Rapid mix contact chamber, Fall 2016

Mythri Krishnamoorthysujatha, Joao Carlos Moraes, Javier Escanciano

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Abstract

The Rapid Mix Contact Chamber Team worked to assess the utility of a contact chamber in improving the efficiency of the rapid mixing of raw water and coagulant. The nanocluster deposition on the walls of the flocculator increased the headloss in the flocculator. The team built the apparatus with a straight tube flocculator and tests were run for different flow rates to find the relationship between headloss and nanocluster buildup. The variation in the nanocluster buildup with the change in diameter of the straight tube flocculator was studied. The team explored the difference in the headloss values when the tests were run with and without the contact chamber. It was found that for the current flocculator chosen, adding a contact chamber did not help in reducing the headloss accumulation. In other words, there was no significant reduction in the deposition of nanoclusters on the flocculator walls on adding a contact chamber unit to the apparatus.

Introduction

The Rapid Mix Contact Chamber team's first goal was to deal with the problem of coagulant loss in the rapid mix tube and flocculator of the AguaClara plants. Coagulant loss leads to higher operating costs. It was demonstrated that only 1.6 percent of coagulant used attached to clay particles and the rest was attaching to the walls of the flocculator (Weber-Shirk, Monroe, 2016). Hence to increase the efficiency of the process and reduce the operating costs in aguaclara plants, the team wanted to explore the idea of adding a contact chamber and determine how the headloss accumulation varies with changing diameter of flocculator, changing flow rates and changing turbidity.

The team's goal was to assess the utility of a contact chamber in minimizing the coagulant loss. Tests were conducted on different diameters of the flocculator. The headloss increases when the nanoclusters are deposited on the walls of the flocculator. Nanoclusters are tiny particles of coagulant which gets attached to the walls of flocculator instead of attaching to the clay particles. The accumulation of nanoclusters decreases the diameter of the flocculator and results in the increase of headloss. Tests were conducted for different flow rates and team found a particular flow rate at which there is no coagulant deposition. While exploring these ideas,the team also found out that there is a particular flow rate beyond which the flow in the flocculator becomes turbulent and hagen pouiselles equation becomes invalid for the flows beyond that point. The team then selected a flow rate for which there is a reasonable headloss accumulation and a contact chamber was built for this headloss. A flow rate with reasonable (noticeable) headloss was chosen so that the effects of contact chamber could be observed better. The team conducted tests with water of different turbidities and different conditions (one with contact chamber and one without contact chamber). The team tested a straight flocculator looking for a velocity gradient in order to prevent deposition of clay particles but to allow deposition of nanoclusters of coagulant. The objective was to find out forces involved in attachment of particles to the flocculator walls.

Literature Review

Rapid mix is the operation in water and waste treatment employed for the purpose of achieving complete homogenization of a coagulant chemical with the stream to be treated. (Vrale and Jorden, 2016). This is accomplished by applying turbulence to the combined streams and has been done in a variety of ways (Eg. mechanical agitators or baffled basins). In the rapid mix units used in water treatment plants, a mechanized method is used to generate turbulence. However, this method uses electricity, which is expensive and unreliable in some parts of the world. Also inefficient rapid mixing has two harmful effects:1) loss of chemicals 2) slower particle aggregation rates for a given volume. Hence the main objective of a rapid mix contact chamber is to provide the appropriate conditions for maximizing collisions between nanocluster coagulant particles and clay particles

Rapid mixing of water and coagulant chemical at the point where the chemicals are added is essential. This may be achieved with a mechanical mixer or by hydraulic means, such as weir or hydraulic jump. (World Health Organization, 2012). This phenomena contribute to mixing: Molecular diffusion (perikinetic diffusion), eddy diffusion and non-uniform flow. Flow expansions causes turbulence which results in large scale eddies. These large scale eddies move packets of fluid around at the scale of the flow(or the scale of the separation distance of the injection points). Smaller eddies move packets of fluid over smaller length scales. Smaller eddies create even more smaller eddies until the viscosity kills inertia.

A breakthrough study last year showed that turbulence is a great mixer down to about 50 times the Kolmogorov scale.(Weber-Shirk, Monroe, 2015) It is defined by:

$$L = \left(\frac{v^3}{c}\right)^{\frac{1}{4}} \tag{1}$$

$$IV = 50\ L \tag{2}$$

Where the variables are as follows:
L - the Kolmogorov length scale, m
v - the kinematic viscosity, m^2/s
c - the energy dissipation rate, mW/kg
IV - Inner viscous length scale, IV

At this scale, viscosity dominates and the turbulent kinetic energy is dissipated into heat. Any mixing below the inner viscous length scale is by molecular diffusion. Molecular diffusion is due to thermally induced Brownian motion.

Past research on rapid mix chambers has concerned itself with electric mixing methods. While our goal is to find an efficient electricity-free method using the insights from the past AguaClara, past research can still provide insights into reaching our goal.

Previous Work

In AguaClara plants, Rapid mix is a tube which connects the entrance tank and flocculation tank. Rapid mix contact chamber serves as an area in which

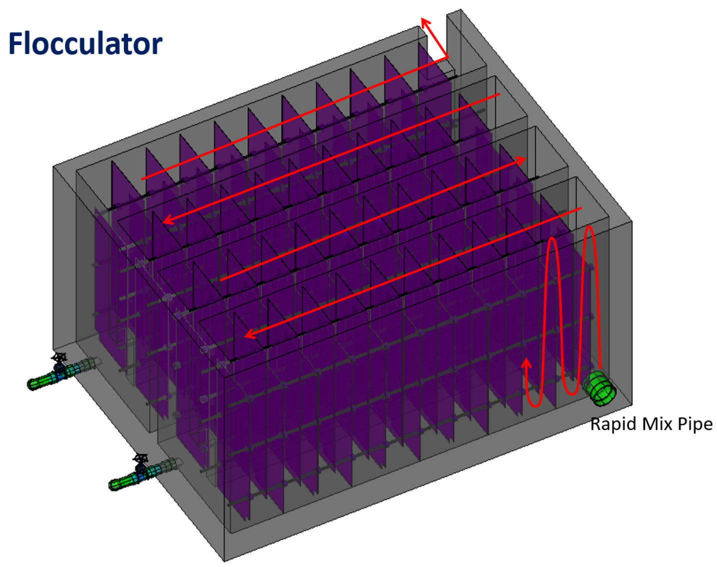

Figure 1: Rapid mix unit and flocculator unit of AguaClara plants. Water enters through the rapid mix pipe to the flocculator baffles. The purple color sheets in the figure represent the vertical baffles.

the raw water can get mixed with the coagulant. The goal of this team is to explore the various parameters affecting the process and find out the basis for a rational design. The figure1 shows the three dimensional image of rapid mix and flocculator of AguaClara plants The team of Spring 2016 demonstrated that contact chambers improved the performance of the tube settler, which indicated a reduction in coagulant lost to the walls of the apparatus. They showed that all of the contact chamber designs had a better pC* (which is a dimensionless measure of removal efficiency) than the control (The regular tubing without the contact chamber is the control).

$$pC^* = \text{-log}\frac{\text{Effluent Turbidity}}{\text{Influent Turbidity}} \tag{3}$$

The team inferred that the increased pC* was the effect of less coagulant being lost to the walls. The team also concluded that measuring pC* without a contact chamber was effective and accurate, because the tube settler was performing consistently for an appropriate period of time. (AguaClara RMCC, 2016)

The team tested two variables in contact chamber performance, residence time and radius. The figure 2 shows the rapid mix chambers designed by the spring 2016 team.

