Linear Chemical Dose Controller Spring 2012 Research Report

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Abstract

Continuous, accurate chemical dosing is an essential part of AguaClara plant function. Proper dosing ensures effective flocculation, sedimentation, filtration and disinfection. The chemicals that must be added at different points during the water treatment process are coagulant (PACl or Alum may be used) and chlorine. The linear chemical dose controller (LCDC) is a device that the plant operator can use to directly set doses of coagulant and disinfectant based on the flow rate into the plant. Previous LCDC designs have only been configured to add coagulant prior to flocculation. The triple-doser design is capable of adding coagulant before the influent water enters the stacked rapid sand filter and of adding chlorine for disinfection before the treated water enters the distribution tank. The Spring 2012 team is introducing a more sophisticated LCDC device that will allow the operator to set and monitor the two doses of coagulant and the dose of disinfectant, for a total of three chemical doses, on a single dosing apparatus. In order to ensure accurate chemical dosing, we are testing and documenting the calibration of the new LCDC. Ultimately, we will determine a method for the triple-armed dosing mechanism to be built and added to plants on site, putting a focus on simplicity and elegance of design so that the AguaClara LCDC can be constructed with local resources.

1 Literature Review

Over the years, the design of the chemical doser has changed to accommodate new technology and innovation. Back in Fall 2008, AguaClara researched, tested and documented a nonlinear chemical doser to accommodate high flow plants with turbulent flow in the dosing tubes. The advantages of using a nonlinear chemical doser is that higher chemical flow rates can be used. During the semesters in which this design was explored, different constraints on the lever arm were established and a function to determine what the the optimal lever arm length was (See Fall 2008-Summer 2009). Furthermore, these LCDC teams discovered relationships between the float and the moment balance around the pivot arm and developed a float sizing algorithm. A similar analysis was undertaken by the 2012 LCDC team for the triple-dosing linear dose controller.

Improvements were also made to the linear chemical doser in the same time frame that the non-linear doser was being considered. Calibration techniques were refined and the assembly of the float was clarified (AguaClara Wiki: Linear Chemical Doser). The assembly of the float from this time is still of use in the 2012 design, with the addition of a bigger float option for plants with bigger flow rates. Through calibration calculations seen on AguaClara Wiki: Installing a Chemical Doser, it was determined that the center of mass of the float should be below the water line and the dimensions of the float were established.

In Spring 2011 the AguaClara team decided to focus on the linear version of the chemical dose controller due to its simplicity and good track record. The operator's ability to better understand this device compared with the nonlinear chemical doser makes the linear dose controller a more attractive option for AguaClara. The Spring 2011 team identified three primary minor head loss sources. These were 1) entrance losses from the CHT to the barbed fittings prior to the small diameter tubing, 2) expansion losses as the flow enters the small diameter tube from the barbed fittings leaving the CHT, and 3) exit losses as flow enters the drop tubes through the barbed fittings as hypothetical locations for sources of minor losses in the doser. The team also analyzed the hydraulic tradeoff between tube diameter and the length of tubing used for chemical dosing (Spring 2011 final research report).

Further progress in all aspects of the fabrication was made during Summer 2011. At this time, the calibration technique was improved and minor head loss was modeled with help from an equation which can be found in the LCDC Summer 2011 final research report. It was concluded that calibration must occur at maximum chemical flow point, or head of 20cm. In this report it was further concluded that a more efficient method is necessary to attach the float to the non-dosing side of the lever arm. The method includes using a slider with 2 screws, a turnbuckle and a chain. These materials combined are able to make precise corrections in setting zero chemical flow point during calibration and altering the position of the float to achieve maximum flow rate (Summer 2011 final research report). The influence of the minor head loss coefficient was studied further during Fall 2011. Several methods for reducing minor losses were testing, including a method of usuing a weight to ensure that longer sections of tubing were kept straight and limiting curvature to a short span near to the weight. This method was referred to as the split tube method, and can be read about in depth in the Fall 2011 Final Research Report.

This Spring 2012 team is working from the research and knowledge passed down from previous teams through research reports and Mathcad files documenting experiments. We have documented fabrication and calibration of the LCDC with the capability of triple dosing. Our aim is to make the linear chemical doser a device AguaClara plants worldwide can showcase as operator-friendly and reliably accurate. We will strive to maintain the ease of use of a single-armed system while increasing the power of the design.

2 Background

The linear chemical dose controller (LCDC) and the linear flow controller (LFC) use major head to regulate chemical flow to the water treatment plant. This relationship between major head 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 (h_f), the diameter of the small diameter tube (D_{Tube}), which connects the constant head tank (CHT) to the drop tube, the kinematic viscosity of the solution being used (ν) and the length of the small diameter tube (L_{Tube}).

$$Q_C = \frac{h_f g \pi D_{Tube}^4}{128 \nu L_{Tube}} \quad (1)$$

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 is rearranged in regards to the major head (h_f), one can see that this variable increases proportionally as the length of the small diameter tube (L_{Tube}) is increased.

$$h_f = \frac{128 Q_C \nu L_{Tube}}{g \pi D_{Tube}^4} \quad (2)$$

Past LCDC and LFC designs assumed that the length of the small diameter tube was sufficient enough to ensure that the major head losses dominated the Equation. These designs also believed that the linear relationship between the chemical flow rate and the major head would be maintained, as shown in the Hagen-Poiseuille Equation (1). However, during the Spring 2011 semester, the LCDC team observed quadratic tendencies in the relationship between head and chemical flow (see Spring 2011 Final Report "Initial Laboratory Results" section for an analysis of the experiments that gave these results. Minor heades result from flow expansions through the system and are proportional to the square of the chemical flow rate. 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 CHT from being mounted on the 80x20 apparatus frame and placed it at a further distance away. Another method developed to minimize minor losses, which originate from expansions and curves, was to use smaller barbed connectors than necessary for the inner diameter of the used small diameter tubing. This greatly reduced the minor loss through the system, though there is still a large enough value in the system to require further analysis of the experimental apparatus.

To determine the magnitude of minor head losses though the LCDC or LFC systems, the minor head coefficient (k_e) can be calculated. The minor head coefficient (k_e) is a function of the minor head (h_e), the diameter of the small diameter tube (D_{Tube}) and the chemical flow rate (Q_C).

$$k_e = \frac{h_e g \pi^2 D_{Tube}^4}{8 Q_C^2} \tag{3}$$

After collecting data from numerous experimental setups (see Spring 2011 "Experimental Design" section for a depiction of the group's experimental apparatus), the team applied Mathcad's genfit function to each experiment's data set. The genfit function was given an Equation developed from the fact that the total head through the system (H_{Total}) is the sum of the major (h_f) and minor (h_e) heades.

$$H_{Total} = h_f + h_e \tag{4}$$

The Equation used to calculate major head is given above as Equation (2). By rearranging Equation (3) according to minor head, one can see that the minor head (h_e) is a function of the diameter of the tube (D_{Tube}), the chemical flow rate (Q_C) and the minor loss coefficient (k_e).

$$h_e = \frac{8 Q_C^2 k_e}{g \pi^2 D_{Tube}^4} \tag{5}$$

Therefore, by substituting Equations (2) and (5), Equation (4) can be represented as:

$$H_{Total} = \frac{128 Q_C \nu L_{Tube}}{g \pi D_{Tube}^4} + \frac{8 Q_C^2 k_e}{g \pi^2 D_{Tube}^4} \tag{6}$$

Equation (6) was input into the Mathcad's genfit function. Genfit is given an array of observed flow rate data for the given experimental setup. This array is composed of the total head values, and an approximation for both the kinematic viscosity (ν) and the minor head coefficient (h_e). Mathcad then calculates a value for kinematic viscosity and the minor loss coefficient that will fit the input experimental data. Since there are two terms in Equation (6), one with a linear relationship between head and chemical flow rate, the other showing a non-linear relationship, the genfit function allows the group to separate the non-linear influence and quantify its effects.

