Chemical Dose Controller, Spring 2015

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Abstract

The Chemical Dose Controller is a device that maintains a constant chemical dose as the plant flow rate changes. After working alongside the foam filtration team in El Carpintero, Honduras this past January, the CDC team has changed the lab set-up to be more reflective of the systems in the field. Specifically, the major head loss element was changed to be vertically-oriented instead of horizontal to decrease the footprint of the CDC system.During the Spring 2015 semester, the CDC team will run a variety of experiments with the new system including head loss testing, determining flow breakpoints, and testing units at stock concentrations. In addition to testing the system through a variety of experiments, several design changes will be looked into this semester. This includes tasks such as making the constant head tank from locally available items in Honduras, as well as making the constant head tank chlorine resistant. Finally the team is is compiling a system of equations to convert the CDC system into a modular, packaging item for future shipment. With design changes in mind, a major goal of the CDC team this semester will be to create an assembly manual and parts-list.

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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 despite plant flow changes. The CDC consists of a calibrated lever arm with a slider that the operator can use to adjust the dose of the chemical based on the turbidity of the influent water.

The unique design 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 dose of the chemical added is set by the plant operator by using the slider, and the system automatically adjusts with the incoming flow rate to maintain a constant dose.

Literature Review

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. 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. Image taken at an AguaClara plant in Honduras.

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.

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

By substituting equations for major and minor losses, the expanded total head loss equation is formed below. The CDC system is designed so that the first term, which is the contribution due to major loss dominates the second term or the contribution due to minor loss. The major head loss element (MHE) of the CDC system allows for major head losses to dominate by utilizing two long segments of straight tubing which provide shear (see Figure 3). This is done to maintain a linear relationship between H_{Total} and Q_c.

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

Sizing the Float Valve Orifice in the Constant Head Tank

In order to demonstrate the following equations, sample parameters from the AguaClara plant in Tamara are used (i.e. flow rate)The maximum coagulant flow rate, Q_{Coag}, is 2.9 mL/s for a plant flow rate of 12 L/s 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 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 head loss due to orifice equation below:

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

Another factor that was considered were the minor losses from the tubing. However, since the systems are designed as to mitigate the head loss due to minor losses, they were not included in the calculations.

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:

$$\tau = rF_b$$

F_b is the force applied to the rod by the buoyancy of the water and 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 needs. 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:

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

Previous Work

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.

Fall 2014

- Performed an experiment with the stainless steel type 316 eye-bolt on the entrance tank float that concluded it would not corrode when exposed to water.
- Performed a 10 cm head loss test with 1/16th inch tubing. This data collected from this experiment was graphed and reaffirmed the linear relationship between level position and flow rate.
- Constructed a method for calibrating the lever arm in the CDC system.
- Researched Constant Head Tank design alternatives and conducted a cost benefit analysis of each iteration

Additional previous work dating back to Spring 2011 can be found on the Google Drive.

Methods

Reconstructing the CDC System

Current Design

As of Spring 2015, the Chemical Dose Controller team has relocated. Thus, the original design was deconstructed and moved. The team has reassembled the system. However, this time, the team has made certain adjustments to the overall design in order to improve the CDC system. First and foremost, the team is hoping to compress the system overall for spatial efficiency.

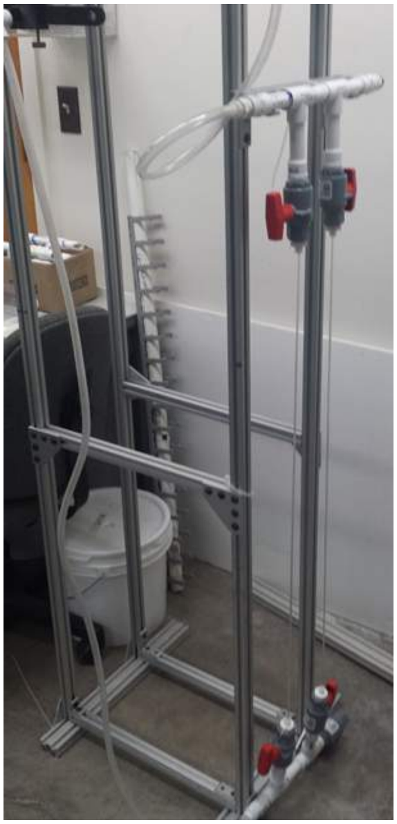


Figure 2: Manifolds are oriented vertically for spatial efficiency.

Because the manifolds were originally oriented horizontally, this required the entire system to span a distance of approximately 7 feet. However, this semester, the team has changed the design so that the manifolds run vertically (Figure 3). Furthermore, the team has included sliders throughout the CDC apparatus. These parts allow for easy manipulation of calibration and/or testing. For example, when testing for higher flow, the distance between the manifolds must be larger. With the sliders, these adjustments can be made with ease (Figure 3).

Figure 3:The sliders that the manifolds sit on. This piece slides up and down the system, which assists the with adjusting the manifold length.

Another alteration that was implemented in the new design was the location of the lever arm. From previous semesters, the lever arm was located on a separate system, approximately 7 feet from the constant head tank. This distance is illustrated in Figure 4.

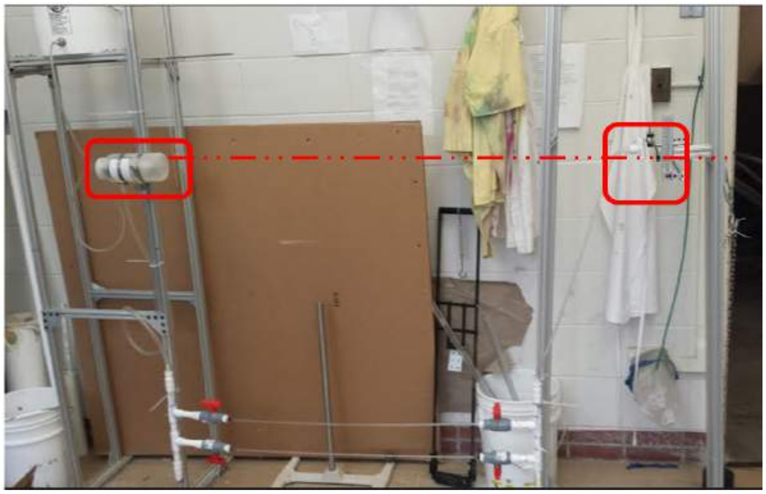


Figure 4: CDC set up for Fall 2014. Note the distance between the CHT and lever arm.

