AguaClara Program Challenges Fall 2016

We continue to develop improved technologies to solve a wide range of water quality challenges. We are developing innovative technologies to remove particles and dissolved contaminants to produce safe drinking water and to treat wastewater so that it can safely be returned to the environment. We assume that there are significant opportunities to improve traditional technologies by building on a fundamental understanding of the science of water treatment.

We are preparing to deploy a mobile 1 L/s surface water treatment plant to Honduras sometime this fall, deploy a 0.1 L/s fluoride removal plant to India next summer, and develop a lower cost anaerobic digester for wastewater that can be tested in Honduras in the fall of 2017. These projects all require creative innovation, excellent engineering, attention to details, early recognition of failure, and willingness to take risks and try new approaches. It's going to be a great semester!

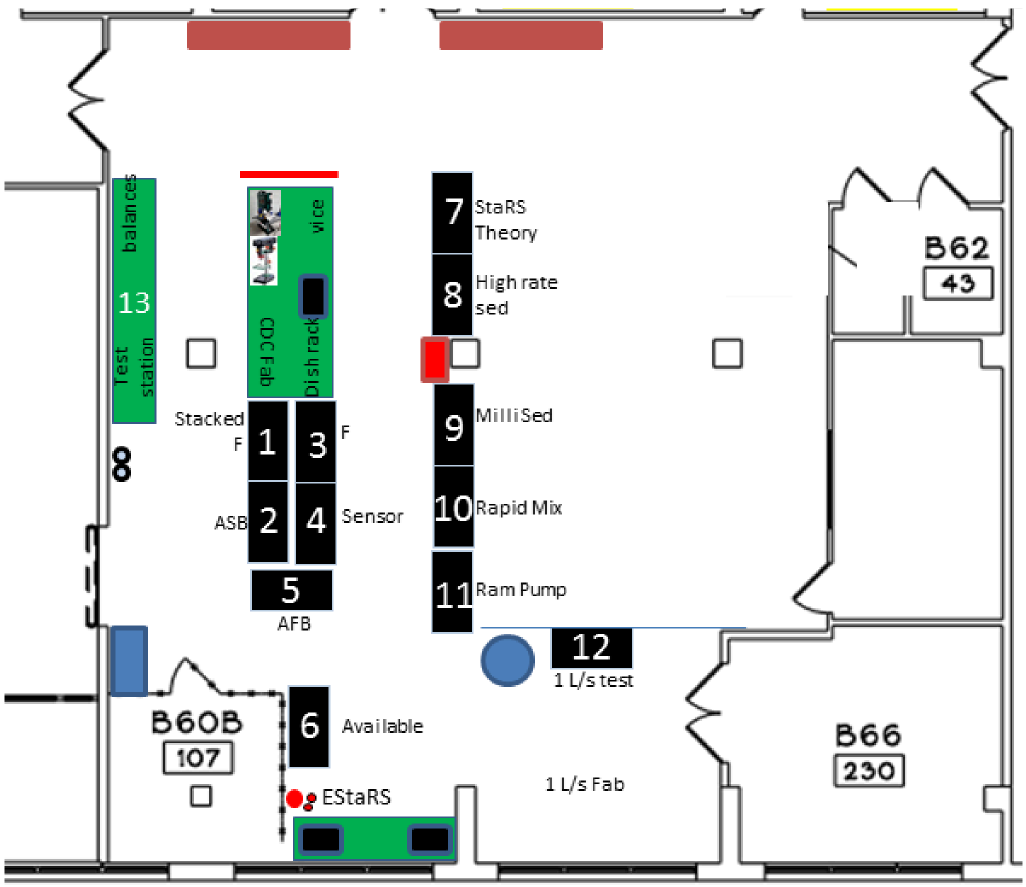
Team (with link to wiki)	link	**Contact For info**	**#**	**NTU**	**Perist Pump**	stirrer	Location
Going Global Teams							
Public Relations (3) + Webmasters(2) (CEE 2550 only)	↓	Erika Axe, Serena	5				B63
Business Team (CEE 2550 only)	↓	Daniel Cheong	3?				B63
Apps and Algorithms Teams							
Design	↓	Meghan, Kevin Juan, Serena	5				B63
Floc size and count app	↓	Casey	3				B63
POST app for plant operators	↓	Nicki Dell	3				B63
Wastewater Research Teams							
Anaerobic Fluidized Bed (AFB)	↓	Zoe Maisel	3	0	2	0	5
Anaerobic Settled Bed (ASB or UASB)	↓	Evan Greenberg	3	0	2	0	2

Sensor Development (Biogas production, Fluidized bed solids concentration, floc hopper probe)	↓	Zoe Maisel	3	0	1	03	4
Particle Removal Research Teams							
Rapid mix	↓	Jillian Whiting	3	2	3	1	10
High Rate Sedimentation (HRS)	↓	Josiah Hinterberger	3	2	3	1	8
Milli-Sedimentation	↓		3	2	3	1	9
StaRS Filtration Theory	↓	Theresa Chu, Lucinda Li	3	2	3	1	7
1 L/s plant testing	↓	Josiah Hinterberger	3	2	2	1	12
Dissolved Species Removal Research Teams							
Fluoride (EPA P3 Phase II grant)	↓	Auggie Longo	3	0	3	0	3
Countercurrent stacked floc blanket reactor (EPA P3 Phase II)	↓	Auggie Longo	3	1	3	0	1
Fabrication and Physics Teams							
Ram Pump	↓	Juan Guzman	3	0			11
Chemical Dose Controller (CDC)	↓	Auggie Longo	2				
Prefab 1 L/s Plant	↓	Juan Guzman	6				
Design and build 2nd Enclosed Stacked Rapid Sand (EStaRS) Filter	↓	Subhani Katugampala	3				
Total (19 teams)			57+6				

Opportunities for technical writing credit (by permission of instructor)

- EPA Phase I proposal (topic TBD, perhaps AFB piloting)

- Website content update
- 1 L/s plant brochure
- Document experience removing contaminants in Honduras based on operator reported data.
- Present a poster at the [New York Section of the American Water Works Association conference](#) (Submission deadline is November 4, 2016 for the spring conference. April 25 - 27, 2017 Saratoga Springs City Center and The Saratoga Hilton, Saratoga Springs, NY)
- Publish your team's research. The following teams have results that could be published this fall.
    - EStaRS theory
    - Ram pump



Going Global Teams

Public Relations ↥ CEE 2550 only

Skills: Writing, graphical design, networking

Tasks and goals

- Use social media to spread the word, raise funds, and recruit students to Cornell
- Biweekly synthesis of what is happening with the research effort to share with APP and post as a blog (assign this to one of the RAs)
- Introduce first year students to AguaClara at Engineering 1050 sessions
- Delete all of the spam comments from the wiki. You may need admin rights and if so we can provide them.

Business team ↥ CEE 2550 only (or through Cornell Business)

Skills: Writing, networking, business plans, financing

Challenges

1. Capital Inadequacy: communities *do not have sufficient capital* to invest in building with AguaClara technology
2. Development Risks: various risk factors that *hinder the flow of capital* into water treatment projects
3. Scarcity of External Capital: *few right-fit investors* that are able to align interests with communities desiring AguaClara technology

Tasks and Goals

1. Industry Mapping: understand the impact investing space, identifying and contacting investors and capital owners that have the potential to partner in AguaClara projects
2. Product Structuring: explore and iterate different private-public funding models that are *feasible for communities* and *attractive for investors*
3. Business Planning: translate models into scalable business plans that can be presented to potential investors and interested parties.

Webmasters ↥ CEE 2550 only

Skills: web design

Tasks and goals

1. Review the current website and create a new organizing framework
2. Rebuild the AguaClara.cornell.edu website to be mobile friendly
3. Update content in collaboration with the PR team
4. Improve the organization and navigation on the wiki

Timeline

- Dates of plant construction
- Dates of newly implemented technology
- Other notable events

Technology Pages

- Contains a higher level description of how the technology works
- Tells the story of how the technology developed
- Contains links to the current pages of the unit processes

Wiki upgrade

- Create unit processes pages in the wiki that contain links to all the related research. Example: there will be a sedimentation page with a brief overview of sedimentation then the links to all the sedimentation research with accompanying descriptions.

Plant Pages (could be in aguaclara.cornell.edu or in wiki)

- Contain funding, construction dates, basic plant info
- Detail when and what innovations occurred in the plant
- Contain links to project site webpages to supply viewer with up to date information (ex: https://confluence.cornell.edu/display/AGUACLARA/Ojojona)

[Idea: Transfer all this info to the existing project site wiki web pages?? Also it might be better to keep them separate so users don't have to sift through mountains of history to get to current info]

Upgrade the Design Engine web to be mobile friendly

The web pages created by the design engine need to be made mobile friendly. These pages are generated automatically by the design engine (coded in LabVIEW) and thus the page editing will be done by writing new LabVIEW code.

Apps and Algorithms Teams

'Design ↥

Skills: Writing, graphical design, coding, networking

Goal is to recruit a few students who are willing to commit more than one year to become experts in the AguaClara design approach.

