Hydrogen from Microalgae and the Collection and Sensing Systems

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3 April 2015
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ABSTRACT

Although it may not be readily apparent, energy directly correlates with the quality of life and technological resources that are available to people. As societies grow and become more advanced, the consumption and need for more energy increases. The augmented demand can put a strain on available resources, which is why there has been a heightened interest in alternative energy. This project will focus on hydrogen as an alternative energy source. A photobioreactor has been developed to aid in the production of hydrogen gases by allowing for a controlled environment. This controlled environment creates conditions in which microalgae can steadily create hydrogen gases. With steady self-sustainable hydrogen production, the hydrogen gases can be used in applications to create energy, such as fuel cells. This project seeks to create a photobioreactor that will operate continuously and cultivate micro algae for semi-continuous production of hydrogen.

I. FUNCTIONAL ANALYSIS / FUNCTIONAL DIAGRAM

The main function of this project involves the semi-continuous production of H_2 from algae in a continuously operated photobioreactor (pbr). A second function of this project is the concentration measurement of H_2 being produced by the algae in the pbr. The production of H_2 is made possible by several components of the pbr, which include:

A. Airlift Photobioreactor
B. Algae concentration sensor
C. Addition/Extraction ports
D. Air/CO_2 input

The secondary components serve the purpose of purification and analyzing the system's functionality. These components include:

E. H_2 purifier
F. H_2 % concentration sensor

Figure 1 shows the overall system diagram, which includes the components listed above. Components A-D function to assist H_2 production while components E and F help in analyzing the system. As can be seen in figure 1, the main component is the photobioreactor, and the secondary components are attached.

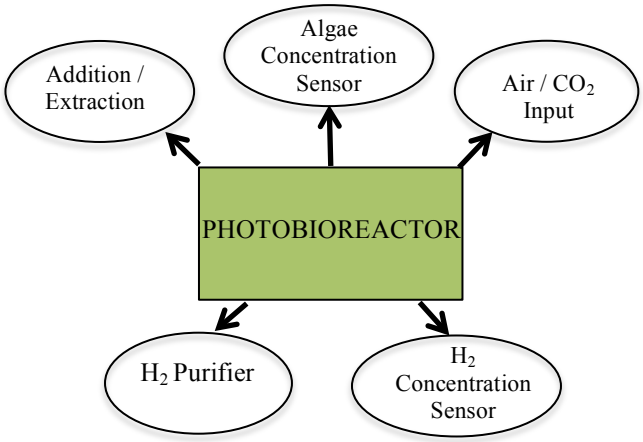


Figure 1: Overall system diagram showing all components

In order for the system to function correctly, in terms of hydrogen production, a specific procedure must be followed. Figure 2 is used to determine a correlation between the hydrogen production and the system components. The graph shows the concentration of algae as a function of time of time. This plot is key to the sequence of operation of each component and will be discussed in detail later.

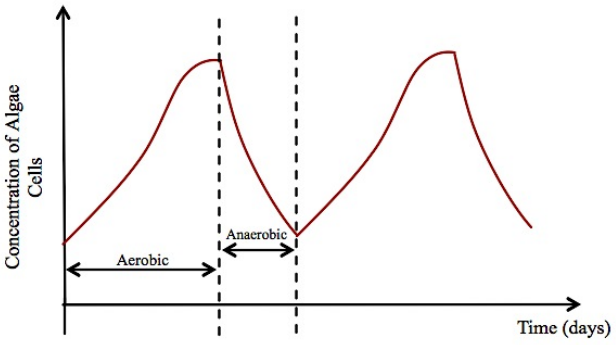


Figure 2: Correlation between hydrogen output and sequence of operation.

