ANC Control Spring 2010 Research

Created by Chengfeng Wu, last modified by Lorna Ximena Aristizabal Clavijo on May 28, 2010

ANC CONTROL

Spring 2010 Research

INTRODUCTION

The Spring 2010 ANC team is continuing research with lime feeders where the Fall 2009 team left off. The original idea was to create lamellar sedimentation by placing a slanted tube on top of a vertical one and running water upwards through the reactor. With appropriate fluid velocities, one can maintain a fluidized bed of lime particles in the lower segment but prevent the vast majority of solid lime particles from leaving with the effluent (see 2009 design). This semester the team modified the reactor design in order to improve its performance and provide an easy way to feed lime while the reactor is running (see new lime feeder design).

Following the set-up described in each experiment found below with both the new apparatus and the old one, the team is conducting a series of experiments in order to determine which mechanisms are important in producing effluent saturated with lime for long periods of time. The tests are based on hypotheses which the team has developed over the course of the semester. Following the recommendation of previous ANC teams, the Spring 2010 team has tried to isolate variables and test them separately. In all of the experiments, the team has tried to vary only one parameter at a time so that comparisons between tests are more meaningful.

Nine comparison experiments have been carried out. The results and analysis are shown on each of their respective pages.

Experiment 1: Minimum amount of lime input in two reactors

Experiment 2: Testing Carbonates Hypothesis

Experiment 3: Repeated lime input to overload large reactor

Experiment 4: Overloading the reactors with lower flow rate

Experiment 5: Overloading the reactors with different up-flow velocities in each one

Experiment 6: Blending the lime slurry

Experiment 7: Pulsing in a stock solution of lime

Experiment 8: Formalizing blender methods + continued pulsing

Experiment 9: Increased lime concentration + continued pulsing

From the experimental observation and results analysis, the Spring 2010 team proposed several suggestions on how to improve the design in the future, discussed the feasibility of implementing the design in Aguaclara plant and provided the next team with future challenges.

No labels

Experiment 1 Minimum amount of lime input in two reactors

Created by Lorna Ximena Aristizabal Clavijo, last modified by Chengfeng Wu on May 17, 2010

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Experiment 1: Minimum amount of lime input in two reactors

Introduction

In the first experiment of Spring 2010 team, the goal was to evaluate the lime feeder's performance with respect to its effluent pH with a minimum lime input based on theoretical calculations. This is the mass of lime which would dissolve in 12 hours given the flow rate and the calcium hydroxide solubility constant (equation 1.1). In equation 1.2, the theoretical lime requirement is based on what could dissolve in twelve hours, and didn't take into account other factors which limit how much of the available lime will actually dissolve.

Procedure

The team basically used the same procedure described in the materials and methods section, although the lime is now fed through a vertical tube.

To make the experiment comparable to that carried out by the Fall 2009 team (Experiment 3, Trial 4), the Spring 2010 team used the same flow rate, which was 40mL/min in both reactors, and a lime mass of 8gm based on the solubility calculations (figure 1.1). One important change was that the lime in this experiment was fed dry, not mixed with water as a slurry. This may affect the particle size distribution, which is discussed in the hypotheses section. The following was used to determine the amount of mass necessary for a 12-hour run with a given flow rate. K_{sp} is the lime solubility constant, MW is the molecular weight of lime, Q is the volumetric flow rate, and $[OH^-]$ in the second equation is the concentration of hydroxide in a saturated lime solution (pH ~12.6).

Equation 1.1:

$$[Ca^{+2}] \times [OH^-]^2 = K_{sp}$$

Equation 1.2:

$$Lime(Q) = \left(\frac{K_{sp}}{[OH^-]^2}\right)(MW)(Q)(12hr)$$

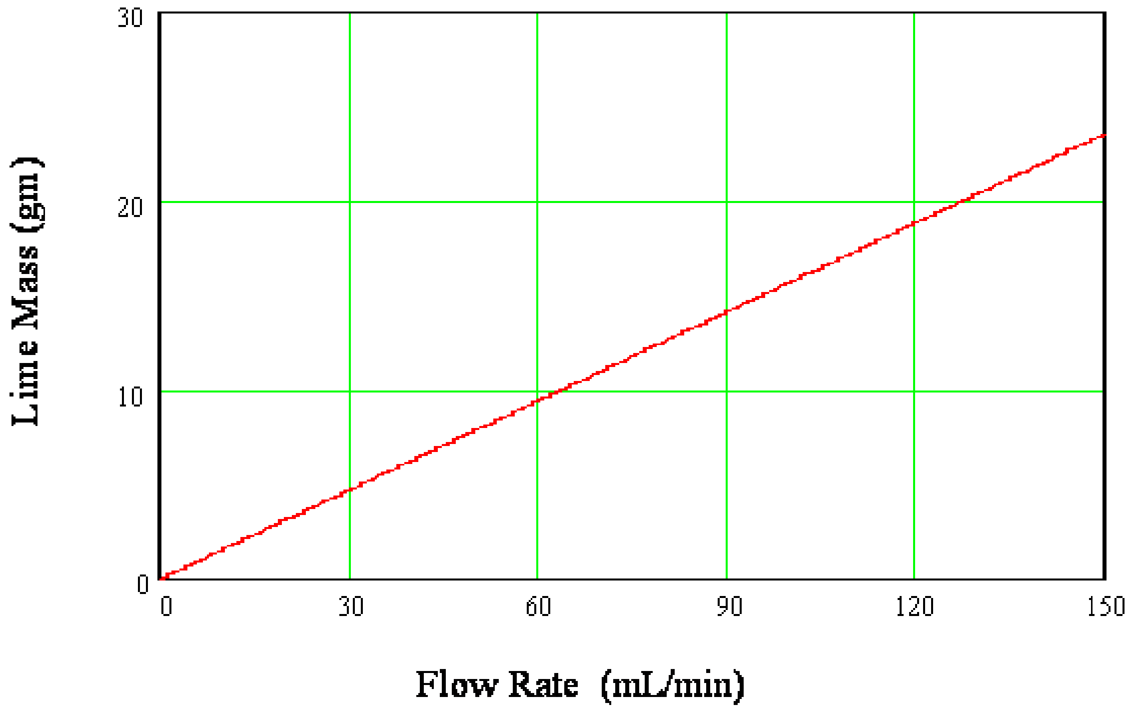

Figure 1. Theoretical lime required as a function of flow rate

Results and Discussion

From the experimental data shown in figure 1.2 we can see that the small reactor (A1) failed to reach saturation and the large reactor (A2) produced saturated effluent only very briefly. In contrast to the experiments run in Fall 2009, the lime in this experiment was added as dry powder instead of mixed with water in the form of a slurry. This likely has an effect on particle size, as the large particles are never broken up if the lime is never stirred with water. A discussion of particle size can be found in the hypotheses section. The results of this run also suggest that the new large reactor performs better than the small one. For this particle size and this amount of lime, the team observed that the flow rate of 40mL/min is too low to get the best suspension; the large reactor, in particular, could have handled a much higher flow rate. However, we believe that the poor results were a result of not having enough lime at small enough particle size to provide the contact time necessary to produce saturated effluent.

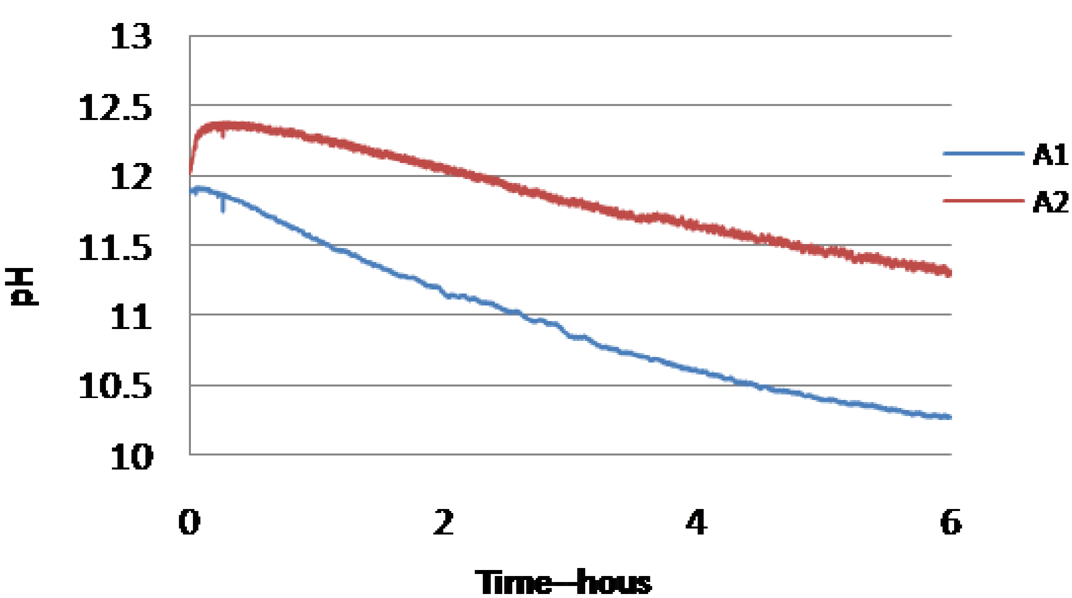

Figure 2. Experiment result of 1 trial

No labels

Experiment 2 Testing Carbonates Hypothesis

Created by Lorna Ximena Aristizabal Clavijo, last modified by Katherine Anne Weible on May 12, 2010

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EXPERIMENT 2: Testing Carbonates Hypothesis

Introduction

In order to test the calcium carbonate hypothesis developed by the Fall 2009 team, the Spring 2010 team ran a second experiment to compare the performance of the reactors using distilled water versus tap water. There should be no carbonates present in the distilled water, so if the formation of calcium carbonate precipitate inhibiting dissolution is what is limiting the reactor's performance, the use of distilled water should produce better results. The two runs in this experiment were identical except for the water type so that that variable could be isolated.

