Chemical Dose Controller Spring 2014

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Abstract

The Chemical Dose Controller team completed the design and fabrication of the single lever arm assembly. This assembly will be utilized in low flow plants that only require a chlorine doser. The new Chemical Dose Controller maintains the same functionality of the previous model. It will also be chemically resistant and require fewer materials, lowering fabrication and shipping costs. The team also created a float valve for the constant head tank that has fewer corrosive metal components and has the floatin line with the orifice. The team hascreated a new height adjustment system for the constant head tank and a dosing tube air removal system that utilizes a wye channel. Additionally, the entrance tank float was redesigned to be smaller and lighter, for easier and cheaper shipping. Finally, the team created an items catalog that contains every single component - and it's corresponding McMaster-Carr identification number - used in a Chemical Dose Controller system. This catalog will help future Chemical Dose Controller teams order components and construct new systems.

1. Introduction

While developed countries have the resources and infrastructure to provide clean water to their citizens, developing countries may not have the same resources. AguaClara, works to combat this problem by creating energy efficient, cost-effective water treatment plants.

The Chemical Dose Controller (CDC) is an important component of an AguaClara plant. It is a simple mechanical device which maintains a linear relationship between the plant flow and the chemical flow rate in order to deliver the appropriate dosage of coagulant (Polyaluminum Chloride (PACl) or Aluminum sulfate (Alum)) to the influent water and disinfectant (Calcium Hypochloride) to the effluent water. The CDC consists of a calibrated lever arm which the operator can use to adjust the dose of the chemical based on the turbidity of the influent water.

The unique designs of the Linear Chemical Dose Controller (LCDC) and the Linear Flow Orifice Meter (LFOM) allow the plant operator to set and maintain the desired dose of coagulant and disinfectant without the use of an electric supervisory control and data acquisition system (SCADA). The purpose of the Chemical Dose Controller in an AguaClara plant is to automatically add the proper amount of coagulant to the influent water in order for downstream processes (flocculation and sedimentation) to occur. The LFOM creates a linear relationship between the height of the water in the entrance tank and the plant flow rate. The LCDC responds to the change in water level created by the LFOM to dose the appropriate amount of coagulant or chlorine to the system. The concentration of the chemical added is set by the plant operator and automatically adjusts with the incoming flow rate.

2. Literature Review

2.1. Mathematical Development
Governing Equations

The linear chemical dose controller (LCDC) is dominated by major head loss and uses a constant head tank to maintain a constant driving head to regulate chemical flow to the water treatment plant. The relationship between major head loss and the chemical flow rate is given by the Hagen-Poiseuille Equation. The chemical flow rate (Q_C) is a function of the major head loss (h_f), the diameter of the tube (D_{Tube}), the kinematic viscosity of the solution being used (υ) and the length of the small diameter tube (L_{Tube}).

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

The Hagen-Poiseuille Equation assumes that the chemical flow used is laminar (see Spring 2011 Final Report, Introduction to Current Research section for an explanation on how this laminar flow is ensured), viscous and incompressible. This equation also assumes that the flow in the tube passes through a constant, circular cross-section that is significantly longer than its given diameter. When the Hagen-Poiseuille equation is rearranged in regards to the major head loss (h_f), one can see that this variable increases proportionally as the length of the small diameter tube (L_{Tube}) is increased as shown in Equation.

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

The total head loss through the system (H_{Total}) is the sum of the major (h_f) and minor (h_e) head losses. Major losses are due to viscous shear on the pipe walls whereas minor losses are due to various flow expansions as shown in Equation.

$$H_{Total} = h_f + h_e$$

Substituting equations for major and minor losses results in Equation. The LCDC system is designed so that the first term, which is the contribution due to major loss, dominates versus the second term, which is the contribution due to minor loss. This is done to maintain a linear relationship between $H_{Total}$and Q_C.

$$H_{Total} = \frac{128 Q_C \nu L_{Tube}}{g \pi D_{Tube}^4} + \frac{8 Q_C^2 K_e}{g \pi^2 D_{Tube}^4}$$

