Stock Tank Mixing Team

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Part I
Abstract

The Summer 2011 Stock Tank Mixing Team is tasked with improving the coagulant stock tank mixing process currently used in many AguaClara plants. Previous teams have determined the major differences in properties of Aluminum Sulfate (alum) and Polyaluminum Chloride (PACl) and experimented with the 'double bucket,' 'constant upflow,' 'simple stirrer (stick),' and 'centrifugal pump' designs. This team has made several modifications to the existing centrifugal pump design and performed mixing rate experiments to compare its efficiency to that of the previous model. In addition, we have examined the MathCAD program that calculates the energy input of the centrifugal pump for errors, begun development on a more efficient mixer based on the designs found in a bicycle, and constructed a standard curve for a hydrometer using concentrated sugar solution that can be utilized to create stirring guidelines for AguaClara plant operators in Honduras.

Part II
Introduction

AguaClara plants rely on a source of coagulant solution for the flocculation of solids found in a given source water. This solution is typically water and either PACl or alum. Most of the AguaClara plants currently use alum coagulant but this coagulant is being gradually replaced with PACl. Although we used sugar instead of PACl, we believe that our experiments accurately represent what would occur with PACl solutions because we are analyzing concentration gradients and not the actual dissolving of granular particles. As PACl dissolves very readily in water, we feel that this is a safe assumption to make.

The current method used in AguaClara plants to create the solution is to simply stir the solid coagulant with water until all solid particles seem to dissolve. However, due to the unreliability and inaccuracy of this method, new ways of mixing the solution have been considered. It is one of the tasks of the Summer 2011 Stock Tank Mixing team to work with one of these considerations, the centrifugal pump, and to find ways of modifying it to maximize its efficiency.

Part III

Centrifugal Mixer

One of the modifications to the centrifugal mixer (depicted in Figure 1) that we considered was the addition of impellers to the vertical axis of the pump to create horizontal mixing. Although the centrifugal pump is very successful in mixing vertical layers, it does very little to mix horizontally. Another modification we considered was the addition of baffles to the inner wall of the tank to disrupt any solid body rotation that may occur. Ultimately, we dedicated most of our time towards improving the seal between the rotation rod and the suction rod, allowing for more force to drive the concentrated solution from the bottom of the tank up the length of the rotation rod.

We substituted clear 1 inch diameter PVC pipe for solid 0.75 inch diameter PVC in the rotation rod for improved visibility and shaved off the end of the PVC tube to allow it to freely rotate while also fitting more snugly into the suction rod, reducing head loss and thus improving suction. To hold the pipe more securely in place as we conducted our experiments, we glued an elastic ring to the bottom of the pipe, but we anticipate the need for rings made from plastic or other nonreactive material for use in the actual plant. While the previous design had a 90 degree elbow attached to the end of the spout, we were not able to find a 1 inch diameter elbow in the lab. In the interest of time, we conducted our experiments without any attachments to the end of the spout. In addition, future models of the centrifugal mixer should use the longest possible spout (close to the diameter of the tank) in order to maximize torque during rotation.

1 Centrifugal Mixer Design

Experiments involving the rotation rate of the mixer are conducted in the following fashion:

1. The final desired concentration for the fully homogenized solution is decided (360 g/L).
2. For the desired tank volume, the mass of sugar needed for the desired concentration is calculated.
3. The volume of a sugar solution at its solubility limit is found that, when mixed with a volume of pure water, would result in the creation of a solution at the desired concentration and volume.

