Chemical Dose Controller, Fall 2016

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Abstract

The Linear Chemical Dose Controller (CDC) system was designed to maintain a constant chemical dose to the treatment train as the plant flow rate and influent turbidity change. Past CDC teams worked on improving the design of the Constant Head Tank (CHT), and making the CDC system modular. This semester the CDC team redesigned the CHTs so that all four tanks were connected to each other, and so that the calibration columns were attached to the CHT module. Additionally, the team recreated and modified the modular CDC system designed in past semesters to address the goals of being fully chemical resistant, compact, and simple in operation and maintenance. The new CHT will be demonstrated and eventually implemented in Honduras.

Introduction

The Chemical Dose Controller team refined the overall design and layout of the CDC, particularly the Constant Head Tank. The main goal of the team was to make the design modular so that very little assembly is required at the plant. To do this, all the constant head tanks were joined together in one larger tank separated by dividers. This allows the plant to operate in a much easier way and should benefit AguaClara plants. The main function of the CDC was to couple the plant flow rate with the flow rate of the coagulant and disinfectant stock solution. There are two constant head tanks for coagulant and two for chlorine so that the maintenance of one tank does not hamper the overall process of the plant. The team changed the shape of the constant head tank from cylindrical to cuboid. The team also came up with a first iteration of the CHT, as discussed later in the report, but this was set aside to work on the second iteration which addressed the issue of bulky piping. The team aimed to improve on the previous designs for a modular CDC. The team did that and came up with a much more modular and compact design and made a model for that. The model was ready as per the team's initial aim but it failed to account for the Honduras team's need for it to be put up against the wall, while having the tubes in a vertical manner. To account for this, the team came up with a new model. The model is a much more modular and compact design compared to the previous one and the team has been working on it. The model is ready and is projected to work as per the team's initial aim and the Honduras team's needs. This model accounted for the Honduras team's need for it to be put up against the wall by utilizing a vertical piping system and including a backboard that can be mounted against a wall. These changes result in the design including longer dimensions for the CHT and the height of one face to be much larger.

Literature Review

Traditional Chemical Dosing Technology

Traditional chemical dosing systems typically involve a dosing tank and dosing pump. The dosing pump traditionally is a solenoid pump, which regulates the chemical dose by adjusting stroke length and/or frequency. However, if it is necessary to reduce the stroke length, this will reduce dosing accuracy. Additionally, there may be times when the dosing pump cannot operate at 100 percent, which reduces the performance of the valves and reduces their life span (Grundfos).

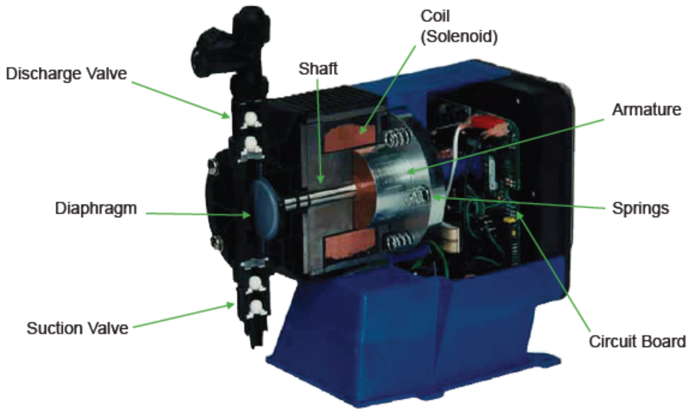

Figure 1: This is a diagram of a traditional solenoid-powered diaphragm pump that could be used for chemical dosing. The solenoid valve regulates the chemical dose by adjusting stroke length and/or frequency.

There are also digital dosing pumps, which use a stepper motor to continuously operate at 100 percent, while adjusting the chemical dose by the discharge stroke speed. This leads to better dosing accuracy (Grundfos, 2016)

The disadvantage to both these chemical dosing technologies is that they are expensive both to purchase initially and expensive to replace. Additionally, they are made to dose a constant amount of water, and as the amount of water in the entrance tank varies depending on incoming flow, they would have to be adjusted constantly by the plant operator.

AguaClara Chemical Dose Controller Theory

The Chemical Dose Controller (CDC) system was designed to maintain a constant chemical dose to the treatment train as the plant flow rate changes and as turbidity changes. A schematic of the CDC system can be seen in Figure 2.

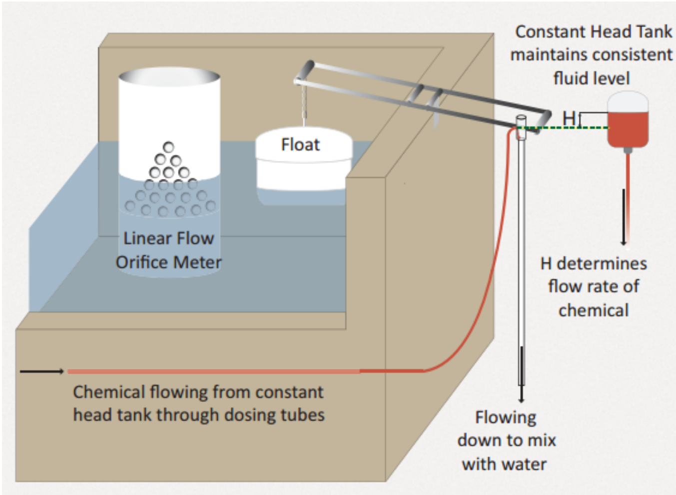

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Figure 2: A schematic of the Chemical Dose Control (CDC) system. The chemical flow rate into the treatment train is automatically controlled based on the elevation difference between the free surface in the CHT and the dosing tube level determined by the water level in the Entrance Tank.

The CDC system consists of the chemical stock tanks, the constant head tanks, the dosing manifold tubes, and the lever arm. The chemical stock tanks hold either coagulant (Polyaluminum chloride, or PACl) or disinfectant (Calcium hypochlorite). These stock tanks deliver chemical to the constant head tanks (CHTs). There are four constant head tanks, two for coagulant and two for chlorine. This is so that one tank can be closed off for cleaning/maintenance without interrupting the flow of chemicals to the plant. A float valve in each of the CHTs keeps the free surface of chemical in the CHT constant, thus maintaining constant head. Chemical then flows out of the CHT into the dosing tubes, and then up to the lever arm, where it flows into a drop tube that is open to the atmosphere. The chemical then flows down the drop tube to mix with water entering the treatment drain (Cashon, et al. 2015).

