```
from aide_design.play import*
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import matplotlib
from scipy import stats
import Environmental_Processes_Analysis as EPA
import importlib
importlib.reload(EPA)
```

#Group 5 Final Research Report
####Simon Fines & Andrew Kang

##Introduction

The goal of this project is to explore a novel approach to flocculation that repeatedly exposes all of the flocs to an extremely high shear so that flocs are broken dow n to several more flocs the size of just a few clay particles. This w ould hopefully allow clay particles to attach to flocs. The ultimate goal is to produce low turbidity below 2 NTU after filtration. Our team's focus in this research project w ould be the rapid sand filter, and testing the effectiveness of the high speed flocculation. It is important to design a cost-effective yet efficient model to achieve the required w ater standard.

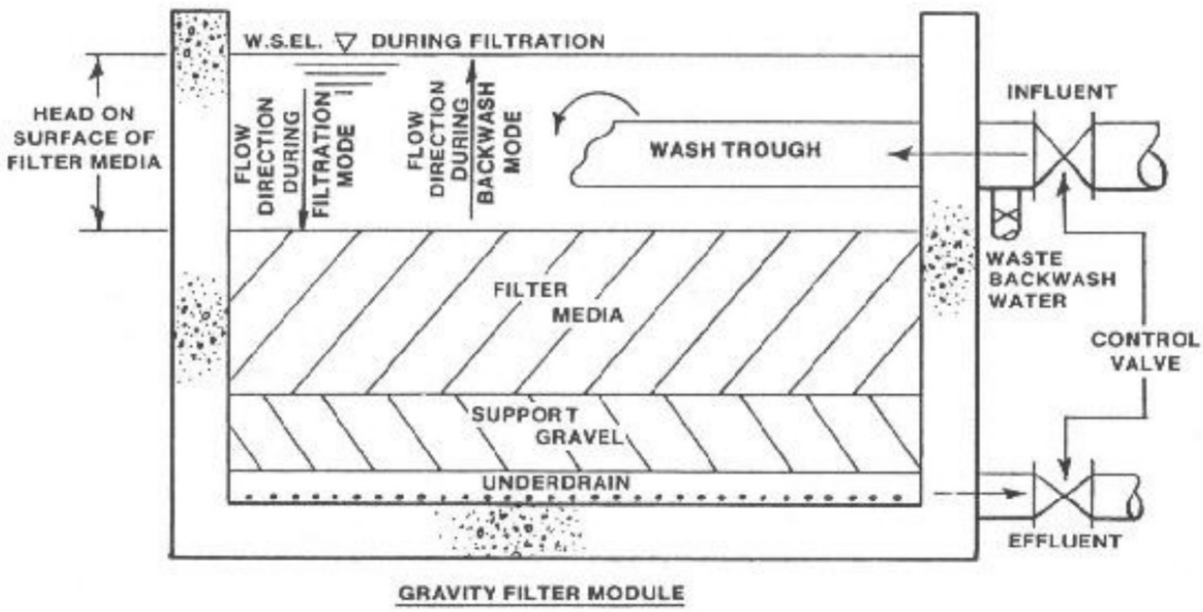

Figure 1:
The figure above is a diagram of a rapid sand filtration for a w ater treatment system.

