Linear Chemical Dose Controller Fall 2012 Final Report

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Abstract

Accurate chemical dosing is an essential part of an AguaClara plant. Proper dosing is required for effective flocculation, sedimentation, filtration and disinfection. Coagulant (Poly Aluminum Chloride or Alum) and disinfectant (Chlorine) are chemicals used for dosing in an AguaClara plant. The linear chemical dose controller (LCDC) automatically maintains a linear relationship between the influent flow to the plant and the chemical dose. The plant operator therefore only adjusts the dose of coagulant based on the turbidity of the influent water. Previous designs for the LCDC functioned at lower flow rates, but design changes were necessary for increased flows and dosing of two chemicals: a coagulant and a disinfectant. The Fall 2012 team created and refined a prototype of the proposed dosing system design. Also, the team concentrated on system aesthetics by: creating a new counter weight, engraving the lever arm scale, adding an engraved AguaClara logo and anodizing the lever arm assembly. Once complete a refined calibration method was devised and documented and the system was tested for linearity of the chemical dosage with respect to the dosing scale and linear flow orifice meter (LFOM) height changes due to varied plant flow. Both tests resulted in a linear fit with an R^2 value of 0.9967 for the chemical dose percent data and an R^2 value of 0.9955 for the plant flow height data. The maximum percent error in the linear relationship between chemical dosing and dosing percentage was 63%. The maximum percent error in the linear relationship between chemical dosing and the LFOM height change was 34%. Errors were below the desired 10% at all data points except the data point corresponding to the lowest chemical dose, which suggests that the LCDC maintains a linear relationship at higher flows and is less accurate at low chemical flows. Error associated with chemical dosages with respect to the percent dosage can be attributed to the scale being offset from the zero (or pivot) point of the lever arm by approximately two centimeters. Error associated with changes in chemical flow rate with respect to changes in the plant flow rate can be attributed to the weight of the drop tube assembly.

Introduction

Accurate chemical dosing in water treatment plants is imperative to ensure optimal efficiency of flocculation and disinfection. Linear chemical dose controller (LCDC) and linear flow orifice meter (LFOM) systems have been designed to allow plant operators to easily and reliably set and maintain the desired doses of coagulant and disinfectant. The combined system adjusts the chemical flow rate automatically in response to changes in plant flow rate to maintain the target chemical dose without requiring an electronic supervisory control and data acquisition (SCADA) system. A linear relationship between head loss and chemical flow in the LCDC is created by using the major head loss through a small diameter tube to control the chemical flow rate. The dose controller design minimizes minor losses through the chemical flow control system to reduce the error from non-linearities. The LCDC adjusts for plant flow rate changes by tracking the water level in the entrance tank to the water treatment plant. The LFOM maintains a linear relationship between height of water in the entrance tank and plant flow rate to create a linear input to the LCDC.

The new linear chemical dose controller design reduces the error associated both with the weight of the sliders in high flow rate plants and by reducing the non-linear effects of curved small diameter tubing. The new design also has the possibility of reducing the cost of chemical dosing by keeping the flow rates closer to the theoretical ideal rather than over dosing in the middle range of chemical flow rates. A scale up of the Summer 2012 design was fabricated, with design modifications, to supply coagulant for a design flow rate of 44 L/s. This design is tentatively scheduled for use in the Piedras Amarillas plant for the town of Las Vegas, Honduras. Detailed instructions have been provided including a parts list, the lever arm assembly dimensions, photos, calibration and use of the unit. The aesthetics of the LCDC were also improved.

Literature Review

Mathematical Development

The linear chemical dose controller (LCDC) uses major head loss and a constant head tank, which maintain a constant driving head elevation to regulate chemical flow to the water treatment plant. The relationship between major head loss and the chemical flow rate is given by the Hagen-Poiseuille Equation, Equation 1. The chemical flow rate (Q_C) is a function of the major head loss (h_f), the diameter of the tube diameter (D_{Tube}), the kinematic viscosity of the solution being used () and the length of the small diameter tube (L_{Tube}).

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

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 equation is rearranged in regards to the major head loss (h_f), one can see that this variable increases proportionally as the length of the small diameter tube (L_{Tube}) is increased as shown in Equation 2.

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

The total head loss through the system (H_{Total}) is the sum of the major (h_f) and minor (h_e) head losses. Major losses are due to viscous shear on the pipe walls whereas minor losses are due to various flow expansions as shown in Equation 3.

$$H_{Total} = h_f + h_e \tag{3}$$

Substituting equations for major and minor losses results in Equation 4. The LCDC system is designed so that the first term, which is the contribution due to major loss, dominates versus the second term, which is the contribution due to minor loss. This is done to maintain a linear relationship between $H_{Total}$and Q_C.

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

Previous Work

Past LCDC designs assumed that the length of the small diameter tube was sufficient to ensure that the major head losses dominated the system. These designs also assumed that the linear relationship between the chemical flow rate and the major head loss would be maintained, as shown in the Hagen-Poiseuille Equation (see 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 produced these results). Minor head losses 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 a 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. The Fall 2011 team focused on eliminating minor losses in the system and further developing the calibration methods. The Spring 2012 team focused on the design of a triple doser to dose coagulant prior to flocculation, dose coagulant before the filter and dose disinfectant after the filter.