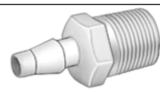
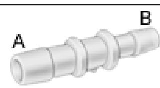
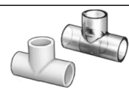
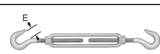
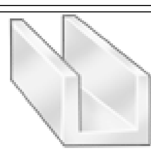
3 Methods

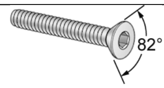
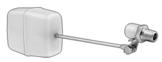
3.1 Doser Setup

To determine the most effective design that meets the constraints for the LCDC, our team generated a list of parts to construct a prototype with. Table 1 documents the parts that we used for our lab setup. Depending on the plant capacity, different quantities of fitting and other parts may be required. The following parts list also does not include the float; additional float sizing and component information is specified in Appendix A. We selected and ordered the following McMaster-Carr parts to create our prototype, but the guide that we will send to the communities building future plants includes, in addition to the part number, a listing of which properties make the chosen parts appropriate for the LCDC. This helps accommodate for the fact that the locations where the plants are being built might not have access to the exact commercial parts we have specified.

Table 1: Table of parts

	Part Name	Picture	Part Number	Quantity	Description and Explanation

1	Barbed Fitting for Constant Head Tank		5463K811	5	Durable Nylon Single-Barbed Tube Fitting Through-Wall Adapter for $\frac{5}{32}$" tube ID, black. More secure than push to connect
2	Barbed Fittings for Drop Tubes		5116K83	7	Threading of $\frac{1}{4}$", so can easily retrofit the drop tube fitting. It allows the chemical to enter the drop tube from the $\frac{1}{4}$"ID tube
3	Reducing Barbed Fittings		53055K131	4	Reducing barbed fitting connects $\frac{3}{16}$" ID to $\frac{1}{4}$" ID. Allows for split tube method which reduces minor loss coefficient
4	Drop Tubes		49035K83	3	Clear for clog detection, $\frac{1}{2}$" inner diameter. Must be long enough to reach from the lever arm pivot height to the minimum water level in the entrance tank, lightweight is desirable
5	$\frac{1}{4}$" ID Large Diameter Tubing		5231K161	4ft	Clear plastic $\frac{1}{4}$" ID, connects to drop tube
6	$\frac{1}{8}$" ID Small Diameter Tubing		5233K52	36ft	Attached to the base of the CHT and the larger diameter tube via a reducing barbed fitting
7	$\frac{1}{2}$" Tee		9161K31	1	Used for a T-drop tube. This configuration allows a higher dose by attaching more $\frac{1}{4}$" ID tubes to drop tubes
8	$\frac{1}{2}$" " Pipe Cap		4880K51	5	Schedule 40 White PVC Pipe Fitting attached to the ends of the "T" and bottom of the drop tubes
9	Turnbuckle		2997T51	1	Connects the float to the center lever-arm using durable canvas thread
10	Constant Head Tank		42955T2	3	Translucent plastic, 64 oz, 2000 mL, 5-7/8" Base Diameter, 6-1/4" Height with $\frac{5}{32}$" hole drilled in bottom center
11	Lever Arm		6023K153	3	Aluminum, 3' in length. Light, durable
12	Dose Indicator Sliders		9001K32	3	Aluminum, U-Channel, 1/8" Thick, $\frac{1}{2}$" Base x $\frac{3}{4}$" Legs, 4" long. Attached to top of the lever arm to vary the dose.
13	Aluminum Set Screw Shaft Collar		9946K13	7	$\frac{3}{8}$" bore, $\frac{3}{4}$" outer diameter, $\frac{3}{8}$" width; secured on either side of each lever arm to prevent shifting of their positions

14	Hex Nut		90545A111	4	Between the drop tube and the slider. Permits the drop tube to swing freely
15	$\frac{1}{2}$" 10-32 screws		92210A302	3	1 for stopper, 1 to hang drop tube
16	Stainless Steel pipe for insertion into SDT		6100K192	1	Attaches to the end of the lever arm to "flow rate" board to measure chemical flow rate during testing
17	Float Valve		4605K81	3	Attached to side of the constant head tank, keeps the water level constant inside the CHT.

The scope of the LCDC starts with the the chemical stock tanks, which connect to the three constant head tanks, one for each chemical being dosed. The scope ends at the base of the dosing drop tubes attached to the lever arms, where the chemical dose enters a tube which will carry it to the location (before flocculation, prior to entering the stacked rapid sand filter, after filtration) where it is to be administered. The scope of the LCDC tested is shown in the photograph in Figure 1.

Figure 1: Side View

The chemical stock tank is located at a higher elevation than the constant head tank to ensure that the stock solution flows into the CHT. The stock tank connects to the CHT with large, $\frac{1}{2}$" diameter tubing that has a valve that can be shut on or off. Within the CHT is a float valve that controls the constant level of liquid in the tank. Flow tests are only valid if taken when the constant head tank is at equilibrium. The dose from the stock tank will enter the CHT when it falls below this desired, constant level. A $\frac{5}{32}$" through-wall barbed fitting in the base of the constant head tank provides the attachment point for the small diameter tubing. A rubber o-ring prevents leaking at this connection. The barbed fitting is to be placed in the center of the bottom of the constant head tank. The smaller tubing, which measures $\frac{1}{8}$" in inner diameter, attaches to a larger, $\frac{1}{4}$" inner diameter tube with a reducing barbed fitting. The Fall 2011 team observed that attaching $\frac{1}{4}$" inner diameter tube to the drop tubes rather than directly attaching $\frac{1}{8}$" inner diameter tube reducing barbed fitting reduced the system k-value, which is proportional tominor losses, by approximately 35%. Therefore, the $\frac{1}{4}$" inner diameter tube is to be included even in plants where additional length is not required. The length of the larger diameter tubing is at the discretion of the plant operator, but it must be larger diameter tubing, and not smaller diameter tubing, that connects to the dosing tube to benefit from the 35% reduction in k-value.

In the span from the constant head tanks to the drop tubes, a weight adds tension to the tubing and shapes it into a "V." Isolating the majority of curvature to this point reduces the curvature of the system as a whole, which minimizes minor losses. Keeping minor losses to a minimum is essential to getting the proper dose of chemical to the influent water. In Fall of 2011, the LCDC Research Team determined that the aforementioned "V" shaped tubing configuration minimized minor losses. This semester we determined that a weight of 100 grams is a suitable weight to be used for this purpose in future plants.

During testing we discovered that in addition to including a weight and large diameter tubing, the radius of curvature surrounding the weight can have a substantial impact on flow rates if it is permitted to become excessively obtuse. We recommend that during the tube trimming calibration process, if the operator observes that flows begin to decrease with shorter tubing additional large diameter tubing be added to the span, or the CHT should be moved closer to the LCDC if possible, to reduce the radius of curvature so that the flows increase with shorter small diameter tube lengths.

There is a specific length of small diameter tubing calculated for a given plant to ensure the proper flow rates due to major losses. Major and minor losses associated with the large diameter tube can be considered negligible; its purpose is to allow for flexibility in plant setup. The purpose of cutting the small diameter tubing is to compensate for the minor losses that cannot be prevented. Individual plants can locate their constant head tanks where they see fit by adjusting the length of large diameter tubing.