II. PROJECT / PRODUCT SPECIFICATION

A. Photobioreactor

The photobioreactor used for this project is an external loop airlift photobioreactor with a tube separator [1]. Figure 3 shows the CAD drawing of the photobioreactor. The photobioreactor is constructed from schedule 40 clear PVC pipe and standard PVC pipe fittings. Clear pipe should be used to allow sunlight utilization by the algae. Clear PVC schedule 40 is manufactured from a type I, grade I Polyvinyl Chloride (PVC) compound with a cell classification of 12,454 per ASTM D1784. This class of pipe offers high impact strength, long life when exposed to weather, and low cost. Specs of the photobioreactor are as follows:

- Total length of piping = 16 feet (9 ft of 1.5" pipe, 3 ft of 3" pipe, and 12 ft of 1" pipe)
- Total volume = 2.09 gal (7.91 L)
- Total volume w/ headspace = 1.31 gal (4.95 L)
- Weight = 25 lbs
- Max height = 6 ft
- Max width = 3 feet 5 inch

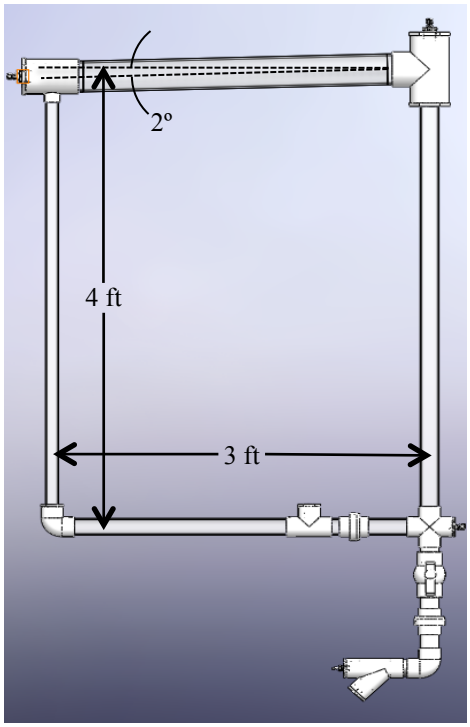


Figure 3: PBR drawing without components

Two crucial components of the photobioreactor are the gas separator and the downcomer tube, which can be seen in Fig. 4. The gas separator allows for liquid circulation and gas disengagement. The downcomer tube is also important, in terms of it's cross sectional area. A 60 percent area reduction was used in order to maintain a pressure similar to that in the riser tube. Reducing the cross-sectional area of the downcomer will help with gas holdup, mass transfer of CO_2, and other important fluid flow patterns [1].

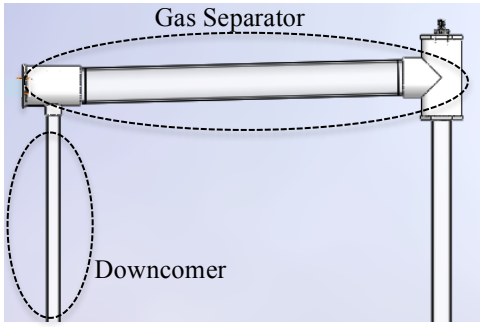


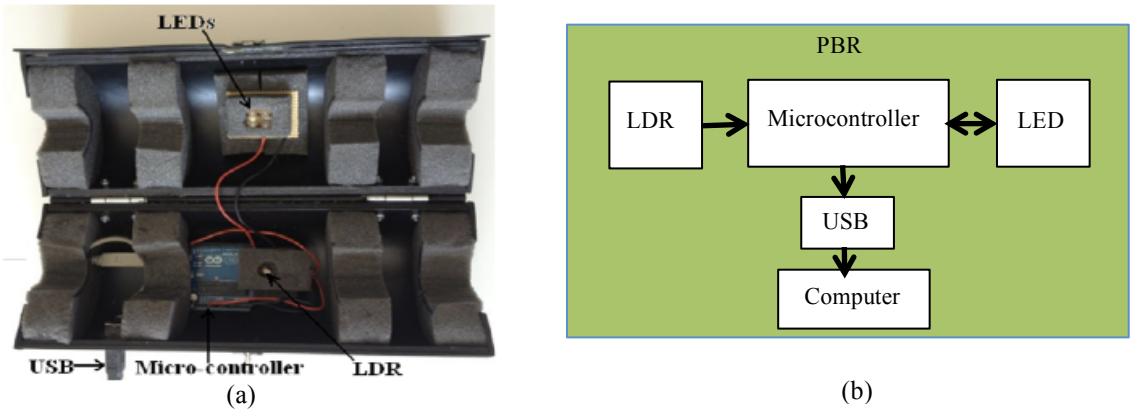
Figure 4: Downcomer and gas separator components of PBR