The CHT currently implemented is made of Type I PVC, Other common plumbing materials that are resistant to chlorine include Type II PVC and PTFE. Type I PVC is most commonly used for this team's purposes because of the low cost and lack of need for high impact resistant material. Type II PVC is strengthened to be more impact resistant and is therefore more expensive, but is unnecessary for this team's purposes. PTFE is a hard plastic that will be used in valves on the CHT which is more resistant to chlorine than HDPE, which tends to show wear after prolonged exposure.

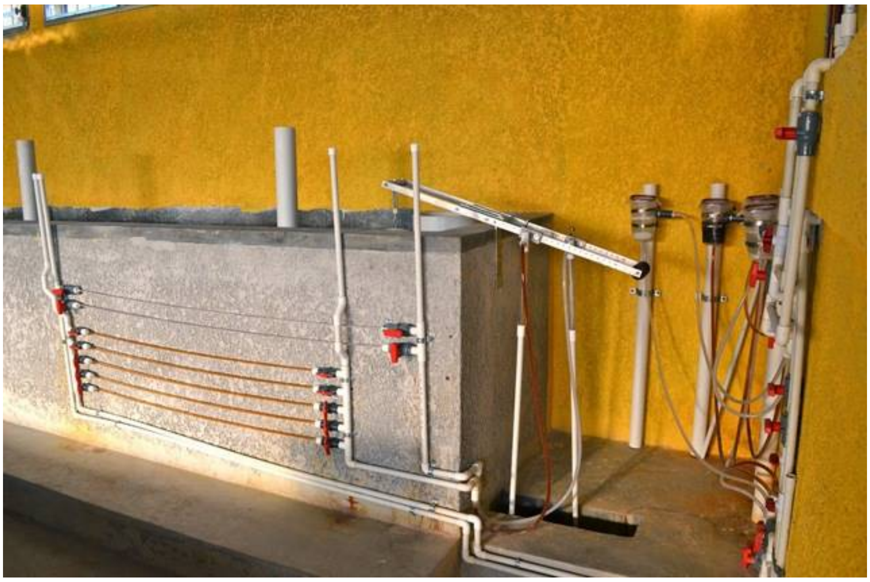

Figure 3: A view of the CDC in an AguaClara treatment plant. All components of the chemical dosing system can be seen, including the CHTs, the dosing tubes, and the lever arm. (Weber-Shirk, 2016)

The dose of chemical added to the plant is based on influent turbidity, and is set by the plant operator using a slider mechanism attached to the lever arm, as can be seen in Figure 4. The chemical flow rate into the treatment train is automatically controlled based on the elevation difference between the free surface in the CHT and the dosing tube. This height difference can either be changed manually by the plant operator moving the slider and therefore adjusting the dose, or will be changed automatically by a change in the flow rate into the plant. Any change in the flow rate into the plant will cause the float in the entrance tank to either rise or fall, which adjusts the lever arm (Doyle, et al. 2016).

Figure 4: The slider attached to the lever arm is used to set the dose of chemical being added to the plant. It can be adjusted by the plant operator in the event that the turbidity of the influent water changes. (Weber-Shirk, 2016)

Governing Equations

The chemical flow rate through the system is a function of major loss, the kinematic viscosity of the chemical, the length of the dosing tubes, and the diameter of the tubing (Cashon, et al. 2015).

$$Q_C = \frac{h_f g D_{Tube}^4}{128 \nu L_{Tube}} \tag{1}$$

The relationship between major head loss and the chemical flow rate is given by the Hagen-Poiseuille equation, which assumes laminar flow. Rearranged in terms of major head loss, the Hagen-Poiseuille equation is a function of the length of the tubes in the dosing manifold, the diameter of the tubing, the kinematic viscosity of the chemical used, and the chemical flow rate (Cashon, et al. 2015).

$$h_f = \frac{128 Q_c \nu L_{Tube}}{g D_{Tube}^4} \tag{2}$$

Total head loss through the CDC system is the sum of the major losses due to friction shear, and the minor losses due to flow expansions (Cashon, et al. 2015).

$$h_{total} = \frac{128 Q_c \nu L_{Tube}}{g D_{Tube}^4} + \frac{8 Q_C 2 K_e}{g \pi^2 D_{Tube}^4} \tag{3}$$

Previous Work

Modular Chemical Dose Controller System

The Spring 2015 CDC team was also tasked with designing a modular CDC system, so that it would be easier to assemble the system at the plants. The team designed a vertical CDC, with the hope that the new orientation would reduce the amount of space the CDC system takes up in the plants.

Figure 5: The vertical manifold system the Spring 2015 CDC team designed. The goal was to make the system more spatially efficient by having the dosing tubes run vertically instead of horizontally.

This semester the CDC team will be attempting to recreate this vertical design, using the newest iteration of the Constant Head Tank once it has been fabricated.

Current Implementation Design: Constant Head Tank

The current implementation of the CHT in Honduras is a re-purposed Tupperware container, as seen in 6. The tubing at the inlet of the container, shown at the right side, connects the chemical feed stock and the custom float valve.

To the left is the outlet tube, which transports chemicals from the CHT to the lever arm.

At the bottom of the CHT is the drain tube, which serves maintenance purposes. When sediment, namely calcium carbonate, builds up and settles at the base of the CHT, the CHT is taken off line and flushed with vinegar to clear off the calcium deposits. At this point, the inlet and outlet tubes are closed off and the drain tube is open to clean out the tank.

Although the CHT in Figure 6 uses locally available materials, the Tupperware is not chlorine resistant and must be replaced periodically. Additionally, there is sediment build up on the sides of the tank that will not be completely solved by the drain. (Cashon, et al. 2015)

Figure 6: The currently implemented CHT design

In Spring 2016, the design of the constant head tank was created from large diameter PVC pipe. This design, shown in Figure 7 solved the issue of periodic tank replacement since the PVC is fairly resistant to chlorine oxidizing effects. The design still implements the custom made float valves, which are shorter in length than the manufacturer made ones. The bottom of the PVC pipe tank is a fitted pipe cap that is drilled through to make room for the drain valve. The rounded nature of this CHT design's bottom resolves some of the issue of sediment build up and aids in simple maintenance.

