Coagulant Management

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Abstract

Coagulants are an essential part of a water filtration plant as well as a signifiant operating cost. Therefore, it is very important that they be used as effiently as possible. This semester, the Coagulant Management team has calculated and analyzed the relationship between PACl density and concentration that was ultimatley used in calculations necessary for centrifugal pump parameters and for hydrometer recommendations. In addition, the team brainstormed fabrication ideas for the coagulant injection point. The centrifugal pump was partially fabricated, but because of the density vs. concentration relationship calculated, the pump, once fully fabricated, can be tested using PACl. In addition, the Coagulant Management team has recommended the testing and use of a plastic (polycarbonate) hydrometer from Krackeler Scientific Inc. with a specific gravity range between 1.000 and 1.220.

Literature Review

Hydrometer

Hydrometers (see Figure 1) are a useful piece of equipment that could be used by AguaClara plant operators to measure the specific gravity of a stock tank solution and thus be provided information about the density and concentration of the solution, and whether it has been mixed properly (formed a homogeneous

Figure 1: A Generic Lab Hydrometer

mixture). Specific gravity is the unit-less ratio between the density of the liquid and the density of the water. See Equation 1.

$$SG_{true} = \rho_{sample}/\rho_{water} \tag{1}$$

To accurately measure specific gravity in the range of the system, three different types of hydrometers were researched. The first type, which is composed of glass and has a minimum price of under $20, is fairly economical for the level of calibration and quality. Glass hydrometers are the most common and have a wide application. Nevertheless, potential hazards are introduced due to the fragility of the product, which makes it easily susceptible to shattering in a plant setting. This leads to the loss of hydrometer records, as well as additional costs and time lost in getting replacements in place. Shattered glass also introduces a safety risk to the population being served if the hydrometer breaks in the stock tank or injures the operator.

The second type of hydrometer is composed of plastic. The benefit of the plastic hydrometer is that it is much more robust and is better able to withstand the conditions of a water treatment plant. The potential economic advantage compared to a glass hydrometer is that it does not need to be replaced multiple times. If a hydrometer is to be purchased to be used specifically in an AguaClara plant, the plastic one is recommended because it is the most robust and cost-effective in the long term, while maintaining the required level of calibration. It also poses little or no safety issues.

The third option is to fabricate the hydrometer. The main advantage of a fabricated hydrometer is its extremely low cost; the main issue is the calibration. The accurate calibration of the hydrometer is essential to its implementation and the fabrication of an instrument in a different country introduces the risk of non-homogeneity. Even slight differences during the fabrication of the hydrometer in Honduras could lead to discrepancies in the expected and measured values.

Centrifugal Pump

Past stock tank mixing teams developed the “centrifugal pump”, which uses rotational motion to create a pressure gradient in the tank and raises the higher concentration solution at the bottom of the tank to the top. The apparatus as designed by previous teams is depicted in Figure 2 with proper labels and in 3 with original dimensions.

The pressure gradient causes water to flow into the suction rod, through the rotation rod, and out the spout rod. The apparatus is extremely effective for vertical rotation, but is not as effective for horizontal rotation. Problems arise with the stability of the apparatus in the tank. Also, the suction rod and rotation rod are extremely difficult to connect in the tank due to low visibility caused by the turbidity of the solution.