With the current design, the location of the lever arm is significantly closer to the CHT, while performing the same function. The current system is now significantly more spatially efficient (Figure 5) compared with previous designs. This smaller, more compact CDC system uses the same length dosing tubes as the previous semester, but spans roughly only 50% of the previous design. The team plans to validate the design parameters to ensure accuracy in future weeks. One final addition was the inclusion of the calibration mechanism attached perpendicular to the lever arm. This calibration identifies where the zero mark on the lever arm is, and is used to measure the headloss.

Figure 5: New CDC design of Spring 2015

Finally, the team has stabilized the design. In previous semesters, the system was constructed with vertical beams upon two parallel beams for a base. However, because there was no additional support connecting the vertical beams together, the system overall was unstable and shaky. The team has connected support beams and added additional support to hold up the stock tank. All the new additions are able to slide up and down with minimum adjustment hassle, which will ultimately aid in setting future parameters for testing.

Troubleshooting

The team continues to make modifications to the current CDC system. A new CHT replaced the old CHT (as will be discussed in later sections). Also, the tubing connecting the manifolds was changed so that the CHT now connects to the bottom of the manifold while the lever arm connects to the top of the manifold. This was done so that the pathway of the water flows upwards through the manifolds, and thus will help reduce the amount of air bubbles lodged in the system; air is able to flow up and out of the tubing along with the water as opposed to being pushed out the bottom. A problem found during testing was that the fluid did not effectively flow out of CHT into the manifold. The team believed that this was due to the design of the constant head tank itself, as the water level within the it did not fully reach the exit opening leading to the manifolds. To address this issue, the float inside the CHT was modified to be smaller and placed at a higher position. This allowed the float to have more mobility without hitting the roof of the CHT. This modification also allowed the water level inside the CHT to be raised. Once the water level was raised, the flow appeared more steady and reliable. The team also changed the size of tubing between the two manifolds from 1/16 inch to ⅛ inch. This was done to allow a greater fluid flow throughout the system, which was later confirmed by testing results. Finally, the team changed all additional tubing (i.e tubing connecting CHT to manifold and manifold to dosing tube) from ¼ inch to ½ inch tubing. The motivation behind this was to keep the system standardized and to reduce head loss. Previously, when the team used ¼ inch ID tubing throughout the system, the team found the overall flow rates to be unlinear. For example, when the team doubled the number of dosing tubes, the flow rate only increased by 140%. It was speculated that smaller tubing lead to more lead loss, which then resulted to less flow. With the switch to ½ inch ID tubing, the team saw greater and more linear rates. For example, when the team doubled the number of dosing tubes, the flow rate increased to around 200%.

Redesign the Constant Head Tank

The design of the Constant Head Tank (CHT) has been an issue in Honduras for several years and has been researched by the CDC team for the past few semesters. The CHTs used in Honduras are locally-sourced tupperware containers fitted vertically. Using these containers brings two main concerns: (1) the containers are not chlorine resistant and require frequent replacement since they degrade rapidly, and (2) since the CHTs are attached vertically, the mini-float valve used in the design must be small in order to fit inside. This means that the cross sectional area at the liquid's surface plane is smaller than the longer float-valves used in the labs and therefore the system is less accurate. Furthermore, the float-valves in San Nicolas (as illustrated) are turned incorrectly in order to fit; this makes them work much more inaccurately. Both of these concerns are illustrated in Figure 6 below.

Figure 6: Current CHT tupperware design implemented in Honduras (San Nicolas). Some chlorine stratification can be seen.

While testing the CDC system in El Carpintero, Honduras (see “El Carpintero” section for more information on this project), it was discovered that the coagulant in Honduras “settles-out” if not continuously mixed (see Figure 7). This stratification is thought to be due to the fact that the coagulant available in Honduras is a different chemical makeup of that used in the labs. The main issue is that the tubing which leads to the MHE is attached to the bottom of the CHT and therefore solid particles of coagulant are drawn into the rest of the system which could cause blockage or possible discrepancies in coagulant concentration entering the influent.

Figure 7: Stratification of coagulant as seen in Honduras.

All of the issues described above were driving factors in the design change of the CHT.

Design Characteristics

The new CHT was designed with the following characteristics in mind:

- Chlorine resistant: the “body” of the CHT as well as the mini-float valve and fitting will be completely chlorine resistant.
- Transparent: the operator will be able to open the CHT easily to see if the system is working correctly and if maintenance is required.
- Stratification control: the design of the CHT will be so that any coagulant stratification will not affect the efficiency or effectiveness of the system.
- Locally-sourced: all materials can be found and purchased locally in Honduras. This will reduce issues associated with shipping materials from the United States.

Current Design

The current design of the CHT utilizes a 3” PVC tee as the main body which is situated horizontally. The float valve is attached to a PVC plug on one side via the through-wall barbed fitting built into the valve itself. On the opposite side of the float is a hex bushing that attaches to the MHE (see figures below).

Figures 8a, 8b: From left to right: (a) the new CHT design housed by a 3” PVC tee, (b) aerial view of the mini-float valve inside of the CHT.

A full materials list available from McMaster-Carr is shown below:

Table 1: Parts list for the current CHT design.

Part Description	Part Number	Quantity	Price	Purpose
(1) Standard-Wall White PVC Pipe Fitting, 3 Pipe Size, Tee, Socket Female x NPT Female x Socket Female	4880K399	1	11.53	The main component of the CHT; "the body"
(2) Drain, Waste & Vent Standard-Wall White PVC Fitting, 3 Pipe, Square-Head Plug, NPT Male, Schedule 40	2389K79	1	3.63	Will go onto the threaded end and will be easily removed to exam the inner parts of the CHT and for cleaning access.
(3) Standard-Wall White PVC Pipe Fitting, 3 Pipe Size, Plug	4880K849	1	4.46	Will be cemented onto one side. A hole will be drilled into the center for the float to be attached (thru-wall barbed fitting).
(4) Standard-Wall White PVC Pipe Fitting, 3 Pipe End Male x 1 NPT Female, Hex Bushing	4880K222	1	3.23	Cemented to the side opposite the float; used to connect to MHE.
(5) Standard-Wall White PVC Pipe Fitting, 1 NPT Male x 1/2	4880K348	1	1.25	Used for compatibility/sizing reasons to allow attachment for

NPT Female, Threaded Hex Bushing				correct barbed fitting for system.
(6) Durable Nylon Tight-Seal Barbed Tube Fitting, Straight for 1/2" Tube ID x 1/2 Male Pipe Size	5463K469	1 (packs of 10)	0.82 (8.16 for 10)	Tubing will connect to barbed fitting that runs to manifolds (MHE).

