Midterm Report, Concept Development

Senior Design Project (EML 4551C) - Fall 2013 Deliverable
Team 07 - Microalgae Photobioreactor

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1.0 Problem Statement

The customer defined the problem statement in the project proposal as:

> "The UFPR-FSU senior design teams have worked in the past with photobioreactors that work in batches. Growth media is added initially to microalgae to be grown in the photobioreactor for a period of approximately 15 days. At the end of that period the biomass is extracted and a new batch starts.
>
> We anticipate enhance biomass productivity by using a continuous growth system (as opposed to batch) in which biomass is continuously extracted as new cells grow attempting to maintain a nearly constant ideal cell concentration within the photobioreactor. Media (nutrients and water) will need to be added in the necessary amounts to make up for the extractions.
>
> The implementation of a continuous system, requires at least: (i) a concentration sensor, (ii) an automatic unit of media supply, and (iii) a biomass extraction unit. The concentration sensor was partially developed by the 2012-2013 team (see link under background), and it will be further enhanced as part of a master thesis. What you are asked to design is the units (ii) and (iii), and amend the previously developed concentration sensor (i)."

Thus, the customer needs a way to transform the photobioreactors' current "batch" growth systems into "continuous growth systems." In order to achieve this, the customer is requesting the design or development of an "automatic unit of media supply" and a "biomass extraction unit", as well as an improvement to the "previously developed concentration sensor."

2.0 Background and Justification

Coal, petroleum, and natural gas are all nonrenewable resources commonly used today. As consumption continues to increase, these resources are becoming more and more unsustainable. If changes are not made or alternatives are not found, these resources will eventually run out, crippling infrastructures and industries on a global scale. In addition, greenhouse gasses will continue to increase and negatively affect the environment. New methods of energy production and consumption must be implemented before significant consequences occur. Alternative fuels, such as biofuels derived from oils in crops, present one solution to this energy problem. Some examples of biofuel crops are corn, soybean, sugar cane, canola, and microalgae. Microalgae are the only biofuel that can completely replace our existing fuel sources. Microalgae take little room to grow compared to crop biofuels and produce biomass much quicker than other crops. According to Yusuf Chisti, within twenty-four hours, microalgae can double its biomass (*Biodiesel from Microalgae*).

The Florida Agricultural and Mechanical University – Florida State University College of Engineering (FAMU-FSU COE) in Tallahassee, FL, USA and the Federal University of Paraná (UFPR) in Curitiba, Paraná, Brazil started a partnership on senior design projects in 2005. The projects are unique in that they require international collaboration between universities. In this section, brief reviews of the past projects are explained. We will focus on the projects from 2010-present because the 2010 group was the first team to implement the microalgae in their objectives. The designs and prototypes mentioned below are currently at the FAMU-FSU COE. These were created based on existing photobioreactor systems and research at UFPR.

Figure 1 shows the Trigenerator System with Photobioreactor. This was completed by the 2011 Senior Design team. (Senior Design Project)

Starting in 2010, the combined team, consisting of a group at UFPR and a group at FAMU-FSU COE, developed a new way to monitor the effects of carbon dioxide on microalgae. The FAMU-FSU COE team built a bench-top airlift photobioreactor. The CO_2 was supplied though the bottom of the airlift tubes, rose through the algae, and exited out the top. The microalgae concentration was monitored by counting the cells under a microscope and the optimal amount of CO_2 to get the most cell growth was determined (*Senior Design Proposal*).

In 2011, the team implemented this knowledge of the effect of CO_2 on microalgae into a trigeneration system. The trigeneration system was built by the 2005 senior design team. It is a system that created hot water, electricity, and refrigeration from fuel in an internal combustion engine. The final project is shown in fig. 1 (*Senior Design Proposal*).

The 2012 team went in a different direction. They built a mini-photobioreactor at the FAMU-FSU COE, designed as a small-scale prototype of the one in Brazil. In addition, they designed and implemented concentration and mass flow rate sensors to determine the optimal time to extract the microalgae in order to obtain the most biomass before it starts to die. The use of these sensors, when calibrated correctly, can save significant time compared to the previous method of manually counting microalgae cells. The mini-photobioreactor built in 2012 is shown in fig. 2 (*Senior Design Proposal*).

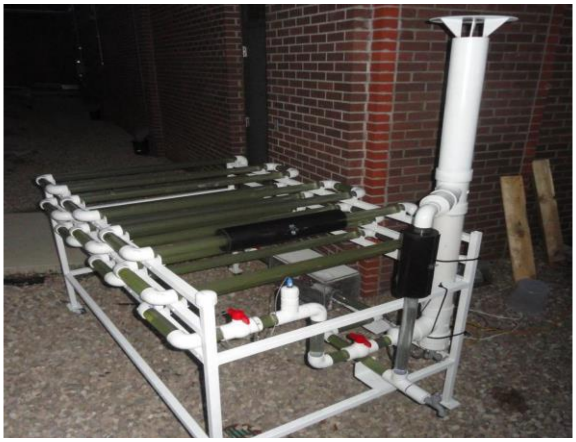


Figure 2 shows the Photobioreactor created last year. It incorporated sensors to monitor the microalgae growth. (Senior Design Project)

This year's project will include several objectives that build on the efforts of previous groups and a few objectives that require the design of new devices, as well. The project is intended to reach a milestone of continuous photobioreactor operation, as well as to build more resources for research at UFPR and FAMU-FSU COE to strengthen this collaborative international project.