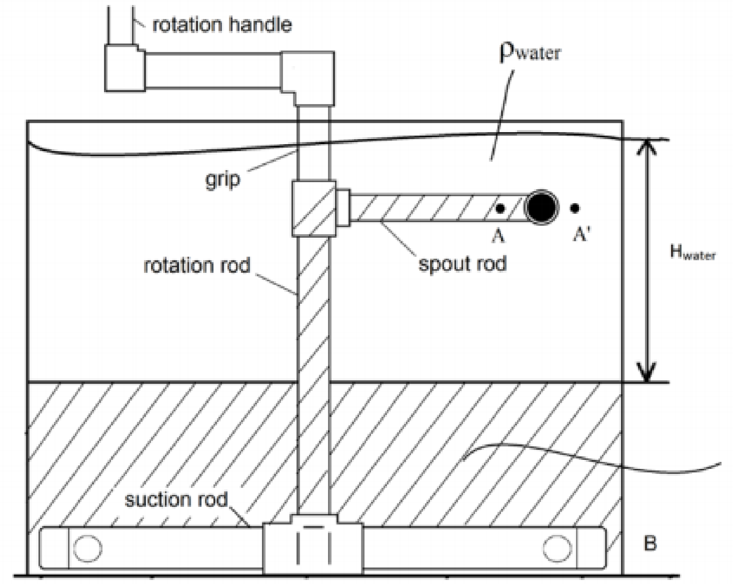


Figure 2: Previous Design Figure for Centrifugal Pump Prototype with Labels

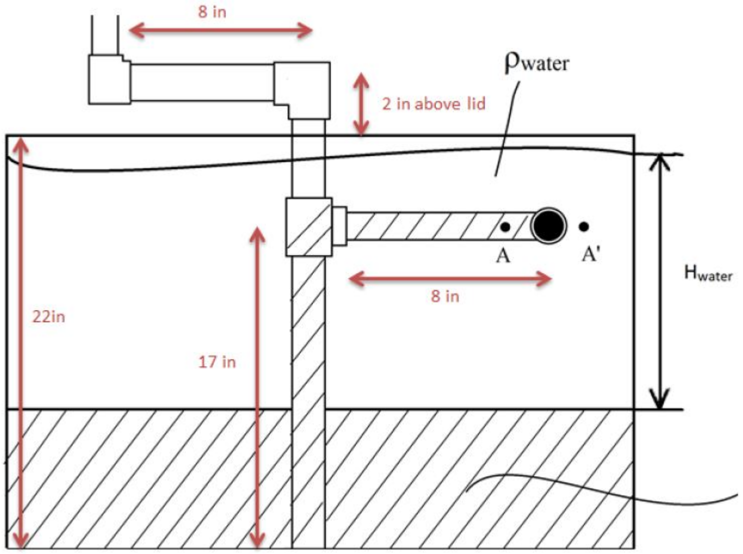


Figure 3: Previous Design Figure for Centrifugal Pump Dimensions

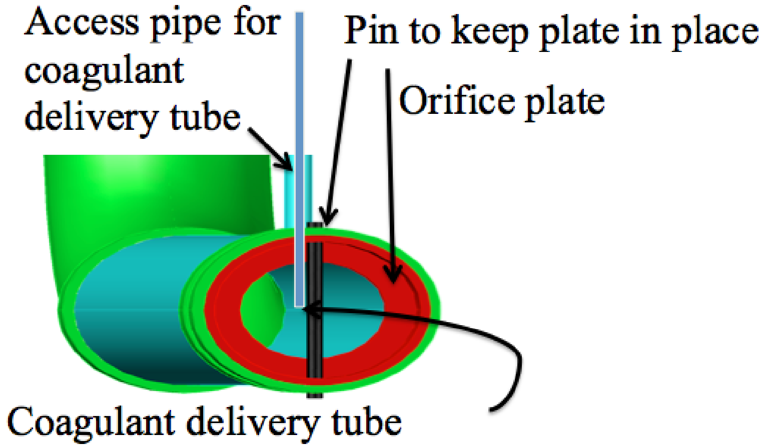


Figure 4: Preliminary Injection Point Drawing by Monroe Weber-Shirk

Injection Point

AguaClara has used several methods for injecting coagulant into raw water but has yet to provide detailed drawings showing the exact injection method. Coagulant injection is critical for successful operation and efficient usage of the coagulant. The failure modes include low head losses which cause oscillating flow at the entrance of the injector. This can create a build-up of coagulant along the delivery tube wall and thus increase head loss. Another failure mode is placing the injection point close to a rapid mix pipe wall, which will create inefficient mixing and cause coagulant build-up along that wall. In order for the injection point to be easily managed, it must be easily serviced and can be replaceable while the plant is operating. In addition, the injection point should be in the vena contracta upstream from the macro mixing location. Figure 4 shows a preliminary drawing of an injection point made by Monroe Weber-Shirk.

Introduction

Coagulants play a significant role in any water treatment plant, making it important to develop processes that allow the addition of coagulant to be both easy for the operator and highly efficient.

One aspect of coagulant management is stock tank mixing. Currently, operators must manually mix a solution of water and coagulant together with a stirring rod prior to use in the AguaClara plant. This activity in itself requires significant labor and can be optimized via a centrifugal pump system. A major issue associated with the stock tank itself is when PACl is used it has a tendency to concentrate at the bottom of the stock tank. A centrifugal pump system paired with the use of hydrometers can alleviate this issue. The use of hydrometers can specifically help with optimizing coagulant stock tank managing by measuring the specific gravity, which can be related to density and concentration, and thus give the operator an idea if the coagulant solution is properly homogenized.