Sizing the Float Valve Orifice in the Constant Head Tank

The maximum coagulant flow rate, Q_{Coag}, is $0.576\,mL/s$ for a plant flow rate of $2.4\,L/s$, a maximum coagulant dose, $C_{CoagMax}$, of $40\,mg/L$ and a stock coagulant concentration, $C_{CoagStock}$, of $166.7\,g/L$, as shown by Equation.

$$Q_{Coag} = \frac{Q_{Plant} C_{CoagMax}}{C_{CoagStock}}$$

The float valve orifice diameter of 0.142 inches, or 0.36 centimeters, was sized through constraints set by the manufacturer, Kerick Valve. Q_{Coag} is the chemical flow rate, the vena contracta coefficient,Π_{VC}, is 0.62, and g is the gravitational constant. Using these values, and the height difference between the water in the constant head tank and the water leaving the stock tank, Δh, is 0.17 centimeters, as shown by Equation. The low value implies that Δh is not a constraint, and the system will work as long as Δh is at least 0.17 cm.

$$\Delta h = \frac{1}{2g} \left[\frac{1}{\left(\frac{d}{2}\right)^2 * \frac{\pi \Pi_{VC}}{2 Q_{Coag}}} \right]^2$$

2.2. Float Size in Constant Head Tank Float Valve Assembly

The float valve assembly of the LCDC consists of the float, rod, and valve in a clear horizontally placed Nalgene bottle with length of $6'3/4''$ and diameter of $3'1/4''$.

The size of the float can be mathematically determined by using the torque equation:

$$\tau = r F_b$$

where $\mathrm{F_b}$ is the force applied to the rod by the buoyancy of the water. $\mathrm{F_b}$can be related by to the volume of the float, percentage of the float submerged, and the specific gravity of the fluid by the following equation:

$$F_b = V(\%V_{submerged})\gamma$$

Rearranging the equation for V,

$$V = \frac{F_b}{(\%V_{submerged})\gamma}$$

The force required to close the valve and the specific gravity remains constant. Therefore, by increasing the percentage of the float submerged, the size of the float can be decreased. The previous ellipsoid float that measures 10.6 cm by 12.7 cm needed to be 2% submerged. If the float can be submerged by 89%, it can be scaled down to 1 cm by 2 cm.

3. Previous work

Past LCDC designs assumed that the length of the small diameter tube was sufficient to ensure that the major head losses dominated the system. These designs also assumed that the linear relationship between the chemical flow rate and the major head loss would be maintained, as shown in the Hagen-Poiseuille Equation. However, during the spring 2011 semester, the LCDC team observed quadratic tendencies in the relationship between head loss and chemical flow (see spring 2011 Final Report Initial Laboratory Results section for an analysis of the experiments that produced these results). When the spring 2011 LCDC team observed these results, they designed a method to model the magnitude of the minor head losses and sought to eliminate their sources.

The summer 2011 LCDC team discovered that a large percentage of the minor losses originated from the curvature of the small diameter tube. To reduce this minor loss, the small diameter tube was straightened by using a PVC trough, which was done by moving the stock tank and constant head tank (CHT) from being mounted on a frame to being placed at a further distance away. Another method developed to minimize minor losses, which originate from expansions and curves, was to use larger barbed connectors than necessary for the inner diameter of the small diameter tubing used to ensure there were no flow contractions producing minor losses. This greatly reduced the minor losses throughout the system.

In fall 2011, the LCDC team experimented with connecting an intermediate tube between the large and small ID tubes to create a connection that increased the flow rate and generated new minor loss coefficients. They also devised a straight tube setup that allows water to go from 1/8in ID to 1/2in ID tube without expansion, decreasing minor losses. The team also tested the "T" design for drop tubes and found that it may not be necessary in plants with moderate flow rates. Finally, the team suggests if a 6" float is to be used, the slider weight must be reduced to reduce error if two single drop tubes are used . If a "T" design is used for high flow rates, then an 8" float should be used. The LCDC team also replaced the lever arm with a 2" wider arm so that operators can read the dosage easier since the dosing stickers will be less prone to damage by the slider screws.

