Countercurrent Stacked Floc Blanket Reactor, Spring 2016

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Abstract

Floc blankets, which are suspended layers of highly concentrated flocs, have the potential of being a more efficient option for removing arsenic, fluoride, and certain dyes in terms of energy and water consumption than currently employed techniques. For floc formation, a coagulant needs to be added to the water, allowing particles to adsorb to each other when they collide. Previous research has shown that the coagulant, polyaluminum chloride (PACl), has properties that allow arsenic, fluoride, and certain dyes to adsorb to its surface. The first iteration of this research used three floc blankets in series with a counter-current flow of contaminated water and flocs. By feeding flocs from the last reactor into the second, and from the second into the first, the PACl's surface area can be saturated. To test this theory and apparatus, a dye, Remazol Brilliant Blue R (RBBR), was chosen to be the contaminant due to its less toxic nature and visual component. With this apparatus and contaminant, this semester's goals were to test dye removal efficiency from water with varying concentrations of clay, PACl, and dye. With a 1:1 ratio of PACl to dye, a dye removal efficiency of roughly 80% was achieved. However, the transportation of flocs from the third reactor to the second and first was not sustainably achieved.

Introduction

Arsenic and fluoride are naturally occurring elements found in rock and soil that are toxic in their inorganic form. In many parts of the world, people are exposed to elevated levels of these contaminants through groundwater. Long-term exposure to arsenic and fluoride can lead to organ failure with internal hemorrhaging, and calcification of ligaments, respectively Choubisa and Choubisa (2016). Presence of these inorganic contaminants in water, therefore, is a major health concern for communities around the world. These carcinogenic elements are known to contaminate groundwater sources in countries such as India, Bangladesh, Vietnam, and Argentina, and exposure to those compounds ultimately decrease living standards and increase mortality rates. Figure 1 and Figure 2 illustrate areas of fluoride and arsenic contamination around the world .

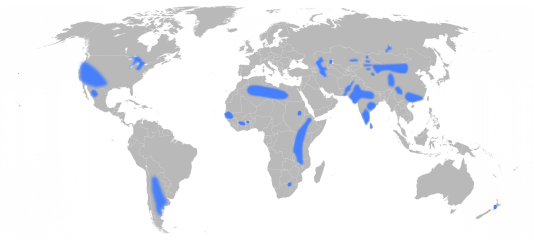


Figure 1: Groundwater fluoride contamination areas Yeung (2008).

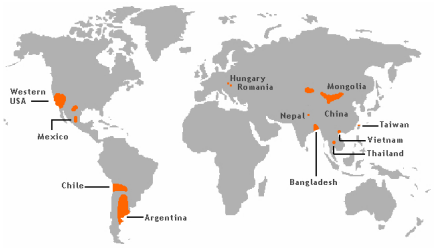


Figure 2: Groundwater arsenic contamination areas.

Another rising problem with water quality is textile dye contamination. Untreated dyes cause chemical and biological damage in aquatic systems, which threaten species of fish and aquatic plants. Furthermore, if untreated and ingested, synthetic dyes are known to be carcinogens and hormone disruptors. Figure 3 illustrates the extent of textile dye contamination.

Figure 3: Industrial dye contamination in the waterway of the Wenzhou province in China.

Sand bed filters are an example of a granular, loose media depth filter that can be used to treat water contaminated with dye, arsenic, and fluoride. These filters can be loaded with a coagulant, such as PACl, and the pollutants can adsorb to the coagulant to form flocs. Unfortunately, these sand filters quickly

become clogged after a period in use and require backwashing, an approach that uses large amounts of potable water and also disrupts the treatment process. Taking these consequences into consideration, a new treatment design was proposed. Instead of using a sand filter, the AguaClara team is researching methods of removing contaminants with floc blankets. The PACl and contaminated water are sent into a flocculator which creates flocs. These flocs then enter a treatment reactor where they become more dense as more chemical contaminants are adsorbed. As density increases, the flocs settle and eventually create an area of suspended, concentrated flocs, a floc blanket. This blanket builds and eventually spills over a floc weir, where they can be transported to the next reactor, or removed. This proposed treatment process is continuous and would not require backwashing. Ultimately, the amount of PACl used and water wasted would both be minimized in the new design. The aim for this process is to maximize the PACl surface area utilization, thereby extracting as much chemicals from the water as possible with the amount of PACl added.

The two teams that are investigating this removal process are the Fluoride Filter team and the Countercurrent Stacked Floc Blanket Reactor (CSFBR) team. The Fluoride Filter team will be experimenting this theory while removing fluoride from water, but with one reactor instead of three, and no countercurrent flow of water and flocs. The CSFBR team will be experimenting this theory while removing RBBR from water, but with three reactors, and countercurrent flow of water and flocs. For comparison, the single reactor for the Fluoride Filter team will be the aggregated height of the three reactors for the CSFBR team. The purpose of having two different apparatuses for testing the same theory is to see if PACl's surface area becomes saturated (or near saturated) after one floc blanket, or if it still has significant surface area available for adsorption after one floc blanket.

Literature Review

Various pieces of literature have been referenced to understand the properties of dye in the presence of PACl. One of the key pieces of work that has been referenced is the the study done by Nourmoradi et al. (2016) and his team on the adsorption of RBBR dye from water by PACl. This study specifically looked at the properties of RBBR dye and its removal efficiency based on different concentrations. The characterized RBBR by its UV-visible light spectrum and determined that the λ max was 663 nm, which corresponds to a red wavelength. Hence, this information demonstrated the effectiveness of using a red LED light within the photometer to pick up traces of the RBBR dye during experimentation. The literature also discussed testing 100 $\frac{mg}{L}$ of dye in various concentrations of PACl. The results are summarized in Figure 3. As the concentration of PACl increases, so does the percent removal of dye. The results from this experiment were used as a basis for experimentation. Furthermore, RBBR was chosen as a testing agent in the experiment.

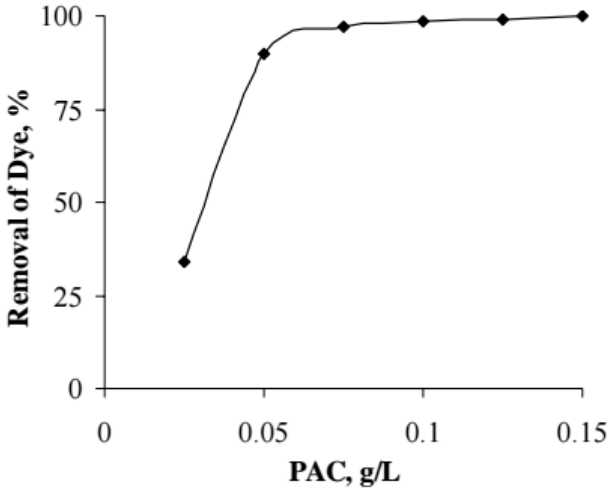


Figure 4: The percent removal of blue dye versus the concentration of PACl for a given influent dye concentration of 40 $\frac{mg}{L}$.