The total cost for the new CHT system (not including the mini-float valve which is approximately $12.00) is under $25.00 which seems reasonable. Since the entire CHT (not including the cotter pin on the mini-float valve) is made from PVC, it is chlorine resistant. Furthermore, since the attachment leading to the MHE is located on the side approximately 1.5” above the bottom, it will be above the coagulant stratification and will not draw solids into the system. While the materials in Table 1 are those available in the United States, the original idea for the new CHT design was made in Honduras by a group of AguaClara students and all of the materials were found to be locally available. This means that the price of the CHT design might vary when locally-sourced materials are used, but shipping costs will no longer be an issue.

Float-Valve Redesign

One of the main issues with the new CHT design was that the mini float-valve could not be easily removed for cleaning or maintenance. The first step to solving this concern was to replace the 5” float with a smaller 2.5” float (of roughly the same diameter and shape) that could more easily fit through the top opening of the PVC tee. The new float can be seen in the figure below.

Figure 9: Comparison of the old 5” float (top) and the new 2.5” float (bottom).

Another issue with removing the mini float-valve was that the through-wall barbed fitting was threaded into the hole drilled in the center of the PVC plug. This meant that the entire mini float-valve had to be unscrewed from the cap by putting a hand inside the PVC tee before it could be removed. To make this process easier, the hole was drilled out to remove the threading so that the mini float-valve could simply be pushed or “tapped” through for removal.

Figure 10: The barbed fitting connection originally screwed into the PVC plug.

Several experiments have been run since the smaller float-valve was implemented. Each of the tests aimed towards measuring the head loss (lever-arm position) versus flow rate of the system resulted in a linear graph; this means that implementing the smaller float-valve did not disrupt the desired linear relationship between flow rate and dosage.

Flexible Drop-tube Unit

Several design changes were made to the drop-tube unit this semester, including replacing the existing rigid PVC tube with flexible tubing and removing the calibration system from the drop-tube unit. The newly designed drop-tube unit can be seen in the figure below:

Figure 11: newly designed flexible drop-tube unit.

It should be noted that the ball valve on the bottom of the drop-tube will not be used in AguaClara plants. The original use of the ball valve was for calibration: the valve would be closed and liquid would fill the tube over a timed period (i.e. one minute). Then the volume of liquid in the tube would be divided by the time to determine the flow rate. However, this practice is no longer used in AguaClara plants, and a separate calibration column is utilized instead. The CDC team has chosen to keep the ball valve on the lab drop-tube for use in experimentation and to prevent leaking when the system is not in use.

Design Considerations

The main consideration when designing evaluating the feasibility of the flexible drop-tube was the idea of “free fall.” It is important that the drop-tube allows either chlorine or coagulant to fall freely from where the barbed fitting connects from the MHE without backing up at the top of drop-tube. Any backup of liquid would mean that the constant head line would be raised from the original point and thus the calibration of the CDC system would be thrown-off. In order to ensure free fall, diameter of the drop tube is important. Through discussions with Monroe, the diameter of the tubing would have to be quite small (around ¼” depending on flow) for free-fall to be inhibited. Since the design of the flexible drop-tube uses ½” inner diameter tubing, the free-fall criteria should be met.

Another consideration of designing the drop-tube is the length of the flexible tubing. The drop-tube should reach from the lever-arm down to the minimum height of water in the flocculator. This is to ensure that the very bottom of the drop tube is always filled with water;

allowing air to travel up and out one side of the tubing and liquid to travel down the other (also important in allowing free-fall), as illustrated below:

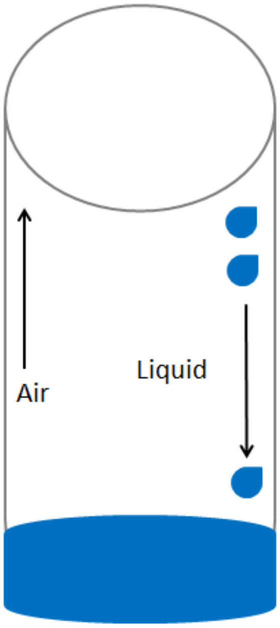


Figure 12: Diagram showing ideal flows through the drop-tube.

The minimum height of water in the flocculator is driven by the height of the weir in the outlet channel of the sedimentation tank. This height (which controls the length of the drop-tube) is dependent on plant design flow rate and can be determined through the AguaClara designCAD.

Feasibility of Design

Through testing in the lab, the flexible drop-tube has proven feasible in all design aspects. The diameter theoretically allows for free-fall and no backup of liquid has been seen during experimentation. Furthermore, since the flexible tubing is made from PVC, it is chlorine resistant and ther\efore chemically compatible with an AguaClara plant. The last design criteria was the length of the drop-tube. Since the flexible tubing is available in a variety of lengths from McMaster-Carr ranging from 25’ to 100’, it can be cut to fit the minimum required length for each plant. One of the most useful features of the flexible drop-tube is that it can be folded up for easy packing or shipping to plant sites.

Introduction to MathCAD Formulation

The CDC team started experimenting with MathCAD to formulate a set of equations that, given a plant flow rate, will produce all the parameters for the manifold tubing such as diameter, length, and number of tubes. In the current plant design, the team is setting the Π error to a maximum of 0.1, meaning that the maximum amount of error within the system must be 10%.

Using the equation:

$$Q_{MaxError} = \frac{\pi}{4} D_{Tube}^2 \sqrt{\frac{2gh_L \Pi}{(\sum K)}}$$

The maximum flow rate can be determined for each chemical dosing tube. Similarly, the maximum average velocity can be determined by dividing $Q_{MaxError}$ by the cross sectional area of the tubing.

$$V_{MaxError} = \sqrt{\frac{2gh_L \Pi}{(\sum K)}}$$

The length of the tubing that will accommodate the given parameters is found through the relationship:

$$L_{Tube} = \frac{(1 - \Pi) D_{Tube}^2}{64\, \nu} \sqrt{\frac{\sum K 2gh_L}{\Pi}}$$

The number of tubes required to deliver the given flow rate for the given tubing diameter is the following equation rounded up to the nearest integer:

$$N_{Tube} = \frac{Q_{Min}}{Q_{MaxError}}$$

Where Qmin is

$$Q_{Min} = \frac{Q_{Plant} C_{DoseMax}}{C_{StockMax}}$$

Those variables formulated above reflect the parameters of the plant. A typical plant in Honduras has a $C_{DoseMax}$ of about 60 mg/L. The $C_{StockMax}$ may be around 400 g/L. These numbers vary based off the PAC concentration. The Q_{Plant}, or the influent plant flow, varies with location as well. For example, in the following table, there is a list of various AguaClara Plants in Honduras and their Q_{Plant} in liters per second:

Table 2: AguaClara plants in Honduras and respective flow rates.

