CDC Design Summary

Chemical Dose Controller History

By far, the biggest hurdle in the development of AguaClara technology has been devising a method for accurately and precisely administering process chemicals while adhering to the fundamental AguaClara design constraint of creating solutions which do not rely on electricity. Modern water treatment plants have computerized control and precise metering pumps at their disposal and while an AguaClara engineer has neither of these, this does not diminish the need for accurate metering.

To that end, AguaClara engineers have been developing a Chemical Dose Controller (CDC) which utilizes principles such as gravity, head pressure, major losses in pipes, etc. to predictably meter process chemicals. The first CDC developed by AguaClara engineers was the Linear Dose Controller, named so because of the linear relationship that exists between flow rate and the head-loss that occurs as fluid flows through a pipe. This was a simple design that utilized this principle to meter the flow, and therefore the chemicals, administered to the plant. This relation only holds true under laminar flow conditions and therefore fails as plants increase in size because the required increase in chemical delivery rate causes the fluid to enter the turbulent range.

To overcome this, AguaClara engineers are developing a CDC that utilizes the head-loss through an orifice (rather than through a pipe) to meter the flow of process chemicals. This is the Non-Linear Dose Controller, so-called because relationship between flowrate and head-loss is no longer linear.

Current State of the Nonlinear Dose Controller

The AguaClara engineers from academic year 2009/10 not only designed, but built and installed a Non-Linear Dose Controller (NDC) in a new AguaClara plant in Algateca, Honduras. The current NDC is installed on top of the entrance tank of the plant and consists of a float connected to one end of a lever arm and the dosing orifice connected to the other end.

Figure 1. NDC As Installed in Aglateca

The entrance tank is connected to the hydraulic flocculator by way of a rapid mix orifice. A change in flow rate through the plant is indicated by a change in the level of the entrance tank. This is transmitted to the lever arm by way of the float. For example, if the flow rate of the plant were to decrease from 100% to 80%, the entrance tank would drop by a proportional amount. Since the pivot is in the center of the lever arm, each centimeter of change in the entrance tank will translate to a corresponding change in the angle of the lever arm.

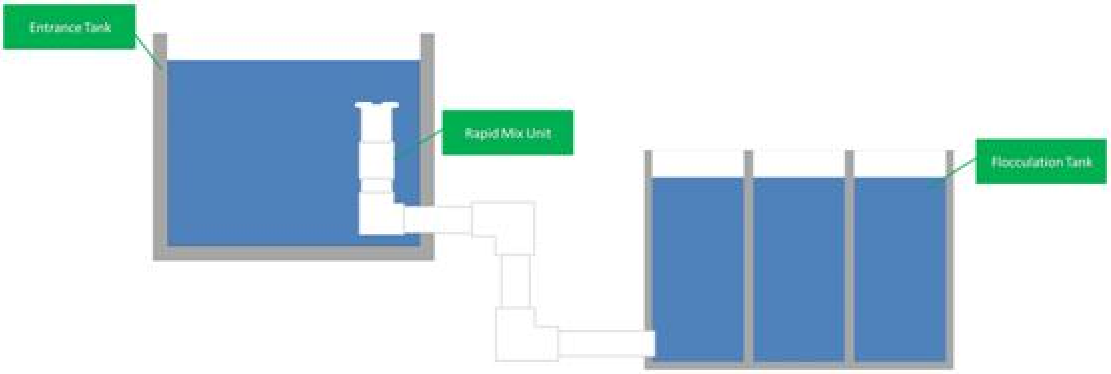

Figure 2. Entrance Tank Connection to Flocculator via Rapid Mix Tube

Alum is piped from a 120 g/L concentration stock tank to a constant head tank and from there to the metering orifice. The metering orifice is connected to the lever arm by way of a movable slide. The lever arm has an incremental scale on the top surface which corresponds to specific alum concentrations. The operator is able to set the chemical dose concentration according to the values on the scale and the lever arm will automatically adjust the flow rate of alum to maintain the correct concentration of alum as plant flow rates change.

Figure 3. Stock Tanks and NDC

Feedback from operators and engineers in Honduras along with results from our own experimental lab-work provide us valuable information on the accuracy and ease of operation of the NDC. Additionally, brainstorming continues on how to improve and expand the function of the current design. Derived from these topics are the following recommendations for next semester's team.

Design Parameters

Some important parameters to keep in mind as the design of the CDC evolves.

- Chlorine dosing is accomplished with 70% Calcium Hypochlorite. A 5 pound bag is mixed with water in a 55 gallon drum. This gives a chlorine concentration of 7.625 grams / Liter.
- One 55 pound bag of alum is mixed with water in a 55 gallon drum providing a concentration of 120 grams / Liter.
- The CDC should be able to maintain an alum concentration of 10 to 80 mg/L in the plant. The low and high end of this scale can be manipulated slightly in order to create a uniform scale. For example, the triple-scale uses a range of 8 - 88 mg/L.