Another aspect of coagulant management is the injection point within the rapid mix pipe. Optimization of coagulant injection is important for successful plant operation and efficient coagulant use. Several methods for coagulant injection exist, but detailed drawings are yet to be made. The failure modes include low head losses which cause oscillating flow at the entrance of the injector. This can create a build-up of coagulant along the delivery tube wall and thus increase head loss. Another failure mode is placing the injection point close to a rapid mix pipe wall, which will create inefficient mixing and cause coagulant build-up along that wall. In order for the injection point to be easily managed, it must be easily serviced and can be replaceable while the plant is operating. In addition, the injection point should be in the vena contracta upstream from the macro mixing location.

Methods

Density vs. Concentration

Although thought of to be similar, if not the same, density and concentration are two different characteristics of a solution. Density is the mass of a solution per a given volume, whereas concentration is the number of moles of a substance per a given volume. However, density and concentration exhibit an interesting relationship: as a substance is added to a solution (increase in concentration), there is an increase in the mass per volume of the solution (increase in density). This relationship can be applied to the coagulants used in AguaClara plants. Due to the fact that the majority of AguaClara plants utilize PACl, however, our analysis will be made solely on the lab density measurements acquired for PACl.

Calculations/Measurements

The density of PACl was related to concentration by utilizing the following procedure over a range of viable stock tank PACl concentrations:

1. Take 100 mL volumetric flasks and measure the mass of each using an accurate electronic balance

2. Fill each volumetric flask with about a third of distilled water

3. Add 0, 9, 18, 27, 36 g of PACl to each flask, respectively (maximum mass based on twice the concentration of a typical stock tank solution in

Figure 5: A 0.36 g/mL PACl Solution in 100 mL Volumetric Flask

Honduras : 180 g/L*2 = 3600 g/L = 36 g/100 mL)

4. Mix solution well by shaking
5. Once the PACl has completely dissolved, add addition distilled water until the 100 mL line on each flask (Figure 5)
6. Measure the mass of the solution and the volumetric flasks using an accurate electronic balanace
7. Subtract the previously measured mass of the volumetric flasks from the total mass, giving the mass of the PACl solution

Results

Following the steps outlined above, the following results table shows the values acquired:

Mass (g) of PACl added per 100 mL	**Mass (g) of resulting PACl solution**	**Concentration (g/mL) of PACl Solution**	**Density (g/mL) of PACl Solution**	**Specific Gravity of PACl Solution**
0	99	0.000	0.990	0.990
9	104	0.090	1.040	1.040
18	108	0.180	1.080	1.080
27	113	0.270	1.130	1.130
36	120	0.360	1.200	1.200

Hydrometer

Initially, the Coagulant Management team purchased glass hydrometers from McMaster Carr with the specific gravity range of 1.200 to 1.420. This was done when Challenge 2 was still thought to be an actual task and an incorrect density for alum was assumed. However, upon deciding to concentrate on PACl density measurements, these hydrometers are not viable anymore, especially with the specific gravity range for PACl calculated as being between 0.990 and 1.200.

Centrifugal Pump

Calculations

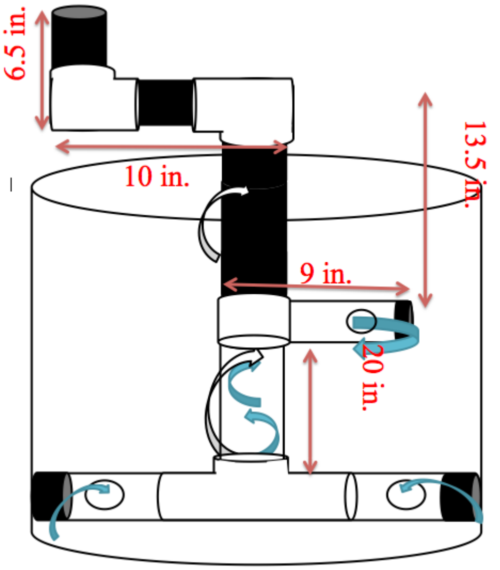
Most of the parameters used for fabricating the centrifugal pump were arbitrary. However, the height of the orifice (See Figure 8) was calculated using a Mathcad file, with the PACl density vs. concentration relationship (See Figure 12) inputted, provided by Monroe Weber-Shirk; the file is currently uploaded to the Coagulant Management team web page. Figure 6 shows the updated design for the centrifugal pump with the calculated orifice height (20 inches) using 1.5 inch diameter pipes.