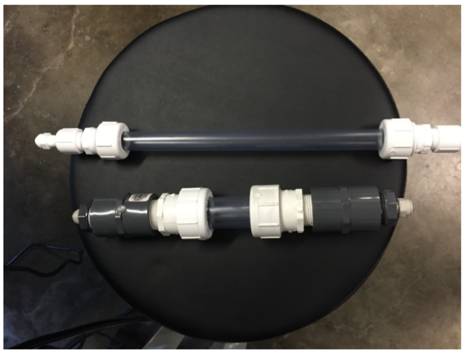

Figure 2: Figure shows the contact chamber made by the spring team

They found that residence time was a key factor in designing an effective contact chamber. Longer contact chamber performed better than the shorter ones. They also found that radius was not a key factor in the design of contact chamber and hence does not have a large effect on contact chambers effectiveness.

Methods

The first step was to find the relationship between head loss in a flocculator and the amount of coagulant nanoclusters residing in the tube walls. The increase in head loss is hypothesized to be due to the residue decreasing the diameter of the flocculator tube. This was tested using a straight tube flocculator with a pressure sensor connected to each end of the tube. The flocculator was designed to have about 17.5m of headloss with a velocity gradient of 1000 Hz and greater. The pressure sensor took the difference in pressure between the two ends in terms of cm, giving the head loss. There was an increase in the headloss values than the anticipated headloss values. The team presumed that this increased headloss was due to the minor losses in the tube ends. And tube had lot of bends. A reasonable headloss (almost equal to the theoretical value was obtained after cutting the ends). The goal was to find the maximum flow rate in which coagulant would still attach to the tube walls. A flow rate any higher than this would have enough torque to prevent nanocluster buildup, which would be signified by a lack of head loss accumulated between running the apparatus with tap water and tap water with a coagulant injection.

In order to find the new, shorter diameter once coagulant coats the flocculator walls, the team used the relationship:

$$\tau = \frac{\Delta P D}{4L} = -\mu \frac{du}{dr} \quad (4)$$

The velocity gradient du/dr can be determined experimentally with the Hagen-Poisuille equation since the head loss and flow rate will be known. The team can then solve for D.

However, this approach was limited due to the minor losses associated with the water flow through the flocculator. The Hagen-Poisuille equation was calculating head losses different from the head loss measured experimentally. In order to correct for this difference the team also ran a "ramp test." This test was done by measuring the head loss through the flocculator over a range of flow rates from 0 to 2.5 mL/s. A correction can be achieved by comparing a plot of these results to the Hagen-Poisuille's linear relationship between flow rate and head loss.

Knowing the reduced diameter due to coagulant buildup, one simple model to find the coagulant loss is treating it as a different, smaller tube. The volume of this cylinder created by the coagulant would be the coagulant loss, and could be calculated by

$$Volume = \frac{\pi}{4}(D_0^2 - D_c^2)L \tag{5}$$

Where D_0^2 is the radius of the flocculator tube, D_c^2 is the smaller radius caused by the coagulant buildup, and L is the length of the flocculator.

Experimental Apparatus

Apparatus setup

The flocculator of the apparatus was designed to acquire a headloss of 1 m with a tube of 1/16 in in diameter. With these requirements, the length of the tube was calculated to be 0.917 m. At each end of the tube a pressure sensor was connected in order to determine the head loss. The figure 3 shows the schematic representation of the test setup.

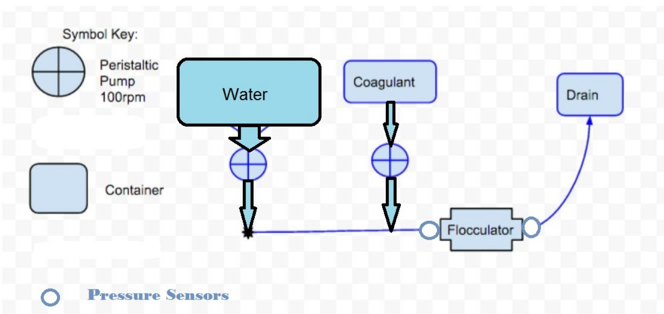

Figure 3: Schematic Representation of the setup. The water comes into the system from a feeding tube connected to the lab's tap water supply. This tube then connected to the water pump which drives the water through the rest of the system. The coagulant is solution is contained in a 1 L plastic contained which feeds into the coagulant pump. Pump injects the coagulant into the system right before entering the flocculator.

The figure 4 shows the experimental apparatus setup. Different components of the apparatus are labeled as shown. For the first experimental tests, zero turbidity water was used to run the tests.

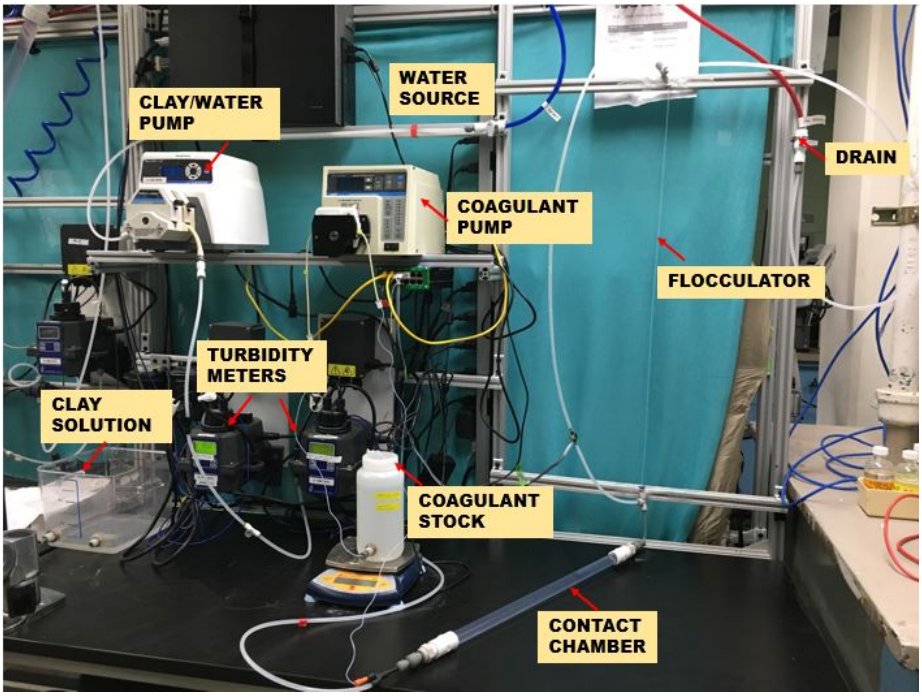

Figure 4: The experimental apparatus built by the Fall 2016 team. The apparatus consists of clay and coagulant pumps, turbidity meters,contact chamber and flocculator.

Flocculator Design

Assuming a head loss h_f of 1m, a tube diameter of $\frac{1}{16}$ in, and a velocity gradient G_{ave} 3000 Hz. The length of the flocculator was calculated from Velocity and the residence time:

$$\theta_{Tube} = \frac{h_{fTube} * g}{\epsilon_{ave}} = 1.09s$$

and

$$V = D\sqrt{\frac{h_f * \rho * g}{32 * \mu * \theta}} = 0.842\frac{m}{s}$$

Even though the flocculator was designed with these assumptions, the actual microtubing used was $\frac{1}{32}$ in in diameter. This means the actual head loss and velocity gradient at the flow of 1.66 mL/s were much higher than what it was assumed to be. Working backwards with the equations and a tube length of 0.917 m, the actual expected headloss was found to be 17.5 m. Figure 6 shows the first flocculator built by the team.