Plant Location	**Flow Rate (L/s)**
Ojojona	6
Tamara	12
Marcala	30
Cuatro Comunidades	6
Agalteca	6
Marcala Expansion	22
Aluaca	12
Atima	16
San Nicolas	32

Using MathCAD, a system of plant flow rates and their specifications were produced. For flow rates of 5, 10, and 15 L/s, the tubing lengths appear reasonable in length. However, for flow rates higher above that, the lengths of the tubing become too long, and thus are not optimal for spatial efficiency and shipment. A sample of flow rates and their respective parameters are given in the following table:

Table 3: Note the tubing length and diameter of higher flow rates.

Q.plant (L/s)	**Length of Tubes (m)**	**Number of Tubes**	**Diameter (in)**
1	1.141	1	1/16
5	0.445	2	1/16
10	1.781	1	1/8

15	1.141	1	1/8
20	1.781	2	1/8
25	2.582	1	3/16
30	2.936	1	3/16
35	2.468	1	3/16
40	2.109	1	3/16

In designing the dosing system, it is important to keep error low ($\Pi < 10\%$) and low length (spatial efficiency). Unfortunately, these two parameters vary inversely with each other; the longer the dosing tubes, the more accurate the system is and vice versa. The larger the flow, the larger the tubing diameters must be, and the larger the diameters, the longer the tubing must be to maintain a minimal error. To address this, the team began to manipulate the mathCAD files.

The team kept the inner diameter of the dosing tube at constant 1/8th inch. From this diameter and other standard parameters, the team found that the minimum dosing tube length would be approximately 0.7 meters to be within the 10% error range. According to the calculations, with a length of 0.7 meters, the amount of chemical dosage with one tube would accommodate flows up to 12 L/s. It was also seen from the formula that having two tubes would double the the maximum plant flow rate and so on. This is significant as it offers a solution to maintaining accuracy and spatial efficiency. Instead of larger diameter and longer dosing tubes for higher flows, it may be possible to only add more tubes to reach higher flows. This theoretical model appears promising with the given equations, however, with more tubes, there is more head loss. Also, the connector tubing (tubing connecting the CHT to the manifold, tubing connecting the manifold to the drop tube, etc) must also be considered. If the ID of this connector tubing is too small compared to the flow, then there will be too much error due to friction. This will thus cause the system to lose its linearity and its accuracy.

The CDC team began to run experiments with different tubing sizes with the ultimate goal of validating the mathCAD formula. The experimental data is displayed in the following section.

Experimentation: Testing for Head Loss

Introduction

The CDC team wanted to test the linearity of various tubing diameters and parameters. The purpose of these tests was to determine which sizes maintain accuracy and spatial efficiency.

From these results, the team could then determine the best approach to standardizing the CDC system overall.

General Procedure

Testing the CDC system was done with water and not with Chlorine or PACl. Thus, in the governing MathCAD equations, the team used parameters based off the properties of water.

For testing flow rates, water was run throughout the system from the stock tank and collected from the drop tube. The team collected the effluent water and weighed it. Using the relationship of the density of water (ρ=1 g/mL), the total volume was then calculated. This volume was divided by the time of collection (in seconds) to obtain a flow rate in mL/s. The results were graphed, and a line of best fit was established to observe the linearity of flow.

Testing Inner Diameters of the Dosing Tube

The team tested with 2 types of dosing tubes: one had an ID of 1/16” and the other had an ID of ⅛”. The motivation behind testing these diameters was to compare the linearity between the 1/16” and the ⅛”. Also, the team wanted to see if there would be any complications for tubing at smaller sizes. These complications could have been clogs, air bubbles, etc. Finally, the team included a test of the slider on the lever arm to ensure linearity.

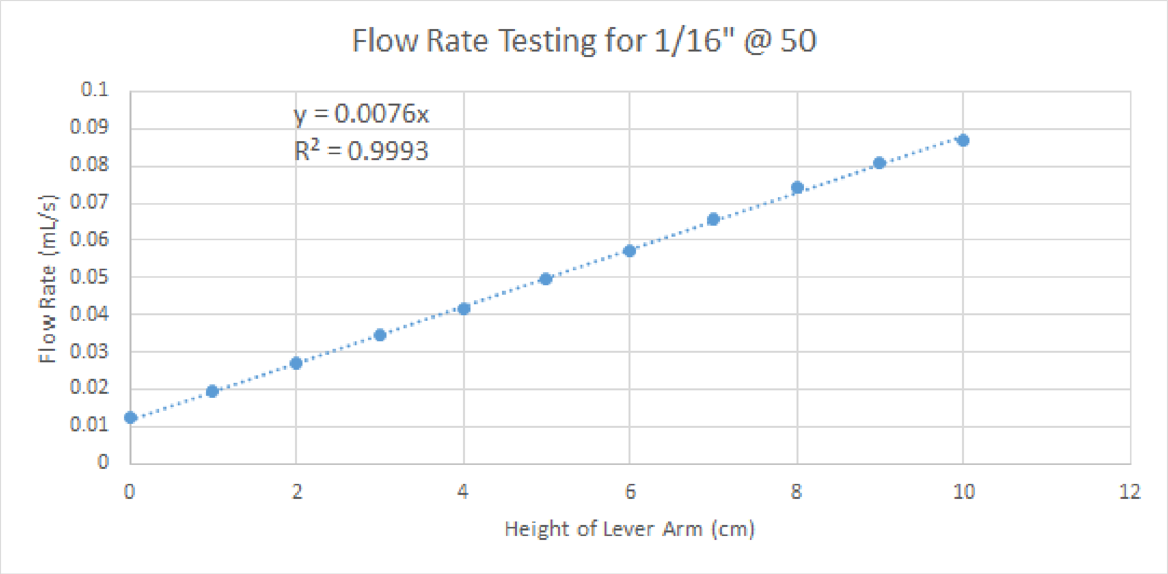
Results and Discussion

Testing with 1/16” ID Dosing Tubes

It should be noted that during these tests, the connecting tubing throughout the system was 1/4th ID

As can be seen by Graph 1 below, the testing at the 50 mark led to a linear line with an r-squared value of .9993 which means there was an almost “perfect” linear relationship.