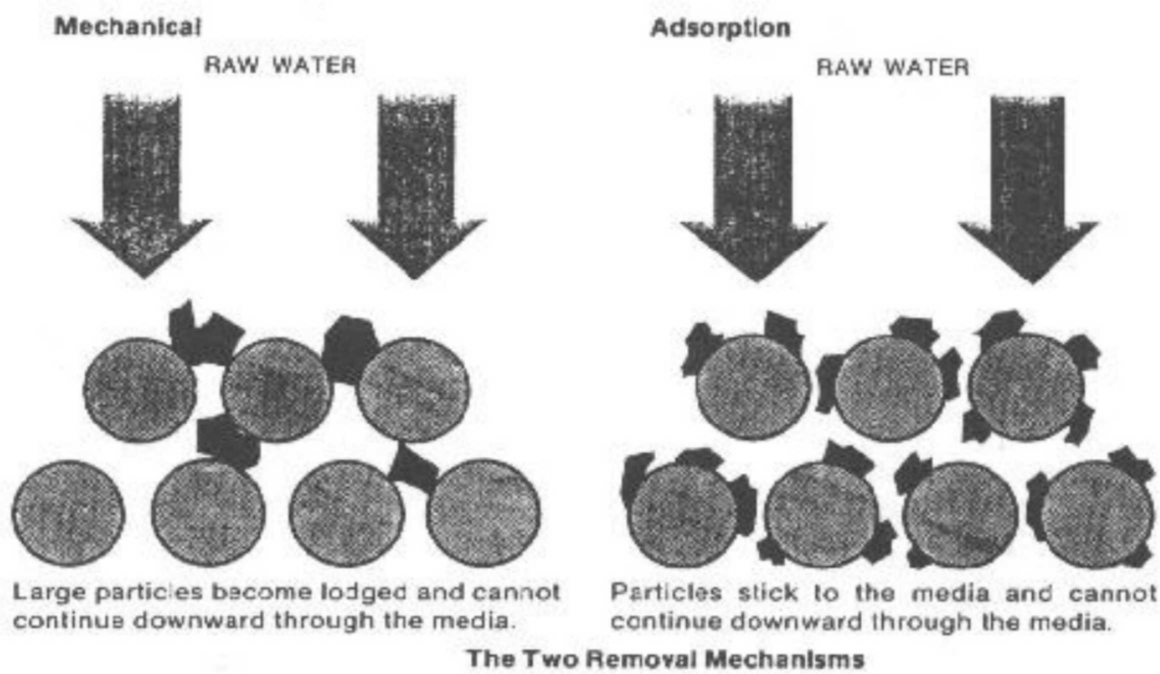

Figure 2:
The figure above is the mechanism behind sand filtration. The left is a mechanical removal mechanism and the right is the adsorption removal mechanism.

##Objectives

Our hypothesis is that high shear flocculation coupled with a sand filter will achieve an incredibly low NTU. We will test that hypothesis by designing a rapid direct sand filtration system that will be able to efficiently filter the flocculated water and be able to back wash and clean the filter without any modification of the apparatus.

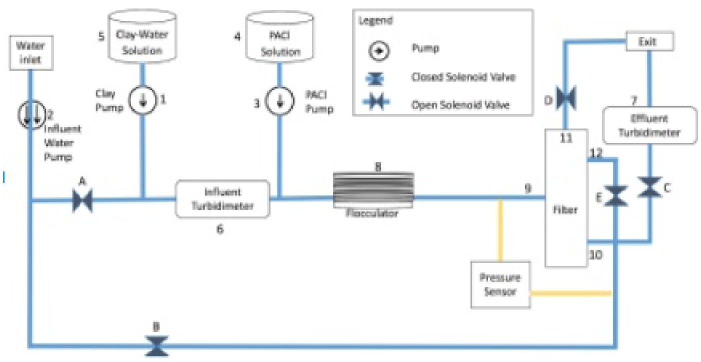

Figure 3:
The figure above is the design apparatus from the StaRS filter team from Aguaclara in 2017. We based our design off of theirs but modified it to work more efficiently with our desired goal.

##Apparatus
Our apparatus was designed to filter the effluent of the flocculator, then be able to run a backwash process to self-clean the sand filter of flocs. In order to design an apparatus like this, we needed solenoid valves that could be opened and closed by ProCoDA. We built our sand filter using a 65 cm filter column with about 42 cm of sand and 17 cm of space. At the inlet, we have a t connector that branches into 2 different tubes, one that brings effluent from the flocculator into the sand filter, and one that drains the backwash water of the sand filter. At the outlet of the sand filter, we have a pump that controls the flow of the entire system, including the flocculator section. And after the pump, we have a t connector that branches into two different tubes, one that brings the filtered water to the reservoir, and one that brings the filtered water from the reservoir to the drain through the sand filter. That process is only during the fluidization of the sand and the backwash to clean the filter.

#

#

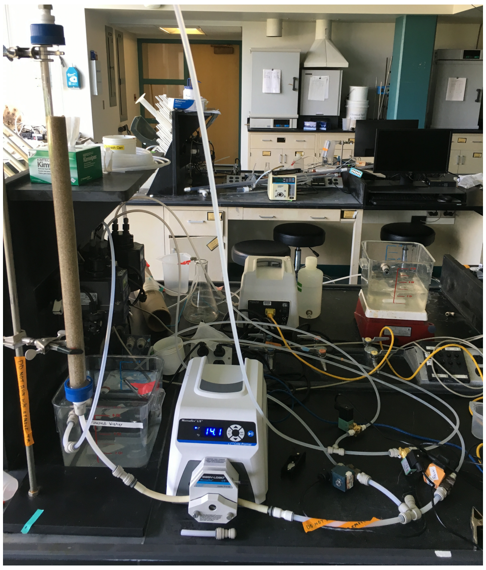

Figure 4:
The figure above is our final design apparatus. To the left you see the sand filter, pump, and the reservoir. To the right on the table, you see the solenoid valves controlled by ProCoDA that will direct the flow of water depending on the state.

