Stock Tank Mixing

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Abstract

Stock tanks holding homogeneous liquid solutions of coagulant and chlorine are key components of AguaClara water treatment plants. The plant operators provide the mixing required to produce those homogeneous solutions by stirring with a piece of pipe or by rotating a crude mixing element inside the tank. The stock tank mixing team is working to develop high efficiency human powered chemical mixers and measurement methods that allow the operator to know when the solution is fully mixed. In the future we anticipate that higher concentration stock solutions will be used to facilitate use of the linear chemical dose controller for larger flow facilities. Achieving homogenous solutions at higher concentrations will require more mixing and it is important that the operators have methods to ensure that mixing is complete.

students	3
skills	fabrication, experimentation, fluids

Introduction

Stock tanks hold concentrated liquid coagulant or chlorine. The liquid chemical stocks are prepared on site from granular chemicals. The chemicals must be in liquid form so that the AguaClara chemical dosing system can be used to meter the chemicals into the water at a controlled dose. The granular chemicals must be fully dissolved and then mixed to form a homogeneous solution in the stock tanks. In conventional mechanized water treatment plants this mixing process is accomplished with an electric motor connected to an impeller on a long shaft inside the chemical tank. In AguaClara plants the mixing is done manually by stirring the tank contents with a piece of pipe or by rotating a simple mixing unit assembled from pipes. In either case the operator mixes for some time and then assumes that the solution is homogeneous. The operator doesn't have any way of testing the solution to confirm that it is homogeneous.

The mixing process requires two steps. In the first step the granular material dissolves. For alum it takes significant mixing for all of the granules to dissolve. Powdered PACl (Poly aluminum chloride) dissolves more quickly than alum. Calcium hypochlorite may dissolve relatively quickly, but it leaves behind a precipitate of calcium carbonate. In all cases the chemical solution is more dense than water and if no mixing is provided the dense solution will form a density stratified solution in the stock tank with a high concentration at the bottom of the tank and a low concentration near the top. The challenges are to develop an efficient method to mix the chemicals in the stock tanks to produce a homogeneous solution of the desired concentration and to develop a method for the operator to know when a homogeneous solution has been created.

If a low mixing intensity is used (as may easily occur with manual mixing), then it is possible for packets of dense fluid to be lifted high in the stock tank. Because the mixing intensity is low these packets of dense fluid are relatively large and molecular diffusion is ineffective at blending the high and low concentration liquids. After mixing stops the high density packet of fluid can settle back down to the bottom of the tank. If a higher mixing intensity or energy dissipation rate is used, then the turbulent eddies are smaller and the packets of fluid are broken into tinier pieces that molecular diffusion can then completely blend to form a homogeneous solution. Once a homogeneous solution is created it is no longer possible for gravity to "unmix" the solution.

The mixing process may seem trivial for small stock tank volumes. However as AguaClara plants are built to serve larger cities it is imperative that we understand how much mixing is required and that we design efficient mixing systems. An AguaClara philosophy is that the operator should receive feedback for each step of the treatment process. Thus the operator needs to know when mixing is complete. The alternative is to specify a certain amount of mixing that would be different for each chemical, concentration, tank volume, and mixer design. The operator could confirm that mixing is complete by comparing the density of the fluid in the top of the stock tank with the expected value (based on the chemical concentration).

The mixing process can be idealized as beginning with two distinct concentrations with their respective densities. The theoretical minimum amount of energy required to mix two fluids with different densities can be calculated based on the difference between the potential energy of the two fluids and the potential energy of the mixed solution. Unfortunately the mixing process is highly inefficient and most of the mixing energy is dissipated as heat without effectively blending the two solutions. Thus it isn't possible to use the potential energy difference as a guide for how much mixing energy or shaft energy is required to create a homogeneous solution.

1 Density and Concentration

Density and concentration information is required to understand the nature of the mixing problem and to develop strategies to conduct laboratory experiments using substitute chemicals that will have similar mixing problems. Given that a significant goal of mixing is to blend two solutions of different densities it will be possible to use a glucose solution with red dye as a surrogate for the chemicals used in AguaClara facilities.

Figure 1: Coagulant stock tanks (blue drums in middle of the photo on the left) provide more than 24 hours supply of liquid coagulant. The chlorine tanks (photo on the right) contain a concentrated bleach solution made from calcium hypochlorite. The pipe mixing device used to stir the chlorine solution is visible on the right.

The density of many solutions can be modeled as

$$\rho_{Solution} = \rho_{H_2O} + m_{Solute} C_{Solute} \tag{1}$$

where the dimensions of density, ρ, and concentration, C_{Solute}, are the same and the coefficient m_{Solute} is different for each solute.

The maximum alum concentration is set by a dramatic increase in viscosity above 550 $\frac{kg}{m^3}$ [1].

Commercial PACl is often shipped in liquid form in the United States and has a concentration of 69.3 $\frac{kg}{m^3}$ as aluminum and a liquid density of 1240 $\frac{kg}{m^3}$. It appears that the maximum stock concentration for PACl and alum have very similar aluminum concentrations. PACl is also available as a dried powder and it is this dried powder that is used at AguaClara plants in Honduras. The powder form of PACl should be used to create a 5 to 10% solution according to Asia Chemical Engineering Co. More dilute solutions may begin hydrolysis and slowly lose their effectiveness. Dilute solutions should be used within 24 hours. The powdered PACl is 30% Al_2O_3 equivalent or 16% Al (*). An estimate of $m_{PACl_{powder}}$ can be obtained from published density and concentration information for liquid PACl*.