The fall 2012 team focused on improvements to the lever arm dosing assembly, including an improved drop tube that reduced leakage and improved aesthetics. The lever arm design allowed more precise adjustments of the lever arm and the arm was anodized and engraved with the logo, scale, and labels. The spring 2013 team continued to make improvements to the LCDC setup. They designed a new coagulant dosing tube system, incorporating four dosing tubes and a PVC manifold systems, which allows for more dosing flexibility.

In spring 2013, the LCDC team improved the design of the dosing system by using a manifold with ball valves, which allowed each tube to be closed separately if needed. The manifold can accommodate an extra dosing tube to allow for flow to be adjusted or to allow for maintenance. The team also improved the design of the drop tube. They used a rigid PVC tube to allow for maximum free fall height ($73\,cm$) to ensure that water is present at the bottom of the drop tube, which will improve chemical conveyance. They experimented with the coating of the lever arm and found that powder coating is a better option than anodized coating. The new lever arm was fabricated by Hancock Precision and periodic table symbols (Al for the coagulants that are aluminum based and Cl for chlorine) were used as new, universal labels on the lever arm. Additionally, the team employed a turnbuckle mechanism for adjusting the height of the constant head tank.

Up until the summer of 2013, the designs for the CDC have been for higher flow plants. As a result of the new low flow stacked rapid sand filters being constructed in India, there was a need to optimize the design for lower flow systems. The summer 2013 team tested the effectiveness of using 1/16' dosing tubes to accommodate the low flow conditions for the plants in India. They tested with the maximum plant flow rate, $2.4\,L/s$, and maximum coagulant dose rate (100%), using only water. The results of this experiment showed that the size of the lever arm has significantly less effect on the performance of the Chemical Doser in comparison to the diameter of the tubing used in the PVC manifold. Thus the team fabricated a half size doser with a shorter lever arm that reduced the amount of material keeping the same performance level.

In fall 2013, the LCDC team fabricated three half size dosers and sent them to India with detailed instruction manuals. The effectiveness of the 1/16" dosing tubes was also tested. The team replaced the ball valves in the dosers with new ball valves that had fluoroelastomer seals instead of EPDM. The team then conducted experiments to test the effect of the ball valve's weight on the performance of the lever arm. The result was that there were no significant effects on the performance of the lever arm from the weight of the newly added ball valve.

4. Methods

4.1. Current Laboratory Set-up

The current set up was modified from the spring 2013 design based on the characteristics of the plants in India. There are currently two interchangeable lab setups being utilized. The first being a double lever-arm as used in Honduras and the second being a single lever-arm that was recently fabricated in the lab and used in India. In addition, the major changes to float valve, dosing tube diameter, and lever were made in summer 2013, as mentioned in the previous section. Extra tubing and pipes were eliminated to reduce the start up time, as well as to avoid bending that may lead to unwanted increase in minor loss. Parameters resulting in the current set up are shown below:

- Target plant flow rate: $2.4L/s$
- Chemical flow rate: $0.19ml/s$
- Maximum PACl dose: 2.0 mg/L

- PACl stock concentration: 25.7 g/L
- Dosing tube diameter: 1/16 in
- Dosing tube length: 0.81 m
- Smaller float valve and constant head tank

The system calibration method developed in spring 2013 was largely kept with some minor changes, including an improved bubble release method and utilization of the drop tube. Detailed calibration steps will be shown in discussion.

4.2. Chemical dose controller for plants in India

AguaClara is currently working with PRADAN and the Tata Foundation on two water treatment facilities in Gufu and Ronhe in addition to several other plants that are currently under construction. The communities in India are much smaller than the ones that AguaClara has previously worked with, thus requiring a treatment facility that has a much smaller plant flow rate. Consequently, the chemical dose controller needs to be modified to meet specific requirements in India as well as to improve its performance in future plants. There were two major changes in the chemical dose controller designed for low plant flow rates. First, the dosing tubes as well as other tubing used for connection were reduced in size and length to accommodate the lower flow rate. Another major change is made to the lever arm used to for dose adjustment. Since the source water in India is groundwater and, therefore, a low turbidity, there is only a need for the chemical dose controller to dose chlorine. As a result, a full size single lever was designed with a simpler fulcrum and more rigidity. These design changes will also be applied to full size and double levers in the future.

