1 L/s Plant Testing, Fall 2016

Yang Pei, Erica Marroquin, Alicia Barrientos, Manuel Queijeiro

Fall 2016

Abstract

The 1 liter per second AguaClara water treatment plant was created in the summer of 2016 for small villages where it was not cost-effective to build full-sized plants. It was the culmination of 10 years of progress in AguaClara and featured new technology, including a crimped pipe flocculator and a free-standing sedimentation tank constructed from corrugated sewer pipe. The Fall 2016 team began the semester with performance checks; the team tested for leakages, dosing apparatus precision, floc blanket formation, and turbidity removal. After the team reached the conclusion of a good performance and shipped it satisfactorily to Honduras, where the work will be continued. The flocculator was re-designed to improve the existing one and test were performed to check that it gave the expected head loss. Finally, it was built.

Introduction

Figure 1: 1 L/s plant in AguaClara laboratory at Cornell University.

The 1 L/s plant was created to broaden the accessibility provided by the AguaClara technology. It was designed to handle flow rates between 0.7 and 1.0 L/s, targeting the needs of small communities of 200-400 people. Communities of this scale have struggled to find a cost-effective way to treat their water; the costs associated with a full-scale municipal plant, even an AguaClara design, have typically been too expensive. This plant was created as a solution – with a much smaller area, it was significantly cheaper to fabricate than a conventional design. The plant included its own gravity-powered chemical dose controllers and stock tanks, which allowed it to be operated completely free of electricity.

The other intended application of the 1 L/s plant was use as a testing platform. Most AguaClara technology was tested up to this point in bench-scale models operating on clean tap water with clay added back in as a simulated contaminant. However since the 1 L/s plant was made small enough to fit in a lab or transport and assemble easily, it would provide a new platform to develop and test novel technology for water treatment in more real-world settings. It was intended to be used as larger, more accurate way for research to be performed either in the lab or actually attached to a contaminated water source, before being applied to a full-scale municipal water treatment plant.

As a pilot project, the Summer 2016 team created the minimum functional design, incorporating only a coagulant dosing apparatus, a flocculator with a rapid mix, and a sedimentation tank with plate settlers. Typically conventional water treatment processes have also included filtration and disinfection processes, however these were not necessary to construct since AguaClara designs already existed for modular sand filters that could attach to the plant, and the same dosing system used for coagulant would be used for disinfectant. The dosing system used a miniturized version of the standard AguaClara design, but the other processes required significant modification.

A new flocculator and sedimentation tank were designed specifically for the plant. In typical AguaClara plants, flocculation was done hydraulically in deep, in-ground concrete tanks where the water traveled over and under a series of baffles. This was replaced with a new flocculator composed of a series of connected PVC pipe sections, in which the water traveled through evenly-spaced crimped constrictions. The sedimentation tank, also typically a deep, in-ground fixture, was fabricated from a 7 foot long, 3 foot diameter corrugated PVC pipe into a two-sectioned structure. The lower section stood upright and contained a jet diffuser to re-suspend flocs that fell to the bottom, hence generating a floc blanket, while the top half of the tank held plate settlers and was angled at 60 degrees to the horizontal, the typical AguaClara angle for plate settlers.

The primary goal of the Fall 2016 team was to quickly evaluate performance before the plant was shipped to Honduras in early November for field testing. The team tested for leaking components, the accuracy of coagulant dosing, the formation of a floc blanket, and for acceptable effluent water turbidity.

All of the plant was shipped to Honduras except for the flocculator. The flocculator used for testing the plant was not the one that there was going to be in Honduras. We designed a new flocculator that is going to be used in Honduras with the pipes that they have there. Our main goal was achieving the head loss that the plant needs in order to work adequately. Instead of changing the shape of the pipes we decided that the losses will come from turbulences created by PVC disks with holes that the water find while it is flowing through the tube. After testing it and obtaining positive results, we started building the disks that we were going to send to Honduras.

Literature Review

AguaClara Treatment Process

This section was based in an currently operable AguaClara treatment plant existing in Honduras with a maximum flow rate of design of 20.0 L/s. This report was also based in other documents that can be found in the Bibliography, and was made by the AguaClara team at Cornell University, under the supervision of Monroe Weber-Shirk in September 2016.

The treatment process was initiated in the entrance tank, where the flow rate was measured and part of the coagulant dosing. Flow rate was measured with the Linear Flow Orifice Meter (LFOM), a tube with several orifices which followed a pattern converting the flow rate to be proportional to height of water in the entrance tank. Ordinary flow through a single hole was proportional to the square root of the level of water, but through this specific pattern of multiple holes, flow had a lineal relation to water height.

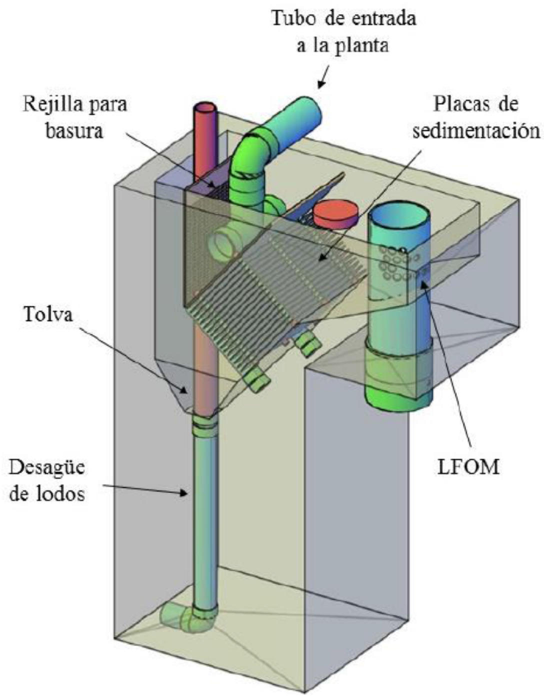

Figure 2: Entrance Tank of the 20.0 L/s plant in Honduras.