B. Concentration Sensor

The concentration sensor consists of a light dependent resister, 4 LEDs, a microcontroller, and an enclosure. The sensor was designed and built by 2012-2013's senior design team 7. Figure 5 shows the (a) finished concentration sensor and (b)

function diagram developed by team 7 [2]. The sensor measures the concentration through light obscurity i.e. the higher the concentration of algae cells, the lower the amount of light will hit the LDR. The amount of light hitting the LDR is measured as a voltage, which is then converted to an 8-bit value used in the programming of the sensor. Some of the specs of the concentration sensor include:

- Length = 11.5 inch
- Diameter = 4.5 inch
- Diameter of opening = 1.5 inch
- Arduino Uno microcontroller
- LDR max operating voltage of 100 VDC, 2 ~ 6 (10Lx) (KΩ)
- 5 mm LEDs with operating voltage of 3.2 VDC, and 20 mA



(a) (b)

Figure 5: (a) Prototype and (b) function diagram of algae concentration sensor

C. Addition / Extraction ports

Both addition and extraction ports are necessary in order to achieve a continuously operating system. The components of the addition / extraction system include:

- 2 – solenoid valves
- A microcontroller
- A motor driver

The solenoid valves are powered through a motor driver and controlled by an Arduino Uno microcontroller. Figure 6 shows the wiring schematic of the addition and extraction system. Component specs of the addition / extraction system are:

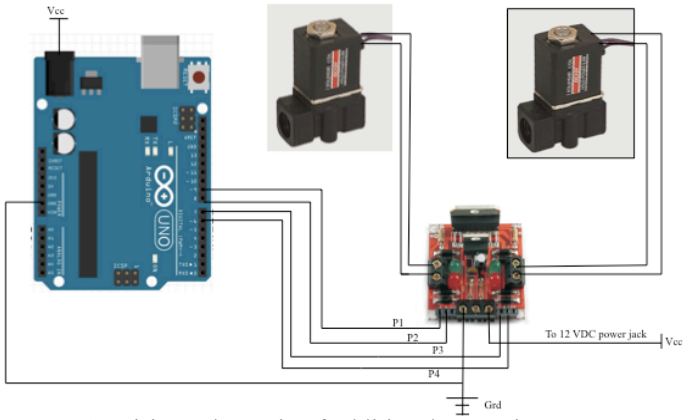


Figure 6: Wiring schematic of addition / extraction ports.

- Valves: 12 VDC, 2 way normally closed, Cv = 0.23, ¼" NPT port size, Operating power ~5 W
- Motor Driver: 5 – 26 VDC operating, 5 VDC control input, peak output current = 3 A

The addition and extraction are gravity fed systems, which requires a 6 liter container or bucket arranged so that the bottom outlet of the bucket is at least one foot higher than the addition port in order to provide an adequate flow rate.

D. Air/ CO_2 Input

To increase algae concentration in the pbr, air and CO_2 must be supplied. For this project, the CO_2 supplied comes from atmospheric air and not an external CO_2 tank. A compressor was used to supply the air, while the relay switches the compressor on and off at specific intervals. The specs for the compressor and relay are as follows:

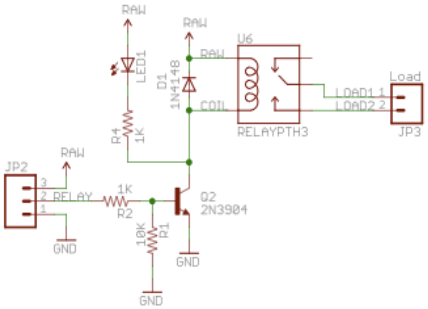
Air Compressor

- Capacity = 1 gal
- 0.51 SCFM at 40 PSI, 0.39 SCFM at 90 PSI
- Voltage = 120 VAC
- Amperage = 2 A
- Weight = 16 lbs.