Procedure

The team used the same procedure described on materials and methods. The lime was added as dry powder. For the up-flow velocity of 3.6 mm/sec, it was calculated that 20g of lime were required for the effluent to be saturated for 12 hours. The amount of lime was calculated as explained in Experiment 1., proportions were kept.

Results

Figure 1. shows effluent pH over time. The green line represents the 2.5cm diameter tube settler, and the 5cm diameter tube settler is represented by yellow and orange lines. We can see that none of the runs were anywhere close to reaching the goal of twelve hours with a saturated effluent. Both tap water and distilled water runs with the 5cm diameter tube settler failed within an hour and a half, while the run with the 2.5 cm diameter tube settler never produced any saturated effluent. There is certainly no performance improvement running the reactor with distilled water.

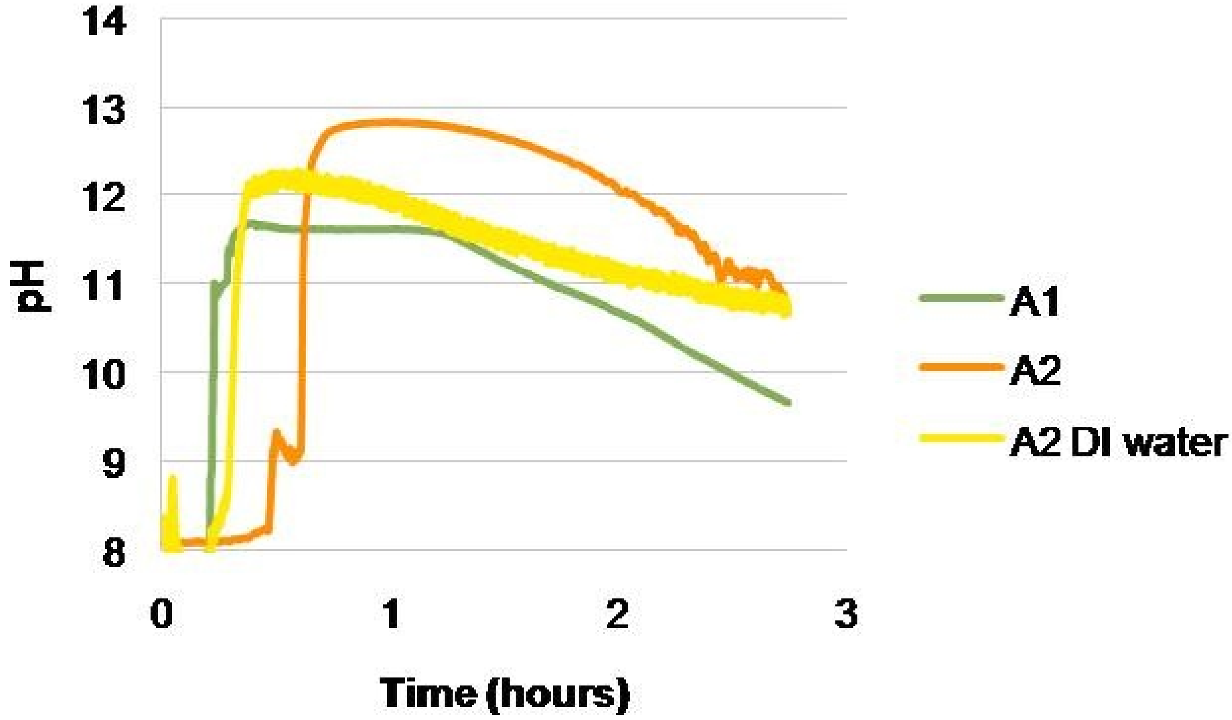

Figure 1. Effluent pH vs time in hours. Comparison of performance between tap water and distilled water.

Figure 2. shows the fraction of saturated hydroxide concentration versus the fraction of time the run is theoretically calculated to last. This is simply a clearer way to display the reactor's performance over the course of the experiment relative to our goal, which would be to have a straight line at an OH fraction of one. In this case, Figure 2. illustrates what are likely measurement errors: a hydroxide concentration nearly double the saturation value in one run and a failure to reach saturation in what should be an identical trial.

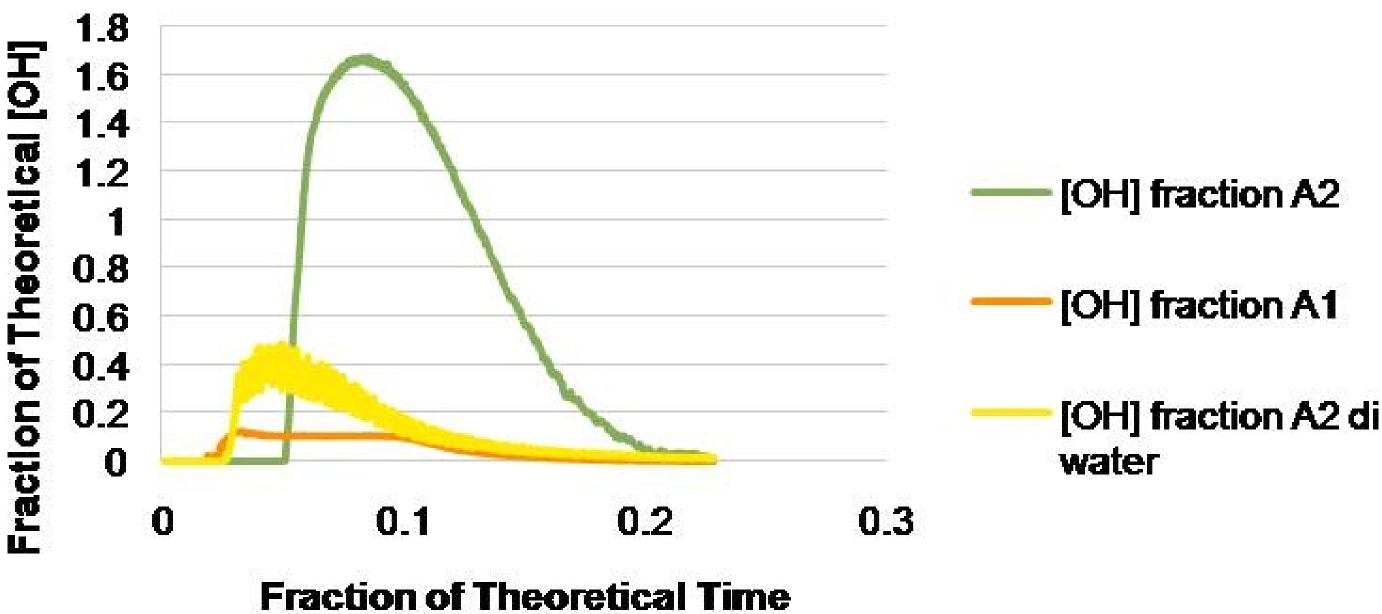

Figure 2. Fraction of saturated hydroxide vs Fraction of time

Discussion

The similarity in performance between the 5 cm diameter tube settler run with tap water and the same apparatus run with distilled water indicates that calcium carbonate precipitate may not be the main issue. Failure with distilled water suggests that there must be another issue. See the hypotheses page for further information.
Even with the results, one experiment is not enough to reject the carbonates hypothesis. Other factors could affect such as coating of the pH probe with lime particles. Further experiments are required to compare results.

No labels

Experiment 3 Repeated Lime Input to Overload Reactor

Created by Andrew B Hart, last modified by Chengfeng Wu on May 16, 2010

Experiment 3: Repeated Lime Input to Overload Large Reactor

Overview

After the failure of the second experiment in which distilled water was used, the team decided that calcium carbonates were probably not the source of the problem. It was thought instead that reaction kinetics were the limiting factor and that lime/water contact area needed to increase. The idea for the third experiment was to dramatically increase the volume of the lime in the reactor in order to provide more solid lime surface area. With the same flow rate as was used in experiment two (120 ml/min), 200 grams were added instead of 20, a ten-fold increase. In an effort to determine what the failure mode would be if lime were continually added without cleaning the reactor in between, the team decided to add an additional 200 grams whenever the effluent pH dropped below saturation. Because it seemed to perform better than the original, particularly with large amounts of lime, only the large reactor was used in order to save water.

Procedure

The 200 grams lime were mixed with distilled water and stirred to form a slurry. This was fed through the vertical column. The flow rate was 120ml/min. All the other procedures were the same as described on materials and methods.

Results and Discussion

As can be seen from figure 1 below, the effluent pH remained at saturation for approximately six hours after lime was added each time. Because excess lime was not removed from the reactor before adding the next 200 grams, a total of 600 grams of lime had been added to the reactor by the beginning of the third segment seen in the graph. Despite the fact that the reactor was overloaded, it seemed to perform no better with the new addition of lime than it did with the first, when there was far less solid lime in suspension. This suggests that only the "new" lime is effective in saturating the effluent.

Possible failure modes could be:

1. Because the smallest particles dissolve fastest and are most prone to being carried out with the effluent due to their low settling velocities, they do not persist in the reactor even though it appears to be filled with solids. Since they have the highest surface area to volume ratio, the small particles are the ones that dissolve most effectively, whereas the larger particles, which may remain for a very long time, do not dissolve well enough to saturate the effluent within the residence time of the reactor. See hypotheses.
2. Preferential flow paths form over time in the densely-packed reactor, so that eventually clean water is allowed to pass through with very little contact time with solid lime.
3. Although the results from experiment 2 suggest otherwise, chemical/physical interference by calcium carbonate precipitate may still be part of the problem. See hypotheses.