Graph 1: Results of the head loss experiment with the slider at the 50% mark.

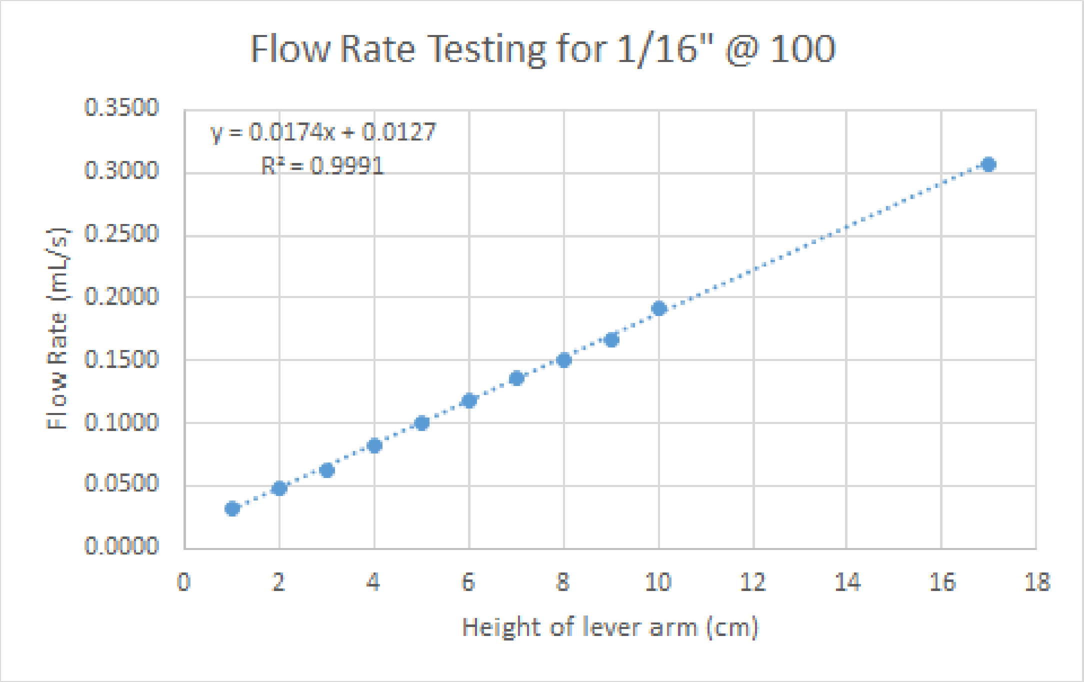


Furthermore, when testing 1/16”, the linear relationships suggest that there was little complications with flow delivery. Air bubbles/ other clogs did not seem to be a problem, and thus, for smaller plant flows, 1/16” tubing may be an viable option.

Testing the Slider

Additionally, the CDC team tested at the 100 mark and as can be seen Graph 2, the line was linear with an r-squared of .9991, which again suggested a near-linear relationship. An outlier at 17cm was included in the graph to ensure linearity at all ranges of the lever arm.

Graph 2: Results of the head loss experiment with the slider at the 100% mark.



From these results, the initial hypothesis was correct, 1/16 tubing did provide a linear relationship. Furthermore, the adjustment of the slider did not affect linearity. When testing the max flow rates at the 50 and 100 mark, the flow rate for the 100 mark was almost double the flow rate at the 50 mark, which confirmed the accuracy and effectiveness of the slider. These results are summarized in Table 4.

Table 4: Results of testing max flow rates the the 50 and 100 marks. These results confirm the hypothesis that the flow at the 100 mark should be double that of the 50 mark in order for the system to follow a linear relationship.

Height of lever arm (cm)	**Mass of water (g)**	**Volume (mL)**	**Time (s)**	**Flow Rate mL/s**
Max @ 50	12.409	12.409	60	0.2068
Max @ 100	18.174	18.174	45	0.4039

The fact that this line is so linear suggests that the tubing length could be much shorter. By shortening the length, the CDC system can be made more compact, thus reducing the overall cost and materials.

To increase the overall flow rate, the team increased the inner diameter of the dosing tube from 1/16” to ⅛”. Tests were done to ensure linearity. Also, with the ⅛” tubing, the team began to test with different number of tubes and different lengths. The team hypothesized that the flow rate would double from one tube to two tubes. The results are as follows:

Testing with 1/8th ID Dosing Tubes

It should be noted that during these tests, the connecting tubing throughout the system was 1/4th ID.

Testing with 0.70 m Dosing Tubes

Graph 3: This graph shows the relationship of flow rates between one dosing tube and two dosing tubes, both at a length of .7 m. The overall connecting tubing has an inner diameter of ¼ " while the dosing tubes have an inner diameter of ⅛"tubing.

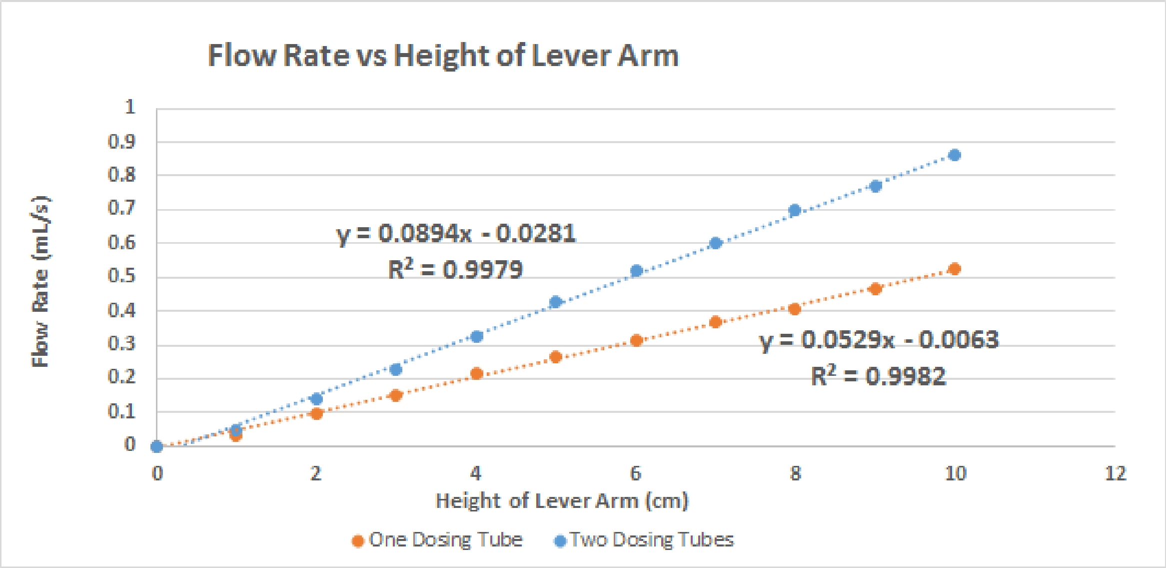


Table 5: The table shows the data plots for Graph 3. When the number of dosing tubes double, the flow rate does not double. The flow rate only increases by a factor of **1.69**

