Sensor Development, Fall 2016

Andrea Pozo, Cheer Tsang, Grace Mitchell, Sidney Lok

December 10, 2016

Abstract

The fall semester of 2016 marks the beginning of the Sensor Development subteam to AguaClara, which was created in response to the needs of the Upflow Anaerobic Sludge Blanket (UASB) and Anaerobic Fluidized Bed (AFB) subteams. This semester, the primary goals of this subteam were to develop a gas measurement sensor and a fluidized bed solids concentrator sensor for AguaClara plants. The subteam finalized a method of gas measurement, programmed settings in ProCoDa, and built four final product gas sensors for the AFB subteam. For the fluidized bed solids concentrator sensor, the subteam took measurements of the photosensor output and developed a method to correlate photosensor output to the existing intensity of fluidized solids.

Introduction

The Sensor Development subteam was created in response to the needs of both the Upflow Anaerobic Sludge Blanket (UASB) subteam and the Anaerobic Fluidized Bed (AFB) subteam. The UASB and AFB teams require a gas measurement system to measure the production of biogas in the reactors. The UASB Spring 2014 subteam faced several problems in reactor performance which led to a mismatch between the experimental data and the theoretical predictions for biogas production. The AFB subteam began implementing methane sensors after several iterations of testing. After attempting to create a prototype for testing and calibration curves with the standard methane sensors, it was concluded that the sensors read a very narrow range of methane concentrations and that the reactors often produced concentrations above the sensors' range. The creation of a new biogas sensor tailored to the needs of AguaClara reactors is the primary task of the Sensor Development subteam. It is hypothesized that the biogas sensor will be capable of measuring the volume of biogas produced by the AFB and UASB's anaerobic reactors, and from this measured volume, the concentration of methane can be calculated using theoretical methods.

After completion of the biogas sensors for the AFB subteam, the secondary task of the Sensor Development subteam was to design a photosensor to measure the solids concentration within AFB reactors. Since the solids concentration will indicate the amount of biomass in the reactors, this measurement will allow the AFB subteam to quantify the reactor's efficiency in converting organic waste into methane and carbon dioxide.

Literature Review

AguaClara's wastewater treatment teams are working on designing and building energy and cost efficient anaerobic reactors. Previously, the term "biological treatment" referred to aerobic processes, in which oxygen was fed into the reactor to allow aerobic bacteria to break down wastes. However, the process was not cost effective, as air supply was expensive. The process also produced large amounts of sludge, creating the problem of sludge disposal (Ronald Droste, 1997). Currently, anaerobic treatment is typically used in treating concentrated wastewater (Huybrechts, 2010). Anaerobic treatment requires large amounts of heat energy to run the system, but the methane produced compensates for much of the energy cost.

Anaerobic processes produce biogas by optimizing the growth of methanogenic bacteria. First, organic wastes are collected into a mix tank, and water is added to fluidize the waste material. The waste is then sent to an anaerobic reactor, where anaerobic bacteria degrade waste while producing biogas. The biogas produced by bacteria bubbles to the surface, accumulating within the head space of the reactor. The biogas is then pumped from the reactor and collected. After removal of carbon dioxide and hydrogen sulfide, the remaining biomethane gas can be used as fuel or combusted to generate electricity (Ken Krich et al., 2005).

In anaerobic processes, biogas is composed of 60-70 percent methane, 30-40 percent carbon dioxide, and small quantities of hydrogen gas, hydrogen sulfide, water vapor, and ammonia. Biogas contains 994 Btu/ft3 of energy, which is reduced to 591-698 Btu/ft3 due to the presence of carbon dioxide (Ronald Droste, 1997). The equation relating the rate of methane production to substrate removal and flow rate is:

$$Q_m = Q(S_{T0} - S_{Te})M = QEMS_{T0}$$

where

Q_m is the quantity of methane per unit time
Q is influent flow rate
S_{T0} is the total influent COD (suspended + soluble)
S_{Te} is the total effluent COD (suspended + soluble)
E is an efficiency factor (dimensionless, ranging from 0 to 1)
M is the volume of CH_4 produced per unit of COD removed

COD (chemical oxygen demand) is the standard method for indirect measurement of the amount of pollution (that cannot be oxidized biologically) in a sample of water. The chemical oxygen demand test procedure is based on the chemical decomposition of organic and inorganic contaminants, dissolved or suspended in water. The result of COD test indicates the amount of water-dissolved oxygen (expressed as parts per million or milligrams per liter of water) consumed by the contaminants, during two hours of decomposition from a solution of boiling potassium dichromate. The higher the chemical oxygen demand, the higher the amount of pollution in the test sample.

The AguaClara teams focused on implementing two systems: the upflow anaerobic sludge blanket (UASB) and the expanded granular sludge bed (EGSB). These systems were variations of the upflow reactor (Huybrechts, 2010).

Methane Sensor

For the purpose of this research, a specific methane sensor was studied: the MQ-4 gas sensor made by Henan Hanwei Electronics Company, Ltd. This is a typical model that is representative of general gas sensors.