A float was hung on the side of the tank to rise and fall with the level of water in the tank. The float was connected to a dosing arm which allowed semi-automatic chemical dosing chemical level, in a way that the coagulant concentration of water entering the plant remained essentially constant even when the inflow rate varied. Thanks to the linear relation obtained by the LFOM of water height and flow rate, the float caused the dosing arm to also be have a height proportional to flow rate. Coagulant was stocked in a deposit higher above, so the higher the flow rate, the lower the other end of the dosing arm fell, and the faster the coagulant flowed. To ensure a linear relation between head losses and discharge, the design of the plant looked for minor losses negligible compared to major ones. Several analytical information is provided in the document.

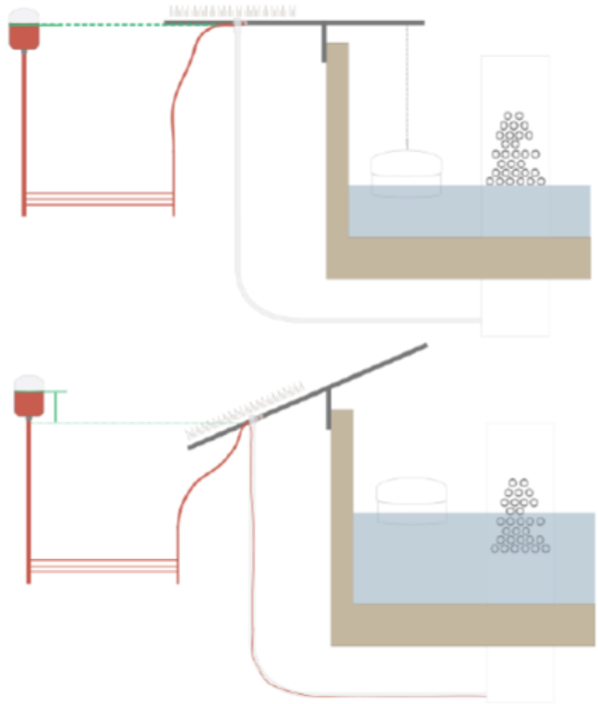

Figure 3: Balancing in accordance to water level regulates the chemical dosing.

The coagulant joined the water just before the rapid mix. In the plant it consisted of a sudden constriction in the tube, creating a zone of high turbulence where the coagulant was uniformly distributed in the water.

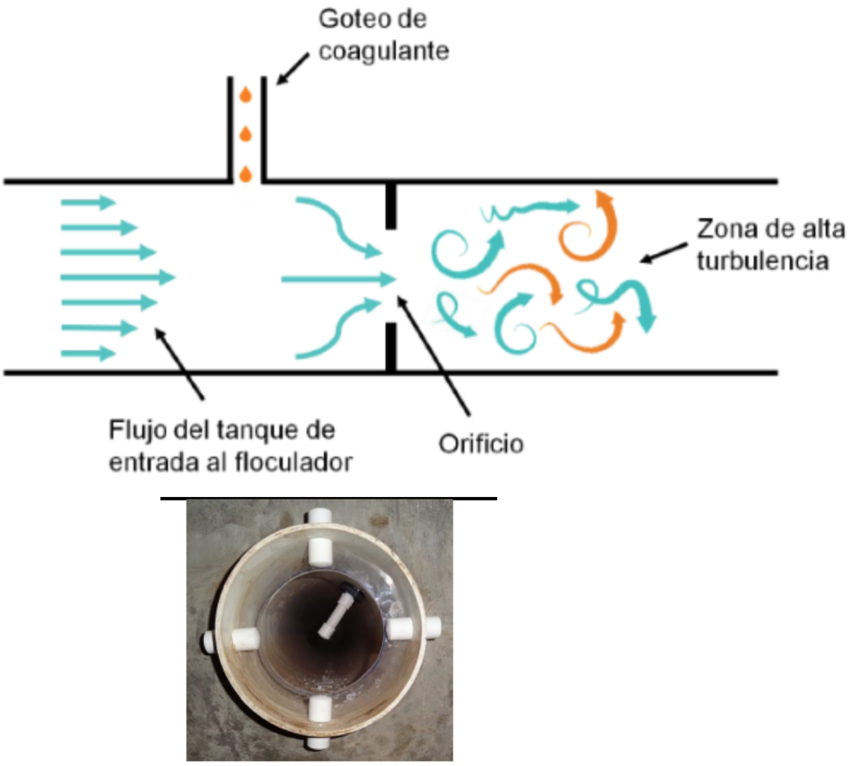

Figure 4: Rapid mix of the 20 L/s plant in Honduras.

Until this point, the mechanisms were identical to the case of the 1 L/s plant but in a larger scale. The entrance tank also had a small sieve to retain gross particles and the LFOM was performed with the same theoretical basis. The coagulant dosing system acted in the same way with height differences, and the major losses were provided by friction of the water in long narrow tubing.