Height of Lever-arm (cm)	One Dosing Tube Flow Rate (mL/s)	Two Dosing Tubes Flow Rate (mL/s)
0	0	0
1	0.030166667	0.0455
2	0.098416667	0.138166667
3	0.152633333	0.224583333
4	0.21443333	0.322916667
5	0.267216667	0.427083333
6	0.3126	0.518833333
7	0.36665	0.60375
8	0.408333333	0.6975
9	0.466433333	0.77125
10	0.523533333	0.860416667

Testing with 1/8th ID Dosing Tubes

It should be noted that during these tests, the connecting tubing throughout the system was ¼” ID.

Testing with 1.06 m Dosing Tubes

Graph 4: This graph shows the relationship of flow rates between one dosing tube and two dosing tubes, both at a length of 1.06 m. The overall connecting tubing has an inner diameter of ¼” while the dosing tubes have an inner diameter of ⅛” tubing.

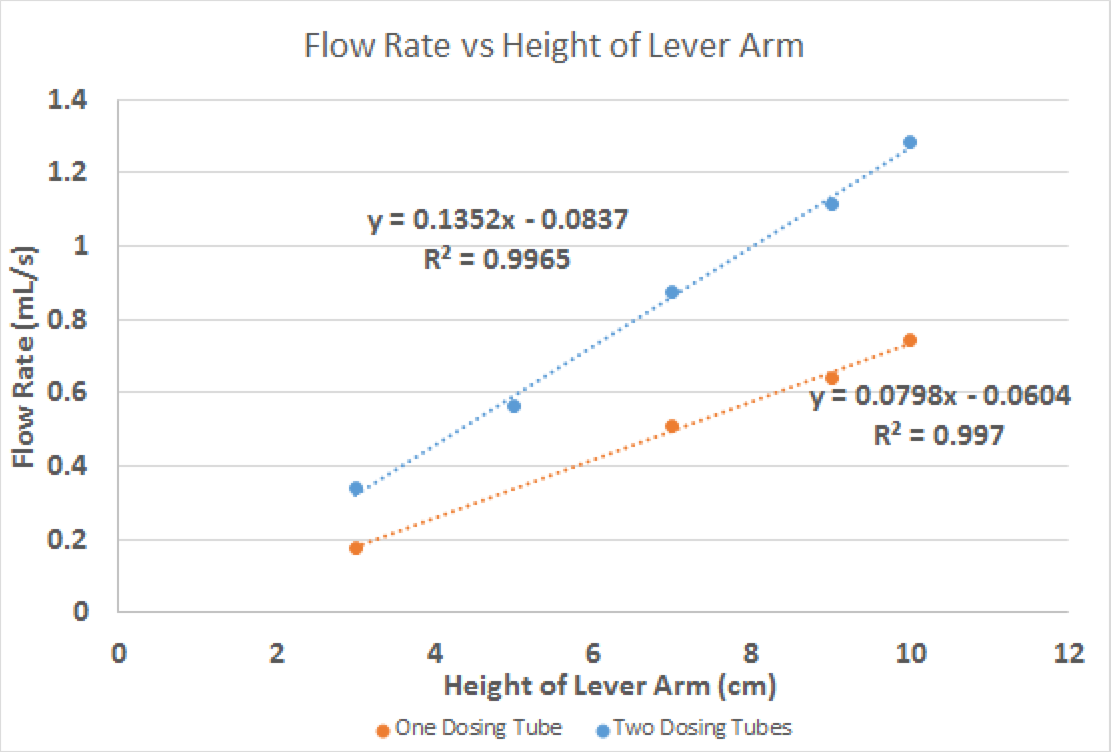


Table 6: The table shows the data plots for Graph 4. When the number of dosing tubes double, the flow rate does not double. The flow rate only increases by a factor of **1.63**

Height of Lever-arm (cm)	One Dosing Tube Flow Rate (mL/s)	Two Dosing Tubes Flow Rate (mL/s)
0	0	0
1	0.0769	0.10275
2	0.179383333	0.283683333
3	0.269716667	0.440183333
4	0.394416667	0.6374
5	0.483733333	0.793383333
6	0.584233333	0.94255
7	0.6786	1.094216667
8	0.768916667	1.245116667
9	0.858433333	1.400416667
10	0.937383333	1.528516667

Overall Observation

When the number of dosing tubes doubled, the flow rate did not double. The flow rate ratio between 2 tubes and 1 tube was around 1.60:1. Furthermore, the flow rate from 0.7 meter tubes was less than the flow from the 1.0 meter tubes. This was an interesting result, as the mathCAD formula said it should have been the other way around. The team speculated that these results were because of the 1/4th ID connecting tubing. Because these tubes have a smaller diameter, there is more loss due to friction, which therefore inhibits flow.

Afterwards, the team did the same experiment again but with ½ inch ID connector tubing to test if the ratio was closer to 2.

Testing with 1/8th ID Dosing Tubes

It should be noted that during these tests, the connecting tubing throughout the system was 1/2th ID.

Testing with .70 m Dosing Tubes

Graph 5: This graph shows the relationship of flow rates between one dosing tube and two dosing tubes, both at a length of .70 m. The overall connecting tubing has an inner diameter of 1/2 inch while the dosing tubes have an inner diameter of 1/8 inch tubing.

