Design and Construction of Five Gallon Anaerobic Digesters

By:

Daniel Schricker

Bio-Resource Agricultural Engineering
California Polytechnic State University
San Luis Obispo
2014

SIGNATURES

TITLE: Design, Construction, and Analysis of Small Scale Waste Treatment Using Activated Sludge and Algae

AUTHOR: Daniel J. Schricker

DATE SUBMITTED: ______________________

______________________ ______________________
Senior Project Adviser Signature

____
Date

______________________ ______________________
Project Head Signature

____
Date

ACKNOWLEDGMENTS

Thanks to my girlfriend Samantha for all the assistance editing and redrafting my report.

Thanks to everyone that helped. Thanks Virgil, Nathan, Andrew, and Mike for all the help in the shop 7 fabricating.

Thanks to Nate and Ruth for their help with the tipping meter design and the experience working with their digesters.

Thanks to Professor Schwartz for all the guidance, help shopping for parts, and the many weekends he opened lab 4.

Thanks to Josh for doing research on anaerobic digester feeds available around Cal Poly

ABSTRACT

This project discusses the design, construction, and testing of a laboratory scale anaerobic digestion reactors. It included four digesters and two gas measurement devices. The outside dimensions of the digester were 22 inch tall with a 10.5 inch diameter. They were constructed from schedule 40 PVC pipe, with a wall thickness of 0.5 inches. They were designed to be filled with 20 liters of digester feed stock, at a height of 16 inches from the bottom, leaving 5 inches of head space above the digester feed for biogas accumulation. Two of the reactors were heated with Hydrofarm seedling heating pads controlled by Hydrofarm thermostat that operate at a maximum temperature of 42°C. Two digesters were complete mixed reactors mixed with a mixing paddle. Two digesters were fixed film digesters, packed with media, and mixed with a peristaltic pump. The gas produced by the digesters was piped to the gas measurement tipping meters and the volume of gas was recorded on a data logger in 90 ml intervals.

DISCLAIMER STATMENT

The university makes it clear that the information forwarded herewith is a project resulting from a class assignment and has been graded and accepted only as fulfillment of a course requirement. Acceptance by the university does not imply technical accuracy or reliability. Any use of the information in this report is made by the user(s) at his/her own risk, which may include catastrophic failure of the device or infringement of patent or copyright laws.

Therefore, the recipient and/or user of the information contained in this report agrees to indemnify, defend and save harmless the State its officers, agents and employees from any and all claims and losses accruing or resulting to any person, firm, or corporation who may be injured or damaged as a result of the use of this report.

TABLE OF CONTENCE

	Page
SIGNATURE PAGE	ii
ACKNOWLEDGEMENTS	iii
ABSTRACT	iv
DISCLAIMER STATEMENT	v
LIST OF FIGURES	vii
LIST OF TABLES	viii
INTRODUCTION	1
Background	1
Justification	2
Objectives	2
LITURATURE REVIEW	3
PROCEDURES AND METHODS	6
Design Procedure	6
Anaerobic Digester Unit	6
Tip Meter	8
Construction Procedure	10
Anaerobic Digester Unit	10
Tip Meter	11
RESULTS	15
DISCUSSION	16
Design Changes	17
Difficult Construction Procedures	17
REFERENCES	18
APPENDICES	19
Appendix A: Parts List & itemized costs	19
Appendix B: Cut layout for tip meter	20
Appendix C: Additional tip meter construction notes	21

LIST OF FIGURES

Page

1. Figure 1. Metabolic pathway of anaerobic digestion………………….. 1
2. Figure 2. Types of anaerobic digesters…………………...……………. 3
3. Figure 3. A diagram showing two stage digestion…........……………. 5
4. Figure 4. Side views of the digesters…………………….……………. 6
5. Figure 5. The complete mix digester lid………………...……………. 7
6. Figure 6. Isometric view fixed film digester……..……..……………. 7
7. Figure 7. Isometric view of the complete mix digester....……………. 8
8. Figure 8. The assembly of the tip meter………………………………. 8
9. Figure 9. Overview of the tipping meter………………………………. 9
10. Figure 10. The 10 inch pipe being cut…………….………………….. 10
11. Figure 11. Drilling the holes in the lids………………….……………. 10
12. Figure 12. The finished digesters……………………..……………. 11
13. Figure 13. All the pieces cut out for the tip meter……………………. 12
14. Figure 14. Assembling the seesaw for tip meter………...……………. 13
15. Figure 15. The calibration weight for tip meter………………………. 13
16. Figure 16. Water tank for tip meter…………………...……………. 14
17. Figure 17. The finished tip meter……………………..……………. 14
18. Figure 18. Seal testing…………………………..…….……………. 15
19. Figure 19. The calibration process for the tip meters…………………. 15

LIST OF TABLES

Page

1. Table 1. The cut list for the parts for the tip meter……..…………….. 10
2. Table 2. The cut list for the parts for the tip meter……..…………….. 15
3. Table 3. The prices of the digesters and the tip meters…..…………… 21

INTRODUCTION

Background

Anaerobic digestion takes place when various micro-organisms breakdown organic matter (OM) in an environment with no oxygen. This process produces methane, carbon dioxide, and biological sludge. Anaerobic digestion is helpful because it can stabilize waste OM and produces biogas (McCarty 1964). A common application of anaerobic digestion is to treat wastewater, both municipal and industrial, by reducing biological oxygen demand, volume of waste and suspended solids (Szűcs et al. 2012) & (McCarty 1964). Another common use for anaerobic digestion is to produce biogas, which is a renewable energy resource. Biogas can be used as a replacement for natural gas or to generate electricity. Electricity from renewable resources has been a growing market since the Renewable Portfolio Standards were passed in 2002 requiring 33% of California's energy to come from renewable sources. Renewable energy sources are currently at 20% in California, with biogas producing 10% of the renewable energy (CPUC 2014).

The bacterial reactions that occur during anaerobic digestion are hydrolysis, acidogensis, acetogenesis, and methanogenesis seen in Figure 1.

- During hydrolysis, acid forming bacteria break down insoluble organic polymers (carbohydrates, proteins, and fats) into acids that can be consumed by other bacteria.
- During acidogensis, bacteria convert these simple acids into carbonic acids, hydrogen, and carbon dioxide.
- During acetogenesis, bacteria break down carbonic acids and alcohols into acetic acid.
- During methanogenesis, bacteria convert hydrogen and acetic acid to methane and carbon dioxide (Girard et al 2013).

In a healthy digester all these bacteria are balanced, so as acids are produced they are used, leaving the digester at a neutral pH (McCarty 1964). If one process occurs to quickly and the pH inside the digester fluctuates too much, the bacteria inside will die and the biogas production will stop.

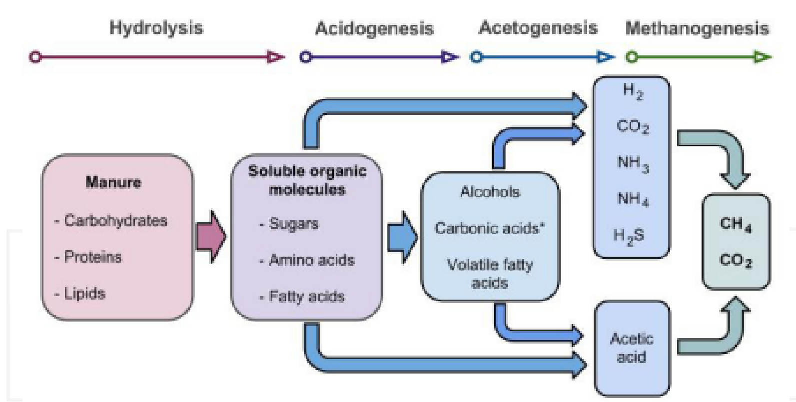


Figure 1. Metabolic pathway of anaerobic digestion (Girard et al 2013).

Anaerobic digestion also reduces the volume of waste because cell growth during the anaerobic process is slow; more OM is converted into gas than into cell material. This cell material can be reused as compost or animal bedding. The liquid effluent from the digestion can also be reused as fertilizer, recycling the nutrients from waste to produce crops. Volatile compounds are also reduced during anaerobic digestion. Normally the volatile compounds would break down in landfills releasing greenhouse gasses, but during anaerobic digestion the gasses are captured and put to good use (McCarty 1964).

