Stock Tank Mixing

Julie Silva

May 3, 2012

Abstract

The Stock Tank Mixing team is required to improve the mixing process for the coagulant and disinfectant in the stock tank. Previous teams have developed the "centrifugal pump" design, which can mix the following chemicals: aluminum sulfate (alum), polyaluminum chloride (PACl) and calcium hypochlorite ($Ca(ClO)_3$). This team decided to focus on the use of polyaluminum chloride. Due to its chemical properties, it is most likely the future coagulant of most AguaClara plants. The stock tank mixing team plans to design a mixing system that will improve operator ease in use of the mixer, achieve a truly homogeneous mixer, and be scalable to larger plants. The team will also create operator guidelines, and provide the operator with a verification of homogeneity.

Introduction

The stock tank mixer mixes the chemical solution for flocculation, filtration, and disinfection. This solution generally includes a mixture of water and either aluminum sulfate, polyaluminum chloride or calcium hypochlorite. While these chemicals will be used in AguaClara plants, sugar is used for all demo experiments. If PACl (or sugar) is added to water without proper mixing, a concentration gradient is created. The bottom of the tank has a high concentration, while the top of the tank has a low concentration. A proper homogeneous solution must be attained for the chemical dose controller, which is fed by the stock tanks, to function optimally. If said homogeneous solution is attained, the reactants will never separate. Accurate dosing of chemicals is essential for the plant to perform properly.

Currently in AguaClara plants a straight PVC pipe, known as the "simple stirrer" is used to mix the stock tank. This method has been determined to be inefficient and ineffective, and must be improved upon.

Literature Review

Hydrometer

A hydrometer will be used by the AguaClara plant operator to measure the specific gravity of the solution and determine whether or not the stock tank mixer is functioning properly. Specific gravity is the unit-less ratio between the density of the liquid and the density of the water. Past experimentation to develop a standard curve has determined the optimal value of the specific gravity of polyaluminum chloride with a stock concentration of 360 g/L to be 1.0114. Experimentation has shown the centrifugal pump and other past apparatus to produce a solution with a specific gravity of 1.012. 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 ofunder $20 and 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 and costs approximately $60 from Krackeler Scientific, Inc. 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 of the plastic hydrometer is that it will most likely be a one-time expenditure compared to a glass hydrometer that may need to be replaced multiple times. If a hydrometer is to be purchased, 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 no safety issues.

The third option is to fabricate the hydrometer. The simplest model for such a hydrometer included a plastic tube (similar to a straw) with modeling clay on the end that is submerged in the water. Standards with different relative densities can be used to calibrate the fabricated hydrometer. The main advantage of the fabricated hydrometer is its extremely low cost. The main issue in the fabrication 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

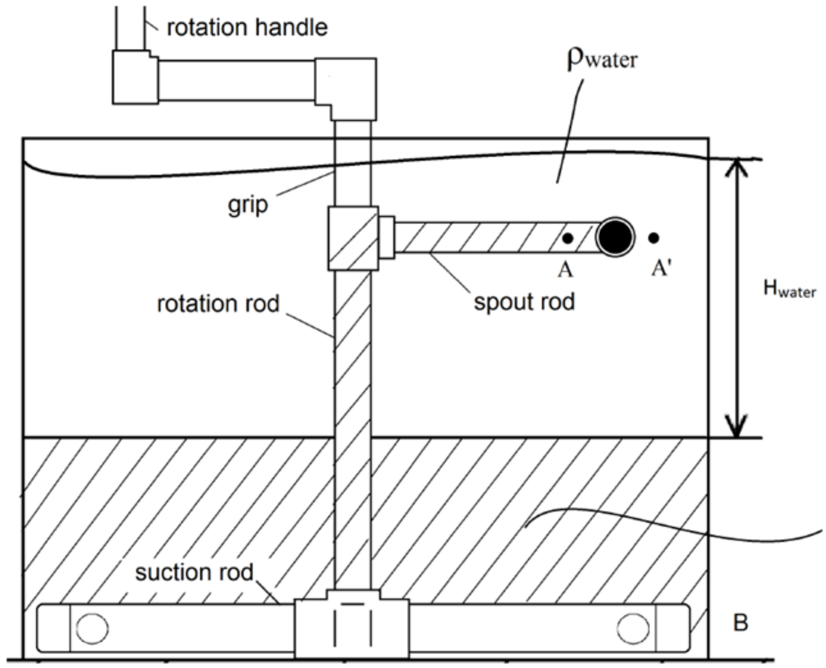

Figure 1: Centrifugal Pump Prototype

is depicted with proper labels below. The given names for the parts of the centrifugal pump will be used for the duration of this report.