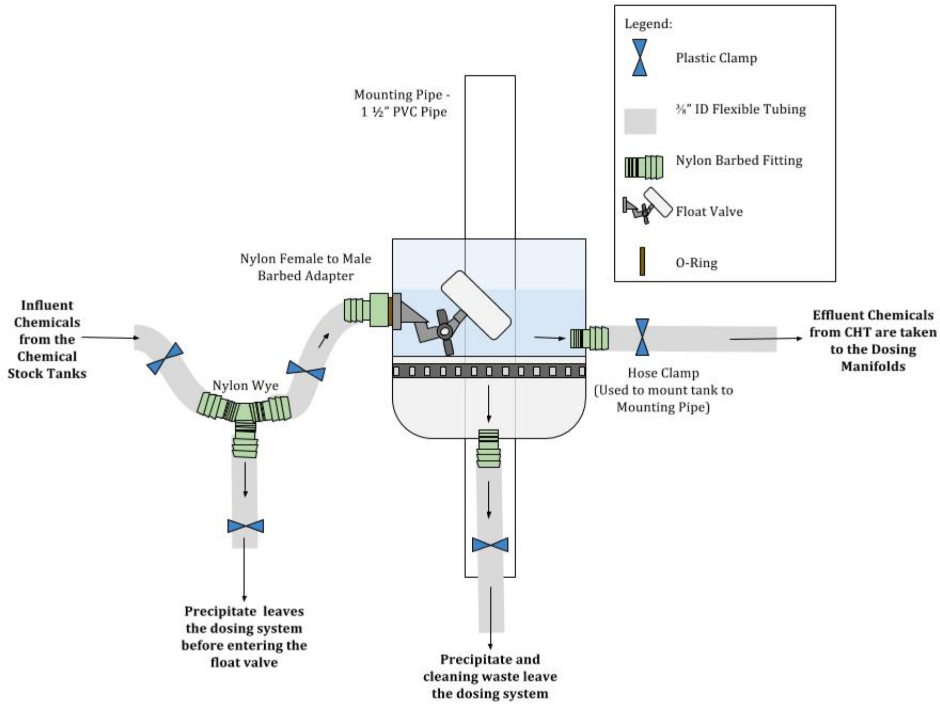

Figure 7: Spring 2016's PVC Pipe Tank Schematic

Although this CHT design is quite simple to fabricate, like its predecessors, it is not yet modular. There are four separate tanks that all need to be carefully mounted as opposed to one unified CHT with four compartments. The CHT tubes use tube clamps to keep fluid passing though the CHT, but over time, these clamps have shown to deform the tubing. The CHT's custom made float valves are also cumbersome as an additional step in fabrication. Additionally, this CHT design does not have a top so particulates may fall into the tank. (Doyle, et al. 2016)

Methods

CHT Design

The chemical dose controller consists of four total stock tanks, two calibration columns, and four constant head tanks. There are two stock tanks for chlorine and two stock tanks for polyaluminum chloride. If one tank for a particular chemical runs out, the second stock tank serves as a backup. The two chlorine stock tanks have individual outlet tubing but this tubing joins together into one tube. At this point, there is a diverted pipe that leads an upright rigid clear PVC pipe which serves as our calibration column. There is one calibration column each for chlorine and for polyaluminum chloride.

The calibration columns serve to measure the dosage of the chemicals being added to the treated water. The calibration columns function by first closing the valve to the CHT and then opening the valve to the calibration column from the stock tank. The plant operator allows the calibration column to fill, closes the valve to the stock tank, then opens the valve to the CHT. The operator then measures how much much time it takes for a predetermined amount of chemical to drop and based off this, determines the dosing rate.

The first iteration CHT consisted of one tank with four identical compartments, two for PACl and two for chlorine. The rigid inlet piping was oriented horizontally and used an adapter to connect to the float valves. The exit and drainage plumbing was flexible tubing.

The team made the decision to change the orientation of inlet piping to better accommodate the CHT in the context of an actual plant in the Honduras. The first iteration employed horizontal inlet piping, which quickly became bulky and required the need for a separate shelving unit to be built to accommodate it. These issues led the team to redesign the CHT and yielded the second iteration.

The design of the second iteration maintained the same basic structure as the first iteration of Fall 2016, save for the alterations in plumbing orientation. In the second iteration, the tanks were extended in the direction of the float valves, so that the plumbing can be vertically oriented in the back of the CHT and attached to the wall as opposed to being horizontally oriented through the back of the CHT.

The designs for the first and second iterations of the CHT were based on the following constraints:

1. Resistance to chlorine: The new CHT was made from PVC, so it would not degrade as quickly as the current tupperware CHT and therefore will not have to be replaced as often.

2. Ease of maintenance: In order to make maintenance of the CHT easier for plant operators, the new designs had drainage tubing so that the tanks could be filled with vinegar for cleaning and then drained easily. Additionally, a spoon or spatula may need to be implemented to scrape precipitate out of the corners of the tanks.

3. Accommodation of original float valve: The current CHT design uses a modified version of the float valve, while the new designs accommodate the original size of the float valve. The modified version is more expensive because of the labor costs it requires in fabrication.

4. Size of PVC welder: The tank height was constrained by the size of the PVC welder, as the head of the welder needed to be able to fit inside each tank so that the corners could be properly welded.

5. Addition of calibration columns: The new CHT designs incorporate the calibration columns into the module, making the CDC system more streamlined and easier to ship to Honduras. For the time being, the CDC system will be built in the US because of welding limitations in Honduras, but when demand in the Honduras picks up, production will occur in Honduras.

First Iteration

Figure 8 shows a top view of the first iteration of the CHT design. The influent water flows through the calibration columns and pipes, into the tank, then out through the outflow tube. The drainage tube is not shown but has the same layout as the outflow tubes.