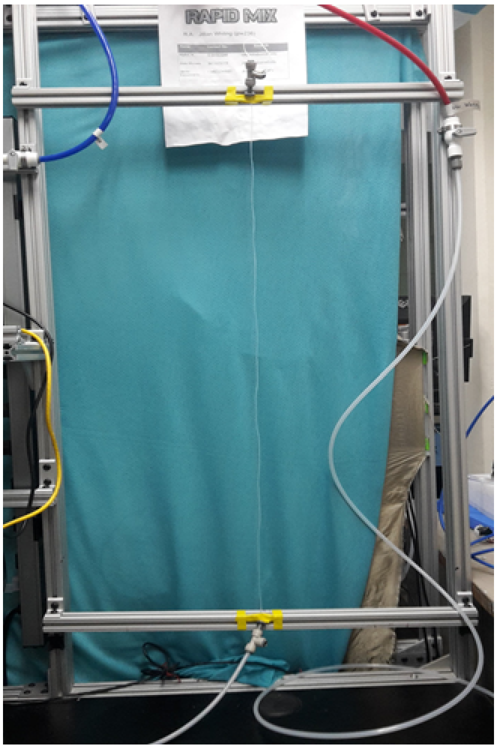

Figure 5: The 0.917 m flocculator. A pressure sensor was connected at each end of the tube to measure head loss over the tube length. Water comes in from the bottom and is injected with the coagulant solution just before entering the flocculator. The top end is then sent to the waste-water tube.

A second flocculator was built with a diameter of 0.042 inches and length 0.925 meters in length. The expected headloss for this flocculator was 2.2 meters when the system is run with a flowrate of 0.6 mL/s.Figure 6 shows the second flocculator built by the team.

Mix Chamber Design

The mix chamber was designed arbitrarily choosing a tube 0.5 meters in length and 0.52 inches in diameter. The size of the orifice was $\frac{1}{16}$ which was the smallest hole that could have been drilled. The rest of the characteristics of the chamber such as residence time were calculated using the same methods as the Spring semester.

Procedure for Finding Headloss

Headloss over the length of the flocculator was the test variable the team used. A step by step procedure for testing the headloss for a test can be found in Appendix B. The ProCoDA methods used can be found in Appendix A

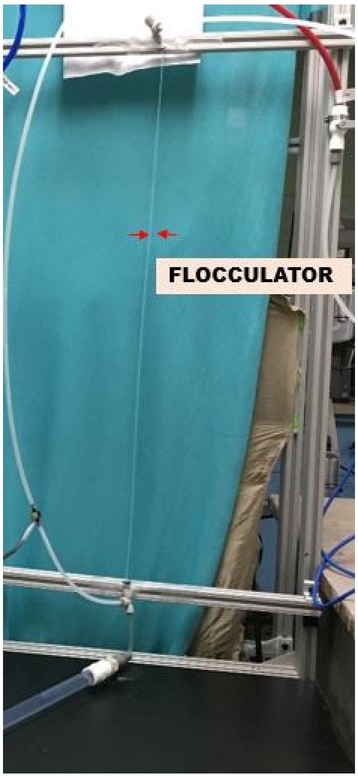

Figure 6: The second straight tube flocculator of length 0.925 metres and diamter of 0.042 inches.A pressure sensor was connected at the ends of the flocculator to measure the headloss across the ends .

Procedure For Finding Shear Stress at a Flow Rate with coagulant

For the next experiments, in order to test the strength of the coagulant and how much it can stick to the wall depending on the shear stress applied, the team first ran the apparatus with water and coagulant at the desired constant flow rate. This test was then ran until head loss was no longer accumulating in the flocculator, determined by looking at pressure sensor data in ProCoDA.

Once head loss was no longer accumulating, the team switched off the coagulant pump but left the water pump at the same flow rate. This was done to see how quickly and how much the tap water would shear off the coagulant in the tube walls.

Procedure for finding head loss as a function of flow rate

In order to get an experimental relationship between head loss and flow rate, the team used ProCoDA's ramp function as a flow rate. This was done by running the water pump only and allowing the ramp state to change the flow rate over time.

Figure 7: The rapid mix chamber. It has a length of 0.5 meters and 0.52 inches. When used, it is after the coagulant is injected into the system's water flow. The solution then enters the chamber through a 1/16 in orifice through a push-to-connect connector.

Procedure for testing effectiveness of Rapid Mix chambers

Once the headloss-coagulant relationship was found, the team built rapid mix chambers following the guidelines and equations used by the previous semester's team. These rapid mix chambers were then added to the apparatus right after the coagulant is injected into the water. In order to test how well the chamber works, the team did two separate experiments with and without the mix chamber. When using clay, the blue water source tube was not used. Instead, a clay solution with the desired NTU was prepared in a large container, and then instead of having the water pump tube draw water from the lab supply, it was drawn from the clay solution container.

First, the team ran the apparatus without the mix chamber using the clay stock solution and injecting coagulant right before entering the flocculator. Then the team recorded the headloss over time to find the rate of headloss accumulated as well as the maximum headloss accumulated. This procedure was then repeated with the same flowrate, but the mix chamber was added before the flocculater and after the coagulant injection. Comparing the headloss accumulation between the two tests allowed the team to see the effectiveness of the mix chambers.

Results and Analysis

The goal of the first task was to find out if there is a velocity gradient that prevents deposition of nanoclusters of coagulant. To do so, the team designed a straight tube flocculator of about 0.917 m length with two ends attached to one pressure sensor (20m,200kPa) to monitor the head loss. The team varied different flow rates to determine if it is possible to find a point at which there is no nanocluster attachment to the tube wall.

In our first trial, the team used a flow rate of 1.66 mL/s examined the head loss versus time for two cases: first, adding only water to the system and then adding water and coagulant to the system. The graphs for these values were plotted and there was no significant difference in head loss in these two graphs. The graph 8 shows the variation of headloss (cm) versus time (min) for the water only and water with coagulant states for a flow of 1.66 mL/s.

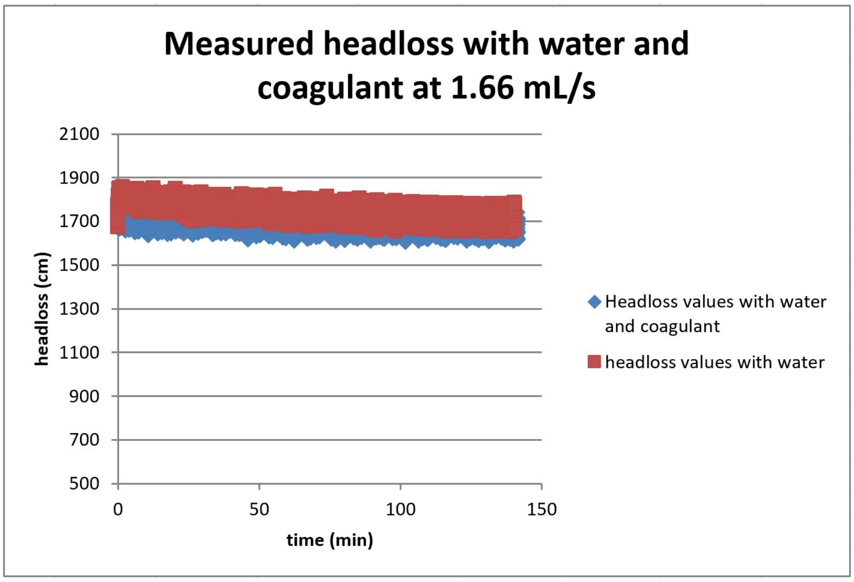

Figure 8: Headloss vs time-1.66 mL/s. There is no significant difference in the headloss, indicating that a flow rate of 1.66 mL/s is high enough to prevent nanocluster accumulation

The flow rate was then decreased to 0.8 mL/s to determine if the difference would increase, and it was confirmed that the difference in head loss was higher at a flow rate of 0.8 ml/s than at a 1.66 ml/s flow rate. The graph 9 shows the variation of headloss (cm) versus time (min) for the water only and water with coagulant states for a flow of 0.8 mL/s. While the headloss remained constant in the 600 to 650 cm range when there was only water going through the flocculator, it slowly increased when coagulant was introduced indicating coagulant attachment.

