Upflow Anaerobic Sludge Blanket (UASB)
Fall 2015

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December 4, 2015

Abstract

The Fall 2015 Upflow Anaerobic Sludge Blanket (UASB) group has continued the previous work of the AguaClara anaerobic wastewater groups. A literature review of technical journals was conducted to gain familiarity with the current state of anaerobic wastewater treatment technology internationally. The reports from previous wastewater groups were also reviewed to provide insight into the current state of anaerobic wastewater technology within AguaClara. The literature review served to identify common challenges to address during this and next semester including reactor leakage and creating an airtight design, combining a UASB unit with a GSBR unit in an attempt to improve overall treatment capacity, and oxygen stress testing to determine the robustness of the reactor. The beginning of the semester was spent cleaning and removing biomass from reactors, testing for leaks using a bubble solution, and performing a single-day pressure test in an attempt to approximately quantify the volumetric leakage rate. Two UASB reactors were inoculated and began producing biogas within the first week of operation. COD analysis and gas chromatography were performed to characterize the efficiency of COD treatment and methane production within the reactors.

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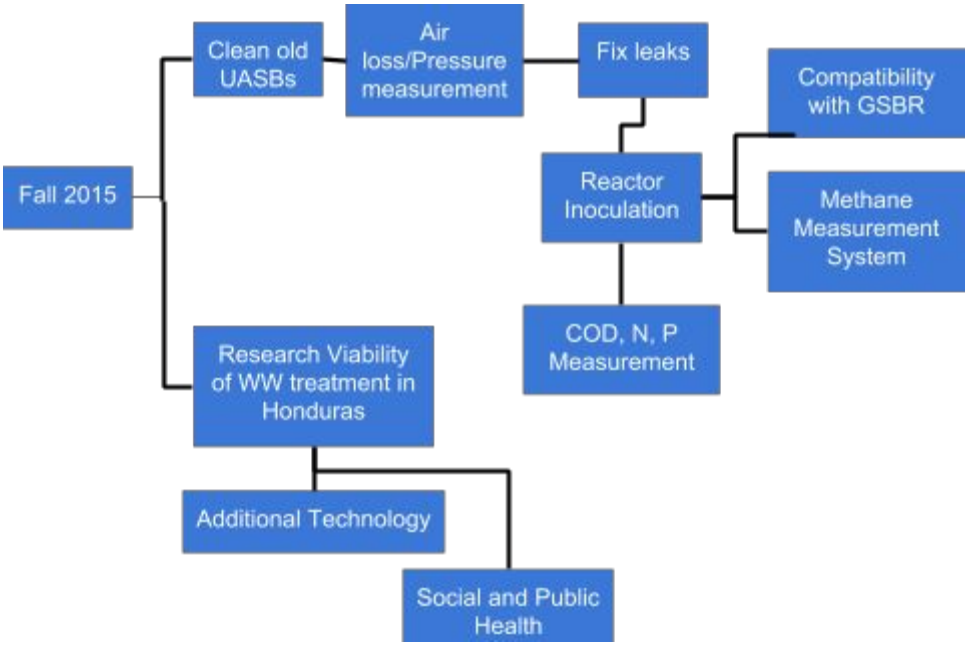
Task Map



Task Details

*Dates refer to the beginning of the week that task should be completed by

I. **Literature Review** – Status: Complete
   a. Read past reports to understand state of reactors and determine future work
II. **Clean old UASBs and Identify Leaks** – Status: Complete
   a. Lead group member: Zoe
   b. Clean out biomass in existing reactors - Complete
   c. Identify source of leaks - Complete
      i. Soap solution around connections test
   d. Determine degree of severity of air loss - Complete
      i. Pressure sensor tests
   e. Solenoid valve tests for more precise air loss measurement
III. **Fix Leaks** – Status: Complete
   a. Replace some valves and joints

IV. **Choose 2 UASBs to run further experiments on** – Status: Complete
    i. Two reactors for oxygen stress tests - one control, one experimental
b. **Inoculation** Status: Complete
c. **Experiments** – Status: Complete
    i. Lead group member: Mason
    ii. COD, N, P Measurement
d. **Methane Measurement System** – Status: Complete
    i. Lead group member: Zoe
    ii. Bubble Meter
    iii. GC/MS
        1. Partial pressure methane measurements

V. **Research Social, Political, and Health Impacts** – Status: Incomplete (research will continue through winter break during trip to Honduras)
a. Lead group member: Evan
b. Alternative technologies to UASB/GSBR for WW treatment
c. **UASB - GSBR coupling** - Status: Incomplete **TBD**
    i. Research coupling possibilities

VI. **Draft Final Report** – Status: Complete

Trainings: will be completed as needed throughout semester

1. Process controller / ProCoDA
2. Media preparation
3. COD analysis
4. Nitrogen and Phosphorous Assays
5. GC

Introduction

AguaClara's mission of providing sustainable wastewater treatment necessitates the development of a functional, low-energy or energy-neutral, and compact wastewater system. The Upflow Anaerobic Sludge Blanket (UASB) reactor is necessary to this mission because it offers an efficient means to anaerobically treat wastewater influent. When paired with an aerobic Granular Sequencing Batch Reactor (GSBR), the UASB can potentially offset or support the energy needs to run a wastewater treatment system based on an average energy content of 6 kW/h per cubic meter of methane gas produced [1]. Previous research has developed a reactor design and methodology to test quality of wastewater effluent. Further work will include different gas measurement and collection to make the system as efficient and self-sufficient as possible. This will include focus on a sustainable pairing of the UASB reactor with a GSBR reactor. Tests on the resilience of microbes in granules will be conducted in the form of oxygen stress tests to study impacts of oxygen in the anaerobic design. In addition to running three reactors over the course of the semester, other reactors will be modified to develop a reactor that is more easily adjusted to fix potential problems. These modifications will facilitate the work for future semesters, and result in a more

user-friendly reactor design. Tests on UASB efficiency and ability to treat influent will bring AguaClara closer to understanding how wastewater treatment systems could work in implementation and future success.