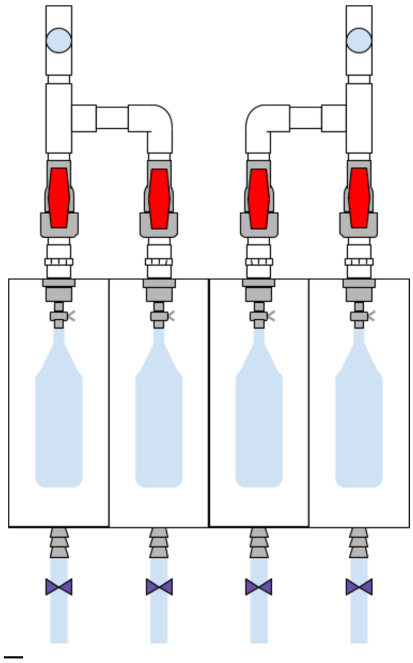

Figure 8: Top view of the CHT design

From the single pipe that contains chlorine and diverts to the calibration column, the pipe splits into two pipes that are inlets to the constant head tank. The two pipes with the same chemical have valves on them so only one needs to be in use at a time. This allows one constant head tank to be taken off line for maintenance while another runs functional. The calibration column and offset layout were chosen because of sizing constraints due to the pipe size and the tank compartment width.

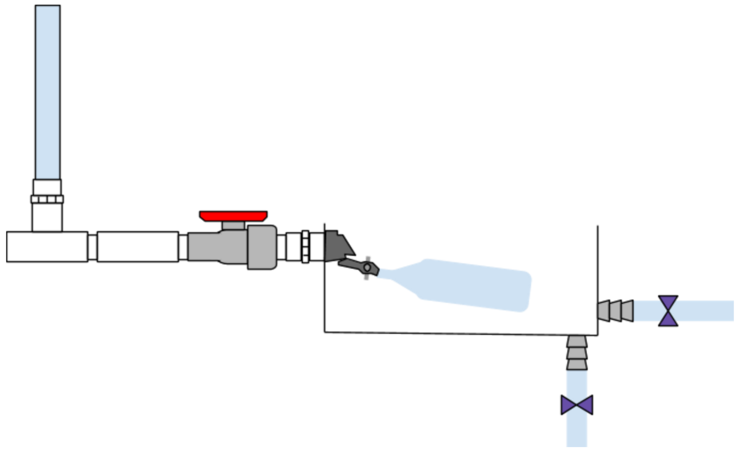

Figure 9: Side view of the CHT compartment that is in line with calibration column.

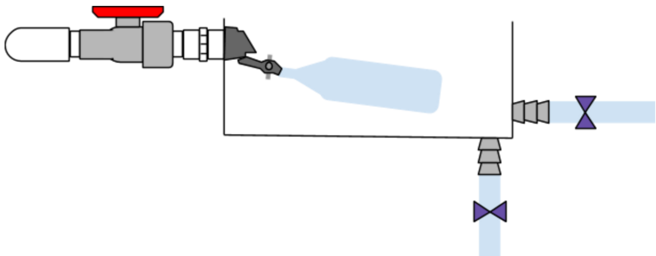

Figure 10: Side view of the CHT compartment that is not in line with the calibration column but needs to be connected by elbows.

The four constant head tanks are connected to one another in order to make the system compact. Each of the constant head tanks has an inlet, outlet, and drainage tube. The constant head tank dosage is regulated by a float valve that controls the chemical dosing. The outlet tubes of the chemical dose controller that treat entrance tank water are connected to a lever arm. This lever arm has a scale on it that the plant operator can adjust to accommodate different levels of turbidity since the chemical dosing tube along the lever arm can scale with the plant flow.

Second Iteration

The second iteration of the CHT addresses the problems of the first iteration concerning the large amounts of space needed to accommodate the piping going into the CHT. The largely horizontal spread of the first iteration required a large amount of space and an adjustable shelf system for the CHT. Figure 11 shows the new CHT design. This design incorporates a large back and a longer tank. The float valve is attached to an elbow that will orient the piping in the vertical direction. All the pipes lay against the back of the CHT and the whole CHT with piping system can be fastened to a wall. This improves the space requirements of the CHT and yields a more compact and portable CHT.

Figure 11: Front view of the second iteration of the CHT. Note the extended length of the tank design.

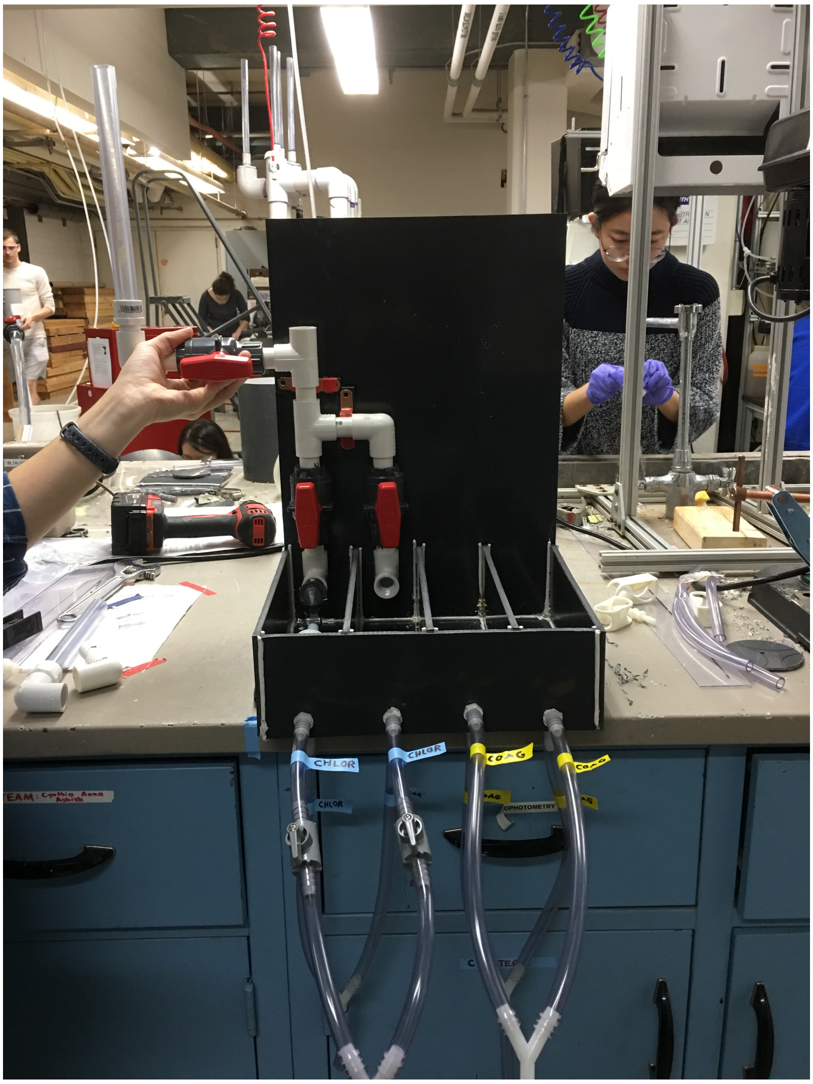

Figure 12: The second iteration of the CHT with the chlorine resistant valves and labeled tubing.