- The CDC should be functional and accurate down to a plant flow of 50%.
- 5% variance between fabricated orifices is the current goal.

Recommended Work for Fall 2010

The CDC team is unique in that research, design and development are all key components of this team's challenges. To help clarify the work this team needs to accomplish, 3 sub-teams should be created. This is a suggestion, not a requirement. The three sub-teams are described at length below along with a recommended number of participants in each sub-group.

Orifice Validation and Scale Development (2 - 4 Persons)

One of the priorities of AguaClara engineers is to ensure their designs are locally sustainable. It is easy to create the walls and foundations from locally manufactured materials but becomes increasingly difficult when very specific components are needed to perform very specific tasks. This proved true with the float valve used in the constant-head tank and may prove true with a metering orifice. The team that originally developed the NDC was not able to fabricate precise (e.g. repeatable) orifices for their lab tests. This team also noted that surface tension effected accuracy of a metering orifice when less than 4 cm of head was available. The Summer 2010 team concentrated on documenting the extent of the precision problem and researched various solutions. It is the belief of the Summer 2010 team that we can not properly quantify the inaccuracies associated with surface tension until the material and manufacturing techniques are finalized since material finish, or smoothness, has a strong influence on surface tension.

Parameters and guidelines for selecting and fabricating a metering orifice are:

- The orifice must be made from a material that is impervious to all process chemicals that are used or will be used in the future in an AguaClara plant. This includes alum, chlorine and saturated lime.
- The material selected must also have certain machinable characteristics. Initial attempts at fabricating the orifice from plastic "quick connect" caps proved fruitless. These plastics do not machine well and produce unreliable metering between orifices of the same size.
- It it preferred that the orifice be manufactured from "commonly available" fittings of a "commonly available" material, particularly one that would be available in the communities/countries we service. Correctly defining "commonly available" is part of this challenge.
- Drilling methods are important and must be repeatable. Effects of drill-bit break-through will be at the exit region if drilled in the direction of flow. However, when drilling in the direction of flow the angle created by the centering bit must be consistent from one orifice to the next or a different K.vc is created. Drilling opposite the direction of flow is possible with hard materials where drill-bit break-through is less of a concern.

The Summer 2010 Team attempted to determine if it was reasonable to expect that a precise metering orifice could be fabricated in-house. The extent of this research is documented on the team's wiki pages, however, a few key lessons-learned are summarized below.

- Acetal and Polyamide are not suitable materials for producing precisely machined orifices. These materials do not "chip" but instead heat-up and deform. This leads to a slight collapse of material around the orifice hole as the drill bit is removed and marked deformation at drill-bit break-through. We attempted to correct for this by drilling in the direction of flow so the drill-bit break-though would occur at the exit region instead of the entrance region (which has a significant effect on the coefficient of discharge). This still did not produce acceptable results; 15 - 18% variance between orifices was measured.
- As metals possess better machinability characteristics than plastics, two styles of brass caps were selected for review. Admittedly, brass may not be the best choice for chemical compatibility (particularly chlorine), it is extremely machinable. Our thesis was that if we could not machine the parts from brass in-house, it would be unlikely to find a more suitable material from which we could. We selected brass refrigeration tubing caps and SAE flare caps. Our first trial showed similar variations between orifices meaning that we were not any more successful at machining precise orifices in-house We were still drilling in the direction of flow and determined that the centering bit created a different shaped entrance region in each cap, thereby changing the K.vc for each cap. The caps were then drilled against the direction of flow so the bevel created by the centering bit occurred at the exit region. Drilled brass does not create significant burrs at drill-bit break-through so the entrance region should be the fairly consistent between orifices.
- Less than 5% variance between brass caps which were drilled against the direction of flow was recorded, proving that we could indeed fabricate precise orifices in-house. The next step is to reproduce similar results with a material that is compatible with our process chemicals. At the time of this writing, the CDC Team was planning to machine orifices from solid PVC stock. This will most likely be the starting-place for the Fall 2010 team. Note, an engineer with Kerick Valves has explained that the orifices in the float valves are created during the injection molding process and are not machined-in separately. He claimed that the process of injection molding produced much more repeatable results.

Thorough research of off-the-shelf orifices has not yet been completed. The Summer 2010 team investigated the use of carburetor jets as metering orifices and these results can be seen on their wiki page. Additionally, orifices can be found in many industrial applications such as paint sprayers, "line coolers" (jets of fluid used to cool parts in an assembly line) and burner jets, to name a few. These will be manufactured under more exacting standards than we could hope to replicate especially in the some of the remote areas where our plants are best suited. One manufacturer that needs further research is Bird Precision, maker of lab-grown ruby orifices. These orifices are impervious to chlorine and can be installed in virtually any style of fitting. Additionally, their orifices are fabricated by piercing a lab-grown ruby cylinder with a laser, followed by drawn wire. This results in the best surface finish possible which may help in mitigating the surface tension issues.