The team used a flow rate of 2.5ml/s of tap water in between the tests to clean the flocculator and remove any coagulant that was attached to the walls of the flocculator. It was found that at 0.6 ml/s, the coagulant water increased headloss from the control tap water by 0.75 m. After backwashing , the control

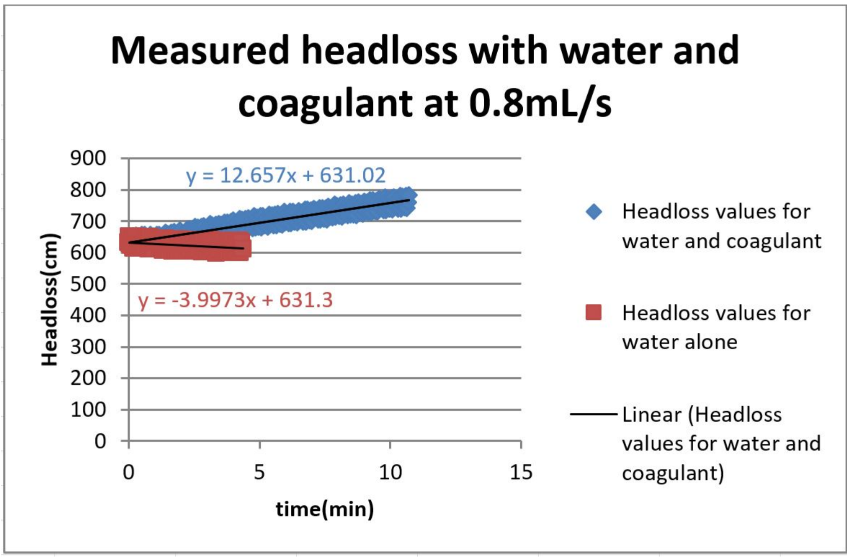

Figure 9: Headloss vs time-0.8 mL/s A steady increase can be observed, indicating that coagulant is slowly building up in the tube walls. This test will be repeated for a longer period of time to see at which point the headloss levels off

test was repeated and the results did not change indicating that the backwash was successful

In an attempt to find out the flow rate value at which there is no attachment, the team decided to use a higher value for the flow rate.

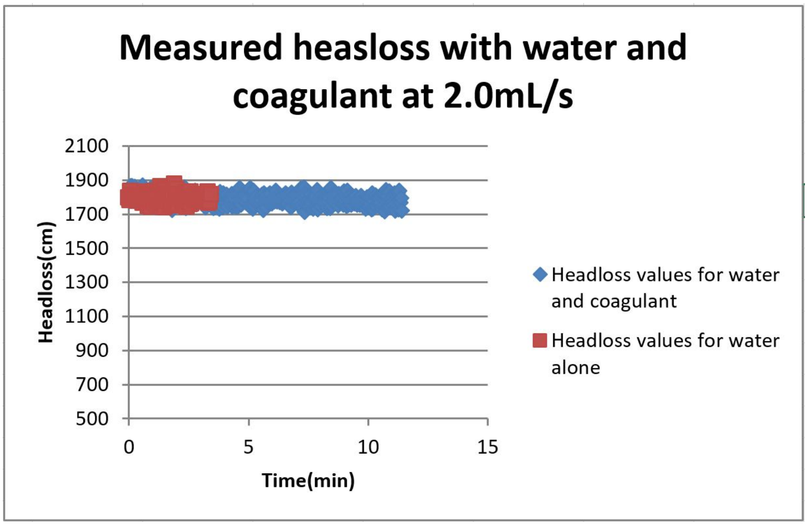

Figure 10: Headloss vs time-2 mL/s. No increase in the headloss values on adding coagulant indicating no coagulant buildup. Test with water alone was stopped after a shorter period of time as there is no variation in headloss values over time for water only state

The team decided to use a significantly higher value for the flow rate, in this case 2.0 mL/s to prove that the head loss in both cases remained constant The graph 10 shows the variation of headloss (cm) versus time(min) for the water only and water with coagulant states for a flow of 2.0 mL/s.

Finally, the flow rate was changed to 1.8 mL/s, obtaining very similar values (with few cms difference) for the head loss when running with water alone and when running with water and coagulant, indicating that the this flow rate did not allow coagulant attachment. Refer figure 11. The duration for the different

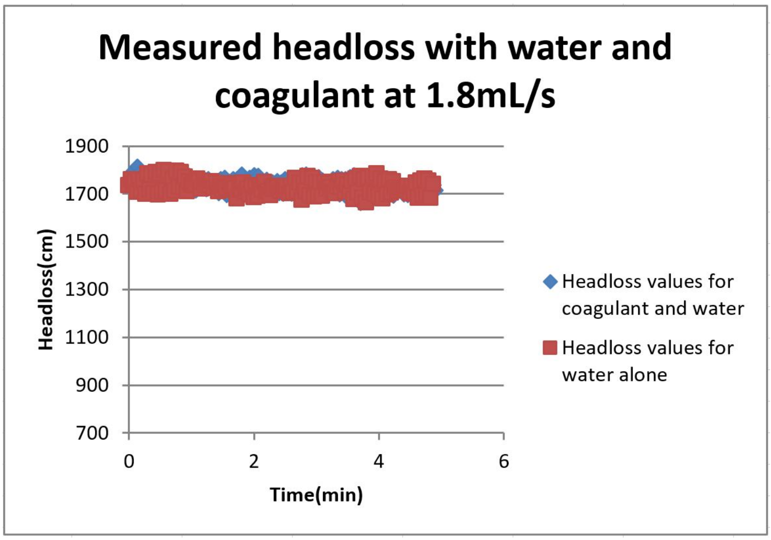

Figure 11: Headloss vs time-1.8 mL/s. No increase in the headloss values on adding coagulant indicating no coagulant buildup

flow rate cases was not longer than 15 minutes, so the team decided to perform longer tests thereafter. And also performed continuous tests first with water and coagulant and then testing with water at the same flow rate to find out how the coagulant detaches from the walls of the flocculator.

To find out a more closer value of flow rate at which there is no coagulant attachment,the team ran the experiment for a flow of 1.3ml/s first with coagulant and then without coagulant. Figure 12 shows the variation in headloss on adding coagulant for the first 40 minutes and then running the experiment without coagulant for the next 40 minutes. The graph clearly shows that there is a coagulant build up for this flow rate.

To examine if the coagulant buildup detaches due to shear (torque produced by the flow of water which breaks the coagulant off from the surface of flocculator walls) or due to dissolution (as coagulant is soluble at lower PH values), tests were conducted with water and coagulant and then water alone to see how headloss decreases when water with the same flow rate is flowed through it. Figure 13 shows a sudden drop indicating that the coagulant detachment is due to shear and not dissolution. If it showed a gradual decrease, it would have meant that the coagulant was detached due to dissolution. From the previous experiments, the team found that a high water flow rate (above 2.5mL/s) can make all the particles detach from the flocculator.