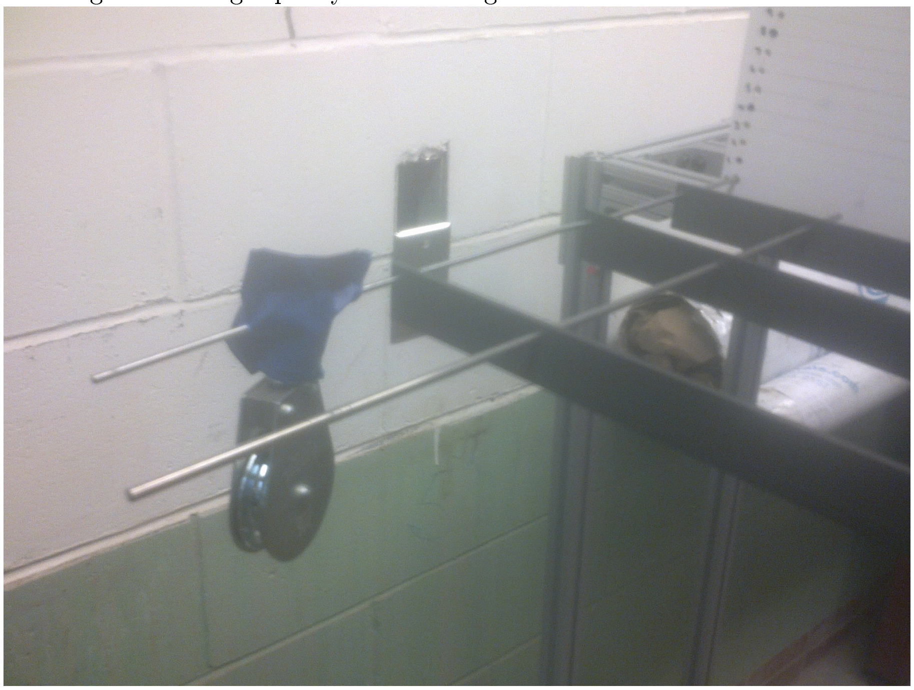
To accommodate large flow plants, we assembled a "T"shaped drop tube setup in which there is a horizontal segment of plastic PVC, capped at either end, that can allow additional dosing tubes to be connected to the drop tube. We are going to test the "T" design with three additional barbed fitting inputs in the prototype built in the lab. If all tubes can supply the desired chemical doses simultaneously, this will mean that the LCDC can be used to dose plants with high flow rates and more turbulent influent water. The top bar of the "T" is made of the same clear PVC as the drop tubes, and each of the barbed fittings is located along a horizontal bar that adjusts to be level with the ground as the flow rate causes the lever arm to move up and down. For this design, since multiple tubes will come out of the constant head tanks, we need to determine how to handle any curvature that might arise in these tubes as they reach their connection points at the dosing tubes. It is quite possible that a "T" might prove valuable for only the first coagulant dose even in large flow plants since we anticipate this flow rate to be much greater than the second coagulant and the chlorine dose. Testing done in the Spring 2012 semester included ensuring that the "T" is capable of delivering the same flow as a single drop tube through each of its inputs.

3.2 Doser Calibration Procedure

Calibration of the LCDC has two main steps. First, the system must be calibrated to the situation where there is no flow of water into the entrance tank, and thus no dose administered by the LCDC. To calibrate for zero flow using water, the stock tank valve is opened and water flows into the constant head tank until the water in the CHT has reached a constant level. This level is indicated by the float valve inside the constant head tank. The CHT is brought to its constant level while it is beneath the drop tube inlet barbed fitting to ensure that water does not flow into the drop tube while the CHT is filled. The constant head tank is then raised incrementally until water just does not enter the drop tube at the opposite end of the tubing. At this point the lever is at the zero head setting and there is no dose flowing into the plant. Accurate calibration for zero head ensures that no chemical flows when there is no influent water entering the plant for treatment. If slightly raising the CHT results in an immediate response in flow to the dosing tube, this is a sign that calibration is accurate. The tubing connected to the drop tube should have liquid all the way to the barbed fitting. This can be checked by raising the lever to "one" head setting, to see if there is flow, and then returning the lever to the "zero" setting to make sure the flow does actually stop at this point. Once this is done, you have successfully calibrated the doser to zero flow.

It is not possible to configure the LCDC such that the dose setting can be set equal to zero. This is due to the fact that the drop tubes cannot be placed directly at the pivot point of the lever arms. The team did not look for a manner in which to construct a doser for which the dose can be set at zero, because such a design would probably require reworking the current LCDC as a whole and because no chemical will flow through when there is no influent water coming in, and anytime there is influent water, there will be some

Figure 2: 500 gm pulley used as weight used to ensure uniform horizontal level across lever arms



degree of dosing. Thus, there will not be a scenario at a plant when the doser will need to be set to zero.

The triple-lever-arm setup posed a difficulty during testing because when the apparatus was first set up, the lever arms farther from the attachment board curved down; the farthest lever arm was below the zero flow level, which meant that all three lever arms were not calibrated to the same zero point. This was due to the weight of the drop tubes and sliders, and the distance away from the float simulator, the white board. The further away the lever arm is from the white board, the lower the arm is from the zero point. To ensure that all three arms are on the same level, the 2012 LCDC team placed a weight on the float side of the arm farthest from the white fiberboard to offset the height difference in the lever arm. Figure 2 shows how the weight, a 500gm pulley, was attached using blue electrical tape.

This weight offsets the weight placed at the end of the lever arm and makes all three level. A 500gm pulley was used in the lab, but this weight will not be necessary at plants where floats are actually being used. The float will attach at the center lever arm and give a uniform angle to all three arms. We speculate that once the float is added to the design, a weight will not be needed to level the three bars.

Another aspect of the design modified to ensure uniformity across all three lever arms is the method of connecting the arms to the white fiberboard. Initially, only the closest lever arm was connected to the board with a metal drillbit pin. We decided to connect all three lever arms to the white fiberboard using a longer stiff metal rod. This insures that all of lever arms are level. To make the design even sturdier, another thin axle connects all three lever arms at another point nearer to the pivot. Currently there are two stiff metal rods connecting the three lever arms together to maintain a uniform response to a change in flow rate. These rods are visible in Figure 2.

Due to the weights of the sliders and drop tubes on the slider side of the LCDC lever arms, there will be a measurable but inevitable error as the masses move and their associated torques change. The extra mass on the slider side of the pivot will displace water on the float side. The total additional weight on the slider side will equal the weight of the water displaced by the float. We want to minimize the volume of water displaced by the float when the slider is moved, because each unit of depth that the float is submerged in the water corresponds to an equal rise in height of other end of the lever arm, which will affect dosing. As the sliders move farther from the pivot point for larger doses, they produce greater moments, so error associated with the sliders' weights will increase for higher doses. Since we aim to limit total error of the LCDC to 10%, it is necessary that the error resulting from these torques is minimized. To reduce the volume displaced, we can

Table 3: LCDC Data Sheet

Assumption: Flow of Plant (Q_{plant}) = 12 L/s

	Coagulant Flocculator	Coagulant SRSF	Chlorine
Stock Concentration	360 g/L	120 g/L	50 g/L
Flow of Chemical (Q_{chem})	2 mL/s	2 mL/s	2 mL/s
Dose Range	0-60 mg/L in alum	0-18 mg/L in alum	0-2 mg/L
Length of Small Diameter Tube	2.285 m	2.574 m	2.285 m
Length of Large Diameter Tube	variable	variable	variable
Number of Tubes connecting CHT to Drop Tube	1	1	1

increase the base area of the float to distribute the volume of displaced water over a larger area. In order to get an idea of how large the float's surface area needs to be to make the change in head error sufficiently small, we weighed the components on the slider side of the pivot. A float analysis was performed that took into account the weights of simple drop tubes with just one connection, the weight of a Tee that allows for multiple inputs, the current weight of the sliders as well as shortened, more lightweight slider designs.

Increasing the surface area of the float decreases the amount that it will change in height since it will distribute the area across which the water is displaced. The width of the entrance tank and the diameter of the LFOM (linear flow orifice meter) constrain how large the float can be. Geometric constraints of the entrance tank dictate that the maximum diameter of the float should be 8" without dramatically increasing entrance tank costs. At present, we have a float made from a PVC cap 6" in diameter. We have the space in the entrance tank to expand this to a similar float with a PVC cap with a diameter of 8" but the bigger float is considerably more expensive. When possible to attain a 10% or smaller error with a 6" float, this will be the recommendation. If the plant is large enough to warrant a Tee for additional flow, then the added weight of the Tee will push the error higher, and require an 8" diameter float.

3.3 LCDC Data Sheet

In order to effectively fabricate the LCDC, certain specifications must be calculated. The following table summarizes recommended properties of each dosing mechanism for a 12 L/s plant size. The table is split up by the different chemical feeds. For flow rates different than 12 L/s, the data sheet should be updated using the LCDC Mathcad file.

The table was filled out by first collecting desired dose ranges from AguaClara sub-teams. The Hagen-Poiseuille equation provided us with the flow rate of the chemicals given the viscosities, which can be extrapolated from curves AguaClara LCDC teams have constructed for the individual chemical solutions. We took the maximum dose information to the LCDC Mathcad file and combined it with the plant flow rate and chemical flow rate in order to optimize the stock tank concentrations. We used the existing LCDC Mathcad file to calculate the length of small diameter tubing. This file manipulates the Hagen-Poiseuille equation given the input constraints of viscosity, diameter and chemical flow rate. The Mathcad file has a parameter for the maximum stock concentration allowable through a single tube so that it will indicate the need for additional tubes when the solubility limit for the chemical is reached. If the plant requires more than 2mL/s, the maximum flow rate of chemical through one tube, the "T" design is called for. Using this "T" the chemical flow is split into multiple of tubes to provide enough total chemical flow to the drop tube. For a 12 L/s plant, we concluded that a single connection from the CHT to the drop tube would be adequate for each feed. However, we tested the "T" with this setup to make sure that it was still able to deliver the same dose through each connection.