Design algorithm changes

- Fix the drawing created by EtFlocSedFi method to show all layers when it is published. It currently only shows the walkways.
- High flow rate designs need to be repaired. Flow rates above about 60 L/s should switch to multiple treatment trains. This transition is not well defined yet, but the inlet channel for the sedimentation tank begins to be too large and it forces the creation of an oversized floc hopper. The transition flow value needs discussion with the engineers in Honduras, but for now it would be reasonable to make the transition at 60 L/s. Requests for high flow rates (100 L/s) currently result in a design for a 50 L/s plant. Apparently there is design code that sets it to 2 treatment trains, but that isn't incorporated into the rest of the design. Fix this so that higher flow rates draw a double treatment train and determine what flow rate is the actually transition to two treatment trains.
- In the piping structure of the major head loss hoses in the CDC, the four ½" pipes that extend upward have cap at the top with small holes drilled into them for air release. These pipes need to be extended further up, since the max chemical level in the system is approximately at the height of the entrance tank. Perhaps we extend 10 cm above that level.
- Change the entrance tank and floc drain elbows that exit into the drain channel into small, inclined openings or clefts to avoid elbow clogging. The opening need only be as wide as the OD of the union plus S.Fitting on each side. It will need to be located completely below the floc slab. We'll want the floor of the opening to slant down into the drain channel, perhaps at 45 degrees.
- Redefine the HW.SedInletChannelMax constraint in the Inlet Channel area in the Sedimentation Tank file dynamically according to sed tank and sed plate geometry so that there is always at least a 20 cm opening between the top of the floc weir and the bottom corner of the slab of the sed channels. (Perhaps this is a constraint on max flow per treatment train??) There is a note copied into that area which discusses other considerations for this change. Consult with Jon Christensen (jsc377) on this change because he was editing sed tank geometry in the summer of 2016.
- The float attached to the CDC balance in the entrance tank is being drawn askew. It looks like the float is in the right position, so the balance needs to be shifted over a bit.
- Add another union into the LFOM pipe so that the LFOM is not permanently poured into the slab there - the union allows the LFOM to be fabricated in a removable pipe stub. The top of this union should be slightly below the first row of orifices in the LFOM, and at least as high as the slanted concrete surface in that section of the entrance tank. Perhaps S.Fitting below the bottom of the lowest orifices? You may have to lengthen the pipe downwards so that the two unions (the existing rapid mix union and this new union) don't overlap.
- Add the dampener pipe stub into the LFOM pipe. This pipe stub dampens the free fall of the water into the LFOM pipe so that not as much air is entrained into that pipe which later exits into the flocculator. In the linked photo this pipe stub is fixed to an inner side of the LFOM pipe, but it would ideally be suspended in the middle of the pipe. What size pipe stub should we use so that we're not impacting flow through the orifices but still achieving some dampening? The

length of the pipe stub should be defined so its bottom is S.Fitting below the water level in the LFOM pipe, and extends up to S.Fitting above the top orifice(s) in the LFOM.

- Change the upper valve on the sed tank floc hopper drain to ½” to give the operator finer control over sludge wasting; the vertical piping could be 1” with a reduction down to ½” at the valve.
- We’ve found the filter inlet flow control weir system as drawn is not buildable because the masons can’t access the space between the two weirs. The thought is to make the second weir (the one with the slot) as drawn, and to install the first weir with plastic or metal sheeting once the masonry is complete. Could the first weir be one single removable sheet? How strong would it need to be? What’s an easy way for the operator to remove and reinsert it? Could it function like a sluice gate, or is that over designed? (Monroe’s suggestion is to build both weirs using ferrocement stop logs that are slid into vertical slots. Thus the masons would be able to access the weir system easily. This could be a structures challenge that is similar to the concrete canoe design.)
- When we are comfortable with the filter inlet modules with orifices, we should remove the purge valves from the inlet piping in the pipe gallery. This limits the draining of water from the filter with those purge valves to the lowest *exit*, so to be able to drain lower we’ve been installing an additional 1” drain at the floor of the filter box with a slotted pipe inside and a brass ball valve outside.
- In a 60 L/s design, one of the three pipes delivering water from the sedimentation exit canal to the filter distribution box appears in the middle of the plant walk way and does not connect to the filter distribution box.
- The filter overflow box/filter bypass that exists between filter entrance boxes does not need to be elevated, and can instead be left at the same floor level as the filter entrance boxes.

Create Design Engine website methods for individual components

These methods should give a good level of control to the user. Note that there were versions of these previously and then need to be tested and debugged given major software upgrades that occurred in the past year. Some of these are already completed. Test them over a wide range of user inputs to verify that the code is robust.

- Flocculator (input for depth should be total depth of water leaving flocculator rather than the depth of the floc blanket in the sed tank)
- Sedimentation Tank (Fix sed tank drawing error for high upflow velocity)
- Labels for LFOM, calibration columns (write code to add labels to drawings)

Documentation updates

- Verify that all variables that a client might want are being reported in the About file
- Make sure that no variables are undefined in the top level Mathcad file
- Repeat this check for all methods that are published by the design engine
- Create the stock set of flow rates in consultation with AguaClara LLC and APP. It is likely that the designs would simply increment the number of sed tanks and always make the sed tanks the same size for flows with more than 2 sed tanks.

Section cuts

Implement section cuts to show critical components of the plant and find a method to publish those sections cuts. It is possible that section cuts can be published as png files for display on the web page and as layouts in the AutoCAD file. A key for cut locations should be visible in the drawings. Work closely with a team of AutoCAD and MathCAD experts from AutoDesk to develop the Section Cuts capability of the tool. Students working with the team will help develop the project plan and establish the deliverables. Students will be responsible for explaining the goals of the tool and how it relates to AguaClara as a whole, and for keeping the team on track. This will include weekly meetings with the AutoDesk team remotely.

Graphic art

Create professional images for design specification documents.

Backwash recycle

Add an option for Backwash recycle. Evaluate options for a low head, low flow pump that could be used to slowly pump water from a lagoon or holding tank below the plant to the entrance tank. The other option is a high flow rate pump that would be located in the drain channel and that would pump all the backwash water to a holding tank uphill from the entrance tank. The first option may be better because it would allow some sedimentation in the holding lagoon and thus reduce the solids management that would be required in a holding tank uphill of the plant. Continue work from Spring 2016 on determining the necessary capacity given a specified flow rate. Communicate with engineers in the field to discuss Zamorano plans (not currently implemented).

OStaRS filter upgrade

Work with the fabrication team starting later in the semester to add any new components for the filter design that are ready to incorporated. This will likely include filter slots, hinged platform for filter assembly, and new filter module spacers. Continue work from Spring 2016.

OStaRS molds (completed by Cinthia Spring 2016)

Paul Charles recently provided his AutoCAD files for these molds and they are included in the sourceforge docs. Publish the design of these molds with the design engine.

Facility coordinates from AutoCAD to the Construction site

How could the design data be taken all the way to construction site in as convenient a format as possible? There is undoubtedly a place for printed drawings to provide guidance for the construction team. Could the critical elevation data and xy location data for plant components be connected to a total station? What would be the best way to ensure that elevations are correct in a facility?

Floc size and count app ↥

Skills: User interface, coding in LabVIEW

Turbidity measurements provide the primary source of performance monitoring at many water treatment plants. Turbidity provides an excellent way to measure overall plant performance, but it does not provide insight into WHY the water treatment plants are performing well or poorly. We are learning more about the interaction between collision potential, energy dissipation rate, floc strength, and floc size. It is becoming clear that a low cost meter capable of measuring floc size distribution could provide much needed insight and diagnostic power to improve the flocculation, sedimentation, and filtration processes.

Digital cameras are capable of counting and sizing clay particles and flocs with the right software. Designing hardware to collect the images is relatively easy. The more challenging task is to create an app that is user-friendly and that provides real time useful interpretation of particle size distributions. The goal is to develop an app that is capable of being deployed in the AguaClara project lab and in water treatment plants in Honduras. It is possible that this tool will be used routinely for floc size measurements in the flocculator to guide coagulant dosages.

The app will need a well designed architecture for acquiring and processing images. The image processing routines will need to be carefully designed to handle changing lighting conditions and to provide feedback to the user to optimize image analysis.

The app is written using LabVIEW for easy deployment on a laptop. Licensing of the National Instruments vision acquisition software and vision development module costs approximately $430 per installation and National Instruments will subsidize that to help us develop a market for this new tool.

Features of the app will include:

- event loop to handle user actions
- configuration dialog box
- configuration files to store user settings (pixel size, image processing inputs)
- visual feedback on the step by step image processing with advice on how to improve the identification of in focus flocs.
- real time particle size distribution analysis with options for continuous sampling or for grabbing a set number of images for analysis
- data storage format for processed image data to allow rapid viewing of trends over time (perhaps a sorted array of floc areas)
- Possible integration with other data streams including turbidity, plant flow rate, coagulant dose

The current design of the image acquisition hardware requires that a sample stream flow through a cell. This flow cell will likely be the best option for deployment in water treatment plants although options for building a submersible unit could also be explored.

A draft version of this app was created during the spring of 2016. The goal for this semester is to add image acquisition, demonstrate the app using the imaging hardware, and then test the app with one of the AguaClara research teams. As testing with real users begins additional features can be added based on user needs.

Resources

Sun, Siwei; Weber-Shirk, Monroe; Lion, Leonard W. Characterization of Flocs and Floc Size Distributions Using Image Analysis. Environmental Engineering Science, Volume: 33 Issue 1: January

26. (201tion. Reducing the environmental impact requires reducing the emission of greenhouse gasses (dissolved methane in the effluent), biodegradable organics, and nitrogen and phosphorus. 6).

Plant Operations Smartphone Tracker (POST) ↥

Skills: Computer science, Graphical User Interface

The Plant Operations Smartphone Tracker is a suite of programs for monitoring, analyzing, and packaging daily water quality information from AguaClara plants. Currently operators from three plants (Morocelí, Jesus de Otoro and San Nicolas) regularly record water quality information with the POST data collection app (data). The goal for this semester is to improve the visualizations and data analysis in the POST visualizations app. If implemented well, the visualizations app could become a critical tool for helping operators run a well performing plant by providing coagulant dose recommendations, filter backwash reminders, a stock tank concentration calculator, stock refill reminder and more. More proposed visualizations/ automated operational feedback are located here. This team will be in regular contact with the field engineers in Honduras to collect plant operator feedback on the app design. Additionally, this semester should be focused on implementing an automated analytics collection component that will collect data on which functions of the app are used most. If done through Google Analytics, we could use the batch updating function to attempt to send the analytics only when connected to the internet.

Lessons learned from last semester:

- The plant data can only be synchronized when connected to the internet. We store the data for viewing offline at the plant. However, ensuring the synchronization is operating correctly is challenging and requires an exposed API through Google Fusion tables. We need a point person to ensure the backend is maintained and exposes the right functionality for the front end.
- Getting feedback from the field takes a long time, and any changes to reporting procedures take a long time to push to the operators.
- Testing directly on an actual android device is necessary to ensure the program is working correctly.
- Well-maintained documentation in code and on the repo wiki and in github issues is necessary to keep the project organized and efficient.

Wastewater research teams ↥

Another goal of this project is to generate a publishable paper recording our design and execution process including insights we've gained from analytics data. This will be done in collaboration with Nicki Dell, our faculty advisor.

Our goals are to reduce the capital cost, the operating cost, and the environmental impact of wastewater treatment. Reducing the capital cost requires decreasing the hydraulic retention time in the treatment processes. Reducing the operating costs requires elimination of aera

The long residence time required in anaerobic settled bed, UASB, reactors is likely the result of poor mass transport to the settled sludge containing the anaerobic microorganisms. Given the slow growth rate of anaerobic bacteria it is critical that the reactor design keep all of the bacteria in contact with the nutrients that must be digested.