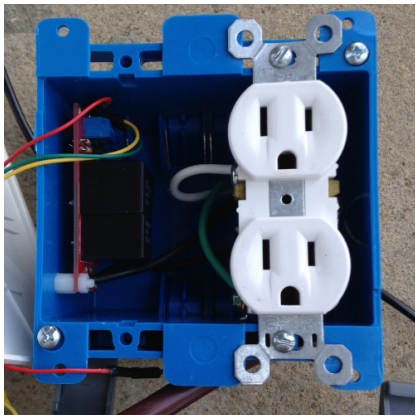
Relay

- JQX – 15F solid state relay
- Control voltage = 5 V
- Control amperage = 185 mA
- Rated load of 220 VAC, 20 A

The wiring schematic and completed assembly can be seen in Fig. 7 (a) and (b), respectively. Figure 7 (b) shows the relay housed in an electrical box and connected to a standard 120 VAC electrical outlet.



(a)



(b)

Figure 7: Wiring schematic for relay (a), and completed assembly (b).

E. H_2 Purifier

A purifier was used in order to remove impurities from the produced hydrogen gas. It is important to purify the hydrogen as much as possible for gas storage, increased

energy output, and to prevent the release of pollutants. The purifier is a disposable OxiClear gas purifier and can be seen in figure 8. Some of the specs include:

- Length = 7 ½ inch,
- Diameter = 1 ½ inch
- Disposable when capacity ~ 1200 cubic ft. standard grade H_2 gas
- Min working pressure drop = 0.3 psi
- Reduces O_2, H_2O, and other impurities to < 15 ppb
- ¼ OD compression fittings

Figure 8: Hydrogen gas purifier used.

F. H_2 Concentration Sensor

The concentration of hydrogen gas produced can be measured using the assembled system seen in figure 9. The system includes a MQ-8 gas sensor, an Arduino Uno microcontroller, a LCD display, and a 100 mL Erlenmeyer flask. The specs of the hydrogen sensor are as follows:

- Sensitivity ≥ 100 ppm H_2
- Operating voltage = 5 VDC
- Working O_2 concentration between 2% and 21%
- Requires 24 hr. preheat time

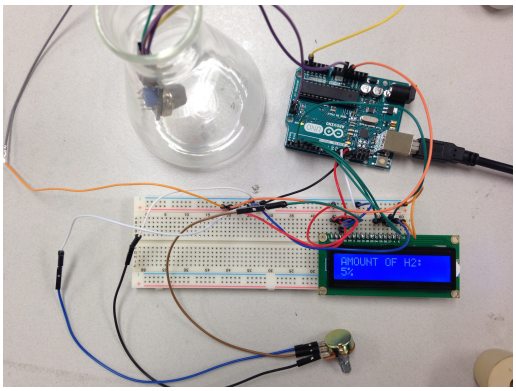


Figure 9: Current H_2 concentration sensor

G. Photobioreactor Stand

The photobioreactor stand was assembled using 2013's prototype and new materials. It is composed of pressure treated 2" x 4" and 2" x 6" wood, along with roofing brackets and galvanized wood screws. The purpose of the stand is to support the photobioreactor and the DAQ system, which is used to control the electrical components. Figure 10 shows a CAD drawing of the pbr stand. Some of the specs include:

- Height = 8 ft, Width = 3.5 ft.
- 41 ft of pressure treated wood
- Weight = 40 lbs
- Platform for addition solution storage

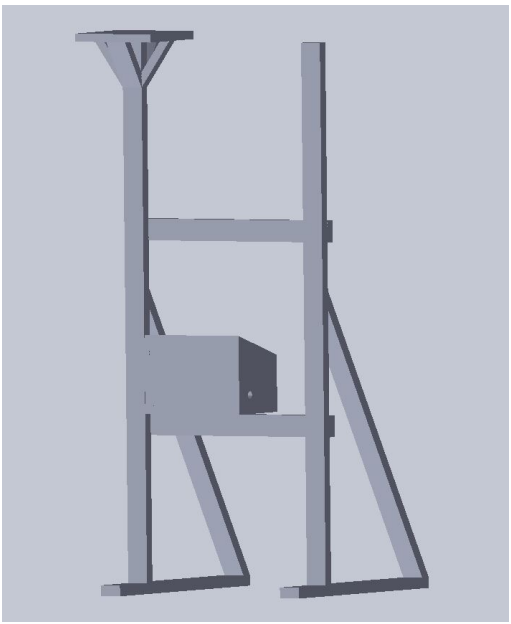


Figure 10: Photobioreactor stand.