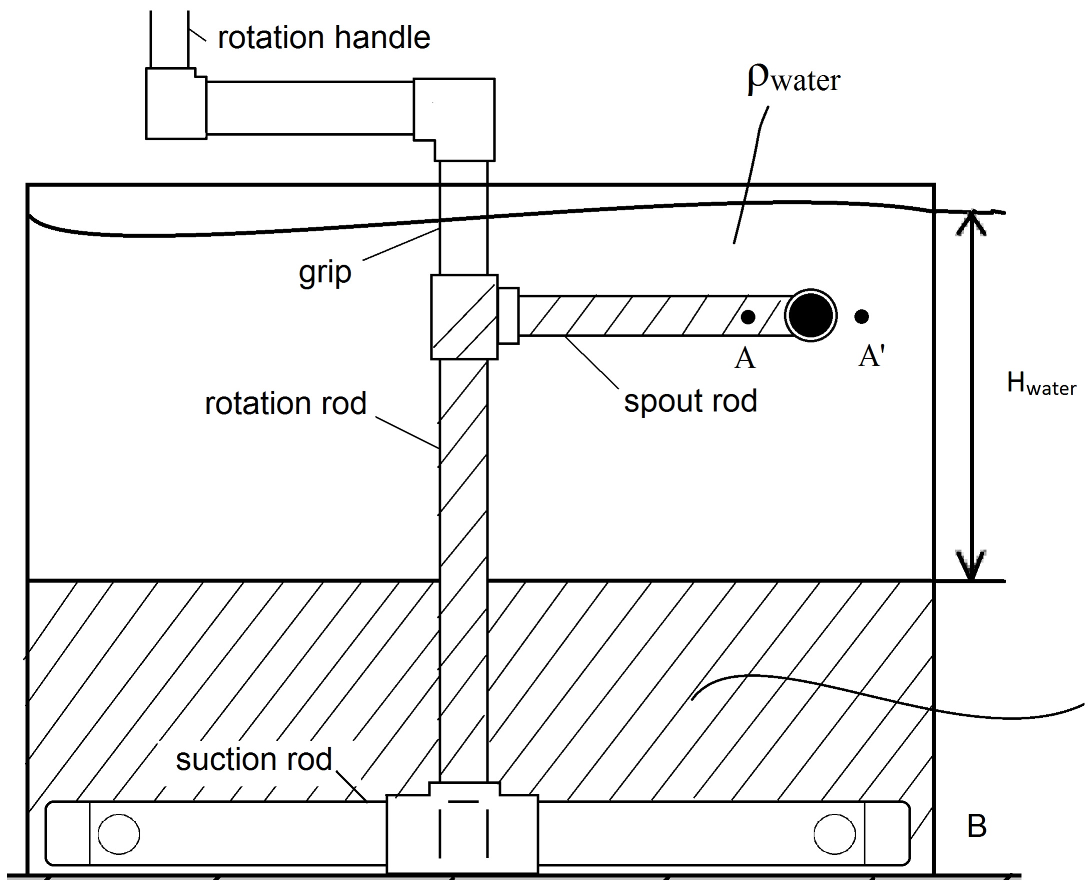


Figure 1: Centrifugal pump mixer design.

Figure 2: The tighter seal between the suction rod and the rotation rod (left) contributed to the improved efficiency of the new pump (right).

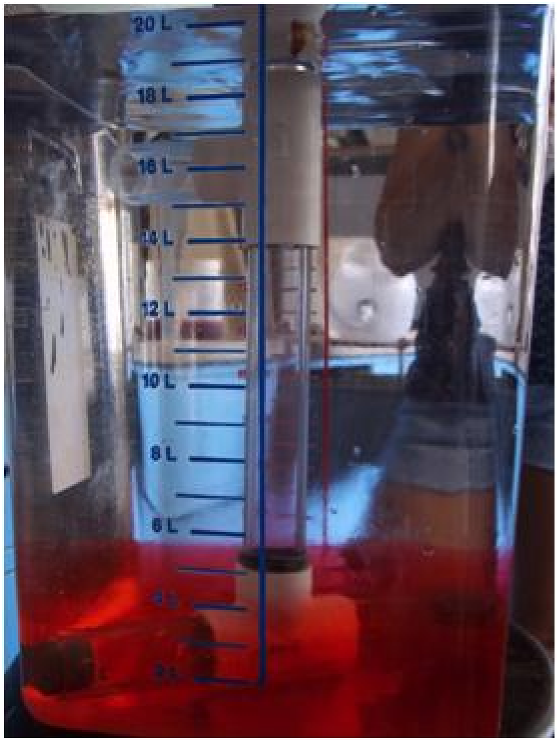


Figure 3: Improved centrifugal mixer assembled in a clear plastic 20 L tank with concentrated sugar solution at the bottom.