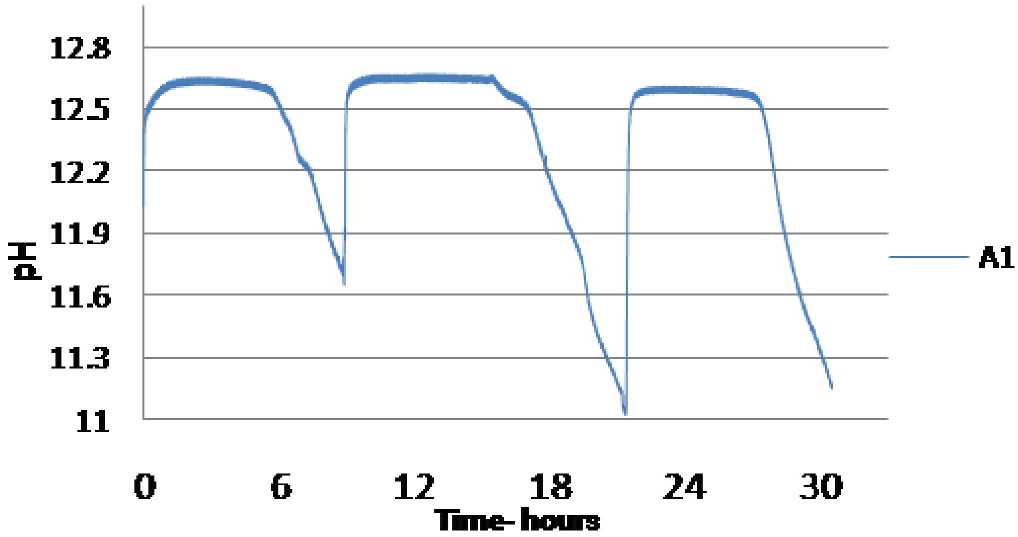

Fig 1. Experiment 3

This experiment used only the large reactor to test overloading the apparatus with lime, adding 200 grams of lime initially and whenever the pH dropped.

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Experiment 4 Overloading the reactors with lower flow rate

Created by Katherine Anne Weible, last modified on May 13, 2010

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Experiment 4: Overloading the reactors with lower flow rate

Overview

According to the results of the third experiment the team discussed that the best way to achieve the saturation pH value in a longer period of time was by reducing the flow rate. Flow rate reduction will imply a reduction in the up flow velocity and will allow a longer retention time in the reactor. To probe this hypothesis, the team continued with the idea of increasing the volume of the lime in the reactor in order to provide more solid lime surface area, repeating the conditions of the third experiment but reducing the amount of lime to 100g and changing the up-flow velocity to 0.9 mm/sec.

Procedure

100 grams of lime was mixed with tap water and stirred to form a slurry. This was fed through the vertical column. The up-flow velocity was 0.9 mm/sec in both apparatuses. All the other procedures were the same as described on materials and methods.

Results and Discussion

This was the first experiment in which pressure and temperature gauges were implemented. Those devices control the influent water, avoiding floods and providing a continuous source of tap water.

The experiment ran for almost 80 hours; results are divided in two plots to facilitate their reading. As can be seen in the first figure, the effluent pH remained above 12 units for a short period of time in comparison with the total time. The 2.5 cm tube settler lasted for 12.5 hours and the 5 cm tube settler for 18 hours. It is longer than the results observed in experiment 3. However, it is important to remark that readings above 12.6 were observed; that is not chemically possible due to the saturation pH of lime. Those readings were associated with problems in the pH probes that the team wanted to fix for future experiments. The great drop in pH is due to a trial to calibrate the pH probe; that reading corresponds to buffer solutions.

The second half of the experiment corresponds to a new addition of 100 grams of lime after 45 hours. Low readings are due to pH probe calibration. It can be observed that the increase in pH was dramatic and that both reactors remained above 12 for 19 hours (2.5cm tube settler) and 27.5 hours (5cm tube settler). Despite these promising results, the high fluctuation and the readings above 12.6 make them inaccurate and nullify the data. It is necessary to repeat the experiment when there is more certainty regarding the pH probe readings.

In order to ensure accurate pH readings, the pH probes were grounded to reduce the potential for high voltage fluctuations that damage the data acquisition system. In addition, when non experiments are running, pH probes are placed in a 4 pH solution to avoid lime clogging into the pH probe membranes.

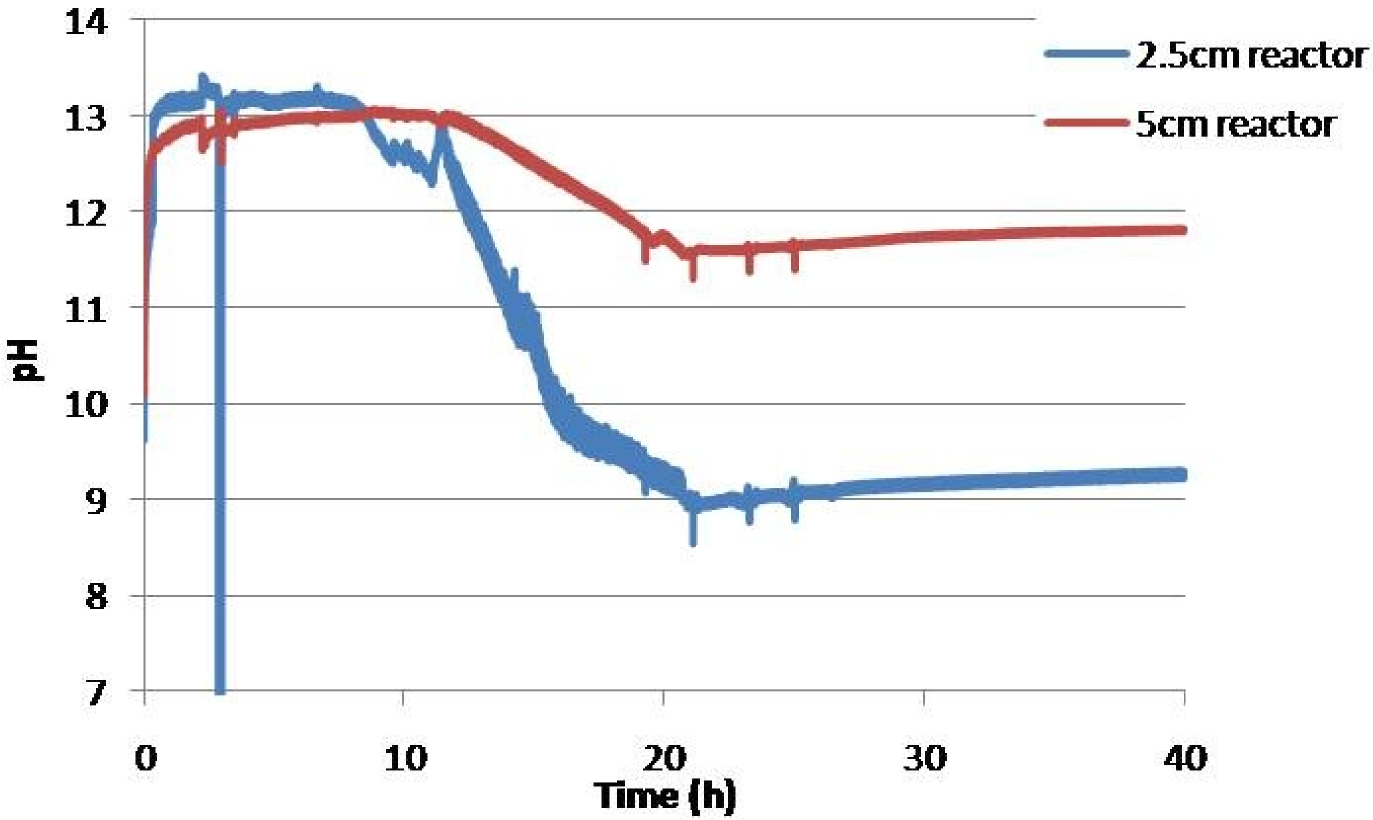

Figure 1A. Experiment 4 performance. First 40 hours. (pH vs time)

The purpose of this experiment was to decrease the upflow velocity in order to increase residence time. The mass of lime added was also decreased to 100 grams.