A required input for the Hagen-Poiseuille equation is the viscosity of the chemical solution. This value can be calculated for the coagulant doses of either Alum of PACl since a former LCDC team had manually prepared the solutions and determined their viscosities with a viscometer and constructed a curve to estimate the viscosity of any Alum or PACl solution. For the calculations in this report, Alum viscosity values were

Table 4: Chlorine Viscosities

g/L	Volume (ml) = 200	Dynamic Viscosity	Kinematic Viscosity ($\frac{mm^2}{s}$)
25	5 g	1.15 cp	1.0880 $\frac{mm^2}{s}$
50	10	1.35 cp	1.1667 $\frac{mm^2}{s}$
100	20	1.38 cp	1.1190 $\frac{mm^2}{s}$
200	40	1.61 cp	1.0966 $\frac{mm^2}{s}$

used. Should PACl be the coagulant desired, the LCDC Mathcad file has an option for switching to this viscosity curve. The Spring 2012 team prepared chlorine solutions of 25g/L, 50g/L, 100g/L and 200g/L for viscosity testing. These values will provide data points to form a curve that can provide a viscosity value for any stock concentration from this point forth. This data will be added to the existing LCDC Mathcad file. The table below shows the four chlorine solution samples we prepared and their measured viscosities. Unfortunately, the chlorine samples did not dissolved completely, so these values could incorporate significant errors.

If the size of the plant increases, we could extrapolate from the above measured viscosities. The solubility limit puts an upper limit on the concentration possible through a single tube, but a "T" design that uses additional attachments can be used with a smaller chemical concentration. The solubility limit for the chlorine in water is 21gm/100ml, so our tested concentrations are all within the solubility limit, but were not observed to dissolve in the allotted time. Due to the errors associated with conducting a viscometer test on undissolved solution, we will continue to approximate the value for the viscosity of the chlorine solution with the viscosity of water, $1.0\frac{mm^2}{s}$.

3.4 Fabrication and Durability

For each plant, we select coagulant and chlorine concentrations for the stock tanks depending on the plant flow rate, and accordingly create the dosing scale to print on the lever arms for the operator's use. We are currently considering methods for printing the scale on the lever arms; we can use stickers, which have been used in the past, but we are considering more durable methods as well, such as printing directly on the lever arms with permanent ink, or stamping into the rods. We have proposed a new part to use as the lever arm, McMaster-Carr part #8910K534, which is similar to the current lever arm but the dimension on which the scale will go is 2" as opposed to the current 1". This bigger area will allow for the same stickers to be used that have been printed in the past; the screws for setting the dose will not need to contact the stickers at all so that wear and tear on the stickers will be minimal. We will continue to print the dose in mL/s, ratherthan shift to a unitless or % scale, so that engineers and future users of the LCDC will be able to determine how much chemical is being added if the original documentation is lost.

A method to clean the device will also be necessary. The majority of our LCDC components that come into contact with the chlorine solution are PVC or stainless steel, and as such will not react with the chlorine in an unsightly manner. These parts include the CHT, barbed fittings, small and large diameter tubing, drop tube, and the stainless steel screw. Calcium carbonate precipitate forms when the chlorine solution comes in contact with open air. Consequently, we anticipate that the upper, open end of the drop tubes will develop significant calcium carbonate precipitate. Periodically, this will need to be removed or dissolved with vinegar so it does not interfere with the chemical flow. One method to deal with this issue is to supply the plant operators with a spare set of drop tubes that can be substituted so that cleaning can occur without shutting down plant operation. In order for this to be feasible, we need to attach the cap in such a way that it is relatively easy to remove on occasion. Perhaps we can use a screw on cap or a removable barbed fitting.

The Spring 2012 team is verifying the flow rates through the small and large diameter tubes and into the drop tubes. In order to test this, the maximum dose at maximum head was tested for the different lever arms. Once the system is calibrated to zero flow at zero head with the lever arms level, we ranged the head from 0 cm to 20 cm head in increments of 4 cm to observe the flow rate response. At each position, we conducted three 60 second trials. For each test, the mass of the water that left the drop tube was measured and converted to a flow rate in ml/sec. This resulted in a linear correlation between flow and head, as we expected. This test was conducted for small diameter tubes for the required lengths of each dose.

The LCDC Experimental Results Mathcad file is programmed to provide the flow rate of water, our test substance, equivalent to the desired chemical flow rate (Q_{chem} = 2.0 mL/s) using inputs of the viscosity of the test substance in addition to the type of chemical (Alum, PACl, chlorine) it is substituting and its concentration. We conducted our first round of tests for a tube of length 2.285m, the calculated length of the small tubing to be used for the chlorine dose.

After initial testing, maximum percent error through system plots suggest that head to calibrate the system with for minimum total error to be about 12cm for the chlorine dosing tube in a 12 L/s plant. Calibration points for different size plants can be obtained with the LCDC Experimental Results Mathcad file. All that is needed to produce a maximum percent error through system plot is the length of tubing, the chemical identity, and its stock concentration. At this recommended calibration point, 12cm head, a 1.6 mL/s chemical flow rate is desired. This corresponds to a 1.301 mL/s water flow rate. To achieve this flow rate, the team ran three trials at 12cm head for 60 seconds and calculated the chemical flow rate with the originally calculated length of small diameter tubing. Minor head losses had the effect of reducing the experimentally obtained flow rate. We compared the observed flows to the values that the Hagen-Pousielle equation predicted. The flows were too low; the errors ranged from -3.8% to -12.95%. To increase the flows to attain 1.301 mL/s of dosed flow, the small diameter tube must be reduced in length. In our process we erroneously used the Mathcad file and determined that 1.24 mL/s was the flow rate that ought to correspond to 12cm head. This resulted in error of -4.369% at 12cm head as can be seen in Table 5. The process of trimming the small diameter tubing was done incrementally, so that the relationship between length and flow rate could be observed. First, flows were taken at 2.285m, which are provided in Table 4. We decreased the small diameter tubing length at increments of 1cm at a time. We marked out the 1cm increments prior to cutting to ensure that the same amount was cut each time. When we reached the flow rate we targeted for 12cm head, the small diameter tube measured 2.26m in length. Table 5 includes the flow rates observed at each of 4cm, 8cm, 12cm, 16cm and 20cm and associated errors at this calibration.

Though this process of using Mathcad to determine the head setting to calibrate to in order to minimize total error was accessible to the AguaClara team since we have easy access to Mathcad, we wanted to explore simpler calibration techniques that could be used in Honduras or other sites for plants. It was decided that we would try calibrating to 2.0 mL/s at 20cm head, as was recommended back in Summer 2011, and then compare the resulting errors to our more sophisticated method which involved the Maximum percent error through system analysis, presented in Figure 4 for the chlorine dosing tube.

We started the test again with the 2.285m tube, this time making the incremental cuts until we reached 2.0 mL/s flow at 20cm. The final length of tubing was 1.82m, and the resulting flow rates are presented in Table 5. With the exception of a 10% error at 4cm head, all errors were very small, each less than 1%. This led us to conclude that calibration at 20cm for 2.0 mL/s provided not only a uniform way to instruct plant operators how to calibrate but also a method that was comparable in accuracy. For the coagulant tubing we would only calibrate to 2.0mL/s at 20cm rather than use the maximum percent error through system analysis, although we did generate this graph with Mathcad. In Figure 8, the maximum percent error through system is plotted for the coagulant tube, indicating that total error for the system would be minimized near 18cm head, so calibrating to 20cm is close to what the more complex method suggests, and is simpler to explain to operators.

For the 2.574m tube, initial flow rates prior to calibration can be found in Table 7. Maximum error at the observed points peaked at just under 5% at head values of 16cm and 20cm. After just one 1cm cut, we achieved the target flow rate, 2.03 mL/s of water (the equivalent of 2.0 mL/s of chemical) at 20cm head. The flow rates for head values of 4cm, 8cm, 12cm, 16cm and 20cm are available in Table 8.