III. PROJECT ASSEMBLY

Upon assembling and testing each component mentioned above, the entire photobioreactor system was assembled. First, the photobioreactor was connected to the stand via the upper supports and pipe clamps. Second, the H_2 purifier and addition/extraction valves were connected to the reactor using ¼" 304 stainless steel tubing. Next, the air compressor and hydrogen gas sensor were connected via plastic tubing. Finally, the algae concentration sensor was set, and the components connected to the their appropriate ports. Figures 11 shows the CAD drawing of the photobioreactor system assembly.

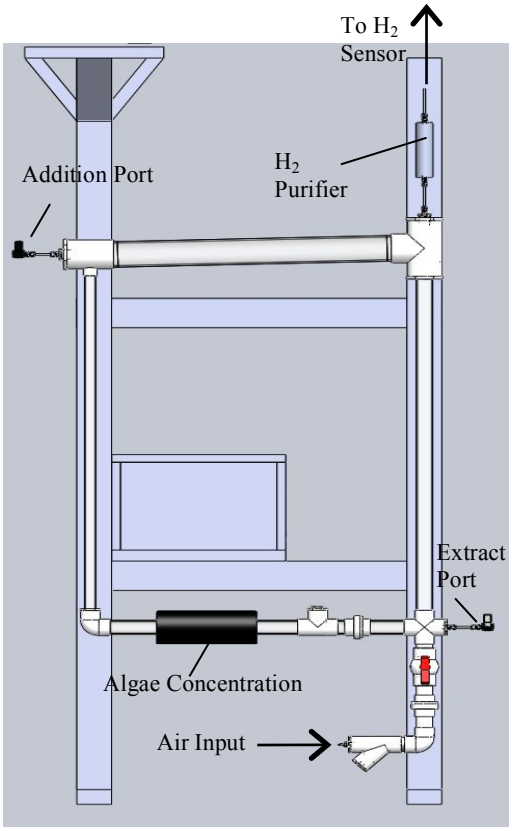


Figure 11: Assembled photobioreactor system on stand.

IV. OPERATION INSTRUCTIONS

A. Photobioreactor

For the operation of the photobioreactor to be continuous and to work properly, there are several factors that need to be correctly connected and checked to make sure they are functioning. Once the components are assembled as stated previously, the code for the master controller and the code for the slave controller are to be uploaded to the two Arduino boards. The master controller controls the solenoid valves and the relay, while the slave

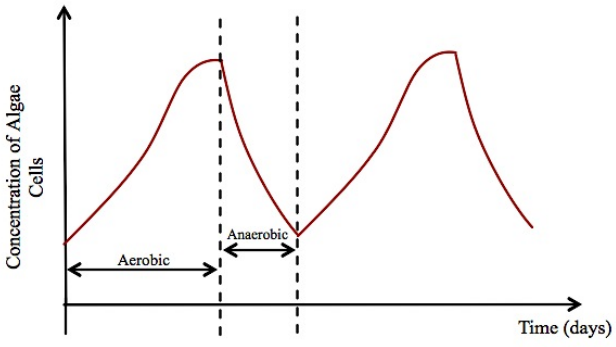


Figure 12: Correlation between hydrogen output and sequence of operation.

controller controls the concentration sensor. Both of the controllers work together to maintain the continuous process seen in Fig. 12.