Justification

Anaerobic digestion produces biogas, which is mostly composed of methane. This can be used as a renewable replacement for natural gas or burned to generate electricity. Biogas is used to make energy by burning it in micro turbines or modified gas generators. Biogas can be stored easily so it is available for on demand use; it does not require wind or sun like other renewable energy sources. Biogas is a valuable resource as the deadline for California's renewable energy portfolio grows near. It can also provide an environmentally friendly way of producing natural gas to power household stoves and heaters.

Objectives

To design and build four anaerobic digesters that can be incorporated into Cal Poly classes to help students understand the anaerobic digestion process. There will be two types of digesters a complete mix (CM) digester and a fixed film digester along with two gas volume measurement meters (gas tip meters).

LITURATURE REVIEW

Anaerobic digester designs vary by application. Some of the different types of digesters are lagoon, plug flow, dry digestion, complete mix, and fixed film, shown in Figure 2. The difference between each reactor is the shape of the reactor, the method for mixing, and if biofilm is retained (Moletta 2005). Biofilm is a layer of slime that contains the microorganisms that carry out the processes involved in anaerobic digestion. Four design variables apply to all these digesters: residence time, complexity, temperature, and solids content.

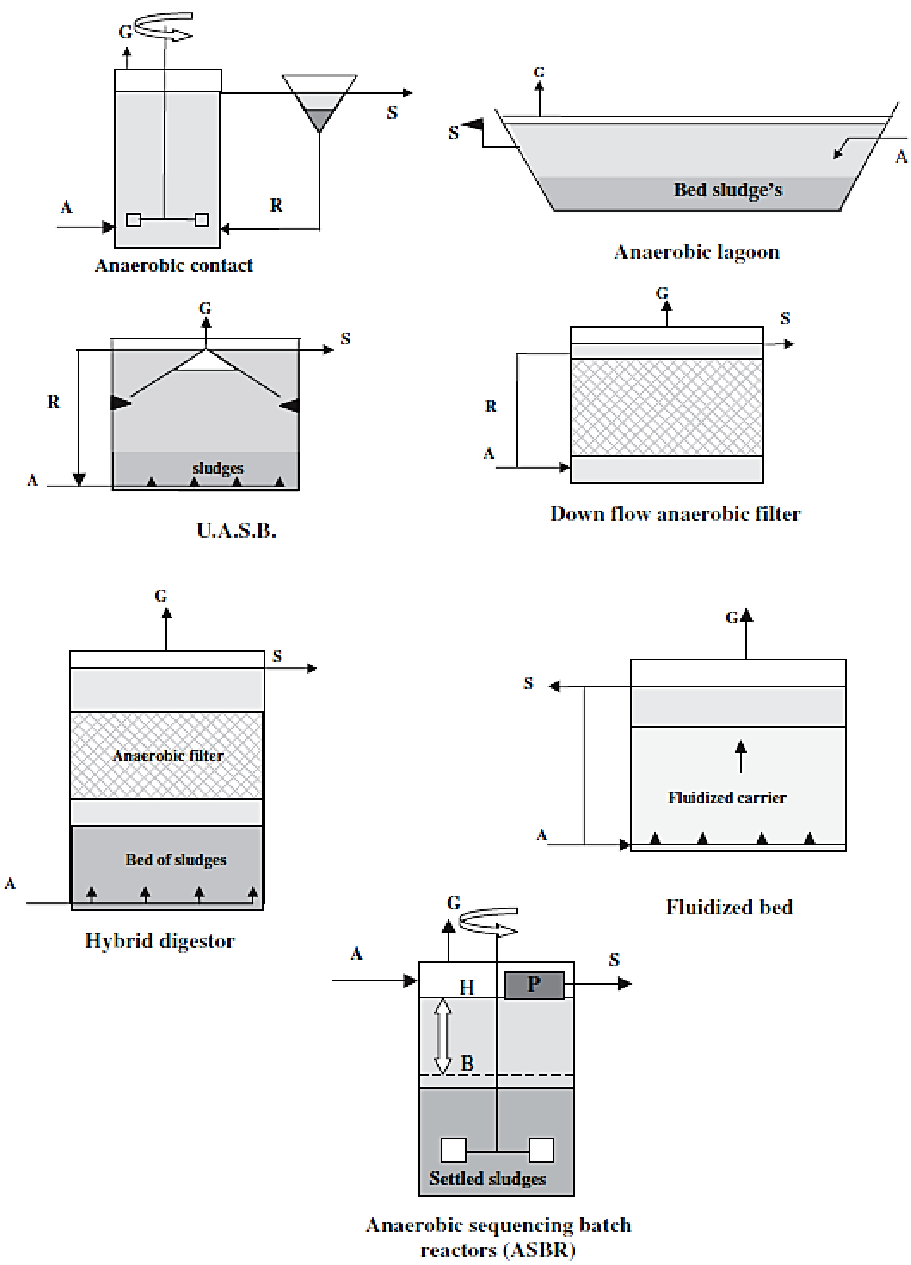


Figure 2. Types of anaerobic digesters, A is feed, S is effluent, G is gas (Moletta 2005).

Residence Time. Anaerobic digesters can operate in batch or continuous flow modes. Batch flow is when a digester is operated so that it is emptied after the organic matter (OM) has digested for the desired time. Then a fresh batch of OM is loaded into the digester along with digester seed. Digester seed is the effluent from the previous digestion that includes the microorganisms that carry out the digestion processes. The optimal seed ratio for this type of digester digesting is 1:1.25, feed to seed (Szűcs et Al. 2012). The feed to seed ratio may be different with extreme types of feed, Szűcs used municipal waste water in dry batch digestion. Another flow process is continuous flow. This process has OM continuously entering the digester and digested sludge continuously leaving. For continuous flow reactors hydraulic retention time, HRT, and solid retention time, SRT, are important. HRT is the amount of time that the liquid is retained inside of the digester. SRT is the amount of time that solids are retained inside of the digester. In conventional complete mix and plug flow digesters, HRT=SRT, and in retained biomass reactors SRT>HRT. The equations for HRT & SRT are:

$$HRT = \frac{V}{Q} \qquad SRT = \frac{VC_d}{Q_w C_w}$$

(Burke 2001)

V = Volume [m^3]
Q = Flow rate [m^3/sec]
C_d = Solid concentration in the digester [g/m^3]
Q_w =Volume of effluent per day [m^3]
C_w = Solid concentration in effluent [g/m^3]

The ideal hydraulic retention is about 20 days for manure under optimum conditions (Marsh 2008) this can vary from 10 to 40 depending upon the complexity of the design and type of feed. One way that the HRT can be changed is by using a different digester design, for example: complete mix digester usually require a longer HRT to allow for growth of the microorganisms that carry out the anaerobic digestion. Fixed film digesters require a shorter HRT than other digesters because the microorganisms are retained in the digester by the fixed film. The film of biomass is retained by media in the digester that provides a growing area for the bacteria to attach to.

Complexity. There are many different types of digesters, as seen in Figure 2, and they can operate in many different configurations. Single stage digesters have all the digestion process happening in the same reactor. Multi-stage digesters have a reactor for the digestion process up to acetogenesis and a separate reactor for the remaining processes. By breaking up the bacteria by group the reactor can be operated to optimize the growth of the bacteria responsible for that stage of the digestion. More advantages of multistage digestion are, to stabilize pH of feed to the second digester, for additional waste treatment, or to produce various gasses for example hydrogen in the first stage of the digester seen in Figure 3. The advantage of producing hydrogen is that it can be mixed with the methane produced during methanogenesis to produces cleaner burning biogas, lower NOx emissions (Ruth et al 2014).