Calcium hypochlorite is unstable at high liquid concentrations. Further literature review is required to determine the maximum acceptable stock tank concentration of calcium hypochlorite.

The maximum flow for a linear dose controller with a single dosing tube is approximately 2 $\frac{mL}{s}$. The flow ratio for the chemical feeds suggests that a 20 $\frac{L}{s}$ plant would only need a single dosing tube for PACl and that a plant flow of 50 $\frac{L}{s}$ would only need a single dosing tube for calcium hypochlorite.

The minimum stock tank volume that AguaClara facilities have used is a 220 L plastic drum. At the maximum flow rate of 2 $\frac{mL}{s}$ the 220 L would last about

Table 1: Properties of chemicals used in water treatment and surrogates for testing mixing requirements

Solute	Formula	Molecular Weight $\frac{g}{mol}$	Solubility $\frac{kg}{m^3}$	m_{Solute}	Maximum recommended stock concentration $\frac{kg}{m^3}$	ρ_{Stock}	Max dose $\frac{mg}{L}$	Flow ratio $\left(\frac{Q_{Plant}}{Q_{Chem}}\right)$
Alum	$Al_2\left(SO_4\right)_3 \cdot 14.3H_2O$	600	800	0.0125	500 $\frac{kg}{m^3}$ as alum	1225	80 $\frac{mg}{L}$ as alum	6250
PACl (liquid)					69.3 $\frac{kg}{m^3}$ as aluminum (commercial standard)		7 $\frac{mg}{L}$ as Al?	10000
PACl (powder) (16% Al)					436 $\frac{kg}{m^3}$ as powder (69.3 $\frac{kg}{m^3}$ as aluminum)		4.4 $\frac{mg}{L}$ as powder?	10000
Calcium Hypochlorite	$Ca\left(ClO\right)_2$	142.98	210 (*)		80$\frac{kg}{m^3}$ (based on 5% estimate as equivalent Cl_2)		3 $\frac{mg}{L}$ as $Ca\left(ClO\right)_2$	25000
Glucose	$C_6H_{12}O_6$	180.16	910	0.378				
Salt	$NaCl$	58.44	359	0.698				

24 hr. This suggests that the 220 L drums will be adequate for the coagulant for plants up to 20 $\frac{L}{s}$. Smaller flow rate plants would simple use more dilute stocks. Thus the volumes and corresponding chemical concentrations and densities can easily be computed for the coagulants.

2 Evaluate mixer designs

Evaluate the three mixer designs based on required energy input to move fluid from the bottom of the tank to the top of the tank, the resulting energy dissipation rate, and the total flow that is generated. Use sugar water to create a dense solution and add red dye #40 to make it visible. Use a transparent tank to make it easy to see the depth of the more dense sugar water and to see the effect of the mixing unit on the two fluids. A hydrometer that can measure up to 1220 $\frac{kg}{m^3}$ is available to determine if mixing is complete.

2.1 Centrifugal Pump

Build a completely transparent model of the centrifugal pump and stock tank. See Figure 2 for an example. A transparent container is available for your use. A new design for the pumping system is needed. An analysis of the pumping system is available in a Mathcad worksheet on the stock tank mixing wiki page. Design a better system to hold the bottom of the pump centered in the tank and to allow the high density solution to enter the vertical pipe. Devise a pumping system that can easily be installed in a 55 gallon drum. The pumping system must be stable and held in place both at the bottom of the tank and near the top of the tank. Verify using the experimental model that the analysis in the analytical model is correct. If the analytical model is incorrect, determine the source of the error and correct it. Use the analytical model to determine the best pipe sizes for the centrifugal pump and calculate the time required to mix the contents of a 55 gallon drum.

2.2 Axial Flow Impeller

Axial flow impellers (think airplane propeller or window fans) cause flow primarily along the axis of rotation of the impeller. There is plenty of literature on impeller mixers. See the literature reviewfrom spring 2011. The impeller will need to provide sufficient velocity to the fluid to cause high density fluid to flow into the low density fluid or vice versa. Impellers may be needed at multiple elevations to provide enough mixing energy to blend the two fluids.

2.3 Radial Flow Impeller

Radial flow impellers cause flow in the radial direction. The goal could be to cause flow towards the outside of the bottom of the tank and then up along the inside of the tank walls. It isn't clear yet whether radial flow or axial flow impellers will create the highest vertical velocities.

Figure 2: The centrifugal pump is able to lift the dense red sugar solution and discharge it near the surface of the tank. A movie of this is posted online.

3 Baffles to minimize solid body rotation of fluid

The three design options all require rotation of a mixer and that rotation will tend to set up solid body rotation of the fluid in the tank. This fluid rotation will reduce the effectiveness of the mixing because it will reduce the velocity of the impeller relative to the fluid. The solid body rotation of the fluid can be reduced by adding vertical baffles attached to the tank walls.

Experimental methods

Use a hydrometer to measure density and use visual observation and a rule to measure height of the red dye solution in the vertical shaft of the centrifugal pump and in the transparent stock tank. Use the rate at which the interface drops initially to measure the flow rate from the centrifugal pump. Determine whether the hydrometer is well suited for the plant operators to use in Honduras. Evaluate whether it would be better to fabricate our own hydrometers or to purchase them.

References

[1] GUREVICH R. A., BALMAEV B. G., LAINER Yu. A., and YAMPUROV M. L.: A study of density and viscosity of aluminum sulfate solution. 2003