Shown below in 13 and 14 are schematic drawings of the second iteration of the CHT. Note that in 14 after the valves there is a barbed Y to join the effluent from the outlet and drain valves. These valves can be opened or closed as needed for regular operation and maintenance of the CHT.

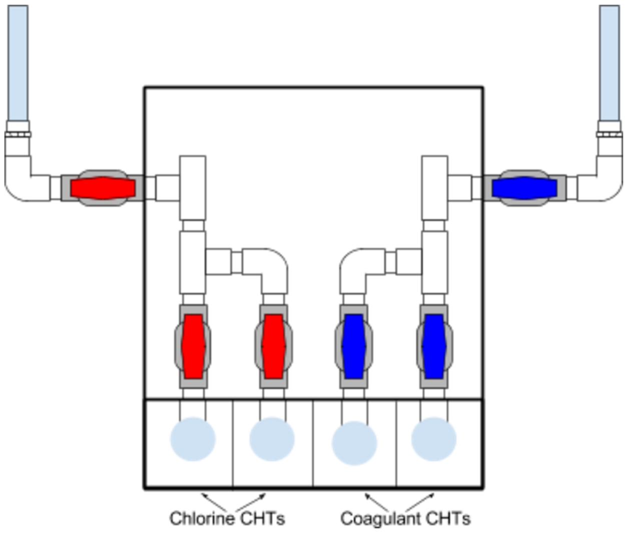

Figure 13: Front view of the second iteration of the CHT. The design is able to be mounted against a wall. The side that doses chlorine will be made of chlorine resistant PTFE which is why there is a distinction between the two sides. Note: This figure does not show the outlet and drain tubing.

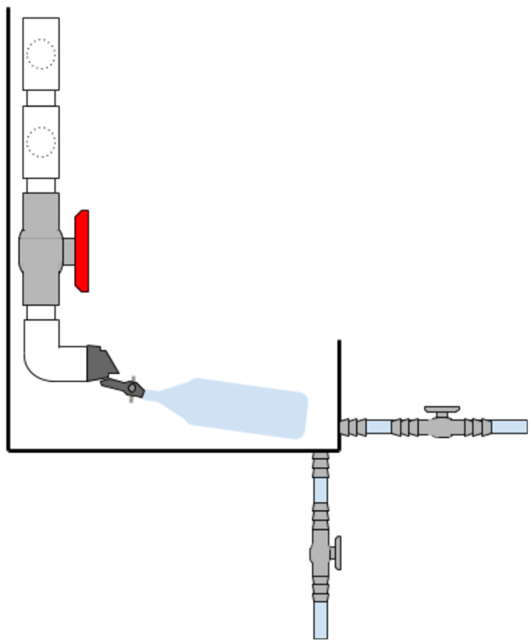

Figure 14: Side view of the second iteration of the CHT. This schematic figure shows the outlet and drain tubing, complete with valves.

Fabrication

First Iteration

Fabrication of the constant head tank began with cutting the PVC sheeting to size (dimensions can be found in Table 2). The tank was then assembled using PVC welding. Once PVC welding was complete, holes for the fittings were drilled. Eight 3/8" holes were drilled and threaded for the barbed fittings for the exit and drainage tubing, and four 7/8" holes were drilled for the float valves. Once the holes had been drilled, the inlet piping and exit tubing was assembled in accordance with the team's new design. Assembly of the CHT can be seen in Figures 15 and 16.

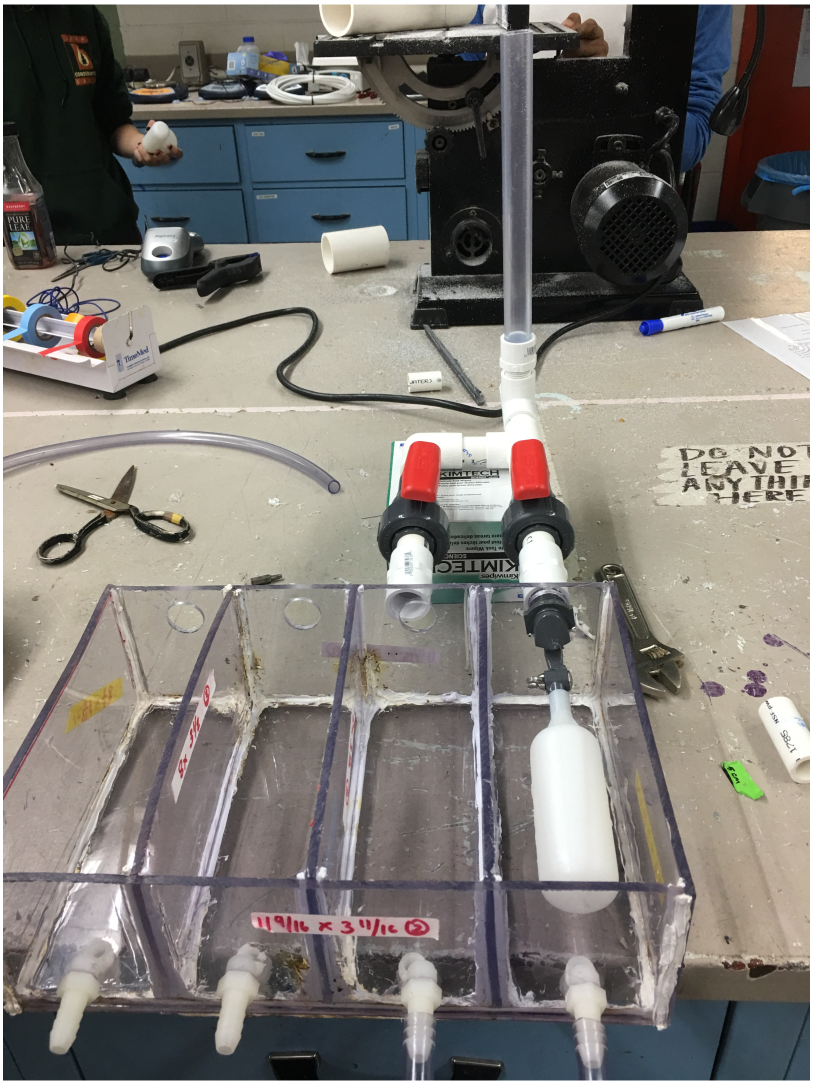

Figure 15: Top view of the Constant Head Tank during fabrication. Here the inlet piping and calibration column can be seen.