Summer 2012 Changes to Designs

- Two sided arm
- Two dosing tubes
- Tubing connection manifold and tubes on tank wall
- Counterweight addition
- Sleeker design
- Benefits
  - Looks better/community ownership
  - Removed cumbersome parts of the former design like the hanging weight on the tube, which was being removed by operators

The linear dose controller has been re-designed to contain fewer minor losses and improved aesthetic appearance. One issue with the previous dose controller is that numerous tubes were needed to connect to the dosing tube for adequate dosing. This caused a cumbersome design with many minor losses. In the new design, a two sided lever arm, one for a disinfectant and one for a coagulant (Figure1), which attaches to the plant entrance tank as shown in Figure 2 was developed. Dosing tubes extend along the length of the entrance tank and are attached via manifolds. Two pipe manifolds (Figure3) connect to small diameter tubes which are connected to the entrance tank wall to ensure that the tubes remain straight and also to eliminate a potential tripping hazard. This design also has a greater aesthetic appeal, which is beneficial for community and operator ownership and has removed the need for certain cumbersome parts of the former design such as the hanging weight on the tube and the numerous tubing inlets as described above.

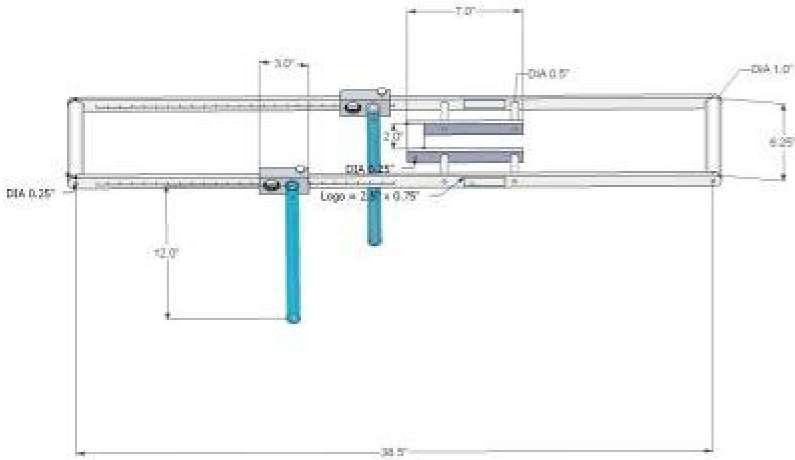


Figure 1: Lever Arm Assembly

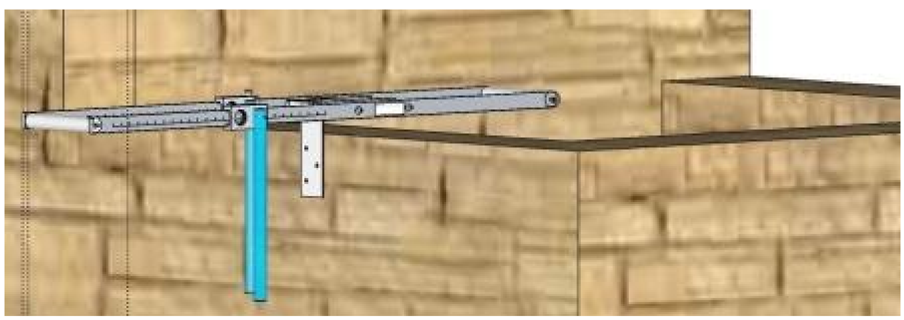


Figure 2: Lever Arm Plant Attachment

Figure 3: Manifold Smaller Diameter Tube Connection

Design Modifications

Design Overview

The need for a reliable, robust method of dosing coagulant and chlorine solutions at municipal scale water treatment plants led to the development of the linear chemical dose controller (LCDC). With the linear relationship between height of water in the entrance tank and plant flow rate provided by the linear flow orifice meter (LFOM), the chemical dose controller utilizes a float in the entrance tank to connect the chemical flow rate to the plant flow rate. When the plant flow rate increases, the water level in the LFOM rises proportionally and the float and lever arm rise as seen in Figures 4 and 5. A stock tank provides a reservoir of the chemical solution (coagulant or disinfectant) and is connected to a constant head tank (CHT). The CHT is regulated by a float valve which keeps the chemical depth constant, as shown in Figures6 and 7. A large diameter tube leads from the stock tank to one or more small diameter long straight dosing tubes as shown in Figure 8. A large diameter flexible tube leads to a rigid drop tube with open channel super critical flow that delivers the chemical to the chemical injection point. The drop tube is connected to a lever via a slider. The plant operator sets the slider at the desired coagulant dose based upon characteristics of the influent.

Figure 4: Zero flow through the plant and LCDC system

Figure 5: Maximum flow through the plant and maximum chemical dose flow through the LCDC system. Note: the slider is set at 100% dose and the level in the entrance tank is at the maximum height of 20 centimeters from the zero level

Figure 6: Chemical stock tank (gray bucket) connected to the constant head tank (white container)

Figure 7: Constant head tank with float valve

Figure 8: Large diameter tubing leading from the constant head tank to the small diameter long straight dosing tubes (3 clear PVC tubes)

Chlorine Resistance

All major components that were in contact with chlorine in the system are chlorine resistant (i.e. PVC) except for the manifolds, which were polypropylene. The manifolds should be fabricated from PVC or other chemical resistant material in future models.

