Chemical Dose Controller, Fall 2014

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Abstract

The Chemical Dose Controller is a device that maintains a constant chemical dose as the plant flow rate changes. This semester, the Chemical Dose Controller team has started doing research on chlorine compatibility with the constant head tank. Part of this assignment includes exploring alternative CHT designs in hopes of maximizing durability and efficiency while minimizing costs. The team is also considering scaling the CDC system down by looking into the single lever arm design. The team has begun recording these adjustments in a CDC assembly manual for future CDC teams that includes photos and item lists. Finally, the team has reached out to the team in India, in hopes of working out a cost effective and reliable system for future shipments.

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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. With respect to the manifold system (Figure 1), the relationship between major head loss and the chemical flow rate is given by the Hagen-Poiseuille Equation.

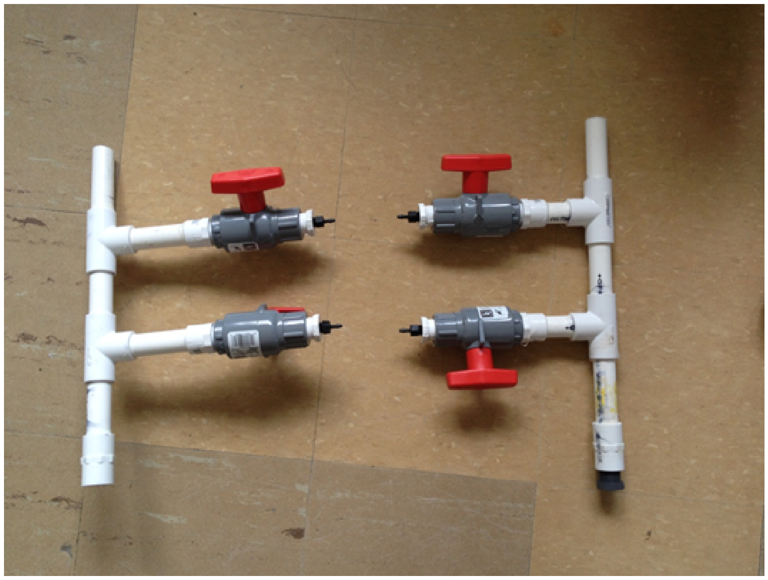

Figure 1: CDC manifold system to which these governing equations refer to.

The chemical flow rate (Q_C) is a function of major head loss (h_f), the diameter of the tube (D_{Tube}), the kinematic viscosity of the solution used, and the length of the small diameter tube (L_{Tube}).

$$Q_C = \frac{h_f g \pi D^4{}_{Tube}}{128 v L_{Tube}}$$

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 increases as shown in the following equation.

$$h_f = \frac{128 Q_c v L_{Tube}}{g \pi D^4{}_{Tube}}$$

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 below.

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

Substituting equations for major and minor losses results in the Equation below. 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.

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

Sizing the Float Valve Orifice in the Constant Head Tank

The maximum coagulant flow rate, Q_{Coag}, is 2.879 mL/s for a plant flow rate of 12 L/s (as implemented in Tamara and Aluaca), resulting in a maximum coagulant dose, $C_{CoagMax}$, of 40 mg/L with a stock coagulant concentration, $C_{CoagStock}$, of 166.7 g/L, as governed by the following 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 using 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 value the minor head loss due to the orifice of the float valve is Δh, which is 0.25 centimeters, as shown by the equation below.

$$\Delta \mathrm{h} = \frac{1}{2\mathrm{g}} \left(\frac{1}{\left(\frac{\mathrm{d}}{2}\right)^2 * \frac{\pi \Pi vc}{\mathrm{Q}_{\mathrm{Coag}}}} \right)^2$$

Another factor that was considered were the minor losses from the tubing. We determined that these minor losses were insignificant, and therefore they were not included.

The head loss due to major losses was calculated using a MathCAD file named ConstantHeadTankHeight located in the Fall 2014 CDC folder. The major head losses from the assembly - which was calculated using the Hagen-Pouiselle equation - are 5.7 centimeters, therefore, the total head loss is 5.95 centimeters. This means that the stock tank must be located at least 5.95 centimeters above the constant head tank to overcome the headloss and have the laboratory system deliver the appropriate flow rate.