	Parts	Materials
1	Gas sensing layer	SnO_2
2	Electrode	Au
3	Electrode line	Pt
4	Heater coil	Ni-Cr alloy
5	Tubular ceramic	Al_2O_3
6	Anti-explosion network	Stainless steel gauze (SUS316 100-mesh)
7	Clamp ring	Copper plating Ni
8	Resin base	Bakelite
9	Tube Pin	Copper plating Ni

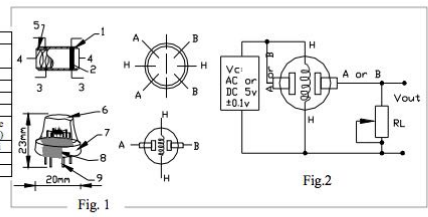

Figure 1: Design of the MQ-4 methane sensor made by Henan Hanwei Electronics Company, Ltd. (Henan Hanwei Electronics Co., Ltd., 2016)

The MQ-4 is comprised of a gas sensing layer made of tin dioxide, an electrode made of gold, an electrode line made of platinum, a heater coil made of a nickel-chromium alloy, a microtube ceramic made of aluminum oxide, an anti-explosion network made of stainless steel gauze, a clamp ring, a resin base made of plastic, and tube pins. The gas sensing layer, electrode, electrode line, heater coil, and tubular ceramic form a gas sensing system. This system is enclosed by the anti-explosion network, which is supported by the resin base. The clamp ring encloses the anti-explosion network and seals it to the resin base. The base is supported by four tube pins. The sensor is 20 mm in width and 23 mm in height (Henan Hanwei Electronics Co., Ltd., 2016).

When the gas interacts with the sensor, it is ionized and adsorbed by the gas sensing layer. Adsorption creates a potential difference across the gas sensing layer, which then travels through the gas sensing system and out of the tube pins in the form of current. The potential difference creates a difference in resistance across the gas sensing layer. The heater coil provides the necessary conditions for this process to occur. The anti-explosion network protects the gas sensing system, filters suspended particles, and keeps the sensor intact in the condition of high temperature and pressure.

Both the Upflow Anaerobic Sludge Blanket subteam and the Anaerobic Fluidized Bed subteam demonstrated need for a more refined methane sensor than the one they used in the past academic term. After one week of uninterrupted operation, the reactors produced a significant amount of methane. A better methane sensor is needed to monitor this production. When methane reacts with oxygen, it produces carbon dioxide and water. The production of methane is problematic because it depletes the COD. After one week, approximately 40 percent of the COD was consumed by methane production.

Ambient Light Sensor

The Anaerobic Fluidized Bed subteam has demonstrated need of an ambient light sensor to determine the concentration of sludge in a given reactor at a certain time and location.

The TEMT6000 Ambient Light Sensor is a 1 cm by 1 cm phototransistor, which acts like any NPN transistor. It detects the brightness of its surroundings, measures illuminance (lumens divided by square meters), and outputs a voltage. TEMT6000 was designed as a voltage divider circuit, which takes incoming light and outputs it at a fraction of the input, in order to make the difficulty of taking light measurements as small as possible. There are three pins labeled on top of the TEMT6000 breakout board: SIG, GND, and VCC. The SIG pin is the "emitter" and provides the output voltage from the divider circuit. The GND pin acts the "ground" or reference voltage in the circuit of 0 V. The VCC pin is the "collector" in the phototransistor. TEMT6000 acts like a resistor in the divider circuit. As light that hits the "base" of the sensor changes, the SIG output voltage will also change. As light gets brighter, the SIG pin will output a larger voltage and vice versa. In order to read those voltages, the SIG pin needs to be connected to an analog to digital conversion pin on a microcontroller (Michael Bartlett, 2016).

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.

Upflow Anaerobic Sludge Blanket Team

In the summer of 2013, six reactors were constructed. Three of the six reactors were Upflow Anaerobic Sludge Blanket (UASB) reactors and the other three were Anaerobic Fluidized Bed Reactors (AFBR). The team began operating with these reactors but were unable to collect a significant amount of gas production data due to leaks in the reactors and the lengthy start-up time required for steady state operation. The group then proposed a new gas chamber sealing method based on the coupling of a pressure sensor with a Process Controller, which would potentially release accumulated biogas once a certain gas pressure had been reached. The group then developed mathematical models for particle fluidization and settling within the reactor, reaching the conclusion that both fluidization velocity and settling velocity increases as granule diameter and density increases.

The Spring 2014 group faced several problems in reactor performance: inconsistencies between theoretical and experimental gas production, inconsistent COD (chemical oxygen demand) feed concentration delivery, and vessel leakage. Due to these problems, 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. For the second method, the reactor was filled with air and submerged underwater; as a result, the team was able to observe whether or not bubbles escaped the reactor. Consequently, the identified leaks were repaired. However, leaks continued to appear, so more investigation must be done completely solve this issue.

Anaerobic Fluidized Bed Team

In Spring 2014, the AguaClara Wastewater Group used the gas chromatography method to measure methane concentrations from the reactors. Then, biogas volumes could be obtained by the off-gassing method. However, there were "inconsistencies between theoretical and experimental gas production" due to issues with COD feed concentration delivery and air-tightness of the reactions (Qiu Shen et al., 2016). In addition, a portion of the methane produced became dissolved in the water, causing some methane to be lost in liquid form. In the following year, the Fall 2015 team calculated a 3.94 percent biogas loss rate and ran tests to find the sources of leakage within the reactors. They found the "fraction amount of methane in biogas" to be "48 to 59 percent of theoretical methane production" (Qiu Shen et al., 2016). In Spring 2016, the Expanded Granular Sludge Bed (EGSB) Team worked on finding solutions to the problems that the Fall 2015 team encountered, such as air leakage resulting in loss of biogas. To remedy this particular problem, the 2016 EGSB team focused on designing airtight biogas capture chambers.

The 2016 EGSB team designed a reactor "comprised of 4 smaller reactors in series" (Qiu Shen et al., 2016). The biogas generated in each of the smaller reactors was taken and measured independently of the others. In order to test different biogas collection and methane measurements, two different systems were designed to determine the effectiveness of using methane sensors. The reactor was designed to be converted to the off-gases method from Fall 2015 UASB team's design if the option of using methane sensors failed. In the first iteration, the first design included the use of the methane sensors. Biogas was collected from the headunit of the reactor and released through microbore tubing. The methane was then diluted by a constant air supply, which passed the methane through the methane sensor.