Other pieces of literature referenced include looking at various dyes to experiment with in the future. A study was conducted by Kang et al. (2003). to test the efficiency of removal for different types of dyes with PACl. The highest efficiency was observed with the turquoise DG dye, which resulted in a PACl concentration drop from 95.4 $\frac{mg}{dm^3}$ to 0.6 $\frac{mg}{dm^3}$. The lowest reaction efficiency was observed for the red DB-8 dye, which decreased the concentration from 107 $\frac{mg}{dm^3}$ to 35.9 $\frac{mg}{dm^3}$. This experiment further solidified the decision to experiment with blue dye.

Another cited literature was from Zonoozi et al. (2009), which examined the effect of different concentrations of PACl on the removal of arsenic and fluoride in groundwater. A treatment line consisted of acidification (to pH 6.4–6.6), followed by the addition of PACl (doses of 100 to 125 $\frac{mg}{L}$), then alkalinization (to pH 7.2–7.6) and finally rapid filtration, was tested. In raw water, arsenic and fluoride concentrations ranged from 70 to 90 μg/L and from 2.8 to 3.1 $\frac{mg}{L}$, respectively. This treatment process allowed arsenic and fluoride to be jointly removed, and efficiency achieved ranged from 75 % to 85 % for arsenic and 50 % to 55 % for fluoride. Arsenic concentrations in treated water were 20 μg/L and fluoride concentrations remained at 1.3 $\frac{mg}{L}$ to 1.7 $\frac{mg}{L}$. These results from the experimental process allow for future modifications and removal processes on the CSFBR experiment.

Previous Work

Fall 2015

Theoretical Flow

In Fall 2015, the schematic for the reactors in series was finalized. The final layout is illustrated in Figure 5.

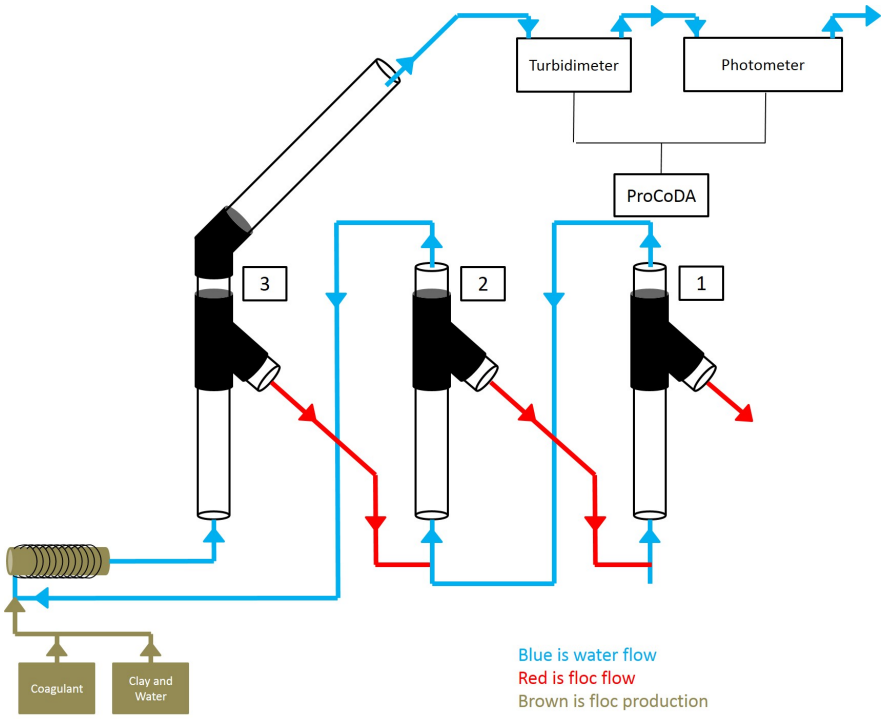


Figure 5: Schematic of final setup.

In theory, the goal of the reactors is for flocs and water to flow separately and in opposite directions. PACl enters Reactor 3. The coagulant binds with chemical particles such as arsenic and fluoride (or dye, as done in the experiment) and flocs are formed. The small, flaky flocs begin to aggregate and increase in density, thus settling to the bottom and recirculating with the jet in Reactor 3 to form a floc blanket. When the floc blanket gets high enough, the flocs spill over the weir. Ultimately, flocs and PACl are sent (pumped) to the feed stream of the second reactor. The process repeats where the PACl coagulates with chemicals in the water and the floc blanket builds. Finally, PACl and flocs from the second reactor get pumped into the first reactor. Again, the process repeats once more. The flocs should accumulate in Reactor 1, where they will be drained into a waste stream. In this design, the dirtiest water enters through Reactor 1 and through the coagulation and flocculation process, chemical contaminants are removed, and the cleanest water exits at the top of Reactor 3. The outlet stream is analyzed with a photometer and turbidimeter.

The steps leading up to the construction of the reactor were determining the design and calculating flow rates, residence times, and concentrations.

Weir Design

The following considerations were discussed when planning the design and placement of the weir: re-suspension of flocs in the reactor, floc break-up, and water flow between reactors.

Because the aim was to get a physical split between the flocs and water within

each reactor, the flocs had to be maintained at a constant height. Furthermore, this height must not be too close to the reactor exit. This will reduce the amount of flocs in each reactor's effluent.

Based on these considerations, a weir was installed at approximately 70% of the reactor height. At this level, the floc blanket would have enough space to develop and collect, while still being far enough from the reactor top to not flow out with the water effluent. A 1 inch wye fitting was used as a weir for each reactor. Lastly, a small, clear section of pipe was added to the top of each reactor to increase visibility of the reactor's effluent for observations during experimentation.

Flocculator Design

The purpose of the flocculator was to encourage mixing and increase particle collisions so that sizable flocs can be created and enter the reactor. The design was determined by using the principles of velocity gradients G and the dimensionless mixing parameter Gθ The θ goal, residence time, was determined to be 29.502 min. Using the relationship:

$$L = \frac{\theta_{goalQ}}{A * D}$$

where L is the length of the tubing, A is the cross sectional area, and D is the diameter. The total length of the tubing for the flocculator was determined to be 45.845 ft. The length of the flocculator body,as shown in Figure 5, was determined to be 1.09 ft. Finally, the tubing diameter was set to quarter inch, in order to prevent flocs from settling at the bottom of the coils.

Turbidimeter and Photometer

Towards the end of the Fall 2015 semester, a turbidimeter and photometer were incorporated into the design apparatus. The purpose of the turbidimeter was to record the amount of particles (clay and flocs) in the effluent. The purpose of the photometer was to record dye concentrations in the effluent. ProCoDA was used to calibrate the photometer and monitor the concentrations of dye digitally.