The importation of components, however, cannot be taken lightly. Although we have determined that it is possible to fabricate a fairly precise orifice in-house we have not yet done so with a material that is suitable for use with chlorine. The next step is to find a material that is not only suitable for use with our process chemicals but possesses the machinability characteristics that allow for repeatable fabrication of the orifice. Further, this component would then need to be readily available is the areas we service. As impossible as all this sounds, the success of an AguaClara plant would be greatly improved if an operator could easily replace any lost or damaged orifice by simply drilling an appropriately sized hole in a pipe cap.

Concluding, this sub-team faces many challenges. This team must first find a material which is not only compatible with our process chemicals but also possesses sufficient machinability to allow precise (repeatable) manufacturing of a metering orifice. This team must then determine if it would be possible to obtain this component in the areas we service. In-house fabrication versus importation of parts is the driving question. Further, surface tension and accuracy issues will need to be quantified (but only after the orifice is selected).

Once a final decision has been made as to what material will be used for fabricating the orifice, the dosing scale will need to be developed. Again, because surface tension is directly related to material finish, fluid flow through a drilled PVC orifice is apt to behave quite differently than a laser pierced ruby. Fall 2009 developed a dual-scale, dual-orifice system. This scale does not accommodate surface tension in anyway and therefore fails at low plant flow rates and low dosing concentrations. Spring 2010 attempted to solve this problem with the development of the triple-scale, triple-orifice. This scale works well for all concentration ranges by starting the scale farther from the pivot point. However, at 50% plant flow rate, the head-loss through the plant is only 10 cm. We could easily enter the range where surface tension (depending of the material selected for the orifice) restricts flow at low concentrations of alum. The Summer 2010 team attempted to correct this by moving the float during periods of low flow so that a 4:1 relationship exists between plant flow and dose height. This solution maintains the dual-scale but does incorporate triple-orifice and requires an additional action from the operator.

Ultimately, one of the above listed scales or a newly developed scale needs to be selected. Coding is then developed so the Automated Design Tool can generate the scale-template needed for the CDC.

Constant Head Tank Valve and Material Research (2-4 Persons)

A key component in any CDC is the Constant-Head Tank (CH Tank). The CH Tank is connected between the stock tank and the dosing device and its purpose is to mitigate the effect that a change in level in the stock tank would have on the dosing instrument. Since our CDCs rely on head as their driving force, as the stock tank level drops, the available head drops, thereby changing the flow rate through the metering device, whether it be a tube or an orifice. The CH Tank is comprised of a small reservoir with a float valve installed. As chemical is metered to the plant, the float valve opens and replenishes reservoir, meaning a fairly constant level is maintained at all times.

The current float valve is manufactured by Kerick Valve Inc. The MA2P2 or MA3P2 are both used in our plants and both have an internal orifice diameter of .093" (2.36 mm). The flow rate through the valve is limited by this orifice and as plant's increase in size, the valve will not be able to maintain the correct proper level in the CH Tank. In fact, two CH Tanks are installed in parallel at Marcala, one of our larger plants, to accommodate this issue.

A dedicated sub team is needed to research and create a data base of float valves. This information will eventually be incorporated into the design tool so that the appropriate sized valve is selected for each application. The persons working on this part of the team will therefore also gain experience in the design aspect of AguaClara.

As the CDC design evolves and final decisions are made, it is important that appropriate materials are selected along the way. The CDC administers chlorine, alum and in the future saturated lime, making material selection a critical part of this design. Additionally, there are a plethora of fitting styles available on the market. Cost, longevity, ease of use and availability are all important considerations. It is important to have a working knowledge about materials, pipes, tubing and fittings before any decisions can be made. This information should be posted on the wiki as a reference for future teams.

A suggested list of materials for inclusion in the database is:

- PVC
- Polyethylene
- Kynar
- Polyamide
- Acetal
- Brass - Include various types
- Stainless Steel - Include various types

At a minimum, chemical compatibility between these materials and chlorine, alum and lime needs to be established and documented. Material cost should also be discussed. Availability is more difficult to quantify but it is important to avoid specialty fittings or materials. This list should not be considered comprehensive; it should be updated as the project evolves.