Lever Arm Weight

A steel rod (having a higher density than aluminum) was hollowed out and a set screw was used to hold the weight in place on one end rod of the lever arm. The inner diameter was 2.54 centimeters (1 inch), the outer diameter was 5.08 centimeters (2 inches) and the length was approximately 14 centimeters (5.5 inches). This resulted in a weight of approximately 1.7 kilograms (3.7 pounds). The weight is shown in Figure 9.

Figure 9: Lever Arm Counter Weight

Calibration Device

The center of the end rod on the float end of the lever arm was whittled down in the center as shown to fit a turnbuckle, which is used to make fine tune adjustments during calibration of the lever arm and is shown in Figure10.

Figure 10: Turnbuckle attached to the lever arm

Lever Arm Assembly Cross Bracing

The original design did not include cross bracing that spanned the entire width of the lever arm assembly. This caused slight bending of the lever arms. To rectify this problem, rods were added as shown in Figure11.

Figure 11: Lever Arm Assembly Cross Bracing

Drop Tube Design

The existing design for the drop tube consisted of a flexible tube inserted into a rigid PVC pipe, did not include fittings, and was prone to leakage. Constraints for the new design were:

- The drop tube connection system should be light so that the slider cannot be weighed down
- All components must be chlorine resistant
- The connections should be leak-free
- The water can easily be viewed by an operator as it comes in and goes out of the drop tube
- The entire drop tube connection system should look professional,
- The dosing solution must come up into the drop tube from the bottom through an elbow to ensure a constant height from which the solution drops.

The current design meets all of the above criteria, except for the weight of the tube connection as described in the Analysis section of this report.

Figure 12: Rigid drop tube connection to the slider on the lever arm

Scale and Logo

Several companies were contacted to obtain quotes for the lever arm scale and logo. The most largely applicable scale for the lever arm (for future plants) was determined to be a dimensionless scale from 0 to 100 percent dosage, in increments of five percent. The lever arm contains two scales that are each approximately half of the length of the lever arm, or about 40.6 centimeters (16 inches). The scales are labeled for Chlorine and Coagulant in Spanish on each scale as follows: Cloro and Coagulante.

Hancock Precision is a CNC machine shop that could manufacture the lever arms (for future units), anodize the lever arm, engrave the scale, and laser engrave the logo on the lever arm assembly. Anodization is a protective electrolytic coating that provides corrosion and chemical resistance. This method was chosen, because it provided a simple sleek design that did not include numerous different plates or scales that needed attachment. The engraving was 0.25 millimeters (0.010 inches) deep (the thickness of the lever arm is 3.175 millimeters or 0.125 inches). See Figure 13 for a pre-anodized model and Figures 14 and 15 for the final lever arm scale and logo.

A few other options were considered, but ultimately rejected. A representative from Andersen Engraving suggested anodizing the lever arm in black, engraving it afterward, and paint filling it. However, concerns with paint chipping eliminated the paint option. Two other companies replied but were not suitable for the job (Sign Inn, which primarily does surface engraving for awards and name plates, and AllSpec Finishing, which provides a silkscreen service).

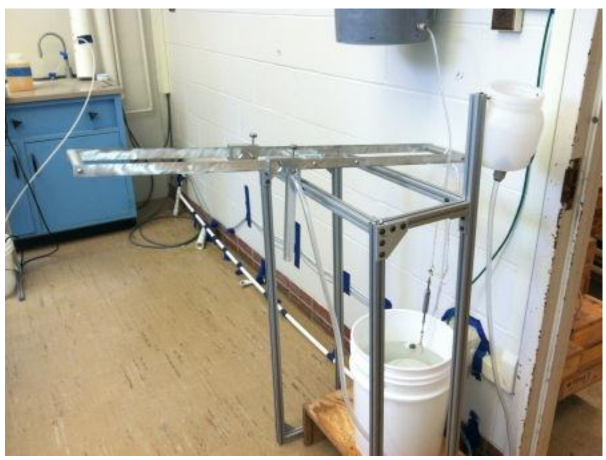


Figure 13: LCDC System Setup Pre-Anodization of the Lever Arm Assembly, with an Undersized Constant Head Tank

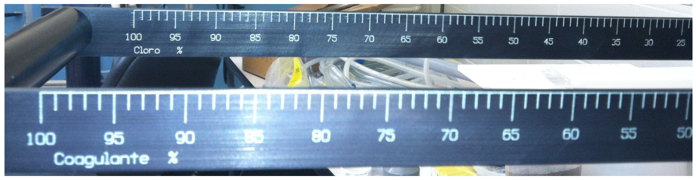


Figure 14: Anodized Lever Arm with Scale Engraving

Figure 15: Anodized Lever Arm with AguaClara Logo

Methods

LCDC System Laboratory Setup

The LCDC was fabricated from components that can be found in the Table 1 parts list and a picture of the overall system is shown in Figure 16. The main constraint for building the LCDC test system was the wall length in the lab (2.74 meters). The AguaClara Source code was used to generate a system design with a 2.74 meter length constraint. The design parameters that were used in the experimental setup are shown below.