##Experimental procedure

1. 25 mm diameter filter column. With 42 cm of sand and 17 cm of room on the top.
2. Design and build a sand filter (~1.5-2 ft) with a uniform sand size.
3. Attach a pump after the filter with a 18 mm rubber tubing.
4. Place a t connector after the pump and valves on each branch of the t.
5. Place turbidimeter on one branch of the t and direct the outflow from the turbidimeter into a reservoir with an overflow mechanism.
6. Connect the other branch of the t to the outflow of the reservior.
7. On the influent side of the sand filter add another t connector with valves on each branch of the t. Connect one branch to the effluent of the flocculator and the other branch to the drain.
8. Run ProCoDA on Fluidize sand, which runs for 5 minutes.
9. It will automatically go into the settling state, which give the sand 30 seconds to settle down into the filter.
10. Next, ProCoDA will go into the filter adjustment state for 5 minutes. This will give the turbidimeter time to go into a steady state after an increase of turbidity from the water flow.
11. Next, ProCoDA will automatically go into a filter state for 100 minutes because that was how long the clay/water stock can run for before becoming empty.
12. After "filter" state, ProCoDA will automatically go into "backwash" state for 5 minutes. We ran the effluent from the backwash state through the turbidimeter to get data for backwash. The outflow of the turbidimeter will be directed into the drain.
13. ProCoDA will go into an "OFF" state after backwash.
14. After the flocculator team cuts down the flocculator, the experiment was ready to run again.

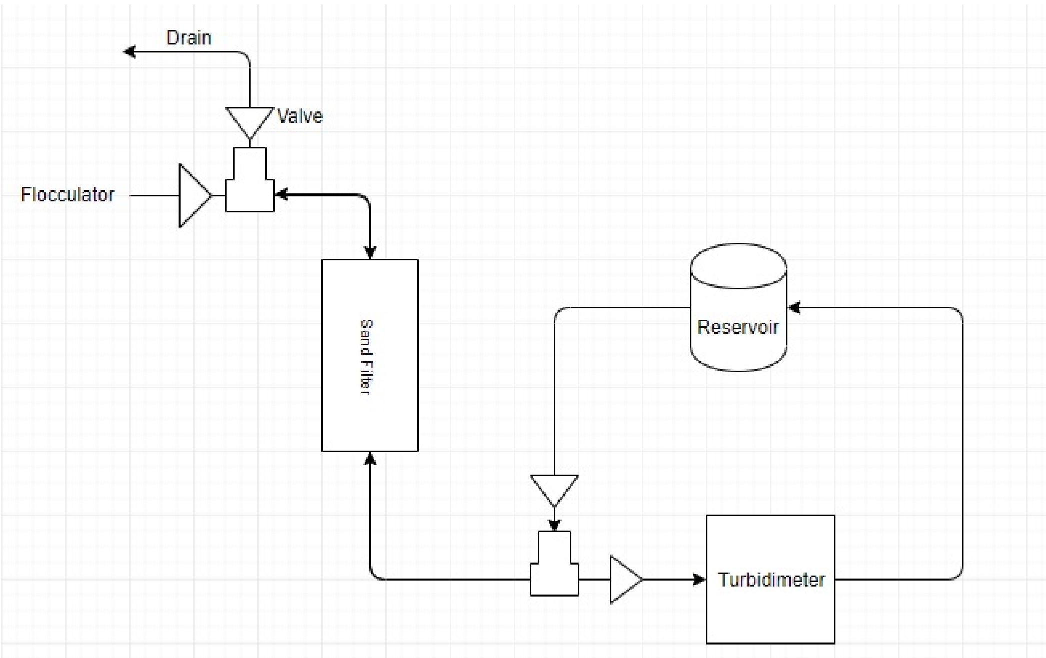

Figure 5:

The Figure above is our preliminary design for our apparatus in this experiment. We designed it so it will be easier to backwash our sand filter using recycled filtered water, instead of continuously using clean water.