In regards to fitting styles, some key points to consider:

- Compression fitting are for use on rigid tube. They are currently in use to connect the float valve in the CH Tank. Elimination of compression fittings is ideal as they are made up of a nut and two small ferrules which must be installed the correct way in order to obtain the seal. It is too easy for one of these components to get lost, dropped etc, rendering the fitting useless.
- Quick-connect fittings are also used on rigid tube. Their longevity is in question as is their availability outside of the US. Use of PEX rigid tubing is becoming increasingly more popular in water distribution systems and improvements on fitting styles and availability is likely to follow.
- Barb fittings are quite stout, easily available and are fabricated from many different materials. They are used on flexible tubing (based on the ID of the tubing, not the OD.) The biggest drawback to a barbed fitting is that they can be difficult to remove from the tubing once assembled, especially after a long period of time. It is not uncommon to have to slice the tubing off from around the barbed fitting. This is not necessarily a show stopper, especially if a connection doesn't need to be undone very often.
- PVC pipe is ubiquitous; it is currently used throughout the existing AguaClara design, is available world-wide and is suitable for use with all process chemicals involved. The current line-of-thought is to use 1/2" PVC rigid pipe and socket solvent-weld fittings for all delivery pipes (i.e. from chemical stock tanks to the CDC) and flexible tubing within the CDC instrument.. When needed, PVC threaded to barb adapters will be used to convert to flexible PVC tubing.

Once the materials and fittings are decided upon, this information needs to be incorporated into the Automated Design Tool. The goal is for the design tool to eventually include the CDC and to have a material list and AutoCAD drawing of the installation included as part of a standard design package.

Concluding, this sub-team will improve on the Constant Head Tank design and valve selection so that this device will "scale-up" as AguaClara plants increase in size. Additionally, this sub-team will make final decisions on the materials and fitting styles that will be used in the CDC.

Design Upgrade of the NDC (3-6 Persons)

An NDC was installed in the water treatment plant in Algateca. This was the first time an NDC was used in a real world application. This device was installed on top of the entrance tank and was only designed to administer alum to the plant. Aglateca is currently using an LDC for the administration of chlorine.

The ultimate goal is to design an NDC that is a stand-alone device which is capable of controlling all liquid chemical feeds for the plant. Currently, this includes alum and chlorine but will eventually include saturated lime. The mechanics of this design have yet to be worked out and are the challenge of this sub-team. Ideas and concepts to help with the initial stages of design:

- "Stand-alone" means the NDC would no longer be installed on top of the entrance tank but would be more centrally located in the plant. The float for the NDC could be in an 8" diameter pipe which is connected to the bottom of the entrance tank via a 1/2" PVC pipe. The use of the 8" pipe would require that the float move in a pure vertical motion but would significantly save on space.
- The current float attachment point (one end of the lever) does not provide pure vertical motion . As the lever responds to min and max flow rates, the vertical location of the chain shifts approximately 15 cm. Connecting the float to a pulley instead of a lever arm would provide true vertical motion, allowing the float to move vertically withing the confines of an 8" pipe. This could be accomplished using stainless steel bike chain and sprockets (both available through McMaster Carr) or any other type of pulley-cable arrangement.
- A dosing lever is still needed, even in the new design. The dosing lever would eventually need to accommodate three process chemicals. Triple-scale, triple-orifice for three chemicals all mounted on one dosing lever seems quite cumbersome. One solution is to build a structure to support a shaft that is supported between two bearings. One end of the shaft could be connected to the center point of the pulley and the dosing arms would be connected to the shaft in a fashion similar to our current installation.

Additionally, Monroe recently provided a document with his thoughts on some of the mechanics involved. The complete document can be found in CDC Summer 2010 Google Docs but to summarize a few key points:

- The float could be attached by cable to a pulley mounted on the ceiling. The cable would be connected to the dose controller side of the lever arm since the cable (after returning from the ceiling) and will move in the opposite direction as the water level changes. The range of lever motion would be adjusted by moving the attachment position. The slight angle of the cable from the pulley on the ceiling to the lever would be inconsequential.
- This float could be in the entrance tank rather than in a separate connected tank! Two pulleys mounted on the plant ceiling could transfer this motion to the CDC allowing the CDC to be placed wherever is most convenient. Each pulley adds a potential friction point as corrosion and dirt accumulate.
- Have a float attached to a cable that wraps around a very large pulley that is connected to a lever arm. This introduces error into the lever displacement. The pulley changes the equation of motion. Instead of applying a change in height to the point of connection with the lever, the float applies a change in angular rotation. These would be similar for small angle displacements, but there will be significant error for large displacements.
- The float could be a large diameter, shallow float with a small submerged weight that gives it stability. The float must have a large submerged AREA so that the depth of submergence is not changed by more than perhaps 1 cm when the dosing slides are moved. The buoyant weight of the slides (including the vertical drop tubes) will be larger if they are not submerged in water. Thus the float area will need to be larger if the CDC isn't mounted on top of the entrance tank (where the drop tubes were partially submerged).

Concluding, this sub-team will be responsible for designing an improved LDC that will be capable of metering all process chemicals to the water treatment plant.