- Target plant flow rate: 44 L/s
- Dosing tube length: 2.64 meters (The source code output calculated 2.59 meters but the length was left longer to allow for calibration.)
- Dosing tube diameter: 0.1875 centimeters (3/16 inches)
- Number of dosing tubes: 3

Water was used in place of coagulant for test purposes in the lab. The LCDC system was modeled in the laboratory. The lever arm assembly was mounted on an adjustable aluminum T-slotted frame. One end of the lever arm assembly was connected to a float in an 18.9 liter (five gallon) bucket filled with water to mimic the flow in the LFOM. For the remaining LCDC system, an 18.9 liter (five gallon) bucket served as the coagulant stock tank, which was connected to a constant head tank (CHT) regulated by a float valve. The CHT was mounted on an aluminum T-slotted frame. The coagulant exited the CHT and entered 1.27 centimeter (1/2 inch) diameter PVC piping which extended along the length of the dosing tubes (approximately 2.74 meters). The coagulant entered the three dosing tubes via a manifold. The dosing tubes were connected to the manifold using barbed fittings of 0.635 centimeters (1/4 inch) inner diameter (ID) - one size larger than the tube ID to reduce minor losses due to contractions. Additional manifold openings were plugged with black hex-head polypropylene plugs. The chemical exited the second manifold and entered the drop tube attached to the slider on the lever arm assembly.

Figure 16: Overall System Setup

LCDC Calibration

The LCDC can be calibrated as follows:

1. Add water to the entrance tank to ensure that the lever arm assembly adjusts properly to changes in flow. If it does not, then the entrance tank float is not sufficiently sensitive to changes in water height and will need to be modified.

2. Move the slider to the pivot point (zero flow).

3. As a starting point, measure the following heights, using the floor as a common reference:

   (a) height of the water entering the drop tube.

   (b) height of the inlet to the constant head tank (CHT) from the stock tank (i.e. the height of the float valve inlet on the CHT).

4. Adjust the height of the lever arm assembly until the above-mentioned heights are approximately equal.

5. Set the height of the water in the entrance tank to zero to simulate a zero flow condition.
6. Run water through the system and ensure that air is not trapped in the system (push any air bubbles out by squeezing the tube exiting the constant head tank).
7. Re-adjust the height of the lever arm assembly until there is no flow through the system.
8. Level the lever arm assembly using the float chain for course adjustments and the turnbuckle for fine adjustments.
9. Repeat steps 5 through 8 until the lever arm assembly is level and flow rate is zero; this calibrates the lever arm assembly at zero flow.
10. Raise the height of the entrance tank water level to 20 centimeters above the current level (the maximum flow rate through the LFOM).
11. Move the slider to the 100 percent dosage setting (the maximum percent dosage).
12. Measure the flow rate using a graduated cylinder for one minute.
13. If the flow is lower than the desired maximum chemical flow, evacuate water from the system and cut the dosing tubes by a small amount.
14. Place water back into the system ensuring all air has been removed.
15. Repeat steps 11 through 13 until the maximum flow is reached and the system is fully calibrated.

Scale Linearity

The lever arm assembly was calibrated at zero flow. Next the height of water in the entrance tank was increased by 20 centimeters, which corresponds to the maximum plant flow rate through the LFOM. Five measurements were taken at the following chemical percent dosages: 0, 20, 40, 60, 80, and 100 percent dose. The dosing tube length used was 2.64 meters. Chemical flow rate measurements from the drop tube of the LCDC were taken using a graduated cylinder and one minute time increments were used for each measurement.

LFOM Linearity

The linearity of the plant flow changes was tested along with the scale linearity to verify that the new system was maintaining a linear relationship. Markings were added to the inside of an 18.9 liter (five gallon) bucket to measure changes in height. Water was added or removed from the bucket to adjust for a specific height. Three chemical flow rate measurements from the drop tube of the LCDC were taken at heights of 0, 5 and 20 centimeters. Fewer repetitions were used with these data because it was determined that three would be sufficient. Also, five chemical flow rate measurements from the drop tube of the LCDC were taken at 15 centimeters because flow at this point was more variable.

Analysis

Scale Linearity

The data was plotted and fit to a linear trend line as shown in Figure 17. The R^2value for the linear fit was 0.9967. The y-intercept was not set equal to zero since the "0" on the scale bar is offset by approximately two centimeters from the true zero, or pivot point. Therefore, the dose at the "0" mark on the scale is approximately 0.4 milliliters per second and all doses on the scale are actually five percent higher than the value presented on the scale as shown in Figure figure 18. Additionally, since the system was calibrated by moving the lever arm assembly along the T-slotted framing until the observed flow rate was zero, there is error (estimated at less than 1 centimeter) associated with the calibration height.