Literature Review

Aiyuk et al. (2004) suggest that there is a large need to develop domestic wastewater treatment in developing countries and that such a task is a nontrivial undertaking. There are many constraints for widespread application in the developing world including "simple design, use of non-sophisticated equipment, high treatment efficiency, and low operating and capital costs" to name a few. The UASB reactors have been widely used in the wastewater industry for a number of reasons including simplicity, scalability, and the ability to process a variety of wastewater strengths[2].

Chong et al. (2012) provide an overview of the current state of UASB technology [3]. The typical UASB consists of a cylindrical column and a gas-liquid-solid (GLS) separator with a geometry traditionally similar to a funnel (Figure 1). Wastewater is fed into the bottom of the reactor and the particles separate due to differences in density. The dense sludge forms a bed at the bottom of the reactor and the smaller, more dispersed particles form a blanket above the sludge bed. The reactors are inoculated with bacterial biomass that eventually undergoes a process called granulation that occurs in three main steps: adsorption, adhesion, and multiplication. After inoculation and granule formation are complete, the influent COD is converted into biogas, a gaseous mixture consisting mainly of methane (CH_4) and carbon dioxide (CO_2).

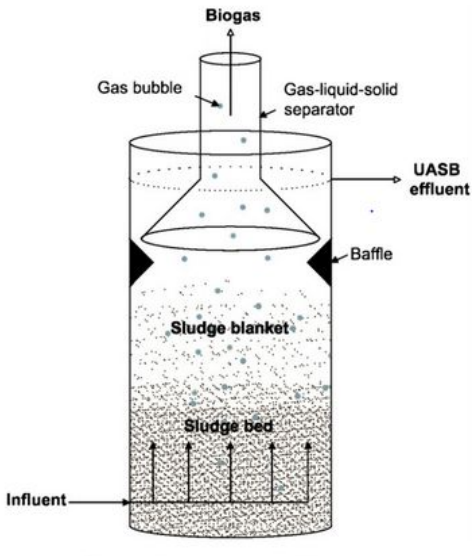


Figure 1. Schematic of UASB Reactor (Chong et al. 2012)

Yu et al. (2001) describe granulation as "the process in which suspended biomass agglutinates to form discrete well-defined granules." Bacteria may adsorb or adhere to inert matters, inorganic precipitates, and/or to one another. Once the bacteria are attached to a stable substrate they are free to multiply and eventually form granules. The authors continue on to mention that the microbial cultures formed within a UASB are a complex mixture of microbial species and that their survival and usefulness derive from the way in which the different species coexist and thrive off of one another [4].

The complex mixture of bacteria convert the influent wastewater and chemical oxygen demand (COD) into biogas via the process overview in Figure 2 (Mes et al. 2003). The chemical digestion process includes hydrolysis of non-soluble biopolymers into soluble organics, acidogenesis or the conversion of soluble organics into fatty acids and CO_2, acetogenesis in which the fatty acids are converted into acetate (or acetic acid) and hydrogen gas (H_2), and finally, methanogenesis in which the acetate, CO_2, and H_2, are converted into CH_4 gas. Acidogenic bacteria are usually responsible for the hydrolysis and acidogenesis steps, acetogenic bacteria for generation of acetic acid, and methanogenic bacteria for the final conversion into methane [5].

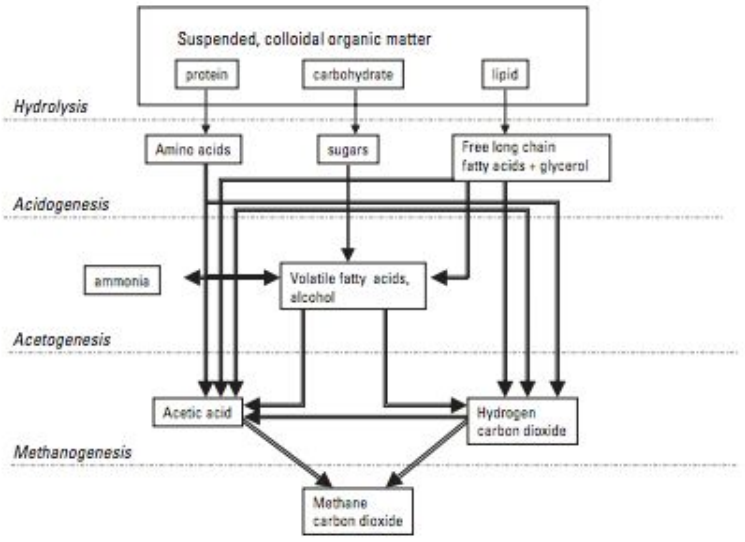


Figure 2. Wastewater to Biogas Chemical Conversion Process Flow Diagram (Mes et. al 2003)

UASB reactor technology has undergone a number of performance enhancements in the last decade including start-up and granulation characterization, coupling with post-treatment units, and general improvements in operating efficiencies. The technology faces limitations when applied in developing countries, most notable of which involves the ability of the reactor to maintain a steady performance in a fluctuating climate [3].