Float Size in Constant Head Tank Float Valve Assembly

The float valve assembly of the LCDC consists of a flat rod and valve in a clear horizontally placed Nalgene bottle with length 6’ ¾” (17.145 cm) and diameter of 3’ ¼” (8.255 cm).The size of the float can be mathematically determined by using a series of force balances. The torque equation:

$$\tau = rF_b$$

where F_b is the force applied to the rod by the buoyancy of the water. F_b can be related 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 specific gravity remains constant. However, the force required to close the valve varies with the height of stock in the stock tank; the fuller the tank, the greater force required to close the orifice, and therefore more of the float must be submerged to provide that force. This variation must be accounted for during calibration.

The accuracy of the dosing system is reliant on the cross-sectional area of the float at the water surface in the constant head tank. When a float with a large cross-sectional area moves up or down to open or close the orifice, a smaller water height change is necessary to submerge the float enough to exert the necessary force on the orifice than a float with a small cross-sectional area. This means that a float with a large cross-sectional area is more sensitive to water height changes in the CHT than a float with a smaller cross-sectional area, which means that the float with a larger cross sectional area will maintain the water level in the CHT more accurately as the stock tank empties. The force balance below shows the balance between the force of the float and that of the stock from the stock tank:

$$F_{float} = P_{water} * A_{orfice} = F_{buoyant} - mg$$

Introduction

The Chemical Dose Controller (CDC) is an important component of an AguaClara plant. It is a simple mechanical device which approximates 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 potential flow of the chemical added is set by the plant operator by using the slider, and the system automatically adjusts with the incoming flow rate.

Previous Work

Spring 2011

- 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).
    - Designed a method to model the magnitude of the minor head losses and sought to eliminate their sources.

Summer 2011

- Discovered that a large percentage of the minor losses originated from the curvature of the small diameter tube.
    - 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.
    - Used larger barbed connectors than necessary for the inner diameter of the small diameter tubing in order to ensure there were no flow contractions producing minor losses.

Fall 2011

- 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.
- Devised a straight tube setup that allows water to go from 1/8in ID to 1/2in ID tube without expansion, decreasing minor losses.
- Tested the “T” design for drop tubes and found that it may not be necessary in plants with moderate flow rates.
- Replaced the lever arm with a 2” wide arm so that operators can read the dosage easier since the dosing stickers will be less prone to damage by the slider screws.

Fall 2012

- 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.

Spring 2013

- Designed a new coagulant dosing tube system, incorporating four dosing tubes and a PVC manifold systems, which allows for more dosing flexibility.
- 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.
- Improved the design of the drop tube by using 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 - improves chemical conveyance.
- Experimented with the coating of the lever arm and found that powder coating is a better option than anodized coating.

Summer 2013

- Tested the effectiveness of using 1/16’ dosing tubes to accommodate the low flow conditions for the plants in India.
    - Tested with the maximum plant flow rate, 2.4 L/s, and maximum coagulant dose rate (100%), using only water.
    - Results 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.

Fall 2013

- Fabricated three half size dosers and sent them to India with detailed instruction manuals.
- Replaced the ball valves in the dosers with new ball valves that had fluoroelastomer seals instead of EPDM.
    - 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.

Spring 2014

- Created a single lever arm chemical doser, designed as a response to the low flow plants that require only a chlorine doser, such as in India.

- Fabricated 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.
- Created a new entrance tank float which is a 6” diameter PVC disk that is 2 cm thick, 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.
- Created a height adjustment system for the new constant head tank. The final design of the height adjustment is a simple system utilizing a pipe, a metal tee, and four couple hose clamps.

Methods

Rusting Eye-Bolt Experiment

<u>Purpose</u>: The purpose of this experiment was to explore different metals and test for water resistance.

In the case of material degradation due to water /chemical exposure, research alternative materials and test their resistance in water (or the corresponding chemical). Leave the material in liquid for at least 7 days and record any observations over time. Specifically, look for color changes and/or precipitates on the material. The ideal material will show no change during this testing period.