In the second design used, biogas accumulates in the headunit, which then pushes the water level down in the collector. The design uses offgas events, which begin when the water height increases to a certain point, opening the solenoid valve, and end when the water height falls below a certain point, closing the valve. Thus, the biogas production can be calculated by determining the volume of the biogas over offgas events. Once this volume of biogas is determined by the sensor, gas chromatography is used to determine the fraction of methane produced. The total amount of methane produced from the reactor is then determined using this fraction and the total volume estimated from the flow rate of the reactor.

By the third iteration, methane sensors were implemented. The team purchased purchased 4 MQ-4 model methane sensors from Zhengzhou Winsen Electronics Technology Co., Ltd. The team used one of the methane sensors "to create a prototype for testing and calibration curves" (Qiu Shen et al., 2016). The resulting calibration curve was fitted to the function:

$$P = 0.0017\exp(1.3739x)\ atm$$
$$R^2 = 0.9461$$
$$Q_{CH4}(Q_{air}) = PQ_{air}$$

where P is the partial pressure of methane in atm, x is the sensor output in voltage, Qair is the air flow rate, and Q.CH4 is the methane flow rate (Figure 2). However, because the team used a different resistance during the fabrication of the new methane sensors, a new calibration curve is needed to convert the data from volts into the correct units of methane flow rate.

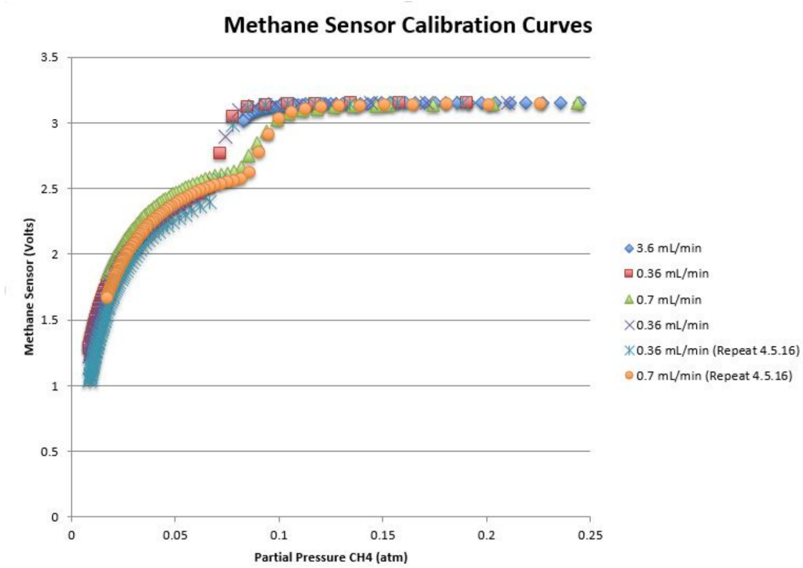

Figure 2: Methane Sensor Calibration Curve from the methane sensor prototype designed by the 2016 EGSB team.

The team concluded that the sensors “have a very narrow range of methane concentrations” (Qiu Shen et al., 2016). However, the reactor often produced concentrations above the sensors’ range. Therefore, the new methane sensors should be recalibrated in order to take into account the change in resistor size. The new sensors should also account for the dissolved methane in the total calculation of methane production, which can be calculated using Henry’s Law. In order to do this, the partial pressure of methane within the reactor headspaces, the surface area of the air-water interface, and the total methane production must be estimated. Another issue that should be resolved is the size of the biogas bubbles within the water. Since large bubbles skew the methane sensor readings, an agitator should be designed to break up the bubbles.

Various Gas Measurement Systems

The previous semesters’ Anaerobic Settled Bed and Anaerobic Fluidized Bed teams considered four gas measurement systems for usage in their research: compressed gas pressure-vent, the methane sensor MQ-4, wastewater fill pressure-vent, and clean water fill pressure-vent.

In the compressed gas pressure-vent, the setup involves a small tank full of gas connected to a pressure sensor. This small tank collects gas and vents to the atmosphere when pressure exceeds a specific target. However, this system will not be further explored because of concerns with large pressure fluctuations affecting the wastewater reactors. The methane sensor will also not be further explored because of findings from the wastewater teams as mentioned below.

The wastewater fill pressure-vent and clean water fill pressure vent have the same set up design shown in Figure 3. A peristaltic pump pumps air into the setup and displaces the water from the bottom chamber into the top chamber. Pressure in the system is measured by the pressure sensor. Once the water gets to the top of the top chamber and the pressure sensor reads a specific minimum value, the solenoid valve will open and gas is released, moving the water back into the bottom chamber. Once the water displaces back into the bottom chamber, the pressure sensor reads a specifc maximum value and the solenoid valve will close again, restarting the water displacement cycle. The difference between these two measurement systems is the fill. The wastewater fill pressure-vent utilizes wastewater fill while the clean water fill pressure-vent utilizes clean water. It was decided that the clean water fill pressure-vent will be further explored rather than the wastewater fill pressure-vent because of concerns with the setup being filled with solids; clean water is much easier to work with.

