# Chemical Dose Controller Fall 2013

Zeyu Yao, Saugat Ghimire, December 13, 2013

**Abstract**

The Chemical Dose Controller is an important of component of a AguaClara plant. The CDC delivers the coagulant (Polyaluminum Chloride (PACl) or Aluminum sulfate (Alum)) to the influnt water and disinfectant Calcium hypochloride to the effluent filtered water. The Chemical Dose Controller is a simple mechanical response device which maintains a linear relationship between the plant flow and the chemical dose. It consists of a calibrated lever arm which the operator can use to adjust the dose of the chemical based on the turbidity of the influent water. The Fall 2013 team started off by putting together three half size doser units for stacked rapid sand filters constructed in India. All the parts were shipped to India with a detailed instruction manual to aid the assembly. The dosers sent to India contained CPVC ball valves with flouroelastomer seals that are more resistant to cholrine than the previously used PVC ball valves. The ball valves in all the AguaClara plants will now be replaced with these CPVC ball valves. Similarly, a lock-and lock container will now be used as the Constant Head tank for both chlorine and coagulant suspended with a chain and a turnbuckle for height adjustment. Although the lock-and-lock container degrades when in contact with chlorine, it is locally available and can be easily replaced. In addition to this, the design of a new half-size doser with single arm which only doses chlorine has been completed. A 3D sketchup file has been created and sent to Hancock Precision for fabrication. This new doser will primarily be used in low flow plants in India which only require chlorine delivery.

# Introduction

The unique design of the Linear Chemical Dose Controller(LCDC) and the Linear Flow Orifice Meter (LFOM) allows the plant operator to set and maintain the desired dose of coagulant and disinfectant without the use of an electric supervisory control and data acquisition system (SCADA). LCDC and LFOM together adjust the chemical flow rate automatically in response to the change in plant flow-rate. The major head loss through a small diameter tube ensures the linear relationship between major head loss and chemical flow in the LCDC to controll the chemical flow rate. The LCDC responds to the change in water level in the entrace tank to adjust for plant flow rate changes while the LFOM creates a linear input to the LCDC by maintaining a linear relationship between the height of water in the entrance tank and plant flow rate.

The new Chemical Dose Controller is fully chemical resistant as all the non-chemical resistant components from the previous design were replaced with better material for longivity. Similarly, a new version of the chemical dose controller was designed and has been sent to Hancock Precesion for fabrication. The new doser has a single arm and will be used in plants that only require chlorine doses. The main goal of this design task was not to create a new Chemical Dose Controller but to create a modified version of the old design to maintain consistency with rest of the plant. This report starts contains a literary review of the various components of CDC and elaborate discriptions of the tasks, processes, results from the semester.

## Literature Review

### *Mathematical Development*

### *Governing Equations*

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

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

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

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

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

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

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

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

*Sizing the Float Valve Orifice in the Constant Head Tank*

The maximum coagulant flow rate, $Q_{Coag}$, is $7.7\,mL/s$ for a plant flow rate of $32\,L/s$, a maximum coagulant dose, $C_{CoagMax}$, of $40\,mg/L$ and a stock coagulant concentration, $C_{CoagStock}$, of $166.7\,g/L$, as shown by Equation.

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

The float valve diameter of 0.142 inches, or 0.36 centimeters, was sized through application of the orifice equation, where $Q$ is the chemical flow rate, the vena contracta coefficient,$\Pi_{VC}$, is 0.62, $g$ is the gravitational constant, and the height difference between the water in the constant head tank and the water leaving the stock tank, $\Delta h$, is 30 centimeters, as shown by Equation.

$$d = 2\sqrt{\frac{2Q}{\pi \Pi_{VC}\sqrt{2g\Delta h}}}$$

*Float Size in Constant Head Tank Float Valve Assembly*

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

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

$$= rF_b$$

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

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

Rearranging the equation for V,

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

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

### Previous work

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

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

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

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

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

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

# Method

## Current Laboratory Set-up

*The current set up was modified from the spring 2013 design based on the characteristics of the plants in India. In addition, the major changes to float valve, dosing tube diameter, and lever were made in summer 2013, as mentioned in the previous section. Extra tubing and pipes were eliminated to reduce the waiting time at start up, as well as to avoid bendings that may lead to unwanted increase in minor loss. Parameters resulting in the current set up are shown below: .*