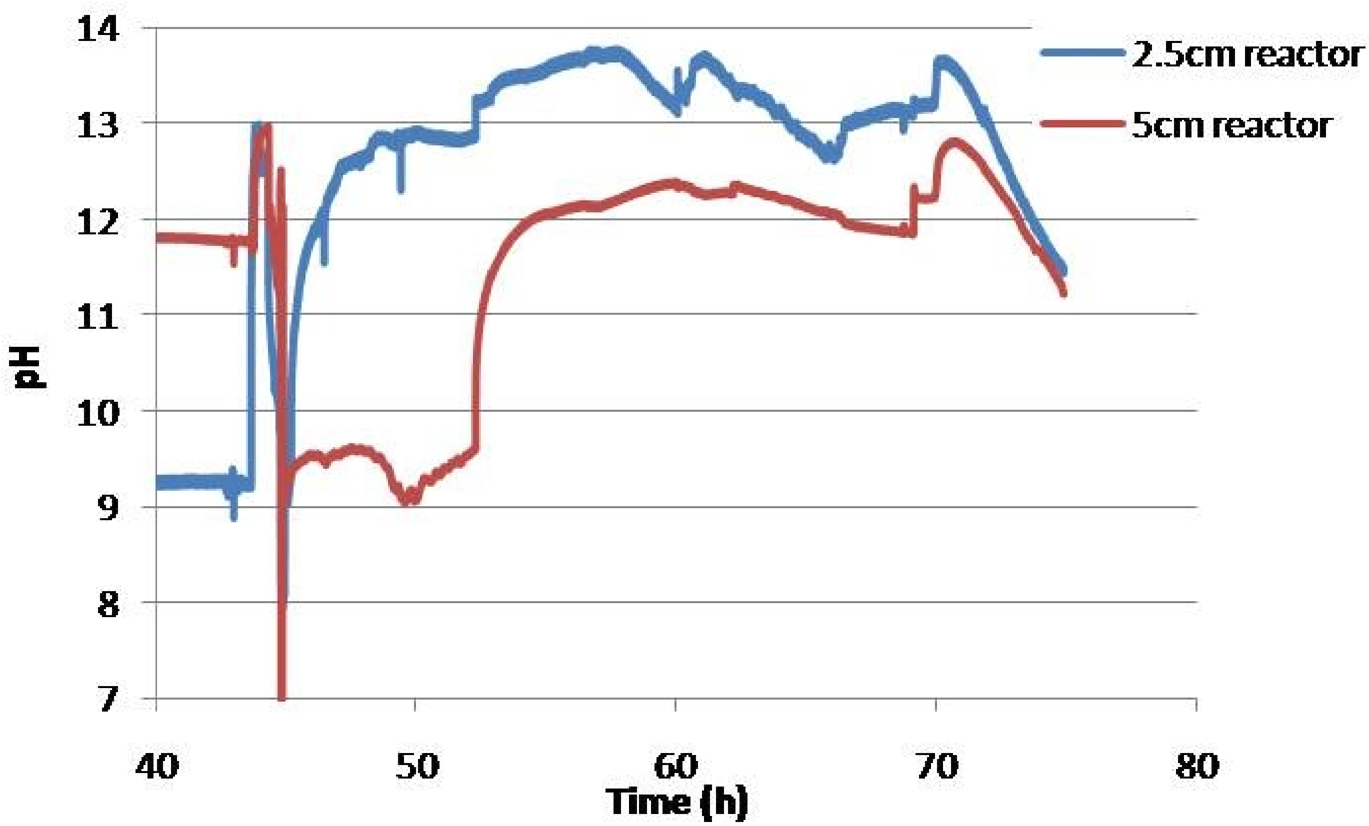

Figure 2A. Experiment 4 performance. Second 40 hours.

(pH vs time)

The purpose of this experiment was to decrease the upflow velocity in order to increase residence time. The mass of lime added was also decreased to 100 grams.

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Experiment 5 Overloading the reactors with different up-flow velocities in each one

Created by Katherine Anne Weible, last modified on May 13, 2010

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Spring 2010 Research

Experiment 5 Overloading the reactors with different up-flow velocities in each one

Overview

The results of the fourth experiment showed that decreasing the up-flow velocity was a good way to increase the efficiency of the reactors, but 0.9 mm/sec might be too low for the 5cm tube settler. In this experiment, all conditions of the fourth experiment remained the same; the only change is the up-flow velocity in the 5 cm tube settler that was increased to 1.8 mm/sec. It was observed that fewer lime particles were reaching the diagonal column in the 5cm tube settler in comparison to the 2.5cm tube settler. The team hypothesized that it was due to the concentration of lime in the middle section of the reactor and the larger apparatus needed a higher velocity to facilitate particles flowing in the slanting tube. The team wants to test if the efficiency of the 5cm tube settler will increase with a higher flow rate and if the clogging into the elbow can be prevented by implementing this measure.

Procedure

100 grams of lime were mixed with tap water and stirred to form a slurry. This was fed through the vertical column. The flow rate was 30ml/min for the 2.5 cm tube settler and 60mL/min for the 5cm tube settler. All the other procedures were the same as described on materials and methods.

Results and Discussion

As the figure shows, the 5 cm tube settler never reached a pH above 12 units. It is difficult to know the reason for this. A lot of lime remains inside the elbow and might cause clogging. It creates preferential paths to lime particles and reduces the available space inside the diagonal column. By increasing up-flow velocity in the 5cm tube settler, it is possible that the contact time of lime in the fluidized bed was reduced and the space between particles increases. If particles don't have enough time to dissolve, they will flow with the effluent without contributing to increase alkalinity.

The 2.5 cm tube settler had a better performance, as seen in Figure 1, staying above a pH of 12 for 14.6 hours and after approximately five more hours, it increased again to above 12 for 2 hours. The fluctuations in the graph near the 30 hour point are due to washing the pH probe and switching pH probes between both reactors to determine if there was a problem with the readings. Readings above 12.6 are observed again, thus it is strongly probable that there is a problem with the pH probes or with the data acquisition system. It is difficult to accurately measure pH when the solution is flowing.

After analyzing the results the team now considers that by increasing up-flow velocity the amount of lime in the reactor can decrease and the performance will get worse. Therefore, the team is now considering the effects of lime particle size. Because the slurry and mixing method is not exact and reproducible, it is possible that all the experiments have been done with different particle size distributions. Big particles remain trapped in the middle part of the elbow and it is difficult to clean the reactors after each experiment. For future experiments a blender or a coffee grinder will be required in order to ensure a homogeneous distribution of particles size. In addition, the team asked for new pH probes and signal conditioning boxes.

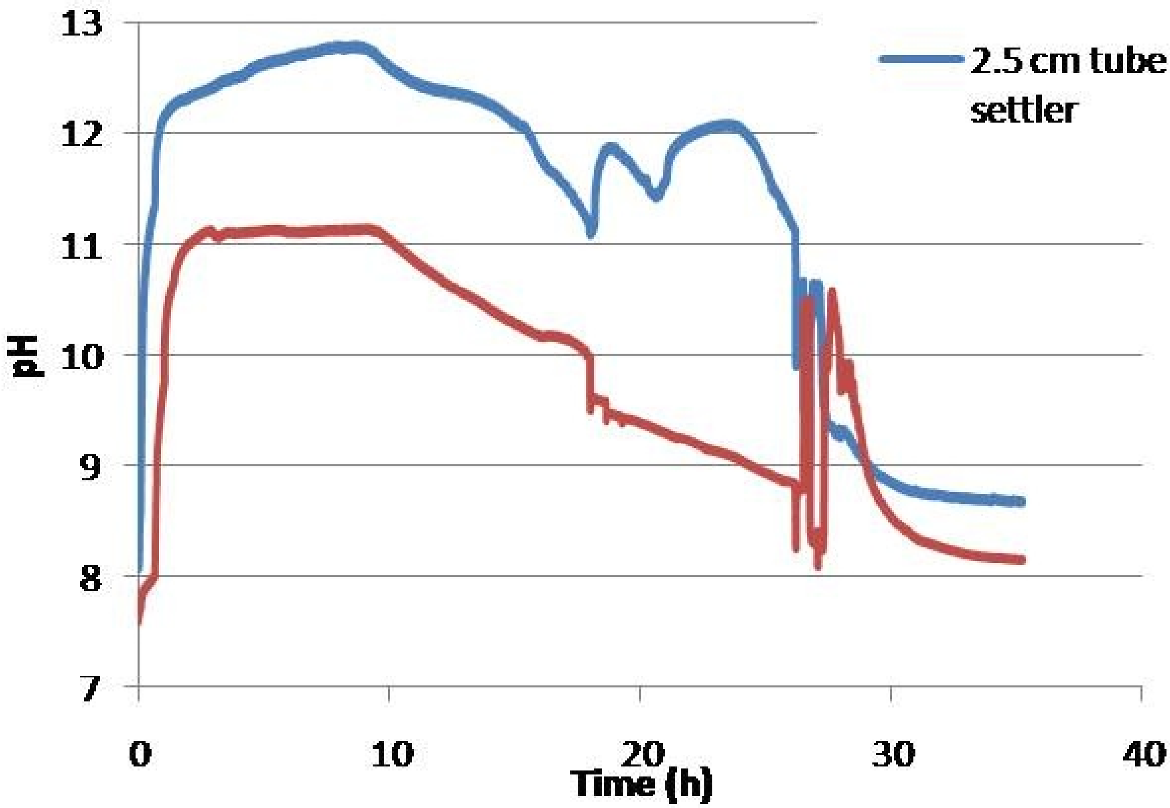

Figure 1 - Experiment 5

The purpose of this experiment was to keep the same conditions as Experiment 4 but to double the upflow velocity in the 5 cm tube settler apparatus.

Experiment 6 Blending the Lime Slurry

Created by Katherine Anne Weible, last modified on May 12, 2010

Experiment 6: Blending the Lime Slurry

Overview

The purpose of this experiment was to test the effect of blending the lime into a lime slurry before feeding it to the apparatus. It was suggested that by blending the lime, smaller lime particles could be achieved and possibly more surface area available for lime to dissolve and interact with the water. 100 grams of lime was chosen in order to easily compare it to previous experiments in which 100 grams was added, both as dry powder and as a lime slurry that was manually blended.

Procedure

Two 100 gram samples of lime slurry were prepared by blending them in the blender on the "liquefy" setting. Unfortunately, the lime slurries were not prepared in the same manner with the same amount of water - this is an issue that the team corrected in Experiment 8. The slurries were then fed into each apparatus via the vertical column. The water used was tap water and A1 had a flow rate of 30 mL/min and A2 had a flow rate of 40 mL/min. The overall method followed is outlined in the materials and methods page.