4. The tank is filled with pure water and the sugar solution at its solubility limit is carefully siphoned into the bottom of the tank using a plastic funnel and a length of PVC pipe. No mixing between the water layer and the sugar concentration is assumed.

1.1 Height Experiments

For our first set of experiments, we planned to mix 2 L of a 360 g/L red sugar solution into 18 L of pure water at rates of 15, 30, 45, and 60 rpm and to measure the height reached by the sugar solution in the clear PVC tube. These height measurements could then be used to calculate the energy required to fully mix the solution at each mixing rate.

We observed that at a rate of 15 rpm, the colored sugar mixture did not rise high enough in the tube to record a measurement, but that at rates of 30 rpm and 45 rpm, the sugar solution rose 9 cm and 20 cm respectively up the height of the tube. At 60 rpm, the sugar solution rose the full height of the tube and exited the spout. We recorded that a mixing time of 78 seconds at 60

Rotating speed (rpm)	Time (s), old pump	Time (s), new pump
30	X	X
45	111	145
60	31	23
75	20	10

Table 1: Comparison of average mixing times for old and new pumps. X: solution did not reach spout.

rpm was required to fully mix the solution. However, some problems with our method of experimentation became apparent during and after experimentation. The heights recorded at 30 and 45 rpm were approximate, because the height of the solution rose and fell as significant amount with the natural variation in the motion created by our human mixers. In addition, the mixer was found to be still somewhat awkward to use, as the grip of the mixer was around eye level for Christine and Aliya, making it difficult to maintain a constant rate of mixing.

1.2 Interface Experiments

Our second set of experiments took into account the problems we encountered earlier. For these experiments, we stirred the same 2 L of red 360 g/L sugar solution into 18 L of pure water at rates of 30, 45, 60, and 75 rpm. Justin, being the tallest member of the group, mixed the solution at hopefully a more constant and accurate rate. We measured the time required for the water-sugar interface to reach the bottom of the tank, which is summarized in Table 1 below at each of the different rates and depicted graphically in Figure 4.

From this experiment, we concluded that feasible mixing rates for our system ranged from about 45-75 revolutions per minute with mixing times ranging from about 140-10 seconds for the improved mixer. We determined that a rotating speed of roughly 45 rpm represents a threshold rate for the mixer to function correctly; at this rate, the sugar solution just barely reaches the height of the spout, only exiting the spout some of the time. Therefore, the mixing times obtained for each mixer at 45 rpm are not reliable data points and our conclusion that the new mixer is a more efficient model due to its improved seal is still valid.

We then calculated flow rate through the new pump for each mixing rate while assuming that total flow volume in the centrifugal pump was 20L for the whole mixing process, and we compared our calculated flow rate with the flow rate predicted according to the prediction file developed by the previous research team as shown in Table 2 below:

The disparities seen in our calculated flow rates and the flow rates calculated using previous teams' equations led our team to take a closer look at the files provided by previous teams. To use MathCAD to calculate and evaluate the centrifugal mixing systems, previous teams created the 'worst case scenario' for a given target concentration. Simply put, the worst case scenario is the case that would require the most energy input to achieve full homogenization. However,