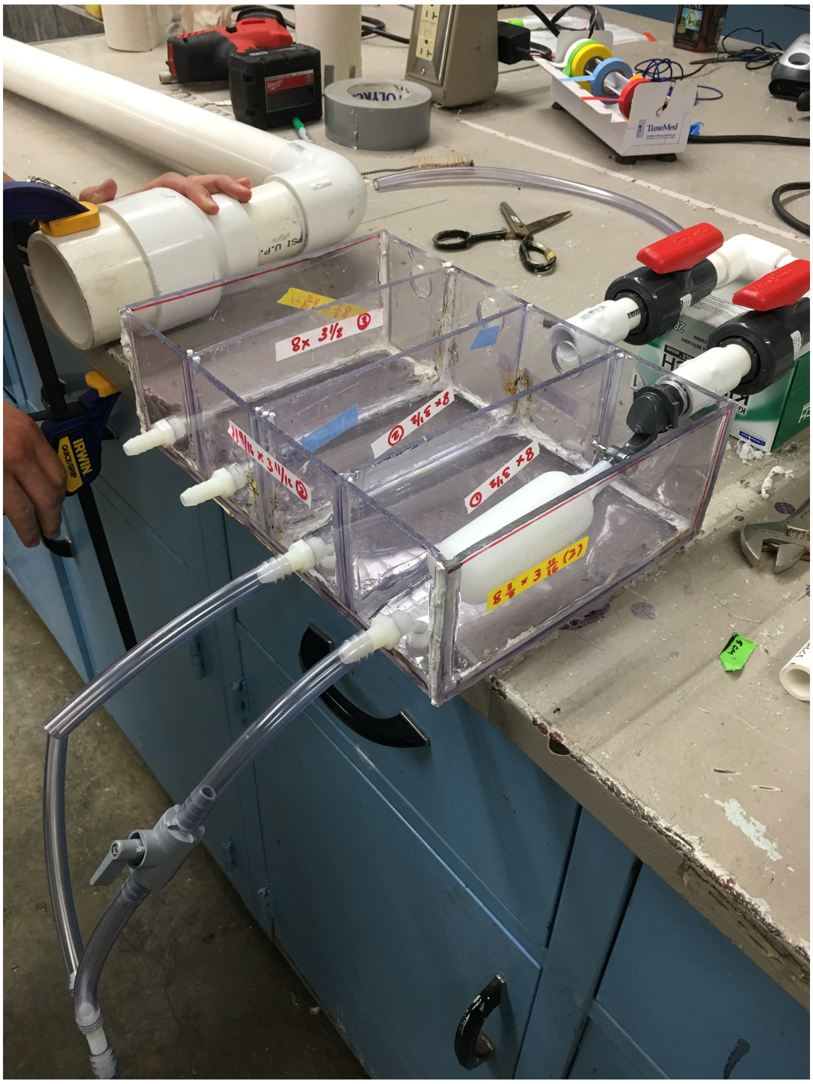

Figure 16: Side view of the constant head tank during fabrication. Here the float valve and the exit tubing can be seen.

Table 1: Components of First Iteration Tank Design

Part Description	**Item Number**	**Quantity**	**Price per Unit**
Clear PVC Sheeting, 24 x 24 inches	87545K431	1	$48.69
PVC Float Valve	23136	4	$8.67
Threaded Pipe Tee	4880K392	2	$0.50
Adapter, Unthreaded F to Threaded M	4880K61	2	$0.27
Adapter, Unthreaded F to Threaded F	4880K81	4	$0.35
Single Union, Socket-Weld Valve	4953K721	4	$16.48
Barbed Valve	4757K18	8	$11.57
Barbed Fittings	5372K118	8	$0.47
White Welding Rod	7899A65	18 ft	$1.40
Average Total Costs			**$249.95/CHT Module**

Table 2: Fabrication Materials for First Iteration Tank Design (available from McMaster-Carr and US Plastic)

Component	**Dimensions**	**Quantity**
Bottom	8” x 11 9/16”	1
Shorter Side Walls	8 6/16” x 3 11/16”	2
Longer Side Walls	11 9/16” x 3 11/16”	2
Dividers	8” x 3 3/8”	3
PVC Float Valve	1/2” ID	4
Threaded Pipe Tee	1/2” ID	2
Adapter, Unthreaded F to Threaded M	1/2” ID	2
Adapter, Unthreaded F to Threaded F	1/2” ID	4
Single Union, Socket-Weld Valve	1/2” ID	4
Barbed Valve	3/8” ID	8
Barbed Fittings	3/8” ID	8

Second Iteration

At the beginning of the fabrication process, PVC sheeting was cut to size according to the dimensions listed in Table 4, and the team used PVC welding to assemble the tank, as can be seen above in Figure 11 and below in Figure 17. Holes for the exit and drainage tubing were drilled and threaded, and barbed fittings were threaded into said holes. Flexible tubing was attached to each barbed fitting, and barbed valves were attached to each exit or drainage line. The holes drilled were the same size as those in the first iteration design, and the flexible tubing was the same size as that used in the first iteration design as well. Then the exit lines for the two chlorine tanks were joined using a barbed Y, and the exit lines for the two coagulant tanks were joined in the same manner. This process was repeated for the drainage tubing as well. The completed exit and drainage tubing system can be seen in Figure 19.

The plumbing was attached to the back of the CHT using copper clips, PVC spacers, and small Philips-head screws. The clips were placed around the 1/2” pipe sections of the plumbing and were screwed into the PVC spacers. The PVC spacers were then attached to the back of the CHT using PVC glue, as can be seen in Figure 20.

Figure 17: Front view of the second iteration of the CHT. Note the extended length of the tank design.

Figure 18: Angled view of the second iteration of the CHT. Note the extended length of the tank design.