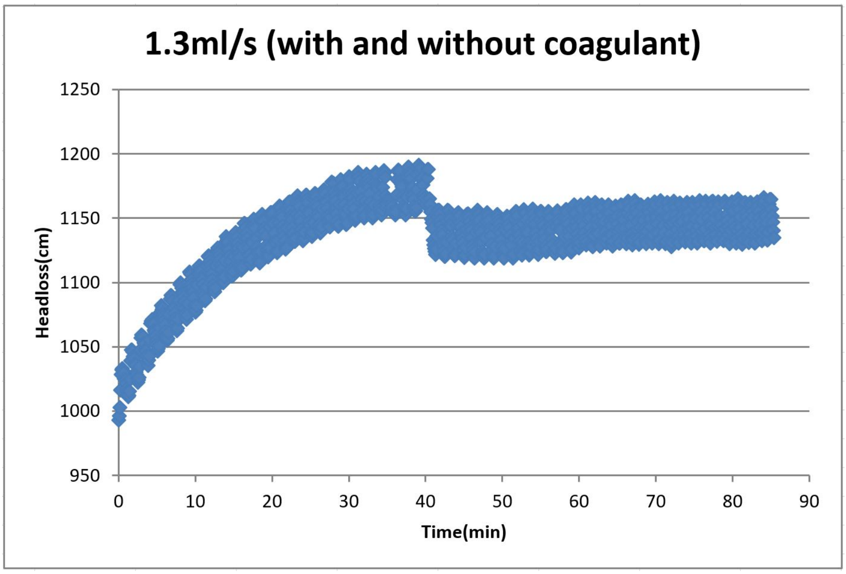

Figure 12: Headloss vs time-1.3 mL/s (water and coagulant). There was a coagulant buildup when the test was run with coagulant and the headloss values dropped when the test was run without coagulant at the 40th minute

Figure12 shows that the headloss values didnot reduce to the initial values on passing water of 0.6mL/s after the coagulant buildup. Figure 13 shows that even for 1.3mL/s, the headloss value did not reduce to the intial value on passing water of 1.3mL/s. Thus, from graphs 12 and 13 it can be concluded that as the flow rates increases, the amount of nanocluster detachment also increases.

The team also conducted ramp tests to determine the headloss flow relationship and see how headloss varies with flow for different flow rates. It was found using the mathcad design equations that for a flow upto 1.0ml/s for the given conditions , the flow is in the laminar range and beyond that the headloss goes to the turbulent range. However the ramp tests conducted did not confirm our results. The team anticipate that there could be minor losses in the flocculator tube due to bends. Figure 14 shows that the graph is approximately linear for a flow upto 1.0ml/s confirming that it is linear and obeys Hagen Poiseuilles equation for lower flow ranges.

The team then compared the ramp test results with the values obtained from Hagen Pouiselle equation to check the accuracy of the values obtained from the experiments. Figures 15 and 16 show that the values obtained from experiments are approximately 2m less than the theoretical values. This could mean that the pipe diameter was not the same as we assumed.

The team figured out that the actual diameter of the flocculator used was smaller than the one used in the calculations, so the team decided to build a new one with a known diameter (larger than the previous one). However, team decided to retain the results from the first flocculator to compare the variation in headloss accumulation with the change in the size of the flocculator.

With the new flocculator, team repeated the tests for those flow rates used in the previous flocculator. It was found that, the headloss accumulation was

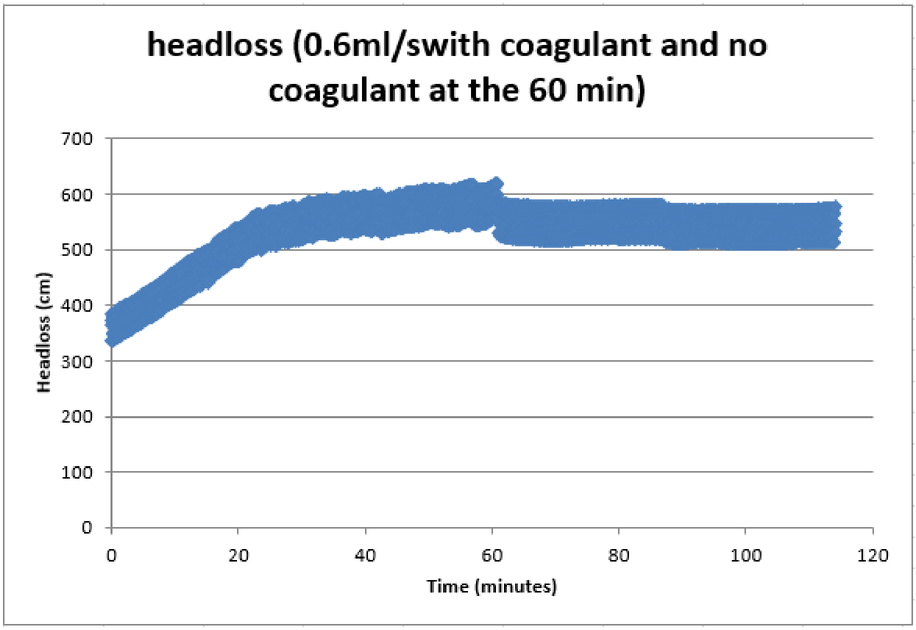

Figure 13: Headloss vs time-0.6 mL/s (water and coagulant state for 60 minutes and then water alone to examine how the coagulant built up detaches from the flocculator walls.)

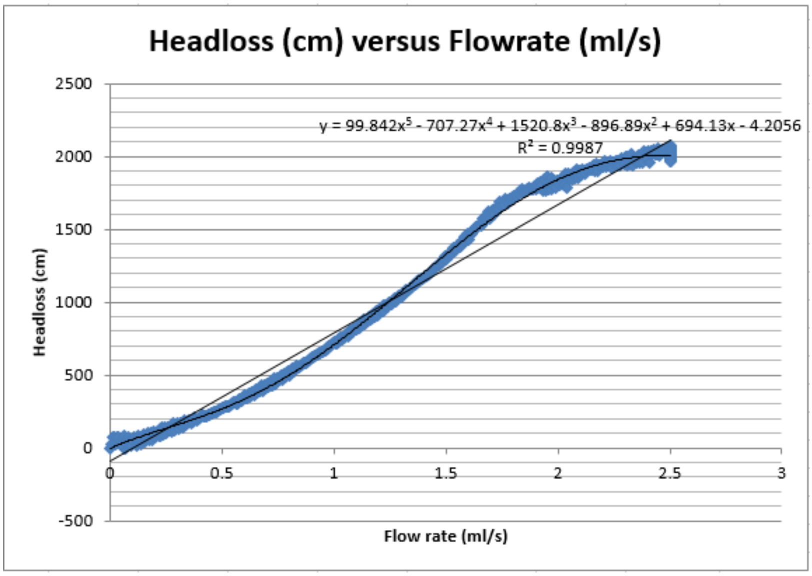

Figure 14: Headloss vs Flow rate(ml/s)- Flow rate gradually increased from 0ml/s to 2.5ml/s in 15 minutes

not significant as in the previous case where the diameter of the flocculator was small. Therefore, the team decided to choose a flow rate of 0.6mL/s for the

	Experimental values			
	Polynomial fitting	Linear fitting		
Flow rate (Q,mL/s)	Headloss ,m	Headloss,m	Theoretical headloss values,m	Difference
1	6.54	6.98	9.60	3.06
1.5	12.25	10.47	14.40	2.15
0.6	3.21	4.19	5.76	2.55
1.6	13.60	11.17	15.36	1.77

Figure 15: Comparison between results obtained with Hagen Poisuelle equation and lab experiments.Polynomial and linear shows the value of headloss obtained on polynomial and linear fitting of the experimental curve.