An effective wastewater treatment reactor must be very effective at separating the retention of the solids from the hydraulic residence time. Upflow fluidized bed reactors with plate or tube settlers above the fluidized bed have the potential to have a high ratio between solids retention time and hydraulic retention time.

To bring anaerobic wastewater treatment technology to the place where it is viable for more communities in the global south we need to do the following:

- decrease hydraulic residence time
- design, invent, and test reactor geometries to obtain high reliability and minimal maintenance
- ensure that the reactor operation is stable during startup, shutdown, and flow fluctuations.
- design and fabricate a portable scale model plant that can be tested in a community using fabrication techniques that are being developed for the 1 L/s sedimentation tank.

Lessons learned for design of laboratory anaerobic reactors

- Wastewater superstocks containing the trace ingredients should be prepared to simplify preparing synthetic wastewater
- Tubing carrying tap water should enter the fridge and dilute the stock on its way to the inlet of the reactors
- Tubing carrying the synthetic wastewater to the reactor should be as short as possible
- Tubing carrying synthetic waste must have a high velocity (perhaps 0.1 m/s) to prevent sedimentation and excessive biological growth.
- Reactors in series must be closed (not open to the atmosphere) to reduce risk of overflow.
- Rising plugs can be eliminated in ASB reactors by using very low upflow velocities.
- Rising plugs in AFB reactors are a major problem that must be solved before research on AFB can proceed.
- Gas measurements based on fill and vent of a cylinder based on pressure measurements is effective, but the sensor/cylinder should be separate from the reactor column and filled with clean water to prevent solids build up in the measurement cylinder.
- Quick connect fittings should not be used where gas tight fittings are required.

Anaerobic Fluidized Bed (AFB) ↥

Skills: fluids, fabrication, ProCoDA, Mathcad

Big questions to answer

- Is it necessary/helpful to reduce the mass transport of nutrients to the biomass to prevent excessive volatile acid concentrations? If so then...
  - slope the reactor to promote short circuiting
  - invent a different method to reduce the concentration of nutrients around the biomass

- Do we need a method to reduce dissolved methane before we take a prototype reactor to the field? If so, then...
    - Use a venturi in a low pressure zone to inject air
- How can the bacteria concentration in the AFB be increased to reduce the
- required Big questions to answer

1. What is the maximum organic loading rate that can be a residence time? This may require a redesign of the AFB geometry and could benefit from floc blanket concentrators (plate settlers in the sludge blanket) if that technology proves viable. (Collaborate with High Rate Sedimentation teams)
2. What minimum hydraulic residence time is needed for adequate waste degradation?

Tasks and goals

- Develop a method to prevent rising plugs of solids held together by friction and surface tension. The selected method doesn't have to be scalable to reactors in Honduras because this problem is most likely only a problem in very small diameter reactors. This must be the first task. One option is [a solenoid]that would be attached to a long rod with crossbars to vibrate the solids in the reactor. Don't assume the link is the best solenoid! Note that ProCoDA delivers 24 V DC that can be used to directly drive a solenoid.
- Build new reactors (or modify the existing ones) with tube settler zones sloped at least 60 degrees (this can be done with heating/bending), with the reactors in series closed to the atmosphere to prevent overflows, and with gas vents that are tall enough to ensure that the hydraulic grade line never gets to the top of the gas vent. A microbore tube can connect the vertical gas vent tube on the top of the tube settler to the [gas sensors].
- Use 1.8 mm/s upflow velocity initially based on the settling velocity of the granules.
- Head loss was greater than expected because we didn't account for the fluidized bed density. This head loss makes it imperative to switch to closed reactors (last one can be open) to eliminate overflow.
- Measure gas production as the primary source of data. The hydraulics of the reactor and sensor system must be designed together to ensure that the gas collection system doesn't fill with wastewater. There is no need to measure Chemical Oxygen Demand, COD, on a routine basis. Use the gas production data corrected for the soluble methane fraction to assess how much of the COD is being degraded by the reactor system.
- Develop a Mathcad sheet that calculates gas production for your experimental apparatus

Resources

- Literature on UASB variations including Expanded Granular Sludge Bed (EGSB)
- [SSWM's page on UASBs].

Anaerobic Settled Bed (ASB or UASB) ↥

Skills: microbiology, fluids, fabrication, ProCoDA, Mathcad

3. plied to the UASB without causing failure? Industrial uses of ASB reactors treat waste exceeding 10 g/L COD. How does this compare with the maximum COD of a toilet water collection system?
4. What is the hydraulic residence time in the settled bed of granules?
5. Is autoclaving stocks necessary? Refrigeration would prevent significant biological growth for approximately 1 week. Thus if the stocks are replaced at weekly intervals then there is no need to autoclave. The stock containers must be thoroughly cleaned (perhaps with dilute bleach) before reuse.

Tasks and goals

- Measure the hydraulic residence time of the settled bed reactors. Fluoride could be a good tracer given that we have a fluoride probe and fluoride should be a good conservative tracer.
- Red dye may also be worth testing for residence time unless it is degraded by the granules before reaching the effluent.
- Switch to improved gas sensor as soon as the sensor team fabricates them
- Measure performance as a function of organic loading rate (holding upflow velocity constant) to determine the maximum organic loading rate
- Develop a Mathcad sheet that calculates gas production for your experimental apparatus

Sensor Development ↥

Skills: electronics, fluids, fabrication, ProCoDA, Mathcad. LabVIEW coding

Big questions to answer

1. How can the gas production (and hence the efficiency of the anaerobic reactors) be measured easily, continuously, and accurately?
2. How can the solids concentration in the AFB reactors be measured routinely (ideally with a turbidimeter or other continuous measurement system)?

-Tasks and goals

- Evaluate gas measurement systems, choose the best one and develop it for use by the AguaClara Wastewater teams. Ideally complete this task by the end of September so that the AFB and ASB reactors can begin using these sensors.
- Design, build, and test a fluidized bed solids concentration sensor

Gas measurement systems

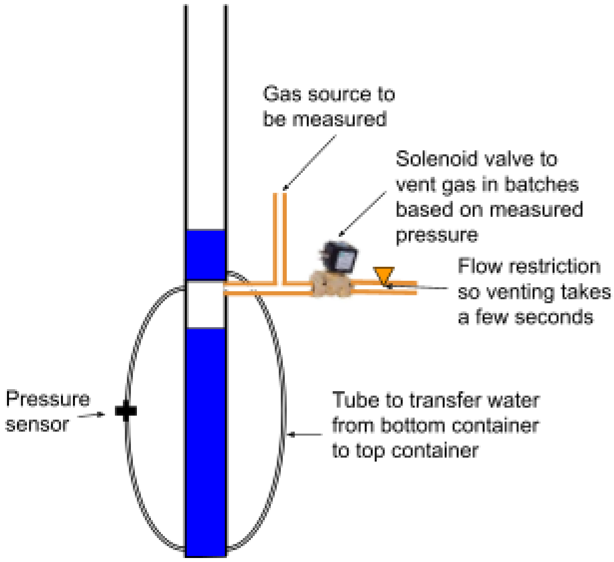
Name	How does it work	challenge
Pressure-vent using wastewater fill	Tube collects gas that displaces wastewater, pressure sensor triggers	Tube fills with solids (not a great option)

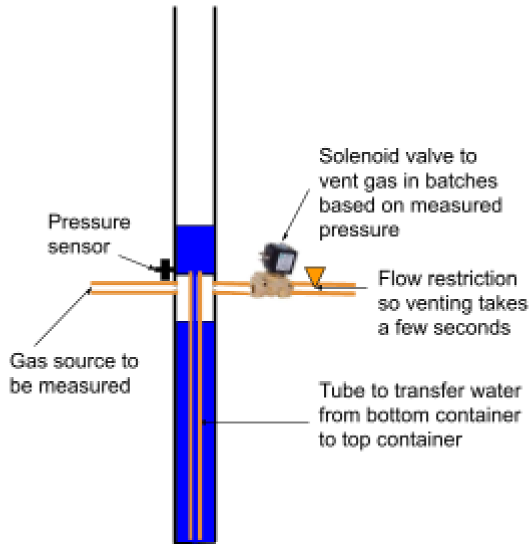
	solenoid valve	
Pressure-vent using clean water fill	Gas is collected from reactor and transferred via tube to a sample column where the gas displaces water.	Design a two container system so that displaced water is recycled. This is the best option for the first set of sensors.
Pressure-vent using compressed gas	Gas is collected in a small tank that is full of gas and connected to a pressure sensor. Tank vents to atmosphere when pressure exceeds a target. PV=nRT. Atmospheric pressure changes will require a correction.	Will pressure fluctuations cause any problems with the wastewater reactors (not preferred due to the larger pressure fluctuations)
Methane sensor	Methane sorbs to sensor surface and changes conductivity. Advantage is that it measures methane rather than total biogas. Disadvantage is requires a pump.	Sensor calibration was inconsistent. Further testing required to determine if the sensors are reliable

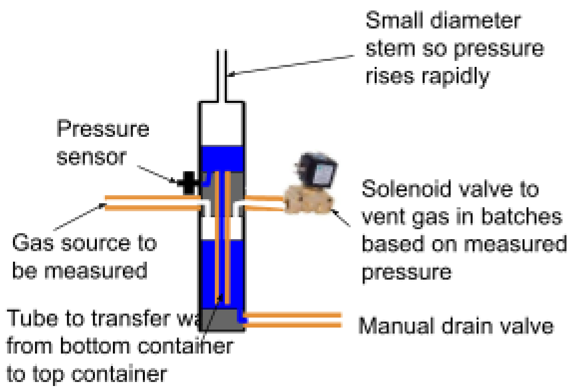
Below are three sketches of the pressure-vent using clean water fill.The 3 sketches show a design progression that simplifies plumbing, shortens the reactor height, and increases the precision of triggering the gas release. The 3rd design can rely on time to exit the vent state rather than on pressure because the upper chamber can empty completely. Thus the solenoid valve can open and stay open for a fixed amount of time. This will improve the accuracy of the volume measurement. An ideal gas measurement device will only create a few cm of back pressure and thus the distance between the bottom of the bottom chamber and the top of the top chamber should be limited to 5 cm if possible.