- Target plant flow rate: $2.4L/s$
- Chemical flow rate: $0.187ml/s$
- Maximum PACl dose: 2 $mg/L$
- PACl stock concentration: $25.7\,g/L$
- Dosing tube diameter: 1/16 inches
- Dosing tube length: 0.811 m

Figure 1:

- Smaller float valve and constant head tank

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

Chemical dose controller for plants in India

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

*The chemical dose controller system includes many small connectors, and the inconvenience of installation and setup could affect the overall performance of the entire system. There were two main motivations for improving the in-lab packaging process, firstly many chlorine resistant parts could not be locally sourced, secondly it would be helpful to have many parts assembled since local people are not as familiar with the system. A packaging spreadsheet and a user setup manual are developed to help faciliate the shipping and system installing processes. The packaging spreadsheet is an excel spreadsheet designed to take input values* *including the desired chemical flow rate and concentration, diameter of dosing tubes, and number of dosers needed, and output the quantity of each component based on Mathcad calculations. The user setup manual is written and packed with all the components to ensure that dosers can be set up by any person with minimum knowledge of the AguaClara system. .*

## Chlorine-resistant Constant Head Tank and Height Adjustment System

*The constant head tank was changed from a 5 gallon bucket to a horizontally oriented 1L Nalgene bottle in summer 2013, becasue this design would allow the use of a more elongated float that has a more sensitive reaction to the level of solution in the tank due to its larger submerge volume. In order to assess the amount of error associated with the new constant head tank, the water level in the bottle was measured while the system ran at different flow rates. the error in the liquid level inside the bottle caused by change in elevation of the stock tank was tested. However, a problem quickly arose since the bottle used in the lab was not chlorine resistant, and several alternative options (listed below) were considered to address this problem. The new constant head tank should be compatible with the current kerick float valve, chlorine resistant, and have a simple height adjustment and mounting system..*

*PVC pipe and caps: A CHT made of segment of clear rigid PVC pipe and two caps, which would resemble the shape of the Nalgene bottle..*

*Chemical resistant bottles and cap liners: a Nalgene FEP Wide Mouth Bottle made with Teflon Resin with a TefZel ETFE screw closure*
*Tupperware: Tupperware, especially Lock&Lock containers could be locally sourced..*

*Bucket: A bucket smaller than the one used in previous designs. (The bucket has not arrived yet, the report will be updated later to include detailed instructions on set-up and height adjustment).*

## Single Lever Design

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

# Results and Discussion

## Laboratory Set-up

*According to the calculations using the parameters listed in the section above, only 2 dosing tubes total were needed if another tube was added to allow for maintenance. To accomodate the fewer numbers of dosing tubes, the current design of PVC manifolds was modified by cutting the 1/2" PVC tube in half so only two pairs of tube connecting sets remained. Some tubings were eliminated so the solution could flow from stock tank to the drop tube with no more meandering. As a result, the constant head tank was directly connect to the manifold by 1/2" tubing, and the other side of the manifold was also directly connected to the drop tube using 1/2" tubing. On the drop tube side of the manifold, a ball valve was attached to the bottom to prevent flow when it is closed and to eliminate air bubbles formed inside the dosing tubes at start up when the valve is turned open.*

.

*Calibration instructions:*
*The following steps should be followed to calibrate the sytem using the drop tube: this should be in the results section.*

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 CHT by shortening the chain or adjusting the length of the CHT turnbuckle 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 (specific bubble release instructions are given below).
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. Make sure the drop tube is well drained and close the ball valve.
13. Measure the flow rate using drop tube for one minute (read the volume using the graduated column on drop tube).
14. 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.
15. Place water back into the system ensuring all air has been removed.
16. Repeat steps 11 through 13 until the maximum flow is reached and the system is fully calibrated.

*Air bubble release*

After experimenting, the most efficient way to get rid of the air bubbles is to work on a single tube at a time. For example, for the tube between the stock tank and the constant head tank, pinch the tube until the air bubbles are pushed into the stock tank and air is released. The same method should be used for the tube between the constant head tank and the dosing tube, only the air bubbles should be pushed to the constant head tank as there is a hole drilled into it for air to escape. For air bubbles in the dosing tubes, open the ball valve on the bottom of the manifold until liquid starts to flow out, then close the valve. Finally, for the tube between the dosing tubes and the drop tube, push the air bubbles to the drop tube opening..