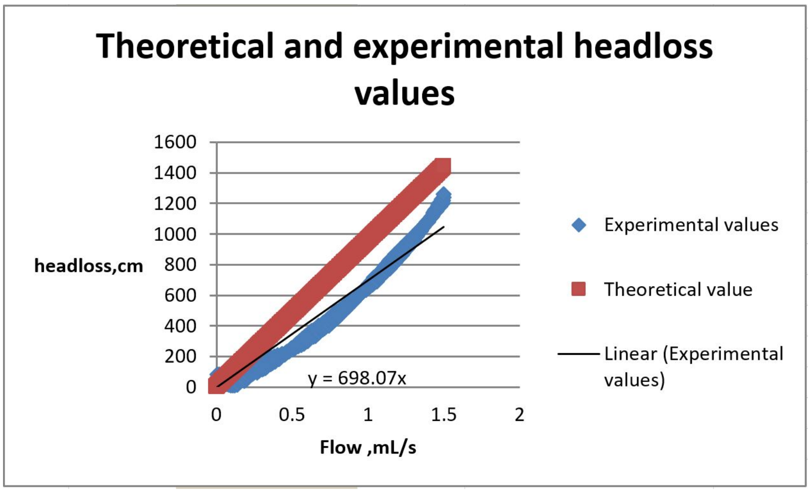

Figure 16: Comparison between Hagen-Pouiselle results (red line) and experimental results (blue line)

future trials, as at 0.6mL/s flow rate, there was significant headloss accumulation ,in other words coagulant buildup. Also team decided to increase the coagulant flowrate to 0.05mL/s (from 0.03mL/s) to get more pronounced coagulant buildup. Team then built a contact chamber and performed tests with and without contact chamber to see what effect contact chambers can bring in the headloss values. Tests were run with 0.6mL/s (with and without contact chamber). Figures 17 and 18 show the results obtained.

Team introduced water with turbidity of 50NTU on a flocculator which had coagulant built up on its walls, but it was found that the clay was able to remove almost all of the coagulant causing the headloss to drop to the initial value. Refer 19

The team then introduced the contact chamber to examine the difference in headloss values. Two tests with different water turbidities (50NTU and 5NTU) were tried. It was found that there was no coagulant buildup for 50 NTU in

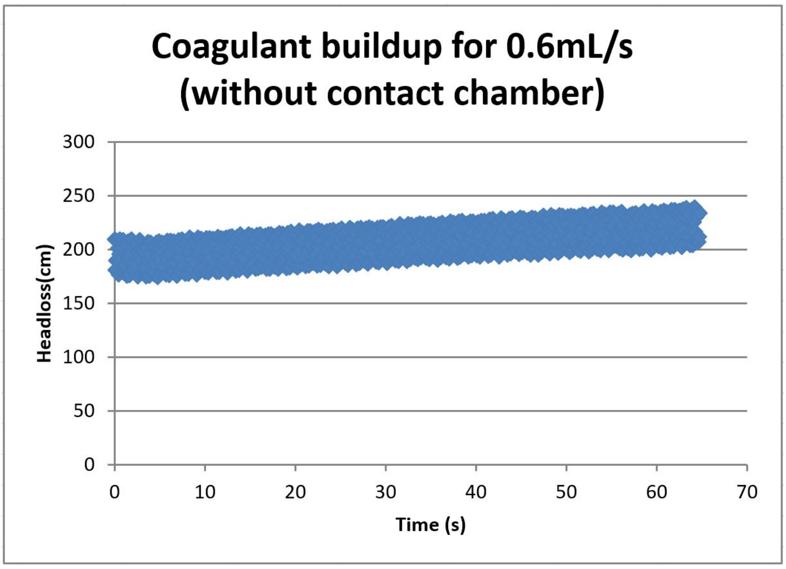

Figure 17: Coagulant buildup for 0.6mL/s. No clay added. This test was run without the contact chamber unit in the system

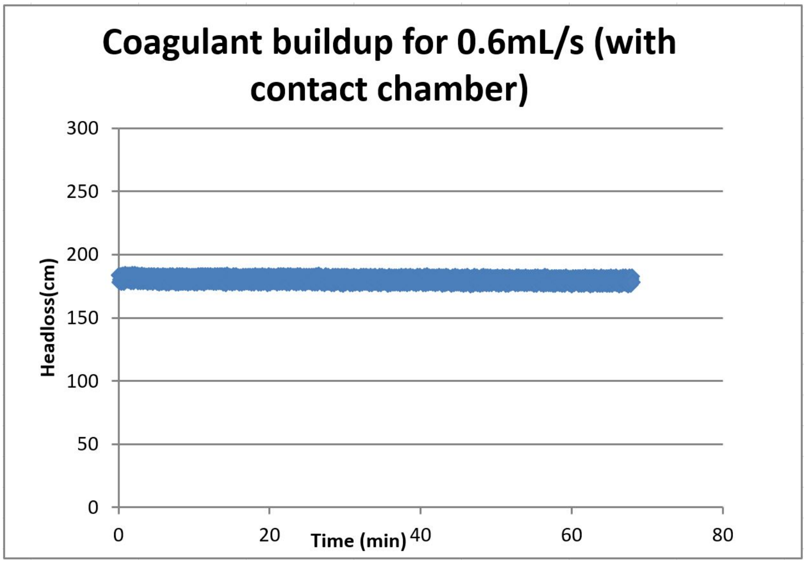

Figure 18: Coagulant buildup for 0.6mL/s. No clay added. This test was run with the contact chamber unit in the system

both the cases when tested with and without contact chamber,indicating that there was no significant difference in the headloss values observed on adding the contact chamber. Refer 20 and 21

Thus the team did not obtain any concluding results from high turbid water (50NTU), as there was no headloss accumulation even without using contact chamber. Therefore, the team then tried a test with lower turbidity (5NTU).But

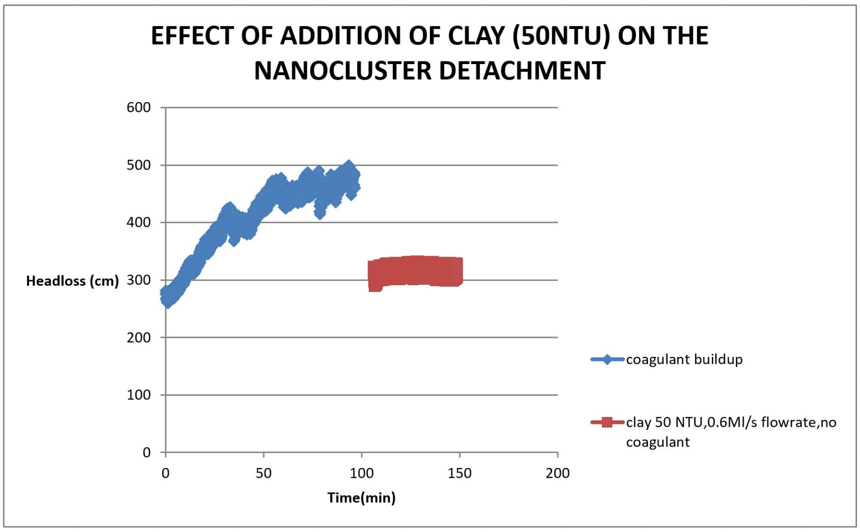

Figure 19: Effect of the addition of clay (50NTU,0.6mL/s flow rate) in the headloss values in the flocculator after the coagulant (0.051mL/s) buildup. The headloss values decreased (equal to the intial value) in a very short time,after the clay was added.