The volume of gas measured in a single cycle should be much larger than any single gas release events (burbs) from a ASB reactor. ProCoDA response time for triggering opening of the vent valve is a function of how much data averaging is required. It is likely that 100 ms of data (25 data points at 2.5 kHz) is sufficient to get a good pressure measurement from the pressure sensor. The vent time must be small (perhaps 1%) of the fill time so that gas lost during venting is insignificant. The sensor software could correct for this loss. The vent time is controlled by the head loss of the water flow from the upper chamber to the lower chamber.

It may be reasonable to vent gas as frequently as several times per minute.







The sensor system will require software to connect the sensor to ProCoDA. The gas sensor software will be a state machine that automatically cycles between fill and vent states. This state machine will be written to be an external code that can be linked to ProCoDA.

External code that connects with ProCoDA can have multiple inputs, but only one output. The sensor system will require an output to control the solenoid valve and a second output that calculates gas production in moles or volume at standard temperature and pressure. Given that each piece of code can only have one output, this can be accomplished by creating two separate pieces of external code. The first code controls the vent valve and will take the inputs of

- pressure sensor
- vent time
- trigger pressure given as change in pressure between empty and full

The output will be either a zero or one to control the solenoid valve

The second code is the gas volume meter and will take the inputs of

- Solenoid valve control (output of the first code)
- Temperature
- Sample cell volume per cycle in mL
- vent time

- Reset state (a state ID number that will cause this code to reset the totalizer for gas production)

The gas volume meter will correct gas production (based on the time between venting events and the vent time) for the time spent venting. The output will update when the vent valve control changes to a 1. The output could be either total moles of gas or volume at standard temperature and pressure.

Fluidized bed solids concentration

The solids concentration in floc blankets and in AFB reactors is a useful parameter required to understand the reactor performance. In AFB reactors the solids concentration is a measure of biomass and hence is related to the ability of the reactor to convert organic waste into methane and carbon dioxide. Build an LED and photosensor (such as the one used in our dye detectors) with the LED held on one side of the reactor and the photosensor on the other side. Perhaps build the first sensor to work on the 1” diameter AFB reactors. Measure the photosensor output with ProCoDA and develop a method to correlate signal intensity with solids concentration.

Floc Hopper probe

This sensor was developed in previous semesters but has not been deployed in Honduras yet. Make it professional. Package it. Test it in the 1 L/s plant. Then take it to Honduras in January to field test it.

Particle Removal Research Teams ↥

Our goals are to reduce the capital cost, reduce the operating cost, and improve the particle removal efficiency so that the AguaClara technologies are the best. We want to...

- Assess the utility of a contact chamber after rapid mix to allow diffusion to transport nanoclusters to coat the particle surfaces
- Test higher rate sedimentation tanks
- Design and test tapered flocculation to increase the floc volume fraction that is actively growing from collisions
- Learn what controls performance of sand filters so that sters to the reactor walls?
- Can coagulant dosages be significantly reduced for low we can improve the performance of the StaRS filters

Rapid mix contact chamber ↥

Skills: Fabrication, fluids, physics

Big Questions to Answer

- How could we design a contact chamber that would allow coagulant to diffuse to particle surfaces while minimizing the loss of nanoclusters?
- Can we and should we create scalable design algorithms for contact chambers especially for

low flow plants?
- Could the floc size and count app be used to monitor deposition of particles on the wall of the flow cell?

Bigger Questions

- What limits the deposition of particles on the inside of a flocculator tube? There is some evidence deposition levels off in high shear flocculators perhaps based on a maximum shear that can be maintained. Is this because of equal rates of deposition and breaking off or because excessive coverage of coagulant nanoclusters reduces the attachment strength?
- Can we learn something about filtration mechanisms by modeling the flocculator tube as a long pore in a porous media filter?
- Is there a maximum shear value at which nanocluster deposition occurs?

Background

Coagulant loss to the flocculator walls is significant especially when influent turbidity is low and for geometries where the distance between reactor walls begins to approach the spacing between particles. This coagulant loss leads to higher operating costs. It may be possible to improve performance and reduce operating costs by adding an appropriately designed contact chamber to allow time for the coagulant nanoclusters to diffuse to the particle surfaces in a flow geometry where the reactor walls are further apart. The rapid mix jet could be used as a source of mixing in the contact chamber to provide initial flocculation.

In the spring of 2016 this team demonstrated that a contact chamber improved performance as measured by turbidity reduction after sedimentation. The original goal had been to measure coagulant build up on the flocculator tube walls based on a change in mass. The mass change was too small to be detectable with an electronic balance and that led to the use of the more indirect measure based on settled water turbidity.

Casey Garland recently demonstrated that there is significant increase in head loss in laminar flow tube flocculators over a period of 24 hrs. This head loss is due to some combination of clay particle and coagulant precipitate nanocluster accumulation on the tube walls. The head loss measurements could be used to determine the thickness of the deposited layer. Ideally 4 differential pressure sensors could be connected each measure a 1/4 of the flocculator.

Flocculation and attachment to the tubing wall happen simultaneously in a tube flocculator. Flocculation causes an increase in the particle size and that likely results in reduced attachment efficiency. Thus there would normally be many more particles that are small enough to attach to the walls at the beginning of the flocculator than at the end of the flocculator. We would like a tube that would allow deposition of nanoclusters, but not of clay particles or flocs. We can likely create a reactor with these characteristics by operating at a very high wall shear.

The ability of clay particles to attach to the tube wall could be reduced by operating the flocculator at a very high wall shear. It is likely that velocity gradients at the wall in excess of 1000 Hz would prevent clay particles (with coagulant nanocluster deposition) from attaching to the tubing walls. Attachment of flocs to the walls would likely be less likely because the torque acting on the particle increases rapidly with particle diameter.

This experimental setup has the potential to give us more insights into how particles interact in filters and in flocculators. The long flocculator tube is a simple model of a porous media filter (one long filter pore).

Tasks

- Design a straight tube flocculator that has about 1 m of total head loss monitored by 4 differential pressure sensors (each monitoring ¼ of the tube length). The average velocity gradient should be 1000 Hz or greater. The goal is to have a velocity gradient that prevents deposition of clay particles but that enables deposition of nanoclusters of coagulant.

$$G_{ave} := 3000\text{Hz}$$

Set to be larger than 1000 Hz

$$\varepsilon_{ave} := G_{ave}^2 \cdot \nu = 9\,\frac{\text{W}}{\text{kg}}$$

$$h_{fTube} := 1\text{m}$$

Set for easy measurement with 7 kPa (70 cm water) pressure sensors when divided into 4 sections

$$\theta_{Tube} := \frac{h_{fTube} \cdot g}{\varepsilon_{ave}} = 1.09\,\text{s}$$

Assume a diameter and a straight tube. Use Hagen Pouiselle equation to find the required velocity.

$$D_{Tube} := \frac{1}{16}\text{in}$$

$$V_{Tube} := D_{Tube} \cdot \sqrt{\frac{h_{fTube} \cdot g}{32 \cdot \nu \cdot \theta_{Tube}}} = 0.842\,\frac{\text{m}}{\text{s}}$$

$$Q_{Tube} := \frac{\pi}{4} \cdot D_{Tube}^2 \cdot V_{Tube} = 1.666\,\frac{\text{mL}}{\text{s}}$$

$$L_{Tube} := V_{Tube} \cdot \theta_{Tube} = 0.917\,\text{m}$$

$$h_f = \frac{32\mu L V}{\rho g D^2}$$

$$L = V\theta$$

$$h_f = \frac{32\mu\theta V^2}{\rho g D^2}$$

$$V = D\sqrt{\frac{h_f \rho g}{32\mu\theta}}$$

$$Q = VA$$

$$Q = \frac{\pi}{4} D^3 \sqrt{\frac{h_f \rho g}{32\mu\theta}}$$

-
- Measure head loss accumulation due to the attachment of nanoclusters to the tubing wall. Use zero turbidity, inject the coagulant at the entrance to the tube, and measure head loss as a function of time. Vary the flow rate to see if you can find the point at which nanoclusters no longer attach to the tube wall. If necessary design a reactor that can operate at even higher velocity gradients.
- Operate the reactor at a velocity gradient that allows nanocluster attachment but that is close to a velocity gradient that doesn't allow nanocluster attachment. Then introduce 50 NTU clay into the raw water. The introduction of clay should reduce the accumulation of head loss because more of the nanoclusters will deposit on the clay.
- If the clay reduces the rate of head loss accumulation, then you have a reactor design that can measure the concentration of free nanoclusters because head loss accumulation rate is related to nanocluster concentration. Use this to measure the effect of adding contact chambers.
- Repeat the previous experiment with 5 NTU and no contact chamber to verify that some nanocluster loss to the walls occurs.

- Repeat the previous experiment and with the two different sizes of contact chambers that were used by the team in the spring of 2016. Measure the head loss as a function of time across the flocculator. If coagulant nanoclusters are coating the flocculator tube walls, then the contact chamber should decrease the accumulation of head loss through the flocculator.
- See if you can develop a model for the required residence time in the contact chamber based on diffusion of the nanoclusters to the clay particles.

This research is fundamental and has the potential to provide many different insights depending on how the research unfolds. We could learn about forces involved in attachment of particles, maximum viable velocity gradients in flocculators, and limitations to particle capture in porous media filters.

ResourcesFractal flocculation model (Mathcad worksheet available in the AguaClara code base)

Rapid mix notes from CEE 4540 with discussion of diffusion time required after rapid mix

High Rate Sedimentation ↥ (EPA P3 Phase I grant)

Skills: fabrication, ProCoDA, experimental design

Our goal is to significantly increase the upflow velocity in sedimentation tanks while keeping settled water turbidity well below 1 NTU so the filter can get it below 0.3 NTU. This project has an EPA Phase I grant and will be competing with teams from about 40 other universities for Phase II funding in April of 2017.

Introduction

Sedimentation is the slowest process in the flocculation, sedimentation, filtration treatment train. The residence time of the current model of the AguaClara flocculator is about 8 minutes. The StaRS Filter residence time is about 1 minutes. The residence time for the sedimentation tank is about 24 minutes (based on version 7127 design for a 20 L/s plant). This is more than 8 times faster than the traditional 4 hour residence time horizontal flow sedimentation tank. Part of the low residence time for AguaClara sedimentation tanks is that our tanks are less than half the depth of traditional sedimentation tanks. Although this reduces the cost of construction somewhat, it is even more helpful to reduce the plan view area of the sedimentation tanks. Thus an increase in the upflow velocity through the sedimentation tanks would result in a direct decrease in plant construction costs.