*Changes to tubing and connectors*

*Tubing (manifold to drop tube): The tube connecting the manifolds and the drop tube has been reduced in length to avoid bending at the junctions. The unwanted bending was causing extra resistance to the flow resulting in inaccurate doses. There is no standard length for this tube as it has to be adjusted based on the characteristic of each plant. A 90 degree elbow degree elbow threaded to barbed (1/2 in) was used in the current set-up, but ideally a 45 or 30 degree elbow could be used to further minimize tube bending. The current CDC design requires the chlorine/coagulant to flow through a very long segment of PVC tubes before reaching the manifold and then the drop tube. Given the low flow rate of 2.4 L/s, the tubes can be shortened in order to achieve higher efficiency at start up. However, replacing the 1/2" tube with 3/8" or 1/4" tube may increase the minor loss, thus deviating from the linear relationship between the flow and total headloss. Whether this deviation is negligible will be checked by future teams.*

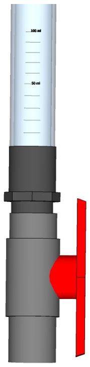

Figure 2:

*Ball valves: The ball valves used in current design were reported to have certain components that were not chlorine resistant. A ball valve was cut open and it was discovered that the seal was made of EPDM, a material that has low Chlorine resistance rating. Initially, tube clips were considered to replace the ball valves, but this option did not have the same flexibility in flow adjustment and system maintenance since it was not possible to turn on and off single dosing tubes.* In order to find a component that was chlorine resistant and would not discount the performance, McMaster-Carr customer service personel was consulted, and a CPVC ball valve witha fluoroelastomer seal was found to be a good replacement. (Reference: http://www.pelseal.com/resist.html). Each unit of this CPVC ball valve costs $21.83.

*Drop tube*

*Drop tube ball valve: A ball valve was added to the end of the drop tube to improve the accuracy of drop tube calibration. However, it adds more weight to the slider, thus resulting in inaccurate dosing at higher flow. Tests were done to look at the errors in chemical flow caused by the addition of the ball valve. The lever was set to be horizontal and the slider was set at 0. The run time of the system and the volume of water collected below the drop tube were recorded to calculate the flow rate. Although the added weight was expected to affect dosing accuracy, the chemical flow rate was recorded to be* $0.0098\,ml/s$*, which was low enough to be neglected. .*

*Drop tube fixation: in the current design the drop tube is inserted into the 1/2" tee with no extra support. Afterward, a ball valve was added to the bottom of the drop tube, the friction between the tee and the drop tube was not enough to hold the drop tube in place. As a result, the tube can be glued on the a threaded rigid PVC pipe could be used..*

*Calibration marking: a graduated column was design to be incorporated into the drop tube design to provide easier and more accurate reading. The figure is a concept drawing of the design, the graduated column is not drawn to scale. .*

**Figure 3:**

Chlorine-resistant Constant Head Tank and Height Adjustment System

*PVC pipe and caps*
*It was not successful at maintaining constant head. First of all, the inner diameter of the pipe was not large enough to allow full movement of the float. In addition, the weight CHT was more than what was desired, and it was not possible to make changes to it once the caps are glued on the pipe using PVC cement. .*

*Chemical resistant bottles and cap liners*
*This was not feasible despite its extraordinary chemical and temperature resistance since the a single 32oz bottle would cost about $235. The second option is to use a High-density polyethylene (HDPE) wide mouth bottle 63mm and a Polytetrafluoroethylene (PTFE) discs/cap liner with a 63mm dimeter. Unfortunately, the cap liner was proven to be inadequate, since dyed water was observed between the cap liner and the top of the cap within 5 minutes of the test. The result of the experiment is shown in the picture below:.*

*Tupperware (Lock&Lock) container*
*As of now, only in Tamara plant is tupperware -a Lock-and-Lock container - used as constant head tank, for coagulant dosing. In some current treatment plants in Hondurus, polyethylene bottles with polypropylene caps are ordred to be used as constant head tank for chlorine dosing. Neither option is not chlorine resistant, but these units are easily replaceable and locally sourced. However, while the tupperwares and polypropylene caps don't need to be replaced for up to 5 years, it is not yet know whether carcinogenic byproducts produced as a result of degradation will create prominent health risks..*

*Small bucket*
*A bucket which resembles the previous CHT but smaller in scale was considered because the material is chlorine resistant, and it is possible to attach to it a turnbuckle to adjust its height. .*

*Although an optiomal choice has not been decided yet, the Lock&Lock container and small bucket seem to meet most of the design objectives. Both constant head tank will be using a turnbuckle as height adjustment but attached differently. The CDC team should design and test both constant head tank, as well as simplify the height adjustment methods in next semester..*