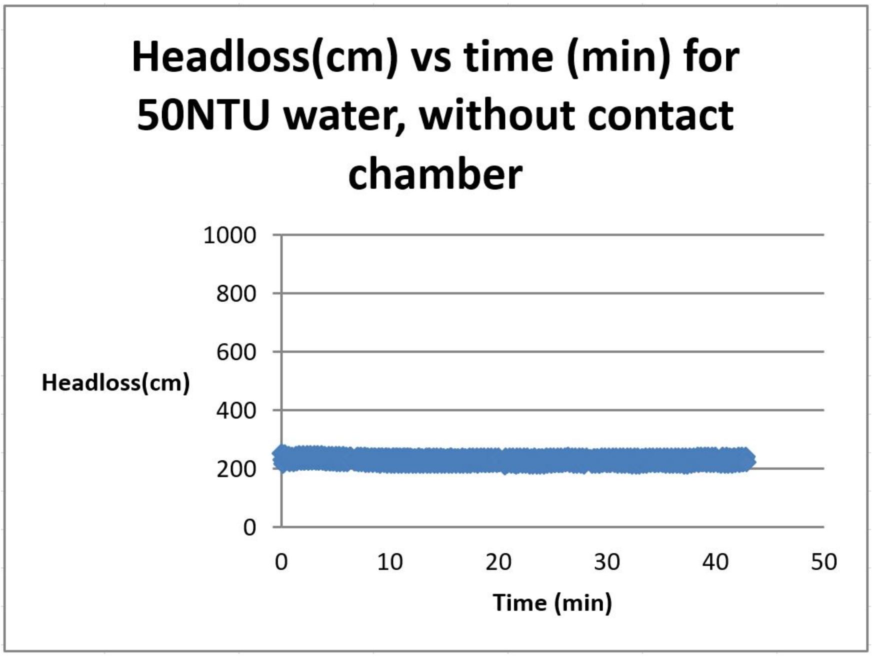

Figure 20: The figure shows the headloss versus time trend for a 0.6mL/s flow of water with 50NTU turbidity, a coagulant flow rate of 0.06mL/s and without contact chamber. The graph shows that there is no coagulant buildup when turbid water is passed through the flocculator.

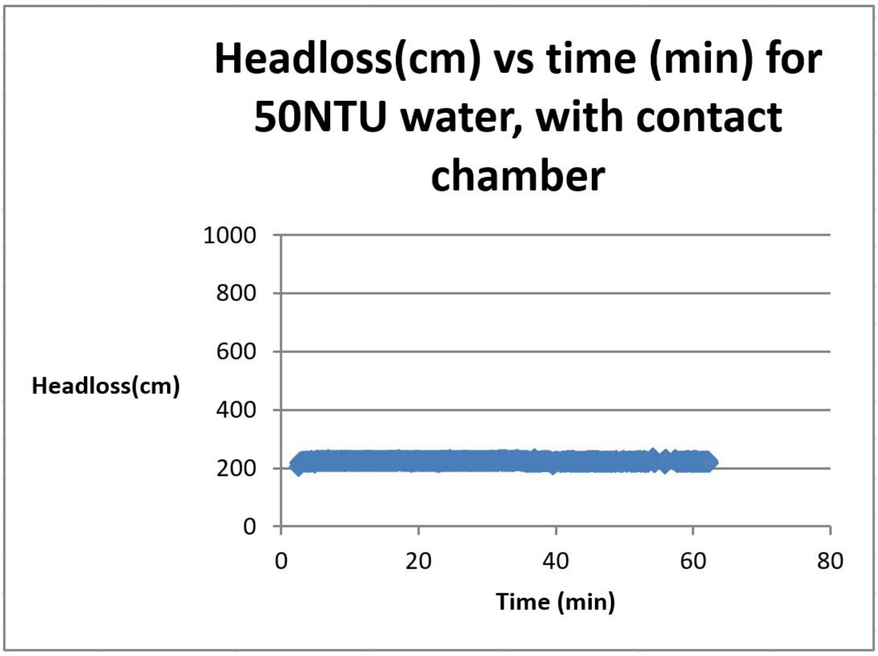

Figure 21: The figure shows the headloss versus time trend for a 0.6mL/s flow of water with 50NTU turbidity, a coagulant flow rate of 0.06mL/s and with contact chamber. Addition of contact chamber didnot cause any change in the headloss values.

the results obtained were the same. These results from our tests showed that for a straight flocculator and for the dimension we used, the contact chamber is not necessary as the clay was able to remove the coagulant nanoclusters attached to the flocculator. All the results found by the team are summarized in the conclusions section

Conclusions

There is a significant increase in the headloss when the experiment is run with water and coagulant compared to water alone. From this, it can be concluded that coagulant loss onto the walls is reducing the diameter and thereby causing the increase in headloss. Headloss decreases as flow rate increases. The difference in headloss is more for a flow of 0.8 mL/s compared to the headloss differences for 2.0 mL/s. It can be concluded that at higher flow rates, there is no coagulant buildup on the tube walls. This likely happens because the higher flow rates have a velocity gradient high enough that the torque produced is enough to not allow coagulant to stick to the surface of the flocculator's tube walls.

The coagulant that is built up on the walls detaches due to wallshear and not due to the dissolution of coagulants. Except for flows higher than 1.6, the shear is only able to shear off some of the built up coagulant (the headloss values after the buildup and then on flowing water soon after did not reduce to the initial value of headloss). For lower flow values, flocculator has laminar flow and obeys Hagen Poiseuilles equation and the flow goes to turbulent range for flows more than 1.3ml/s.

It was found that with a higher coagulant dose, the headloss accumulates higher before leveling off. This is an indication that the shear rate applied is not a property of the coagulant. If it was, the headloss accumulated should not increase as the flow rate, and thus shear rate, was kept the same at the different coagulant doses.

After building up coagulant and then running clay alone, it was also seen that the addition of clay into the flocculator immediately reduced the accumulated headloss all the way. This shows that the binding between clay and the coagulant does overcome the coagulant's attachment to the wall, which could lead into some insight when it comes to cleaning the flocculator.

Lastly, while the effects of clay and coagulant can be seen when they are run independently, this flocculator design did not show any headloss accumulation when clay and coagulant were run together.

Future Work

When the team ran the system with clay and coagulant together for the second flocculator of diameter 0.042inches, there was no headloss buildup in the flocculator in any case. The team also observed that using a higher diameter flocculator, the coagulant buildup decreased and took more time than using the lower diameter flocculator. With this in mind, the next team could try to design a flocculator which achieves a significant headloss accumulation when coagulant is added with and without clay. One different design could be a smaller diameter flocculator, or possibly a coiled flocculator instead of a straight tube.

When the rapid mix chamber was added, there was no headloss accumulated in the higher diameter flocculator even with zero turbidity water. The same experiments should be repeated with a smaller diameter flocculator to study the effect of contact chamber. In the future, the next team should try to study what happens within the contact chamber itself rather than the flocculator. One possible way could be to measure the headloss across the contact chamber, as perhaps the coagulant is building up in the chamber instead of the flocculator.

Once the next team has a flocculator that can achieve a headloss accumulation, it can experiment with different water turbidities.

Explore different shapes of contact chamber once the team has a flocculator which allows nanocluster accumulation, focusing on the improvement of the efficiency of the overall system. It is also a good idea to explore if the point of injection of coagulant varies the results and study the effects of it.

From the tests conducted, the team concluded that bigger diameter flocculators had lesser headloss accumulation, in other words lesser nanocluster attachment. Thus it is also a good idea to explore further on the coagulant attachment properties. Introduction of clay in the tests showed that the clay detaches the coagulant nanoclusters from the walls of the flocculator. This calls for further research on the effects of turbidity on the nanocluster detachment.

References

AguaClara RMCC (2016). AguaClara Rapid Mix Contact Chamber Team Final Report Spring 2016.

Vrale, L. and Jorden, R. (2016). Rapid Mix in Water Treatment.