Results and Discussion

The experiment lasted approximately 12.5 hours for A2 and 16.5 hours for A1. Both failed and then leveled off. Neither apparatus reached the saturation point for lime (pH = 12.6), with A1 reaching 12.3 and A2 reaching 11.6 as the peak pHs. However, it is important to note that this experiment was conducted before new pH probes were purchased and implemented. Visually, it was noted that while the lime remained primarily in the vertical column of A2, it traveled up into the tube settler of A1 sometimes filling up to 80% of it. In A1, the solids particle time was increased while the capture velocity was decreased, allowing some of the particles to leave out the top in the effluent. For both apparatuses, it was discovered that a significant amount of lime was getting caught in the elbows---despite blending the slurry and keeping a low upflow velocity. From observing the experiment after failure, the team also noted that there may be preferential flow paths through the settled lime slurry in the tube settler and this may result in the relatively quick failure (despite having such a large amount of lime).
After this experiment, the team hypothesized that pulsing in a lime slurry could allow the experiments to reach the target ANC levels.

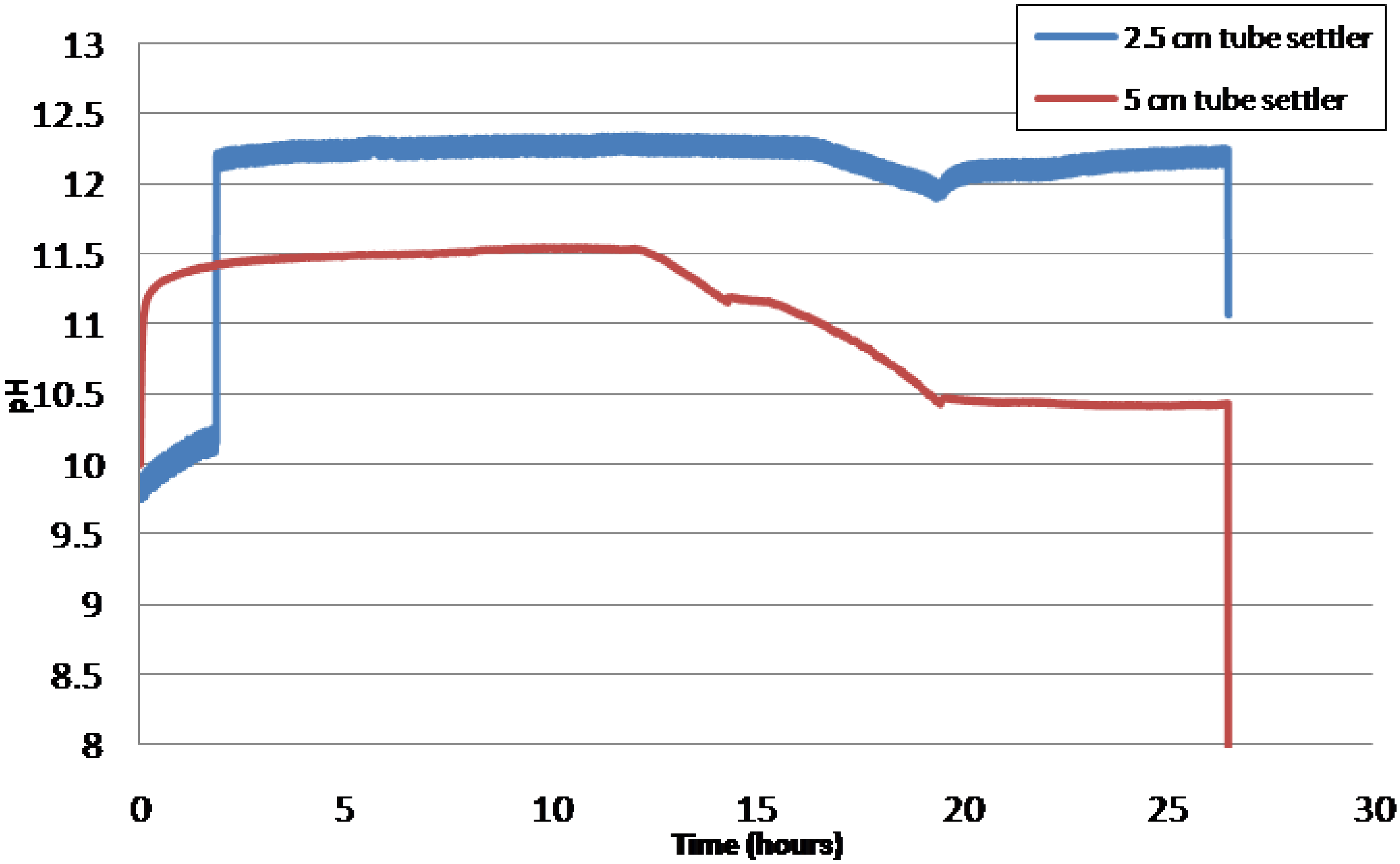

Figure 1 - Experiment 6

This experiment was conducted to test the effect of blending the lime slurry to observe how smaller particles act in the two apparatuses.

No labels

Experiment 7 Pulsing in a Stock Solution of Lime

Created by Katherine Anne Weible, last modified on May 13, 2010

Experiment 7: Pulsing in a Stock Solution of Lime

Overview

The purpose of this experiment was to test pulsing lime into the two apparatuses. Because both apparatuses fail after a shorter time than desired, it was hypothesized that the lime initially added to the apparatus (100 grams) eventually reached a point where it would no longer properly dissolve and raise the pH. Thus, more lime was needed as the experiment progressed. However, adding 100 grams each time would severely overwhelm the system. The following graph (Figure 1) was referenced to determine the appropriate amount of lime that needed to be pulsed in every 6 hours. The mass of lime was calculated in terms of various flow rates by determining the concentration of lime (g/m^3) and multiplying it by the flow rate (m^3/hr) and the time (6 hr).

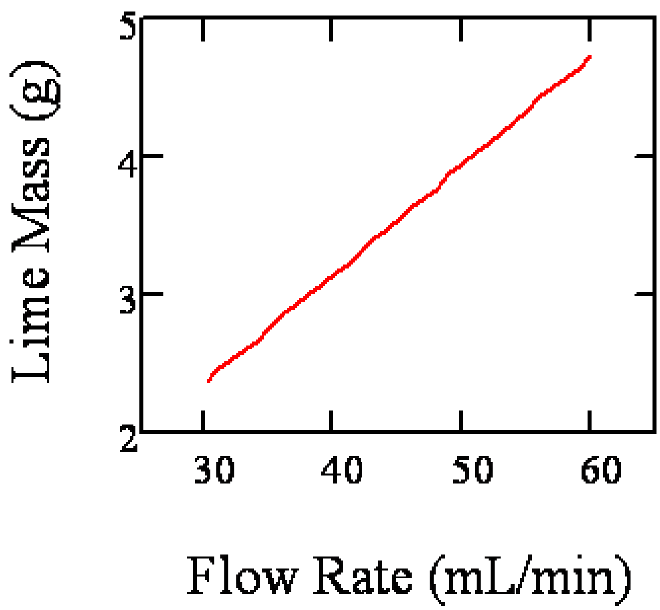

Figure 1

The above graph displays the mass of lime needed to saturate the system given a specific flow rate.

From this graph one can see that the amount of lime that must be added for a flow rate of 30 mL/min is approximately 2.365 grams and for a flow rate of 40 mL/min, 3.154 grams of lime must be added. In determining flow rates, the team learned from experience that when the larger apparatus had too slow of a flow rate the particle settled in the tube settler and this created preferential flow paths through the top half of the settler. Thus, a slightly higher flow rate was chosen for the 5 cm tube settler apparatus.

The group determined that it would be best to pump in the stock solution at the highest possible flow rate, which is 380 mL/min. The group determined that pumping in the lime solution at the highest rate possible for only one minute would not create too much of a disturbance in the overall flow rate of the apparatuses. Thus, 380 milliliters of stock solution are pumped in every six hours. One challenge to this set up is that there is only one pump and one concentration for the stock solution. However, each apparatus requires a different mass of lime to be pulsed in, according to Figure 1 above. To solve this problem, the higher concentration of stock solution was made according to the calculations for the 5 cm tube settler, which resulted in a concentration of 8.3 grams of lime per liter.

The team then installed two pump heads on the third peristaltic pump and used two different tubing sizes to regulate the flow to each apparatus. Referencing the information about peristaltic pumps it was determined that the 2.5 cm tube settler should have tubing size 17 while the 5 cm tube settler has tubing size 18. This allowed for each apparatus to receive the proper lime mass with each pulse while still running off the same pump.

Using a 5 gallon bucket, the team calculated the volume of the bucket and the lime mass needed (taken from Figure 1). By multiplying the concentration of lime needed by the volume of the bucket, it was calculated that 124.5 grams of lime, dissolved in 15 liters of water, can run for approximately 40 pulses, or 240 hours! The set up can be seen in Figure 2 below.

Figure 2

The laboratory set up of a bucket of stock solution connected to a third peristaltic pump that pulses in a specified concentration of lime slurry.

Procedure

For the apparatuses, the same procedure was followed as outlined in the materials and methods page. Two 100 gram samples of lime slurry were prepared by blending them in the blender on the "liquefy" setting. These were then fed into each apparatus via the vertical column. The water used was tap water and the 2.5 cm tube settler had a flow rate of 30 mL/min and the 5 cm tube settler had a flow rate of 40 mL/min.

A third peristaltic pump was added to the system to provide a pump from the stock solution of lime slurry to the tubing that flows to each apparatus. The tubing leaving the pumps connecting the raw water to the two apparatuses met the tubing leaving the third peristaltic pump with as little tubing in between as possible. This was done in order to minimize the amount of lime that might be able to settle out in the tubing. There was tubing attached to the stock concentration bucket (approximately 5 gallons) and then split to run through two separate pump heads on the third peristaltic pump (Figure 3).

Figure 3

This picture depicts the third peristaltic pump with two different pump heads, one for each apparatus with size 17 tubing for the 2.5 cm tube settler and size 18 tubing for 5 cm tube settler.