### Single Lever Design

*The design criteria were met by aligning the height of the drop tube with the pivot point of the lever, which is made possible by using the new slider design shown below. The single lever is based on previous designs, the materials used and the basic dimensions including the height and length of the lever are kept the same. However the lever is made slightly thicker so that it is more rigid. The slider has a space in the middle to allow readings of dose percentage, and the drop tube can be attached on the side to the right of the space at the same height as the fulcrum. The back of the slider is designed to have the fulcrum connected to the lever arm but not the slider. A long rotating rod is needed in order to balance the torque generated by the weight of drop tube and lever arm on one side, so in this design the part of rod between the back of the lever arm and the far end of the box is able to rotate. These changes will be applied to new designs of both single and double levers once the design is finalized with Hancock Precision. .*

# Conclusions

*The main goal of fall 2013 team was to improve the chemical dose controller to accomodate the low flow conditions in the plants in India. A single lever was designed to cater the plants that only require a chlorine or coagulant doser, and several options of constant head tank were considered before we finally narrowed down to a small bucket and a Lock&Lock container. Furthermore, non-chlorine resistant components were identified and replaced. Lastly, a user manual was prepared to give set-up instructions local personel, and an excel spreadsheet was prepared to help simplify the chlorinator packaging process. .*

*Future works.*

*To further simplify the chorinator packaging processes, mathcad functions should be embedded in the excel spreadsheet and the user manual should be updated to reflect the most recent CDC set-up. The single lever design needs to be finalized, manufactured, and tested. Once the new design is proved to be working properly, it can then be applied to double and full size levers. It is also necessary to check whether using smaller diameter tubing will cause minor loss and surface tension to become significant. .*

Figure 4:

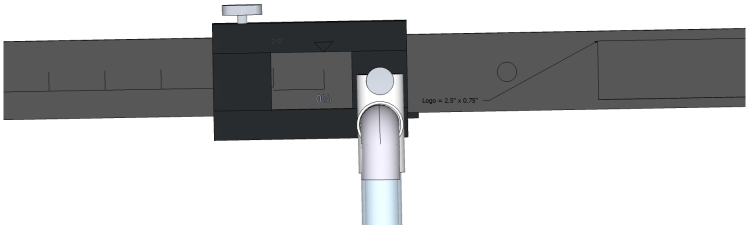

Figure 5:

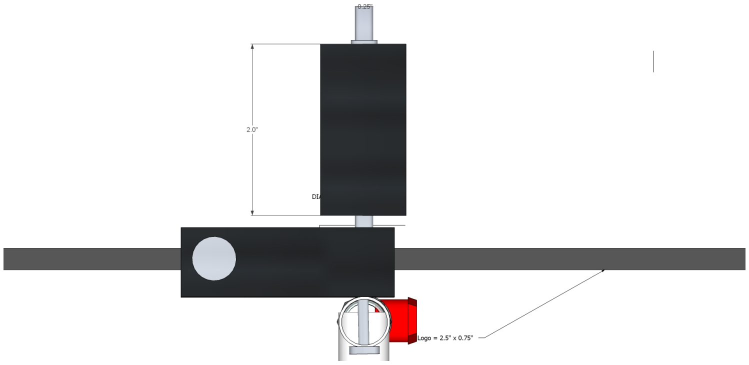

Figure 6:

| Material | Calcium Chloride Resistance Rating | Remarks<br>No effect on the material (http://www.zeusinc.com/technicalservices/technicalbulletins/chemicalresistanceofpoly |
|---|---|---|
| PP | 2 | Satisfactory at 20 and 60 degrees celcius (http://www.borealisgroup.com/pdf/chemical-resistance/chemtab_PP.pdf) |
| HDPE | 2 | at 20 and 60 °$C$ Saturated solution prepared at 20 celcius |
| LDPE | 2 | at 20 and 60 °$C$ Saturated solution prepared at 20 celcius |
| Fluoroelastomer | 3 | Litle or minor attack by the material (http://www.swammelstein.nl/rubber/FKM%20RESISTANCE.HTM) |
| ETFE | 3 | Little to no interaction with the material (http://www.idex-hs.com/materials/compatibility/Tefzel.aspx) |
| Teflon PTFE | 3 | |

Rating ranges from 1 to 3, with 3 being the highest rating

# References

**Aguaclara CDC Spring 2012 Final Report**

**Aguaclara CDC Summer 2012 Final Report**

1. *Chemical Resistance of Frequently used materials*