Weber-Shirk, Monroe (2015). Coagulation and Rapid Mix: A search for a basis for rational design.

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World Health Organization (2012). Coagulation, flocculation and clarification.

Appendix A - ProCoDA Method

There were four main states used in ProCoDA:

- OFF: This state turns of all pumps
- ON: This state turns on only the water pump at the desired flow rate
- Coagulant Water: This state turns both the water and coagulant pumps at the constant flow rate set for each one
- Ramp Water: This state was used for running a test that ramps up the flow rate over time. The range of flow rates used was 0 to 2.5 mL/s. And for a time of 15 minutes was used.At the zeroth time ,it had a flow rate of 0mL/s and it reached a flow rate of 2.5 mL/s at the end of 15 minutes.

The states used were all constant aside from the state for each pump:

- Water pump: This variable state takes in the constants to run the water pump
- Flow rate 1: This is the flow for the water pump, it is a constant but it is changed every time the team wants to try a different flow rate. This flow rate is usually between 0.1 ml/s and 2.6 ml/s.
- Tubing size 1: This is the tube size for the water pump, it is set to 17
- Coagulant pump: This is the variable state that takes in the constants for the coagulant pump
- Flow rate 2: The flow rate for the coagulant pump, it was calculated to be 3.3 x $10^{-3} \frac{mL}{s}$
- Coagulant mL/rev: This is the constant needed for the yellow-blue tube size, it was calculated to be 0.202 mL/rev
- Water ramp pump: This variable state controls the water pump the same way it is controlled for the Water Pump state, except it takes in a variable flow rate instead of constant
- Ramp: This is the state used instead of Flow Rate 1 which gives a changing flow rate, it receives three states for initial, final, and time
- Initial value: The initial flow rate for ramp
- Final value: The final flow rate for ramp
- Ramp time: The amount of time over which the flow rate changes from the initial to final
- Ramp tubing ID: The tubing size received by Water Ramp Pump. It is also 17.

Appendix B - Procedure for Measuring Headloss

1. Disconnect the coagulant tube from the injection point right before the flocculator, place a plug in its place instead
2. Make sure the pump heads are closed and secure.
3. Release the valve allowing tap water to come into the system.
4. Open ProCoDA and set the water flow rate, state Flow Rate 1, to the desired flow rate for testing.
5. Zero the headloss currently being measured by the pressure sensor.
6. Switch ProCoDA into the ON state.
7. Immediately switch open the valve for the waste water tube. This is only done after switching the water pump on because otherwise some waste water tends to flow into the system.
8. Allow water to flow for the desired amount of time.
9. Switch ProCoDA back into the OFF state.
10. Remove the plug at the coagulant injection site and insert the coagulant tube.
11. Switch ProCoDA into the Coagulant Water state.
12. Let the system flow for as long as needed.
13. Switch ProCoDA back into the OFF state

Semester Schedule

Task Map

Task List

1. Set up Apparatus: Completed (9/19/2016) - Joao Carlos Moraes. Rebuild previous semester's apparatus. However, take into account the parameters we plan to test and tweak the design accordingly. We used the data from the previous design available as a MathCAD file on the Google Drive.
2. Test the properties of the coagulant (to create a scalable design algorithm): (3/10/2016) - Javier Escanciano. Vary the flow rates of the coagulant and perform tests to determine the head loss accumulation and determine what affects the detachment of coagulant nano clusters (shear/solubility)
3. Try different flocculators to find the difference in nanocluster attachment (17/10/2016) - Mythri Krishnamoorthysujatha. Determine the difference in the attachment properties of nano clusters based on flocculator properties (Changes in diameter).

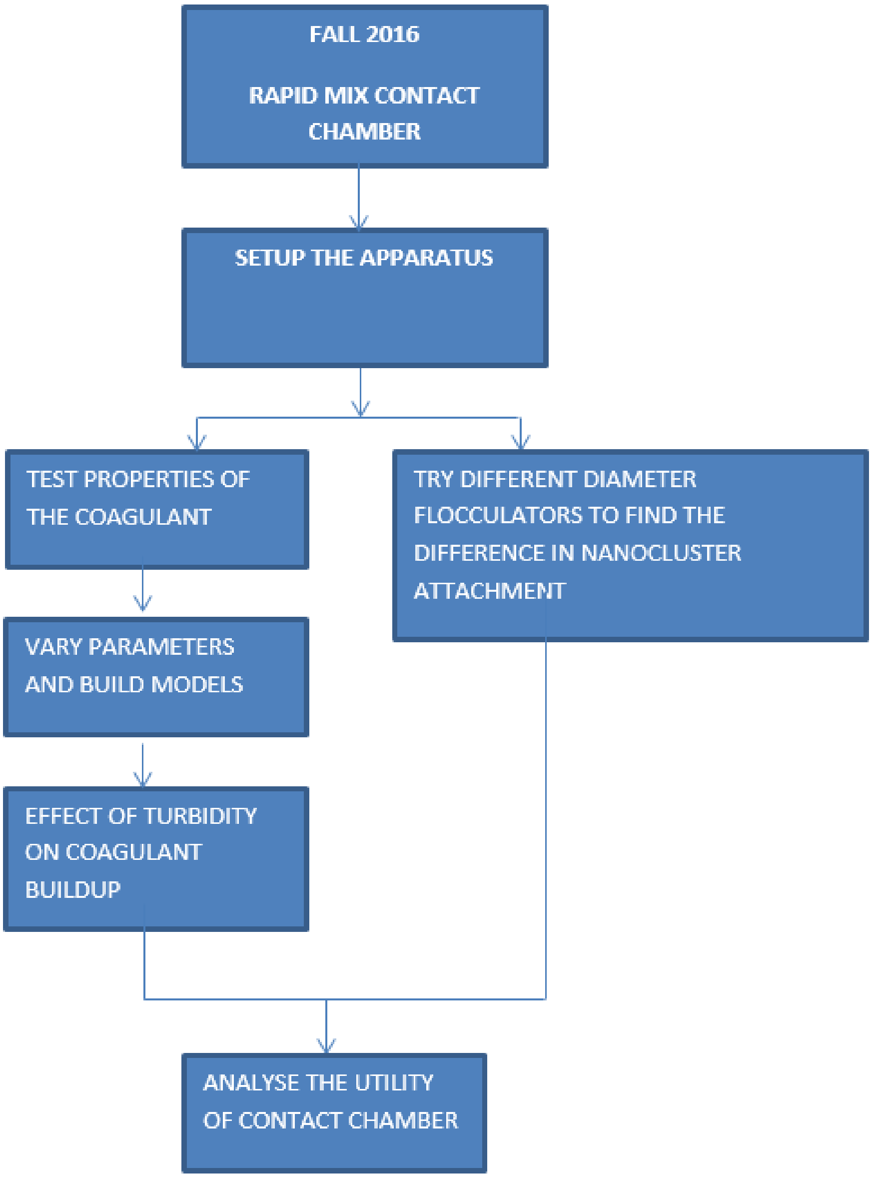

Figure 22: Fall 2016 Task Map

4. Vary Parameters and Build Models: (31/10/2016) - Mythri Krishnamoorthysujatha. With the different flow rates and headloss accumulations, build a model to decribe how much the coagulant is build up in the flocculator.

5. Effect of turbidity on coagulant buildup: (7/11/2016) - Javier Escanciano.

Run tests with different NTU solutions with and without contact chamber.

6. Analyze the utility of contact chamber: (21/11/2016) - Joao Carlos Moraes. Determine the utility of contact chamber by performing the tests with and without the contact chamber using the coagulant properties that we find.

Report Proofreader: Mythri Krishnamoorthysujatha