Having taken flows for each of the head values from 4cm to 20cm in 4cm increments and calculating the errors due to the limitations of calibration, a float analysis was conducted to determine how the slider torques would change the head actually experienced by the chemical. Table 9 in 4.4 below gives a few relevant values from the float analysis conducted. Further analysis of this error source can be found in Appendix B.

Table 5: Flow Rate of Water with Small Diameter Tubing 2.285m in length (mL/s)

Trial	4 cm	8 cm	12 cm	16 cm	20 cm
1	0.417502	0.814963	1.219105	1.548096	1.885437
2	0.414162	0.804943	1.209085	1.546426	1.888777
3	0.420842	0.813293	1.202405	1.544756	1.887108
Average	0.417502	0.811067	1.210198	1.546426	1.887108
Expected	0.434	0.867	1.301	1.734	2.168
% Error	-3.8015	-6.4514	-6.9794	-10.8174	-12.9563

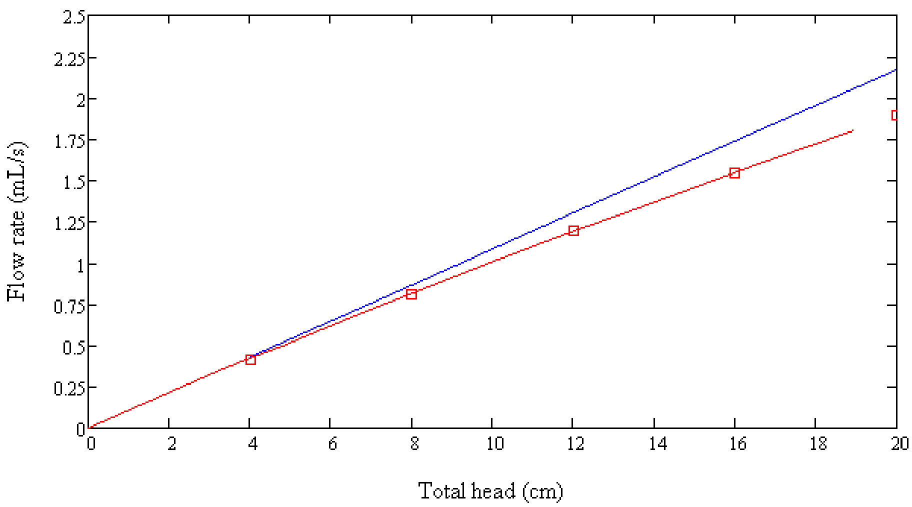


Figure 3: Flow Rate vs Head for the Farthest Lever Arm (2.285m). At zero head, the system is calibrated for zero flow, but errors begin to pick up at the first non-zero test point, 4cm head. Minor losses cause the experimental results curve to have a concave down shape. Deviation from expected flows increase with head.

4 Analysis

4.1 Tube Length: 2.285m for Chlorine and Filtration

In the first experiment, we collected the flow rates of water through a 2.285m small diameter tube when head was 4cm, 8cm, 12cm, 16cm and 20cm using the lever arm at the greatest distance from the white fiberboard. The observed relationship between head and flow was nearly linear. Observed flow deviates from expected flow rates more dramatically at higher head values. Table 4 presents the data from this test; the data is presented graphically in Figure 3.

This data was then input into the Mathcad file to determine at what head we should calibrate to minimize error for the setup as a whole the graph in Figure 4 was obtained.

We first attempted to calibrate the system to 12cm head, which we accomplished at 2.26m small diameter tubing length; resulting flow rates are summarized in Table 5. As the % Error rows show, calibration at 12cm did improved performance all around. However, given the constraints on calibration equipment on site, the team tested how the accuracies would compare should calibration be simplified to achieving 2.0 mL/s chemical flow at 20cm head.

A Mathcad miscalculation led us to calibrate for 2.238 mL/s at 20cm head, although the flow we calibrated to should have been 2.168 mL/s. This error was not discovered until after all of the results were compiled, and time did not permit a retest. However, the following data, paired with less precise calibration equipment available at plants suggest that the error did not have a significant result on flow rates. Had the correct flow been calibrated to, flow rates across the board would have been slightly smaller, which would have

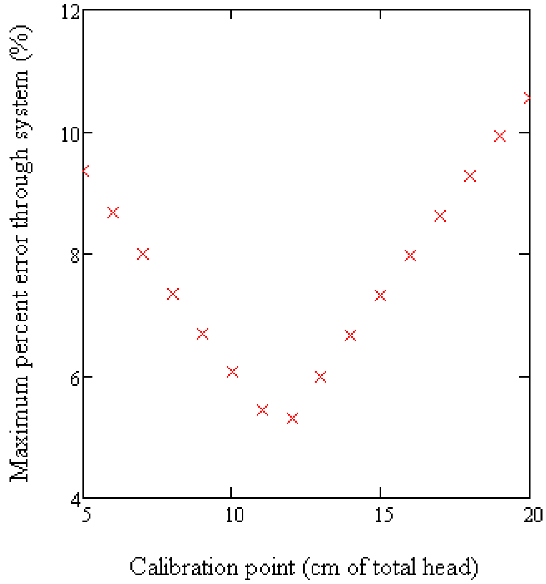


Figure 4: Maximum percent error through system for the Farthest Lever Arm (2.285m). This graph suggests that calibration should occur near 12cm of head. By calibrating at this point, the error in the system should be a minimum across all head values.

Table 6: Flow Rate of Water with Small Diameter Tubing 2.26m in length (mL/s)

Trial	4 cm	8 cm	12 cm	16 cm	20 cm
1	0.424182	0.853373	1.235805	1.618236	1.965598
2	0.420842	0.861723	1.250835	1.609886	1.968938
3	0.417502	0.858284	1.245825	1.614896	1.955578
Average	0.420842	0.857827	1.244155	1.614340	1.963371
Expected	0.434	0.867	1.301	1.734	2.168
% Error	-3.032	-1.058	-4.369	-6.901	-9.439

reduced the error of concern at 4cm head. We do not anticipate the minor error in calibration would have dramatically impacted observed flow rates, especially on-site, because the flow we calibrated to was not significantly different from that which we should have calibrated to.

Additional intermediate cuts and flows can be found in Appendix 1.

4.2 Tube Length: 2.57m for Alum Coagulation Doses

The error for the 2.57cm tube for the alum coagulant before it was trimmed reaches a maximum of 4.821% below expected at 20cm head.

From the values seen in the table and the graph seen above, further calibration is needed in order to minimize error. There will be error in the system regardless of where it is calibrated because some level of minor losses is ubiquitous. The graph below shows where calibration should occur to minimize the total error for the system as a whole. The lowest point corresponds to the calibration point which will results in smallest total error. This is where the system should be calibrated. The Maximum percent error through system vs Calibration point graph suggests calibration should occur at about 16-18cm head. Assuming the correct location to properly calibrate the system is 16cm head, we expect 1.6 mL/sec of chemical flow at 16cm head, which is equivalent to 1.626 mL/sec water flow. We incrementally shortened the small diameter tube until we reach our desired flow rate.

Despite this graph indicating an appropriate calibration point, due to simplicity and ease for the operator

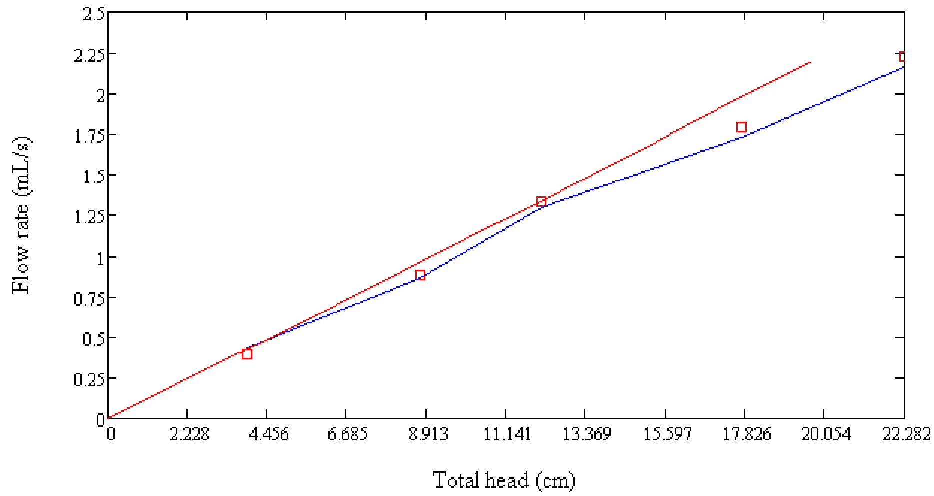


Figure 5: Flow Rate vs head for the farthest Lever Arm (1.82m) when calibrated to 20cm for a flow of 2.234 mL/s. However, our data follows the error accounted by the float which is explained later and calculated in Table 7.