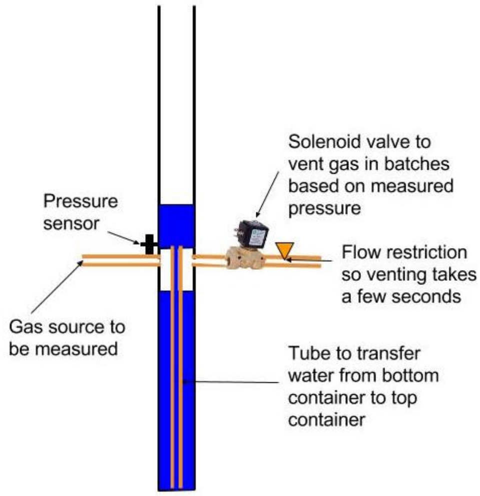

Figure 3: This is the design of the original setup used at the beginning of the Fall 2016 semester. There are two chambers in a clear PVC pipe, a top and a bottom chamber, which are separated by a plug in the middle of the entire pipe. The plug has a hole drilled through the middle and a smaller diameter tube through inside that drilled hole. The smaller diameter tube extends down through the inside of the pipe, but does not touch the bottom of the bottom chamber. A pressure sensor is attached to the side of the pipe near the bottom of the top chamber by a threaded connection. A peristaltic pump pumps air into a tube connected to the side of the pipe near the top of the bottom chamber by a threaded connection and a solenoid valve is connected to the other side by a threaded connection.

The clean water pressure-vent design was completed and tested, but required improvement. The design shown in Figure 3 had a large height and creates a large back pressure into the gas tube. The new design shown in Figure 4 had a smaller height and accommodates for the height of the pipe through the attachment of a smaller diameter stem at the top of the PVC pipe. The gas source and solenoid valve connections go through the plug and open up to the bottom chamber in order to save space on the now shorter pipe. There was also a manual drain valve at the bottom of the pipe to drain water when needed.

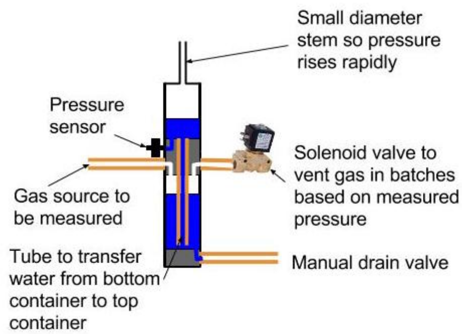

Figure 4: This shows the design of the new setup. This design is similar to the original design from Figure 3 but it is shorter and includes a stem at the top, has the gas source and solenoid valve connections going through the plug in the center, and a manual drain valve at the bottom.

Pressure-Vent System

As the Sensor Development subteam is new to AguaClara, previous research was completed by Professor Weber-Shirk. Professor Weber-Shirk designed all three generations of the pressure-vent system and built the first two generations. The progression of the designs for the gas measurement systems are shown in Figure 5. The subteam created and slightly modified the original design of the third generation as the sensor port was moved to the bottom of the bottom chamber.

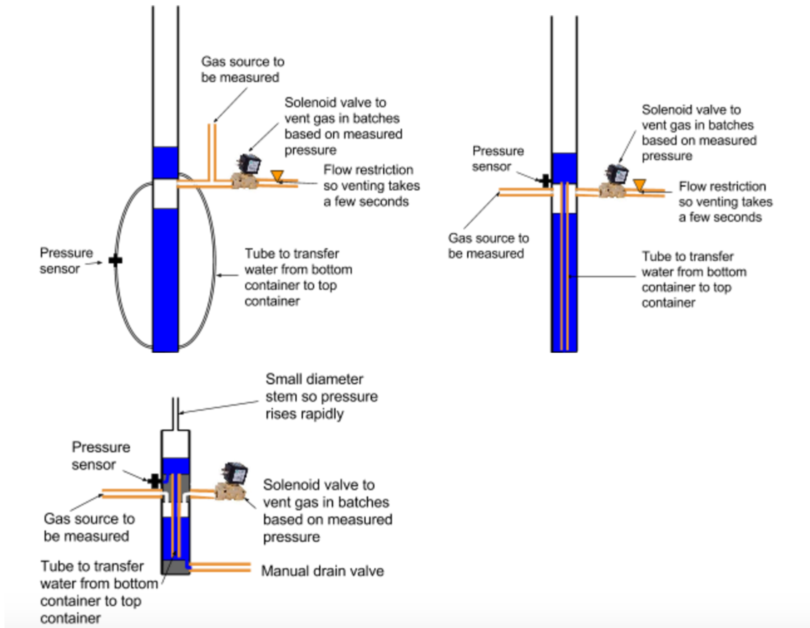

Figure 5: The first generation of the pressure-vent system is shown in the top left. The second generation of the pressure-vent system is shown on the top right. An inner tube was added to the system and the placement of the sensor, gas source, and solenoid valve was modified. The third generation of the pressure-vent system is shown on the bottom left. The apparatus was shortened, with a smaller diameter stem at the top for. The placement of the gas source and solenoid valve was moved to the plug in order to account for the shorter height. A manual drain valve was added to the bottom of the PVC pipe to allow for water drainage if necessary.

Methods

Gas Measurement System

The gas sensor was modified from the original design (Figure 16). To accommodate for the Anaerobic Fluidized Bed and Upflow Anaerobic Sludge Blanket subteams's design constraints, the water height of the sensor was reduced to approximately 10 cm and 6 cm, respectively. The reduced water height will prevent water from flowing in an unwanted direction in the teams' systems. In addition, a manual drain valve will be added to the bottom of the lower chamber to allow venting of gas.