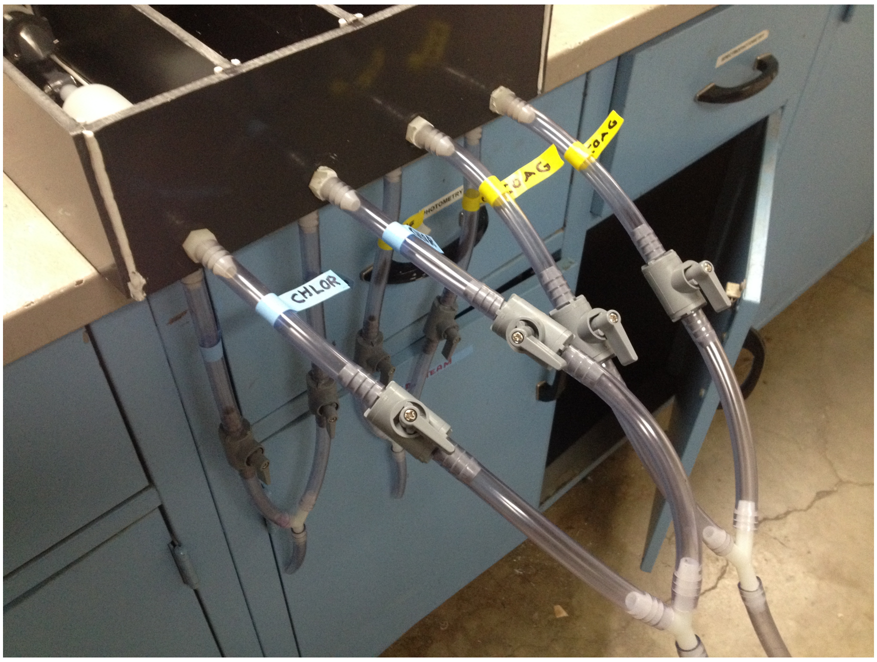

Figure 19: Close up view of the exit and drainage tubing, including the barbed valves, the barbed wyes, and the chemical labels.

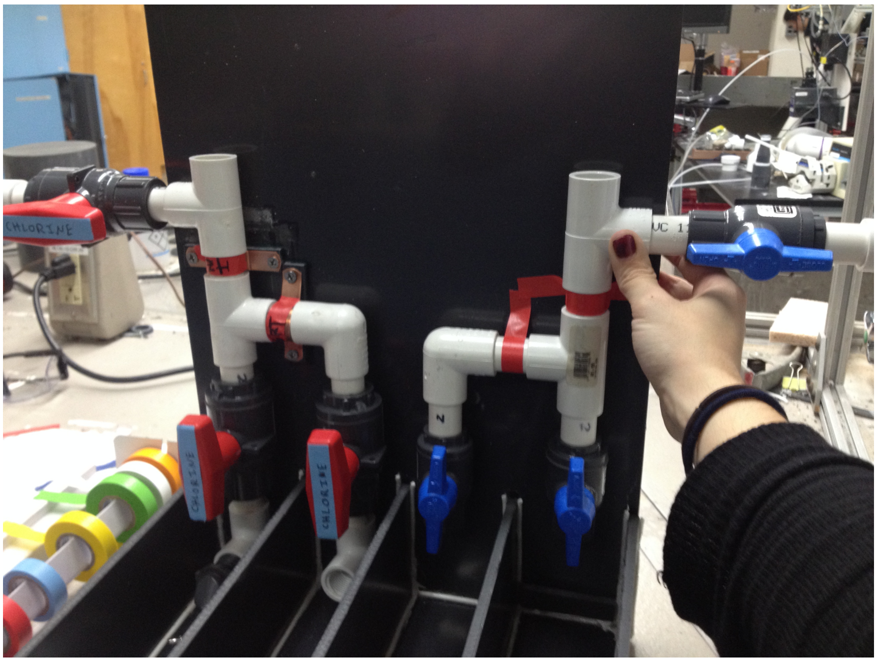

Figure 20: Front view of the second iteration of the CHT, complete with plumbing for both chlorine and coagulant.

Table 3: Components of Second Iteration Tank Design

Part Description	**Item Number**	**Quantity**	**Price per Unit**
Gray PVC Sheeting, 12 x 36 inches	8747K137	1	$23.80
PVC Float Valve	23136	4	$8.67
Threaded Pipe Elbow	4880K321	6	$0.38
Pipe Tee	4880K41	4	$0.38
Pipe Elbow	4880K21	2	$0.30
Adapter, Unthreaded F to Threaded M	4880K61	2	$0.27
Socket Weld PVC/PTFE Ball Valve	4506K26	3	$17.58
Socket Weld PVC/HDPE Ball Valve	4876K21	3	$7.26
Barbed Valve	4757K18	8	$11.57
Barbed Fittings	5372K118	8	$0.47
White Welding Rod	7899A65	18 feet	$1.40
Rigid PVC Pipe	48925K91	21 inches	$0.95
Copper Coated Clip		10	2.26
Average Total Costs			**$236.61/CHT Module**

Table 4: Fabrication Materials for Second Iteration Tank Design (available from McMaster-Carr and US Plastic)

Component	**Dimensions**	**Quantity**
Bottom	11 3/4" x 10"	1
Side Walls	3 3/4" x 10 1/4"	2
Front	3 3/4" x 11 3/4"	1
Back	12 1/4" x 18"	1
Dividers	3 1/2" x 10"	3
PVC Float Valve	1/2" ID	4
Threaded Pipe Elbow	1/2" ID	6
Adapter, Unthreaded F to Threaded M	1/2" ID	2
Socket Weld PVC Ball Valve	1/2" ID	12
Barbed Valve	3/8"	8
Rigid PVC Pipe	1/2" ID	

Shown below in Figure 21 is the completed CHT.