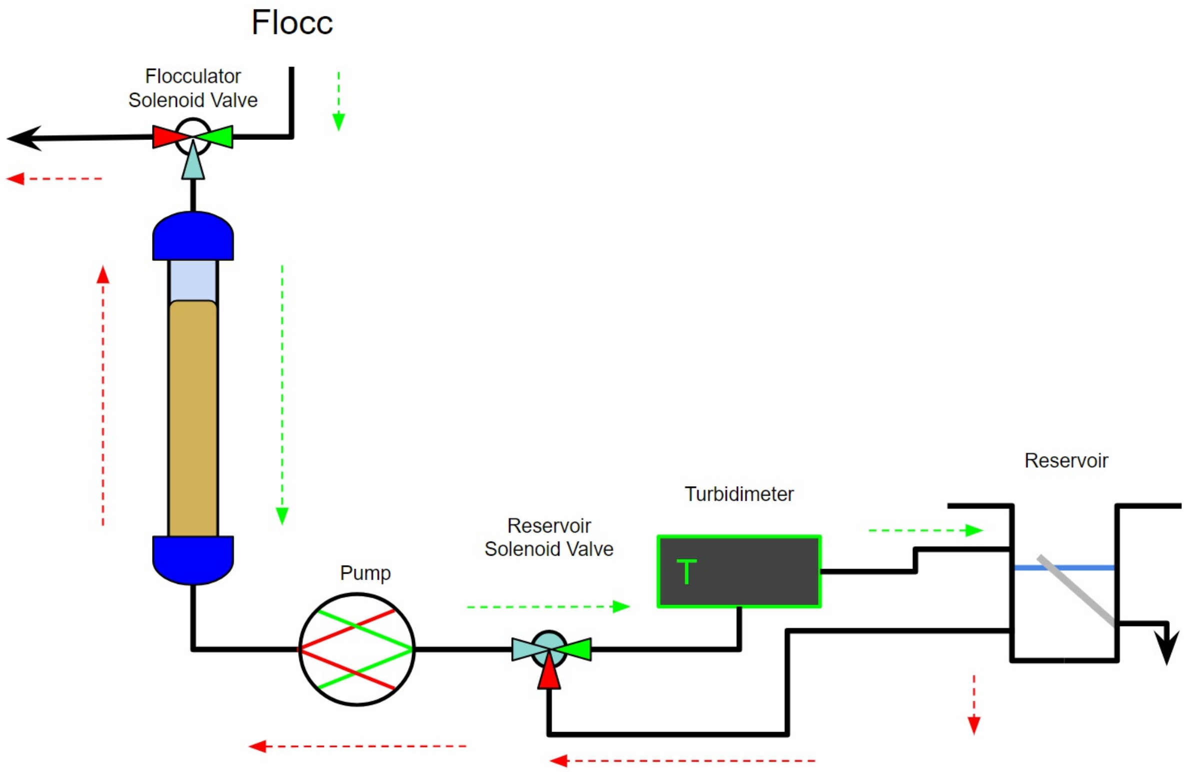

Figure 6:
The Figure above is our final design for our apparatus in this experiment. In the figure, the green arrows indicate the flow of water in the "Filter" state starting from the flocculator and ending in the reservoir. The red arrows indicate the flow of water in the "Backwash" and "Fluidize" state, that start from the reservoir to the drain at the top of the sand filter.

##Key design parameters

The influent flow rate will have to be the same as the effluent flow rate of the other team's flocculator the volume of the filter is constrained by the volume of the filter column and the porosity of the sand. The turbidity of the influent will be the same as the turbidity of the effluent of the flocculator. The parameter we will vary is the effluent from a high shear flocculator and from some kind of control effluent. One parameter will be testing different tubing to allow the flow rates to match with the flocculator team as well as having enough flow rate to fluidize the sand bedding.

Parameters

Constants	value
Volume of reservoir	4L
Diameter of Pump Tube	18 mm
Diameter of Filter Tube	25 mm
Velocity to Fluidize Sand	11 mm/s
Velocity to Filter	1.83 mm/s
Conversion from ml/min to RPM	3.8 ml/rev
Length of water in Filter	17 cm
Length of sand in Filter	42 cm
Residence Time Equation	V/Q
Flow Rate to Fluidize	5.4 ml/min
RPM to Fluidize	86 RPM
Flow Rate to Filter	.9 ml/min