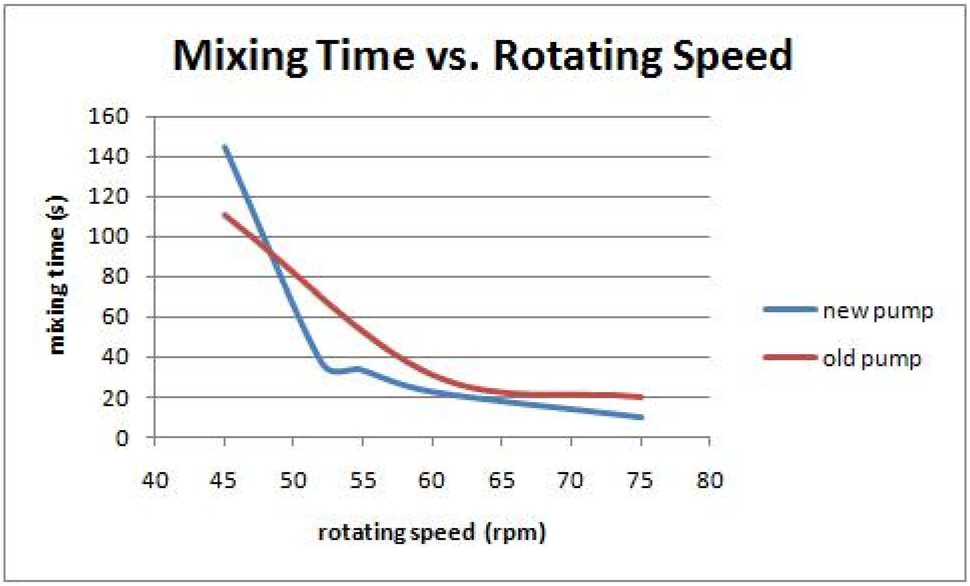


Figure 4: Curve of mixing time as a function of rotating speed using data recorded in Table 1.

Rotating Speed (rpm)	Time (s)	Calculated flow rate (L/s)	Predicted flow rate (L/s)
30	X	n/a	n/a
45	96	0.2	1.4
60	13	1.4	2.2
75	10	2.0	2.8

Table 2: Flow rate as a function of mixing rate for the new mixer. X: solution did not reach spout.

the program assumes that the dimensions of the mixer are ideal (for example, it assumes that the length of the spout rod is equal to the diameter of the tank in order to maximize torque) and neglects to account for some significant sources of head loss: the seal between the suction rod and the rotation rod and the larger dimensions of the clear PVC pipe. For these reasons, our modifications and, we anticipate, future improvements to the mixer may not be reflected in the MathCAD program as written.

Part IV

Bicycle Mixer

One of the models we conceived for an improved water mixing pump implements the designs found in a bicycle. Since an important component of AguaClara's design philosophy is that plants must operate without the use of electricity, mechanical energy transferred by pedaling is an excellent and efficient source of energy; legs provide more power and are easier for operation than hands. Power (kW) can be calculated via the formula

$$P = \tau * rpm * (2\pi radians)/(60sec * 1000W) \tag{1}$$

where rpm is the mixing rate in the tank in revolutions per minute and τ is torque in Newton-meters.

Our first design used the rotation created by the pedaling to operate a system of sprockets, similar to a pulley system. Attached to the axis of the submerged sprocket would be impellers to provide both horizontal and vertical mixing, and rotation of the axis of the sprocket about the vertical axis would serve to further maximize the variety of mixing.

Under this design, the bicycle mixer would need to be built on a platform above the surface of the tank. This platform would need to be large enough and sturdy enough to ensure operator safety and ease of access. In addition, the shape of the tank opening would need to be taken into account; a bottle-like opening as opposed to an wide-mouthed opening spanning the diameter of the tank would require that the impeller part of the mixer remain in the tank. This would make installation and maintenance difficult and limit the materials used to construct the mixer to plastic or a nonreactive metal such as aluminum. Finding a bicycle chain made of these materials would also be a challenge. In light of the complications associated with this design, we developed another version of the bicycle mixer shown in Figure 6. The mixer would be located at ground level and make use of a pulley system attached to the wall of the plant building. Our design was influenced by the models for the Bicycle Rope Water Pump developed by the Guatemalan-based organization Maya Pedal, which builds a variety of "bicimáquinas", or pedal-powered machines, one of which is shown in Figure 7 below.