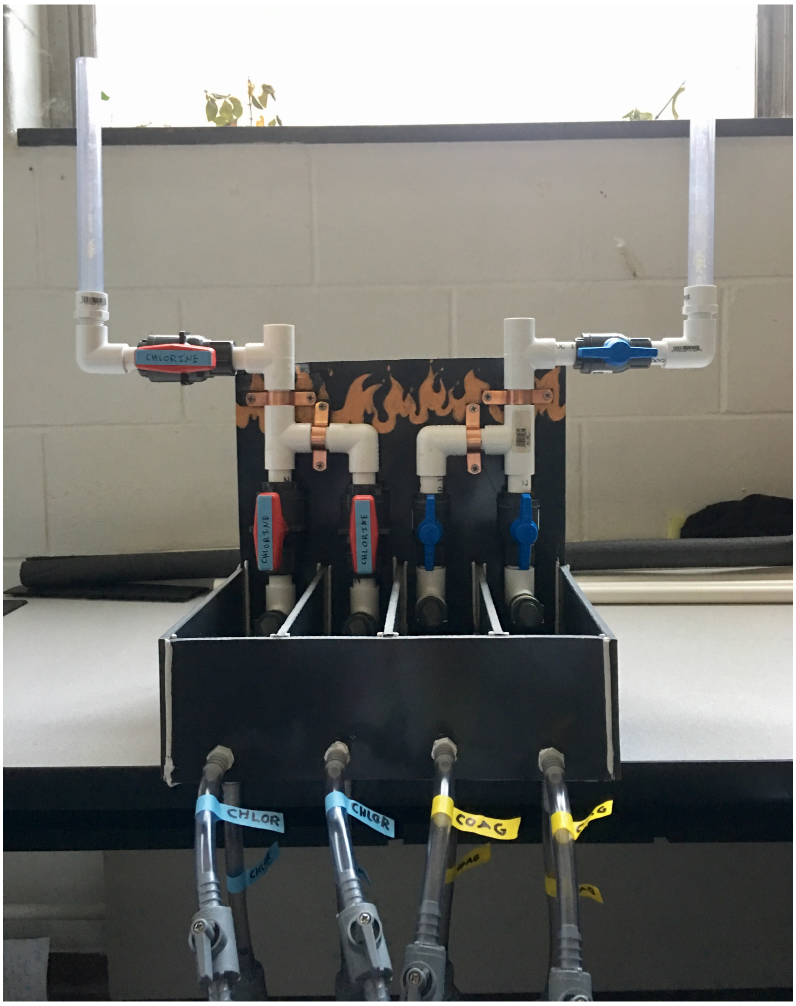

Figure 21: Front view of the completed second iteration of the CHT. Plumbing to the stock tanks is not shown.

Results

The completed fabrication of the second iteration Constant Head Tank was the primary result of this semester. The team spent all semester on fabrication and did not enter the testing/analysis phase, and therefore the physical CHT was the result of the team's work.

Future Work

The CHT fabricated this semester will be brought to Honduras to be shown and demonstrated. In the future, the CHT will ideally be made of clear PVC but for the case of AguaClara lab work, gray PVC was used to cut down on materials costs. The current CHT is not watertight so it can only be used to demonstrate what the new CHT system would look like and to run short demonstrations, but not for actual function within a water treatment plant. The fastenings should also be bought for a larger pipe diameter for future reference, so that the extra width from the pipe fittings can be accommodated.

Aguaclara can utilize the information that the CDC team has come up with to implement more modular chemical dose systems in Honduras and countries abroad. The Chemical Dose Controller subteam was discontinued for the Spring 2016 semester, so it seems that there was the belief that research in this area was no longer needed, but as this team was revived, it seems that more work into this area should continue. Ideally, after the improvements the CDC team completes, research will not need to continue on chemical dose controller design.

References

Grundfos (2016). Dosing and disinfection | Grundfos.

Cashon, A., Leu, C., Longo, A. (2015). *Chemical Dose Controller, Spring 2015.*

Doyle, A., Shao, V., Takada, S. (2016). *Constant Head Tank, Spring 2016.*

Grundfos Dosing and Disinfection Product Overview. [PDF]

Weber-Shirk, M. (2016). *Flow Control and Measurement.* [PowerPoint Slides]

Semester Schedule

Task Map

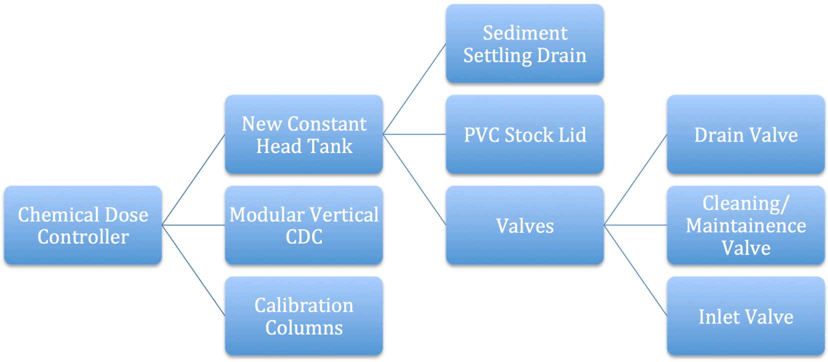

Figure 22: CDC Task Map Fall 2016

Task List

1. Complete fabrication of new constant head tank design. (October 17) - Anna, Cynthia, Ashish. The team will complete fabrication of the first iteration of the Constant Head Tank.

2. Present first Constant Head Tank to Monroe and the Engineers in Honduras. (October 19) - Anna, Cynthia, Ashish. The team discussed with Monroe and with the AguaClara engineers, Ethan and Skyler, in Honduras the CHT design, and made note of any adjustments needed.

3. Assemble the Constant Head Tank with proper plumbing and connections. (October 25) - Cynthia, Anna, Ashish. The team will test whether the calibration columns and connections perform as desired and problem solve if not.

4. Design the adjustable shelf system. - Cynthia, Anna, Ashish. The team will come up with a adjustable shelf system for the CHT, taking note from the design from Fall 15.

5. Complete the adjustable shelf assembly. - Cynthia, Anna, Ashish. The team will complete the shelf assembly and make sure that it fits into the plant layout designs.

6. Redesign and fabricate a new CHT if necessary. - Cynthia, Anna, Ashish. The team will redesign and fabricate a second iteration CHT if necessary, using feedback from Monroe and the engineers in Honduras.

7. Complete fabrication of modular CDC system. - Anna, Cynthia, Ashish. The team will fabricate a modular, vertical CDC system based on the system the CDC team created in Spring 2015. This system will include a chemical stock tank, the constant head tank the team constructed earlier in the semester, the dosing tube, and the lever arm.

Report Proofreader: Ashish Sangai