One of the future goals of the group is to examine how anaerobic granules respond to oxygen stress with respect to COD treatment and methane production. The experiments carried out by Botheju et al. (2010) involved bubbling oxygen into UASBs at various rates with respect to percent of overall biogas production [9]. The influent oxygen content was varied from zero to 10 % biogas production rate by

volume. The results of the study refuted the conventional perception that oxygen can only be toxic to anaerobic digestion cultures. Instead, the researchers found that, "limited quantities of oxygen can even lead to improved AD [anaerobic digestion] reactor performance under certain operating conditions." It is the goal of the UASB wastewater group to conduct an oxygen stress study next semester with a similar experimental design.

Previous Work

The AguaClara Wastewater Group began in the summer of 2013 and three semesters of research with respect to anaerobic wastewater treatment have been conducted to-date. In the summer of 2013 the UASB reactor was first explored; two reactors were constructed and one utilized support media to promote biomass growth. COD removal and gas production were monitored for approximately one month.

In the Fall of 2013, six reactors were constructed. Three of the six reactors were UASBs and the other three were Anaerobic Fluidized Bed Reactors (AFBRs). The Fall 2013 group began operation of these reactors, but was unable to collect a significant amount of gas production data due to leaks in the reactors and the lengthy startup time required for steady state operation. The group proposed a new gas chamber sealing method based on the coupling of a pressure sensor with Process Controller that would potentially only release accumulated biogas once a certain gas pressure had been reached. The group developed mathematical models for particle fluidization and settling within the reactor. These models helped the group reach the conclusion that both fluidization velocity and settling velocity increase as granule diameter and density increase. Finally, the Fall 2013 group used confocal microscopy and chemical staining in an attempt to characterize the granules within the reactor. The group was able to identify regions within the granule involved in active DNA and RNA synthesis as well as groups of aggregated methanogens.

The Spring 2014 group split into three subgroups: a UASB operation improvement group, a gas production and collection improvement through design and scaling modification group, and an aerobic treatment options group. Gas chromatography was used to monitor the amount of methane produced by the reactors throughout the semester. The Spring 2014 group faced several problems with respect to reactor performance: inconsistencies between theoretical and experimental gas production, inconsistent COD feed concentration delivery, and vessel leakage. These issues were provided as explanations as to why the experimental data did not match theoretical predictions for biogas production. In an attempt to fix the air tightness issue, the group used two methods to identify leaks in the reactors. The first method involved filling the reactors with water, sealing the reactors, and monitoring any change in water level over a few weeks. The idea was that a noticeable change in water level would only occur if the reactor were not airtight. The group's second air-tightness test was to fill the reactor with air and submerge it underwater and observe whether or not bubbles would escape the reactor. The identified leaks were at first repaired by reapplying Teflon tape and covering joints with parafilm, but this eventually proved unsuccessful. The group eventually took to sealing the connections with epoxy for reactors 2.4 and 2.5. Reactor 2.4 remained airtight throughout the semester, but reactor 2.5 began to leak a few weeks into operation. It was speculated that methane loss may have been due to dissolved methane leaving the reactor in the liquid phase.

A common theme of the wastewater group has been the difficulty associated with sealing the reactors not only watertight, but airtight as well. This sealing issue will be a primary concern of the Fall 2015 group in addition to operating condition experimentation and testing.

Methods

1. Cleaning the UASB reactors

Before any tests on the reactors could be done, hardened sludge and granules needed to be removed from the reactors, numbered 2.4 and 2.5. This was done in a multistep process of rinsing and cleaning. Filling the reactors with water, agitating them, and then rinsing loosened much of the biomass. However, because the reactor could only be filled and rinsed from the top opening, further work was necessary to target the bottom of the reactor. Some resistant sludge deposits required water to be injected into a valve opening on the side of the reactor using a syringe, to allow agitation closer to the bottom. A metal wire was threaded into the reactor opening and used to scrape biomass from reactor walls. Scrubbing brushes were secured to metal wire and fed into the opening, as well, to scrub the walls as much as possible. Throughout this process, the reactors were frequently inverted and rinsed. To complete the cleaning, the reactors were soaked in diluted bleach, agitated, and then rinsed again.

2. Testing Air Tightness - Soap Test, Pressure Hold-Up Tests and Valve Tests

To test air tightness, two different tests were conducted. The first one was a soap-solution test. First, all reactor holes were plugged and the reactor was pressurized with air. The air supply was left in the reactor to create continuous airflow and high pressure. A soap-solution was sprayed around the connection points on the reactor using a syringe. Areas where there were air leaks showed bubbles in the soap-solution because air was collecting under the soap solutions and producing bubbles.

The second test was pressure hold-up test, which was conducted to determine pressure loss under more normal reactor pressure conditions. The reactors were filled with water and then air was bubbled in until about half of the gas chambers were filled with air. The initial water level in the gas chambers was marked immediately. The reactors were equipped with a recycle stream at its outlet and an inlet flow rate of 6 mL H_2O/min was applied to establish steady state water circulation. Pressure sensor monitored changes in pressure over time. Final water level was marked after the conclusion of the tests. The volume of gas leaked out during this period was approximated based on the change in water level height using equation 2.1. This volume of the leak is compared to the total gas/day production rate of the reactors from Spring 2014, using equation 2.2, to determine quantify the significance of the leak. The test results and equations are shown in Figures 3 and 4 and in Table 2.

$$V_{gas} = \pi r^2 \cdot \Delta h_p \qquad (2.1)$$

h_p: pressure loss (cm H_2O)

r: radius of PVC (cm)

V_{gas}: volume of gas loss (mL)

$$Fraction\ Gas\ Production\ Lost\ to\ Leak = \frac{V_{gas}}{V_{production,2014}} \cdot 100\% \quad (2.2)$$

$V_{production,2014}$: volume of gas production in 2014 is approximated as 250 (mL/d).