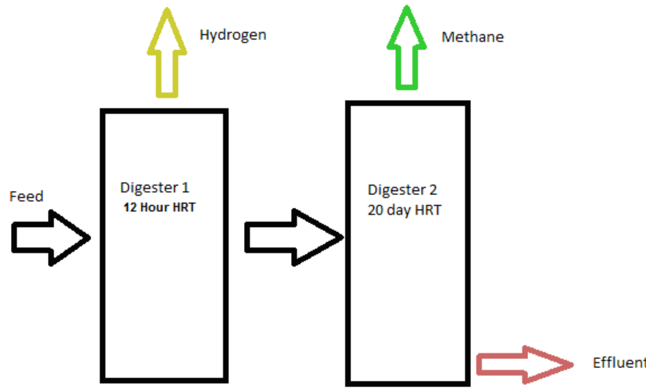


Figure 3. A diagram showing two stage digestion to produce biogas with hydrogen.

Temperature & pH. There are three different temperature regimes that digesters are operated at: ambient 25°C, mesophilic 35°C, and thermophilic 45°C. Digestion rates are optimized for manure by keeping the temperature at 30–60°C, and pH between 5.5 & 8.5 (Marsh 2008). Other substances can be digested at various temperatures. Optimizing anaerobic digestion allows for more efficient waste treatment and gas production. If the climate inside the digester fluctuates the health of the digester does too, and it can cause a drop in gas productions. To maintain the best quality of methane biogas digesters should be kept at a constant pH: between 6.6 & 7.6, alkalinity around 6,000 mg $CaCO_3$/Liter, and a temperature between 30-60°C (McCarty 1964) & (Ruth et al 2014).

Solid Content. The solids content of the available digester feed determines the type of digester that can be used. For higher solids content plug flow digesters are typically used, for lower solid contents fixed film digesters work well (Moletta 2005). The volatile solids in the digester feed also have an effect on the health of the digester. If the feed rate of volatile solids is too high the acid producing bacteria will create a surplus of acid in the digester, lowering the pH and killing the methane producing bacteria (Ruth 2014). High solids content limits the type of digester that can be used with the waste, for example it would clog a fixed film digester. However fixed film digesters have many advantages such as a high treatment rate and high reduction of organic pollutants in water so often an initial treatment of the waste water is done to reduce the solids content in a complete mix digester then a secondary treatment is done to reduce the organic matter in the waste to discharge limits in a fixed film digester.

PROCEDURES AND METHODS

The first step for this project was to develop an initial design using Solidworks. This cad model was used to help lay out all the access ports and develop parts lists. The digester required ports for filling with OM (influent), emptying sludge (effluent), measuring temperature, mixing, and collecting biogas. The gas tip meter design was based off the tip meter used for digester research by the Environmental engineering research group at Cal Poly.

Design Procedures

There were two main assemblies that were designed for this project, the digesters and the gas meter. These are discussed separately in the sections below.

Digester. Two types of digesters were designed for this project: fixed film and complete mixed. Both designs use the same bottom and main body, but have different lids. The difference in the lids was because of the different methods for mixing the digesters. The complete mix digester is designed to be mixed with a paddle. The fixed film digester is designed to be mixed with an external peristaltic pump. A side view of the digesters can be seen in Figure 4.

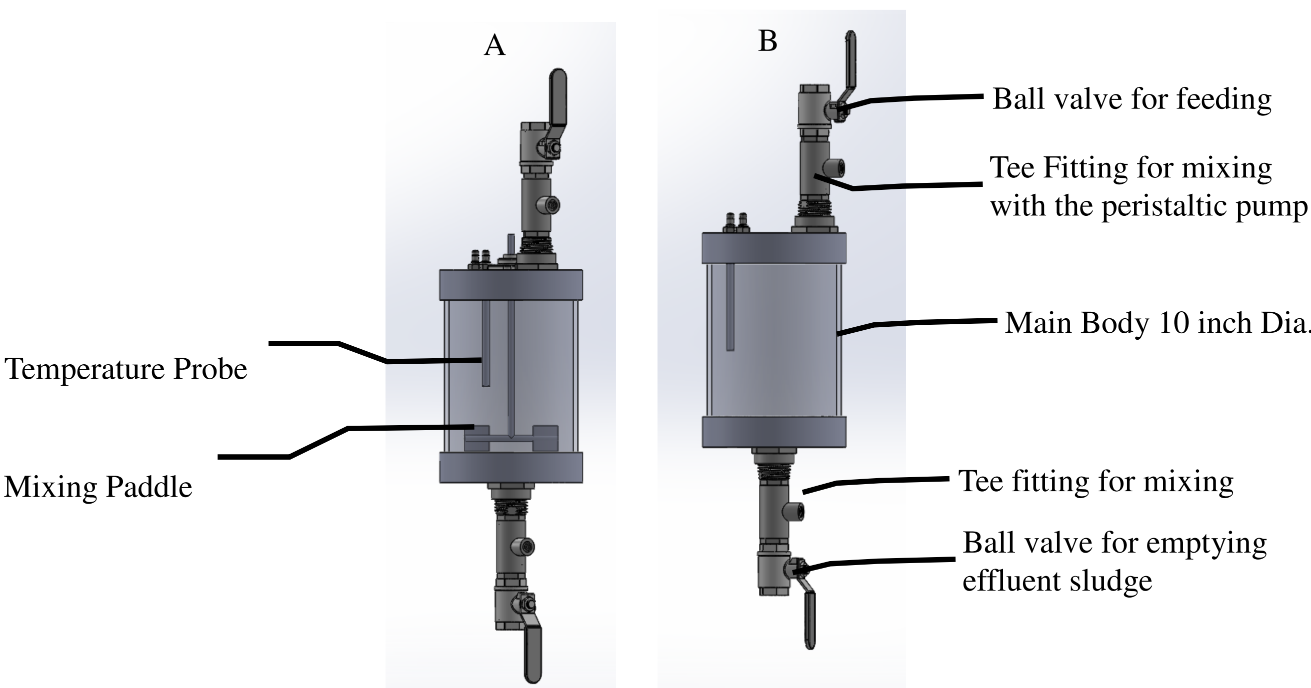


Figure 4. Side view of the digesters, the complete mixed digester is on the left (A) and the fixed film digester on the right (B).

There is a ball valve on top of the digester for manual feeding. Below the valve is a tee fitting for mixing with a peristaltic pump and automating the feeding process. The tee on the bottom is also for mixing and automating the effluent removal process. On the bottom is another ball valve for manually removing effluent sludge from the digester. There is also tubing that protrudes into the digester. This is ½ ID tubing that has been sealed so a temperature probe can be used to monitor the temperature of the digester. Another port that can be seen on the lid in Figure 5 is the gas outlet. This attaches to a tip meter to measure the volume of biogas produced.

The major differences between the two digesters are the top lids. The complete mix digester has an extra hole in the middle so the shaft for the mixing paddle can be operated by an external motor. This was done because any motor or pump exposed to the inside of the digester would quickly corrode and stop working. The shaft of the mixing paddle was sealed with a rotary shaft seal to prevent gas from escaping. The shaft was also supported with a bearing mounted on top of the digester lid. The complete mix digester top lid can be seen in Figure 5.

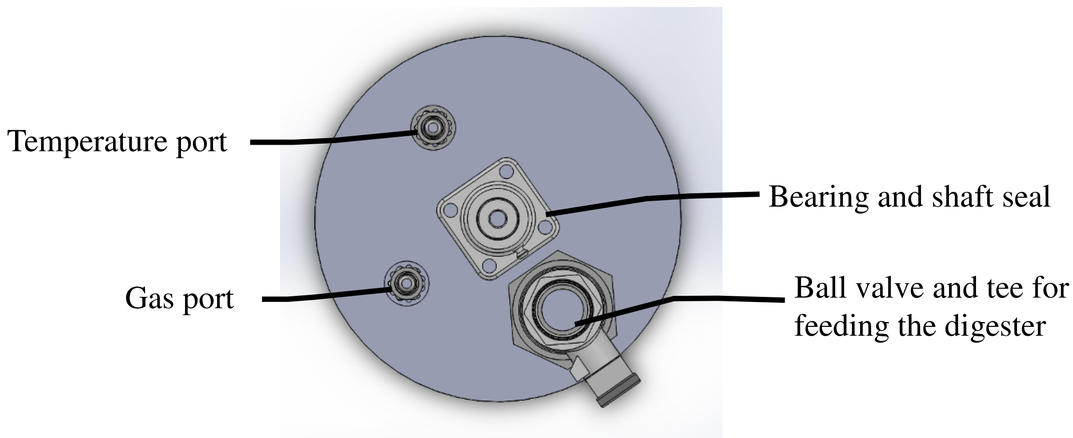


Figure 5. The complete mix digester lid.