Fabrication

The coagulant management team's task was to create a centrifugal pump system based on the specifications left to us from the Spring 2011 and 2012 stock tank mixing teams. Based on the diagram from their final report, the team ordered several feet of 1.5 inch diameter clear PVC, 1.5 inch diameter white PVC, several 1.5 inch PVC elbows and connectors, and a 1 inch PVC t-connector base. After evaluating the task based on our current materials and the guidelines set by previous stock tank mixing teams, the team noticed four key problems for fabrication:

1. Obtaining a stock tank, preferably a 55 gallon one, with clear sides in order to physically observe the path of the denser coagulant up through the pump
2. Fabricating a clear PVC pipe and connector to allow for a water-tight seal that could allow for smooth rotation
3. Finding a connector which would both provide stability to the pipes while allowing for rotation
4. Developing a method of testing which would accurately simulate the difficulty of mixing at a plant in Honduras while being efficient in PACl usage

For the first problem, the team chose not to order a tank due its prohibitive cost. Fortunately, a leftover stock tank was found and was in useable condition after cleaning. The second problem presented more difficulty. First the team



Design is not to scale.

Figure 6: Updated Design for Centrifugal Pump

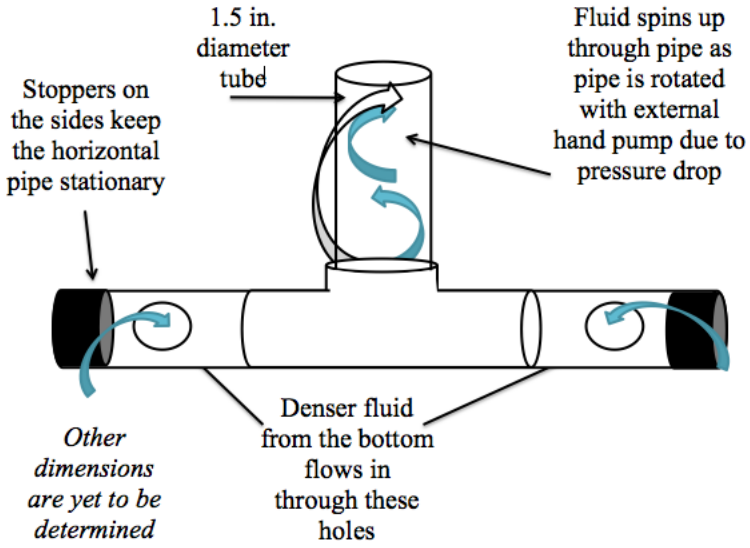


Figure 7: Bottom Segment of Centrifugal Pump

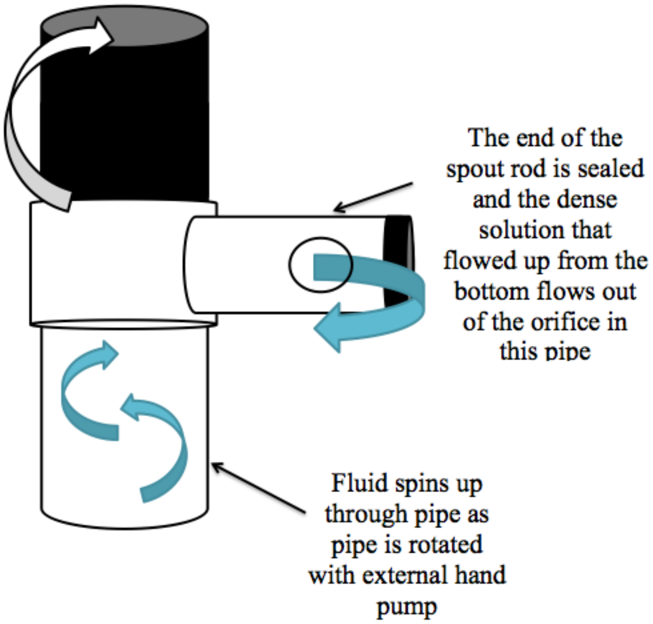


Figure 8: Segment of Centrifugal Pump Showing the Horizontal Pipe Orifice

decided to create a system in which the rotation rod made from 1.5 inch PVC would fit over a 1 inch PVC T-connector that would sit at the base of the tank (See Figure 7)

In order to create the appropriate seal, the outer diameter of the connector was reduced, and the inner diameter of the 1.5 inch PVC was increased in the machine shop so that the rotation rod would fit over the T-connector base, yet still have the ability to rotate. However, in regards to problem 3, there were concerns over the stability of a T-connector due to its rounded base. For that reason, other alternatives that could provide more stability were considered. One such base under consideration was a bronze flanged bushing (See Figure 10).