10 Centimeter Headloss experiment

<u>Purpose</u>: The purpose of this experiment was to determine accuracy and consistency of flow rate from the single lever arm. If the results are consistent, then it can be concluded that they are reliable.

<u>Procedure</u>

1. Calibration

The purpose of calibration is to ensure accuracy. The experiment must contain the point (0, 0). This represents the point when the constant head tank is exactly leveled with the lever arm, thus there should be no flow rate. Any amount of increase from this position will lead to a flow rate. The CDC team has attached a level to the lever arm. This stop indicates when the lever arm is at position 0 cm, as seen in Figure 2. The constant head tank should be at this level to ensure a flow rate of 0.

Figure 2: The stop that stabilizes the lever arm so that it is exactly parallel with the ground. This acts as a reference point for further experiments and ensures consistency.

If in the case there is flow rate at the lever position of 0 cm, the constant head tank needs to be adjusted. Do not move the lever arm.

a. Slide the constant head tank up or down until the flow is barely drips.
b. Wait one minute and observe flow.
c. With minor adjustments, move the constant head tank down until the flow stops
d. Repeat if necessary

NOTE: They key is minor adjustments. If the adjustment is too severe, then the calibration will be off. The goal is to get the constant head tank just right so that a flow happens with the slightest tilt of the lever arm.

> **Before Testing**: Make sure the slider is locked on the 100 cm position on the lever as a controlled variable. See Figure 3 below:

Figure 3: The slider on the lever arm should always be set to the position 100 cm to ensure accuracy of results.

2. Testing Flow Rate

   a. With the manifold closed (shutting off one manifold is enough), adjust the lever arm to the 1 cm position.
   NOTE: the level contraption attached to the lever arm will position.

   b. Open the closed manifold and begin timing when the first drop comes out
   NOTE: It may take a few moments for the flow to actually come out. Do not count these moments in the time.

   c. Close the manifold after 2 minutes of dripping and stop the timer.

   d. Adjust to the next position and record the data.

3. Additional Notes and Tips

   a. Make sure the stock tank is always at full capacity during testing. If the water level drops during the experiment, then the calibration will be off.

   b. During the testing in the Fall 2014 semester, the drop tube was removed during testing; Measurements taken straight from what dripped out of the T connector and then measured in a graduated cylinder

   c. When testing flow rate, there may be an initial ‘puddle’ that comes out first. This is water lodged in the tubing left over from the prior trial. Subtract this quantity from final result, as it is not a part of the flow rate

   d. Head loss will have a relatively linear relationship if it is dominated by major losses. This is what we are trying to prove in the experiment. Include the point (0,0).

Results and Discussion

Setup Manual

The team has started to create a new CDC system setup manual for future CDC teams in order to easily create and ship required materials. The entire system is broken up into many different parts, and individual materials for each part are listed. Additionally, any information on fabrication of a piece of equipment, such as the manifold, is included and clearly specified.

Since many of the tasks for this semester involve redesigning certain aspects of the CDC system, the setup manual cannot be completed until the system designs are finalized. The goal for the setup manual is for it to reflect the most current design of the CDC system so that implementation in the lab, and in the field is quick and easy.

The current Setup Manual.

Constant Head Tank

Several options for a new constant head tank design were assembled and tested for ease of use in terms of how easily cleaned the CHT would be. A table comparing the final three designs can be seen below.

Table 1: A comparison of the current options for a constant head tank design.

	Nalgene Bottles	**Clear PVC tubing with PVC caps**	**Trough- Design 2.0**	**Unknown Option 4**
Description	Current design. CHT lies on its side with float inside. Chlorine is in contact with all parts.	Replace Nalgene components with all Chlorine resistant material (caps, tubes).	Have white PVC pipe horizontal with part of the top removed to make a trough. Completely seal sides (leak proof). Covered opening is at top of tank.	A currently undiscovered solution that encompasses all of the characteristics of a feasible CHT while being simple and cost-effective.
Pros	- Cheap and replaceable. - Easy to take apart.	- Chlorine resistant. - Easy to take apart.	- No leaks. - Chlorine resistant.	??