The lid for the fixed film digester is similar to the one seen in Figure 5 except it doesn't have the bearing and shaft seal. The fixed film digester is mixed with an external peristaltic pump that pulls digester sludge out of the tee fitting on the bottom and returns the sludge to the top tee. The fixed film digester, also called attached growth, has an expanded metal grate, seen in figure 6, on the bottom to support media inside the digester. This media gives the anaerobic bacteria film something to attach to so it's not carried out with the effluent.

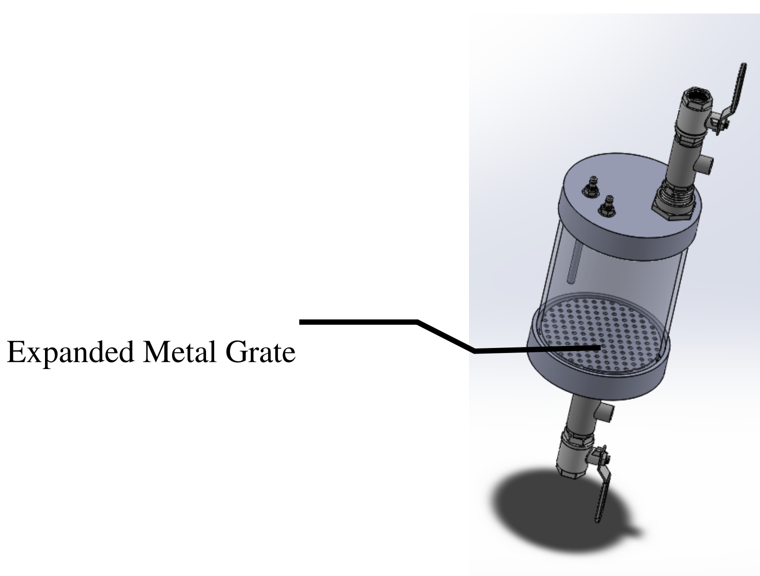


Figure 6. Isometric view of a fixed film digester.

The complete mix digester is mixed with a mixing paddle. It does not retain any bacterial film when the effluent is taken away. This means the digester will require a longer HRT so the anaerobic bacteria have time to colonize the digester feed. It can also operate with higher solids content because there is no media to clog with solids. The final design of the complete mix digester can be seen in Figure 7.

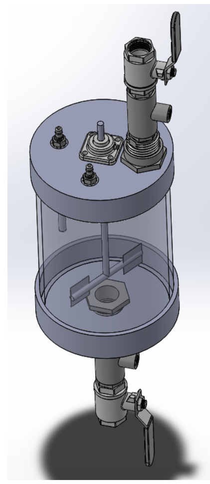


Figure 7. Isometric view of the complete mix digester.

Tip Meters. The tip meter was designed to measure the gas production of the anaerobic digesters using a reed switch attached to a data logger. The design was based from laboratory tip meters that the Cal Poly ENVE department has been using for the WESTT research program. This meter works by using a submerged seesaw with a weight on top to collect bubbles. When enough bubbles have been collected the seesaw tips triggering a data logger that records the tip. The volume of gas required to tip the seesaw was known so the number of tips logged by the data logger can be converted into a volume. The first step for the tip meter construction was to develop a cad sketch using measurements from an operational tip meter and provided instructions (Appendix C). The entire assembly is shown in Figure 8. It has three main parts: the tipping seesaw, the calibration weights, and the water tank.

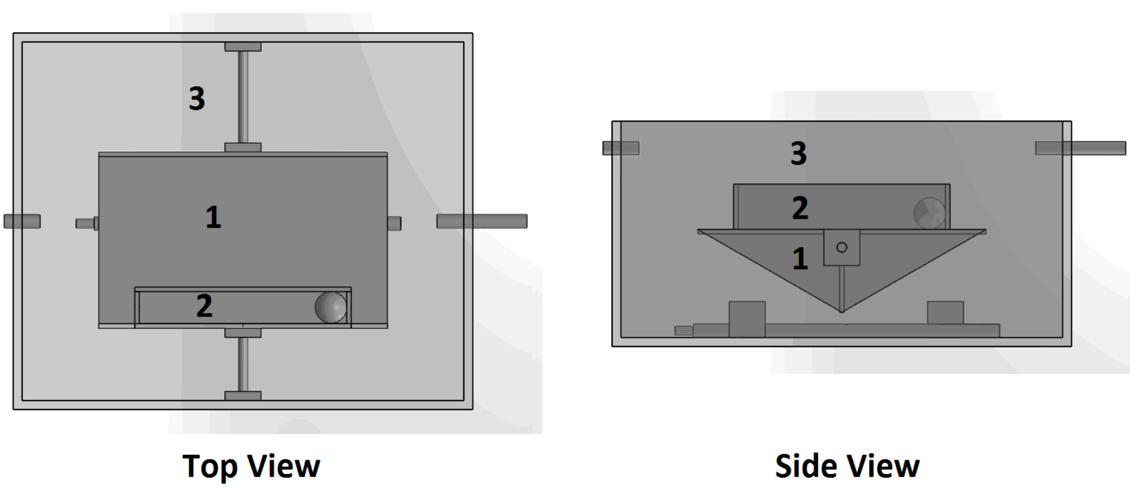


Figure 8. Assembly of tip meter; 1) tipping seesaw, 2) calibration weight, 3) water tank.

The first part to design was the seesaw. It has dimensions that measure approximately 100mL of gas per tip. It rests so that gas bubbles flow into one of the triangular cavities on the bottom. When the force of the gas is greater than the force of the calibration weight the seesaw tips, releasing the collected gas and triggering a switch that records the tip on a data logger.

The second part of the tip meter was the calibration weight. It attaches on top of the seesaw. It was adjusted by screws that are attached at each end of the part, in the holes seen in Figures 8 & 9. These screws allow for the volume required to tip the seesaw to be calibrated; when the screws are tightened the volume of air to tip the seesaw decreases and vice versa. This enables the tip meter to be tuned so that each tip of the meter requires the same quantity of gas.

The third part of the tip meter was the water tank. This houses the seesaw and the calibration weight. It also has a tube along the bottom with a hole drilled so that gas flows into the triangular cavities. The inlet for the gas is the tube that protrudes out the right side of the container, as seen in figures 8 & 9.

The tip meter was made out of polycarbonate, a nonreactive material, so that it doesn't erode from any corrosive gas in the biogas. The parts were cut out with a saw or laser cutter. It was glued together with dichloromethane, a solvent that melts the poly carbonate to its self. The calibration weight was attached to the seesaw with this glue and the seesaw snaps into brackets on the water tank. An overview of all the parts of the tip meter assembled is seen in Figure 9.