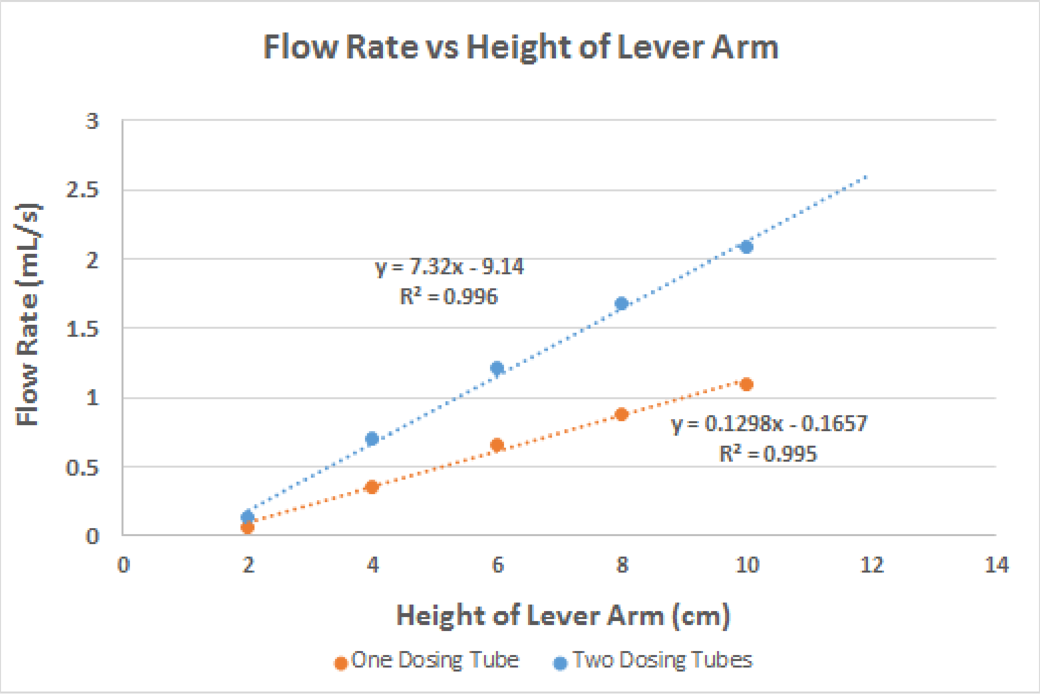


Table 7: The table shows the data plots for Graph 5. When the number of dosing tubes double, the flow rate nearly doubles. The flow rate increases by a factor of **1.88**

Height of Lever Arm (cm)	One Dosing Tube Flow Rate (mL/s)	Two Dosing Tubes Flow Rate (mL/s)
2	0.06666667	0.13
4	0.36	0.7
6	0.65333333	1.21
8	0.88333333	1.673333333
10	1.10333333	2.083333333

As can be seen from the data, the ratio is a lot closer 2, but it is still not perfect. The team again made the length of the dosing tubes longer to see if this would make the ratio closer to 2.

Testing with 1/8th ID Dosing Tubes

It should be noted that during these tests, the connecting tubing throughout the system was 1/2th ID.

Testing with 1.06 m Dosing Tubes

Graph 6: This graph shows the relationship of flow rates between one dosing tube and two dosing tubes, both at a length of 1.06 m. The overall connecting tubing has an inner diameter of 1/2 inch while the dosing tubes have an inner diameter of 1/8 inch tubing.

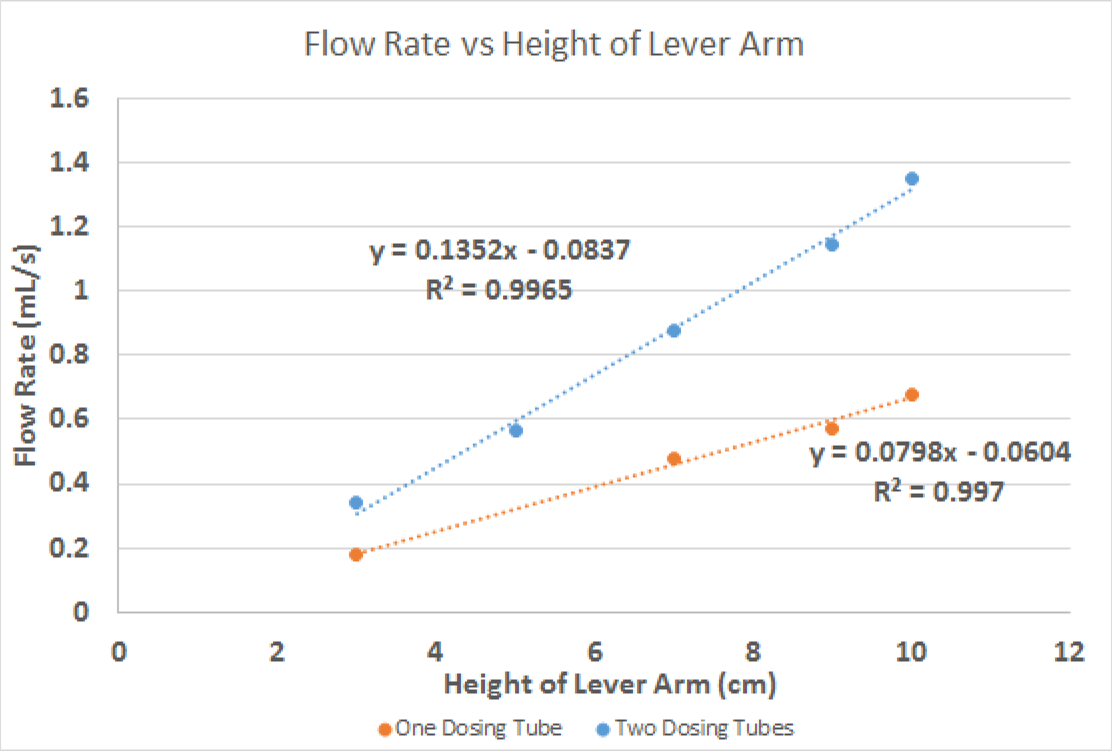


Table 8: The table shows the data plots for Graph 4. When the number of dosing tubes double, the flow rate does not double. The flow rate only increases by a factor of 1.99

Height of Lever Arm (cm)	One Dosing Tube Flow Rate (mL/s)	Two Dosing Tubes Flow Rate (mL/s)
3	0.17666667	0.34
5	x	0.56333333
7	0.476666667	0.87666667
9	0.573333333	1.146666667
10	0.68	1.353333333

Overall Observation

When the number of dosing tubes doubled, the flow rate nearly doubled. Because of the 1/2 ID connecting tubing, head loss was reduced and flow rate was increased. When comparing the .7 m tubing with the 1.06 m tubing, the .7 meter tubing appeared to have more deviation from linearity. This may be explained by the fact that with shorter tubing, there is less major head loss to dominate minor head loss. Ideally, an infinitely long dosing tube would give a perfect ratio, but under constrictions, the 1.06 m tubing does not deviate enough to make a difference.