For this experiment, the lime slurry in the bucket was not blended using the blender but rather using the mixer. The mixer stayed in the bucket throughout the course of the experiment and Process Controller was configured to turn the mixer on for two minutes before the pump was configured to run. Thus, the stock solution would mix for two minutes and then be pumped for one minute at 380 mL/min. This repeated every six hours.

Results and Discussion

As the first pulsing experiment, the apparatuses behaved approximately as expected. However, neither apparatus ever reached saturation (pH = 12.6) which could have been due to a number of things, including on-going difficulties with the pH probes.

The 2.5 cm tube settler apparatus took a while to reach equilibrium but eventually reached a pH of slightly greater than 12. It was fed the 100 grams of lime slurry at approximately 12:15 pm. It then leveled off at a pH of slightly less than 10 until 6:19 pm, the time of the first scheduled lime pulse. It's pH then shot up to approximately 11.5, where it remained until the second lime pulse when it finally reached a pH of slightly greater than 12. After the third pulse around 6:15 am, the pH level started wavering and dropping below 12. By the time of the fourth pulse around 12:15 pm (24 hours after the experiment began) the pH was steadily dropping and continued in this trend, with the occasional spike every six hours with the lime pulse

The first couple of pulses do not create spikes in the graph. This may be due to the fact that the 100 gram lime slurry takes time to settle into equilibrium. It could also be caused by the very fine lime particles that settle slowly.

The 5 cm tube settler apparatus performed similarly, except that it reached a level pH of approximately 11.5 much more quickly. It started failing sooner than the smaller apparatus, at around 6:00 am, only 18 hours after the experiment began.

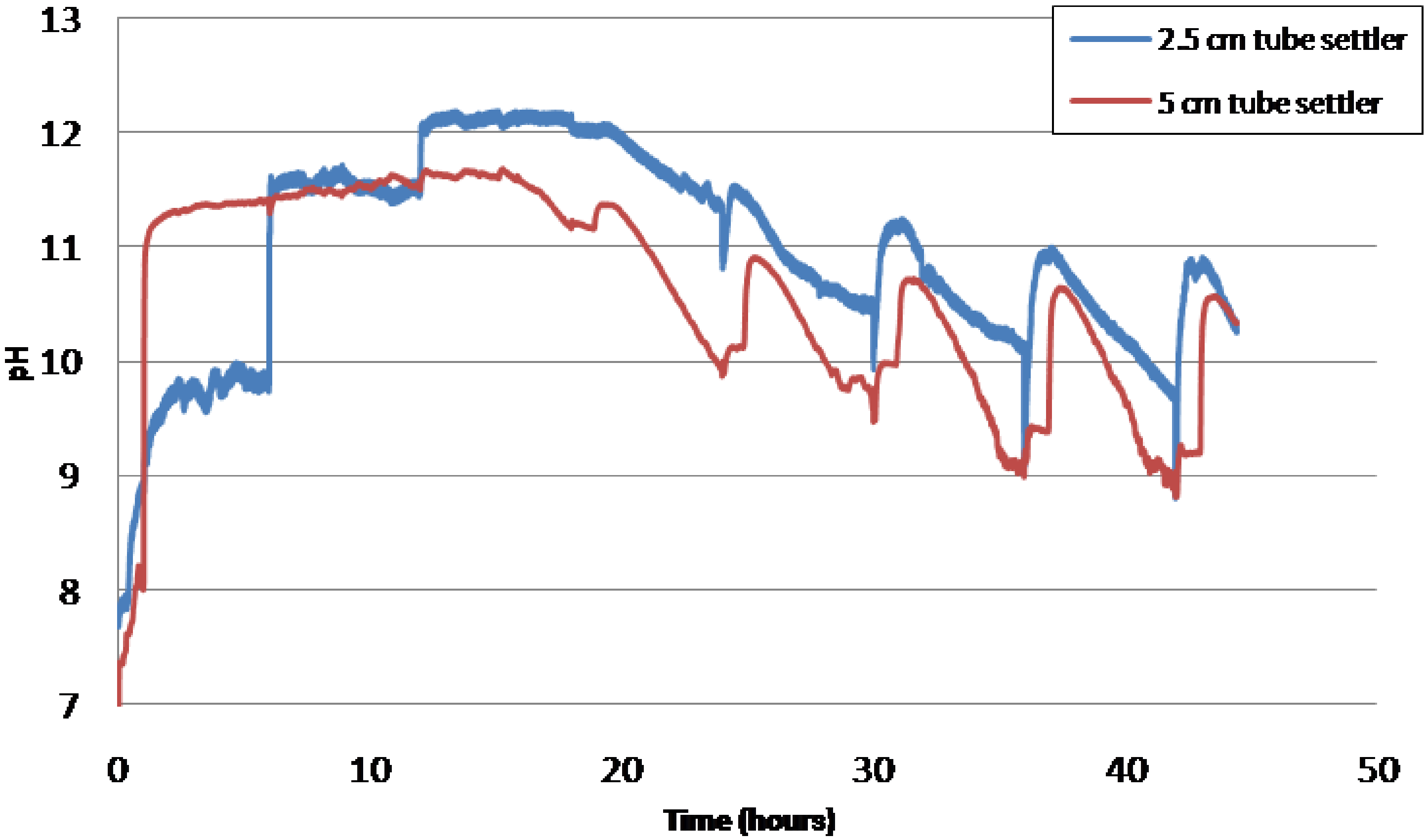

Figure 4 - Experiment 7

This purpose of this experiment was to develop a set up in which stock solution of lime is automatically pumped into the two apparatuses every six hours.

No labels

Experiment 8 Formalizing Blender Methods + Continued Pulsing

Created by Katherine Anne Weible, last modified on May 12, 2010

Experiment 8: Formalizing Blender Methods + Continued Pulsing

Overview

The purpose of this experiment was to develop a more consistent method for preparing and blending the lime slurry that is added to the vertical columns and to the stock concentration. The desired outcome of this experiment was to provide insight into the importance of lime particle size on the performance of the experiment.

Procedure

An almost identical procedure was followed for this experiment as in Experiment 7. A lime slurry of 100 grams of lime plus 1 liter of tap water was prepared for each apparatus, as well as a lime slurry of 124.5 grams of lime prepared in 1 liter of tap water and then diluted further with 14 additional liters of water for the stock concentration. The difference between the two experiments is in the use of the blender to prepare the slurries.
For the 100 grams of lime that were to be fed into the vertical column, the blender was used for 5 minutes on "liquefy". Unfortunately, at the end of the 5-minute period for the second 100 gram slurry, the blender overheated and became inoperable. Therefore, the mixer had to be used to blend the remaining lime slurry needed for the stock concentration. It is suspected that the mixer does not provide the same particle uniformity that the blender does.

Results and Discussion

Despite the consistency in blender methods, the experiment performed approximately the same as it did in Experiment 7. Again, the 2.5 cm tube settler apparatus reached a pH of slightly greater than 12 while the 5 cm tube settler remained closer to 11.6. After approximately 4 hours, the 5 cm tube settler begins to steadily drop off. It then continues a pattern of steady decline followed by a spike every 6 hours, at the time of the lime pulse. The 2.5 cm tube settler apparatus doesn't drop below a pH of 12 until approximately 22 hours into the experiment. However, it then follows the same decreasing rise and fall curve with each lime pulse.