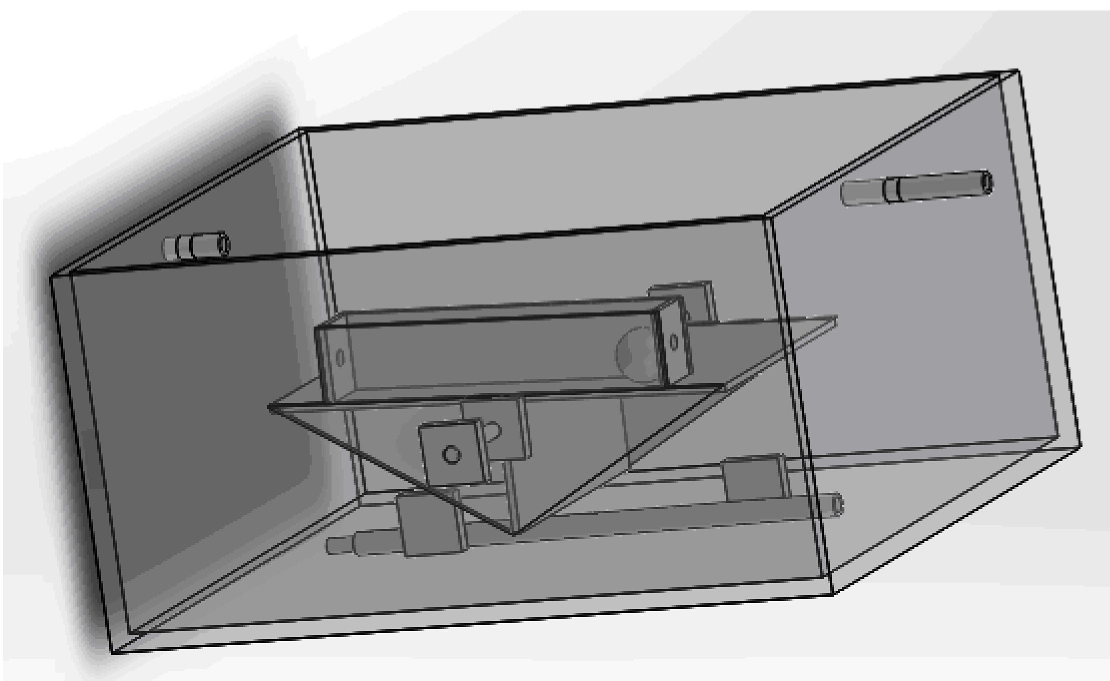


Figure 9. This is an overview of the tipping meter, with all the components assembled.

Procedures for Construction

The construction was broken into two parts: building the digesters and building the tip meters.

Digester. There were very few cuts for the digesters mostly drilling and tapping of holes. A cut list can be seen in Table 1.

Table 1. Cut list for the Digesters.

	Complete Mix Digester		**Fixed Film Digester**	
Tops				
Hole Size	*Amount*	*Location*	*Amount*	*Location*
1” NPT	1	3” off center	1	3” off center
½” NPT	2	3” off center	2	3” off center
17/32	1	In the center, through	0	n/a
1”	1	In the center, 1/8 deep	0	n/a
3/8”	4	1” off center	0	n/a
Body				
Cut Pipe Dia, Sch. 40	*Length*		*Amount*	*Length*
10”	21”		4	21”
	Complete Mix Digester		**Fixed Film Digester**	
Hole size	*Amount*	*Location*	*Amount*	*Location*
¼”-20	0	n/a	4	Even spaced
Expanded Metal 10” dia.	0	n/a	1	n/a
Bottom				
Hole Size	*Amount*	*Location*	*Amount*	*Location*
1” pipe thread	1	In the center	1	In the center

A 10 inch diameter PVC pipe was cut to a length of 21 inches. This is the main body of the digester. The pipe was secured properly when cutting on the band saw, this saw used a strap and a vise, seen in Figure 10.

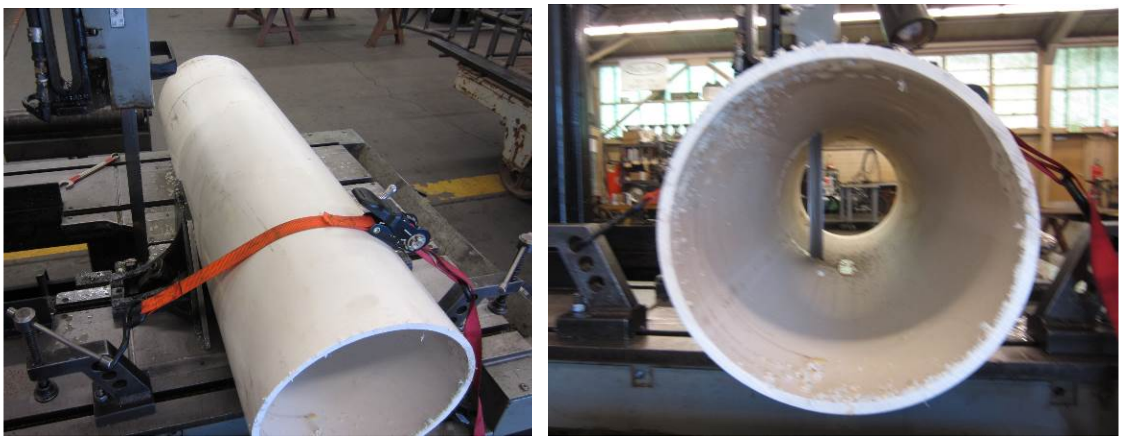


Figure 10. The 10 inch dia. pipe were cut to a length of 21 inches on the band saw.

Next all the appropriate holes in the lid were drilled and taped. The gas and temperature ports required ½" pipe threads, and inlet and effluent required 1" pipe threads. These holes are 3 inches from the center. They were drilled using a very slow speed and feed rate, 60 revolutions per minute worked well. Also if a slow auto feed was not used the larger bits bite the material and chip away large chunks. The drilling process can be seen in Figure 11.

Figure 11. The lid clamped for drilling.

After the holes were drilled and tapped, the fittings were assembled and were sealed with silicone. One of the more important fittings was the rotary shaft seal that prevents gas from leaking out of the top of the CM digester where the mixing paddle that sticks out of the top. The shaft seal can be seen in figure 12.

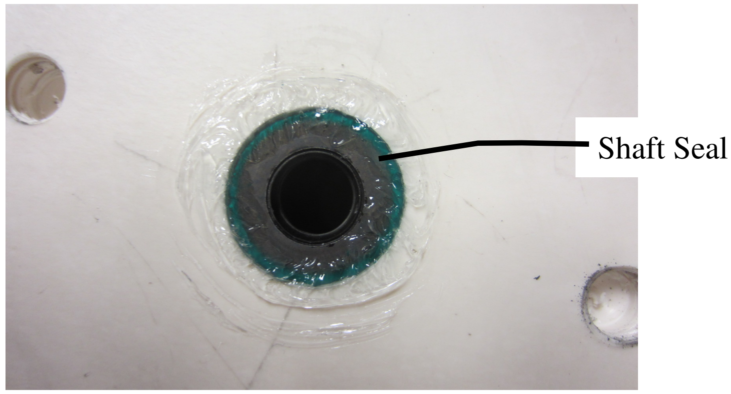


Figure 12. The shaft seal for the CM Digester.

The shaft seal works because pressure inside the digester pushes the “u” channel outwards. This forms a seal with the saft and the lid. The “u” channel of the saft seal can be seen in figure 13.

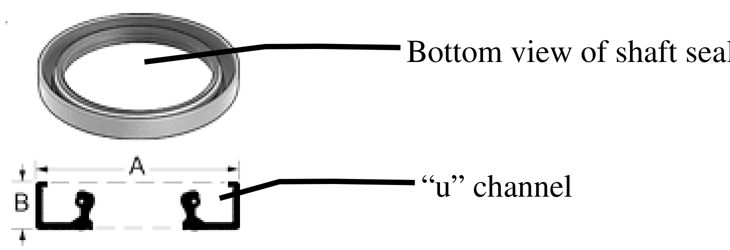


Figure 13. The saft seal detailed drawing.

The next fitting to attach was the port for the temperature probe. For this 0.5 inch ID nylon tubbing was kinked at the end sealed with silicone and zip tied shut. This was done to prevent any thing from leaking out of the digester, but still get an accurate measurment of the temperature inside the digester, see figure 14.

Figure 14. The sealed temperature port.

The temperature port is for a temperature probe for a thermostat that controls the heating pads. The tempature port should be filled with water so that it reads the temperature of the digester not the temperature of the air. The attached temperature port can be seen in figure 15, along with the mixing paddle for the CM digester.

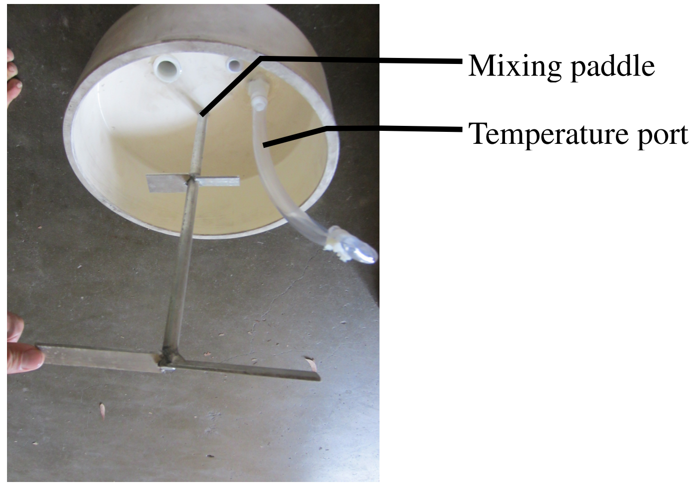


Figure 15. The CM lid showing the mixing paddle and temperature port.