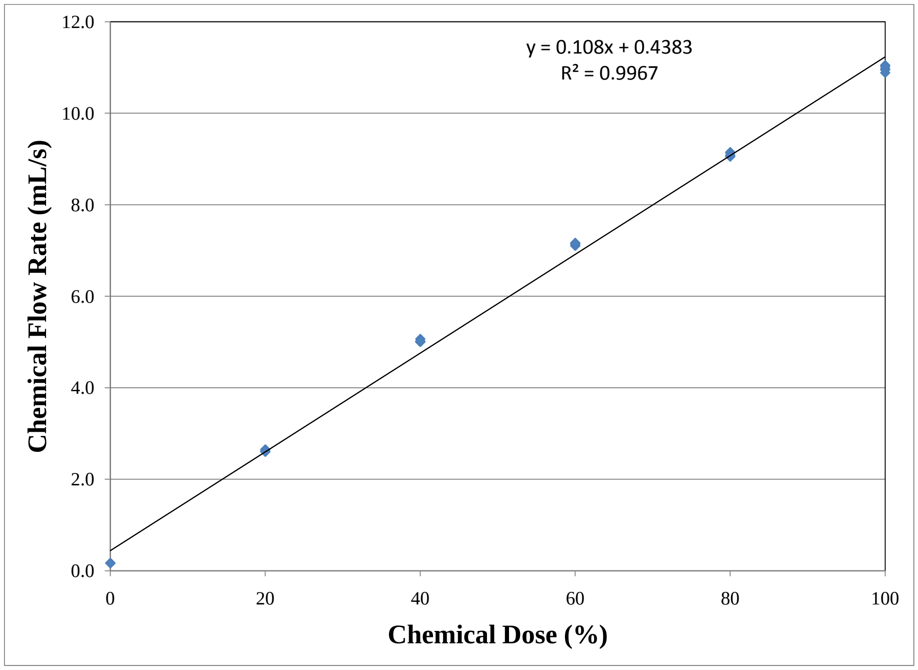


Figure 17: Chemical Flow Rate vs. Chemical Percent Dose for a Dosing Tube Length of 2.64 meters

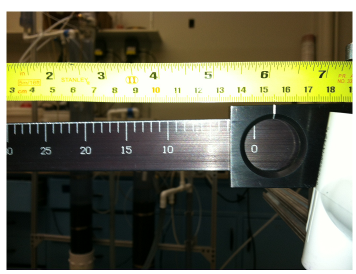


Figure 18: Scale Offset Error

The observations were then compared with the values predicted by the above linear equation. The percent error versus percent chemical dose is shown in Figure 19. Maximum percent error of 63% was observed at zero percent dosage, indicating an unacceptable level of error at low dosages. One explanation of this increased error is surface tension effects of the water at very low flows.The percent error was below ten percent for all other dosages tested above zero percent.

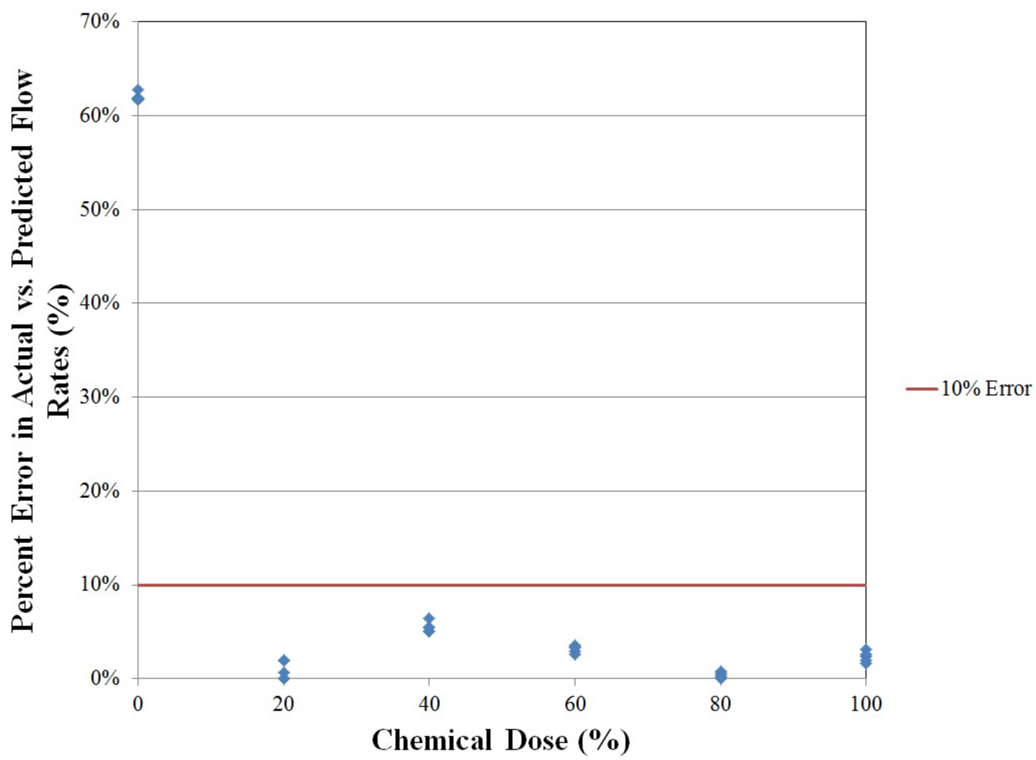


Figure 19: Percent Error between Predicted and Actual Chemical Flow Rates vs. Chemical Dose Percent for a Dosing Tube Length of 2.64 meters

Plant Flow Changes Linearity

The data collected for chemical flow versus height in the LFOM are given in Figure 20. The R^2value for this fit was 0.9955. The y-intercept was not set to zero because there was a small chemical flow at the zero height value at 100 percent dosage. This means the slider and drop tube assembly is too heavy to prevent chemical flow at zero plant flow.