		- Lifespan: ??	- Can reach into CHT for cleaning.	
Cons	- Cap and float are not resistant to chlorine. - Leaks from the bottom. - Lifespan: 1-2 years	- Very high cost - Some leaking from threaded cap is possible. - Heavy.	- Manual assembly. - Open to air? - Heavy.	??
Price Range	$11.40	$23.72	$10.75	??

The practicality of each design was assessed based on the following factors: cost (including shipping cost dependent on weight), ease of use, lifetime with respect to chlorine compatibility, and simplicity. After extensive research and discussion with Monroe, it was determined that the most practical design was the original Nalgene Bottle that has been used in both Honduras and India. Through correspondence with AguaClara engineer Drew Hart, the CDC team determined that the Nalgene bottles do not seem to fail when used in contact with chlorine and that only the lids fail after approximately two to three years. Because the cost of the Nalgene bottle is low ($9.80 a piece), it could easily be replaced every few years once it reached failure. Furthermore, this design can be used in both India and Honduras plants.

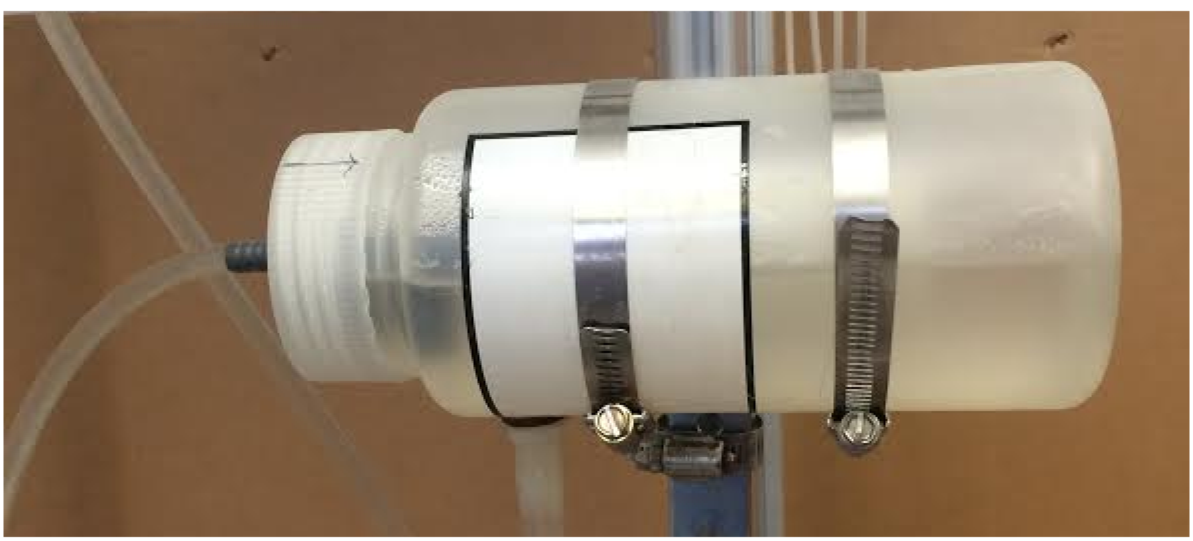

Figure 4: Nalgene Bottle Design

While the other PVC options in the table would provide a longer lifetime, they require fabrication and are quite costly, making these designs impractical for use in AguaClara plants. While testing the trough design, while quite plausible in theory, the team ran into issues involving the size of the trough. Since only the top ⅔ of the trough could be removed due to the chance of either chlorine or coagulant spilling out of the top, the design was not large enough to allow a person to remove the float through the opened top; this was the intended use of this design. In order for the CHT to be large enough to allow a hand inside, the diameter of the tank would need to be drastically increased. This would not only make the CHT much larger than necessary, but it would also increase the cost of each CHT.

The cost alone of the second design Table 1 (PVC tubing with PVC caps) made this option unrealistic. Each CHT with this design would cost almost $24.00 a piece. Considering that most plants in Honduras use four CHTs, this cost would be quadrupled. Therefore the final cost for each plant would be more than double when using the PVC design ($96.00) versus using the Nalgene bottle design ($46.00).

The cost of the finalized design is $11.40 for the Nalgene bottle and fittings (½” barbed through wall fitting and brown viton fluoroelastomer o-ring).The mini float valve, as seen in Figure 5 and Figure 6 has the approximate cost of $12.88, which will be used in each CHT.