Then the process of coagulation started. The chemical acted as a glue that stuck to the particles and caused them to clump together into visible "flocs." After the mix between water and coagulant they entered in a hydraulic flocculator (a channels with deflectors that directed the flow of water). When the flow turned over and under the deflectors, it contracted and expanded, causing turbulent mixing that ensured the collision between the different particles which stuck and remained together because of the coagulant. During this process of flocculation the particles grew as they kept colliding and the formed larger and larger particles, know as "flocs" once they had visual size. In the case of the 1L/s plant the deflectors made of polycarbonate sheets were substituted by baffles of PVC piping system.

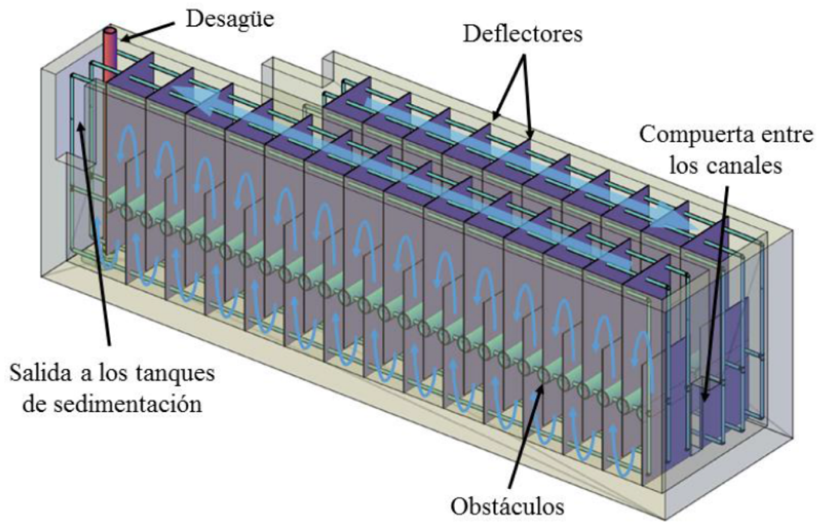

Figure 5: Flocculator of the 20 L/s plant in Honduras.

Once the water left the flocculator, it entered the bottom of the sedimentation tank by the Manifold distributor and slowed down significantly. In the slow-moving water, most of the floc particles were pulled down by gravity fast enough that they could not escape, and instead were removed through a sludge hopper and drain. In the top of the sedimentation tank was a very relevant feature, the function of the sedimentation plates. This plates were inclined 60° in both, 20 L/s and 1 L/s plants, ensuring less time for the flocs falling down and being captured.

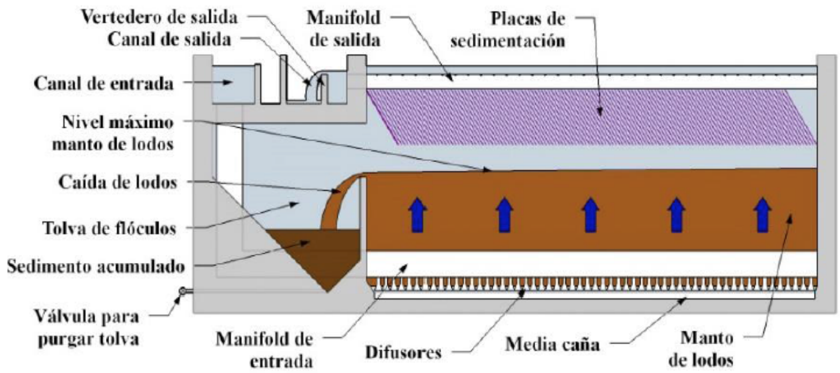

Figure 6: Sedimentation Tank of the 20 L/s plant in Honduras.

Another crucial aspect of the sedimentation tank was that the flocs were not supposed to rest in the bottom – the particles were actually forming what was called the floc blanket, helping to trap smaller particles that would otherwise have escaped without its presence. There was a defined interface between this floc blanket and the clearer water above, behaving as two different fluids. There was a weir there at this point, draining all the flocs at that height and settling them into concentrated sludge waste.

The water flowed in the upper part of the tank by a perforated tube. Here ended the proccess in the 1 L/s plant, nevertheless, in the 20 L/s plant one last section was used before distribution. It was the so called FRAMCA as their initials in spanish Filtro de Arena en Múltiples Capas (sand filter in several layers). It reduced even more the turbidity and eliminates all the microorganisms that are resistant to chlorine. There the particles had enough velocity to be trapped inside the sands instead the surface of it. The advantages of the FRAMCA were the reusing of sedimented water to perform the retrowashing of the accumulated particles, without needing pumps and employing less water or space.

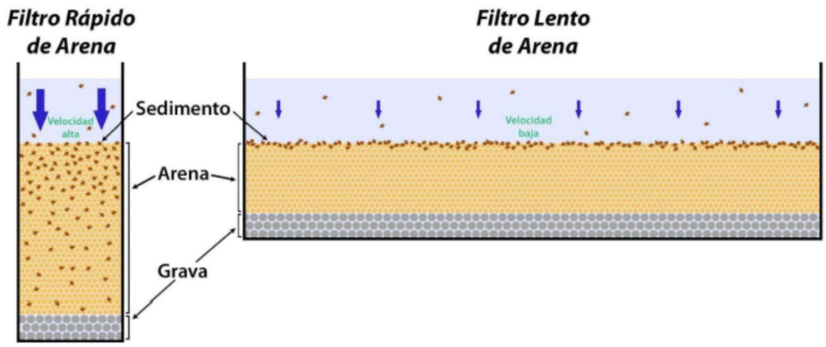

Figure 7: Comparison between FRAMCA and a slow sand filter

Previous Work

Though a new team, this semester's activities were based on the work of the Summer 2016 team, since the Fall team was tasked with evaluating the integrity and performance of the Summer team's fabrication. The 1 L/s is the maximum tangible representative of several years of advances and the work of different subteams, both analytical and practical.