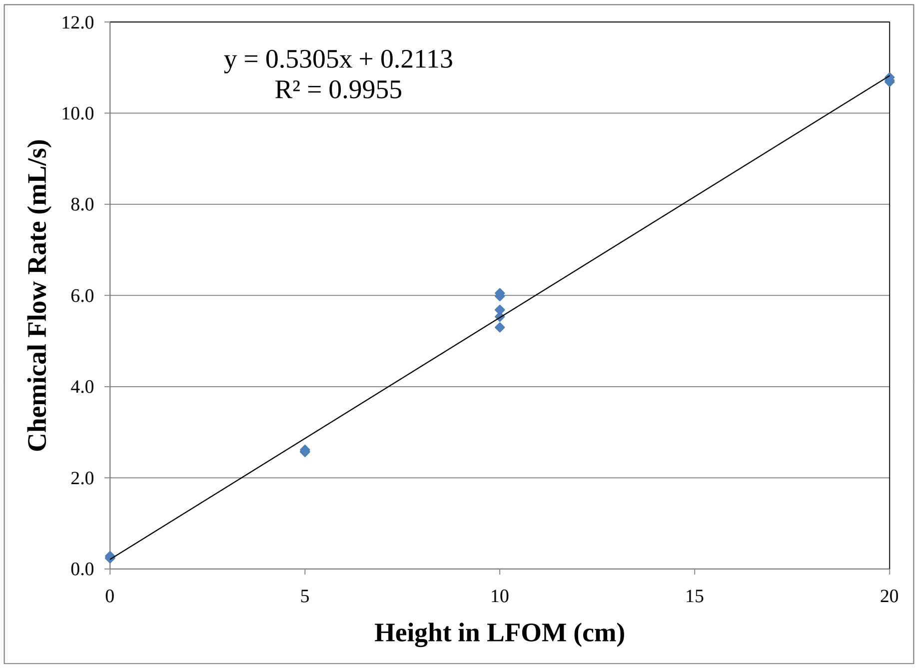


Figure 20: Plant Flow Rate vs. Chemical Flow Rate for a Dosing Tube Length of 2.64 meters

The percent error between the collected data and linear fit model versus LFOM height are presented in Figure 21. The maximum percent error was 34%. As with the percentage dose data, higher percent error occurred at lower chemical flow rates which may be related to surface tension effects at low flow. Other possible sources of error were difficulties with keeping the head tank constant. Possible causes were bends in the tube connecting the chemical stock tank to the constant head tank and the small float rod may not have provided enough torque to properly close the float valve.

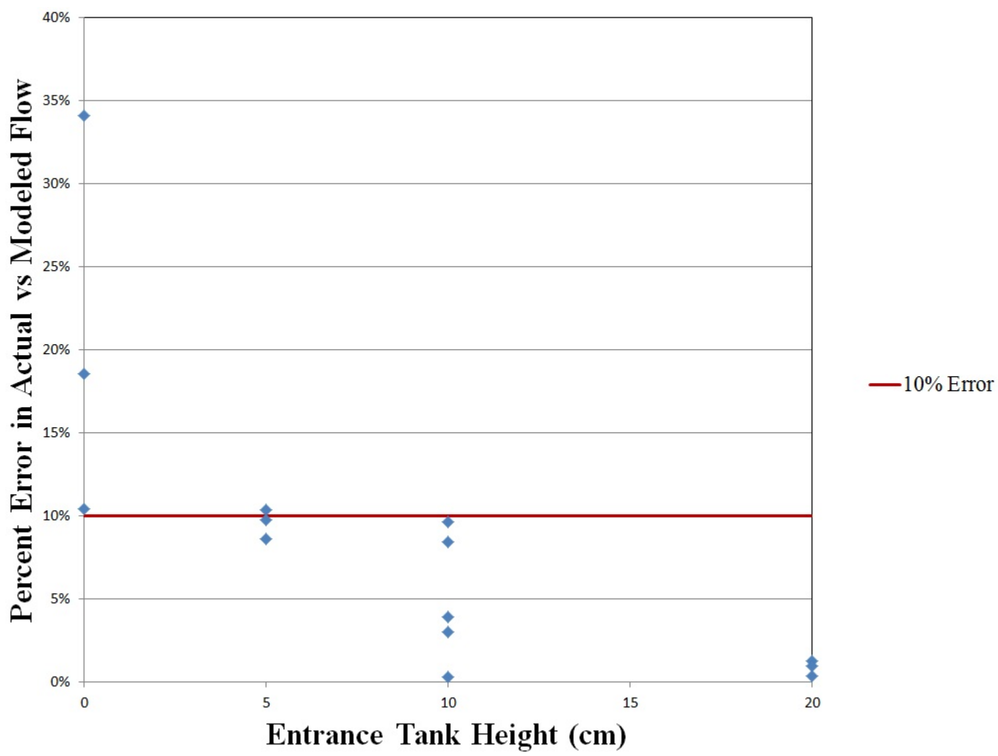


Figure 21: Percent Error between Predicted and Actual Chemical Flow Rate vs. LFOM height for a Dosing Tube length of 2.64 meters