RPM to Filter	14.2 RPM
Residence Time	185 sec

```
V_res = 4*u.l
dia_pump_tube = 18*u.mm


u_fluidize = 11*(u.mm)/(u.s) ##velocity needed to fluidize the sand filter
dia_filter = 25*(u.mm)    ##diameter of our sand filter tube
V_flow_rate_fluidize= ((u_fluidize)*np.pi*(dia_filter/2)**2)
flow_rate_RPM = V_flow_rate_fluidize.to(u.mL/u.min)
flow_rate_RPM     ##the flow rate needed in ml/min to calculate the RPM for fluidize
flow_rate_fluidize = (flow_rate_RPM).to(u.ml/u.s)
flow_rate_fluidize

u_filter = u_fluidize/6   ##1/6th of the velocity of the velocity needed for fluidization
A_filter = np.pi*(dia_filter/2)**2
V_FR_filter = u_filter*A_filter
FR_RPM = V_FR_filter.to(u.ml/u.min)
FR_RPM
FR_filter = FR_RPM.to(u.ml/u.s)
FR_filter


Flowrate_pump = 380*(u.ml/u.min)
Convertml_to_RPM = 3.8*(u.ml/u.revolution)              ### this is for the conversion from ml/min to RPM units: ml/rev
RPM_fluidize = flow_rate_RPM/Convertml_to_RPM         #This is the RPM needed to fluidize the sand
RPM_fluidize
RPM_filter = FR_RPM/Convertml_to_RPM                #This is the RPM for the pump on the filter state
RPM_filter


conc = (5 * u.NTU).to(u.mg/u.L)                   #This is the concentration for the stock
Mass_needed = conc * V_res
Mass_needed

Length_water = 17 * u.cm
Length_sand = 42*u.cm
V_water = A_filter*Length_water.to(u.mm)
V_sand = A_filter*Length_sand.to(u.mm)
V_sand.to(u.ml)
Res_time_sand = (V_sand.to(u.ml)/FR_filter)*0.4  #This is the residence time for the flocs in the sand filter
Res_time_sand
Res_time_water = (V_water.to(u.ml)/FR_filter)
Res_time_water
total_res_time = Res_time_sand+Res_time_water
total_res_time
```

##Results and Discussions

The experiment included four different runs: one w ith no flocculator and three w ith varying flocculator lengths. Using tw o turbidimeters, the turbidity of both the influent and effluent w aters from the sand filter w ere measured. For the tw o of the flocculator trials, a backw ash run w as added afterw ards. This w as done by pausing the program after the filtration cycle and re-plumbing the tubes to have the former influent tube of the sand filter go to the turbidimeter.

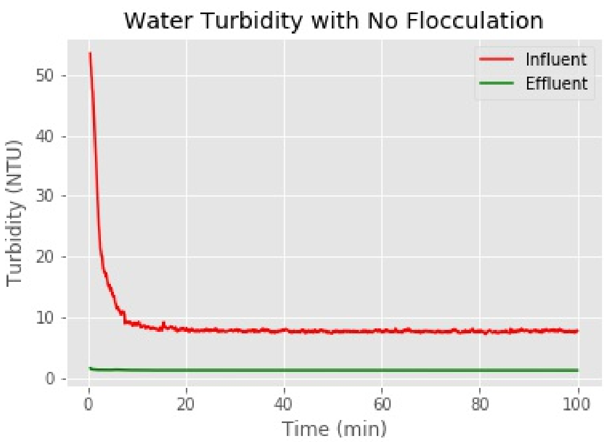

Figure 7
Turbidity before and after sand filtration. No flocculator w as used for this trial.

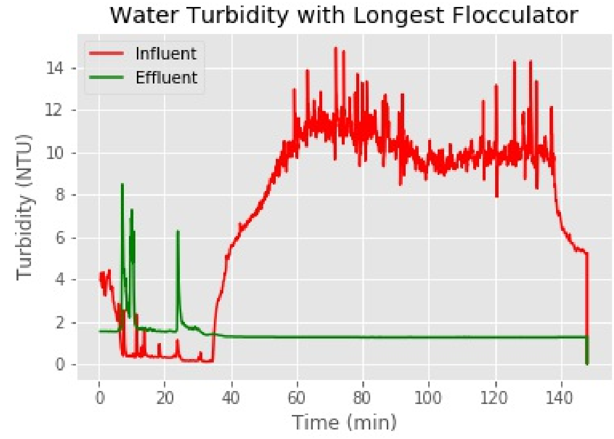

Figure 8
Turbidity before flocculation and after sand filtration. The flocculator w as at full length.

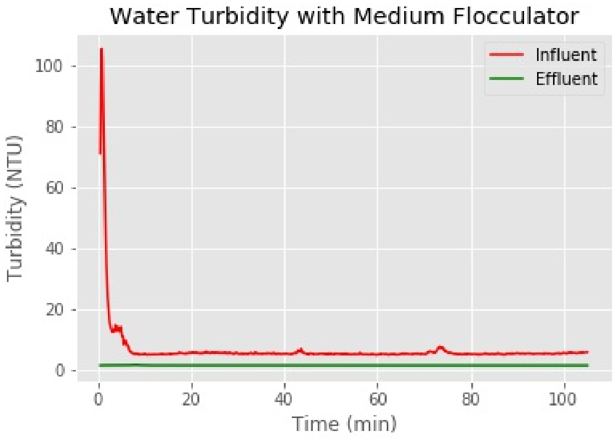

Figure 9
Turbidity before flocculation and after sand filtration. The flocculator w as at medium length.