Experimental Apparatus

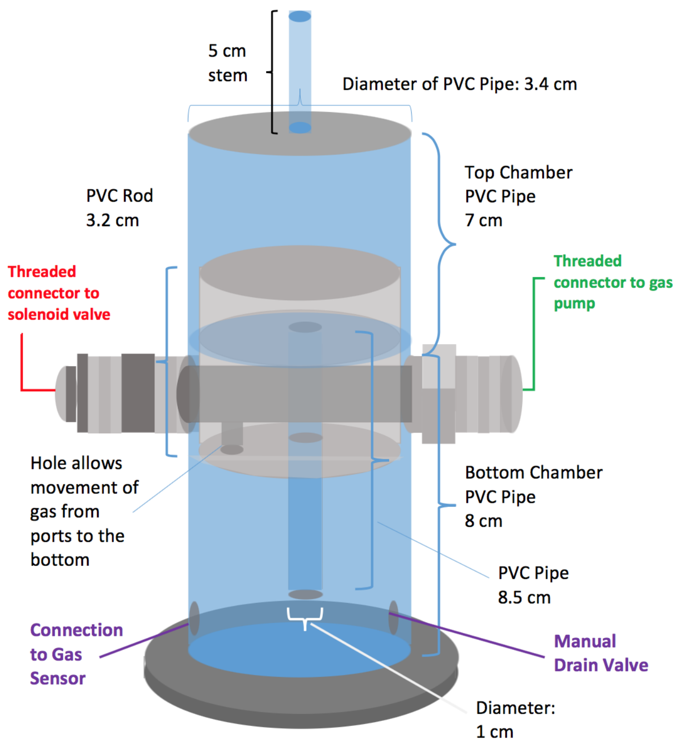

Figure 6: Schematic for new design of gas sensor. The most recent gas sensor was designed with a 10 cm water height, to accommodate the AFB subteam's specifications. The bottom chamber was increased in height to account for water lost by evaporation.

Figure 7: The air pump used to deliver air into the gas sensor.

Figure 8: The solenoid valve, which opens and closes to allow gas venting. When the valve is opened, gas is allowed to vent, and the water in the gas sensor drains from the top chamber into the bottom chamber.

ProCoDA Methods

Coding for the gas sensor was completed on ProCoDa II.

Table 1: List of Set Points

Variables	Type	Value
OFF	Constant	0
ON	Constant	1
Pump Control	Constant	500m
Open Valve	Constant	1
Close Valve	Constant	0
minimum target (cm)	Constant	0
maximum target (cm)	Constant	3

The minimum and maximum targets were set to 0 and 3 cm respectively, for testing purposes only. These values will be changed when the final product is designed, taking into account the size of the finished gas chamber.

A Gas Control variable was established to control the opening and closing of the valve. When the sensor reads a maximum target, it will open the valve, draining the gas from the bottom chamber to allow the water level to decrease. At the minimum target, the valve will be closed, allowing the air pump to deliver gas into the chamber. As a result, the selected set points were Open Valve, Close Valve, minimum target, and maximum target. The selected sensor was set to read at 7 kPa.

The states created were OFF, ON, Run Pump, and Open Valve. In the ON state, the conditions were set so that if the 7 kPa sensor is greater than the set point Close Valve, then the next state will be ON. This condition turns on the air pump when the valve is closed. In the output settings, the pump was set to "on," while the pump direction was set to "off," and the pump speed was set to "Pump Control."

In the Run Pump state, the data average interval was set to 2 s. The condition was set so that if the 7 kPa sensor is greater than the set point "<9>," then the Open Valve state will be initiated. The output settings in Port 2 were set to Gas Control; this allowed the Gas Valve to turn on and off according to the water level within the chamber. In addition, the Pump output was set to "ON," the Pump Direction was set to "OFF," and the Pump Speed was set to Pump Control.

In the Open Valve state, if the Gas Control variable is greater than the maximum target, then the valve is opened. This was achieved by setting the Gas Valve output setting to "on," the Pump to "ON," the pump direction to "OFF," and the Pump Speed to "OFF."

Procedure

In order to construct the tube of the gas sensor, two pieces of PVC pipes were cut for the top and bottom chambers. The top chamber was 7 cm, and the bottom chamber was 8 cm. A 3 cm piece of a solid PVC rod was also cut, and this piece was placed into one of the hollow PVC pipes. A clamp was used to push the two pieces together after they were glued together. A hole was drilled through the top of the apparatus to allow a 1 cm diameter hollow PVC pipe to be inserted through the sensor. A hole was then drilled through the side of the pipe so that it exited the pipe's opposite end. Threaded connectors were added to these side ports to connect to the solenoid valve at one end and the air pump at the other end. Then, a small hole was drilled halfway through the solid PVC pipe, through the hole connecting the side ports; this was done to allow movement of air between the two side ports and the bottom chamber. Two 0.9525 cm holes were drilled into the bottom chamber for the manual drain valve and the connection to the gas sensor. These were attached to the sensor using threaded connectors. A flat disk was then cut and glued to the bottom for the base, as shown in Figure 6.

After constructing the first design of the gas sensor, several alterations were made to accommodate specific size requirements by the Upflow Anaerobic Sludge Blanket (UASB) and Anaerobic Fluidized Bed (AFB) subteams. The UASB team required a smaller sensor, with 6 cm of water height, while the AFB required a sensor with 10 cm of water height. The UASB and AFB subteams will each require four sensors. The gas sensors for the AFB team have been completed.

Fluidized Bed Solids Concentration Sensor

Experimental Apparatus

The team designed and fabricated a fluidized bed solids concentration sensor for the Anaerobic Fluidized Bed subteam. The sensor was fabricated using a 2.54 cm four-way PVC cross, to account for the AFB reactors' 2.54 cm pipe diameter. The PVC cross was cut laterally, and the two PVC connectors were attached to one half, as shown in Figure 9. The photosensor will be mounted on one end, while an LED (light emitting diode) light will be mounted on the opposite end. When the LED light is turned on, the photosensor will be able to detect the intensity of light that passes through the pipes, which correlates with the solids concentration within the reactor. For example, a high measured intensity will indicate a low concentration of solids because more light is able to pass through the tube. Conversely, a low measured intensity indicates a high concentration of solids because the presence of solids within the reactor blocks light from passing through the pipes to the photosensor.