The plan was to fit the rotation rod into the bronze flanged bushing, and then poke holes into the rotation rod to serve as the water intake. The team believed the flat base would add stability that was lacking in a centrifugal pump with a T-connector base. However, a 1.5 inch shaft diameter was mistakenly ordered because the team concluded that the sizes would work as connector sizes would; the 1.5 ibch PVC did not fit inside the bushing.

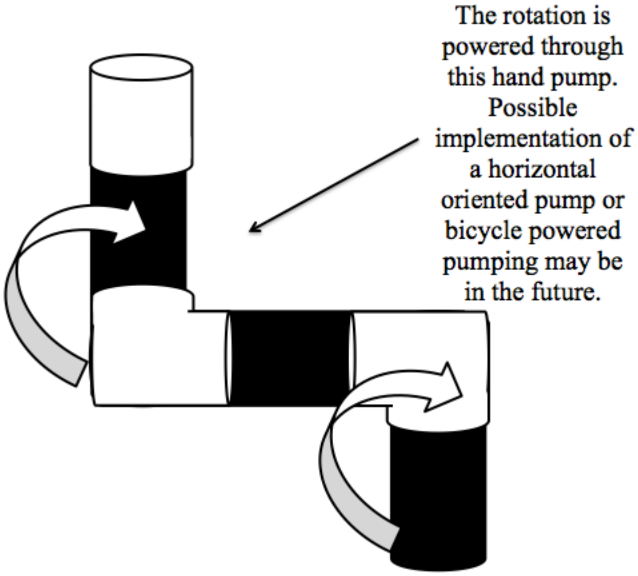


Figure 9: Hand Pump Segment of Centrifugal Pump

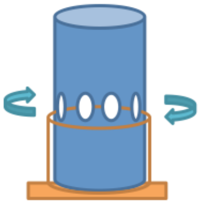


Figure 10: Bronze Flanged Bushing

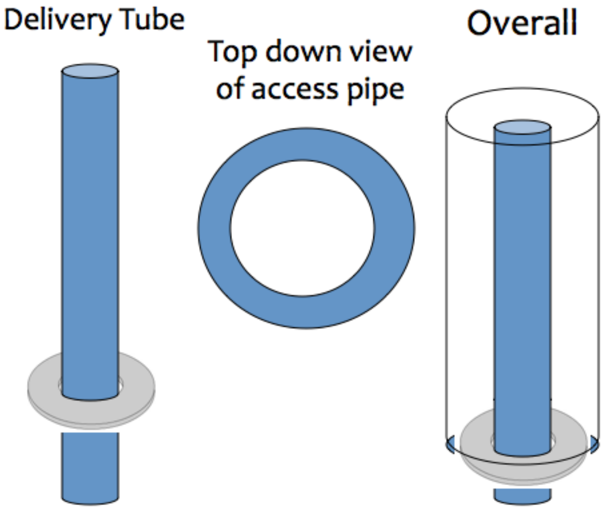


Figure 11: Washer Fabrication Idea for Injection Point Deliver Tube

Injection Point

The Coagulant Management team brainstormed several fabrication ideas for the injection point. These ideas include using an access pipe made out of thin PVC pipe and attached to the rapid mix pipe, a delivery tube that is both stable and easily removable, and a strong, non-corrosive injection point. Another idea that was developed was a fabrication idea for ensuring that the injection point can easily and efficiently be placed in the center of the flow within the rapid mix pipe. This idea (See Figure 11) includes placing a washer between the the outer wall of the rapid mix pipe and the delivery tube to act as a stopper and hold the injection securely in place.

Results/Conclusions

Density vs. Concentration

Figure 12 shows the graph of the PACl density compared to PACl concentration using the data from the results table above.