The plant was constructed supported into a wood column, with the entrance tank in the highest part. The entrance tank was held together with 80/20 aluminum bars.

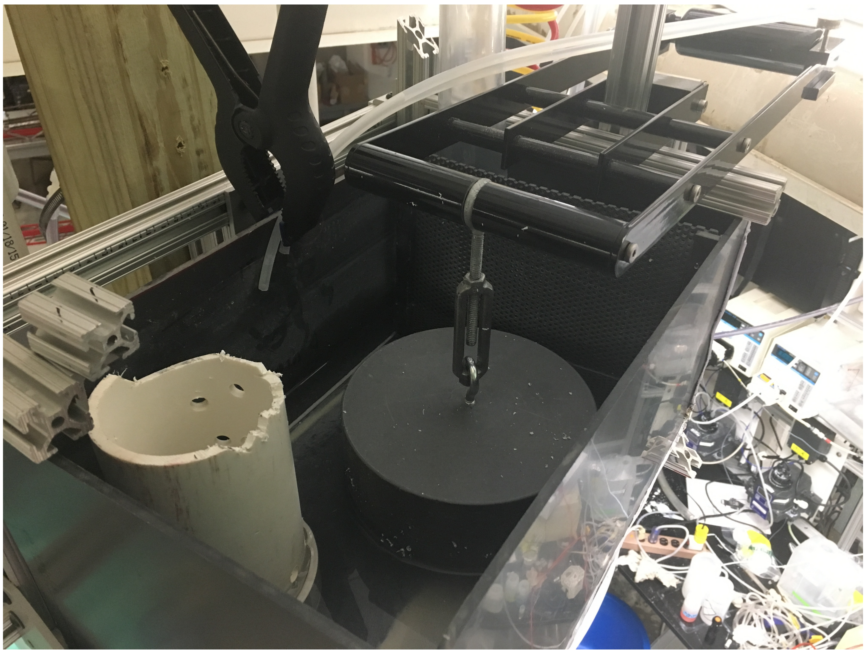

Figure 8: Entrance Tank of the 1 L/s plant.

The 1 L/s plant contains all the elements of a large-scale AguaClara plant. In the bottom left part of the image, the LFOM can be seen, and in the right the dosing arm, with the float and tubing at its sides.

The flocculator had baffles constituted of PVC pipes that turned around itself 4 times create the perfect conditions for the collision and binding of flocs. The previous team also attached pipes to measure the head loss.

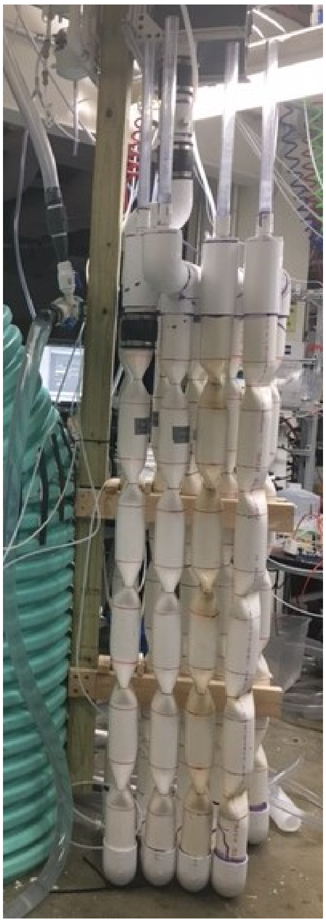

Figure 9: Flocculator of the 1 L/s plant.

Finally, previous team has also created the sedimentation tank containing the plate settlers, and piping similar to the big scale plant seen in the literature review: a Manifold distributor in the bottom part and a gatherer tube with orifices on top. The most varying part was the sludge drain tube because in Honduras the plants use a much larger sludge drain. While with this plant we had to be careful with the valve opening, there they are open all the time without a relative big waste of water.

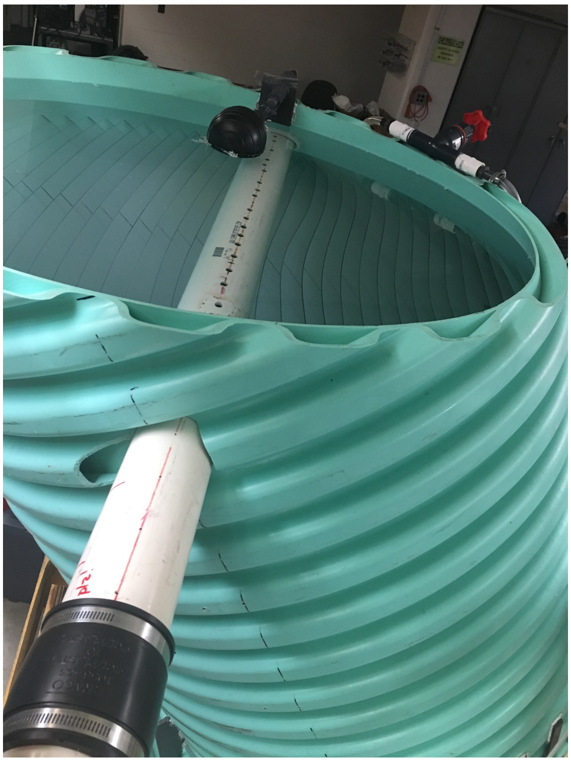

Figure 10: Top view of the Sedimentation plates of the 1 L/s plant.