The two halves will be clamped together using a pipe clamp. This will allow the device to be attached to the AFB reactor, while allowing the device to slide up and down the pipes.

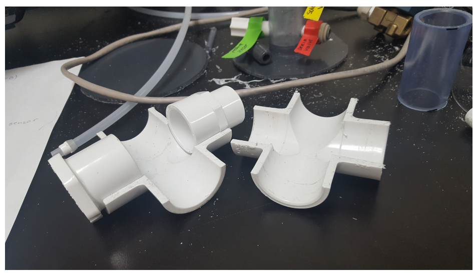

Figure 9: Result of the process explained above

Once the photosensor had been built, the team designed and fabricated the tube to use in the calibration procedure, as shown in 10. The tube is a small model of the the reactors that the AFB team uses. It has a diameter of 2.54 cm and a height of 53.5 cm. The team designed a removable cap for the top of the apparatus so that the granules can easily be introduced in the testing tube. As a result, the tube can be continuously shaken, which keeps the granules in suspension during the process of calibrating the photosensor. The bottom of the tube was completely sealed to ensure that there was no water leakage.

Figure 10: The experimental tube was built to model the tubes in the AFB reactors. Granule samples were taken from the AFB reactors and placed in the experimental tube in varying concentrations to calibrate the photosensor. By measuring the amount of light that passed through the tube, the team designed a calibration curve relating the output in Volts with the concentration of the granules.

Figure 11: In this figure the photosensor has already been implemented in the testing tube (which already contains the granules inside), and it is fixed with a clamp.

Circuit Design

The ambient light sensor on one side of the four-way pipe has three metal wires soldered to each of its SIG, GND, and VCC pins, which connect to the respective positions on the sensor side of the breadboard as seen in Figure 12. The LED light on the opposite side of the ambient light sensor on the four-way pipe has blue and white wires attached to it that are ultimately connected with a yellow wire that attaches in the position on the LED side of the breadboard as shown in Figure 13. The photosensor output will be read with ProCoDa.

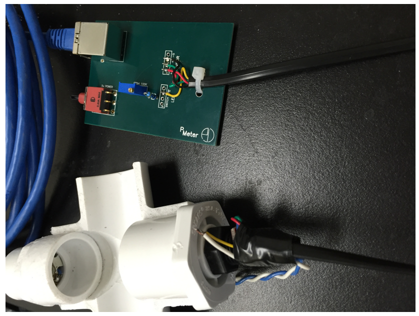

Figure 12: The LED and ambient light sensor are on opposite sides of the four-way pipe and ultimately are connected to respective positions on the breadboard. The breadboard can be connected to the ProCoDa box through the thick blue wire connector.

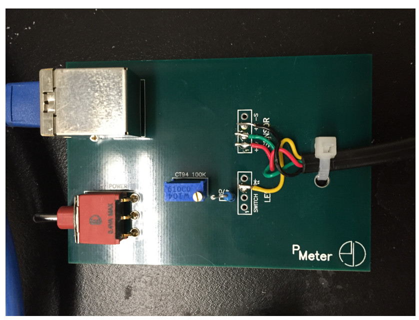

Figure 13: The breadboard has a battery, an LED connection section, and a sensor connection section. The respective wires connect the LED and ambient light sensor to the breadboard in the appropriate places as shown in this picture.

ProCoDa Methods

Calibration for the photosensor output was done in ProCoDa.

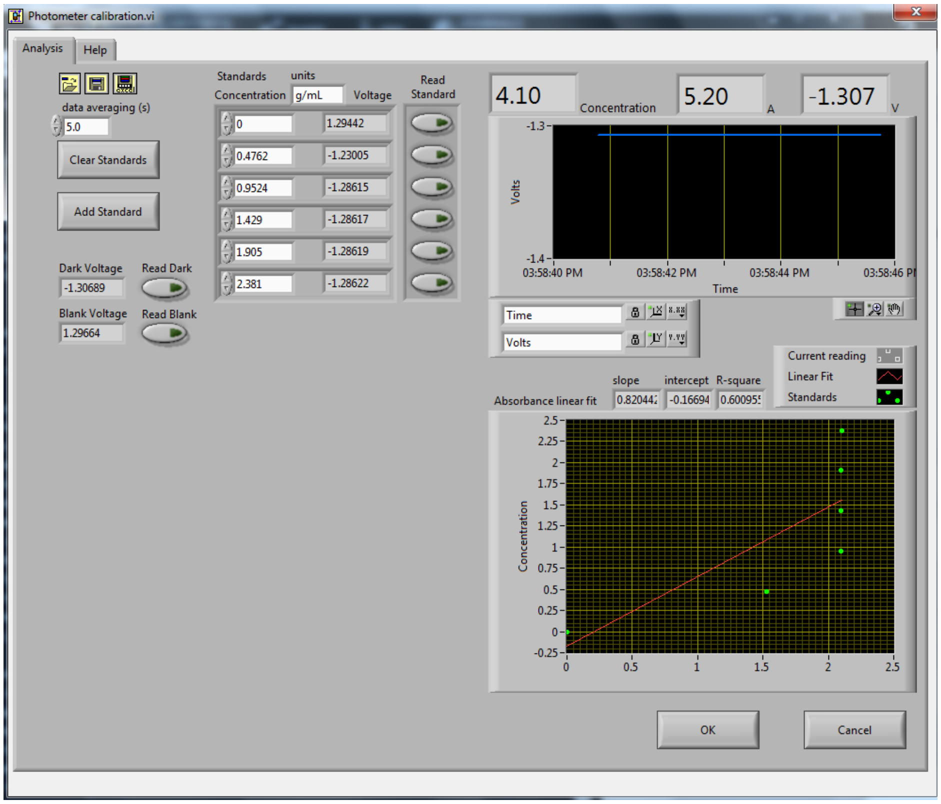

Figure 14: Calibration of the photosensor was done in ProCoDa. Each concentration is associated with a voltage that was read by the photosensor. A blank voltage was read when the concentration was at 0 g/mL and a dark voltage was read when the light was turned off. These readings are shown in the figure. The data points were plotted to show increasing concentration.

