raw water injected below the surface of the sand. The coagulant and clay water were both introduced into a clean water source before the influent turbidity of this water was tested. The water was then pumped to the two filter columns. After leaving the columns, the turbidity of the effluent water was measured and then left the system entirely. We measured both head loss and the effluent turbidity of each filter column as a function of time. We ran different tests at varying levels of influent turbidity, filter velocity, and coagulant dosage to see if any of these parameters significantly affected the head loss or effluent turbidity. In each experiment we also noted any differences between the appearances of the two columns which indicated differences in the location of particle capture.

To backwash the columns, we used turned off the coagulant and clay pumps so that only tap water was used to clean the filters. This water was pumped up through the bottom of the filters to fluidize the sand beds. We noticed that the surface filter was difficult to backwash in this way, even at very high pump speeds, because of the large flocs that had settled on the surface (which occurred in most of the experiments but not all as described further below). These large flocs remained close to the surface of the sand column and did not get flushed out of the filter. Surface washing, the method of using a high velocity jet to effectively clean the surface or scraping off this top layer of floc build-up in the filter, would be necessary to thoroughly clean the filter. The subsurface filter had no visible signs of any large flocs or substantial floc build-up and it had no problems with the backwash method used in the experiment, which suggests that surface washing the SRSF should not be necessary.

Our data suggested that there was no significant difference in the measured effluent turbidities of the two filters. Both filters also show linear relationships in measured head loss over time. However, one advantage we found to using the SRSF design is that the head loss increases at a slightly slower rate over time than the normal surface filter. We also noted that at a higher filter velocity, the surface filter did not show hardly any particle build-up on the surface of the sand column, which suggests that velocity is a determining factor in whether or not depth filtration occurs.

Experimental Apparatus Schematic
Experimental Apparatus in Real Life
Example of Results for Effluent Turbidity
Example of Results for Head Loss
Example of the Difference in Particle Capture Location

Calculations for flow rate
Process Controller Files

Summer 2013

Tasks for this summer involved finding the parameters at which the subsurface injection filter becomes clogged. Using the experimental apparatus built in the Spring 2013 semester, the team continued research comparing the surface and subsurface sand filters. The team ran experiments and changed the influent turbidity, influent velocity, and coagulant dosage. Effects on head loss and effluent turbidity will be observed and analyzed. It was observed that subsurface filtration performed better than surface filtration for shorter periods of time.

Fall 2013

The SRSF Theory team redesigned and built a new filter column and experimental apparatus using a combination of the former experimental apparatus and new parts. Calculations were done to design the apparatus so that it best models stacked rapid sand filters in AguaClara plants. A Process Controller method file was written to run experiments and collect data. Proportional Integral Derivative (PID) Control was implemented so that influent turbidity can be held constant at a desired value. Experiments varying coagulant dosage were run. Effluent turbidity and head loss data were collected and analyzed to assess filter performance and start a mathematical model of filter performance.

Spring 2014

This semester, the SRSF Theory team ran several experimental tests on the redesigned filter column and experimental apparatus. PACl dosages were varied between tests in order to analyze the trends in filter performance and head loss in relation to time and the amount of mass being added to the system. Progress towards developing a mathematical model to relate the maximum amount of head loss and the minimum sand pore diameter were in progress during the semester, but were stopped in order to reanalyze a previous hypothesis on the expected trend of head loss. Due to experimental data, several theories were proposed to explain the linearly increasing head loss after filter failure and are currently being assessed for its validity.

Fall 2014

The StaRS Theory team designed experiments to test the hypotheses on water flow through the filter and the resulting head loss. The team analyzed the effluent turbidity and head loss data from Spring 2014 and found that while head loss depends on coagulant dosage, the results vary greatly. The experimental apparatus was rebuilt from the details of the previous semesters. The sand from the filter was removed and sieved so that sand stratification was reduced within the filter column. With the sand outside of the filter, the team tested for head loss across the mesh of the inlet and outlet pipes for the stacked rapid sand filter. In certain experiments, head loss was significant, though the collected data was rather inconclusive. A motion towards a stacked rapid sand filter without slotted pipes, as well as an accompanying experimental model, was recommended.

Spring 2015

The StaRS Filter Theory team designed and built an apparatus to test the clogging across slotted pipes and evaluate their performance in stacked rapid sand filters. Experiments were run for the sole purpose of clogging the slotted pipe and characterizing the extent of clogging and what conditions caused the slots to clog. The team found that instead of head loss changing as a function of coagulant dosage only, as previously hypothesized, head loss was also affected by the amount of floc buildup on the slots. The coagulant to clay ratio thus affected the clogging rate and amount of head loss that built up over time.

Fall 2015

The StaRS Filter Theory team rebuilt an apparatus with an inlet system that used an orifice, rather than copper mesh or slotted pipes. Experiments were run to test the head loss across our system with certain coagulant dosages and determine the relationship between the coagulant doses and head loss across sand. Our ultimate goal is to build a mathematical model that can be used to access the filtration performance parameters and reflects the filter's effluent turbidity, head loss, and time until turbidity breakthrough or excessively high head loss.

Spring 2016

Filter performance can be described in a mathematical model to promote the understanding of stacked rapid sand filters. A variable that has been suspected to affect filter efficiency is coagulant dosage. The StaRS filtration experimental apparatus was adjusted by removing the flow accumulator to prevent sand from entering the inlet system and adding a flocculator to create small flocs. The collected data will be used to create a mathematical model to examine how coagulant mass affects the filter's effluent turbidity, head loss, and breakthrough time.

Fall 2016

Experiments with varied PACl dosages were ran to test the performance of the stacked rapid sand filter. Head loss and effluent turbidity were collected from the experiments with influent water at 5 NTU. The data from these experiments were used to create a mathematical model on the performance of the filter. The created model will then be used to write a research paper on a model for stacked rapid sand filters. The team hopes to publish this paper.

Spring 2017

This semester, the StaRS Filter Theory team continued to research on the development of a model and summarize the findings and complete the paper that was started last semester. Team started with validating washer model assumptions and found that the washer model does not work. The team also performed literature review and completed the paper by summarizing the new modelling approach.

Fall 2017

This semester, the StaRS Filter Theory team will continue to refine the existing understanding about how the stacked sand filter functions. Current plans include conducting experiments to confirm assumptions made in developing the visual model, translating the visual model into a mathematical model, and ultimately using the mathematical model to optimize filter performance.

Members

William Pennock

Lucinda Li

Lingzi Xia

Dylan Vu

Liz Cantlebary

Email Team

Documents

	Challenges	Tasks	Literature Search	Symposium
Spring '18				StaRS Filter Theory Sy 2018
Fall '17				StaRS Filter Theory-Fa
Spring '17				StaRS Filter Theory-20

Fall '16				Unknown Unknown
Spring'16				Unknown
Fall '15				Unknown
Spring '15		Unknown Attachment		Unknown
Fall '14	Unknown Attachment	Unknown Attachment		Unknown
Spring '14	Unknown Attachment			Unknown
Fall '13	Unknown Attachment			Unknown
Summer '13		Unknown Attachment		Unknown
Spring '13	Unknown Attachment	Unknown Attachment	Unknown Attachment	Unknown