Methods

Short-Term Clay Testing

Since the plant did not have a filter, it was not appropriate to evaluate it against US finished water quality standards. Instead, the team conferred with Dr. Weber-Shirk regarding typical water quality pre-filtration in existing AguaClara plants, and based upon his imput, set the acceptable target at a 1 NTU maximum effluent turbidity.

Experimental Apparatus

To test if the 1 L/s plant produced effluent water less than 1 NTU, the team decided to run tests where clay and coagulant were introduced into the system to simulate treatment of dirty, high-turbidity influent water. However, Cornell was under water usage restrictions due to a local drought, and running the plant would have unacceptably wasted up to 3,600 liters per hour. As a solution, water was recirculated through plant instead of discarded after exiting the sedimentation tank. Mostly-clean water exited the plant, but then had clay re-introduced to make it dirty again, which was fed back into the entrance tank.

The plant was set up as it would be in the field, except that pumps were used. A large inline pump recirculated the water, pulling it from the exit at the top of the sedimentation tank and pushing it up to the the entrance tant. Since the dosing system had not yet been tested, the team decided to use a peristaltic pump to inject the coagulant. Peristaltic pumps were also used to inject a clay solution into the influent water, and to continuously pump samples of the influent and effluent water into turbidimeters for performance monitoring. The use of peristaltic pumps for clay and coagulant also allowed the team to easily manipulate the concentrations by increasing or decreasing the pump speeds.

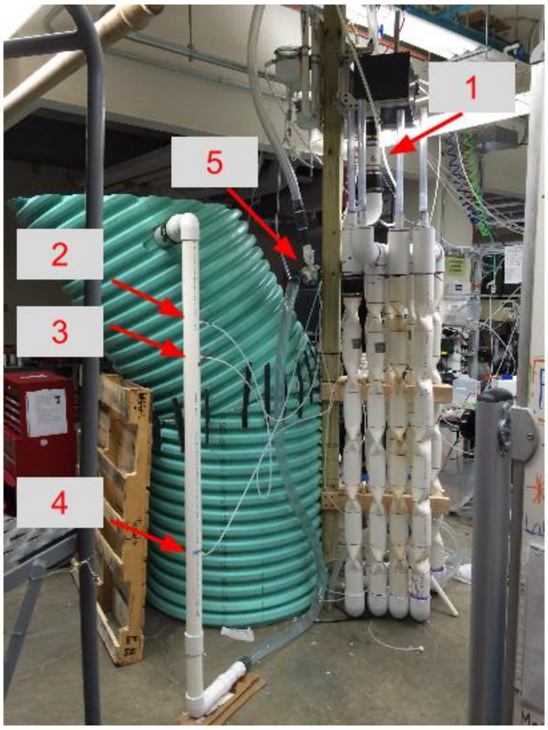

Figure 11: Photo of 1 L/s plant showing clay and coagulant injection sites and pump to recirculate water.

Injection sites are labeled in Figure 11. Coagulant was injected at site 1, right after the entrance tank and the rapid mix pipe. The water then flowed through the plant, until it reached the exit pipe, which contained taps 2, 3, and 4. Site 2 was connected to a turbidimeter where the effluent water NTU was measured. Site 3 was where clay was injected, and site 4 is where influent water NTU was measured using a turbidimeter. The water was then pumped back up to the entrance tank using the in-line pump located at site 5. Typically, in the field, the white PVC pipe that contains site 2, 3, and 4 would not be there, instead the effluent water would go on to a filter, then to disinfection and distribution.

Procedure

The tests were run for short periods of time, ranging from around 40 minutes to 4 hours. The goal of these tests was to see if the plant can produce effluent water that is less than 1 NTU. The team decided to pump clay into the system so that the influent NTU water was around 100 NTU, and added 44.8mL coagulent into 4L storage tank. To start the test, the clay pump was turned on, and it took about 20 minutes to see the correct value of effluent turbidity. 20 minutes was around the time the injected clay and coagulant finally reached the end of exit tube.

High NTU Clay Testing

The purpose of this test was to see if the sludge drain performed as planned - if sludge drain collected flocs at all, and if as time went on could could it be drained so it would not clog. The idea was to push the plant to the point of failure, which the team determined to be when the plant reached an NTU of about 5 and steadily increased.

Experimental Apparatus

The same experimental apparatus as Short-Term Clay Testing (Figure 11) was used during the High NTU Clay Testing.

Procedure

Instead of injecting clay into site 3 in Figure 11, clay (in powder form) was dumped directly into the entrance tank.About 4kg of clay were dumped into the entrance tank. The team decided to do this because the plant needed to be pushed to point of failure, and this was the fastest way to accomplish it. This was done to make the floc blanket fill the lower section of the tank quickly so the team would not have to wait many hours (or even days) that it would take to fill by doing a typical clay test. Failure was defined by when the sludge drain could not hold any more flocs, and needed to be emptied. Once the mass of clay was added, and the plant was allowed to run for about an hour, the team looked in the sedimentation tank to see what was going on. The team expected to see a concentrated floc blanket, but instead the floc blanket was not defined.