Experimentation with Blue Dye

RBBR was used as a testing agent in the experiment. After purchasing the RBBD, the photometer was modified to account for the wavelength. The photometer was created to record red dye, which corresponded to a blue LED light. With the switch to blue dye, the LED light was switched to red in order to obtain reliable absorbance data (a wavelength around 630 nm is required) (See Figure6 for determining optimal wavelength absorbance).

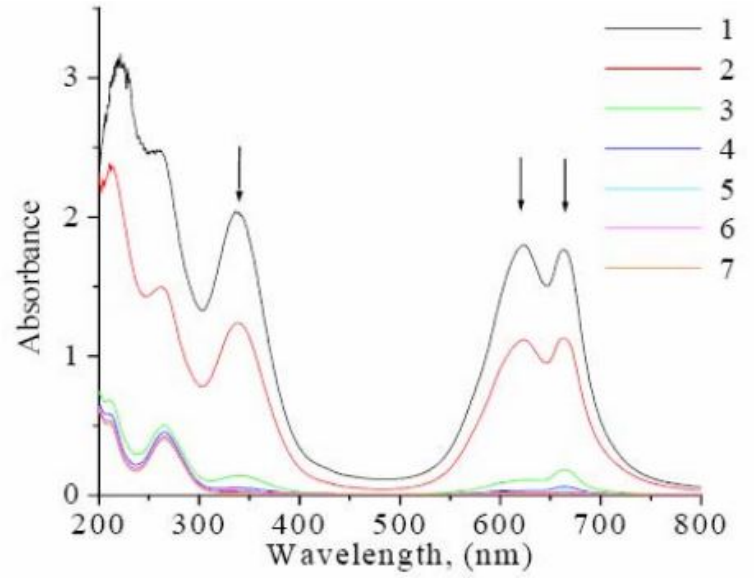
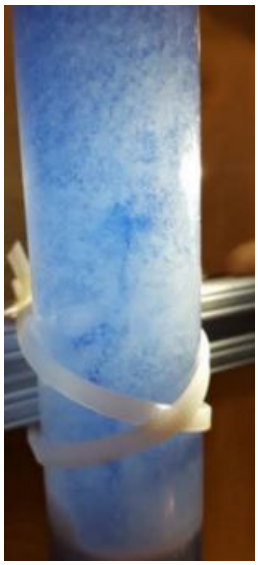


Figure 6: UV visible spectrum showing absorbance of RBBD of PACl at various (1 - 7) concentrations $\frac{g}{L}$.

Once the LED light was implemented, calibrations were created for the blue dye concentrations and absorbency. The concentrations were 80, 40, 20, 10, and 5 $\frac{mg}{L}$. Once the calibration data was obtained, the dye was tested.

The stock concentration of dye was 500 $\frac{mg}{L}$. Initially, when the feed entered Reactor 1, thin streams of blue dye were observed. The dye did not overall diffuse throughout the reactor immediately. Instead, the color was first concentrated within the floc blankets. As this happened, the water within top section of the reactor (where the floc blanket was not present) remained clear. Initial results are depicted within Figures 7a and 7b.



(a) The initial result after introducing the reactor with the dye feedstock. The blue dye was concentrated within the floc blanket.

(b) While the initial result in Figure 5a was occurring within the floc blanket, the top part of Reactor 1 remained relatively clear of blue dye.

However, after a short amount of time, the blue dye left the concentrated floc blanket region and began to enter the rest of the reactor. This process of the dye first saturating the floc blanket and then seeping into the rest of the reactor was observed for all the reactors. The final result was a series of three reactors that all appeared saturated with the blue dye (Figure 6). Figure 7 illustrates shows the concentration of dye in the effluent consistently increasing until the extra PACl was added to Reactor 3 at 6 pm. Unfortunately, the bottle that contained the extra PACl fell and created the disturbance at the end of the graph.

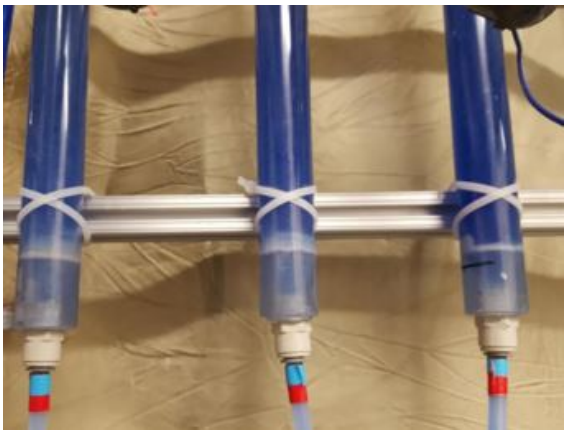


Figure 8: The dye appeared saturated in all 3 of the reactors, indicating that the PACl did not effectively adsorb the dye.

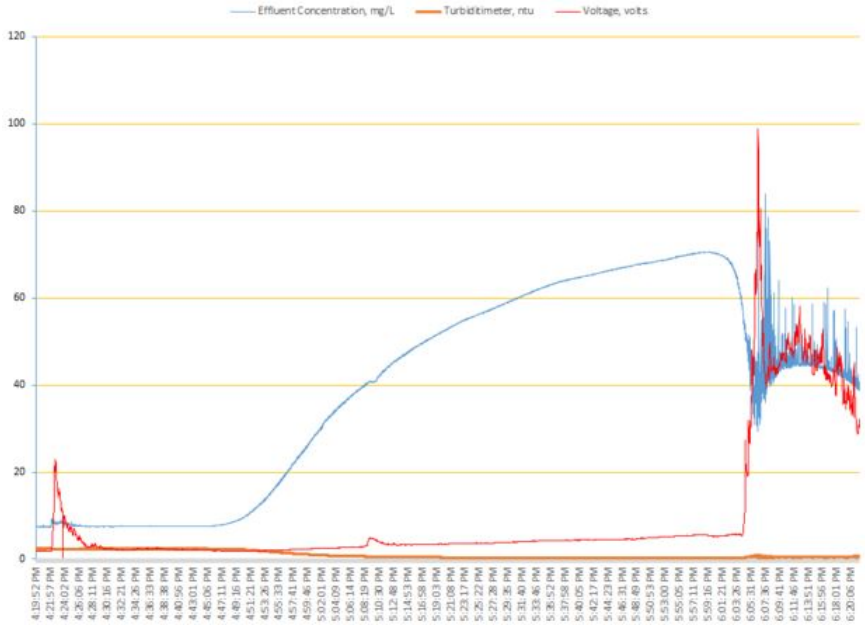


Figure 9: Graph of effluent dye concentration.

It speculated that the reason the dye was not effectively adsorbed onto the PACl was because the ratio of PACl to dye within the reactor was too low. It was estimated that the concentration of PACl into the reactor was approximately 1 $\frac{mg}{L}$, compared to the 500 $\frac{mg}{L}$ of dye feeding into the reactor. From literature, effective dye removal occurred when the PACl concentration was approximately 50 $\frac{mg}{L}$ and the dye concentration was 40 $\frac{mg}{L}$, as illustrated in Figure 19. Thus, the concentration of PACl was increased. A new inlet was created, which directly sent 2.6 g/L of PACl into the 3rd reactor. The purpose of this inlet was to maintain the concentration of PACl in the third reactor to enable efficient removal of dye and thereby lead to a visible reduction in the intensity as reflected by the photometer. Future tests and observations are planned for the Spring semester of 2016.