A trendline was formed along the plotted points, through which an equation relating density and concentration was found. The R^2value (reported as 0.98973) indicates that the trendline is a very close approximation of the actual data values, making this relationship extremely plausible for PACl concentrations ranging from 0 g/mL to 0.360 g/mL. Thus, this relationship can be used in the calculations pertaining to the centrifugal pump.

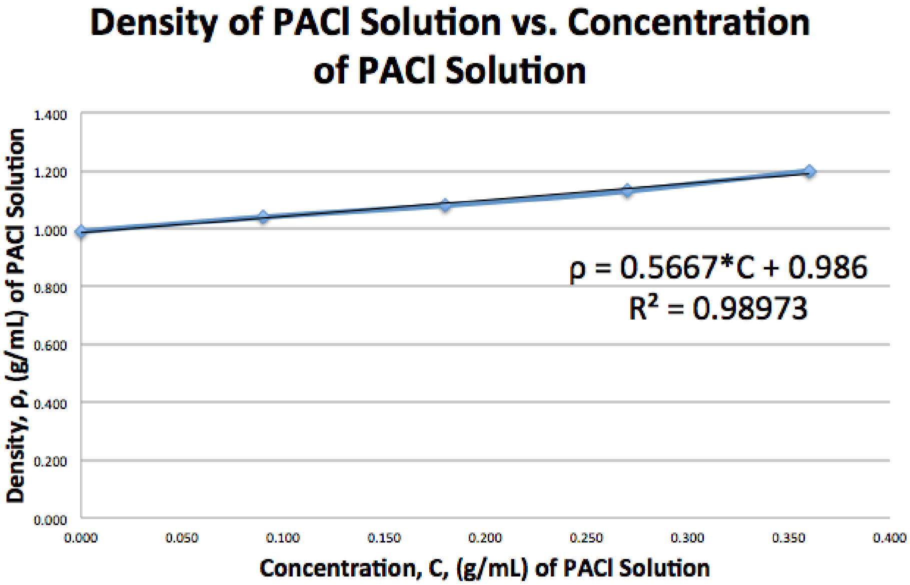


Figure 12: Density vs. Concentration of PACl with Trendline

Figure 13: Krackeler Scientific Inc. Plastic Hydrometer (1.000-1.220)

Hydrometer

Based on previous research done by past teams and the Coagulant Management team's analysis, a recommendation for hydrometer selection has been made. The team recommends the use of a plastic hydrometer due to its durability and longer life span when compared to a glass hydrometer. In addition, the team suggests purchasing a hydrometer that will be non-corrosive. The best option that has been found at this point in time is the $74 Krackeler Scientific, Inc. plastic (polycarbonate) hydrometer with a specific gravity range between 1.000 and 1.220 (Catalog No.: 1202-2540PL) based upon the analysis made of the density vs. concentration data. Figure 13 shows an image of the recommended hydrometer.

Figure 14: Fabricated Centrifugal Pump

Future Work

Hydrometer

The recommended hydrometer, or a better alternative, needs to be purchased and tested with a range of concentrations for PACl to ensure the above calculations and analysis are indeed functional upon application. If indeed the recommended hydrometer is fully functional in the laboratory, it must be sent to Honduras for testing and usage in the field.

Centrifugal Pump

The centrifugal pumped designed this semester and partially fabricated needs to be fully fabricated and/or a better design developed.

Fabrication

For future work, the Coagulant Management team recommends an appropriately sized bronze flanged bushing be ordered and tested it to see if it adds stability within the pump system. For problem 4, there was concern about the cost of using PAC in order to simulate accurate stock tank mixing conditions in Honduras. As an alternative, the team considered using corn starch or corn syrup to increase the water's specific density to be more similar to PACl, while using colored dye to visually track the path of the denser solution through the tank. Future teams should consider similar ways to test the effectiveness of the pump system. Although the centrifugal pump was not fully completed, the piping has been completely put together (See Figure 14), and the necessary tank has been acquired. Future teams should seal each non-rotating joint on the pump, and use an adhesive to set the T-connector base into the bottom of the tank.

Injection Point

More developed thoughts should be put together in order to create a preliminary design of the injection point for fabrication. Future teams must ensure that all parts of the injection point are non-corrosive and easily acquired in Honduras, the system itself easily serviced, and the point of injection be both rigid and placed in the center of flow in the rapid mix pipe.