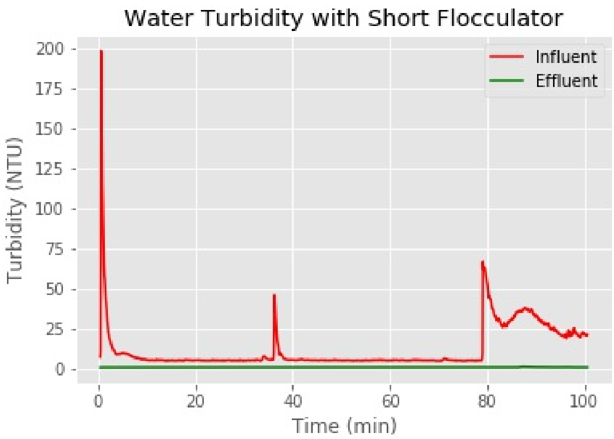

Figure 10
Turbidity before flocculation and after sand filtration. The flocculator w as at the shortest length.

The results seen above w ere as expected: the sand filter effectively low ered the turbidity of w ater for all instances. The series of graphs below reflect the influent and effluent turbidity for each run. Regardless of the flocculation length or even if there is a flocculator at all, the sand filter dramatically low ered the turbidity. Looking closer at just the effluent measurements, w e see that the effluent turbidity levels out for all runs reach to around 1.27 NTU. The flocculator inclusion or length seemed to have no effect on the sand filter's efficiency.

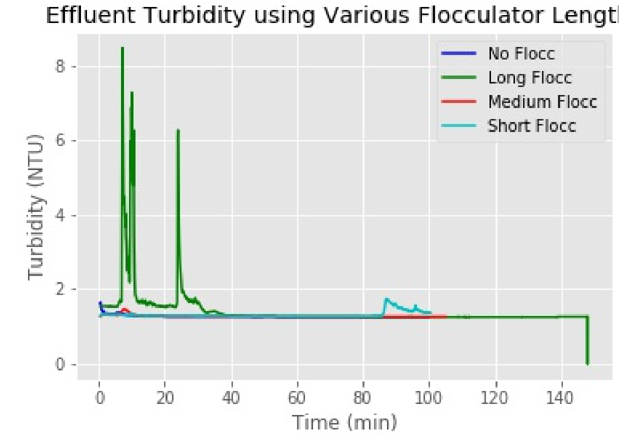

Figure 11
The figure above compares the effluent turbidity of all the trials. All effluent measurements plateau at around 1.27 NTU.

Looking at the backw ash measurements, w e see that turbidity jumped to roughly tw ice the peak of the influent measurement from the respective filtration cycle.

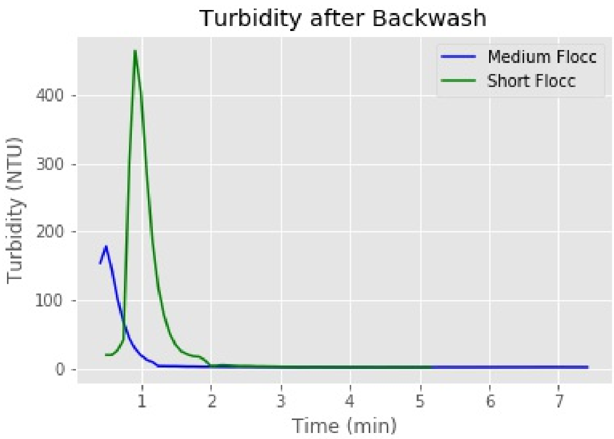

Figure 12
Amount of turbidity resulting from the backw ash phase after medium and short flocculation.

These results w ere both expected and surprising. As expected, w e did see a drastic decrease in NTU after the sand filter, confirming that it w as effective in purifying the w ater. The backw ash results also confirmed the notion that running the pump in reverse w ould w ash out the accumulated flocc. What w as surprising w ere that values of the results. The effluent measurements for each run stayed at a relatively consistent value of 1.27, suggesting that the inclusion of a flocculator did not effect the efficiency of the sand filter. The backw ash measurements w ere also different from expected, as the backw ash turbidity from the short flocculator w as over double than that of the medium length flocculator.

Given the molecular physics of the interaction of granular filters and flocculation, w e had expected that larger flocc developed from a longer flocculator w ould have a higher probability of getting stuck in the sand filter. Since the end result w as the same throughout, w e concluded that the length of the flocculator did not effect the size of the flocc, therefore not effecting the permeability of the particles through the sand filter. Further experimentation could have been done after these results, w here w e w ould vary other aspects of the flocculator in order to successfully increase the amount of large floccs. Since the flocculation is dependent on the shear force, some possible changes include the curvature of the tube and the diameter of the tube. By redoing the experiment using the above parameters as variables instead of the length of the tube, w e could have seen a more obvious difference in filter efficiency.