Conclusions

The main purpose of the semester was to create, refine, and test a prototype of the lever arm assembly based on a basic design for the prototype which needed improvement. There were a few constraints that applied to all modifications which included creating an aesthetically appealing design, eliminating leakage from tubing connections, and ensuring that all components were resistant to chlorine. The team devised a drop tube connection design to reduce leakage, added cross bracing to the lever arm assembly to reduce bending of the lever arms, devised a new calibration device to enable fine-tuned adjustments and completed testing to verify the linearity of the new lever arm assembly. Finally, in order to create an aesthetically pleasing design the team had the lever arm anodized, added a modified weight, and had the label, scale and logo mechanically engraved on the lever arm. The LCDC system was tested for linearity of the chemical dosage with respect to the dosing scale and linear flow orifice meter (LFOM) height changes due to varied plant flow. Both tests resulted in a linear fit with an R^2 value of 0.9967 for the chemical dose percent data and an R^2

value of 0.9955 for the plant flow height data. The maximum percent error in the linear relationship between chemical dosing and dosing percentage was 63%. The maximum percent error in the linear relationship between chemical dosing and the LFOM height change was 34%. Errors were below the desired 10% at all data points except the data point corresponding to the lowest chemical dose, which suggests that the LCDC maintains a linear relationship at higher flows and is less accurate at low chemical flows. Error associated with chemical dosages with respect to the percent dosage can be attributed to the scale being offset from the zero (or pivot) point of the lever arm by approximately two centimeters. Error associated with changes in chemical flow rate with respect to changes in the plant flow rate can be attributed to the weight of the drop tube assembly.

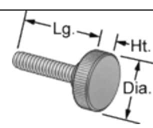
Future Work

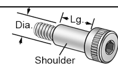
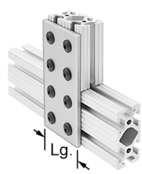
There are various tasks that still need attention with regard to the chemical dose controller. Since we designed for a higher chemical dose than previous teams, a larger constant head tank (CHT) assembly was required. Calibration of the LCDC involved adjusting the outlet on the drop tube on the lever arm assembly with the inlet to the CHT. Either the height of the CHT or the lever arm assembly must be adjusted. The CHT used in the lab included a large tank, which became cumbersome when filled with water. Therefore, the height of the lever arm assembly was adjusted by moving the assembly up and down along the T-slotted aluminum framing. Fine adjustments on this height were difficult. An adjustable constant head tank mounting system or a smaller head tank or float could eliminate this issue. Secondly, the manifolds for the small diameter dosing tubes require fabrication from another material other than polypropylene. The Fall 2012 team used readily available polypropylene manifolds to reduce fabrication labor costs; however, polypropylene is not resistant to chlorine. Alternative options include pre-fabricated manifolds consisting of PVC or another chlorine-resistant material or a custom manifold fabricated from a chlorine-resistant material. Thirdly, the cross bracings for the lever arm assembly are composed of numerous individual pieces. A sleeker, more aesthetically pleasing design would consist of a single piece extending through the entire width of the lever arm rather than several individual pieces. A fourth objective would be to lighten the slider and drop tube to ensure zero chemical flow at zero plant flow and 100 percent dosage. Lastly, the design tool needs to be updated to include the latest design. Once an AutoCAD drawing of the design has been made, then an engraving of the lever arm assembly could possibly be programmed via a computer numerical control (CNC) machine to streamline subsequent engravings of the scale and logo.

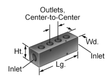
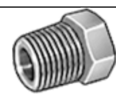
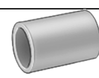
Appendix

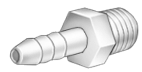
Parts List

Table 1: Detailed list of components for the LCDC. This listing is for a LCDC designed for a 44 $\frac{L}{s}$ water treatment plant. Depending on the plant capacity, different quantities or sizes may be required.

Part Name (Quantity)	Picture	Description and Explanation
Rectangular Bars—Unpolished Finish (2)		Lever arm: Multipurpose Aluminum (Alloy 6061) 1/8" Thick X 1" Width X 6' Length
Rods—Unpolished Finish (1)		Lever end rods: Multipurpose Aluminum (Alloy 6061) 1" Diameter, 3' Length
Rectangular Bars—Unpolished Finish (1)		Lever arm slider: Multipurpose Aluminum (Alloy 6061) 3/4" Thick, 1-1/2" Width, 1' Length
Plastic-Head Thumb Screws (2)		Locks the sliders on the lever arm in place: Plastic-Head Thumb Screw Black Knurled Head, 10-32 Thread, 1" Length
Aluminum Un-threaded Spacers (4)		Lever Arm Spacers: Aluminum Un-threaded Round Spacer 1/2" OD, 1-3/4" Length, 1/4" Screw Size
Aluminum Unthreaded Spacers (2)		Lever arm cross bracing: Aluminum Unthreaded Round Spacer 1/2" OD, 2-1/2" Length, 1/4" Screw Size
Steel Rod (1)		Used as the counterweight against the float, on the opposite end of the lever arm from where the entrance tank float is connected: 4.25" long, with an inner diameter of 1" to fit snugly over the end rod
Set Screw (1)		Used to set the the weight on the lever arm in place
Turnbuckle (1)		Calibration device: used to make fine tune adjustments to the height of the LFOM float