Methods and Discussion for Spring 2016

ProCoDA Calibration

For the spring semester of 2016, ProCoDA was used for data collection and analysis. The photometer can only take voltage readings based on the amount of light that passes through the sample of effluent. ProCoDA takes these voltage readings, and calculates an absorbance based on the following relationship:

$$Absorbance = -log\frac{V_{sample} - V_{dark}}{V_{blank} - V_{dark}}$$

where V_{sample} is the voltage reading from the sample of effluent and V_{dark} is the voltage reading when the voltage sensor is completely covered. Once the

absorbance is determined, ProCoDA converts absorbance to dye concentration, based on a calibration curve. The calibration curve was created by placing dye stock concentrations of 0 $\frac{mg}{L}$, 2 $\frac{mg}{L}$, 5 $\frac{mg}{L}$, 10 $\frac{mg}{L}$, 20 $\frac{mg}{L}$, and 50 $\frac{mg}{L}$, and 100 $\frac{mg}{L}$ in the photometer, recording the respective voltage readings, and calculating the respective absorbance readings. Those absorbance readings were then plotted with their respective dye stock concentration. The calibration curve can be seen below in Figure 10.

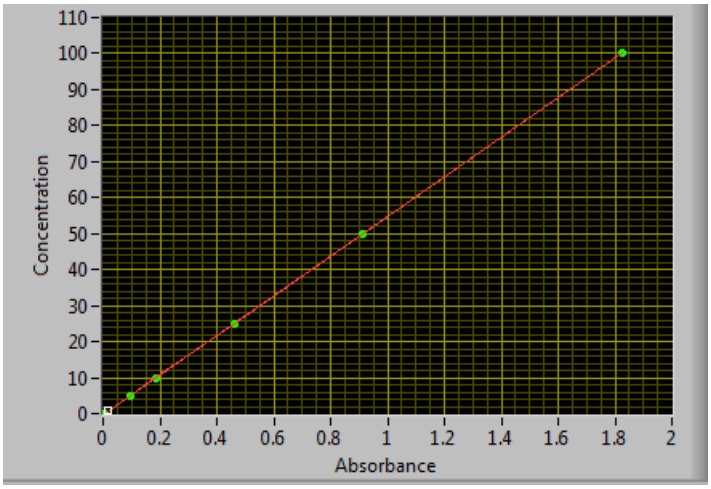


Figure 10: The calibration curve used by ProCoDA to linearly interpolate the relationship of dye concentration and absorbency.

Experimenting with the Jar Test

This semester began with experimenting with dye addition to jar tests. These tests were done in order to observe the adsorption relationship between the concentration of RBBR dye and the concentration of PACl, and the percent removal of dye from water. Various concentrations based on the experimental data in Figure 4 were tested. The goal of these experiments were to see if the literature results were reproducible. The first concentrations tested were 100 $\frac{mg}{L}$ of dye and 75 $\frac{mg}{L}$ of PACl. The solution was mixed for 15 minutes and was allowed to settle for 15 minutes. After the allocated settling time, a sample of the supernatant was extracted to determine the dye removal efficiency.

The photometer calculated the concentration of dye in the supernatant to be 5.56 $\frac{mg}{L}$. With the concentration of 100 $\frac{mg}{L}$ dye and 75 $\frac{mg}{L}$ PACl, there was a 94.44 % removal of dye. This value was slightly lower than expected, as the relationship in Figure 10 showed 75 $\frac{mg}{L}$ PACl corresponding to around 97 %.

In the next jar test, a lower ratio of PACl to dye was tested. The concentration of PACl was modified to 50 $\frac{mg}{L}$ while keeping the dye concentration at 100 $\frac{mg}{L}$. From Figure 4, a 88% removal of dye efficiency was expected. The same procedures were repeated, and the removal efficiency was found to be 44.5%. This result was a much larger deviation from the expected value. It concluded that for future testing, ratios of concentrations of PACl to dye should be approximately 3:4, or higher, for best removal efficiency.

Figure 11 summarizes the results from the jar tests.

Dye [mg/L]	PACl [mg/L]	t = 0 minutes	t = 15 minutes	t = 30 minutes	Top layer concentration [mg/L]	Percent Removal [%]
100	75	Dye added into stirred solution	Deep blue flocs formed. Top (mostly liquid) layer light blue	Very defined separation between liquid and floc layer. Liquid layer looks almost clear when extracting	5.56 mg/L	94.44
100	50	Dye added into stirred solution	Liquid layer is darker than previous trial. Floc formation evident but harder to see	Layers between settled flocs and liquid layer evident but not distinct. Liquid layer has blue tint when extracting	55.50 mg/L	44.5

Figure 11: Results from the first jar test.

Correction Factor

Any amount of turbidity could interfere with the photometer and cause error in the voltage reading. However, the dye within the water did not affect turbidity readings. To adjust for this error in the photometer's voltage readings, a correction factor was incorporated to achieve more accurate data for dye concentrations. Currently, the absorbance reading produced by the photometer consists of the following relationship:

$$A_{photometer} = A_{clay} + A_{PACl} + A_{dye}$$

Clay, PACl, and dye are the three factors that affect the value of absorbance that ProCoDA calculates. The goal of the correction factor was to isolate A_{dye} and remove the interference from A_{Clay} and A_{PACl}.

To do this correction factor, a system was set up to test the absorbency and turbidity of a mixture that received a constant addition of clay over time. The schematic of the experiment is shown in Figure 12.

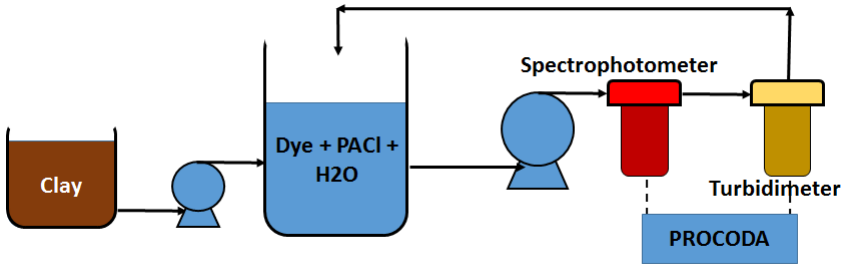


Figure 12: Schematic for determining the influence of PACl and clay on the photometer reading.

In this experiment, various absorbency values were determined along with their corresponding turbidity values. The absorbency values were graphed against the turbidity values to find the linearity between the two sets of values. An R-squared value of 0.9953 was found, and, therefore, the equation for the linear trendline was calculated. The graph can be seen in Figure 13.