$$h_{Total4cm} = \begin{pmatrix} 0.04 \\ 0.08 \\ 0.12 \\ 0.16 \\ 0.2 \end{pmatrix} m \qquad h_{Adder} := \begin{pmatrix} .003 \\ .0067129 \\ .001139 \\ .01628 \\ .0214 \end{pmatrix} m \qquad Error_{1.82} := \begin{pmatrix} -.102574 \\ .008438 \\ .002163 \\ .005368 \\ 0.0071 \end{pmatrix}$$

$$h_{Adder1.82} := \begin{pmatrix} -.102574 \cdot .04m \\ .008438 \cdot .08m \\ .002163 \cdot .12m \\ .005368 \cdot .16m \\ .0071 \cdot .2m \end{pmatrix} = \begin{pmatrix} -4.103 \times 10^{-3} \\ 6.75 \times 10^{-4} \\ 2.596 \times 10^{-4} \\ 8.589 \times 10^{-4} \\ 1.42 \times 10^{-3} \end{pmatrix} m$$

$$h_{scaled1.82m} := h_{Total4cm} + h_{Adder} + h_{Adder1.82} = \begin{pmatrix} 0.039 \\ 0.087 \\ 0.121 \\ 0.177 \\ 0.223 \end{pmatrix} m$$

$$Q_{HP}\left(h_{Total4cm}, \nu_{Est2.285m}, D_{TubeExp}, L_{Tube2.285m}\right) = \begin{pmatrix} 0.434 \\ 0.867 \\ 1.301 \\ 1.735 \\ 2.168 \end{pmatrix} \cdot \frac{mL}{s}$$

Figure 6: Error Calculations include an h_{Adder} modifier that accounts for the error caused by the float. A 6" float with one Tee configuration will cause a 2.14cm shift in height. The other entries in this modifier matrix are based off of a quadratic fit of error as the slider's torques increase farther along the lever arm. Further information about float displacement can be seen in Appendix 3. $h_{Adder1.82}$accounts for the tabulated error at each 4cm increment of head from calibration. $h_{scaled1.82m}$ combines the error source heads with the head values set by the flow.

Table 7: Flow Rate of Water with Small Diameter Tubing 1.82m in length (mL/s)

Trial	4 cm	8 cm	12 cm	16 cm	20 cm
1	0.398111	0.885628	1.359649	1.806680	2.236842
2	0.387899	0.882254	1.342780	1.799935	2.253711
3	0.402047	0.897436	1.320850	1.798246	2.221660
Average	0.402047	0.888439	1.341093	1.801619	2.237404
Expected	0.434	0.867	1.301	1.734	2.168
% Error	-10.257	+0.844	+0.216	+0.537	+0.071

Table 8: Flow Rate of Water with Small Diameter Tubing 2.57m in length (mL/s)

Trial	4 cm	8 cm	12 cm	16 cm	20 cm
1	0.417502	0.814963	1.194055	1.548096	1.943888
2	0.41416166	0.8049432	1.194055	1.546426	1.938877
3	0.420842	0.813293	1.195724	1.544756	1.922178
Average	0.417502	0.811067	1.194611	1.546426	1.934981
Expected	0.407	0.813	1.22	1.626	2.033
% Error	+2.58	-0.238	-2.081	-4.893	-4.821

the Spring 2012 team decided that the LCDC should calibrated to 20cm head for a 2.0 mL/s. This is the most practical solution for calibration in the Honduras. When we calibrated for a 2.0 mL/s flow at 20cm head, the following flow rates were observed at head of 4cm, 8cm, 12cm, 16cm and 20cm.

Table 9: Flow Rate of Water with Small Diameter Tubing 2.56m in length (mL/s)

Trial	4 cm	8 cm	12 cm	16 cm	20 cm
1	0.410822	0.870073	1.254175	1.685037	2.017368
2	0.414162	0.866733	1.257515	1.683367	2.034068
3	0.417502	0.860053	1.264195	1.671677	2.037408
Average	0.414162	0.865620	1.258628	1.680027	2.029615
Expected	0.407	0.813	1.22	1.626	2.033
% Error	+1.7596	+6.4723	+3.1663	+3.3227	-0.1665

In the figure above, float error and calculated error were taken into account by the following set of equations and matrices.

4.3 Tee Analysis

The expected values were calculated by multiplying the expected values for a single tube attachment by two to account for the fact that there are two small diameter tubes attached to the “T” for which the flow rates are given in Table 9. The error when the “T” design was used was substantially greater than when the single tube drop tubes were used. This is probably partially due to the fact that we calibrated to a higher flow rate for 20cm head originally due to faulty Mathcad manipulation. Thus, errors should be expected to be greater by a factor of two due to twice as many tube inputs. However, the observed error was greater than for the single tube by more than a factor of two. Furthermore, the error for this data is not the sort that was expected. If the flows had been too low it could be attributed to chemical being retained in the horizontal segment of the “T” and not entering the free fall part of the drop tube. To confirm the validity of this data, more testing is required. If the “T” requires it’s own length cutting calibration procedure and we cannot directly copy the length of the individual dose tube, perhaps another algorithm needs to be generated. The flows are relatively close, and the “T” remained level during testing, so this can be an option for larger plants, but it will need more testing and refining. Another issue with the “T” is that its inputs from the constant head tank are at the same level as the screw, rather than below, as with the single tube drop tubes. For this

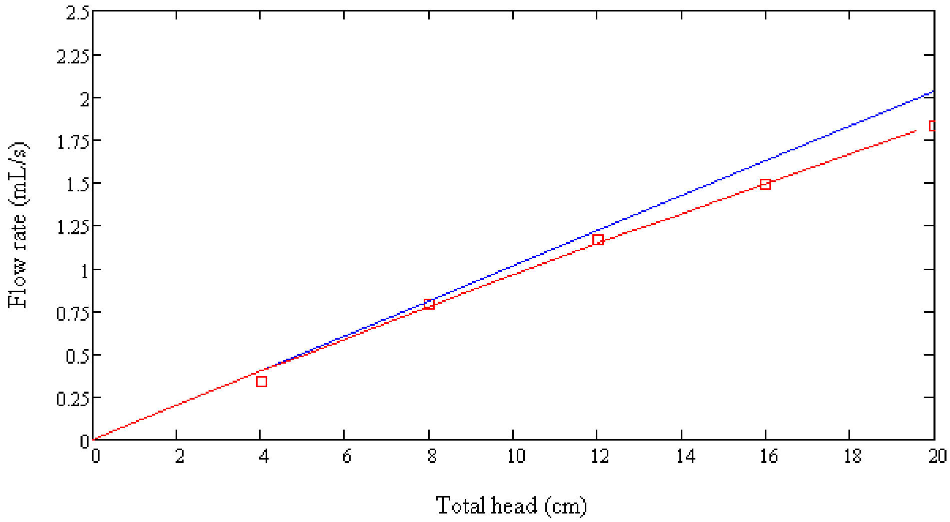


Figure 7: Flow Rate vs head for the Farthest Lever Arm (2.57m). At zero head, the system is calibrated for zero flow, but errors begin to pick up at the first non-zero test point, 4cm head. Minor losses cause the experimental results curve to have a concave down shape. Deviation from expected flows increase with head.

Table 10: Flow Rate of Water with Small Diameter Tubing 1.82m in Length, "T" with (2) tubes (mL/s)

Trial	4 cm	8 cm	12 cm	16 cm	20 cm
1	0.995	2.068	3.037	3.950	4.734
2	1.003	2.073	3.024	3.891	4.749
3	1.005	2.088	3.035	3.893	4.695
Average	1.001	2.076	3.032	3.911	4.726
Expected	0.868	1.734	2.602	3.468	4.336
% Error	+15.322	+19.723	+16.526	+12.774	+8.994

reason, the same "T" PVC part would be applicable, but the constant head tank would be positioned a few centimeters higher to account for the higher position of the dosing tube inputs.