Dose Controller Testing

Experimental Apparatus

Figure 12: Chemical dose controller.

Chemical dose controllers were constructed by a previous AguaClara team and are to be used on the 1 L/s plant.

Procedure

The method used by the team consist on controlling the coagulant dosing by means of a dosing arm. There is a linear relationship between the level of the arm and the amount of coagulant that the plant needs. We tested the arm for different heights in order to get different amounts of coagulant.

Flocculator Design

Procedure

Figure 13: Disc on the rod.

The team is working to design and fabricate a new flocculator which will be incorporated in the next generation of 1 L/s plants.

The constrictions in the flocculator have been modified. As explained earlier, the constrictions generate a high turbulence zone that engages the particles to collide to form flocs. The old flocculator design has two main disadvantages: (1) The method of construction is harder to perform. Heating the pipe and crimping them to shape can lead to imperfections, and therefore leakage. (2) The crimps in the flocculator have an elliptical shape, which leads to more difficult and less accurate analytically calculations of headloss.

The new design consists of placing stainless steel rods inside the 3 inch PVC pipes that have donut-shaped, 1/8 inch PVC sheet disks attached, with a spacing of around 15 centimeters. The donut-shaped holes provide the consequent turbulent zone, without needing the constrictions of the old flocculator.

After the fabrication of discs,headloss test was performed to see whether the new flocculator could have the expected headloss.One end of the pipe was connected to a pump,and the other end of the pipe circulated water back to the tank where the pump drained water from.Just after water goes into the pipe and before water flowed out of the pipe,two holes were drilled and connected to two long transparent small pipes.By reading the difference of the water level of these two pipes,the team could know the headloss created through the new flocculator.

Figure 14: Flocculator headloss test.

Results and Analysis

Results

Short-Term Clay Testing

A 4-hour clay test was run to test the efficiency of 1L/s plant.The main goal for the clay tests was to get an effluent turbidity of less than 1 NTU. When the test began, the effluent turbidity was greater than 1 NTU, but was as the test continued, the effluent turbidity lowered to around 0.5 NTU (Figure 15), an excellent low pre-filter turbidity.

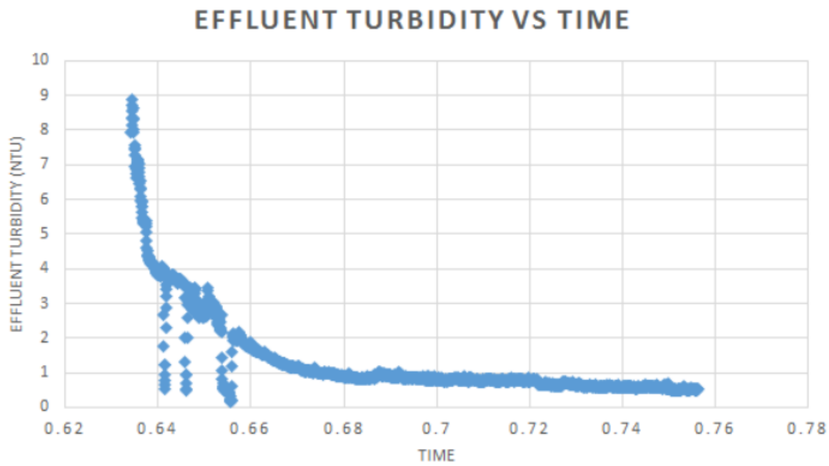

Figure 15: Effluent turbidity versus time.

High NTU Clay Testing

The team dumped large amount of clay into the entrance tank,and used a camera to see what happened inside of the sed tank.Surprisingly,the floc blanket did not form as the team expected.There were only thin and diffuse layers of flocs existing in the sed tank.

Dose Controller Testing

The Chemical Dose Controllers (CDC) created last year were tested to see whether the relationship between the height of the lever arm on the entrance tank and the flow rate coming out of the CDCs is supposed to be linear. As the height of dosing arm increased, flow rate also increased too (Table 2), and a linear trend fit the curve very well (16).

Table 1: Relationship between height of lever arm and flow rate.

Height of dosing arm(cm)	Flow rate(mL/s)
2.5	0.04
2.5	0.042
5.8	0.095
5.8	0.095
9	0.14
9	0.14
9	0.1375
12	0.192

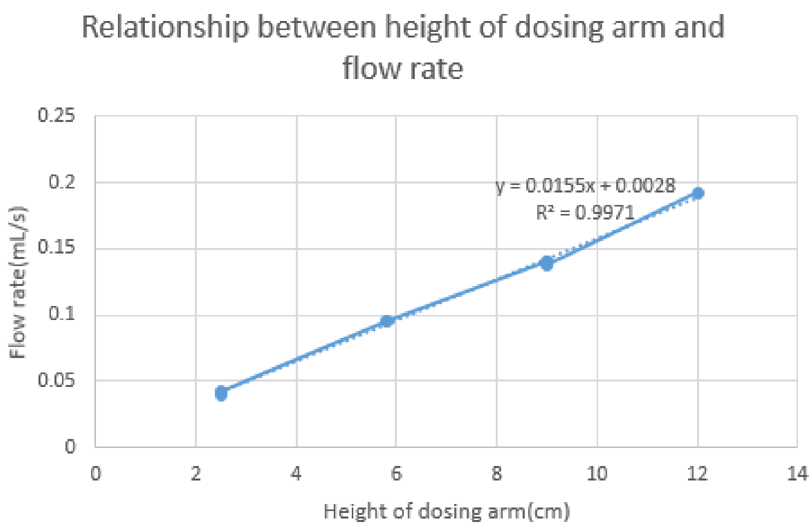

Figure 16: Linear relationship between height of dosing arm and flow rate.