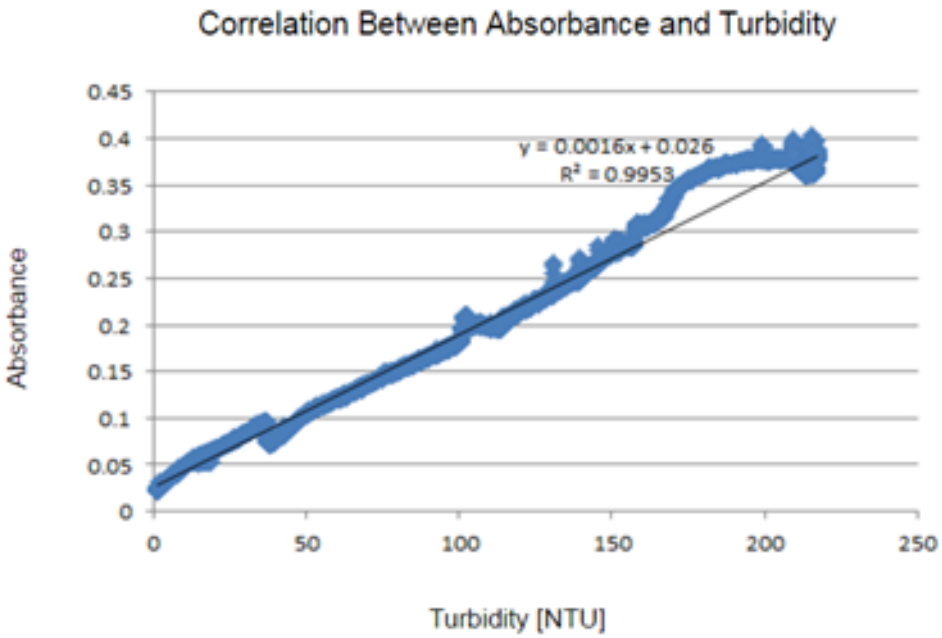


Figure 13: Relationship between absorbance and turbidity.

With this linear relationship, the amount of absorbance interference caused by clay and PACl was able to determined for any given turbidity. This determined absorbance error can be deducted from the total absorbance to arrive at the absorbance caused by only the dye.

Figure 14 below shows a graphical representation of the results from the correction factor throughout an experiment. In the figure, the green line is the concentration of dye that was fed in. The red curve represents the raw data from the photometer, which has clay and PACl interference. After applying the absorbance correction to the raw data, the blue curve was developed. This final blue line demonstrates dye removal from the influent feed.

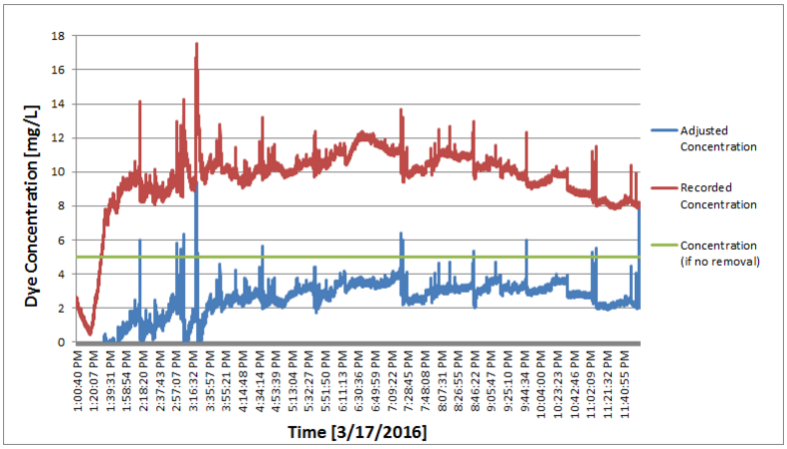


Figure 14: Graphical results illustrating the recorded concentrations of dye in the effluent and adjusted concentrations.

Experiment: March 24, 2016

An experiment was run with a clay stock concentration of 1800 $\frac{mg}{L}$ and a concentration of 25 $\frac{mg}{L}$ for both PACl and dye. The clay, PACl, and dye were pumped at 3.04 $\frac{mL}{min}$, tap water was pumped at 21.282 $\frac{mL}{min}$, and the weirs were pumped at 4.872 $\frac{mL}{min}$. With this stock concentration for PACl and dye, their flow rate, and the system's total flow rate, it was determined that the influent concentration for PACl and dye was 2.5 $\frac{mg}{L}$.

In Figure 15, the data from the experiment has been graphed. Based on the average dye concentration of 0.86 $\frac{mg}{L}$ in the effluent, the average dye removal was 65.78%.

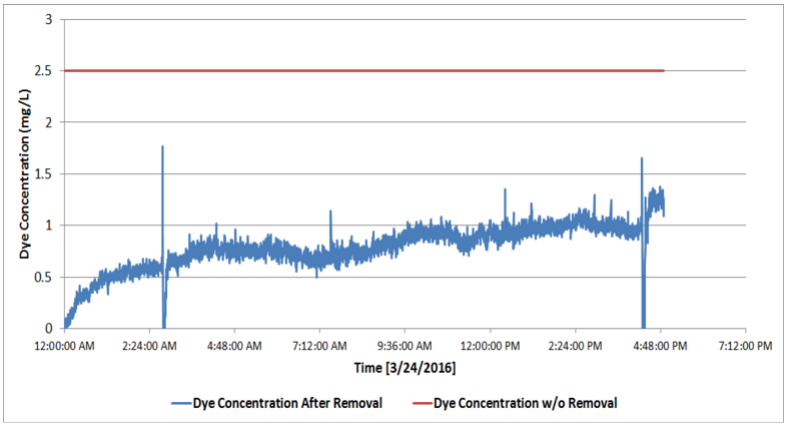


Figure 15: Graphical results for March 24, 2016.

There was successful floc blanket formation in Reactors 3 and 2, but the floc blanket in Reactor 1 was not as dense. There was also a sizable collection of flocs in the weirs of Reactors 3 and 2. In the next experiment, the floc weirs

will be pumped at 5.298 $\frac{mL}{min}$ to prevent floc collection. The average turbidity reading was lower than previous experiments. It was hypothesized that this was due to a lower stock concentration of clay.

Experiment: April 4, 2016

Based on the hypothesis from the experiment run on March 24, 2016, that a decrease in clay stock concentration led to lower average turbidity readings, the team decided to run an experiment in which no clay was added. Also, because a visible difference was desired between the influent dye concentration and the effluent dye concentration, the stock concentration for PACl and dye was increased to 250 $\frac{mg}{L}$, which made the influent concentration for both 25 $\frac{mg}{L}$.

In Figure 16, the data from the experiment has been graphed. Based on the average dye concentration of 4.72 $\frac{mg}{L}$ in the effluent, the average dye removal was 81.11%.