The way the code is written for the master controller board is that once it is initially manually filled with algae, the master controller will then send a signal to the relay, which powers the air compressor. The air compressor will be on during the entirety of the aerobic cycle. Simultaneously, via serial ports, the master controller will be obtaining values from the slave controller, which will be storing values read by the concentration sensor until a maximum concentration is detected. This value will be the peak of algae growth and is the point in which the air pump will be shut off. Once the air compressor shuts off, the anaerobic cycle begins and hydrogen production will take place. The slave controller will continue reading values from the concentration sensor until a minimal value is detected. This is when much of the algae cells are dead, and the extraction port opens until the pbr is emptied. After the extraction valve closes the addition valve opens until the photobioreactor is filled to the appropriate level. There will be a slight delay between the extraction port being closed and the addition port to be opened. It must be noted that the amount of time it takes for the bioreactor to be emptied and filled should be determined experimentally. At this point, the cycle will begin again and will be continued until the compressor's power source is shut off. Any hydrogen that is produced will go through the hydrogen purifier. A storage unit should be added above the purifier to collect the hydrogen to be used in an energy production application.

B. Hydrogen Concentration Sensor

For the hydrogen sensor, it must be plugged in 24 hours before usage. This time is allotted for the sensor to preheat, which allows for more accurate readings. While the sensor is preheating, the connections made between the Arduino board and the LCD should be checked, as well as the code for the Arduino board should be uploaded. There is a code supplied in Appendix A to check that the connection of the LCD is functioning. Once the assembly is finished and the hydrogen sensor is preheated, it is ready for operation. The flask should be evacuated for accurate measurements. The air compressor can be used to evacuate the flask via a hose connected to the inlet side of compressor and the flask. This should only take a couple seconds and will create a vacuum within the flask. The tubing should be connected to the connection found above the hydrogen purifier. Once the valve is switched to open, the vacuum in the flask will cause the gases to move into the Erlenmeyer flask. This is the point in which the sensor will begin working and the LCD will output the percent of hydrogen contained within the flask. The valve should be closed after the flask is filled, which should only take a couple seconds.

V. TROUBLESHOOTING

Several problems may occur and need to be corrected. Below is a list of these problems and ways to troubleshoot:

A. Solenoid Valves

If the valves are not functioning, the first thing to do is to check if power is reaching them. This can be done with the use of a voltmeter. When the valve is charged, it should be powered with 12V from the external battery that is connected to the motor driver. If the voltmeter does not read the 12V during the time in which the valve is energized, then the valve is not receiving the power needed for proper operation. A connection might not be correct and should be double-checked.

B. Relay

If the relay is not functioning, the first thing to do is to check if power is reaching it. This can be done with the use of a voltmeter. When the relay is charged, it should read 5V input from the Arduino microcontroller. If the voltmeter does not read the 5V during the time in which the relay should be energized, then the relay is not receiving the power needed for proper operation. A connection might not be correct and should be double-checked. If the relay is receiving enough power, but the air compressor is still not turning on, the problem might be with the compressor or the connections between the relay and electrical outlet. To check this, simply unplug the compressor from the relay and into a wall outlet. If the compressor does not turn on, the compressor might need to be fixed or a new one might need to be purchased.

C. Hydrogen Concentration Sensor

In order to test the hydrogen sensor to see if it is malfunctioning, a hydrogen source and testing set up is necessary. The calibration for the sensor was performed at the National High Magnetic Field Laboratory in Tallahassee, Florida. The sensor was placed into an airtight Erlenmeyer flask. The air was then pumped out to create a vacuum inside, at the end of which the valve should remain in the closed position. Once that is completed, a specific amount of hydrogen should be obtained to see the accuracy of the sensor. The pressure differences of the hydrogen gas and the vacuum in which the sensor is located will cause the hydrogen gas be sucked into the Erlenmeyer flask once the valves are opened. This will have to be repeated until the hydrogen sensor is either recalibrated or established to no longer work.

D. Algae Concentration Sensor

The concentration sensor is one of the more complex components in the system. First, all of the connections should be checked to make sure it is being powered during operation. Some reasons that the concentration sensor is not functioning correctly

include; LED's burning out or breaking, and/or the LDR is no longer functioning or is obstructed. Another factor that can cause an error in data collecting would be any sort of ambient light leaking inside the sensor. The sensor must be in complete darkness so that the resistors only measure the light from the LED's.