The photosensor output is in Volts and the team needed to calibrate the sensor so that the output in Volts could be associated with a concentration. In order to calibrate the sensor for the AFB team, the maximum bulk density concentration of granules was used as the last standard point. A total of six standard points were determined, ranging from 0 g/mL to 2.38 g/mL, as shown in Figure 14. A blank voltage was read when the concentration was at 0 g/mL and a dark voltage was read when the light was turned off. In order to create the determined concentrations in the experimental apparatus, the PVC pipe was filled with 84 mL of water and at each standard point after blank voltage was read, 40 g of granules would be added to the PVC pipe and the photosensor would read a voltage. To keep the granules in suspension while reading the voltages in ProCoDa, the team continuously shook the PVC pipe.

Results and Analysis

Methane Sensor

Fabrication of four 10 cm water height sensors for the AFB team was completed. The sensors were modified to have a larger bottom chamber in order to account for evaporation of water. The team also modified the design to build a more effective gas measurement system. The height of the sensor was reduced to a maximum water height of 10 cm, in order to stabilize the system and lower the back-pressure, which could affect the research data of wastewater teams. Furthermore, the position of the pressure sensor was moved to the bottom of the gas sensor, in order to simplify the design. Figure 3 shows the design of the original system. In this iteration, the device was too tall, resulting in instability, and has the sensor in the central plug. The current model is smaller and the sensor was moved to the bottom chamber of the PVC pipe, as shown in Figure 6.

Photosensor

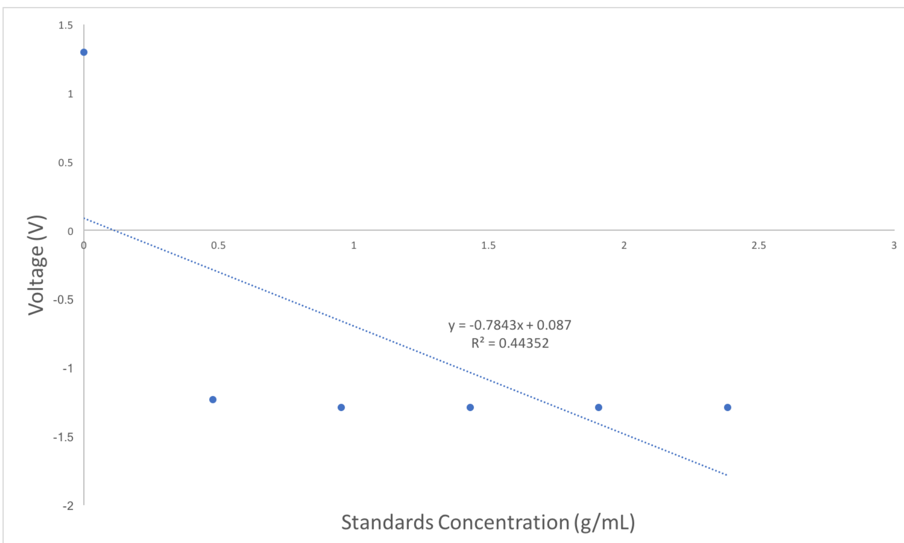

Figure 15:

During calibration of the sensor, the outputs ranged from 1.29 V to -1.29 V 15. At the first concentration, 0 g/mL, where no granules were added, the output voltage was 1.29 V. The positive voltage indicates that the LED light penetrated through the testing apparatus, and the photosensor was able to detect the light. However, for concentrations higher than 0 g/mL, the output voltages were negative, ranging from -1.23005 V to -1.28622. These values were close to dark voltage of -1.31 V, which is the voltage recorded when no light passes through the photosensor. Therefore, the results suggest that the LED light did not have a sufficient intensity to penetrate through the fluidized granule solution. In order to yield a more accurate correlation between the concentration and voltage, a higher intensity could be used for the LED light.

Another possible explanation for the minimal increase towards the dark voltage at each calibration point could lie in the size and shape of the tube. As the pipe is only 2.54 cm in diameter, there is a relatively small maximum amount of granules that can fit in the pipe, at the area where the sensor is measuring, before the granules disperse below and above this area. In the calibration, there was minimal voltage change after the third addition of granules. It is possible that the tube began to approach the maximum amount of granules after the third addition, which would explain the minimal voltage change in the following additions. It is also important to note that there may be minimal sources of error from measurement of granules and human error from shaking the PVC pipe to mimic machine-driven suspension.

Conclusion

In the beginning of the semester, the Sensor Development team worked with the previously fabricated gas measurement system. The team learned how the system worked and configured the ProCoDa code, so that the solenoid valve opened and closed automatically at certain maximum and minimum pressures.

In the last part of the semester the Sensor Development team worked in the design and fabrication of a photosensor for measuring the fluidized sand concretation in the AFB team reactors (described in the previous sections). The team designed and built the photosensor, checked which was the ideal light intensity for it and then fabricated the testing tube modeling the AFB reactors. Once the team knew exactly which were the needs of the AFB team in terms of values of concentrations of the fluidized sand, they carried out the calibration process with ProCoda. After designing the calibration curve for the photosensor, the team discovered that light was only able to pass through the photosensor at a concentration of 0 mg/L, indicating that a higher intensity of light should be used to design a more accurate calibration curve.