The mixing paddle for the CM digester has a shaft that extends out of the digester. This shaft can be turned by hand or automated to mix the digester. The Fixed film digesters are mixed using a peristaltic pump attached to the tee fittings on the top and bottom. These pumps will pull sludge off the bottom and deposit it on the top of the digester. This pump can be seen in figure 16.

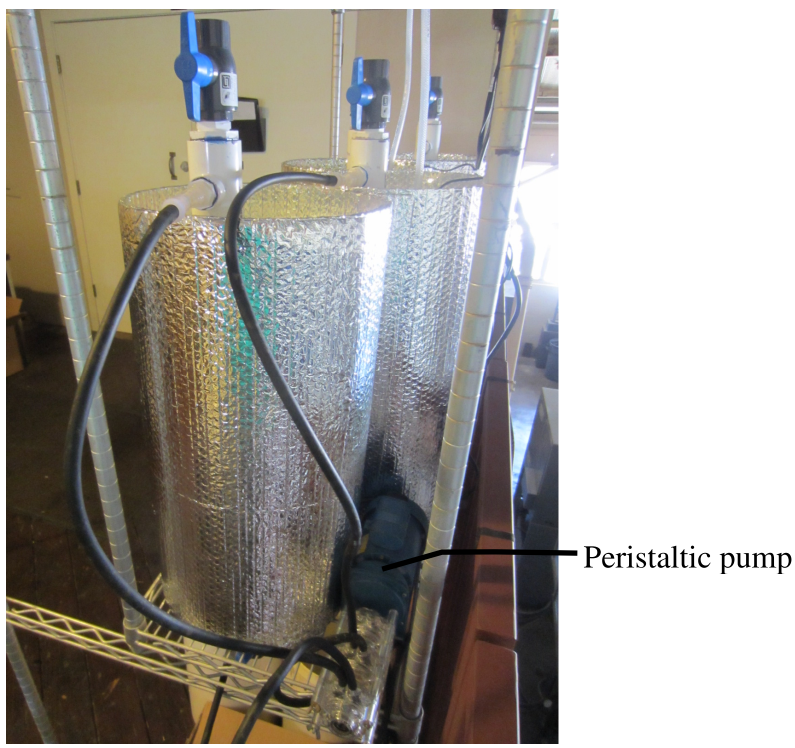


Figure 16. This shows the peristaltic pump for mixing the fixed film digesters

In figure 16 you can also see the digesters are wraped with insulation, under the insulation is a heating pad. This will heat the digesters to 30 C. To maintain this tempature a thermostat was used shown in figure 17.

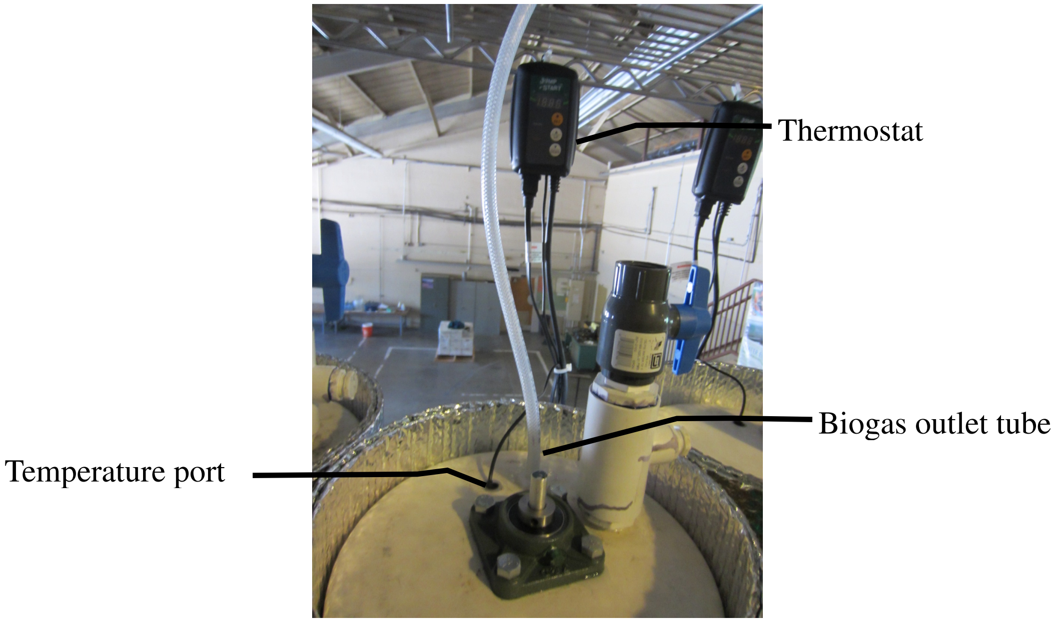


Figure 17. This shows the thermostat and other fittings on a CM digester.

The rack that the digesters are on had holes cut in the bottom to accomidate the effluent valves. The finished digesters can be seen in Figure 18.

Figure 18. The finished digesters, left complete mix, right are the fixed film.

<u>Tip meter.</u> The tip meters are made out of polycarbonate so that they don't corrode if there is hydrogen sulfide in the digester gas. The pieces were glued together using the

solvent Dichloromethane to melt the pieces together. The first step for construction was to develop a cut list for all the parts seen in Table 2 (see appendix B for a cut diagram).

Table 2. The cut list for the parts to make 1 tip meter.

1/4 in Polycarbonate				
Square/Tri.	*Length (in)*	*Height (in)*	*Amount*	*For Part #*
S	1	1	8	1,2
1/8 in Polycarbonate				
Square/Tri.	*Length (in)*	*Height (in)*	*Amount*	*For Part #*
S	8	4.64	1	1
S	2.18	4.64	1	1
S	6	1.25	2	2
S	0.89	1.25	2	2
T	8	2.3	2	1
Tubing by OD				
OD (in)	*Length (in)*		*Amount*	*For Part #*
0.38	8.5		1	3
0.38	1.5		1	3
0.25	1		2	1
0.25	1.8		1	1

All the pieces were cut on a band saw. The poly carbonate was clamped vertically and supported to minimize the deformation. The edges were beveled so the pieces sat flush and glued together completely. All the pieces for one tip meter are shown in Figure 19.

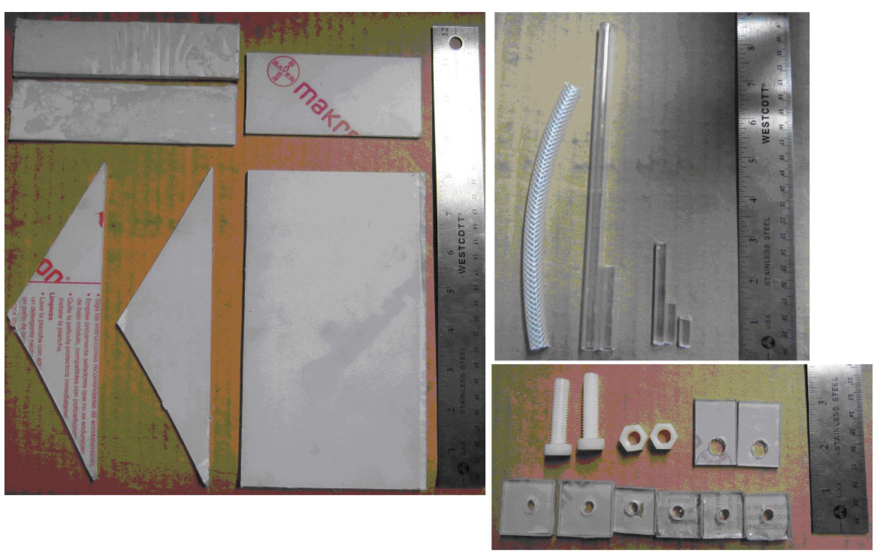


Figure 19. All the pieces cut out for the tip meter.