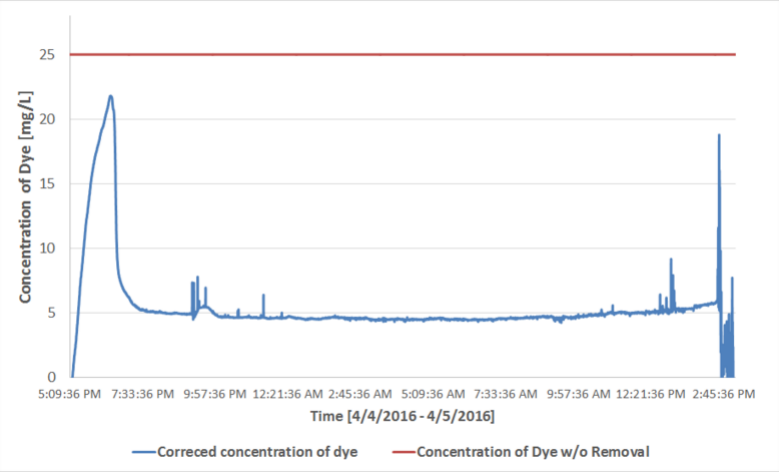


Figure 16: Graphical results for an over night run from April 4, 2016.

Based on these results, it has been hypothesized that clay was acting as a competitor for dye. Both the clay and dye were attempting to adsorb to the PACl. The clay and the dye that was not able to adsorb to the PACl appeared in the effluent of the system. This explains why the average turbidity reading decreased when the clay stock concentration was decreased, and also explains why dye removal increased from 65.78% to 81.11% when the clay was removed.

Experiment: April 25, 2016

To see if the removal performance from Experiment: April 4, 2016 could be repeated, an experiment was run with the same concentrations of PACl and dye, 25 $\frac{mg}{L}$ in the influent, and with no clay.

In Figure 17, the data from the experiment has been graphed. The highest dye removal recorded was approximately 95.2%, but the lowest dye removal recorded was approximately 61.2%.

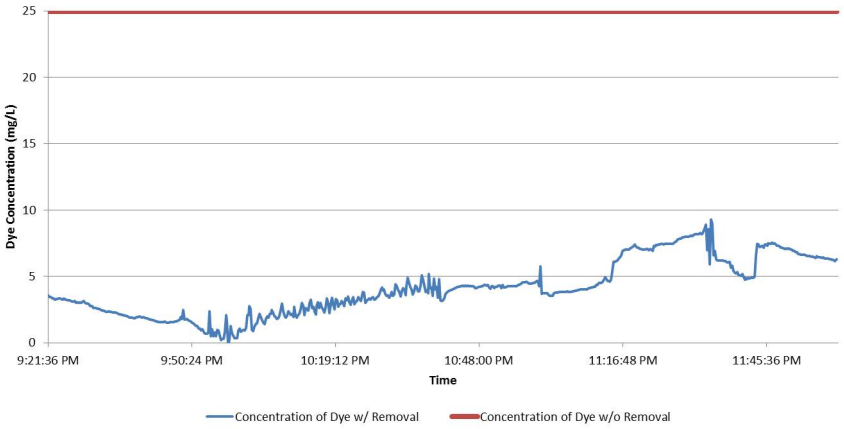


Figure 17: Graphical results from an over night run from April 25, 2016.

As the experiment proceeded, the more dense flocs in Reactor 3 were never re-suspended successfully. They settled in the bottom of the reactor near the jet. This allowed for more flocs to settle leading to sludge formation. Once the section of sludge reached about a third of the reactor's height, the flow of the system began pushing the plug up and out of the reactor and into the tube settler, as shown in Figure 17. This led to the increasingly poor performance in the system.

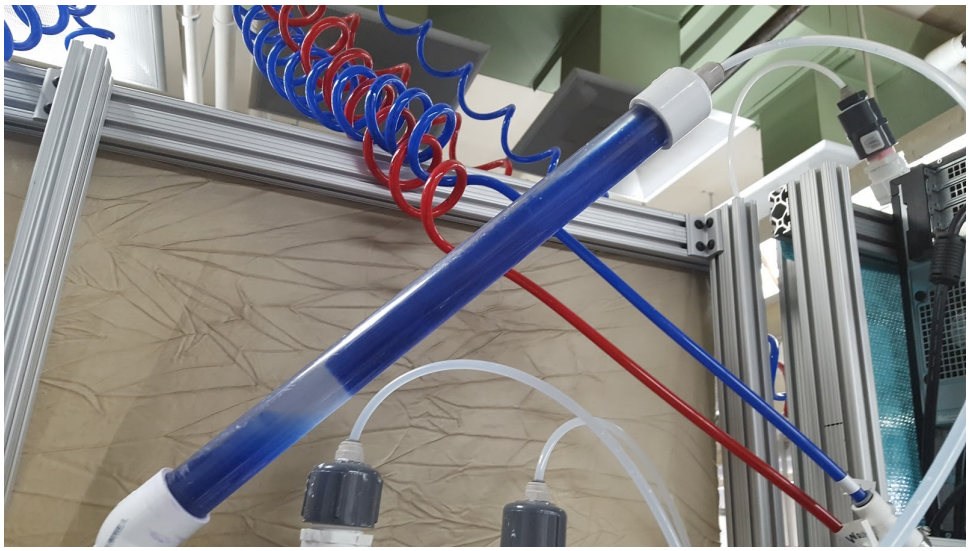


Figure 18: Plug of sludge that traveled from Reactor 3 into the tube settler during the over night run from April 25, 2016.

Due to the sludge formation, there was minimal transportation of flocs from Reactor 3 to Reactors 1 and 2, which prevented any conclusions from being made about whether multiple reactors in series would perform better than a single reactor.

EPA P3 Expo

The EPA's P3 Program is a competition for college students, where they showcase their research to tackle sustainability issues and compete for an additional grant of up to 75,000 USD to apply their design to a real world application. The CSFBR and Fluoride team attended the 2016 EPA P3 Expo from April 14th, 2016 to April 17th, 2016 and presented a method for arsenic and fluoride removal. The team is pictured below in Figure 19.

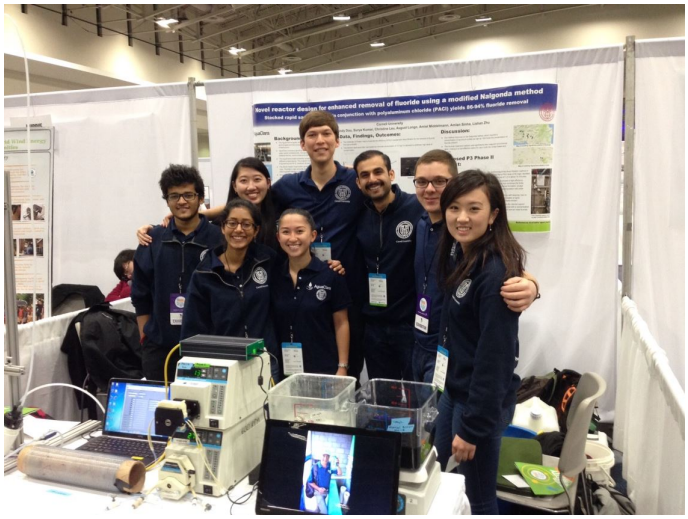


Figure 19: The CSFBR and Fluoride team at the 2016 EPA P3 Expo.