Any significant further reduction in size of AguaClara facilities will likely be in the sedimentation tank. The current design sedimentation tank upflow velocity of 1 mm/s was set prior to 2010 in an effort to produce efficient sedimentation before AguaClara had invented the StaRS filter. Later that upflow velocity was determined to be in an efficient range for floc blankets. The challenge now is to invent an ultra-high rate sedimentation tank with upflow velocities between 2 and 10 mm/s. The plate settler capture velocity of 0.12 mm/s could be increased somewhat, but with a much higher upflow velocity the spacing of the plate settlers may need to be decreased and/or the length of the plates increased.

The constraint of approximately 1 mm/s on upflow velocity for the floc blanket has evolved because higher upflow velocities will produce very dilute floc blankets or no floc blanket because there are few flocs that settle much faster than 1 mm/s. However, it may be possible to invent a whole new approach to floc blankets that will facilitate higher upflow velocities.

Plate settlers can easily have a capture velocity that is 1/10th the upflow velocity. Thus it might be possible to design plate settlers for an upflow velocity of 2 to 10 mm/s and a capture velocity of 1 mm/s. The 1 mm/s capture velocity would capture the same flocs that are normally captured by an AguaClara floc blanket.

Design objectives for the AguaClara sedimentation tank

- Low effluent turbidity (less than 1 NTU under most conditions)
- Can be taken offline for any maintenance by a single operator
- Hydraulic solids removal with zero sludge accumulation
- Floc blanket to improve turbidity removal and to improve flow distribution through the plate settlers
- High concentration of solids in the sludge to reduce the amount of water that is wasted
- The solid components of floc blanket concentrators must not occupy much volume because any volume occupied reduces the residence time in the floc blanket.

Discovered in Spring 2016

- Adding plates in the floc blanket may improve performance, further research required
- Obtained settled water turbidity of 2.8 NTU while operating at 4 mm/s.
- Floc breakup in small diameter tube between flocculator and sed tank caused poor performance.

Challenges for Fall 2016

- Get the settled water turbidity down below 1 NTU
- Design and operate the reactors such that the floc blanket extends up through the plate settlers
- If necessary, design a better apparatus for testing plate settlers in a sed tank
- Possibly add floc app capabilities
- Possibly add method to measure floc blanket concentration

Big questions to answer

- Can the upflow velocity in the AguaClara sedimentation tank be significantly (factor of 2 to 10) increased without degrading performance?
- Can flocs be transported to a floc hopper when there are high upflow velocities in the sedimentation tank?
- What geometry is required for the floc blanket section of a high rate sedimentation tank?
    - Is it important that the floc blanket section of the reactor (including any internal components designed to increase floc blanket concentration) have an axis of symmetry

that is vertical to eliminate excessive transport of flocs by gravity in a horizontal direction? If the floc blanket section should be vertical, then the reactor should include a vertical pipe section followed by a sloped section for the tube or plate settlers. This question is critical for the Prefab 1 L/s plant fab team because it will determine if they can use a single sloped pipe for a sedimentation tank or if they need to use a vertical section joined to a sloped section.
    - Can plates (zig zag, porous, sloped or horizontal, or other geometries) increase the concentration of a floc blanket at high upflow velocities?
    - Should the plate settlers be submerged (perhaps 2.5 cm) in the floc blanket? This might improve flow distribution through the plate settlers and might increase floc blanket concentration.
- What sets the minimum residence time of the 0.12 mm/s plate settlers?
- Why do we need filters? Why can't we design a plate settler system that eliminates the need for subsequent filtration? Could a two stage plate settler system with a small spacing honeycomb used as the 2nd stage in the sedimentation tank eliminate the need for filters? The 2nd stage settlers might be too small to be self cleaning and thus a down flush might be required. This could become a new team!

Floc blanket concentrators

Our current understanding is that the floc blanket provides opportunities for the flocs that exit the flocculator to have additional collisions with each other. The flocs in the floc blanket are at their maximum size and thus the flocs exiting the flocculator can't attach to the floc blanket flocs. Thus the primary role of the floc blanket flocs is to generate shear that produces collisions between the flocs that recently exited the flocculator. The shear in the floc blanket can be calculated based on the floc blanket bulk density, the head loss through a fluidized bed, and the relationship between average velocity gradient and head loss.

$$G = \sqrt{\frac{gV_{Up}}{\nu}\left(\frac{0.687C_{FlocSolids}}{\phi_{FB}\rho_{H_2O}}\right)}$$

The concentration of flocs in the floc blanket decreases rapidly as the upflow velocity increases. The floc concentration is also strongly dependent on the concentration ratio of coagulant to particles and to conditions in the flocculator. In any case, the floc blanket has been demonstrated to significantly improve particle capture by sedimentation tanks and a dilute floc blanket is not expected to be of much value.

Maintaining a concentrated floc blanket with a higher upflow velocity will need an innovation. The goal of this team is to test geometries that keep a high concentration of flocs in the floc blanket and that allow higher upflow velocity through the floc blanket. We also have not tested the limits of the upflow velocity in the current AguaClara sedimentation tank geometry and thus that can be a first step. Perhaps we can increase the depth of the floc blanket to compensate for a decrease in concentration that will be associated with higher upflow velocities.

One option for increasing the floc blanket concentration is to add surfaces with horizontal components in the floc blanket. The floc blanket concentrators should cause flocs to slide horizontally distances that are small compared with the vertical distance between floc concentrators. This will enable the falling plume of flocs to mix with the upward flowing fluid. To avoid having a net flow of flocs in a horizontal direction the floc concentrators should alternate directions.

- Design a simple geometry and experiment to test the hypothesis that sloped surfaced in a floc blanket can be used to increase the floc blanket concentration. It is likely that you can use the sedimentation tank reactor that was fabricated last semester and simply design a better flocculator including the connections between the flocculator and the sedimentation tank. The flocculator could be based on the best available design from Casey Garland. A Gθ of 20,000 and a G of 250 Hz could be a reasonable starting place for the flocculator. Note that you may need to modify the flocculator or operate flocculators in parallel to test higher upflow velocities.
- Porous plates for floc blanket thickeners that have sufficient solid area to create a capture velocity of 1 mm/s. They should also have an L/S ratio of at least 20. Porosity could be 0.5 with initial hole size set to be 1/10th of S

An alternate method to increase the floc blanket concentration is to recycle flocs from the top of the floc blanket through a floc hopper and then down a vertical tube to be resuspended at the jet reverser. This method will require an efficient collection and concentration system for the flocs at the top of the floc blanket and thus the floc hopper will become a larger fraction of the sedimentation tank. This method seems to shift plan view area from the floc blanket to the floc hopper and thus it isn't clear that it is a net gain unless the floc hopper can incorporate plate settlers to increase the rate of sedimentation. The increased density of the sludge in the floc hopper should make it possible to transfer the sludge to the jet reverser with a simple tube (no pumping needed).

Milli-Sedimentation ↥ (EPA P3 Phase I grant)

Skills: lab experience, fluids, ProCoDA, Mathcad

Big questions to answer

- Can horizontal small diameter tubes of approximately 1 mm in diameter be used to capture the small flocs that currently escape plate settlers?
- Do particles stick to the tube walls until the velocity gradient is too high and thus do the tubes progressive fill with flocs from the inlet toward the outlet?
- Could honeycomb packs of small tubes be cleaned by a short duration high flow?
- Would Milli-Sedimentation replace the need for porous media filters?
- Is gravity a significant transport mechanism and hence is horizontal flow important?

Introduction

The big differences between particle capture by a plate settler and by a sand filter is that the plate settler is mostly self cleaning, the flow geometry is bigger in a plate settler, and the streamlines are curved in a sand filter. This raises the possibility that a short section of small diameter extruded plastic honeycomb material could provide the same function as a porous media filter. We have evidence that particles attach to the inside of tube flocculators and thus particles could be removed by a bundle of coffee straws. The potential advantages of a milli-sedimentation tank are

- Much higher porosity than sand
- May be able to design for higher solids capability by using a series of decreasing diameter tubes
- May be more compact than a sand filter
- Will be much lower weight than a sand filter for ease of transport

Potential disadvantages are

- Cleaning may require very high velocities (but a short burst of high velocity may be all that is needed)

Tasks

- Design a milli-sedimentation test apparatus using horizontal flow through plastic honeycomb material or a bundle of straws.
- Measure the pressure drop across the milli-sedimentation apparatus
- Use a similar influent to the design used by StaRS Filtration theory (see below)
- If possible observe how the tubes fill with flocs
- Test methods to clean the straws

StaRS Filtration theory ↑

Skills: lab experience, fluids, ProCoDA, Mathcad

For more information, PLEASE contact Lucinda Li (ll555@cornell.edu), Theresa Chu (tyc29@cornell.edu), and Jonathan Harris (jdh345@cornell.edu)

Discovered in recent semesters

- Need to add humic acid to clay to make a more realistic synthetic raw water
- Increasing PACl dose increases rate of head loss accumulation
- Mass of PACl in filter doesn't directly correlate with head loss
- There is an optimal PACl dose for pC* (this means there are two mechanisms at play to create an optimal value)
- Effluent turbidity first improves with filter runtime (see figure 14 of the Spring 2016 report) and then deteriorates. The deterioration can be explained by the filter pores reaching their particle retention capacity. The improvement that can occur over a period of hours is a puzzle since the top of the filter must be slowly reaching its particle retention capacity and it is unclear why that would improve particle capture. One possibility is that the increased head loss corresponds to an increase in collision opportunities (flocculation)in the pores. Combination of Hagen Poiseuille equation (head loss in laminar flow), definition of the average energy dissipation rate, and Gθ reveals that Gθ will increase as the pore diameter decreases in a filter. Thus

flocculation inside a filter bed will improve as the filter clogs because clogging is essentially a reduction in the pore diameter.

$$h_f = \frac{32\mu\theta V^2}{\rho g D^2}$$

$$\bar{\varepsilon} = \frac{g h_f}{\theta}$$

$$\bar{G} = \sqrt{\frac{\bar{\varepsilon}}{\nu}}$$

$$\theta = \frac{L}{V}$$

$$\bar{G} = 4\sqrt{2}\frac{V}{D}$$

$$\bar{G}\theta = 4\sqrt{2}\frac{L}{D}$$

Gθ for a 20 cm deep filter with 0.2 mm diameter pores is about 6000.