Next, the seesaw, was built. It is made out of the two 2.3” x 8” triangles, the 2.2” x 4.6” rectangle, and the 8” x 4.6” rectangle. Solvent was applied to both pieces and held and clamped in place as seen in Figure 20.

Figure 20. The assembled and glued seesaw.

The next part was the calibration weight. Made from the two 6” x 1.25" rectangles glued to the two 1.25” x 0.9” rectangles. The calibration nuts and bolts were attached to the smaller rectangles, silicone was required because the solvent didn’t work well, see Figure 21.

Figure 21. The calibration weight holder; parts on left, assembled on right.

The water tank was the next part. First the 3/8 inch outer diameter pipe that is 8.5 inches long was attached to the 1.5 inch long pipe using 7 inch of nylon reinforced tubing. Then a 3/8 inch hole was drilled in the polycarbonate bin as close to the top as possible and the short pipe was fit into the hole. Then the 8.5 inch long tube was glued to the bottom of the tank. Then the supports for the seesaw were glued on the sides so that the seesaw doesn’t hit the tube on the bottom of the tank, see Figure 22.

Figure 22. The water tank with 8.5 inch pipe on bottom and seesaw supports on sides.

Finally the counterweight was glued onto the seesaw and it was slid into the water tank supports so it tips back and forth freely. Last the magnets and the reed switch were attached so that the switch was triggered when the meter tips, see Figure 23.

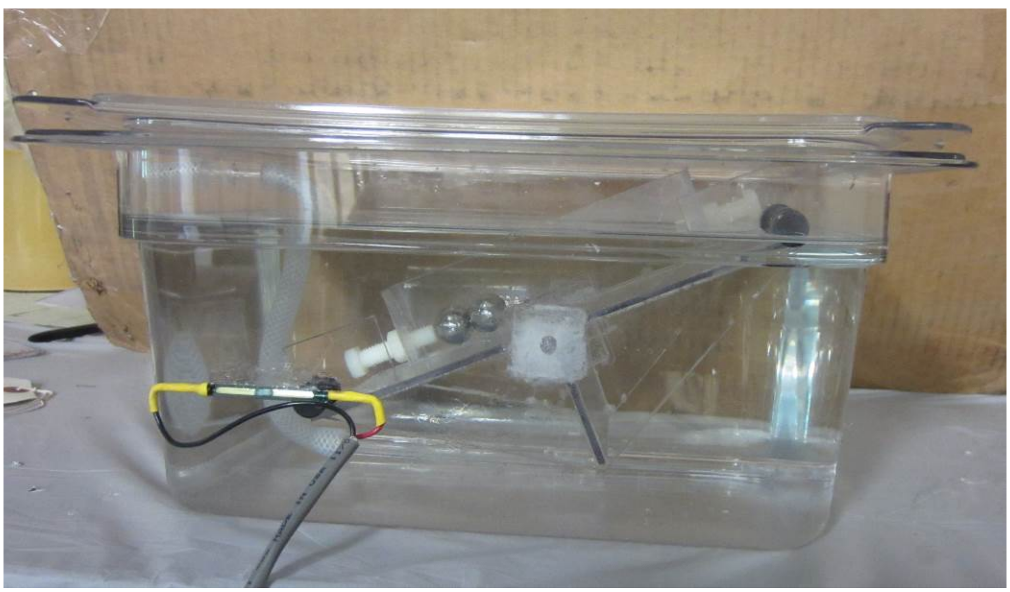


Figure 23. This is the finished tip meter.

The last step was to attach the tip meters to the data logger and run the gas line from the gas port on the digesters to the inlet on the tip meters. The tip meter fully connected can be seen in Figure 24.

Figure 24. The tip meters fully connected to the data logger and gas ports.

RESULTS

Testing

The digester leak test had two phases volume testing and seal testing. First was the volume test, the digesters were filled with 20 L of water and the height of the water was measured at 16 inches from the bottom of the digester, this can be seen in figure 25.

Figure 25. The digester filled with 20 L of water filled it up to 16 inches from the bottom.

The seccond part of the digester testing was the seal testing. Durring the first phase the digesters bottoms held water but the lids still had to be tested. The digesters were filled with water and inverted, at first there were some minor leaks around where the gas hose was attached to the gas port in the lid but that was eaisly fixed with silicone, a hose clamp would have worked too. Next the shaft seal on the CM digester had to be tested so the shaft was spun for a minute. The digester being leak tested is in figure 26.

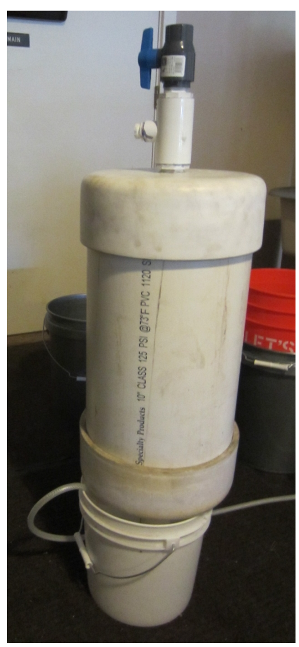


Figure 26. The digester filled water and inverted to check seals for leaks.

There were no leaks from the shaft seal or any of the other fittings on the digesters. They were left upside down for 5 min and no leaks were detected.

Tip meter leak test and calibration was also done. Useing a large syringe to inject air into the meter, check for any leaks out of the triangle cavities of the seesaw. If there are none continue onto the calibration. The calibration process was simple; adjust the screws until the volume of air to tip the meter each direction is equal, see Figure 26. The calibration of tip meter 1 is 90mL and tip meter 2 is 90mL.

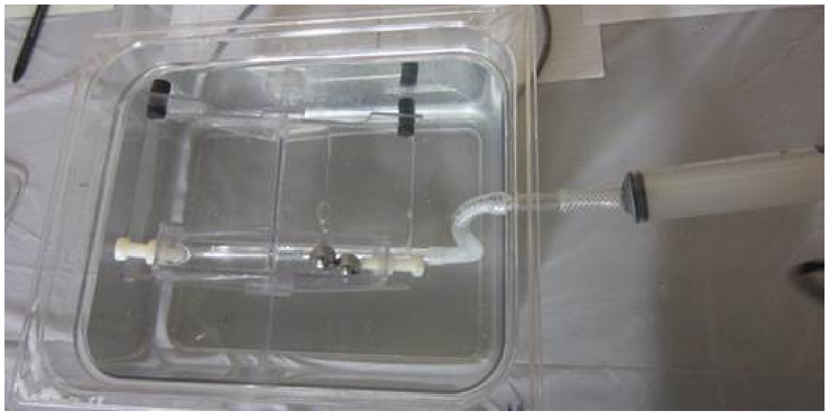


Figure 27. This shows the calibration process of the tip meters.

DISCUSSION

Cost Analysis

The cost can be broken into the two parts of this project: the tip meters and the digesters. This can be seen in table 3. For a complete itemized price list see Appendix A.

Table 3. This shows the prices of the digesters and the tip meters.

4 Digesters	$920.67
2 Tip Meters	$335.89
Total	$1,256.56

This price came out to be a bit higher than desired. It was difficult to find large plastic components at reasonable prices. Even by sizing down some of the components like the inlet and effluent ports, the price was still very high.

Design Changes

There are several problems that came up during the design and construction that had to be modified to achieve the desired results.

The tip meter was a little unstable when operated with a single ball as the counter weight. It would slowly tilt at random volumes if bumped. To overcome this, use two ball bearings for the calibration weight, or one larger one.

The effluent was moved from the side of the digester to the bottom so it would be easier to attach. This meant that a special shelving unit with holes for the effluent valve had to be built.

PVC tees were added to the complete mix digester so that it could be fed/emptied with an automated pump similar to the fixed film digester if desired.