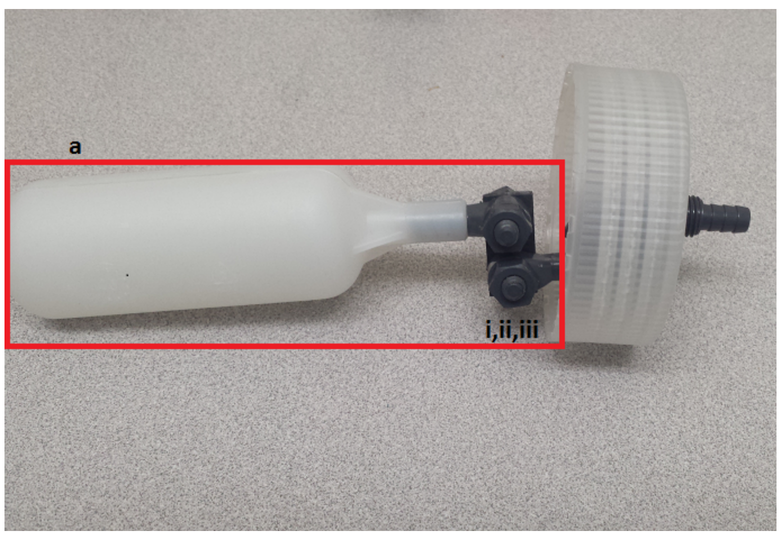

Figure 5: Profile of the fabricated mini-float valve.

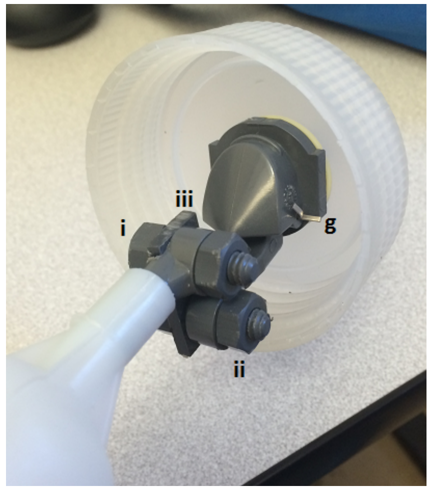

Figure 6: View of the added PVC components to the mini-float valve.

Eye Bolt Corrosion Test

Over the summer the eye bolt attached to the entrance tank float rusted - as seen in Figure 7 - even though it was barely in contact with water. After extensively researching different material properties the CDC team concluded that type 316 stainless steel would be a feasible material to be used in both India and Honduras. Type 316 stainless steel does not rust or corrode and is relatively low cost at $1.45 per eye-bolt. The chain did not show any systems of rusting, and therefore was not replaced.

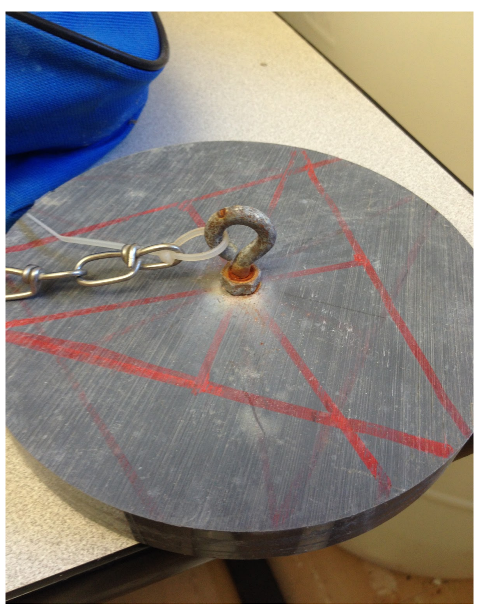

Figure 7: Rusted eye-bolt from Spring 2014 semester.

An experiment was performed in order to reiterate the research findings. A type 316 stainless steel eye-bolt from McMaster Carr, as shown in Figure 8, was submerged in water for the period of one week.

Figure 8: Type 316 stainless steel eye-bolt before experimentation.