The pressure gradient causes water to flow into the suction rod, through the rotation rod, and out the spout rod. This 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 the tank due to low visibility caused by the turbidity of the solution.

Methods

Hydrometer

Theoretical Hydrometer

For a hydrometer to work, it needs to be able to float in the water upright for a proper measurement. This concept sounds simple but is actually a lot harder. The perfect balance must be found, and can be approximated due to the calculations below. Given known properties, one can either solve for the height of the cylinder for a given weight, or solve for the necessary weight given a cylinder height. We will assume it is a simple hydrometer made up of a cylinder (c) and a weight (m). The cylinder has an outer radius and inner radius. $V_c = \pi h_c (r_{outer} - r_{inner})^2$

The hydrometer must sit at or below the center of gravity (H). $H = \rho_c V_c (.5h_c + h_w) + 0.5 m_w h_w$

The volume of the submerged cylinder is $V_{c,sub} = \pi(H - h_w)(r_{outer} - r_{inner})^2$

In buoyancy, the mass of the fluid displaced equals the mass of the submerged object, so $V_{c,sub} \rho_c m_w = \rho_{fluid} \left(\frac{m_w}{\rho_w}\right)$.

Centrifugal Pump

Past analysis has determined the centrifugal pump to be effective in its use to better mix the solution. To more fully understand the benefits of the centrifugal pump, past teams have developed a MathCad model to exemplify the simple stirrer and centrifugal pump methods. According to the given model, the "simple stirrer" requires 8 full revolutions for the solution to be fully mixed with a measured specific gravity of 1.0114

PACl

The PACl used in AguaClara plants has many impurities that will not dissolve in the solution. The design for the PACl stock tank mixer must take this into account, since it is inefficient to attempt to mix these impurities with the mixer. To determine what percentage of the solution is impurities, 10 mL of a 360 g/L solution was created. It was then filtered using a vacuum through filter paper. The remaining solids that did not get filtered were weighed. It was determined that approximately 8% by weight of the PACl was impurities. This experiment needs to be repeated to ensure valid results. Nevertheless, indications are that the design process should probably not consider the PACl at the very bottom of the tank for dosing, unless there is some valve where the impurities in the PACl can exit.

Full-Scale Model

To create a feasible full-scale prototype, a pipe diameter for the apparatus must be chosen. The MathCad model was used, with a few modifications. The height of the spout was assumed to be 26 inches, the radius of the pump 18.5 inches, and the diameter and height of a 55 gallon tank are each known to be 22.5 inches and 33.5 inches respectively. The model uses the assumption that a plant operator could feasibly rotate the pump at an angular velocity of 20 rpm. To finish in 2 minutes, the flow rate exiting the spout rod must be at least 3.5 L/s. The flow rate is the value of the volume to be mixed divided by the time to mix, $Q = V/t$. This minimum flow rate can be reached with a pipe diameter of 1.5 inches (3.814 L/s), and increases as diameter increases. The MathCad model was also used to determine the power required for the operator to turn the centrifugal pump. At 20 rpm and a 1.5 inches diameter, the calculated

Figure 2: Second design using clear PVC. This design is a modification of the previous design to include a small chamber of air at the bottom of the hydrometer.

power required was approximately 116 watts. At a 2 in diameter pipe, this number was significantly increased to around 210 watts. These results show that the increase in the diameter of the pipe significantly influences the amount of power required, thereby potentially making a 2-in diameter pipe impractical. Consequently, a full-scale prototype will be designed using 1.5 in diameter PVC pipes.

Analysis

Hydrometer

Early hydrometer experimentation was done using water instead of the solution. A hydrometer should work for both water (specific gravity of 1) and the solution. A simple hydrometer was developed using a clear 3/16 in PVC tube with plastic plug. The plug had a screw in the end, in order that washers be added to find that weight at which the hydrometer would float upright in the water. The "tank" used in the experiment consisted of water in a 1-inch PVC tube that was plugged at the bottom. Weights were continually added, however the upright position could not be maintained. The hydrometer was either at an angle in the water, or sank to the bottom of the tank.

Different designs for the hydrometers were developed to try to increase the buoyancy of the apparatus. One design included a small chamber of air at the bottom of the hydrometer, as shown above. Ultimately, the PVC pipe was

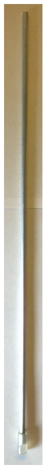

Figure 3: Working hydrometer design which includes 0.115 in diameter Aluminum tubing with a weight attached to the bottom.

determined to be too heavy a material, at .55 g/in.