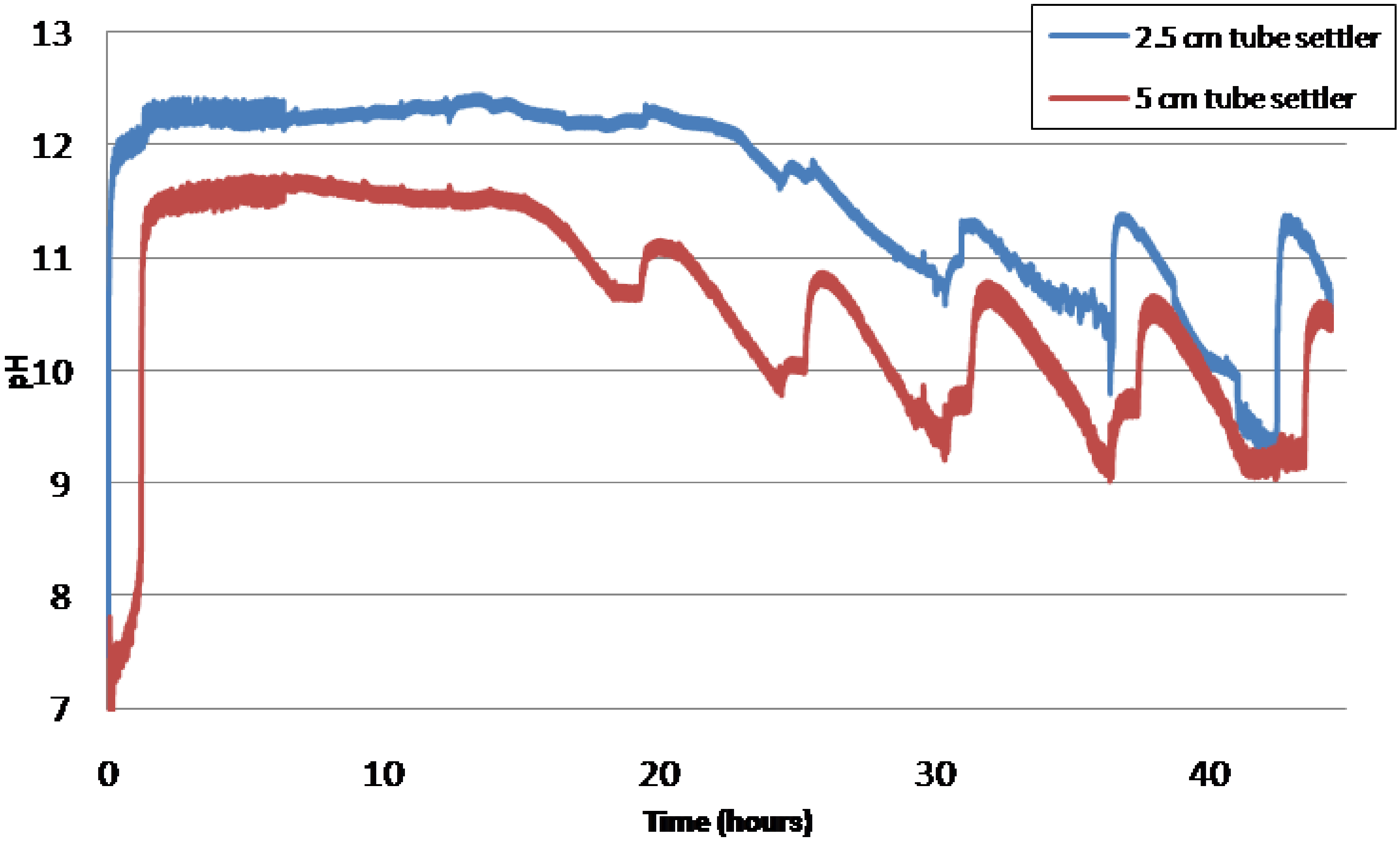

Figure 1 - Experiment 8

The purpose of this experiment was to continue pulsing in a lime stock solution but to improve the uniformity of the slurries by using the same blender procedure for each slurry.

No labels

Experiment 9 Increased Lime Concentration + Continued Pulsing

Created by Katherine Anne Weible, last modified on May 13, 2010

Experiment 9: Increased Lime Concentration + Continued Pulsing

Overview

The purpose of this experiment was to maintain all the same conditions as Experiment 8 but to change the concentration of the stock solution. Experiment 8 failed because the lime pulses did not increase the pH sufficiently. Therefore, it was determined that a more concentrated solution was required. The amount of lime added to the solution was multiplied by 5, resulting in 622.5 grams of lime added to 15 liters of water--a concentration of 41.5 (g/L).

Procedure

An almost identical procedure was followed for this experiment as in the Experiment 8. A lime slurry of 100 grams of lime plus 1 liter of tap water was prepared for each apparatus. Then a more highly concentrated lime slurry of 622.5 grams of lime was prepared in 2 liters of tap water and then diluted further with 13 additional liters of water for the stock concentration.

Because the blender was broken, the large mixer had to be used to prepare all three lime slurries.

Results and Discussion

Approximately 120 hours later (5 days later), the stock solution was refilled with the same concentration (41.5 g/L). However, the blender had been repaired at this time and was used to prepare the slurry, instead of the mixer. At the same point in time (5 days from the beginning of the experiment) the flow rate for the peristaltic pump flowing to the 5 cm tube settler was increased from 40 mL/min to 50 mL/min in an attempt to raise the pH. The team suspects that when the flow rate in the 5 cm tube settler apparatus is too low, the lime particles settle and create preferential flow paths which keeps the lime from interacting with the water.

Below in figures 1, 2 and 3 is the preliminary data from the experiment. The 2.5 cm plate settler was relatively stable, achieving a pH of over 12 for well over a week! The 5 cm plate settler, however, never reached a pH of 12 but rather oscillated around a value of approximately 11.5. As time went on, the amplitude of the data's wave increased and the pH started regularly dipping below 10.

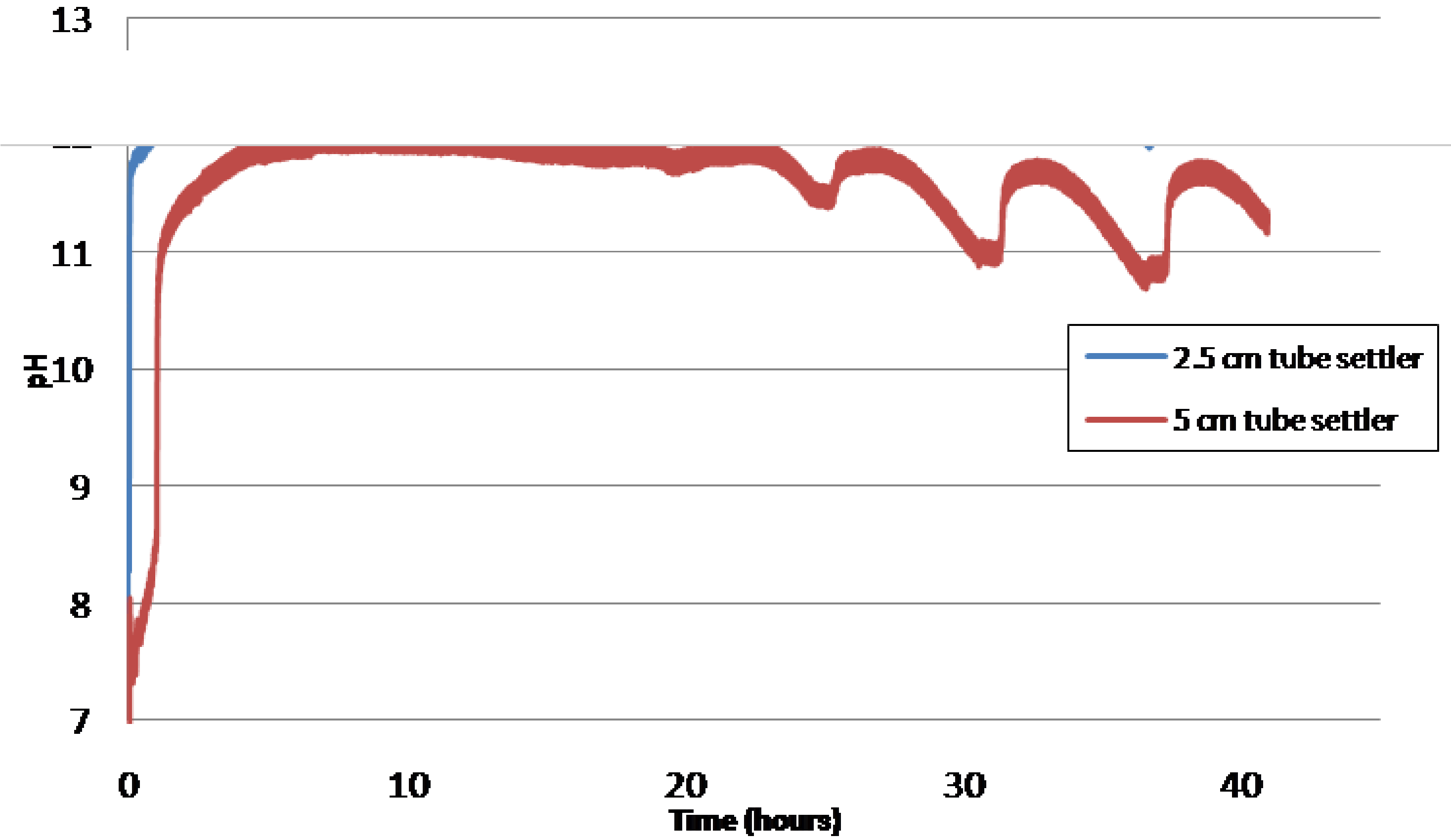

Figure 1 - Experiment 9
The above graph is hours 0 to 40 of an experiment pulsing in 41.5 g/L of lime slurry at 380 mL/min for 1 minute every six hours.