Big questions to answer

1. What is the physics behind floc and colloid removal by StaRS filters?
2. Why do sand filters have difficulty producing water cleaner than 0.05 NTU?
    a. Is this a limit of flocculation caused by the inability of primary particles to attach to flocs larger than a certain size?
    b. Is this a limit of rapid mix to coat all primary particles with nanoclusters of coagulant precipitate?
3. How could we develop a filter performance (particle removal and head loss development) model based on the volume of particles that are removed and the maximum shear that is developed in a filter pore when it is at capacity?

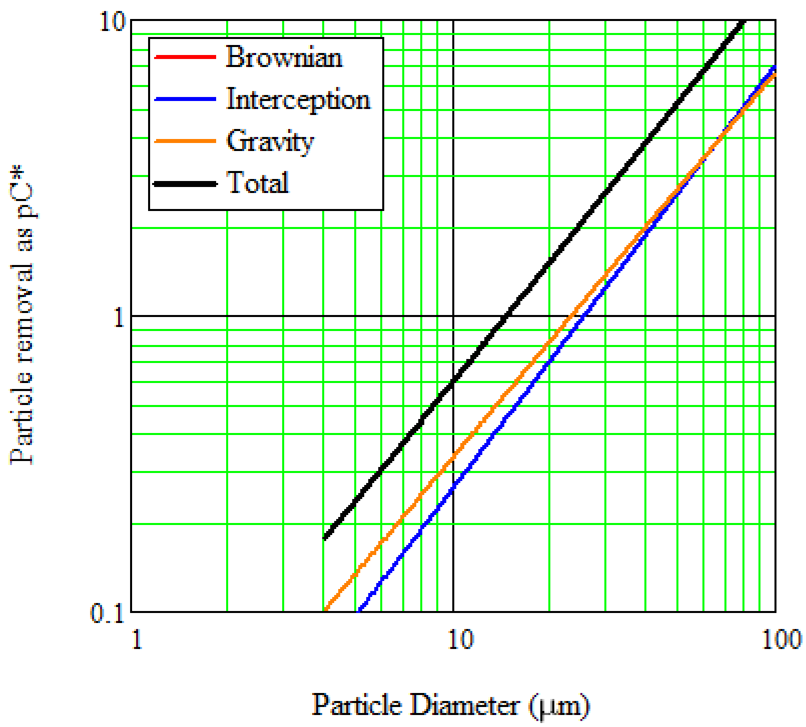
Introduction

Filtration models have a limited ability to describe clean bed performance given a monosized particles, but we don't have a good physical model that describes filter performance over the course of a filter run with a wide range of sizes of flocculated particles. Our goal is to collect a set of experimental data that can be used to test hypotheses and develop a new filter performance model.

Many filtration studies have used test particles of known size without including the steps of flocculation and sedimentation as critical upstream processes. An understanding of what determines particle removal efficiency in sand filters will require using flocculated particles and measuring particle size distributions in the influent and effluent.

We have multiple sets of filtration data (see Hui Zhi's, thesis as well as previous StaRS theory reports and foam filtration reports) showing that filter head loss is proportional to the accumulated mass of coagulant. This suggests that filter pores fill with flocs until the shear in the pore reaches a level that prevents further deposition of flocs. Filter pores fill progressively from the inlet of the filter toward the outlet of the filter. During a filter run the upstream pores are at maximum capacity, the downstream pores are empty and in between the filled and the empty pores there is a zone of deposition that slowly migrates downstream. Filter breakthrough (increase in effluent turbidity) occurs when the deposition zone gets close to the end of the sand bed.

It is possible that sand filters effectively remove flocs larger than a certain size and are ineffective at removing primary particles of clay or pathogens. We have some indication that particle removal occurs in a small layer of the filter and that the active layer progresses down through the filter as it clogs. The figure below assumes flocs with 4 μm clay as the primary particle being filtered by a 5 cm deep active layer of 0.5 mm sand. The filtration model predicts that we don't reach a pC* of 1 until the flocs are at least 15 μm in diameter. We can test the hypothesis that small flocs are not being caught by the filter with the floc size and count app.



Experimental design

Design experiments that measure head loss, influent turbidity, effluent turbidity, effluent particle size distribution (eventually) over the course of a filter run. Collect a family of performance curves (pC* and head loss) by varying the coagulant dose while maintaining a constant raw water turbidity and humic acid concentration.

While the experiments are running, develop a model for the volume of flocs that can fill a pore before the flow path through the pore has a smaller diameter, the velocity is higher, the shear is at the maximum (as yet to be determined value) and hence no more particles attach. See if you can create a model with a minimum of unknown parameters for the pore storage volume as a function of the coagulant dose. The model should also predict head loss as a function of coagulant dose and mass of solids accumulated.

Estimate the number of collisions that could occur between suspended particles in the filter pores given the influent floc volume fraction.

One of the possible applications of this research will be to evaluate the selection of 20 cm as the layer depth for StaRS. In addition it may be possible to provide guidance for the maximum head loss that a StaRS can sustain before particle breakthrough becomes excessive. Finally, it may be possible to provide recommendations on the optimal coagulant/clay ratio for efficient filtration.

Filtration Hypotheses

- Filters preferentially capture flocs larger than about 10 mm and do a poor job of removing smaller particles. Test this with the floc app as soon as possible!
- Filter performance is controlled by the size distribution of the incoming particles.
- Flocculation occurs in the filter pores and this is enhanced by clogging. This may be difficult to test. The other possibility is that pores are made stickier
- The majority of the particles are removed in a narrow band of active filtration that is between the clogged upper section of the filter and the relatively clean lower section of the filter. This active band is apparently much narrower than 20 cm because breakthrough occurs rapidly in comparison with the runtime.
- Filter breakthrough is controlled by the volume of particles captured.
- In direct filtration an increase in coagulant dose results in an increase in floc diameter and because flocs are fractals, the larger diameter means lower density. Thus higher coagulant results in a larger volume of flocs that fill the filter pores faster.
- AguaClara plant designs should work to improve flocculation in the flocculator (perhaps tapered) and floc blanket to eliminate the need for flocculation in the filter.
- Sand size in the filter should be increased to reduce the head loss so we can have longer filter runs.

Resources

Lecture notes from CEE 4540

1 L/s plant testing ↥

Skills: Fabrication, fluids, mathcad, ProCoDA

Introduction

The 1 L/s plant is part of a new strategy for the AguaClara program. As our reputation for designing excellent water treatment plants grows and our partners build ever larger AguaClara water treatment plants it becomes more difficult to push experimental technologies into full-scale plants. The prefabricated, mobile, 1 L/s pilot plant provides a mechanism to develop new technologies and then test them in the field without the risk associated with testing a new technology in a $500,000 municipal water treatment plant.

The 1 L/s plant will enable us to test new flocculator designs, improved floc hoppers,

Big questions to answer

1. Can the 1 L/s plant produce effluent turbidity lower than 1 NTU with a range of raw water turbidities?
2. Does the floc blanket form quickly?
3. Is the floc hopper able to waste a high concentration sludge even with raw water at 500 NTU?
4. Does the flocculator perform well or does it need to be modified?

Tasks and goals

- Test the new 1 L/s plant with a range of raw water turbidites from 5 NTU to 500 NTU to see how it performs.
- Provide regular updates to the team in Honduras about the plant to see what priorities they would have for improvements before we ship a plant to Honduras for testing.
- Upgrade the components that have the biggest opportunities for improvement
  - Eliminate all 80/20 from the pilot plant
  - Fabricate a PVC entrance tank that is strong enough to have the dosing arm mounted directly to the PVC tank.
  - Design and fabricate a flocculator that uses removable orifice inserts
- Ship by Nov 1 to Honduras if at all possible

Dissolved Species Removal Research Teams ↥

The removal of dissolved species using floc/sed/filter systems opens opportunities to bring low cost safe drinking water to communities that are using groundwater contaminated with arsenic or fluoride. Our goal is to develop a good reactor geometry at bench scale using 2.5 cm diameter columns and then build a 0.1 L/s pilot plant for demonstration in India. The 0.1 L/s plant will ideally be built during the spring of 2017 and taken to India in the summer of 2017. The following year we will scale to a 1 L/s plant that could provide safe water for a village of several hundred people.

Fluoride floc blanket removal ↥ (EPA P3 Phase II grant)

Skills: fabrication, ProCoDA, experimental design

This team will use a flocculator/floc blanket/tube settler treatment train for comparison with the countercurrent stacked floc blanket reactor (see below).

Big questions to answer

- What configuration of processes is required to optimize performance (mass of fluoride removed per mass of coagulant, volume of safe water produced per volume of waste produced) and create an operator friendly system?
- Determine if the floc blanket is helpful for removal of red dye? If it is helpful, what floc blanket depth should be used?
- Does a countercurrent reactor design improve efficiency of coagulant use?
- How could the waste be further concentrated or how could the aluminum be recovered?
    - Concentrate the solids by drying or consolidating
    - Extract the fluoride or arsenic by adding an anion that preferentially binds to the aluminum hydroxide (phosphate may be an option)
    - Use phosphate to displace arsenic or fluoride from the wastestream (devise method to further concentrate the waste stream)

Introduction

Fluoride contamination of groundwater is a major health concern. Although this is a well known problem there aren't any highly effective and sustainable technologies available. The World Health Organization suggests that the Nalgonda technique has potential, but it has several serious problems.

- The treatment efficiency is limited to about 70 per cent. Thus the process would be less satisfactory in case of medium to high fluoride contamination in the raw water.
- A large dose of aluminium sulfate, up to 700–1,200 mg/L, may be needed. Thus it reaches the threshold where the users start complaining about residual sulfate salinity in the treated water. The large dose also results in a large sludge disposal problem in the case of water works treatment.

The removal by some form of coprecipitation with aluminum hydroxide opens the possibility that we could use our expertise in flocculation/sedimentation/filtration to design a much more efficient fluoride removal system. It is possible that PACl will be a better coagulant than alum.

During the fall of 2015 the Fluoride filter team demonstrated that fluoride can be removed quite effectively using PACl and a filter column. However, the filter run times are short with high coagulant dosages and thus future research will focus on transitioning to a floc blanket system. During the spring of 2016 the Fluoride team demonstrated that fluoride can be removed with a floc blanket. Flocculation/sedimentation/filtration using PACl as the coagulant is much more efficient than the Nalgonda method.