Another simple hydrometer was developed out of 0.155 in diameter aluminum tubing, plugged by flexible plastic tubing and low-density polyethylene as shown. This hydrometer stayed afloat and upright with 11.56 in submerged in the water with a mass (of the plug plus weights) between 1.79 and 2.1g. Considering past experimentation and guiding calculations, a method to manufacture and calibrate hydrometers has been developed. General steps to this method are below. We will consider the "weight" described below to include the weight of the rod as well as the weight of the plug.

1. Choose your material for your rod. This material must weigh under 0.3 g/in, and for best results should be in the range of 1/8 to 3/16 inches in diameter.

2. Calculate the approximate and reasonable height and weight needed to develop a hydrometer with this rod (see Methods section).

3. Build a prototype for your design. Start with a weight of 0.5 grams less than the calculated value. Carefully increase your weight by 0.1 g until you have determined your range for the necessary weight. Find this range for both 1, the specific gravity of water as well as a solution with a specific gravity of 1.0114 (the theoretical value for the 360g/L PACl solution).

4. Find an attainable value well between these two ranges, and build your hydrometer. It is generally safer to stay on the lighter side.

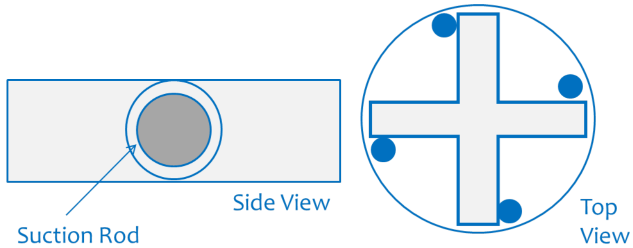

Figure 4: "Stoppers" Design

Centrifugal Pump

Stability Pipes, Intakes, and Stoppers

Several ideas regarding improving performance were discussed. One idea was to increase stability by adding another set of pipes at the bottom of the tank for stability, as shown from the top view above. These added pipes may or may not intake solution, and will be attached to the centrifugal pump apparatus at the suction rod. A "four-inlet" suction rod may lead to possible head losses. The team has also not found an inexpensive PVC fitting with the necessary configuration. To construct the "stability pipes", a "u-cut" will be made in each pipe as shown below from the side view. The stability pipe design was tested.

The original idea behind the stoppers method was to stop rotation of the suction rod, because the original thought was that the suction rod must be stationary to create a pressure gradient. This idea was proven false, however, the suction rod experiment is worth noting due to the valuable conclusions drawn from the experiment.

In this design, a system of four "stoppers" for rotation and a single spout rod were used and tested as shown below. The apparatus was able to rotate radially, but for no more than a limited number of degrees. The suction rod spanned the diameter of the bottom of the tank to keep the rotation rod in place. There was adequate room between the suction rods (a full 90 deg.) for the apparatus to be placed into the tank with ease and little probability of hitting the stoppers from above.

During the experiment the suction rod would not only rotate radially, it would also move horizontally and vertically. Although the length of the suction rod was almost the diameter of the container, it was not long enough to stop this vertical and horizontal movement. This can be fixed by increasing the length of the suction rod. This can also be fixed by defining a point of rotation at the center of the tank. This may be achieved by positioning the rotation rod with a hole in the lid of the tank.

It is also important to note that the duct tape used influenced the experiment. The duct tape was originally used to keep the "stoppers" in place during the experiment, and added the high-friction surface that stopped rotation. This reduction of rotation due to friction may be used advantageously in future de-

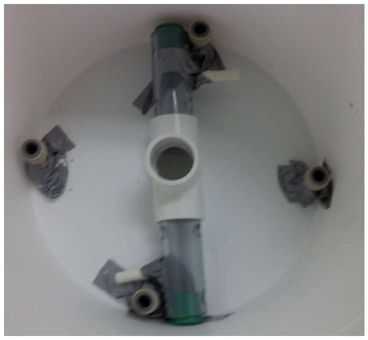

Figure 5: “Stoppers” experimental setup.

signs. Problems still arise regarding permanently attaching the stoppers to the tank; one option is to use the bulk head fitting used for flow out of the tank into the chemical dose controller.

The rotation of the suction rod did not seem to influence the function of the centrifugal pump, so “stoppers” to keep the suction rod from radial rotation are unnecessary. This fact was further proven by experiments without a suction rod.