Materials needed for this design include either a rope or cog/timing belt, 6 wheels (8cm in diameter) made of a nonreactive material, axial impellers, PVC

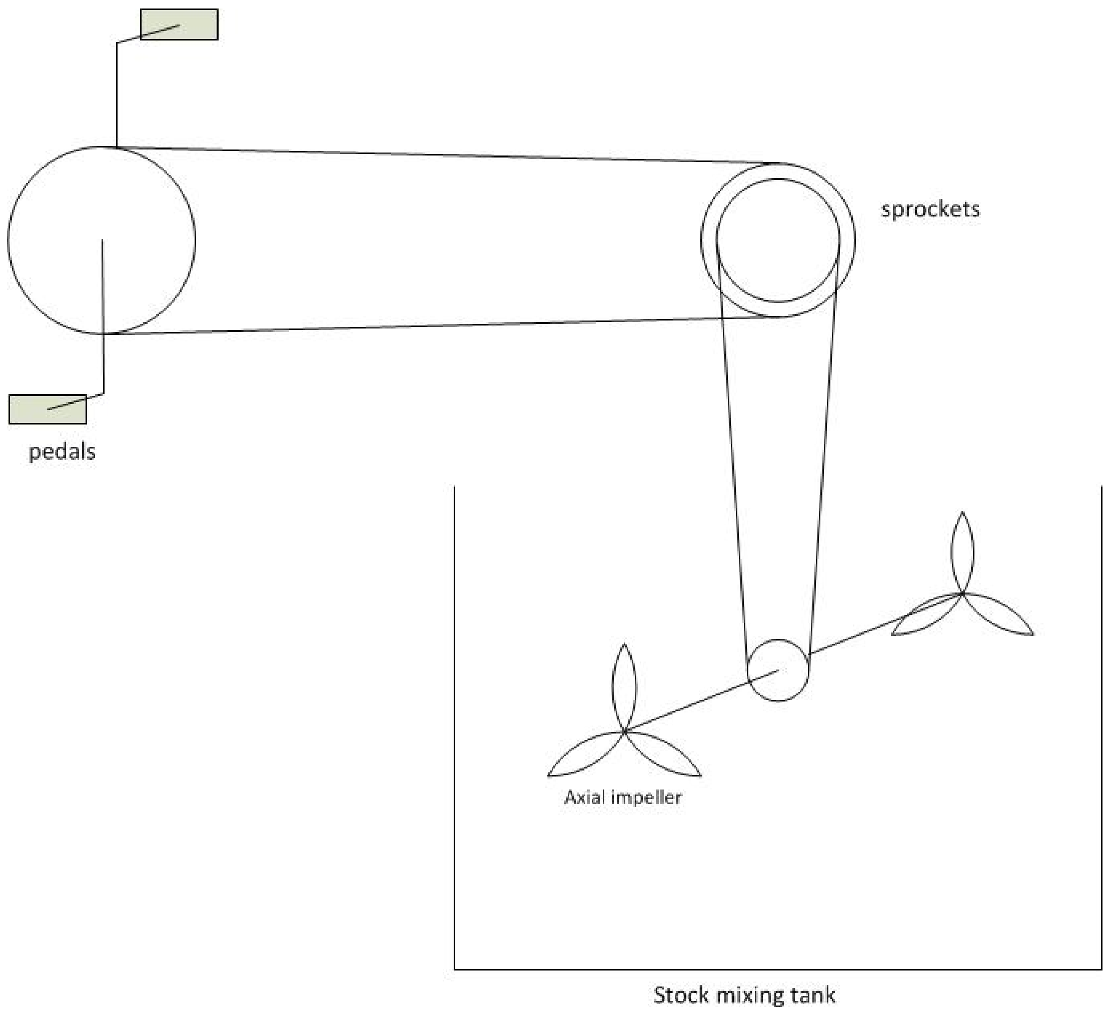


Figure 5: Preliminary design for a bicycle impeller mixer (as viewed from above).