Future Work

As the Sensor Development team has completed both the gas measurement system and the fluidized bed solids concentration sensor, the systems must be first used for data collection to determine whether they are currently successful. This new technology is intended to help the future research and data analysis of the Anaerobic Fluidized Bed team. The next task for the Sensor Development team is to determine a more accurate relationship between the output voltage and the concentration of granules. Another calibration test is necessary to yield accurate data. Whether this subteam should exist next semester, or not, depends on how well the sensors are working now and how critical they are to the research goals of the AFB team next semester.

References

Henan Hanwei Electronics Co., Ltd. (2016). Technical Data MQ-4 Gas Sensor.

Huybrechts, D. (2010). *Anaerobic Biological Wastewater Treatment*.

Ken Krich, Don Augenstein, JP Batmale, John Benemann, Brad Rutledge, and Dara Salour (2005). Production of Biogas by Anaerobic Digestion. In *Biomethane from Dairy Waste*, pages 29–46. USDA Rural Development.

Michael Bartlett (2016). TEMT6000 Ambient Light Sensor Hookup Guide.

Qiu Shen, Stephen Galdi, and Zoe Maisel (2016). *Expanded Granular Sludge Bed (EGSB) Team Report*. Cornell University.

Ronald Droste (1997). Anaerobic Wastewater Treatment. In *Theory and Practice of Water and Wastewater Treatment*, pages 622–632. John Wiley & Sons, first edition.

Appendix

Gas Measurement System

Previous Design

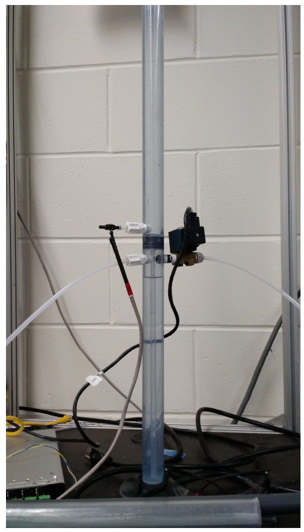

Figure 16: Initial setup of original gas sensor

The gas sensor was modified from the original design shown in Figure 16. The height of the sensor was reduced to approximately 10 cm to increase stability. In addition, a manual drain valve will be added to the bottom of the lower chamber to allow venting of gas.

First Design

The first design fabricated by the Sensor Development subteam, as shown in Figure 17, consisted of top chamber pipe part of 7 cm and a bottom chamber pipe part of 6 cm constructed from 3.4 cm PVC pipe. The two chambers were separated by an inner plug of 3 cm which entered 2 cm into the top chamber and 1 cm into the bottom chamber. The plug has a 1 cm diameter inner tube 8.5 cm tall inserted through it. At the top of the entire apparatus was a plug with a thin hard PVC stem cemented into the middle of the plug. Drilled and tapped through the middle of the PVC pipe and the plug were two 1.11 cm threaded holes for the solenoid valve and gas source connectors. Two 0.9525 cm threaded holes were drilled and tapped near the bottom of the apparatus for the escape valve and the pressure sensor connectors. The bottom of the apparatus was plugged with a plug and was attached to a disk for stabilization. The entire apparatus was 14 cm tall. This design was modified to a top chamber pipe part of 7 cm and a bottom chamber pipe part of 8 cm in order to account for evaporation of water over time, which could cause the system to fail.

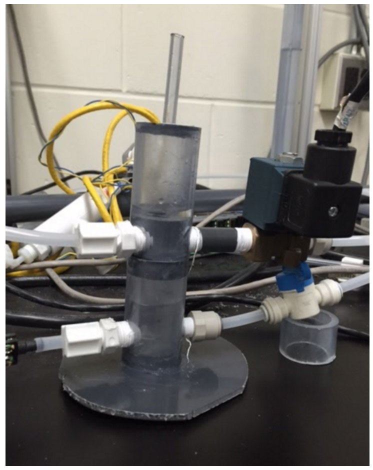

Figure 17: The first design fabricated by the Sensor Development Team. Here, the bottom chamber is 6 cm, 2 cm smaller than the current design.

Semester Schedule

Task Map

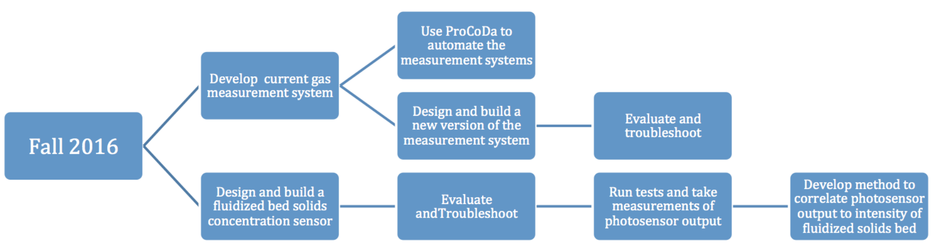

Figure 18: Fall 2016 Task Map

Task List

1. Develop current gas measurement system (10/28/16) - Sidney Lok - Completed
   (a) Use ProCoDa to automate measurement system (9/8/16) - Andrea Pozo - Completed
   (b) Design and build a new version of the measurement system (9/25/16) - Cheer Tsang - Completed

i. Evaluate and troubleshoot (10/22/16) - Grace Mitchell - Completed

2. Design and build a fluidized bed solids concentration sensor (11/22/16) - Sidney Lok - Completed

   (a) Evaluate and Troubleshoot (11/10/16) - Grace Mitchell - Completed

      i. Run tests and take measurements of photosensor output (11/17/16)- Andrea Pozo - Completed

      ii. Develop method to correlate photosensor output to intensity of fluidized solids bed (11/22/16) - Cheer Tsang - Completed

Report Proofreader: Cheer Tsang