Another improvement that could have been made is for the backw ash portion of the experiment. Our initial intention w as to program the system so that the backw ash w ould automatically initiate w hen the effluent turbidity reaches 5 NTU. How ever, due to time and stock volume constraints, this programming could not have been done. An experiment including the automated backw ash w ould have been ideal, as it more accurately represents the automatic cleansing after the sand filter has begun to fail. This w ould also allow us to observe if the time to failure differentiated w ith the size of flocculation.

```
# No Flocc results
NFD = np.array(pd.read_csv('https://raw.githubusercontent.com/simonfines/Final-Data/master/No%20Flocc%20data.csv',header = 6))
NFDtime = NFD[:,2]
NFD_In = NFD[:,5]
NFD_Out = NFD[:,4]

plt.figure(1)
plt.plot(NFDtime,NFD_In, 'r', label = 'Influent')
plt.plot(NFDtime,NFD_Out, 'g', label = 'Effluent')
plt.xlabel('Time (min)')
plt.ylabel('Turbidity (NTU)')
```

```
plt.title('Water Turbidity with No Flocculation')
plt.legend()
#plt.savefig('No Flocc.png')
plt.show(1)

plt.figure(2)
plt.plot(NFDtime,NFD_Out, 'g', label = 'Effluent')
plt.xlabel('Time (min)')
plt.ylabel('Turbidity (NTU)')
plt.title('Water Turbidity with no Flocculation, Effluent Only')
#plt.savefig('No Flocc Eff')
plt.show(2)

# Long Flocc Results
LFD = np.array(pd.read_csv('https://raw.githubusercontent.com/simonfines/Final-Data/master/Long%20Flocc%20data.csv',header = 6))
LFDtime = LFD[:,2]
LFD_In = LFD[:,5]
LFD_Out = LFD[:,4]

plt.figure(3)
plt.plot(LFDtime,LFD_In, 'r', label = 'Influent')
plt.plot(LFDtime,LFD_Out, 'g', label = 'Effluent')
plt.xlabel('Time (min)')
plt.ylabel('Turbidity (NTU)')
plt.title('Water Turbidity with Longest Flocculator')
plt.legend()
#plt.savefig('Long Flocc')
plt.show(3)


plt.figure(4)
plt.plot(LFDtime,LFD_Out, 'g', label = 'Effluent')
plt.xlabel('Time (min)')
plt.ylabel('Turbidity (NTU)')
plt.title('Water Turbidity with Longest Flocculator, Effluent Only')
#plt.savefig('Long Flocc Eff')
plt.show(4)

# Medium Flocc Results
MFD = np.array(pd.read_csv('https://raw.githubusercontent.com/simonfines/Final-Data/master/Medium%20Flocc%20data.csv',header = 6))
MFDtime = MFD[:,2]
MFD_In = MFD[:,5]
MFD_Out = MFD[:,4]

plt.figure(5)
plt.plot(MFDtime,MFD_In, 'r', label = 'Influent')
plt.plot(MFDtime,MFD_Out, 'g', label = 'Effluent')
plt.xlabel('Time (min)')
plt.ylabel('Turbidity (NTU)')
plt.title('Water Turbidity with Medium Flocculator')
plt.legend()
#plt.savefig('Med Flocc')
plt.show(5)

plt.figure(6)
plt.plot(MFDtime,MFD_Out, 'g', label = 'Effluent')
plt.xlabel('Time (min)')
plt.ylabel('Turbidity (NTU)')
plt.title('Water Turbidity with Medium Flocculator, Effluent Only')
#plt.savefig('Med Flocc Eff')
plt.show(6)

# Short Flocc Results
SFD = np.array(pd.read_csv('https://raw.githubusercontent.com/simonfines/Final-Data/master/Short%20Flocc%20data.csv',header = 6))
SFDtime =SFD[:,2]
SFD_In = SFD[:,5]
SFD_Out = SFD[:,4]

plt.figure(7)
plt.plot(SFDtime,SFD_In, 'r', label = 'Influent')
plt.plot(SFDtime,SFD_Out, 'g', label = 'Effluent')
plt.xlabel('Time (min)')
plt.ylabel('Turbidity (NTU)')
plt.title('Water Turbidity with Short Flocculator')
plt.legend()
#plt.savefig('Short Flocc')
plt.show(7)

plt.figure(8)
plt.plot(SFDtime,SFD_Out, 'g', label = 'Effluent')
plt.xlabel('Time (min)')
plt.ylabel('Turbidity (NTU)')
plt.title('Water Turbidity with Short Flocculator, Effluent Only')
#plt.savefig('Short Flocc Eff')
plt.show(8)

# comparing Effluents
plt.figure(9)
plt.plot(NFDtime,NFD_Out, 'b', label = 'No Flocc')
plt.plot(LFDtime,LFD_Out, 'g', label = 'Long Flocc')
plt.plot(MFDtime,MFD_Out, 'r', label = 'Medium Flocc')
plt.plot(SFDtime,SFD_Out, 'c', label = 'Short Flocc')
```

```
plt.xlabel('Time (min)')
plt.ylabel('Turbidity (NTU)')
plt.title('Effluent Turbidity using Various Flocculator Lengths')
plt.legend()
#plt.savefig('Effluents')
plt.show(9)

#Backwash results
BWM = np.array(pd.read_csv('https://raw.githubusercontent.com/simonfines/Final-Data/master/Medium%20Flocc%20Backwash.csv',header = 6))
BWS = np.array(pd.read_csv('https://raw.githubusercontent.com/simonfines/Final-Data/master/Short%20Flocc%20Backwash.csv',header = 6))
BWMtime =BWM[:,2]
BWM_Out = BWM[:,4]
BWStime =BWS[:,2]
BWS_Out = BWS[:,4]

plt.figure(10)
plt.plot(BWMtime,BWM_Out, 'b', label = 'Medium Flocc')
plt.plot(BWStime,BWS_Out, 'g', label = 'Short Flocc')

plt.xlabel('Time (min)')
plt.ylabel('Turbidity (NTU)')
plt.title('Turbidity after Backwash')
plt.legend()
#plt.savefig('Backwash')
plt.show(10)
```