Flocculator Design

According to minor loss equation,the team calculated the diameter of hole that should be drilled on the discs.At first,the team thought the correct diameter should be 2'for a 3' pipe.On each rod,there're 5 discs,and two consecutive pipes were used in the head loss test.However,according to the head loss test,head loss the team got was only about 35cm,which was far smaller than 50cm(what the team desired). Then the team decided to put 10 discs altogther onto one pipe to see whether the head loss can reach 50cm.The experimental data for this test was shown in table 2.

Table 2: Flocculator headloss test data.

Flow rate(L/s)	0.789
Velocity(m/s)	0.165
Minor loss coefficient	2.797
Head loss(cm)	56.4

Shipping Preparation

Figure 17: Shipping preparation.

After ensuring the efficiency of 1L/s plant, the team began to make final steps in order to ship our plant to Honduras. A new entrance tank was fabricated to avoid the usage of 80/20 and then doser, entrance tank, flocculator, plate setters and post were carefully removed. Sedimentation tank including plate settlers were washed and dried;the team cut post so that it can be reattached to side of sed tank. Then the team packed entrance tank, dosers, lever arm system, threaded rod into bottom of sed tank and put plate setters on the upper part of the sed tank. All of the components were labeled and small units were packed in a box.The team also drilled hole at the top and bottom of the sedimentation tank in order to make it fixed during shipping. Finally, the top and the bottom were sealed with plywood and 1L/s plant was shipped to Honduras.

Analysis

Short-Term Clay Testing

In the clay test, effluent turbidity was higher than 1 NTU at first because the floc blanket has not completely formed and adsorbed particles in water. But as the experiment went on,effluent turbidity became stable and lowered to about 0.5 NTU, which can be deemed as a success. The result the team got is similar to the performance of traditional AguaClara sedimentation tanks and flocculators.

Chemical Dose Controller

In the test of CDCs,a linear best fit line shown that the relationship between height of lever arm and flow rate was indeed linear. This indicated that the CDCs were working as anticipated, and could be used to dose the coagulant in the 1 L/s plant.

Flocculator Design

As were shown from table 2, the final total head loss the team got was 56.4cm which was close to the goal, that was 50cm. This result shown, putting ten discs on one rod instead of putting them on two rods could significantly increase the constraction and mixing of the water flow. Also, the mixing efficiency was greatly improved by doing this. As to the reason why the team didn't get the desired head loss in the first test,it may due to the vena contracta value which the team used in calculation were bigger than 0.62. Therefore,contraction effect was not so intense as the team thought; actual head loss was smaller than the team assumed.

However, this flocculator design was still successful because it provided another way to create flocculator. Compared with traditional method by contracting pipes from outside, what the team did was easier, quicker and much more convenient.

Conclusions

The tests that the team has made have taken the AguaClara team to another level in their history, as we can observe that the plants has reached its goals. For the AguaClara team, this means two different conclusions.

The first one, this plant has the characteristics to be used in small communities. As it has been said before, they can not afford a big AguaClara plant and also they do not have the space for it, so this plant suppose a big advanced in the life of small communities. Getting drinkable water from a continuous plant makes this communities independent from bigger ones. Also, it improve the life quality many people that will have access to a plant not just to drink water, but also to prevent people from having diseases transmitted by bad-quality water. Sending it to Honduras means that it is not an experiment anymore. It is prepared to be used in there.

The second one is the importance of this plant as a testing plant. The technologies developed by another AguaClara research teams are the base of AguaClara. However, they do their experiments in the specific parts of the plant that they work with, not as a whole. Previously, the AguaClara technologies that were considered good enough to be tested had to be sent to real plants in Honduras in order to test them. This means that the cost of shipping it had to be paid for something that might not work. With the small plant in Cornell University, this will not happen anymore. All of the discoveries made by AguaClara teams are going to be tested in the AguaClara lab with a real plant. If this new technologies work in the small scale plant, they will work for sure in the big plants. One little step for the AguaClara team means one big step in the achievement of new economical and efficient water treatment technologies.

In conclusion, the advantages that this group gives to the team are enormous and this team should definitely continue in the future working on improvements of the plant.

Future Work

Shipment

The plant has satisfactorily left the laboratory at Cornell University on Monday 7th of November of 2016, with an expected arriving to Honduras by January. There, all the parts of the plant will be assembled again by a team of Cornell students working with local people, following the instructions sent recorded by us during last week prior to shipping.

The main tasks of that team will be ensuring that all the listed components have arrived. They were mostly placed inside the whole sedimentation tank (some of them in boxes or wrapped), which has been covered with two pieces of wood and anchored to a wood board. Furthermore, they will have to screw the wooden post, which has been sawed with that shape intentionally to ease this task.

The limitation of shipping the plant at that early date, impede the team in performing all the test that we would want to do. Therefore, functionally speaking, the big objetive is to clarify the formation of the flocculation blanket. In our last big experiment this fall, we did not obtain a clear contrast in the layer between the clean water and the flocs. It remains to be seen if this was due to the acid concentration of the water, and if the sludge obtained was actually coming partially from the plate settlers instead from a flocculation blanket.