E. Piping

If one of the pipes cracks, it should be fixed immediately before the photobioreactor gets more damaged. Depending where the crack is, there are two ways to fix it. To replace a whole pipe section, a small butane torch will be needed to melt the glue in the fitting. Once the broken plastic is unglued and removed, a new pipe can be installed and glued into the same place. Another option is to cut out the broken part of the pipe and add a new section via pipe unions. The piping will need to be glued into place in the new fitting to avoid and leakage.

F. Arduino Uno Microcontrollers

Table 1: Step-by-step controller troubleshooting

Program Selection	**Master Controller (Addition/Extraction Units and Relay)**	**Slave Controller (Concentration Sensor)**
Set up		
Step 1	Initialize variables and input/output pins	Initialize variables, input/output pins, and onboard hardware (microSD)
Data Acquisition		
Step 1	Send command character, "b" for "begin", to the slave controller to request concentration data. After sending, enter while loop until serial reads the handshaking character. If no response within x seconds, send another character and wait again.	Enter while loop until serial reads buffer command character "b" from master.
Step 2		Once command is received, send handshaking character, "b" for "begin", back to master to indicate that it is ready to send data.
Step 3	Receive the handshaking character, "b", from the slave controller and enter while loop to continuously check serial buffer for concentration data. If waiting for more than x	

	seconds, return to beginning of "Data Acquisition Routine"	
Step 4	Receive measurement and immediately save it into a data file on an onboard microSD card.	Enter data acquisition process: take concentration measurements. Send each measurement to master as it is taken.
Step 5	While in while loop waiting for data: if receive an "e" command from slave, leave the data acquisition while loop and calculate average of all measurements recently received.	When finished taking concentration measurements, send command character, "e" for "end", to master indicating data acquisition is finished.
Step 6	Input average value into concentration calibration equation. If average concentration is greater than or equal to target value, enter "Addition/Extraction Phase". If average concentration is less than target value, pause for a short duration and then return to the start of the "Data Acquisition Phase"	Return to while loop at beginning of "Data Acquisition Phase" to wait for next data request from master.
Relay and Addition/Extraction Phase		
Step 1	Send a digital 5V signal to the port that the relay is connected to. This will power the air compressor.	
Step 1	Send a digital 12V signal to the motor driver, which holds open the extraction solenoid valve. Then, pause for a short time to ensure the valve stays opens for complete algae extraction.	
Step 2	Return the digital signal that controls the extraction solenoid valve back to 0V to close the valve, pause for a short duration.	
Step 3	Wait for a short duration and then repeats steps above for the addition	

	valve.	
Step 4	Exit “Addition/Extraction Phase”, pause for a short duration, then return to the beginning of “Data Acquisition Phase”	

VI. REGULAR MAINTENANCE

Each component of the photobioreactor was chosen for a long lifespan, be self-sustaining, and low maintenance. With this being the case, each component should still be checked regularly to make sure it is functioning correctly. The solenoid valves, the relay, and the concentration sensor should be checked bi-weekly to ensure proper functioning. This can be done by simply using a voltmeter to make sure enough power is reaching the valves and the relay at a point in which the master controller is telling them to be charged or turn on. Checking them regularly will allow for a smoother and more continuous cycle. The photobioreactor should be cleaned out monthly to avoid the build up of any dead algae. The only component that is disposable is the hydrogen purifier. The OxiClear gas purifier at a normal flow rate has a capacity of ~ 1200 cubic feet of inert gas (about 3 standard 300 cubit feet cylinders).