Before inoculation, various tests were conducted under abiotic conditions to determine the functionality of all systems in place. In this case, the air tightness of the valves was measured to determine the degree of functionality. To determine this, the inlet of the valve being tested was attached to the air valve on the lab bench and a pressure sensor was attached to the outlet. Initially air was pumped through the valve when open, then the valve was closed and the data was examined to determine if air was flowing through the closed valve. The testing procedure was identical for the pinch valves and solenoid valves. Figure 5 is included in this report as an example of a pressure test determining that a solenoid valve was airtight. Although the pressure in the reactor during operating conditions will not be as high as the air pressure out of the lab bench, this test was useful for determining which valves were the most airtight. Measurements were tracked using Process Controller.

3. Preparation for inoculation

In order to prepare the reactors for inoculation, many basic tests were conducted to ensure the functionality of all parts of the reactor. The peristaltic pumps and tubing connections were tested by pumping water at the rate determined for operation. Tubing and pump heads were replaced and retested until the desired amount flow was achieved. The pressure sensors and process controller were extensively tested by bubbling air into reactors and ensuring the valves opened when air built up to the desired pressure. Wastewater stock was created and placed in a refrigerator near the reactors for easy access. All of the tubing was color-coded by placing green tape on the tubing for reactor 2.3 and blue tape on the tubing for reactor 2.5 to make identification easier in case repairs need to be made in the future.

Each reactor has two open end tubes with the same color. One open tube was linked to the concentrated wastewater solution with a controlled flow rate of 0.25 mL/min and another one was connected to tap water with a constant flow rate of 6.00 mL/min. The synthetic wastewater recipe is included in Table 1. The other end of both tubes were connected with y-joints, and a larger tube was used to connect with the reactor and the other side of the y-joint. This was done to ensure that the stock was diluted with tap water before entering the reactors. After assembling the tubes, two pumps which were responsible for pumping wastewater and pure water were started. The change of the pressure in each reactor was tested by pressure sensor in order to check if there is a leak problem. At the same time, bubble meters were tested for accuracy in measurement by using a peristaltic pump to test a known amount of air through the bubble meter and compare it to the amount of air measured by the bubble meter.

Table 1: Concentrated Synthetic Wastewater Recipe

Chemical Constituent	Amount added (mg/L)
Urea	1600
NH_4	200
Na-Acetate	1357
Peptone	300
$MgHPO_4$-$3H_2O$	500
K_2HPO_4	305
$FeSO_4$-$7H_2O$	100
$CaCl_2$-$2H_2O$	120
Starch	2100
Milk Powder	2000
Yeast Extract	900
Vegetable Oil	500
$CuCl_2$-$2H_2O$	10
$MnSO_4$-H_2O	2
$NiSO_4$-$6H_2O$	5
$ZnCl_2$	5

4. Biogas Production Measurement

Each reactor began producing biogas soon after inoculation and total biogas production measurement began immediately after inoculation. Two methods of biogas measurement were used; Process Controller and the bubble meter. One method of measurement used Process Controller by having the reactor off-gas at certain pressure, and total gas production was measured by analyzing frequency of off-gas events. Gas was also measured using a bubble meter to get a reading of total gas production. Both reactors were first set up using the Process Controller measurement system, but reactor 2.3 was not off-gassing properly and was not giving useful data because the off-gases were not at consistent pressures. Reactor 2.3 was then attached to the bubble meter in an attempt to get a measurement of total biogas production without using Process Controller. Reactor 2.5 functioned properly with the Process Controller file and data. Biogas production was measured with Process Controller for both reactors, and reactor 2.3 biogas was also measured using the bubble meter. Results of biogas measurements are shown in the analysis section of the report. Biogas composition was then quantified using gas chromatography.

In order to achieve a more consistent off-gas volume, our Process Controller code was modified to read the pressure as an average of the pressure sensor readings over a short period of time. This smoothed out some of the noise in the pressure sensor reading and ensured a more consistent off-gas period. This reduced the error in estimating the volume of each off-gas event yielding a more accurate measurement for total gas production.

5. COD Analysis

COD testing was done to analyze the amount of organic material being delivered to each reactor, and to analyze the amount of organic material that the reactor removed at effluent levels.The influent and effluent water samples were collected from each reactor per day for a week and stored in the freezer between the sampling and COD test to ensure the integrity of the COD samples. All the samples were stored in prepackaged vials from CHEMetrics and left for 2 hours with 150 ℃ incubated temperature. During this period, the decrease in dichromate concentration from the samples were detected colorimetrically by a Hewlett Packard Diode Array Spectrophotometer. By comparing with the existing standard curve from the spectrophotometer, the result of COD concentration of both influent and effluent samples was calculated by the spectrophotometer's software. The removal of COD is the difference between the COD of influent and effluent samples per day.