Also, the work our team has develop must continue in January in Honduras. When the plant reaches there, tests with real dirty water must be performed.

One of the main advantages of getting the plant to work properly will be the future tests that will take place. This plant is easier to build, cheaper and much smaller than usual AguaClara plants. This means that new AguaClara technologies will be able to be tested in this plant (probably in the Cornell lab) without having to take them to a bigger one. Then, those technologies that work can be sent in order to be tested in bigger plants in Honduras. This is a great advantage because it means that all of the new devices sent to the big plants are useful, and when you send them you already know that they work in a big enough test.

This team in the future have the goal of working with the Design team to improve some of the parts of the plant in order to make them more efficient (for example, the flocculator, in which we are working right now), and also perform tests using the technologies developed by other teams to tests in a real plant if it works adequately.

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Semester Schedule

Task Map

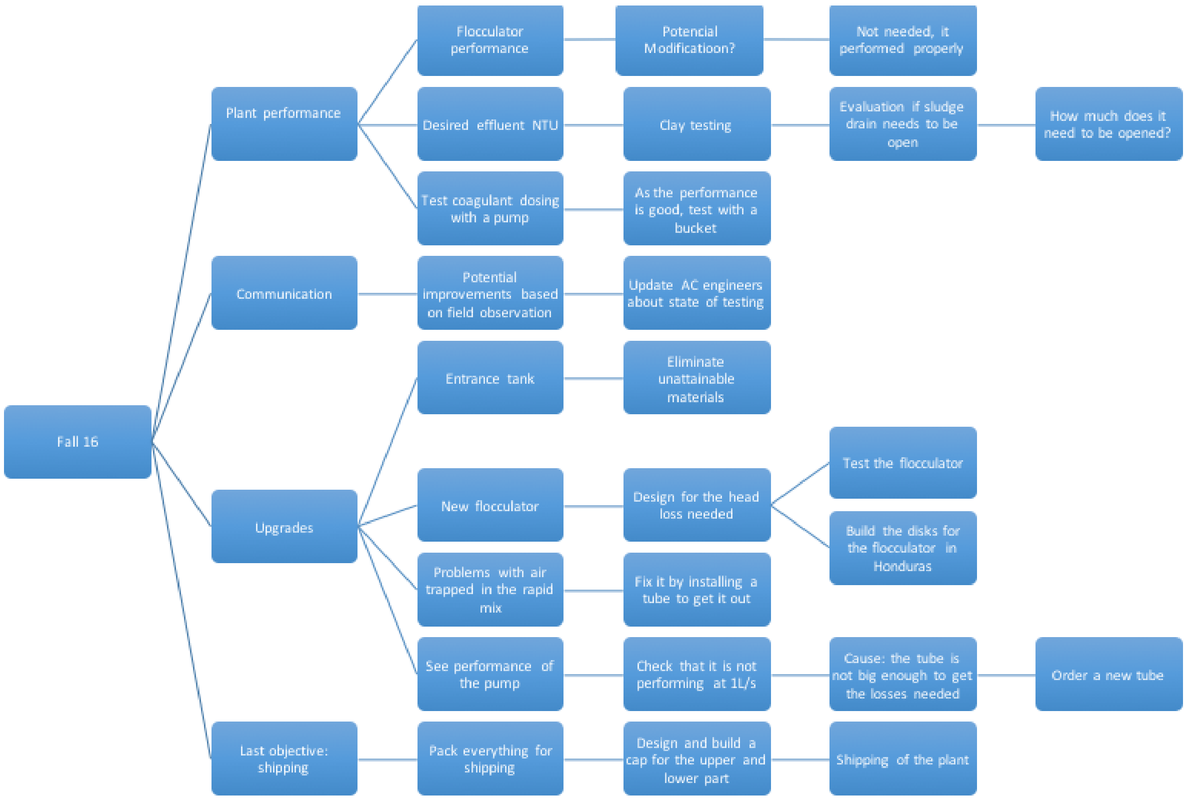

Figure 18: Task Map

Task List

1. Lab Set-Up - Erica Marroquin (9/16/16)
   (a) Connect turbidimeters and pumps
   (b) Tap for tubing attachments
   (c) Make sure everything is functional
   (d) Acquire missing parts for lab bench
      i. 80/20 for connections
      ii. Turbidimeter and pump hardware
2. Plant Performance - Yang Pei
   (a) See if flocculator performance is optimal
      i. Will need to be modified if results are not desirable
   (b) Test various NTUs from 5-500 to achieve less than 1 NTU effluent

            i. Can the sludge drain handle high waste concentration?

3. Communication - Alicia Barrientos
    (a) Speak regularly with AguaClara engineers in Honduras to see if they have any suggestions for the plant
    (b) Keep AC engineers updated with the state of testing
        i. Get plant ready for shipping to Honduras
4. Upgrades - Manuel Queijeiro
    (a) Actual 1L/s plant
        i. Potentially attach dosing arm to tank to minimize space
        ii. Eliminate 80/20 from pilot plant, explore wood/PVC options
    (b) The new flocculator
        i. Group up with 1 L/s prefab to analyze the needs of new flocculator
            A. Test new flocculator systems
            B. Create a flocculator for the following 1 L/s plant

Report Proofreader: Erica Marroquin