VII. SPARE PARTS / INVENTORY

Table 2: Spare Parts / Inventory

Spare Part	**Vendor**	**Quantity**
MQ-8 Hydrogen Gas Sensor	Sainsmart	1

REFERENCES

[1] Samuel Jones, " Gas-Liquid Mass Transfer in an External Airlift Loop Reactor for Syngas Fermentation," PhD Thesis, Iowa State University, August 2007

[2] Senior Design Team 7, " Operational Manual," Florida State University, 2012 - 2013

VIII. APPENDIX A – HYDROGEN SENSOR CODE

```
//Code to sense hydrogen levels

// Arduino Board UNO
// MQ-8 Hydrogen Gas Sensor that uses 5V

// websites to look at:
// arduino.cc/en/Tutorial/LiquidCrystal
// youtube.com/watch?v=HLivlogyNhs

#include <LiquidCrystal.h> // must call out the LCD library

LiquidCrystal lcd(12, 11, 5, 4, 3, 2); // pins where the LCD should be hooked up
int sensor = A0; // port in which the sensor is hooked into
int SensorValue = 0; // this is the number the sensor will output
float h; // this will be the percent of hydrogen number to be calculated

void setup() {
  lcd.begin(16,2);
  lcd.setCursor(0,1); // will write to second line
  //lcd.print("testing 1 2 3 ");  //use this to check lcd is set up correctly

}

void loop() {
   SensorValue = analogRead(sensor);
   lcd.setCursor(0,0); // will write to first line
   lcd.print("AMOUNT OF H2:");

   h = (0.97*(SensorValue/50)); // hydrogen conversion equation – still being calibrated

   lcd.setCursor(0,1); // print percent of hydrogen to second line
   lcd.print(h);
   lcd.setCursor(5,1);
   lcd.print("%");


  delay(500);
  lcd.clear();
 }
```

IX. APPENDIX B – SOLENOID VALVES AND RELAY CODE

```
//Runs Solenoids and Relay

const int SolA = 8; //define pin for add solenoid (green and yellow)
const int SolA2 = 9; //define pin for add solenoid backward
const int SolE = 6; //define pin for extract solenoid (white and brown)
const int SolE2 = 7; //define pin for extract solenoid backward
const int soldel = 750; //delay for solenoid in ms
const int soldelA = 15000; //duration for addition solenoid operation in ms
const int soldelE = 5000; //duration for extraction solenoid operation in ms
const int MPolF = 5; //define pin for "forward" motor pole (HIGH = forward, LOW =
backward)
const int pumpdel = 150; //delay for the pump in ms
const int pumpdur = 10000; //duration of pump operation in ms


void setup()
{
 Serial.begin(9600);
 // initialize the digital pin as an output.
 pinMode(SolA, OUTPUT); //set solenoid pin to output
 pinMode(SolE, OUTPUT); //set solenoid pin to output
 pinMode(SolA2, OUTPUT); //set pump forward pole pin to output
 pinMode(SolE2, OUTPUT); //set pump backwawrd pole pin to output
 pinMode(MPolF, OUTPUT); //set pump forward pole pin to output


 //Start all devices in off position
 digitalWrite(SolA, LOW); //start add solenoid off
 digitalWrite(SolE, LOW); //start ext solenoid off
 digitalWrite(SolA2, LOW); //start forward pump pole off
 digitalWrite(SolE2, LOW); //start backward pump pole off
 digitalWrite(MPolF, LOW); //start forward pump pole off
}


void loop()
{
//*Pump on
digitalWrite(MPolF, HIGH); //activate forward pumping
 delay(pumpdur);

 //turn off pump and allow for short time lapse (pumpdel)
 digitalWrite(MPolF, LOW); //stop forward pumping
 delay(pumpdel);
```

```
  delay(5000); //delay ten seconds between addition and pump turning on (arbitrary)


//*Extraction Routine
  //set solenoids in position for extraction (avoid delay in program)
  digitalWrite(SolA, LOW); //leave addition solenoid closed
  digitalWrite(SolE, HIGH); //open extraction solenoid
  delay(soldelE); // time for fluid to be extracted

  //close extraction solenoid (both solenoids closed) w/ small time lapse
  digitalWrite(SolA, LOW); //keep addition solenoid closed
  digitalWrite(SolE, LOW); //close extraction solenoid
  delay(soldel);


//*Addition Routine
  //open addition solenoid only w/ specificed time lapse = soldelA
  digitalWrite(SolA, HIGH);
  delay(soldelA);

  //close addition solenoid
  digitalWrite(SolA, LOW);
  delay(soldel);


  //delay before next round of concentration measurements
  delay(10000);
}
```