The chemical dose controller system includes many small connectors. The inconvenience of installation and potential for error in setup could affect the overall performance of the entire system. There were two main motivations for improving the in-lab packaging process. First, many chlorine resistant parts could not be locally sourced and second, it would be helpful to have many parts pre-assembled since local people are not familiar with the system. A packaging spreadsheet and a user setup manual have been developed to help facilitate the shipping and system installing processes. Two manuals have begun to be created. The first is a lab assembly manual for parts of the system that are to be shipped pre-assembled, such as the float valve, the manifolds, and the constant head tank. The second manual created is an in-country manual, for plant operators to use to assemble the chemical dose controller in an AguaClara plant. This manual with will utilized mostly by the current CDC team when assembling specific parts the the system, such as the manifolds. It contains the directions for complete assembly from start to finish, while the first manual only goes over how to finish the final assembly using the preassembled pieces. The packaging spreadsheet is an Excel spreadsheet designed to take input values including the desired chemical flow rate and concentration, diameter of dosing tubes, and number of dosers needed. It produces the quantity of each component based on Mathcad calculations. The user setup manual is written and will be packed with all the components to ensure that dosers can be set up by any person with minimum knowledge of the AguaClara chemical dose controller system.

4.3. Single Lever Design

A single lever was designed as a response to the demand for chlorinating systems where only one chemical is dosed in the treatment plants in India. The main considerations for designing the single lever include the placement of the fulcrum, the rigidness of the lever arm, the design of the slider, and the ability to make changes easily by the fabricator. The single lever must be designed so that the chemical flow is zero when plant flow rate is zero, i.e. there must be no flow when the lever arm is horizontal.

5. Results and Discussion

5.1. Float Valve

After visiting Honduras, the CDC team discovered that the cotter pin and carriage bolt were both susceptible to corrosion and eventually failed when used in chlorine. The float valve was taken apart to get a better understanding of the existing metal components and it was determined that the current design has a steel carriage bolt, a steel wing-nut, and a steel cotter pin. After consulting with Tim, it was discovered that there were no existing bolts or nuts of the required dimensions or material. The team contacted Kerick about possibly fabricating a float valve without non-corrosive parts and it was determined that the cost was too high for our budget. After meeting with Dr. Weber-Shirk, the team has decided to fabricate a new float valve with no metal components and a completely submerged orifice.

The newly designed float has a small PVC plate with two holes drilled into it. The two pieces of the float are held together with PVC screws and bolts as seen in the figure 1. Since the existing steel carriage bolt and steel wing-nut were 1/8" and the smallest size of PVC screws and bolts was 1/4", the holes in the float had to be drilled out to make them 1/4" diameter. The excess of material surrounding the hole allowed for this modification to take place without compromising the durability of the float. Aside from holding together the two parts of the float valve, the PVC plate also acts to align the float with the orifice horizontally.

The team discovered that a titanium cotter pin is a chlorine resistant alternative to the current steel cotter pin. However, the cost of these pins is higher than the cost of the entire float, making it an unfeasible option. After consulting with Dr. Weber-Shirk, it was concluded that the most cost effective solution is to send replacement steel cotter pins to the AguaClara plants and modify the rest of the float valve.