6. Gas Chromatography

To measure the amount of methane produced in the biogas, gas chromatography sampling was used. A 100 microliter gas sample is injected into the GC-TCD measuring CH4, O2, and N2. The compounds are separated as they elute through the system due to differing interactions with the walls of the column coated in a stationary phase. The elution profiles are measured by the machine's detector and software compiles this data into elution curves. The quantity, or volume fraction, of each of the gaseous components in the sample is directly proportional to the area under the elution curve. A standard curve was first established by measuring a series of samples with controlled partial pressures of methane ranging from 0 to 0.8. The peak areas from these samples were then plotted vs their know partial pressures resulting in a linear graph and equation which can be used to analyze the methane production in the reactors. This graph can be seen in Figure 7 in the Gas Chromatography results section.

Results

1. Cleaning the UASB reactors

Water removed most of the sludge by physical mechanism and bleach disinfected, and the reactors were determined to be cleaned enough to use and begin testing on.

2. Testing Air Tightness - Soap Test, Pressure Hold-Up Tests and Valve Tests

The soap-solution test revealed that all of the connections have some degree of air loss. The soap-solution bubbles that were created showed that the pressurized air was leaking out of the joints, but the amount of air loss was different for each connection. However, these results cannot be analyzed alone because the reactor was pressurized to higher pressures than normal operating pressure would be. This higher pressure would make leaks appear more severe than they would be under normal conditions. While the test was helpful in identifying where leaks are, it is limited in how the results can be applied to further work because it does not accurately quantify the problem of air loss.

During the pressure hold-up tests both reactors 2.3 and 2.5 were equipped with septa for gas sampling from the gas chambers. To ensure that the reactors were airtight before inoculation, they were filled with a volume of air, water was recirculated through the reactor at 6 mL/min, and the change in pressure inside the gas collection chamber was monitored over 24 hours using pressure sensors. The results of the pressure hold-up tests are shown in the following two figures.

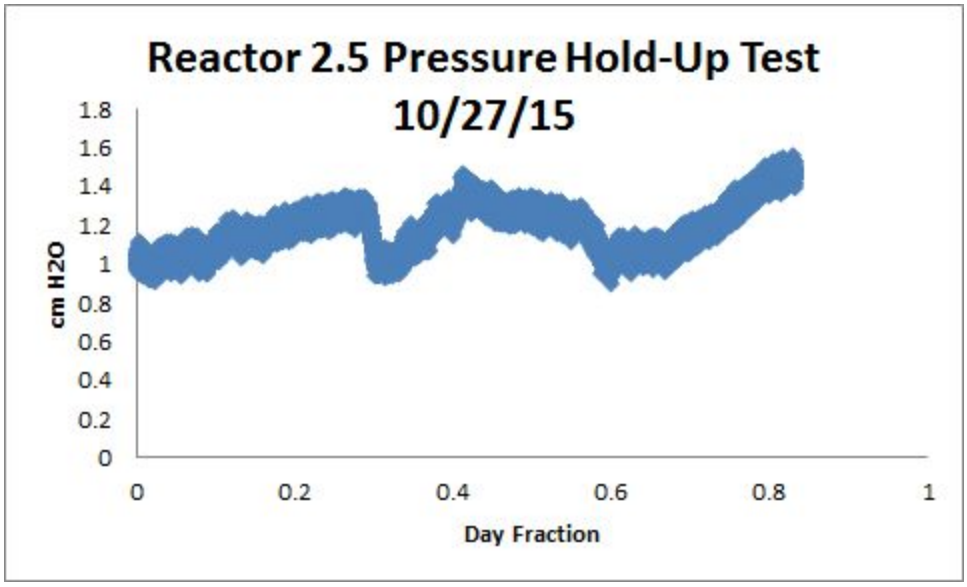


Figure 3. Reactor 2.5 Overnight Pressure Test

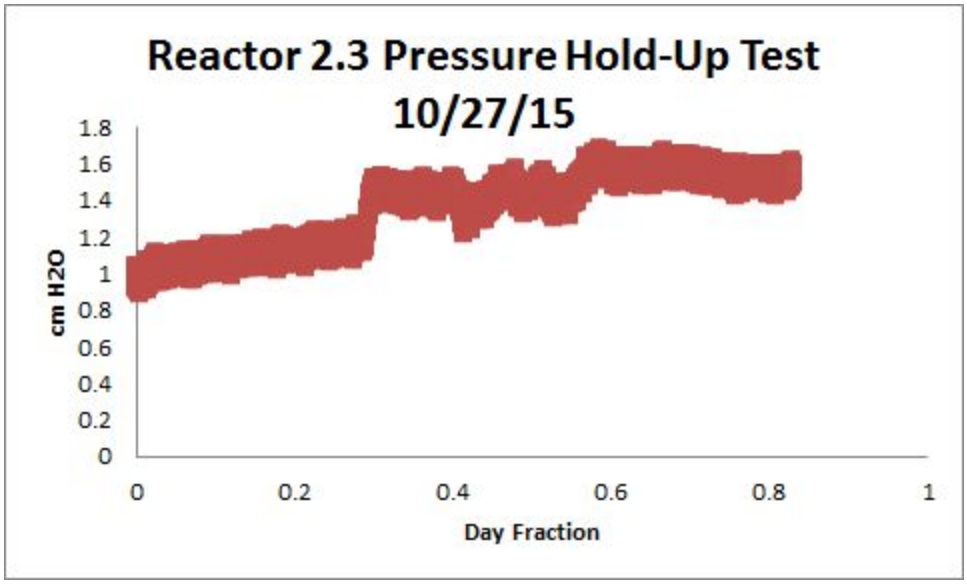


Figure 4. Reactor 2.3 Overnight Pressure Test

Table 2: Calculation of % Biogas Loss Due to Leaks (Reactors 2.3 and 2.5)

Water Level Change (cm/d)	0.75
ID of PVC 40 (cm)	4.09
Area of PVC (cm^2)	13.13
Volume Lost (mL/d)	9.85
Biogas Production (mL/d)	250
Biogas Lost (%)	3.94

The calculations depicted in Table 2 quantify the leakage in Reactors 2.3 and 2.5 as roughly 4% the biogas yield. Due to the small magnitude of the leak, reactor inoculation commenced and the leak was factored in as error when analyzing biogas data in the future.