##Conclusion
The goal of this joint experiment w as to ultimately low er the turbidity of incoming w ater by a significant amount, using a coupled flocculator and sand filter. The sand filter team also included a backw ash system to clean out the filter w ithout w asting w ater. The overall results w ere positive, but left us w ith several questions and opportunities to experiment further. The coupled w ater processes did drastically reduce the turbidity of the w ater, going from around 30 NTU to 1.3 NTU, but the results implied that flocculation had no effect on the effluent turbidity. From the consistency of the effluent measurements, the length of flocculator tube did not increase flocc size as intended. The results did, how ever, provide several opportunities to further the experiments. Know ing that length does not affect the filter efficiency, other parameters of the flocculator could have been changed instead.

##Timeline of tasks/experiments
Week 1:

- Materials and Equipment
- Design and Build sand filters
- Preliminary apparatus

Week 2:

- Testing of preliminary apparatus
- Modification and improvement of apparatus
- Begin testing other variables and designs

Week 3:

- Finalize the design of the apparatus
- Continue experimentations to further conclude our data
- Begin compiling data to make conclusions

Week 4:

- Final testing
- Rough draft of report

Week 5:

- Report w riting/editing

##Possible hurdles/challenges

- Faulty Equipment
- Unable to get correct size of sand for filters
- Miscommunication w ith team and others
- Limited time to optimize our apparatus and design
- Schedule conflicts
- Inconclusive data acquisition

##Resources needed to conduct experiments

- filter column
- stoppers w ith mesh
- tubing
- sand

- 4 solenoid valves
- 2 pump
- reservoir

##Expectations/Anticipated results

An apparatus with high shear flocculation and a rapid sand filter will generate effluent with lower turbidity than traditional flocculation techniques.

##Suggestions/Comments

Future suggestions for this project would be to have better cooperation between the joint groups. Though we definitely collaborated for the preparation and actual experimentation, the results and analysis seemed complicated because we shared the same results/experiment, but were assigned for separate final assignments.

There were several limiting parameters that prevented us from conducting our intended experiment. We didn't have enough stock to run the experiment for enough time for the filter to fail, and hopefully the ProCoda would automatically switch to backwash.

Another issue we had were air bubbles in the turbidimeter. Any modification or accidental leak introduced to the apparatus created air bubbles in the tubing. The air bubbles greatly affected the data acquisition, especially during the transition to backwash, or when the influent stock ran out.

The apparatus could also be changed to reduce the chances of air bubbles. We were limited at the workbench with only two turbidimeters and two pumps. An addition of at least another turbidimeter would have a more effective transition to the backwash cycle.

As part of the sand filter group, we felt like we did not have enough material to properly analyze and test our objective. Since this was a joint experiment, we did not have a variable to change. The only thing we did was run experiments with the flocculator team changing variables. We would have liked it if we could change some variables in the sand filter, such as length of filter, material in filter, thickness, etc. Since filtration theory does not have a consistent and accurate model, we could not compare our empirical data to a theoretical one.

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