4.4 Float Analysis

The float analysis is based upon the weights of each of the components of the LCDC and the moments they cause onto the system. As mentioned earlier, any extra mass on the slider slide of the LCDC, will displace an equal amount of water on the float side. In order to displace a smaller amount of water, the surface area of the float can be increased. Below is the float analysis for different configurations for 2 different float diameters along with its percent error. In general, the smaller float leads to higher percent error, which cannot be avoided. More information about float analysis and the mass of the LCDC Parts can be seen in Appendix B.

The summary of the extensive float analysis in Table 10 shows that that the float with the larger surface area will lead to a lower percent error. Analysis was also performed on the suitability of 6" and 8" floats in the situations that the weights of the sliders was reduced. If the length of the slider could be reduced by 50%, from 4" to 2", the error for a 6" float in a setup with 3 single drop tubes could be reduced from 10.28% to 8.73%. Further analysis in Appendix B details these calculations in addition to more slider weight reduction possibilities and resulting errors.

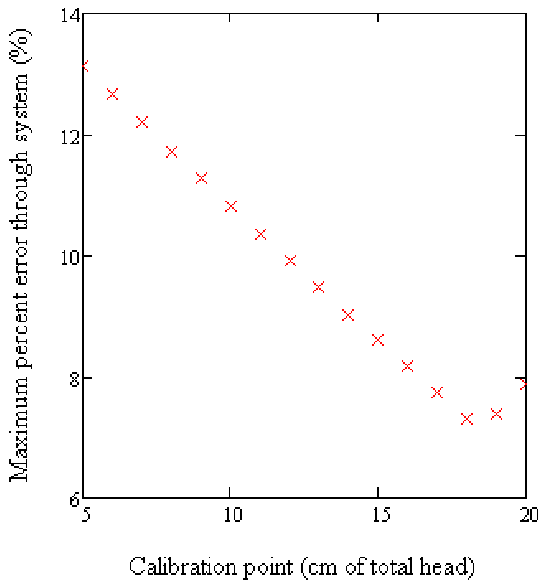


Figure 8: Maximum Percent Error through System for Farthest Lever Arm (2.57m). This graph suggests that 18cm head is the appropriate calibration point to achieve minimum error throughout the system as a whole.

Table 11: Float Analysis

	6" Float	8" Float	6" Float	8" Float
	3 Single Slider	3 Single Slider	2 single 1 "T" slider	2 single, 1 "T" slider
Mass	373.8	373.8	437.3	437.3
Vol Water Displaced	374.906	374.9067	438.5948	438.5947
Base Float Surface Area	182.415	324.2928	182.415	324.2927
Height Change	2.055	1.156	2.4044	1.3524
Maximum Error (at 20cm)	+10.28%	+5.78%	+12.02%	+6.76%

4.5 Error Analysis

At the maximum dosing, 20cm head, there is the maximum float error for the system. The maximum error in the system then can be added up: Error by the float plus error due to calibration being not perfectly linear. This is done in Table 11.

At very low doses, the float error (the error associated with torques lifting the float) will be very low, but since the system is designed to hit the target flow rate at 20cm head, the calibration error will be higher. Table 10 indicates that calibration error at 20cm should be minimal, since this is the flow rate calibrated to, but can be either positive or negative. Thus, if a plant is opting for a smaller (6" diameter) float, it is advantageous to have a slightly lower flow at 20cm to offset float error. It is essential to note that this error analysis separates float and calibration errors because it was put together from our lab situation in which there was no float present when we determined calibration error. The total 20cm head error tabulated in Table 11 represents the total error we would expect our LCDC to demonstrate if their current calibration were to be maintained and connected to a float rather than the white fiberboard. This corresponds to an operator calibrating their plant in a similar manner that does not account for torques moving the float.

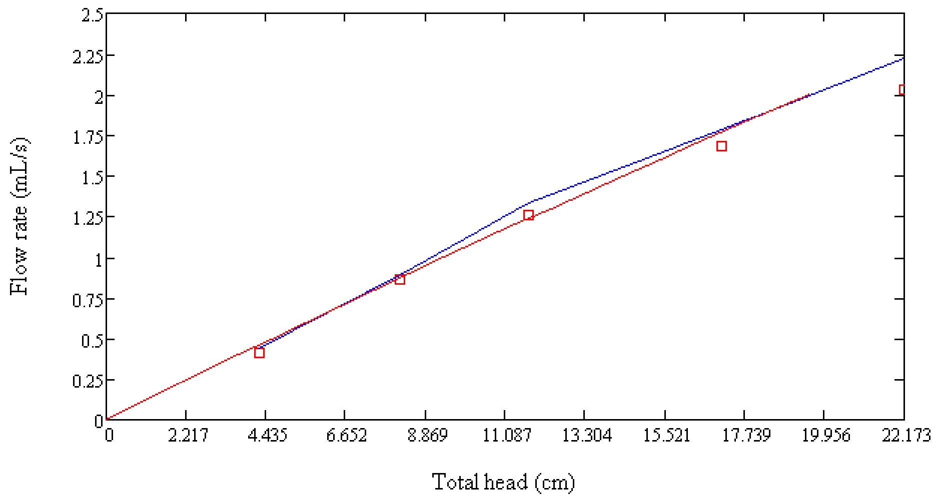


Figure 9: Flow Rate vs Head for the Farthest Lever Arm (2.56m). Errors pick up around around 12cm head. Minor losses cause the experimental results curve to have a concave down shape. Deviation from expected flows should increase due to increased flow rates, however float error and calculated error are taken into account which makes the expected flow values increase or decrease accordingly. The curve seen in the blue trend line has taken float error and calculated error into account.

$$h_{Total4cm} = \begin{pmatrix} 0.04 \\ 0.08 \\ 0.12 \\ 0.16 \\ 0.2 \end{pmatrix} m \qquad h_{Adder} := \begin{pmatrix} .003 \\ .0067129 \\ .001139 \\ .01628 \\ .0214 \end{pmatrix} m \qquad Error_{2.56} := \begin{pmatrix} .0175962 \\ .0647231 \\ .031662597 \\ .033226765 \\ -.001665133 \end{pmatrix}$$

$$h_{Adder2.56} := \begin{pmatrix} .04 \cdot .0175962 \\ .08 \cdot .0647231 \\ .12 \cdot 0.031662597 \\ .16 \cdot 0.033226765 \\ .20 \cdot -0.001665133 \end{pmatrix} m = \begin{pmatrix} 7.038 \times 10^{-4} \\ 5.178 \times 10^{-3} \\ 3.8 \times 10^{-3} \\ 5.316 \times 10^{-3} \\ -3.33 \times 10^{-4} \end{pmatrix} m \qquad h_{scaled.2.56m} := h_{Total4cm} + h_{Adder} + h_{Adder2.56} = \begin{pmatrix} 0.044 \\ 0.092 \\ 0.125 \\ 0.182 \\ 0.221 \end{pmatrix} m$$

$$Q_{HP}\left(h_{Total4cm}, \nu_{Est2.57m}, D_{TubeExp}, L_{Tube2.57m}\right) = \begin{pmatrix} 0.407 \\ 0.813 \\ 1.22 \\ 1.626 \\ 2.033 \end{pmatrix} \cdot \frac{mL}{s}$$

Figure 10: Error Calculations include an H_{Adder} modifier that accounts for the error caused by the float. A 6" float with one Tee configuration will cause a 2.14cm shift in height. The other entries in this modifier matrix are based off of a quadratic fit of error as the slider's torques increase farther along the lever arm. Further information about float displacement can be seen in Appendix 3. $H_{Adder2.56}$accounts for the tabulated error at each 4cm increment of head from calibration. $Error_{2.56}$is the decimal form of the observed error between observed flow after calibration and flows predicted by the Hagen-Poiseuille equation.