El Carpintero

Over winter break, a small group of AguaClara students built a foam filter prototype in the small Honduran village of El Carpintero. A member of the CDC team worked closely with the foam filtration students to implement a fully-functioning CDC system to dose coagulant and eventually chlorine (see Figure 13 below). The system - taken from the lab - was successfully implemented with a few design changes. First, the MHE was attached vertically to reduce the total footprint of the filter; this design change has been implemented in the new lab-setup this semester. The second design change was the utilization of a flexible drop-tube instead of a rigid one. This allows for the system to be more portable while still maintaining the governing fluid principles. The drop-tube design will be tested by the CDC team this semester to ensure efficacy. More information on the work done in El Carpintero and plans for the foam filter prototype in the future can be found in the Foam Filtration Spring 2015 Research Report (see references).

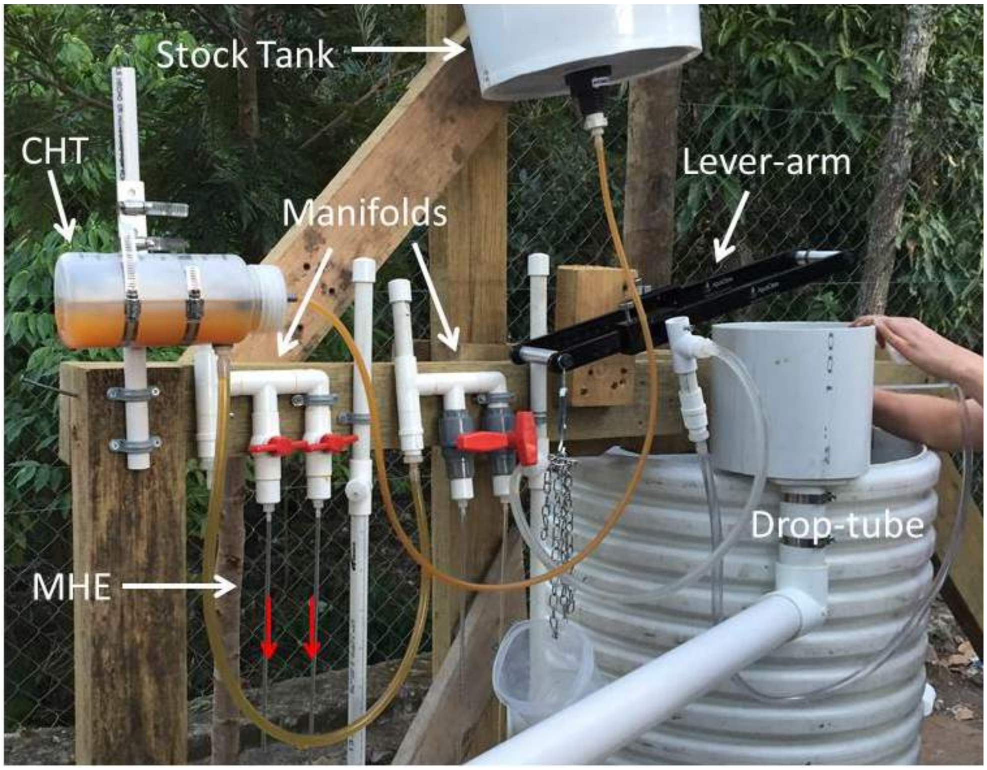


Figure 13: The CDC system implemented in the small village of El Carpintero, Honduras as part of the foam filter prototype.

Set-up Manual

Using the current CDC design, the team has developed a set-up manual that can be used by future teams to assemble the entire system. The manual includes labeled diagrams; material lists with prices, quantities, and links to where the parts can be purchased; as well as detailed instructions for assembly. Since the system is constantly changing, the manual should be regularly updated by team members to ensure accuracy.

Packaging the CDC for Market

Introduction

A new goal for the CDC team is to look into methods of packaging the system for efficient distribution. In the future, instead of producing a CDC design on a case for each plant, AguaClara will be able to use a standardized, pre-assembled CDC system for a specified range of flow rates. The ultimate goal of this proposal is process efficiency and design standardization. Furthermore, this packaging idea is meant to ease assembly and operation for plant operators. Since the flow rate of each plant is dependent on the population - which can range from a few hundred to thousands - the plan is to construct 5-7 modular assemblies to cover the range of doses needed for each situation.

Packaging

Once the equations are finished and verified, the CDC team wants to begin constructing packaging models for the system. As of right now, the team plans to not have tubing exceeding the length of 2 meters. Thus, to accommodate higher flow rates while ensuring system accuracy, the team proposes to use multiple dosing tubes, and possibly multiple pairs of manifolds. In the CDC package, the manifold and lever arm will be the bulk of the weight, while the CHT will make up a bulk of the space. A draft model of the package is shown in the following figure:

Figure 14: Current design for the CDC packaging system.

In this package, there are two main components: (2) The larger box will be composed of the CHT along with the tubing and float. It is speculated that all tubing (including the flexible drop tube) will be contained in this section. (2) The smaller, flatter package will consist of the lever arm along with the manifolds, as these items are thinner components of the plant. The purpose of the separation is to reduce any damage during transportation. Ideally, the smaller package would be able to fit within the larger package to have one final, compact system. For larger scale plant flows that require multiple manifolds and larger lever arms, this package system size may have to be adjusted.

Future Work

In future semesters, the CDC team hopes to build-off of the set-up manual to create a video with voice-over that shows how to put together each part of the system. Since the language barrier may be a problem with a written manual, a video would be a good way to visually convey knowledge. Furthermore, the CDC team plans to create manuals that detail how to calibrate and run the system; these would be separate from the assembly manual and could also be used in the field by plant operators.

For future testing, the team also wants to verify that the dosing tube flow rates predicted on the MathCad files are consistent with the flow rates from testing. This will then ensure that we can implement the idea about the packages in the plants in Honduras. These packages would then have all the same lengths and diameters while only changing the number of tubes depending on the plant flow rate.

References

Cashon, A., Ghimire, S., & Liu, J. (2014). Chemical Dose Controller Spring 2014. 14-14. Retrieved October 1, 2014

Cashon, A., Leu, C., & Liu, J. (2014). Chemical Dose Controller Fall 2014. 14-14. Retrieved February 18, 2015.

Chemical Compatibility Guide. (n.d.). Retrieved October 1, 2014.

Hinkley, M., Hutchinson, A., Keller, E., Peters, A. (2015). Foam Filtration, Research Report 3. Retrieved March 26, 2015.

Labware Chemical Resistance Tab. (n.d.). Retrieved October 1, 2014.