Ideas about which system to bring to the expo were exchanged between the two teams, and the single-reactor system was decided upon with the following improvements: a tube settler at 70 degrees instead of 45, the floc weir at 30 degrees instead of 45, and the entire reactor was to be made of clear PVC. First, the height of the reactor used by the Fluoride team was measured, and a length of one-inch clear PVC pipe was cut based on the measurement. Next, a conical floc re-suspension cap was fabricated and installed into the bottom of the pipe. Then, based on the dimensions of the reactor used by Fluoride team, the pipe was bent at the point where the tube settler would begin by heating it using a heat gun. In order to make the tube settler, half of the circumference of the pipe was heated and bent to 70 degrees. Dr. Monroe Weber-Shirk fabricated a jig that helped guide the drilling of a hole at 60 degrees into the side of the pipe for attaching the weir. A half-inch clear PVC pipe was used to make the weir. The end of the weir was cut such that the cross-section was at 60 degrees with the vertical when attached to the pipe. The weir was then PVC welded to the reactor and a leak test was conducted over several iterations to see if it was watertight. Once it was determined that the connection was watertight, a portion of the weir piping was bent to 180 degrees using similar methods as for the tube settler. The reactor is pictured below in Figure 20.

Figure 20: Reactor built for the 2016 EPA P3 Exposition.

Troubleshooting throughout the semester

In the early testing phase, the reactors did not form floc blankets. The team hypothesized that the clay concentration was not high enough compared to the PACl concentration. Thus, in the next set of experiments, the team increased their clay concentration to approximately 2400 $\frac{mg}{L}$. With this concentration, the floc blankets were able to develop.

There was also settling observed within the tubing and reactors. Initially, the team was using $\frac{3}{8}$ inch tubing to drain the flocs and pump them into the next reactors. Within these tubes, flocs were observed to settle at the bottom as the effluent water passed through. This phenomenon was observed in Reactor 3. This hindered the transportation of flocs. To address the problem, the team changed the tubes pumping flocs with $\frac{1}{4}$ in. tubing. The team also observed the clay and floc mixture settling within the flocculator. Because the flocculator was created with $\frac{3}{8}$ in. tubing, the team also replaced those tubes with $\frac{1}{4}$ in. as well. Settling was also observed in the $\frac{1}{4}$ in. tubing that transported clay from

the stock tank and into the flocculator. The tubing was replaced with micro tubing, and because the PACl stock was using the same pump, the tubing from the PACl stock tank was also replaced with micro tubing. In later experiments, when concentrations of 100mg/L PACl and 500 mg/L dye were used, it was observed that there was no floc blanket formation in the reactors. Instead, sludge formed at the bottom of the reactor due to floc re-suspension failure. Analysis of parameters led the team to deduce that the formation of sludge could be from one or more of the following factors:

- The concentration of PACl was high relative to the concentration of dye
- The presence of flat surfaces in the re-circulation unit (or jet reversal unit) might have allowed the flocs to settle and therefore lead to the formation of sludge. Since the team used a step drill when making the expansion pipe, flat surfaces may have been present in the threads.
- The upflow velocity might be too low, rendering the jet ineffective in re-suspending the flocs.
- The piece of tubing going into Reactor 3 was not straight and could have caused the jet of water to enter the reactor at an angle, resulting in a lower effective velocity.

The team decided to re-fabricate Reactor 3 and smooth the slope in the expansion pipe to make sure there were no flat surfaces in the thread. To ensure that the flow-rates are accurate and a desired upflow velocity of 1.1 $\frac{mL}{s}$ was obtained, pumps were re-calibrated and flow rates were increased to 31.923 $\frac{mL}{min}$. It was also ensured that tubing connecting the expansion pipe was straight. Unfortunately, sludge formation still persisted after the aforementioned modifications.

Conclusions

While several hurdles still exist before the original hypothesis about the effectiveness of reactors in series over the single reactor, several smaller conclusions were made. First, it can be concluded that PACl is effective in removing dye (namely Remazol Brilliant Blue R and Red Dye 40) from water. Evidence of this was clear in jar tests and in the experiment run in the lab. Thus, it can be concluded that provided an optimal experimental setup, PACl is effective in removing dye.

Second, it can be concluded that the current experimental setup is insufficient to test the removal of contaminants. In the experiments following the EPA P3 Expo, two major issues prevented the completion of experiments. These issues were the failure of floc transportation between reactors, and the lack of floc blanket formation due to sludge formation. Thus, it can be concluded that the experimental setup must be altered in the future in order to move closer towards the goal of testing the original hypothesis.

Future Work

The team has two major goals for the future. One goal is to determine a more effective geometry for the re-circulation unit to prevent sludge formation in the bottom of the reactors. After multiple experiments and iterations, it was determined that there must be some problematic aspect with the geometry.

It has been hypothesized that because the cross-section of a pipe reactor is circular for the flux of flocs, larger flocs might settle as a ring around the jet, which allows for sludge formation and failed floc re-circulation. This proposed theory can be seen in Figure 21.

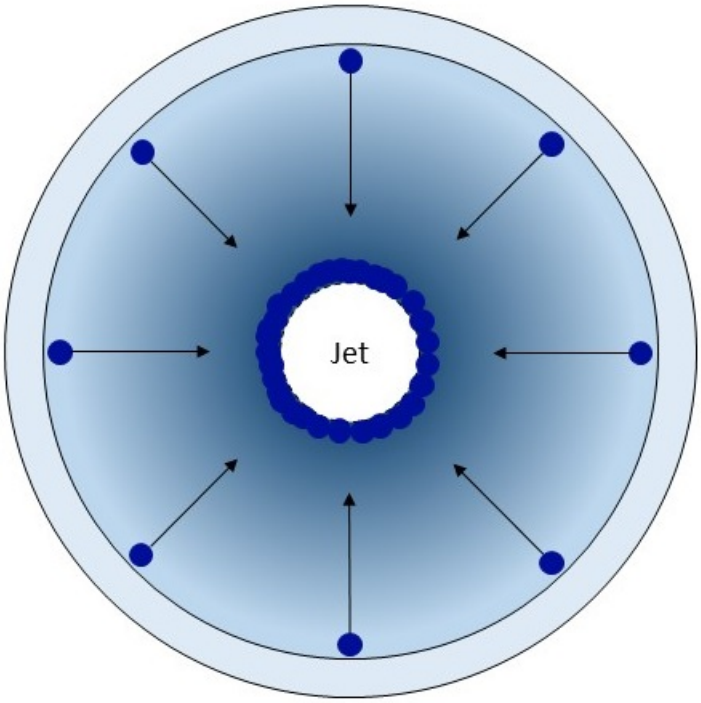


Figure 21: Potential reason for sludge formation in the floc re-circulation unit is that the flocs could settle together and form a ring around the jet and remain stable. This ring would also provide a surface for further sludge formation.