Tasks

- Work with countercurrent stacked floc blanket reactor team to explore improved reactor geometries. Use completely transparent reactors to make it easy to understand success (and failure) modes. Determine what is required to reliably build a floc blanket with sticky, low density flocs. The bottom geometry is critical to prevent flocs from bridging and failing to slide down to the resuspension jet. It is possible that the conical geometry causes bridging and that the valley shape used in AguaClara sed tanks is better. The goal is to figure out what geometry is needed for reliable operation and WHY.

- Build a new clear single floc blanket reactor to enable a comparison with the countercurrent stacked floc blanket reactor. Use red dye and the new photometers to obtain real time performance. The treatment train will consist of a PACl feed, flocculator, floc blanket, and tube settler. The flocculator collision potential design can be based on experiments conducted by Casey Garland. The goal should be to have about 90% removal of the PACl flocs by the tube settler PRIOR to the formation of the floc blanket. A $G\theta$ of 20,000 and a G of 250 1/s is a reasonable starting place for the design.The upflow velocity in the floc blanket is 1 mm/s. The tube settler capture velocity is 0.12 mm/s. The goal is to determine if adding a second floc blanket improves efficiency. That finding will determine next steps in the design optimization
- Measure the effect of varying the floc blanket depth to determine if the floc blanket is helpful. It is possible that the fluoride attaches to the flocs in the flocculator and that the primary role of the floc blanket is to increase the floc size and enhance floc removal. Note that floc blanket depth in the first reactor of a countercurrent stacked floc blanket might have different design requirements than the floc blanket that is downstream from the flocculator because mass transport of the dissolved species to the flocs will take time in the floc blanket.
- Determine if filtration will be needed or if an improved plate settler system could eliminate the need for filtration. Measure the amount of contaminant that is in particulate form in the effluent by dissolving the PACl precipitates by lowering the pH. Add enough hydrochloric acid to lower the sample pH to 3 prior to measuring the dye concentration. This should require an acid concentration of 1 mM plus the acid neutralizing capacity of the groundwater or tap water that you are using.
- After you have a reliable and well designed reactor that efficiently removes red dye #40, then switch to testing fluoride.
- Design a gravity powered reactor system.
- Vary the pH before and after is important because we have seen that PACl removal efficiency changes with pH so I think testing both higher and lower pH's before and after would be good to see how it affects the removals

Countercurrent stacked floc blanket reactor ↥ (EPA P3 Phase II grant)

Skills: fabrication, ProCoDA, Mathcad, experimental design

Big questions to answer

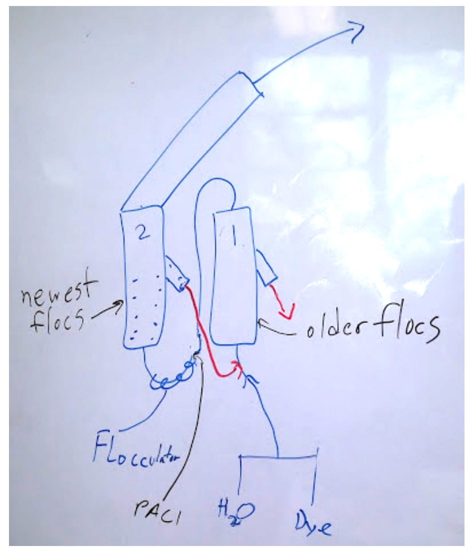
- Is the axisymmetric geometry of the jet reversor inferior to the plane jet used in AguaClara sed tanks because flocs bridge as they slide toward the jet reversor?
- What upflow velocity works well for a floc blanket that is made with PACl and no other suspended solids?
- Can flocs be transported in countercurrent flow between floc blanket reactors in series using

the venturi effect at the base of the floc blanket connected to the floc hopper from the next floc blankets?
- Do PACl precipitate floc blankets effectively remove fluoride or arsenic? If so, what floc blanket depth is required in the first reactor?

Introduction

The goal of the stacked floc blanket reactor invention is to develop a novel reactor that efficiently removes fluoride and arsenic while reducing the volume of wastewater produced by producing a concentrated solid waste stream.

Filters loaded with PACl precipitate are efficient at removing arsenic (and presumably fluoride) in part because they are plug flow reactors and thus upstream PACl precipitate is in equilibrium with influent contaminant concentration and downstream PACl precipitate is in equilibrium with effluent contaminant concentration. This allows efficient use of the PACl because most of the PACl ends up being in equilibrium with influent contaminant levels and thus the maximum mass of contaminant is absorbed per mass of PACl precipitate.



Floc blankets have the potential to hold a large mass of PACl precipitate without generating high head loss and floc blankets can concentrate flocs in a floc hopper and thus eliminate the need for the wasteful process of backwashing. The disadvantage of floc blankets is that the fluidized bed is completely mixed over the residence time of the flocs. Thus flocs at the top of the floc blanket would include flocs that are in equilibrium with influent contaminant levels and thus the removal efficiency will be poor. To improve performance we propose to have countercurrent flow through 3 floc blankets with PACl injection and flocculation occurring at the influent to the 3rd floc blanket and the wasted flocs from the 3rd floc blanket being injected through a venturi (or other means) into the 2nd floc blanket. Similarly the wasted flocs from the 2nd floc blanket will be injected through a venturi into the first floc blanket. The wasted flocs from the first floc blanket will be in equilibrium with the influent contaminant and will be the waste stream from the treatment process.

Tasks

- Coordinate research with the fluoride team on optimal floc resuspension geometry of floc blanket reactors with sticky flocs made with PACl and red dye #40. Use approximately 1 mg of PACl (as aluminum) per mg of red dye #40. Try a very smooth bottom made using a countersink and build a reactor like the one taken to the EPA competition in the spring of 2016. Figure out what is required to get the bottom geometry so that it consistently produces a fluidized bed. This is the big mystery because the EPA apparatus works and the countercurrent floc team's apparatus

doesn't work. The EPA apparatus also failed the first day at the competition. So it is possible that the geometry is not quite smooth enough and that the new smooth geometry will work. It is also possible that the axisymmetric, round jet, isn't reliable and we need to switch to a plane jet.
- After demonstrating a reliable floc resuspension geometry build a 2 floc blanket reactor with countercurrent flow to determine if performance can be improved with countercurrent flow. The reactors should be completely transparent and red dye can be used to test performance. The floc hoppers must be steep so the stick flocs slide down.
- If a 2nd floc blanket improves performance, then vary the floc blanket height to determine the required depth for transport of the red dye to the flocs.
- Develop a model for the removal efficiency of the red dye based on an adsorption isotherm of the dye to the PACl precipitates. Use that model to explain why the second floc blanket improves performance and then make a prediction about the potential gain from a 3rd floc blanket.
- Add a 3rd floc blanket reactor
- Switch from red dye to fluoride and measure fluoride removal efficiency using a PACl feed rate that is identical to the feed rate used by the fluoride team.
- Determine how many countercurrent floc blanket reactors should be used for the 0.1 L/s demonstration plant that will be shipped to India. At this point in product development the decision will be somewhat arbitrary because capital and operating costs will only be estimates and operating complexity may not yet be known.
- Develop a design for a gravity powered reactor system
    - Complete a hydraulic design of the venturi system to see if it is a viable method to generate countercurrent flow of the flocs.
    - Complete a hydraulic design of a countercurrent floc flow system that uses a small diameter tube that serves as a floc hopper and that takes advantage of the higher density in the floc hopper to cause reverse flow down to the upstream floc blanket.
    - Build whichever of these systems seems most likely to succeed or test both.

Resources

- Lecture notes from CEE 4540 syllabus

Fabrication and Physics teams

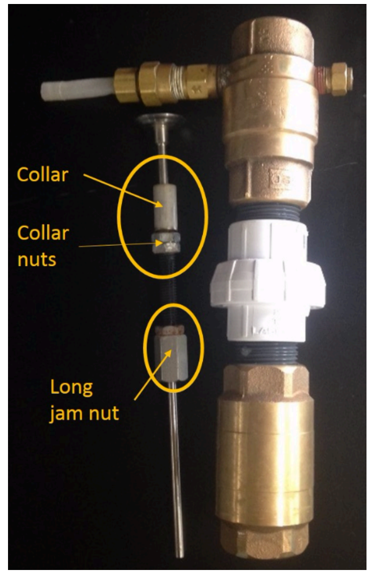
Ram Pump ↥

Skills: Fabrication, fluids, physics

For more information, PLEASE contact Juan Guzman, jfg98@cornell.edu

Big questions to answer

7. What happens if there is water downstream from the pump? How much is the pump affected?
8. What is the optimal force applied by the spring at both ends of the waste valve stroke?
9. What is the optimal opening of the valve (in length) such that fluid pressure will cause the valve to slam shut before the flow reaches the maximum flow rate?
10. How should the sizes of the two check valves be determined?
11. Can leakage from the high pressure line through a closing check valve be reduced by modifying the design or type of check valve used?
12. What are the equations that describe the optimal cycle time?
13. What is required to create a system that automatically starts cycling when water is applied in the drive pipe?



Tasks and goals

- Modify the design of the Union-Collar design based on the recommendations from the Spring 2016 report.
- Test a different high pressure check valve to see if it changes performance. Could try larger or smaller size or a different closing mechanism.
- Test the ram pump with the downstream pipe full of water as would be the case if plumbed inline in an AguaClara plant. It may be necessary to add an air chamber or other modification downstream of the pump
- Determine how to scale the pump for different sizes of plants. Test the pump at a larger scale.
- When the design is excellent, then create documentation for the pump. Evaluate whether the pump should be included in the plant design or whether this is a standalone item that we would provide a detailed design for on the website.

rChemical Dose Controller ↥

Skills: welding (useful),

Introduction

The dose controller is an excellent technology, but it needs further refinement before it is widely deployed. The goals of this team are to refine the design of the constant head tank, work with the design team to create labels and scales for the various components, and work with AguaClara LLC to determine if the dose controller will be packaged and sold by AguaClara LLC or built in country.

- Make it modular so that the whole dosing system only requires a few attachment points to a water treatment plant.
- Add the calibration columns to the constant head tank module.
- Create a new constant head tank. The ideal constant head tank has the following properties
    - Tubing clamps for valves may not be a good option because the tubing deforms and then never rebounds.