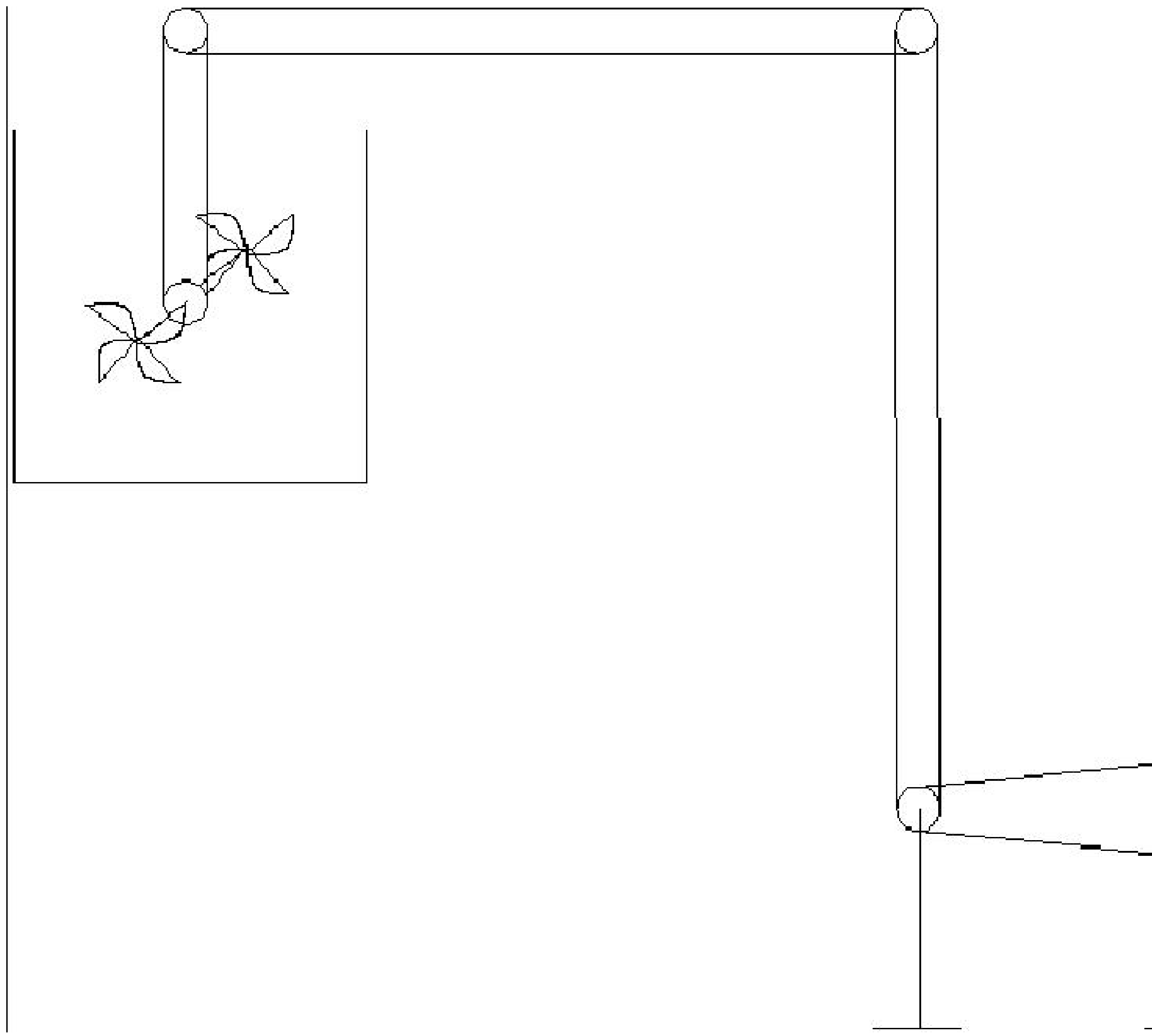
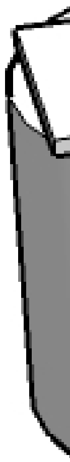


Figure 6: Improved bicycle impeller mixer design (side view).