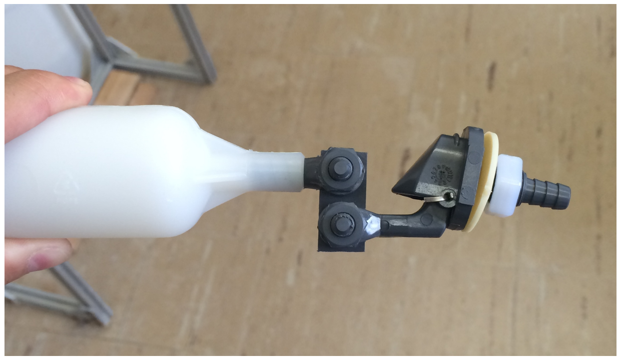

Figure 1: PVC Screws and Bolts on Float Valve

5.2. Single Lever Arm CDC Design

The single lever arm CDC assembly will be utilized in low flow plants that only require a chlorine doser. The single lever design is based on previous designs. The materials used and the basic dimensions such as the length of the lever are kept the same. However, the lever is made slightly thicker so that it is more rigid to withstand torque from the attached drop tube. The slider, that adjusts chemical dosage, has a space in the middle to allow readings of dose percentage. The drop tube is attached on the side to the right of the space at the same height as the fulcrum. The back of the slider is slotted to allow the drop tube to align with the fulcrum. A long rotating rod is needed in order to balance the torque generated by the weight of drop tube and lever arm on one side. In this design, the part of rod between the back of the lever arm and the far end of the box is able to rotate. The metal box acting as the fulcrum has been changed to a U channel in order to use less materials what was it before?. The Sketchup of the new fulcrum design is complete and attached below in Figure 2 below. These changes will be applied to new designs of both single and double levers.

The length of the new single lever-arm is 40 inches, which is the same length as the double lever-arm. The new slider, however, has different dimensions which can been in the figure below3.

5.3. Air Purge Component

One of the current problems with the CDC system in Honduras is that air is getting trapped inside of the dosing tubes and clogging the system during start up. To facilitate air removal from the dosing tubes, a wye-fitting was attached to the top of the PVC channel where the dosing tubes are connected, as is shown in Figure 8 below4. As can be seen from the figure, in one of the channels, a 1/4" tube connects the wye fitting to the lever-arm. This tube will carry the coagulant from the dosing tubes to the lever-arm where it will be added to the entrance tank. The other channel contains a plug which will be removed during the air removal process. Once the plug is removed and the system is open to

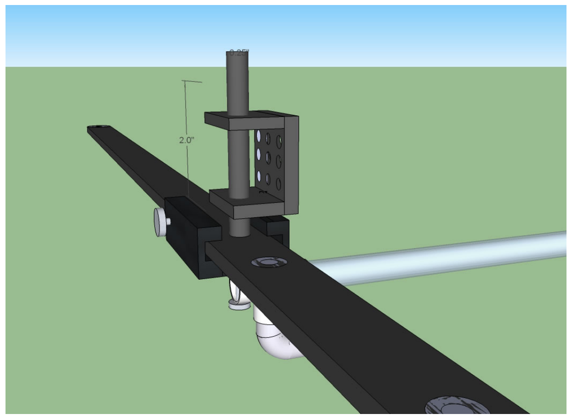

Figure 2: Design of new Single Lever Arm CDC

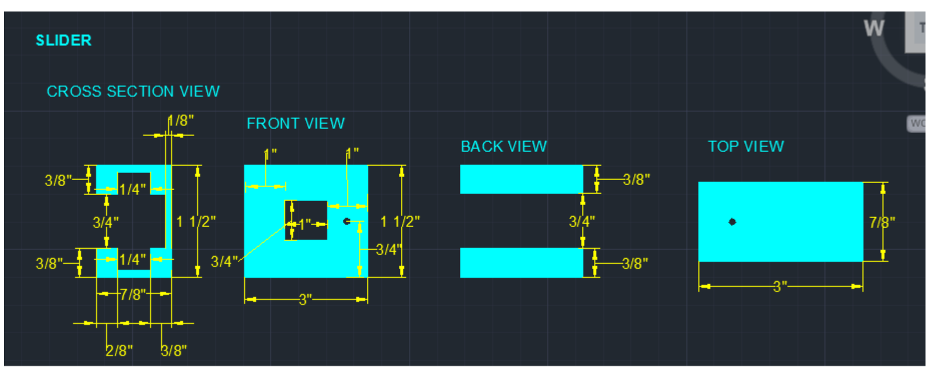

Figure 3: Single Lever-arm Dimensions

Figure 4: Y-channel Air Removal System

the air, all of the air that is trapped inside of the dosing tubes will move out of the system through the open channel. Air removal will be completed once coagulant begins to flow out of the open channel. At this point, the plug will be put back in place and the CDC system will be ready for operation. Since the wye fitting is located after the dosing tubes, the method of air removal should work for both the existing 1/16" dosing tubes and the 1/8" tubes used for higher flow rates.