- Rectangular tank with 4 compartments for the 4 stock tanks that are each just big enough to hold a standard kerick float valve without needing to change the float. (this restricts independent maintenance)
- flat side where float valve bulkhead fitting can tightened to create a seal
- PVC lid to cover the stock tanks?
- Consider fabricating the tank using PVC welding from flat PVC stock.
- Captures sediment and doesn't send the sediment into the dosing tubes

There are two recent designs of the lever system. The most recent design created by the Cornell team is modular and can have 1 or more levers with each lever system made identically. The design currently used in Honduras is a 2 lever system. Evaluate these two designs and in collaboration with AguaClara LLC select the best design.

Prefab 1 L/s Plant ↥

Skills: structural engineering, fabrication, PVC welding, design
CEE 3720 Intermediate Solid Mechanics

Big questions to answer

- How can the structural design of the pilot plant be simplified?
- Are the PVC bars that strengthen the miter joint in the sedimentation tank necessary?
- Is there a less costly (labor and materials) method to fabricate the bottom of the sedimentation tank?
- How can an entrance tank be designed so that it can be mounted on the central column (and so the dosing lever can be attached to the tank) without requiring any metal supports?

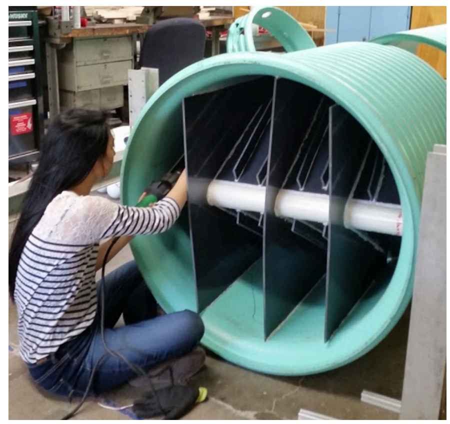
Introduction

The original request from Jacobo Nuñez in 2003 that led to the creation of the AguaClara program was for a method to treat water for Honduran villages. Over the past decade we have created excellent designs for towns and small cities. We have not yet succeeded in creating a low cost, climate friendly, high performing, treatment plant for villages that rely on turbid surface waters. We have determined that the fixed costs associated with design and onsite construction is unfavorable for flow rates below about 5 L/s. The project goal is to develop a new fabrication method for small scale plants that will be easy to operate, high performing, and low cost to deploy.

The need for low flow plants is very large (there are 600,000 villages in India!) and there is a good possibility that AguaClara can create a new solution to this age old problem. We will create a working prototype design and after preliminary testing in the AguaClara laboratory we will turn it over to Agua Para el Pueblo to test it in a pilot project in Honduras. Given that we will begin with proven treatment plant design parameters for the sedimentation tank, the main challenge is to select fabrication materials and develop robust fabrication methods.

The prefabricated AguaClara plant will treat approximately 1 L/s and will provide water for approximately 300 people. The first application of the plant is expected to be purification of sediment and pathogen contaminated surface water.

The flocculator design will take advantage of recent research results that indicate that a short residence time of approximately 1 minute and a high energy loss of approximately 50 cm of elevation is sufficient to provide flocculation prior to a floc blanket. The flocculator may have as few as 9 sections of 2 m long pipes. The flocculator pipes will either have orifices inside the pipes or the pipes will be crimped to create flow expansions.



The AguaClara team built the first 1 L/s prefabricated, PVC, portable, drinking water treatment plant during the summer of 2016. This mini AguaClara water treatment plant opens many opportunities for global deployment of new water treatment technologies. One of the big challenges for the AguaClara program has been spreading new technologies to new countries because governments and funders of infrastructure are appropriately risk averse and thus hesitant to try new technologies. In addition the AguaClara built in place technologies require a skilled labor force of engineers, technicians, and masons and transferring that expertise to a new country is costly. We estimate that building a small 20 L/s AguaClara plant in a new country would cost approximately $500,000 USD and that the majority of those costs would be related to the technology transfer.

The prefabricated plant provides a method to demonstrate AguaClara technologies at a much lower cost. The materials in the prefabricated plant cost approximately $2500. The turnkey construction costs (Design/Build/Operate/Train/Transfer) for a 100 L/s AguaClara plant are approximately $5000 per L/s and thus this mini plant has the potential to have a similar Installed cost if we can lower the labor costs for fabrication.

Tasks

- Estimate the volume and weight of the plant and send that information to the APP engineers by September 7.
- Research the structural properties of PVC and PVC welds with the goal of developing appropriate design guidance for the structural elements of the plant.
- Determine what types of structural testing could be done to confirm that the design approach is correct. Testing could include sample coupons on a universal test machine and scale model loading to failure. Assess if it would be possible to load the bottom of the sed tank to failure to test the strength of the design.
- Explore alternative methods to fabricate plate settlers and flocculator (use orifices instead of crimping) to simplify the fabrication process and hence lower the labor costs.
- Develop a method to package the plant components for container shipment to Honduras. The

goal is to have a plant shipped to Honduras for testing during the January trip. Keep the goal of shipping in mind during the design phase to ensure that all of the components can be protected from breakage during handling. The components shipped to Honduras could be a combination of components built during the summer of 2016 and the fall of 2016.

Project Budget

Description	Budget
Tools for fabrication	$1000
Materials and supplies for 1 plant	$2500
Contingency (due to innovative design)	$1000
Fabrication budget (not including EStaRS)	**$4250**

The project budget does not include an Enclosed Stacked Rapid Sand (EStaRS) filter. The AguaClara project laboratory already has an EStaRS filter that can be used for testing. The decision about whether to build a new EStaRS filter using improved fabrication techniques will be made in the fall of 2016. Fabrication of a new EStaRS is estimated to cost approximately $1000.

The jigs include a platform used to create miter cuts on the 1 m diameter corrugated pipe used to fabricate the sedimentation tank. The jigs may or may not be included in the shipment to Honduras depending on export regulations, whether there is an expectation that the jigs will be needed for further use in the AguaClara project lab, and the strategy for building additional plants in Honduras.

EStaRS ↑

Skills: fluids, **fabrication**, Mathcad

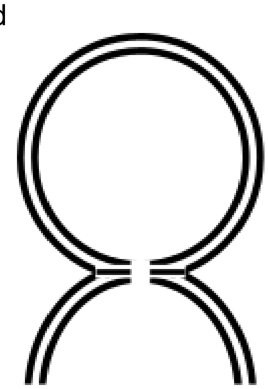
Big questions to answer

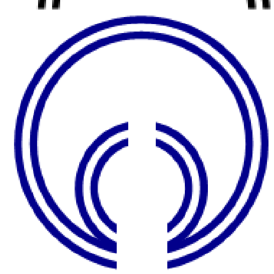
1. Can you design and fabricate an EStaRS that is ready for deployment in a village?
2. Can you design an EStaRS that is short enough to be fed directly from the 1 L/s plant?
3. Can you design a better inlet branch pipe system?

Tasks and goals

- Assess whether it would be possible to shorten the EStaRS for application with the 1 L/s plant. This would be accomplished by reducing the height of each filter layer. Currently the inlet of the EStaRS is too high to receive water from the 1 L/s sedimentation tank outlet.
- Build the next generation of EStaRS for integration with the 1 L/s plant. Use better fabrication techniques including welding.

    - Design for ease of operation. Create a list of what makes operation of the current EStaRS difficult and then devise methods to improve the design.
    - Eliminate flexible tubing
    - Develop an improved through wall piping system that is strong and easy to make leak tight. The protrusions from the filter should be short (less than 2”) so they aren’t vulnerable to breaking during transport.
    - Use Fernco fittings on inlets and outlets
    - Consider using short sections of clear PVC pipe to allow inspection to verify that sand isn’t getting into the inlets or outlets
    - Include manometers to confirm that fluidization has occurred
    - Evaluate connections used at the bottom, middle, and top of the filter to see if improvements are warranted.
    - Make sure that pipe routes are designed to ensure that air isn’t sucked into the filter during backwash when the pressure inside the filter is less than atmospheric.
- Minimize the height of water in the inlet tank to reduce the difference in tank bottom elevation required between the 1 L/s sedimentation tank and the filter. Simultaneously maximize the filter runtime by increasing the maximum head loss that can be achieved. These two requirements are contradictory. See what you can do to solve this problem.
- Test a new idea for wings for the inlet pipes that doesn’t require sheet PVC (currently not available in Honduras). Include the possibility that the wing is inside the branch pipe!





Resources

- CEE 4540 notes on filtration
- Previous reports from EStaRS teams
- Fabrication experience of APP at San Matias and Las Vegas

More Possible Tasks ↥

Low cost Fernco

Perfect a design for a Fernco style fitting that can be fabricated in Honduras, that isn’t necessarily watertight, but that is sand tight. This could incorporate PVC saddles, which are locally available for 6” and 8” pipe, but which are rigid and don’t naturally provide a water or sand seal.

Reduce spacing for plate settlers

- Fabricate ABS-based plate settlers at 1 cm spacing to explore whether we could fabricate a more compact plate settler (See CEE 4540 project Buttermilk.xmcd Buttermilk.pptx).
- Explore options for adding head loss to the top of the plate settlers to improve flow distribution

especially during positive temperature gradients.
- Explore plate settlers that are closer to porous media filtration spacing to see if we could eliminate filters.

Equipment Wish list…

Pump on/off controllers that can connect to the 24 V on/off ProCoDA ports and control up to 4 pumps
Check inventory of

- Peristaltic pumps
- Turbidity meters
- Floc count/size camera systems
- 8 channel pump heads

Knowledge/tool wish lists

- Floc breakup in freefall plane jet or measurement of energy dissipation rate
- Determine if flocculator lower baffles could be cut to optimal length for design flow rate based on calculated head loss. (this can likely be tested in the field)
- Determine if floc break up between sed tank and filter is reducing filter efficiency. If so, then energy dissipation rate into filter should be controlled with a level control valve or by a reduction in the energy dissipation rate as the water is lowered into the inlet box.
- How can we improve our chlorinators? How long can a chlorinator provide a reasonably constant dose? Antonio says the dose only remains constant for about 5 hours. (We need actual data from our plants on this.) We need to find out what the operators do to restore the flow and then see if there is a way to make that process easier. Should we be exploring electrolysis system? (No) Should we add a sand filter between the stock tank and the constant head tank to remove excess calcium carbonate?
- Design high G flocculators
- Is attachment of flocs to plate settlers improved by using highly polar surfaces? Could a stronger attachment be used to hold small flocs in place to avoid floc rollup? Cleaning would be by a strong down flush.
- Develop some "baseline" or "formula" to figure out what species besides dyes and fluoride/arsenic can be removed with PACl