In a traditional AguaClara sedimentation tank, however, flocs only enter the re-circulation unit from one direction of the reactor because the jet of water enters from the other. The next team must find a way to employ the same principles from a traditional AguaClara sedimentation tank to the pipe reactors used for CSFBR.

Due to the difficulties experienced with creating a fluidized floc blanket while removing dye, it was never determined if multiple floc blanket reactors in series would be more advantageous than one. If the issue of sludge formation can be

solved, then the second goal would be to compare a single reactor system to a multiple reactor system through experimentation that places both systems under the same conditions.

References

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Yeung, C. A. (2008). A systematic review of the efficacy and safety of fluoridation. *Evidence-Based Dentistry*, 9(2):39–43.

Zonoozi, M. H., Moghaddam, M. R. A., and Arami, M. (2009). Coagulation/flocculation of dye-containing solutions using polyaluminium chloride and alum. *Water Science and Technology*, 59(7):1343–1351. WOS:000265705200012.

Semester Schedule

Task Map

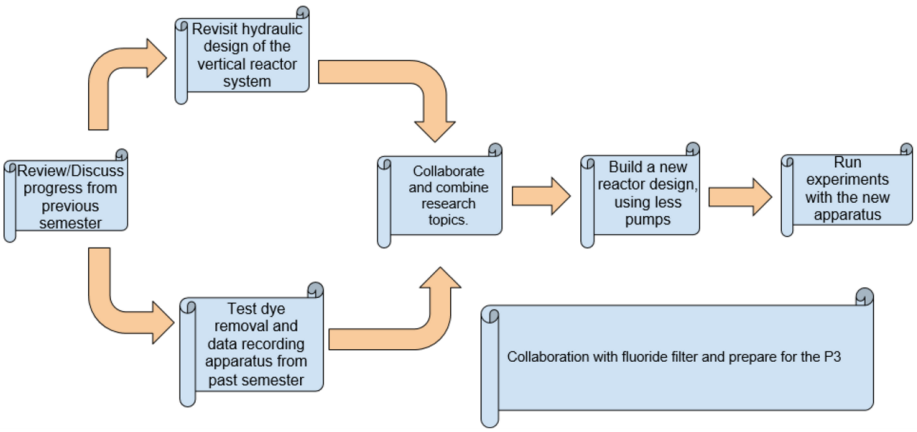

Figure 22: Task Map

Week 1: 2/8 - 2/12
DUE: Detailed Task List 2/12
Reactor setup and Research: Christine + Cindy

1. Read/research concentration ratios about PACl adsorbing dye - Completed
2. Verify current dye / look into other options - Completed
3. Test dye in a jar test setting - Completed
4. Re-calibrate the spectrometer - Completed

Week 2: 2/15 - 2/19
EPA P3: update your profile and enter your exhibit title and description by February 15, 2016.
February break
Reestablish floc blankets: TEAM - Completed

1. Begin running experiments to create floc blankets - Completed
2. Introduce dye with concentrations to reproduce results from jar test - Completed
3. Carefully record observations and recorded concentrations - Completed

Week 3: 2/22 - 2/26
DUE: Research Report 2/26
Proofreader: Christine
Dye Experimentation: TEAM

1. Continue with experiments and observations - Completed
2. Look into varying dye concentrations for optimal adsorption - Completed
3. Look into methods for improvements - Completed

Dye Calculations:

1. Determine PACl concentration entering reactor with dye removal data - Completed
2. Calculate an approximate 15 - 25 $\frac{mg}{L}$ of PACl entering the reactor - Completed
3. Find corresponding dye concentration (based on dye pump speed) - Completed

Week 4: 2/22 - 2/26
Dye Calculations (Finish/ Discuss):

1. Determine PACl concentration entering reactor with dye removal data
2. Calculate an approximate 15 - 25 $\frac{mg}{L}$ of PACl entering the reactor
3. Find corresponding dye concentration (based on dye pump speed)

PACl and Clay Experimentation: TEAM

1. Experiment with PACl and clay concentrations
2. After successful experimentation, create a detailed experimental setup

Week 5: 3/7 - 3/11
DUE: Research Report 3/11
Proofreader: Mickey
PACl and Clay Experimentation (continued): TEAM

1. Look into reducing amounts of clay
2. Look into feeding PACl straight into the reactor (no flocculator use)

Week 6: 3/14 - 3/18
Symposium Week!
DUE: Midterm Peer Evaluation 3/18
PACl and Clay Experimentation: TEAMWORK:

1. Continue testing
2. Begin finalizing a full experimental procedure / results

Week 7: 3/21 - 3/25
P3 Competition: TEAMWORK:
DUE: Midterm Peer Evaluation 3/18
PACl and Clay Experimentation: TEAMWORK:

1. Collaboration with Fluoride Filter team and the rest of EPA P3 competition
2. Review over submission and clarification

Experimentation:

1. Look into finding optimal rates, based on the experimental data
2. Compare and theorize past experimental results

Week 8: 3/28 - 4/1
IMPORTANT: submit your EPA P3 Project Report via Grants.gov by March 31, 2016.
See Monroe's Email (2/4) with instructions
SPRING BREAK - NO CLASS
Week 9: 4/4 - 4/8

1. Research Report Due 4/8
2. Proofreader: Amlan

Experimentation:

1. Finish any remaining steps
2. Ensure procedure and design documents are finished.
3. Determine the removal process of the three series reactor setup
    - How reliable are our results?
    - How does our data compare with others?
    - Is this a practical setup in the field?

P3 Competition

- Begin collaborating with other P3 members on how to what/how to present
- Decide on exhibit setup

Week 10: 4/11 - 4/15

IMPORTANT: EPA P3 exhibition April 15th-17th

P3 Competition

- Prepare for P3 exhibition presentation

Week 11: 4/18 - 4/22
Research Report Due 4/22
Proofreader: Cindy
Reactor Redesigning:

1. Begin drafting vertical designs for the CSFBR

2. Look into literature and past samples

3. Propose/ perform calculations

Week 12: 4/25 - 4/29
Reactor Redesigning:

1. Look into materials list for reactor

2. Look into methods of reducing pump influence

Week 13: 5/2 - 5/6
Wrapping up:

1. Finalize final report

Week 14: 5/9 - 5/13
FINAL Research Report Due 5/11 DRAFT
FINAL Research Report Due 5/17
DUE: Peer Evaluation 5/17
Proofreader: Everybody
Week 15: 5/16 - 5/20
DUE: Final Presentation ppt: Upload by 9:00 AM
Proofreader: Everybody