Figure 11: Flow Rate of Water with Small Diameter Tubing 1.82m in Length, "T" with (2) tubes (mL/s)

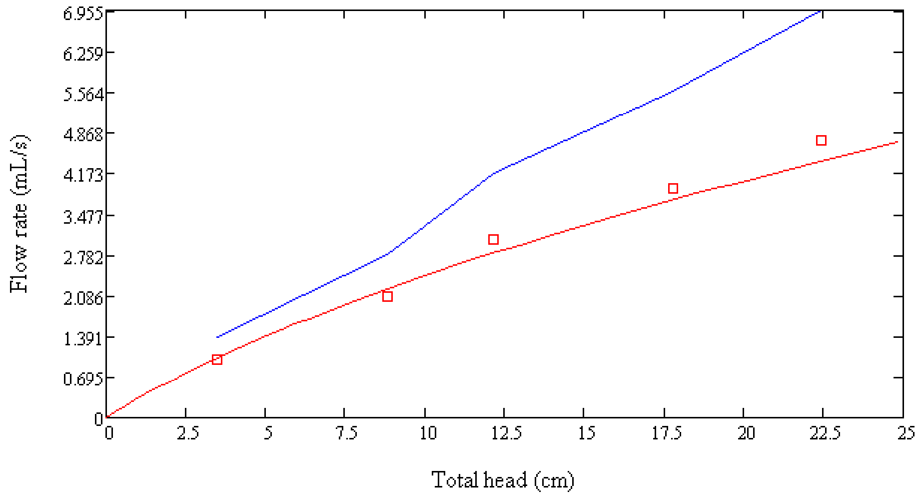


Table 12: Summation of Errors at 20cm head

	Maximum Float Error	Maximum Calibration Error	20cm head error
6" Float, 2.56m tube	+10.28%	-0.1665%	10.11%
6" Float, 1.82m tube	+10.28%	+0.07126%	10.35%
8" Float, 2.56m tube	+5.78%	-0.1665%	5.61%
8" Float, 1.82m tube	+5.78%	+0.07126%	5.85%

However, if the float is present and subject to the torques when the calibration to 20cm is conducted, then the total 20cm error is simply the observed error at this point. The "float error" would need to be represented as a negative contribution to flow at lower head values in this reversed situation.

5 Conclusions

This semester we determined the system for calibrating the lengths of the LCDC chemical tubes, starting at the Mathcad recommended length and cutting in increments of 1cm. At each new length, three trials of 60 seconds are taken, and this process should be repeated until the target flow rate is reached. We analyzed the situation in which the 2.285m chlorine tube was calibrated to the head at which total error is minimized, 12cm. Then we calibrated for the desired 2mL/s flow at 20cm and compared the errors of these two scenarios. Providing instructions to plant operators to calibrate at 20cm is simpler and thus desirable if the error is comparable. We determined that it was a comparable error, and proceeded to calibrate the 2.574cm alum coagulant tube only at 20cm. The errors calculated confirmed the adequacy of calibrating at 20cm.

Our testing and calculations indicated that the error caused by the head change due to the float's movement is substantial and more of a factor than the minor head losses. For this reason, it is not effective to test the LCDC without a float attached and without a water level in the entrance tank. We advise that calibration be done when there is a water level and the chosen float in position. This float error will cause flow rates to be higher than anticipated, so the starting length of the dosing tubes need to be longer. Using the float analysis, the projected float error can be found, and the dosing tube should be cut to the appropriate additional length at the beginning of calibration.

A test of a "T" design for drop tubes were conducted as well. The tests indicated that the "T" with two inputs did not very nearly double the total flow rate of chemical as observed in the single tube test. The small errors due to chemical solution trapped in the horizontal part of the "T" were not significant, but for

$$h_{Total4cm} = \begin{pmatrix} 0.04 \\ 0.08 \\ 0.12 \\ 0.16 \\ 0.2 \end{pmatrix} m \qquad h_{Adder} := \begin{pmatrix} .003 \\ .0067129 \\ .001139 \\ .01628 \\ .0214 \end{pmatrix} m$$

$$h_{Adder1.82} := \begin{pmatrix} -.102574 \cdot .04m \\ .008438 \cdot .08m \\ .002163 \cdot .12m \\ .005368 \cdot .16m \\ .0071 \cdot .2m \end{pmatrix} = \begin{pmatrix} -4.103 \times 10^{-3} \\ 6.75 \times 10^{-4} \\ 2.596 \times 10^{-4} \\ 8.589 \times 10^{-4} \\ 1.42 \times 10^{-3} \end{pmatrix} m$$

$$h_{AdderTee.1.82} := 2 \cdot h_{Adder1.82} = \begin{pmatrix} -8.206 \times 10^{-3} \\ 1.35 \times 10^{-3} \\ 5.191 \times 10^{-4} \\ 1.718 \times 10^{-3} \\ 2.84 \times 10^{-3} \end{pmatrix} m$$

$$h_{scaledTee.1.82m} := h_{Total4cm} + h_{Adder} + h_{AdderTee.1.82} = \begin{pmatrix} 0.035 \\ 0.088 \\ 0.122 \\ 0.178 \\ 0.224 \end{pmatrix} m$$

$$2 Q_{HP}\left(h_{Total4cm}, \nu_{Est1.82m}, D_{TubeExp}, L_{Tube1.82m}\right) = \begin{pmatrix} 0.865 \\ 1.73 \\ 2.595 \\ 3.459 \\ 4.324 \end{pmatrix} \cdot \frac{mL}{s}$$

Figure 12: Error Calculations include again the h_{Adder} modifier that accounts for the error caused by the float. $h_{Adder1.82}$ is multiplied by two since there are two tubes calibrated at that length in order to generate $h_{AdderTee1.82}$. $h_{scaledTee.1.82m}$ sums these two sources of error and combines this value with the flow as controlled on the white fiberboard.

some reason flows were higher than expected; up to 19.723% higher at the 8 cm head setting. However, since only a single three trial test was conducted, this finding should be tested further before being considered conclusive. The "T" is not necessary in plants with moderate flow rates and even in very large plants will only ever be used on the first (prior to flocculation) dose of coagulant. For this reason, float analysis only considered up to one “T” drop tube setup.

We concluded that if a 6” float is to be used, the slider weight must be reduced in order to stay under a total 10% error at 20cm head. This applies to situations in which three single drop tubes (no "T" for multiple inputs) are used. This is as simple as reducing the length of the slider to 2” instead of 4”. It would not be necessary to change the materials which the sliders are made from to sufficiently decrease this error. If flow rates are high enough such that a "T" is required to provide the chemical dosing for the first coagulant dose, an 8” diameter float is in order. In such plants, the financial investment in the plant will be large enough to accommodate the increase in material costs incurred by the larger float component parts.

We determined that the current material used for the lever arms is insufficiently wide at present. A 2” wide replacement will make it easier for the operators to set and read the dose. The recommended replacement is McMaster-Carr part #8910K534 which is a 2” wide, 3’ long, 3/16” thick low carbon steel, with a cost of $17.06. With this new lever arm, the current method of stickers to attach the scale will be less prone to damage by the slider screws. We concluded that the dosing stickers should not be simplified to a mere 0 - 100 scale, but rather maintain the 0 - 2 mL/s scale. This allows for the setup to be more comprehensible; we decided that a 0 - 2 mL/s scale was not too confusing to operators and could be very helpful to a visitor or new plant operator if they should have the need to report or determine how much chemical is being administered in the future.

Another discovery during the testing process that is relevant to an operator calibrating their own system is that the angle of curvature created by the weight on the small diameter tubing can have a significant impact on minor losses and consequently observed flow rates. As we shortened the chlorine dosing tube, the angle or curvature increased substantially, resulting in reduced flow rates. This can be corrected for by adding additional large diameter tubing or by moving the constant head tank nearer to the LCDC. Both of these alternatives serve to reduce this angle of curvature. Increasing the mass of the weight is also an option, but was generally less effective.

6 Future Work

Future work for the LCDC includes testing how the McMaster-Carr part #8910K534 performs as a lever arm and if another product needs to be selected. Currently, implementation of the LCDC on a site relies on the calibration that is performed when the LCDC is installed. We have put together an instructions manual with calibration assistance video, but as the parts lists adapts to locally available and affordable materials, this calibration procedure will need to be modified accordingly.

As of now, the calibration of the LCDC that we are providing to the operators is is a process, not a precise setup; we cannot tell them exactly the length of tube they will need to minimize error, because the minor losses will be different for every LCDC, and as discovered through our own testing, can change rather significantly using the same materials just from calibration to calibration.

Future work should include a plan to further test the "T" design using cross PVC pieces.

A thorough plan for cleaning out the drop tubes due to chlorine reactions needs to be developed, as does a plan for printing sticker labels, though the sticker labels should be an option with the wider lever arm proposed.