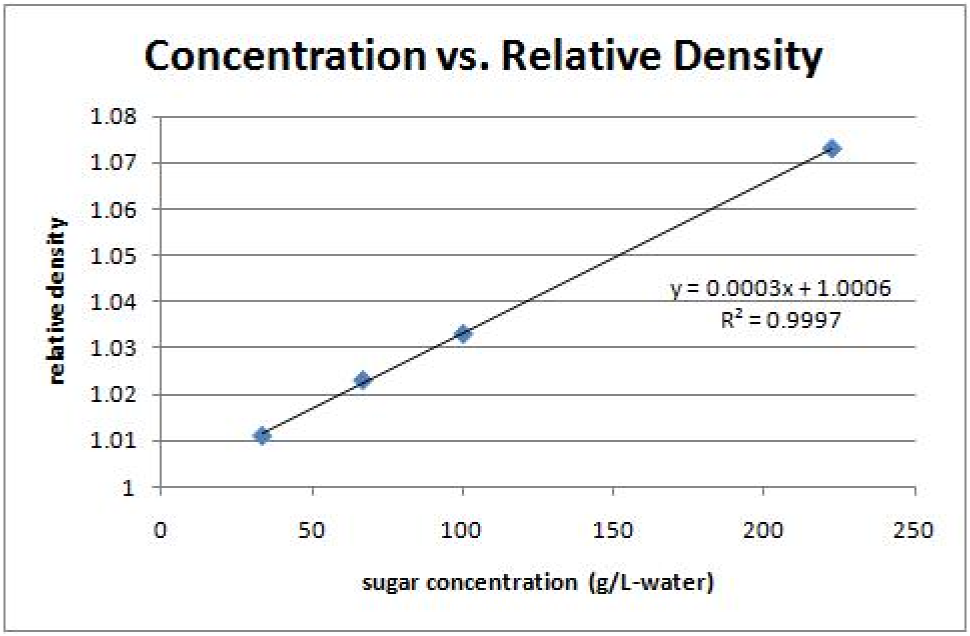


Figure 8: Standard curve of hydrometer.

pipe (or steel for use in the real plant) to construct the pulley system and for bike supports, and large right-angled steel supports for mounting the pulleys on the wall. The dimensions of the tank will be needed to calculate the size of impellers. Modification of this design will most likely be necessary and many design details will need to be decided upon prior to testing, as drilling into the wall of the lab in order to attach the pulley system is not feasible.

Part V

Hydrometer

To address the goal of creating stirring guidelines for AguaClara plant operators in Honduras, we developed a concentration profile using a hydrometer to measure the specific gravity of a sugar solution, as shown in Figure 8 below:

The high coefficient of determination indicates the reliability of our data. In addition, we used the hydrometer to measure the relative density of the mixed solution directly after each trial for the interface experiments (see Figure 9). We found the measured relative density of the solution after mixing to be 1.012, very close to theoretical value of 1.0114 calculated from standard curve (assuming that the solution was fully mixed after we stopped timing). This indicates that the hydrometer can be used to tell the mixing condition of water and sugar.

Figure 9: Obtaining measurements with the hydrometer.

Part VI

Future Work

1. Further improve the centrifugal pump mixing system by adding baffles or impellers to improve mixing efficiency. Determine if the system can be scaled up for the 55 gallon drum.

2. Modify the existing MathCAD file or develop a new file to more accurately reflect impacts of head loss on the energy input required to achieve complete mixing of the system.

3. Develop specific guidelines for stock tank mixing operators using the sugar concentration profile. These guidelines may specify a required mixing time or a final solution concentration to be achieved.

4. Research the possibility of constructing a less expensive, more durable hydrometer. This homemade hydrometer should be properly calibrated and marked with the desired final concentration of the mixed solution. Ideally, it should be easier to read than the hydrometer supplied by the AguaClara lab that we used in our experiments, on which the difference in specific gravity between fully separated and fully mixed solutions is represented by a distance of only about 3 mm. An instrument with larger demarcations would yield more accurate results with less effort on behalf of the operator.

5. Further develop the bicycle impeller mixer.

References

[1] "Bicycle Machines." MayaPedal Guatemala. 2010. <http://www.mayapedal.org/machines.html>.