The data for a valve test was compiled and organized in Figure 5.

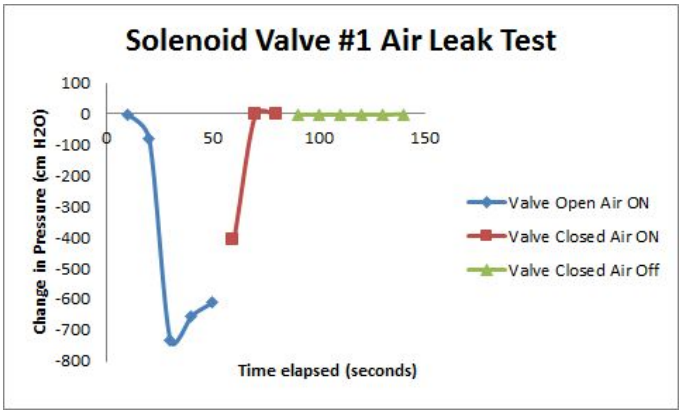


Figure 5. Solenoid Valve Air Tightness Test

For this test, air was pumped through the open valve starting at 15 seconds, then after 60 seconds the valve was closed. As depicted by the graph, the pressure valve returned to the initial zero value once the valve was closed. This indicates a successful test. The three new solenoid valves all had similar data, so they are functioning properly. The three pinch valves on the other hand were proven to be ineffective because when they were closed with air flowing, the pressure sensor continued to register a non-zero pressure indicating leaks.

3. Inoculation Issues

Shortly following inoculation, a series of problems arose that ultimately resulted in a failed inoculation. The refrigerator used to keep the wastewater stock cool was faulty and froze the wastewater stock. This prevented the stock from reaching the granules. After finding this problem, it was decided to unplug the refrigerator and use stock that was not cooled. During this time, the stock became slightly heated due to the constant running of the stir plate in the unplugged refrigerator. This warmed stock caused blockage in the size 13 peristaltic tubing resulting in no stock reaching the granules again. After this long duration of time without being fed with stock, the granules became gray and powdery. The granules were assumed to not be viable for future use due to the issues with wastewater delivery and their lack of methane production. The blocked tubing was purged with water to force the solids out, and reactors were cleaned and prepared for re-inoculation. Previous testing of the bubble meter showed that it was measuring air accurately.

3a. Re-Inoculation

On November 20th, the reactors were re-inoculated with fresh biomass granules obtained from the Syracuse wastewater treatment facility. 500 mL of biomass was added to each of the newly clean reactors (reactors 2.3 and 2.5). 2 L of new concentrated wastewater stock was made and autoclaved earlier in the week. Once the biomass had been added to the reactors, a continuous flow of 6 mL H_2O/min and 0.25 mL concentrated stock/min were fed to the reactors. Pressure logging data was enabled and tracked using Process Controller, and is shown in sections below for biogas production measurement.

4. Biogas Production Measurement

Process Controller data from reactor 2.5 off-gases was recorded. The total number of off-gas events were used to determine the volume of biogas produced. Sample graphed data and calculations from 11-29-15 to show off-gas events and total gas production are shown below in Figure 6 and Table 3.

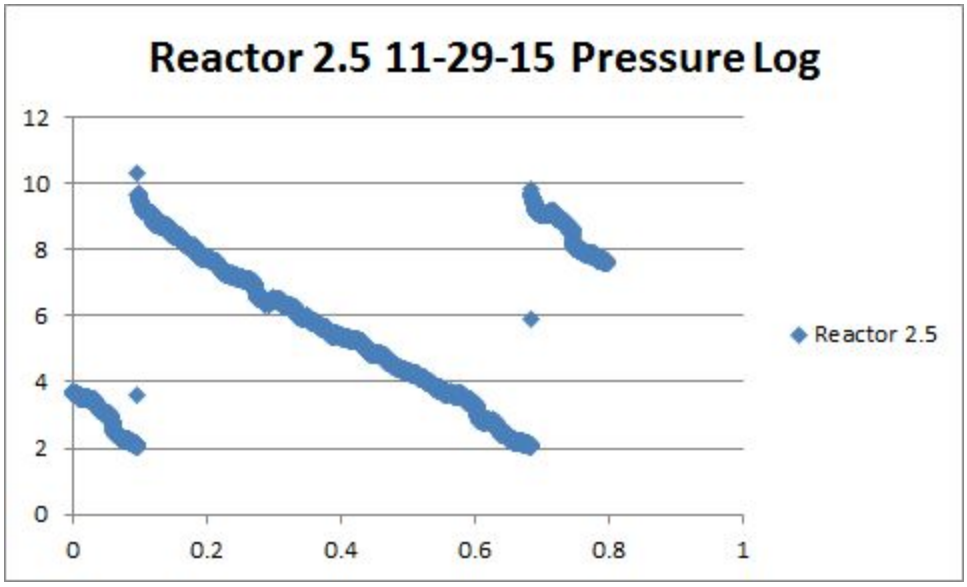


Figure 6. Process Controller Off-gas events for Reactor 2.5

Table 3: Total Gas Production for Reactor 2.5 on 11-29-15.