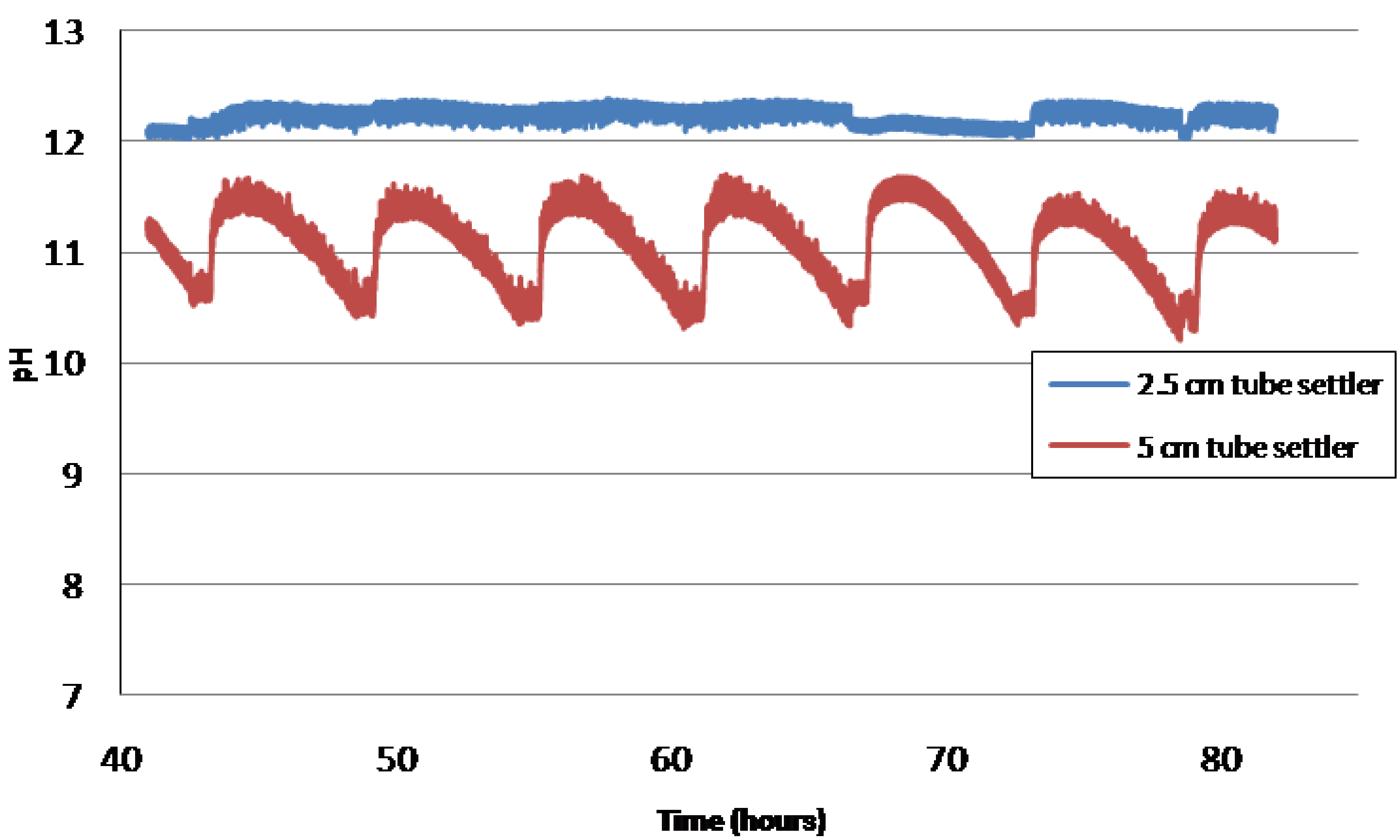

Figure 2 - Experiment 9

The above graph is hours 40 to 80 of an experiment pulsing in 41.5 g/L of lime slurry at 380 mL/min for 1 minute every six hours.

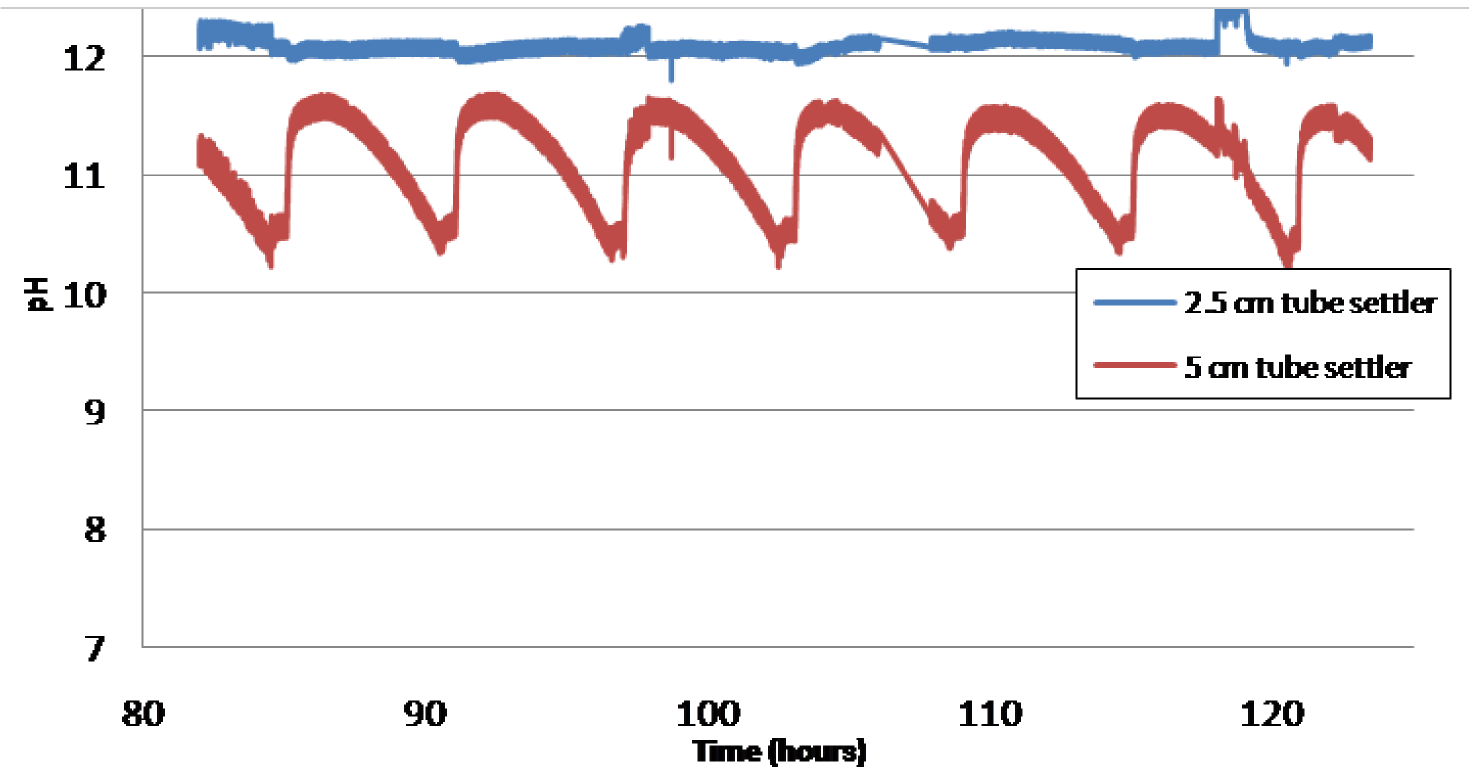

Figure 3 - Experiment 9

The above graph is hours 80 to 120 of an experiment pulsing in 41.5 g/L of lime slurry at 380 mL/min for 1 minute every six hours.

Experiment 9 ran for nearly 10 days before the team shut it down. The performance of the 2.5 cm tube settler remained pretty consistent, with the pH remaining right around 12. The 5 cm tube settler continued its wave-like motion, as seen in Figure 4.

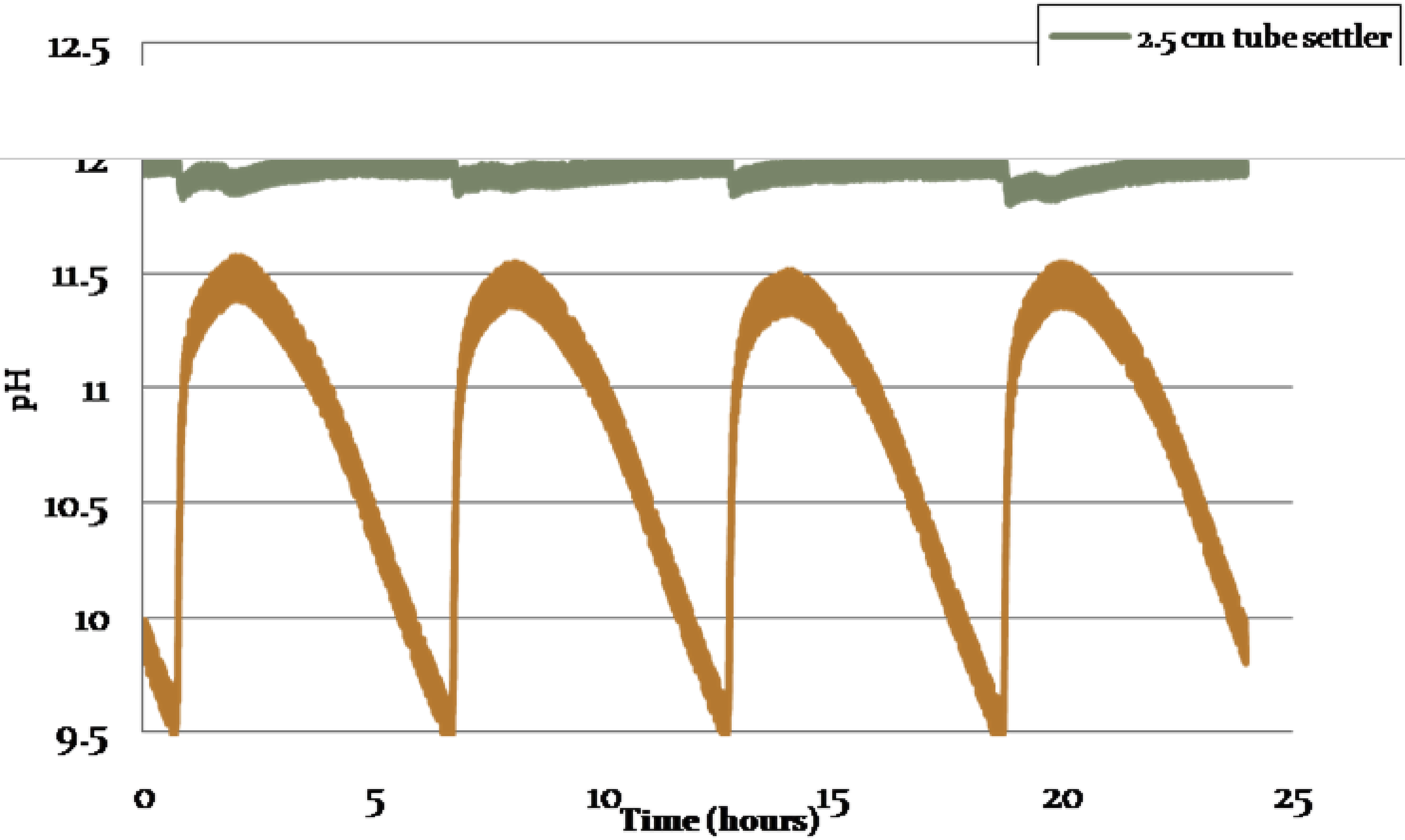

Figure 4 - Experiment 9, Day 9

This graph is zoomed in to display that the smaller apparatus does experience slight peaks with each lime pulse, and to not that the larger apparatus dips below a pH of 10 as the experiment continued.

No labels