Using the Bulk Head Fitting, the “Bulk Head Design”

In theory, the suction rod is not needed for the centrifugal pump to work, as it may only make it easier for the pump to bring in PACl solution from the sides of the tank. Another proposed design, which includes intake through the rotation rod, was tested. This design takes advantage of a bulk head fitting currently in the center of the bottom of the tanks. This fitting is used to attach a pipe for flow out of the stock tank.

In this design, the rotation rod rotates from a coupling in the bulk head fitting at the bottom of the tank, as shown below. This coupling has holes in it to allow the solution to flow into the rotation rod. The design was tested with an early full-scale apparatus in a 21.5-in diameter tank. As shown in the video, it takes only a few seconds for the solution to begin to flow through the apparatus, making the entire solution completely mixed.

Approximate specifications for a full-scale apparatus for a 55-gallon tank are shown below. The same design can be used for similarly-shaped tanks. In any design, the spout rod should be as high in the tank as possible while still submerged (about 4 to 6 inches below the height of the solution), and reach horizontally within 4 to 6 inches of the side of the tank. Any closer position will interrupt the flow out of the spout rod. To keep the system stable from above, a hole will be made in the lid on the tank. Because the coupling stops flow through the bulk head fitting, the apparatus must be removed while the stock tank is being drained.

Figure 6: Coupling attached to the rotation rod.

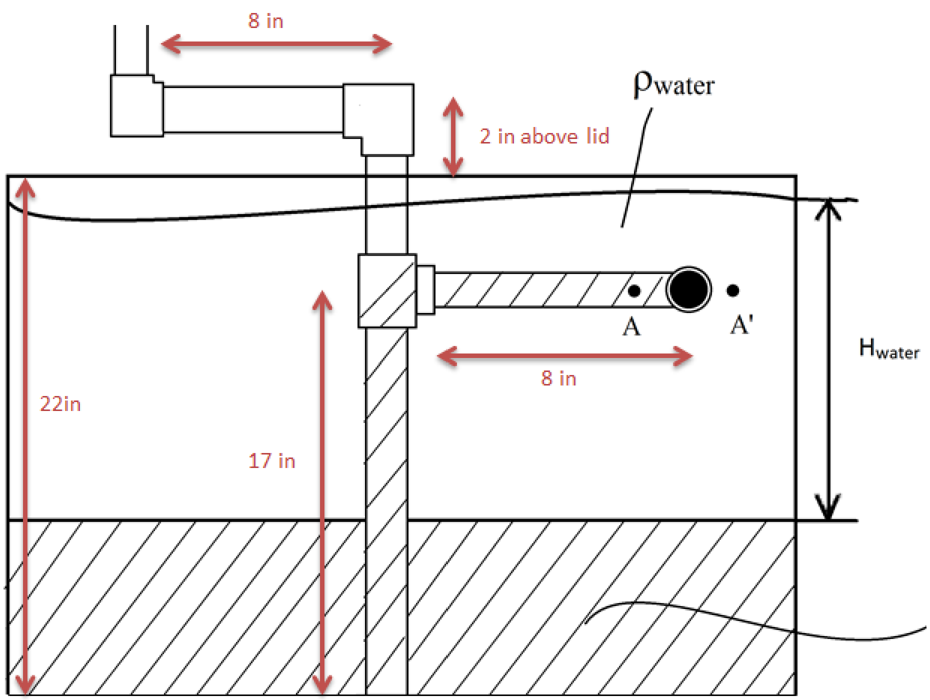

Figure 7: Approximate dimensions for the full-scale model

Conclusion

The fabricated hydrometer will most likely be implemented in AguaClara plants, at a cost of under $10. If an accurate fabricated hydrometer cannot be developed, the plastic shatterproof hydrometer should be purchased. After the centrifugal pump is implemented, the measured specific gravity after each mixing should be recorded in the official log where AguaClara keeps all plant measurements to ensure the plant is functioning properly.

The centrifugal pump will likely be implemented in AguaClara plants using the "Bulk Head Design". This design is preferred because it is simple, does not require modifications to the tank, and can be used with essentially any tank that has a lid.

Future Work

Future teams should use the method outlined for creating a hydrometer to develop a hydrometer that not only works but can easily be mass-produced for AguaClara plants. The goal is to give operators guidelines for a specific hydrometer they can build without first requiring a solution with the desired specific gravity to compare.

Improvements to the current bulk head design may be considered. Also, the design should be tested on tanks larger than 55 gallons. The design should theoretically work, however the design may not be efficient for mixing solution on the bottom outer diameter of the tank if the tank is too large.