1st event		
low P value	2.14	cm H2O
high P value	10.26	cm H2O
Difference	8.12	cm H2O
Area PVC	13.14	cm^2
Volume offgas	**106.69**	**mL**

2nd event		
low P value	4.02	cm H2O
high P value	12.50	cm H2O
Difference	8.48	cm H2O
Area PVC	13.14	cm^2
Volume offgas	**111.40**	**mL**

Total Gas Production 11-29-15	
218.1	**mL**

The bubble meter attached to reactor 2.3 did not accurately measure the total biogas production. It was observed that the bubbles from the reactor were too small to make the bubble catcher toggle to account for the gas production. Since both Process Controller and the bubble meter did not accurately measure biogas production, there is no record for how much biogas reactor 2.3 produced since inoculation.

5. COD Tests

COD tests were used to check if COD delivery was consistent between the two reactors, and what the percent removal of COD was. Samples of influent and effluent were taken from reactors 2.3 and 2.5

everyday over the course of a week. It appeared visually that reactor 2.3 was not receiving as much stock as reactor 2.5, because samples from the influent of 2.5 appeared much more cloudy and filled with stock than the influent from 2.3. Table 4 below shows that the COD delivery between reactors 2.3 and 2.5 was not equal, with each reactor receiving different amounts on the same day, despite the fact that there should have been equal delivery. Because reactor 2.3 did not receive as much stock as reactor 2.5, it was not producing as much biogas as 2.5. It is possible that Process Controller was working correctly but that off-gas events were so few and far between that there were not good results.

It should be noted that the December 1st influent COD value for reactor 2.5 is suspicious. It was determined that there were undissolved solids in the sample that may have interfered with the COD analysis protocol, giving a value much higher than the actual COD delivered to the reactor.

Table 4: Influent and Effluent COD for reactors 2.3 and 2.5 from 11/29-12/1

	Influent COD (mg/L)	Effluent COD (mg/L)	% COD Treated
Reactor 2.5			
29-Nov	789	129	84%
30-Nov	632	72.9	88%
1-Dec	2360	109	95%
Reactor 2.3			
29-Nov	333	57.8	83%
30-Nov	128	43.7	66%
1-Dec	305	-0.549	100%

Table 5 shown below shows the volume of methane produced and the COD removal rate for reactor 2.5. Gas chromatography was used to identify the methane volume fraction on December 1st and the value of 65% methane was used to approximate the volume of methane produced on 11/29 and 11/30.

Table 5: The COD removal rate from reactor 2.5

Date	Total Gas Production (mL)	Volume Fraction Biogas	Volume Methane Produced (mL)	Influent COD (mg/L)	Effluent COD (mg/L)	% COD Treated	% Theoretical Methane Production
11/29/2015	218.1	~65	147.5	789	129	84%	59%
11/30/2015	149.4	~65	97.1	632	72.9	88%	48%
12/1/2015	142.9	65.5	93.3	2360	109	95%	12%

6. Gas Chromatography Results

Methane from only reactor 2.5 was analyzed due to the lack of a functioning septa in reactor 2.3. The peak area measured by the gas chromatography for the sample from reactor 2.5 was 70.84. When inputted into the linear equation given by the Methane Standard Curve (Figure 8), a partial pressure of 0.655 was calculated. This partial pressure is within the expected range of methane and can be used to determine the energy that can be produced by the reactor.

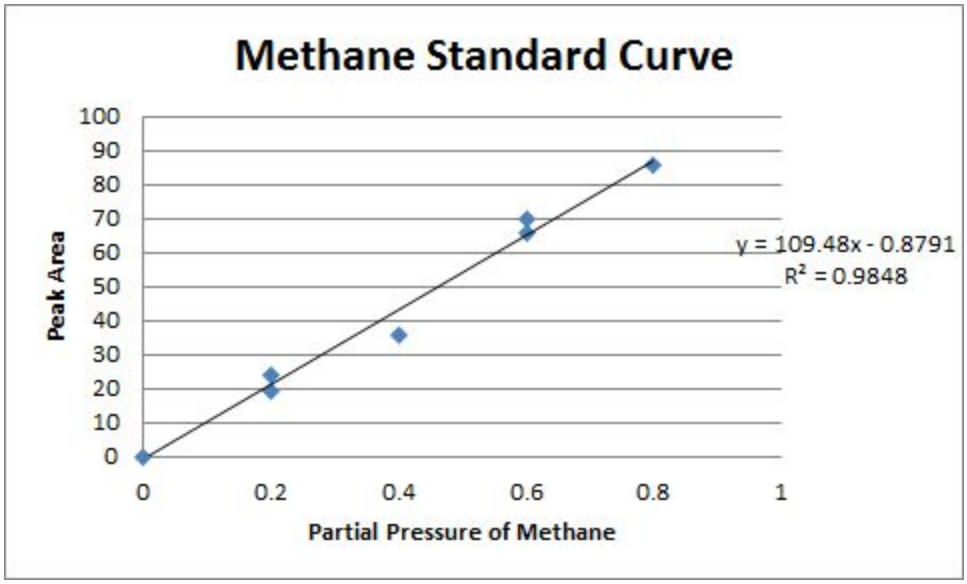


Figure 7. Methane standard curve relating peak area from GC with the partial pressure of methane

Analysis and Conclusions

1. Cleaning the UASB Reactors

In future semesters, reactors should not be stored with biomass still in them. They should be cleaned out during the semester that they are used to facilitate a faster startup period for the next semester.