After one week the eye-bolt was removed and checked for any indications of rusting or corrosion and none were found, as seen in Figure 9. It was thus concluded that this material is suitable for use as part of the entrance tank float.

Figure 9: Eye-bolt after one week submerged in water.

Single Lever Arm: 10 Centimeter Head Loss Testing (1/16th inch)

Background: In the spring semester, the CDC team created a single lever arm to replace the current double lever arm. The advantages of the single lever arm are that it is much lighter (ease of transport) and it can be merged with another single lever arm to form a double lever arm (single lever arms can be used for smaller dosing systems while double lever arms can be used for larger dosing system)The head loss from the single lever arm is displayed in the following table:

Table 2: Head loss from the single lever arm. Tubing tested was 1/16th inch

Headloss (cm)	Flow Rate (mL/2 min)	Flow Rate (mL/min)
0	0	0
1	3.5	1.75
2	6.9	3.45
3	10	5
4	12.5	6.25
5	16	8
6	18.1	9.05
7	21	10.5
8	23.6	11.8
9	26.75	13.375
10	29.2	14.6

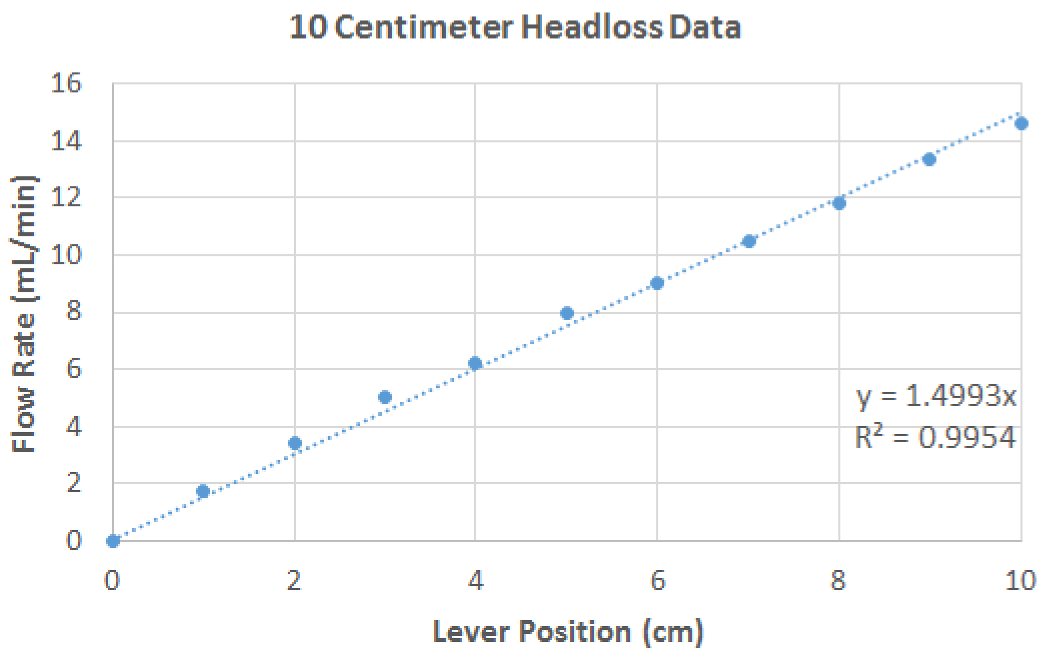

Figure 10: Graph showing results of the 10 cm headloss experiment.

From the results, it can be concluded that the flow rate varies linearly with the lever arm position about the constant head tank. Therefore, with these results, it can be concluded that major headlosses dominate over the minor headlosses. It can also be concluded that the half sized single lever arm that was designed last semester functions properly, and can be utilized in AguaClara plants.

Further Experimentation

- Can the precision of the level on the lever arm be improved?
- Is there a way to remove the water that builds up in the t connector from previous trials?
- Is there a way around manually adjusting the Constant Head Tank?