Difficulties of Construction

One challenge was drilling a clean hole in the lid that could be tapped to form an air tight seal with the pipe fittings. To get a smooth hole use a slow speed for drilling and auto feed the final hole. If the hole was drilled at too high of a speed, the plastic would chip instead of being cut away.

Another challenge was getting everything air tight. This was accomplished by lots of silicone around all the connections. Most of the leaks were around the tubing from the digester to the tip meter. Pipe clamp on the barbed fittings would have worked well too.

Proper installation of the shaft seal for the complete mix digester was also critical in getting an air tight seal. The shaft seal had to be sealed to the housing with silicone.

REFRENCES

Adler, N. C. 2013. “Dairy Manure Flushwater Treatment by Packedbed Anaerobic Digesters” Presentation, Cal Poly Thesis defense.

Burke, D. A., 2001. “Dairy Waste Anaerobic Digestion Handbook” B. © Environmental Energy Company.

CPUC, California Public Utilities Commission 2014. “California Renewable Portfolio Standards” Online, Updated 1/2/2014, Accessed 2/2/2014. http://www.cpuc.ca.gov/PUC/energy/Renewables/index.htm

Girard, M., J. H. Palacios, M. Belzile, S. Godbout, F. Pelletier, 2013. “Biodegredation in Animal Manure Management” Intech, chapter 10.

Marsh, G. 2008. “Rise of the anaerobic digester” Renewable Energy Focus, 9(6), 28-34.

McCarty, P. L. 1964. “Anaerobic Waste Treatment Fundamentals” Part 1-3, Public Works, Sept 107-112, Oct 123-126, Nov p. 91-99.

Moletta, R. 2005. “Winery and distillery wastewater treatment by anaerobic digestion” Water Science and Technology. Vol 51, p. 137-144.

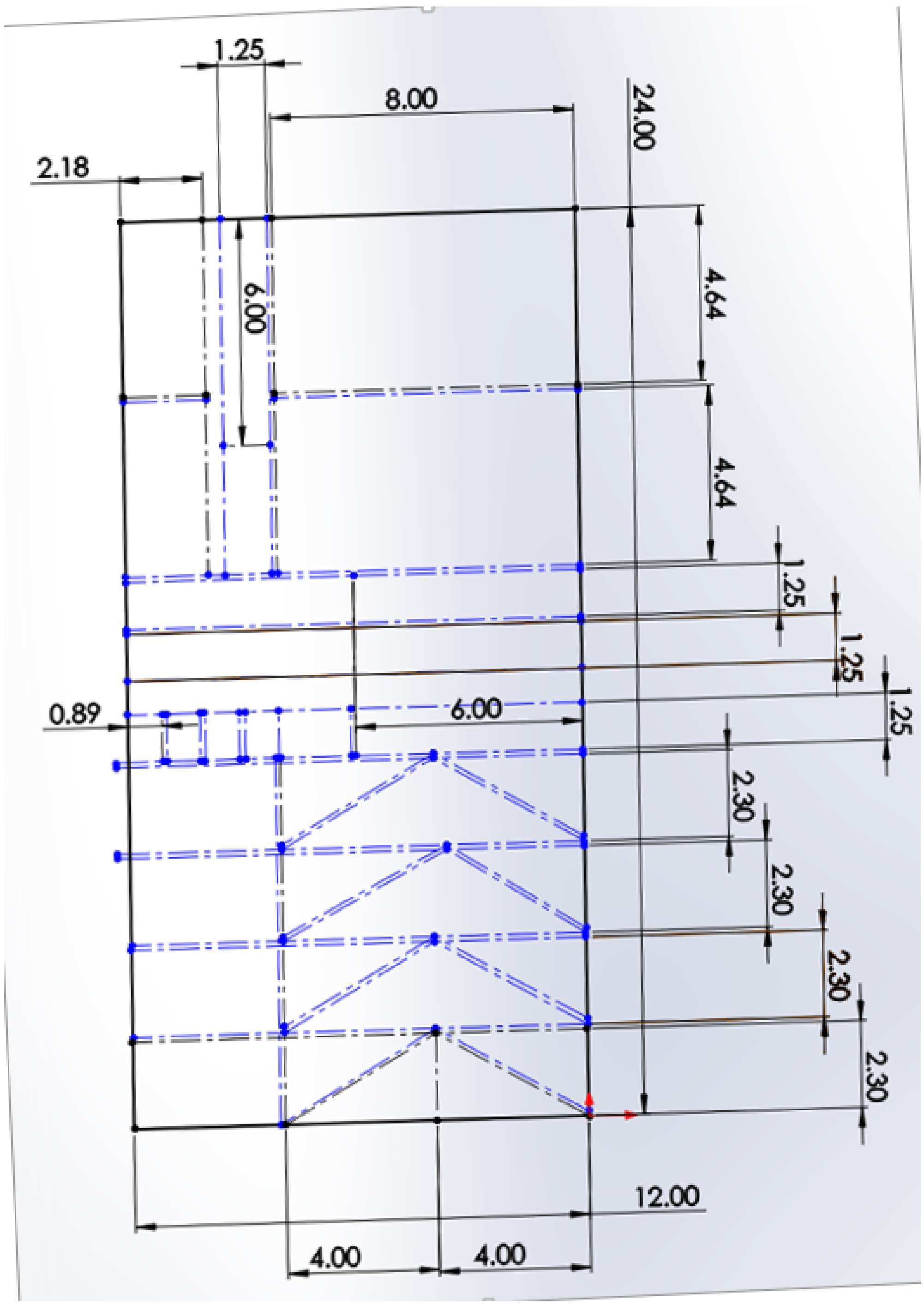
Ruth, D., Nate S. 2014. Presentation & site visits. Cal Poly, Anaerobic Digester Research Lab, Breeze.

Szűcs, B. R.; G. L. Szántó, M. Simon, G. Y. Füleky, 2012. “Process Performance of Dry, Batch Anaerobic Digestion of Sewage Sludge: Methanogenic Seed Mixtures” Water Sci. Technol., 66 (2), 445–50.

APPENDIX A: Itemized cost analysis

Product	Amount	Cost/Unit	Sub Total
10" diameter schedule 40 PVC pipe	7	$16.00	$112.00
10" Schedule 40 Cap	8	$21.45	$171.60
Mixing motor 1/16 HP	2	$0.00	$0.00
Peristaltic pump 1 GPM max will do	2	$0.00	$0.00
Stainless steel rod for mixing paddle 1/4 in	1	$10.00	$10.00
Stainless steel sheet for mixing paddle 12 gauge	1	$10.00	$10.00
25ft of 1/2" tubing	1	$32.53	$32.53
1/2" Bulkhead	5	$17.21	$86.05
1.5" Bulkhead	8	$12.99	$103.92
PVC Ball Valve	8	$10.00	$80.00
PVC Tee 1.5 x 1.5 x 0.5	2	$2.82	$5.64
Mis. PVC	1	$20.00	$20.00
Heating pad 20" by 20"	4	$32.40	$129.60
Hydrofarm Thermostat	4	$33.84	$135.36
Insulation	1	$23.97	$23.97
	0	$0.00	$0.00
Magnets	2	$2.49	$4.98
Wire 18 gauge 25 ft	25	$0.20	$5.00
HOBO 4-Channel Pulse Data Logger - UX120-017	1	$215.00	$215.00
Reed Switches	2	$8.10	$16.20
Poly carbonate Bin	2	$7.49	$14.98
Poly carbonate lid	2	$3.49	$6.98
Nylon nuts & Bolts	2	$2.00	$4.00
Flexible Braided PVC tubing 1/4" ID	1	$0.31	$0.31
3/8" OD x 1/4" ID X 8ft PC Tube	8	$0.58	$4.64
PC sheet 1/8 " x 12" x 24"	2	$9.27	$18.54
PC 1/4" x 12" x 12"	1	$8.06	$8.06
PC Rod 1/4" Di	1	$1.36	$1.36
Dichloromethane Solvent 500mL & syringes	1	$30.00	$30.00
Stainless pin balls	2	$2.92	$5.84
	total		$1,256.56

APPENDIX B: Cut list for 2 Tip Meters ¼" Polycarbonate



APPENDIX C: Additional Instructions for Building the Tip meter