2. Testing Air Tightness - Soap Test, Pressure Hold-Up Tests and Valve Tests

The preliminary tests confirmed that the reactors 2.3 and 2.5 used in previous semesters are not entirely air-tight. However, while the pressure test did indicate an air loss, it is a leak of 3.94% of the total efficiencies ranging from volume of daily gas production escaping during a 24 hour period. For now, this leak will be considered negligible and the reactors should be used. This assumption is supported by the fact that the same reactors were used in previous semesters and useful data was obtained despite this leakage.

Testing of the valves showed that the three new solenoid valves with similar data were in good condition, while the rest of the three old pinch valves with leak problems were not effective. As a result, the solenoid valves were adopted for use.

3. Inoculation

Refrigeration issues have emphasized the importance of keeping the stock cooled, but not frozen. It was determined that the refrigerator temperature sensor was removed from its proper place during refrigerator modification that was done to allow the stock container to fit. After the temperature sensor issue was identified, it was reconnected to its proper location and freezing issues were no longer an issue. A larger refrigerator to hold the wastewater stock would be helpful in future semester work to ensure that the temperature sensor is not disturbed.

There should be close monitoring of tubes to ensure that the suspended solids do not impede stock delivery. Consistent stock delivery at the desired rate is essential to reactor function and success, and it is important to make sure that the tubing functions properly with the stock recipe, which is designed to have some amount of suspended solids.

4. Biogas Production Measurement

The results of methane production from past semesters is compared with the methane production from reactor 2.5 on 11-29-15 in Table 6.

Table 6: UASB Methane Production Summary

Reactor	Fall 2013 Reactor 2.4	Fall 2013 Reactor 2.6	Spring 2014 Reactor 2.4	Fall 2015 Reactor 2.5
Methane Prod. (mL/day)	116.8	139.5	227.53	218.1

5. COD Test

Although the reactors had yet to reach a steady state, they treated influent COD with efficiencies ranging from 66 to 88 % (with the December 1st data being omitted due to the suspect COD influent sample). There were only a couple of days of sampling, but all showed positive treatment.

6. Gas Chromatography

For reactor 2.5 the approximate experimental methane production volume was compared to the theoretical methane production volume (378.21 mL methane/g COD from the AguaClara wastewater Spring 2014 report) as a function of the fraction influent COD treated. The experimental values observed ranged from 48 to 59% of theoretical methane production (with the December 1st data being omitted due to the suspect COD influent sample).

Future Work

In future semesters, more work should be done to improve air tightness, by replacing leaky parts or adding more teflon tape or glue as sealants. Modification of reactors should be considered to try to contain as much biogas that is produced as possible.

Testing on reactor 2.3 will be done to determine if the problem with biogas measurement was the low volume of gas production or if it was a fault with the Process Controller file. If it was a programming error, it should be determined why the Process Controller file did not operate correctly with the system. The end goal is that both reactors 2.3 and 2.5 are connected to Process Controller so off-gas events can be recorded and compared. The bubble meter should be used in the future as a second measurement of biogas production, to ensure that Process Controller values are accurate and to provide another method of long-term biogas measurement over the course of multiple days.

As the COD tests showed, COD was not delivered to the two reactors at the same rate. Tubing connection should be tested to see if the problem is caused by the y-junction, or if it is a problem of tubing clogging. It is not clear why the y-junction would not be delivering the same flow rate to each set of tubing, but testing will be done to determine if this is the problem. If it is, the reactors can be assigned their own stock reserve so that each reactor functions individually and cannot impact the operation of the other. If the problem is clogging, further dilution of stock should be considered to facilitate flow through the tubing. Increased dilution would be accompanied by a change in tubing size to allow the stock to be delivered at the current rate.

Oxygen stress tests will be carried out with one control reactor which will receive no oxygen, and one experimental reactor which will receive sparges of oxygen. This test will be done to test robustness of reactor, and to better understand the role that oxygen plays in the UASB. Based on the experimental design proposed by Botheju et al. (2010) oxygen will be bubbled into the reactor at various rates with respect to percent of overall biogas production. One of our reactors will be used as a control, without any applied oxygen stress, and the other will receive oxygen levels varying from 0 to 10% biogas production rate by volume. Additional COD and GC testing will be done to quantify the impacts of the oxygen stress on reactor operation.

Future work should include research on how to best pair the UASB and the GSBR in wastewater treatment. Coupling of the two could work to more effectively treat wastewater.

Research on the role of UASBs in Honduras will continue throughout the year. Evan and Nisarg from the wastewater subteam will be traveling to Honduras in January. On this trip, the current state of wastewater treatment will be investigated. The local people of Honduras and people working in Honduras such as Walker Grimshaw will also be questioned to determine whether or not there is interest in implementing UASBs in Honduras. Samples will be taken from streams to monitor pathogens and nutrient concentration from untreated wastewater. This research will provide valuable information which will be considered when planning future improvements such as UASBs. Alternative technologies will be explored if research suggests that UASBs are not a suitable fit for communities in Honduras or if there is strong opposition towards the implementation of this technology.

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