5.4. Entrance Tank Float

The entrance tank float currently being used in AguaClara plants in Honduras is extremely heavy and bulky which makes it expensive to ship. An important task was to design a new float that was both lighter and cheaper while still functioning properly. The purpose of the float is to remain on top of the water in the entrance tank so that the CDC will correctly adjust the dosage of either coagulant or chlorine as the height of the water changes. One constraint in the design of the float is that it must be heavy enough to keep the chain connecting it to the lever arm in constant tension. Any slack in the chain would mean that the CDC is not dosing the correct concentration of coagulant into the entrance tank. A 6" diameter PVC rod was ordered and 2 cm thick disks was cut and hung on a chain off of one side of the lever arm. On the other side of the lever arm is an adjustable counterweight that balances the forces so that the float will remain on top of the water and keep the chain in tension. The new float weigh about 600 grams, which is enough weight to keep it from moving around due to water motion.

5.5. Items Catalog

The team has created an Excel document for future CDC teams to use. The document contains every single component used in the CDC setup, and the corresponding McMaster-Carr item identification number for each item. The excel file is called Items Catalog, and it is located in the AguaClara server. The file path to the excel file is smb://files.cornell.edu/EN/aguaclara/RESEARCH/Chemical Dose Controller/Spring 2014/Items Catalog.xlsx.

5.6. Height Adjustment System

The current height adjustment system for the constant head tank in the CDC laboratory setup utilizes an 80/20 design. However, this setup will not be feasible in other AguaClara plants due to cost of materials, shipping and complexity. The team brainstormed cheap and easy variations of the height adjustment system currently used in Honduras that can be replicated in the lab. The final design of the height adjustment is a simple system utilizing a pipe, a metal tee, and four couple hose clamps as seen in Figure 5 5. The metal tee is hose-clamped to the constant head tank, and is also hose-clamped to a pipe. The diameter of this pipe can vary, because the hose clamps can be adjusted.

5.7. Switching Components for Different Flow Rates

The team tested the system for switching the CDC components for different flow rates. This includes switching the dosing tubes, which the team has determined is easy and straightforward. For higher flow rates, the dosing tubes that run between the manifolds will be 1/8" diameter. If the flow rate decreased significantly or a different size of dosing tubes was deemed more desirable by the plant operators, the dosing tubes are easily removed. Depending on the diameter of the dosing tubes, the corresponding barbed fitting will be screwed into the manifold to fit the new size of dosing tubes. While switching components on the lab set-up, the team easily reconfigured the system from a 1/8" to a 1/16" set-up.