Entrance Tank Float (1)		LFOM float: Charlotte Pipe and Foundry Co. 6” PVC with hook screwed into lid
Chain (3’)		Used to attach the LFOM float to the turnbuckle on the lever arm assembly
Float hook (1)		Used to attach the chain to the LFOM float
PVC Drop Tube (1)		The point of discharge from the LCDC into the water supply. 3/4” clear rigid PVC pipe
PVC Drop Tube Elbow (1)		Used to attach the tee in the drop tube assembly to the tubing from the manifold. 1/2” NPT x 3/8” Tube ID
Shoulder Screws (2)		Used to allow the lever arm assembly to pivot along the mounting bracket
Brackets and Braces for Aluminum T-Slotted Framing		Bracket to mount the lever arm to the outer entrance tank wall, and to set up a frame during laboratory testing: Aluminum Inch T-Slotted Framing System Extended Plate, Double, 8-Hole, for 1" Extrusion
End-Feed Fasteners for Aluminum T-Slotted Framing		Screws and fasteners to connect brackets and braces to the framing.
Constant Head Tank (1)		NSF-Certified Plastic Storage Container Polyethylene, 20 qt, 18" L X 12" W X 9" H and Lid with a hole drilled in the side to attach the float and a hole drilled in the bottom center for the through-wall barbed fitting. The cover prevents contamination of the chemical by particles in the air, but does not make the container air-tight.

Constant Head Tank Float (1)		The float valve is attached to the side of the constant head tank, and keeps the water level constant inside the CHT: Kerick Float Ball PF45, 3/8 MIP inlet and outlet, 0.187 orifice. Float Ball and 3” metal rod with 1-4/20” thread
Chemical-Resistant Clear PVC Tubing (20’)		Conveys water from the drop tube to the manifold, the CHT to PVC, and the CHT to the stock tank: Clear PVC Tubing Chemical, 3/8" ID, 1/2" OD
Manifold (2)		Connects the PVC tubing to the dosing tubes: Polypropylene Manifold 4 Outlets, 1/2" NPT Inlet X 3/8" NPT Outlet
Black Hex-Head Polypropylene Plug (2)		Plugs the unused openings in the manifold: 1/2” pipe size
Black Hex-Head Polypropylene Plug (2)		Plugs the unused openings in the manifold: 3/8” pipe size
Standard-Wall/ Schedule 40 PVC Unthreaded Pipe (1)		Conveys water from the constant head tank to the dosing tubes: PVC Unthreaded Pipe 1/2 Pipe Size X 10’ Length
PVC Coupling		Used to shorten PVC length if needed: Couplings, Female Socket Ends
PVC Pipe Fitting (1)		Used to connect the tubing from the constant head tank to the first dosing tubes manifold: Thick-Wall PVC Threaded Pipe Fitting 3/8 Pipe Size, 90 Deg Elbow, Schedule 80
PVC Ball Valve (1)		Allows draining of accumulated sediment in PVC tubing, prior to entering dosing tubes: Low-Pressure PVC Ball Valve 1/2" NPT Female
PVC Tee, Female Unthreaded Socket Ends (2)		Used in the drop tube assembly, also used to connect the manifold and ball valve to the PVC piping: Standard-Wall PVC Pipe Fitting 1/2 Pipe Size, Tee. **One tee needs a threaded middle connection**

Barbed Tube Fitting (1)		Used to connect the CHT to the PVC assembly: Durable Nylon Multi-Barbed Tube Fitting Adapter for 3/8" Tube ID X 3/8" NPT Male Pipe. **Nylon fittings were used but chemical resistant fittings should be used in future designs**
Chemical-Resistant Clear PVC Tubing (20’)		Dosing Tubes: Clear PVC Tubing Chemical, 3/16" ID, 1/4" OD, 1/32" Wall Thickness
Adapters, Tube to Male Threaded Pipe (3)		Connects the tubing from the stock tank to the CHT and the tubing from the CHT to the PVC piping: Moisture-Resistant Acetal Push-to-Connect Adapter for 1/2" Tube OD X 1/2" NPTF Male Pipe
Barbed Fitting Push-to-Connect Insert (3)		Attaches flexible tubing to the Push-to-Connnect Adapter, preventing leaks from directly connecting flexible tubing to the rigid adapter: 1/2” barbed fitting to 1/2” Push-to-Connect
Adapters, Male Threaded End to Female Unthreaded Socket End (2)		Connects the manifold and the ball valve to the PVC piping: Standard-Wall White PVC Pipe Fitting 1/2 Pipe, Male Adapter, NPT Male X Socket Female
Adapters, Hose-to-Threaded Male Pipe (6)		Connects the dosing tubes to the manifold: Nylon Push-on Hose Fitting Adapter for 1/4" Hose ID X 3/8" NPT Male Pipe. **Nylon fittings were used but chemical resistant fittings should be used in future designs**