Shipping and Handling to India

The team is currently looking into cheap, reliable shipping methods to the AguaClara members in India. Currently, the process of transporting parts is via air-line baggage. This method limits the quantity and size of items allowed as well as how often materials can be shipped. The rates found are to be:

Table 3: Shipping Rates to India

	UPS	Fedex	USPS	ipsparcel.com	shipito.com	Baggage
10 lbs	256.71 USD	267.30 USD	78.25 USD	163.13 USD	64.84 USD	25 - 50 USD
20 lbs	256.71 USD	434.92 USD	78.25 USD	X	X	25 - 50 USD

The options listed provide an estimate for shipping overseas. Whereas the first 5 methods can be shipped at any time, they are extremely restricting in terms of price and load. Furthermore, the reliability of shipping to Ranchi is also questionable as there are no direct post office transfers. As of now, the airline baggage is the cheapest, most reliable, and largest option. The CDC team will determine what parts can be obtained in the vicinity of Ranchi and what parts must be imported. Additionally, the team has looked into alternatives to current large equipment. For example, instead of using a three-foot long clear PVC drop tube, the team has discussed using a flexible tube, to make shipping more cost efficient. From there the team can determine exact package dimensions, weight, and cost in the case that airline baggage shipping is not an option.

Air Removal System

In the Spring 2014 semester the CDC team developed an air removal system that implemented a wye channel where one end led to the level arm while the other was plugged. Once the system was running, the plugged channel was opened and all of the air trapped in the dosing tubes moved out of the system through the open channel. Air removal was completed once coagulant - or water in the case of our experiment - began to flow out of the open channel and at this point the channel was plugged to prevent excessive leaking.

This original design was adequate until it was decided that push-to-connect pieces are inappropriate for AguaClara plants since small parts can be easily lost, especially if they are easily disconnected. For this reason the CDC team was tasked to redesign the air removal system this semester. Initially it was thought that a barbed-wye fitting could be used to simply replace the push-to-connect wye channel but this would also require a small “plug” to be used to close one of the channels. Extensive research was done at this point by the team to find an already existing solution to the air removal problem. Since the diameter of the doser tubing (1/16” for the smallest size) is similar to tubing used to remove liquid from a person’s lungs during surgery, it was through that a medical pump attached to one end of the doser tubing could be a viable option. However, since most medical pumps were costly or required some source of power they were not chosen as the best solution. Another option was to use a medical syringe to “pull” the air bubbles from the tubing. Issues with this were that it was difficult to determine the diameter of the syringe and if it would be possible to make an air-tight attachment between the syringe tip and the doser tubing.

After extensive research into a variety of options it was finally determined that an air removal system is unnecessary for the current design of the dosing tubes. By removing the dosing tubes, re-connecting them, and then running the entire CDC system the CDC team saw that air bubbles actually are removed naturally by the drag force of the liquid travelling through the tubing. This was true for both the ⅛” as well as the 1/16” tubing. Unless the current design changes or problems arise in either India or Honduras, an air removal system - based on laboratory evaluations - has been deemed unnecessary.

Future Work

The team will continue to work on the CDC setup manual as improvements continue to be made to individual parts of the system, such as the entrance tank float or the dosing tube. The team will determine the flow range for the mini float valve and then design for higher flow rates using a larger float valve. The team will also focus on stabilizing the entire CDC design, as well as lower the stock tank height to calculated parameters, and test the reliability of this minimum height. Finally, the team will continue testing headloss, changing variables such as different size tubings and different slider positions.

Next Semester Work

1. Make system easier to install in field
   a. Update pictures to reflect current designs. Make manual more readable and easy to understand.

   b. Have team assemble CDC from current instructions/guidelines to get a better idea of setup in the field. Document problems, confusions, etc.

    a. Work with May and Guneet about problems encountered during setup in the field.

2. Assemble and test all the components for chemical dosers of different flow rates.

    a. Assemble two doser systems using the current parts list and verify that everything works well. Propose improvements, test them, and then create CDC kits that are ready to ship. Determine the price per kit.

3. Figure out the flow breakpoints in the design that result in selection of different tubing sizes or different number of tubes.

4. Test units at stock concentrations used at AguaClara facilities.
    a. Evaluate based on errors in dosing, failure modes, longevity, and any perceived operational challenges based on experimentation.

5. Determine the flow range for the mini float valve and then design for higher flow rates using a larger float valve.

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