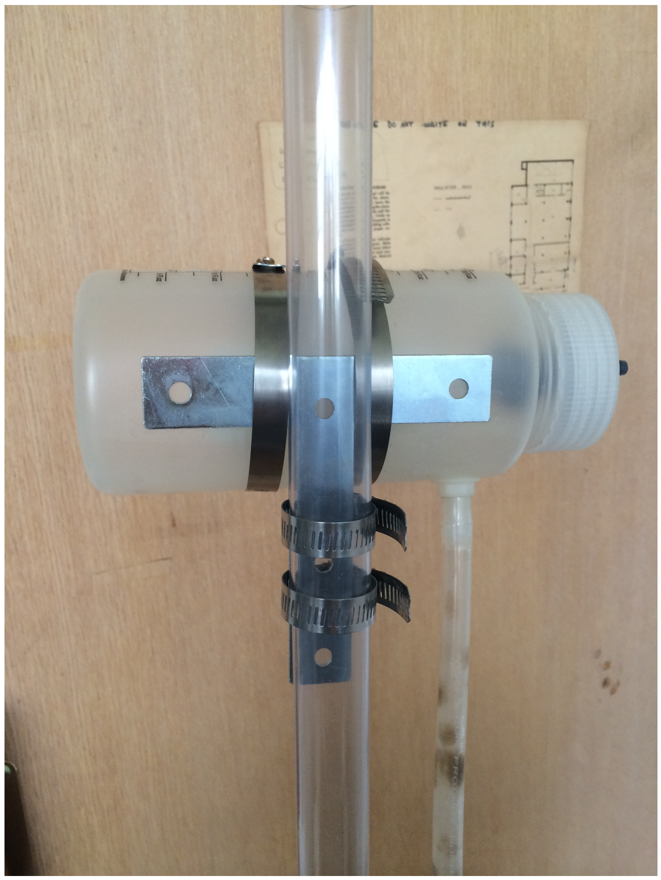

Figure 5: Height adjustment system for constant head tank

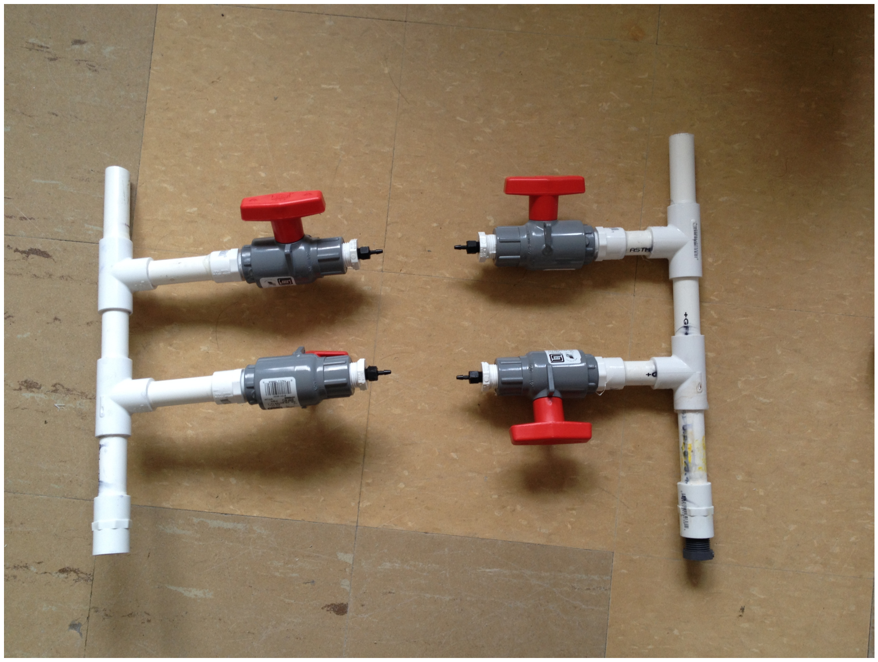

Figure 6: Pre-assembled Manifolds

5.8. Manifold Assembly

The team has created two manifolds for a CDC system that will most likely be shipped to India. The manifolds were assembled in the lab as part of a demonstration to show that the manifolds can be put together by someone unfamiliar with the system in a short period of time. The complete assembly was timed and took approximately 12 minutes.6

6. Future Work

6.1. Lab Testing

The new single lever arm has finally been fabricated. Next semester, the team will set up the lab with this new lever arm, and will begin testing the effectiveness of the wye channel to remove air bubbles, and if 1/16" dosing tubes are viable option for plants. Additionally, the team will run tests involving the calibration of the entire system. This specific test will involve the new single lever arm as well as the height adjustment system for the constant head tank that was designed this semester.

6.2. Shipping CDC Systems

The team has updated the CDC items catalog. The team will have to create two instruction manuals, one for future CDC team members and one for

AguaClara plant operators. The instruction manual for CDC team members will include the items catalog. It will also include instructions for which parts need to be assembled before shipping and how to fabricate them. The instruction manual for plant operators will match the updated design of the CDC system. These resources will be used in the future to aide in the shipping process and to help on-site CDC assembly.

7. References