3.0 Objectives

The main goal of this project is to satisfactorily complete, as defined by the customer, objectives 1-4 listed below and complete objective 5 only if the previous objectives have been completed. The deadline for this goal is the end of spring semester 2014. The FAMU-FSU College of Engineering and Federal University of Paraná will work together to accomplish these tasks. The objectives were either obtained from the project proposal submitted by the customer or through dialogue with the customer about the project.

The main objectives for the FALL/SPRING SEMESTERS are as follows:

1. *Grow two types of microalgae*
2. *"Design and develop two devices (units) for low cost, automatic growth media addition and biomass extraction from photobioreactors."* (*Senior Design Proposal*)
3. *"Submission of an invention disclosure in the US and a patent in Brazil of a concentration / mass flow rate sensor."* (*Senior Design Proposal*)
4. *Improve previously developed mass flow rate and concentration sensors*
5. *"Design and develop a platform (12 L airlift photobioreactor) to test such automatic units."* (*Senior Design Proposal*)

4.0 Expected Results

Customer identified expected results as outlined by Ordonez and Vargas in the project proposal:

1. *"Design and construct operational units."*
2. *"Design and construct an airlift photobioreactor to test the sensors."*
3. *"Provide enough experimental data to test operation of the designed units."*
4. "It should be fully *automated."*
5. *"It should be low-cost."*
6. *"It should be for long term outdoor use."*
7. *"Units must be scalable and readily adaptable to: 12L airlift photobioreactor (to be constructed by the team), existing mini-photobioreactors (at FSU and UFPR)."*
8. *"Write an invention disclosure (FSU team) to be submitted to the USPTO by the OTT/FSU and a patent request (Brazilian team) to be submitted to the Brazilian INPI, for the concentration/mass flow rate sensor developed by the 2012/2013 team."*
9. *"Estimated Costs of Hardware, or Items Provided by Sponsor: Approx. $3000"*

Additional expected results:

1. *Have a healthy culture of microalgae maintained for testing.*

The expected result of the entire project is to have all of the components required for continuous algae-growth both developed and tested. Currently, on the full-scale photobioreactor in Brazil, algae concentration is still determined from manual counting and the entire system operates on “batch” system marked by operational stops for algae extraction, media addition, and system cleaning. By the end of the academic year, the team expects all photobioreactor at FAMU-FSU COE and at UFPR to be capable of operating continuously – where algae are extracted and media added without needing to shut down the system. The team expects significant time savings and an increase in overall rate of biomass extraction.

5.0 <u>Constraints</u>

The time it takes for the algae to grow is a major constraint of this project. Before any of the sensors can be calibrated, a sufficient amount of algae must be grown. This process can take up to two month and must be started right away to not have any delays. Another constraint will be communication. In an international project, it will be vital to keep communication so progress continues according to expected deadlines. Weekly video conferences will be made to keep each team up to date on what the other team is doing. Finally, our budget is a constraint. Our team was given a budget of $1,500. The project budget must stay under this value.

6.0 <u>Project Assignments</u>

Each team member has been assigned a specific field within the project that they are responsible for. It is that team member’s responsibility to be the lead engineer in his/her specified field. The following is a list of the project members followed by their roles.

<u>Stephen Kassing</u>

- *Lead Project Engineer*
- *Deliverable/Report Writer – writes project deliverables*
- *Web Developer – develops and maintains team website*
- *Invention Disclosure Lead – researches and files an invention disclosure through FSU*

<u>Markus Dillman</u>

- *Lead Algae Engineer – grows and maintains two types of algae*
- *Concentration Sensor Calibration Lead – takes lead on calibrating the sensor*

<u>Diego Soler</u>

- *Lead Mechatronics Engineer – leads improvement of mass flow and concentration sensor and*
- *Co-Lead of Addition/Extraction Units – co-leads the development of the addition/extraction units*

<u>Matthew Vedrin</u>

- *Lead international engineer (UFPR)*
- *Co-Lead of Addition/Extraction Units – co-leads the development of the addition/extraction units*

- *Report Editor – edits all deliverables and reports before they are submitted*

7.0 Equipment & Sensor Performance Specifications (last deliverable)

The performance specifications are capabilities and performance characteristics that the equipment or sensors must satisfy in order to successfully meet the needs of the customer.

Performance Specifications of Concentration and Mass Flow Sensors

The following is a set of performance specifications for the mass flow and concentration sensors. More specific details of each sensor are explained later in this section. It is important to note that the performance specifications for these sensors are targeted toward technology modifications, only, and are not intended to be used to completely redesign the previously developed sensors. However, new designs may be considered at the request of the customer.

- The mass flow and concentration sensors should be combined into one case (if possible).
- The sensor case should have its own source of energy so it does not need to be connected to a computer at all times.
- The sensors should be mobile, allowing them to be placed in various locations on any of the photobioreactor at FSU or UFPR.
- The sensors should have a method of viewing information and/or inputting commands on or inside the sensor case.
- The sensors should be able to store information or data that can be extracted without a direct cable connection to any other devices.
- If a single case contains both sensors, the size of the unit should be scaled such that it is still able to easily connect to and function on the existing photobioreactor systems.
- Any hardware additions or improvements to the sensors should be modular, minimal cost, and easy for persons of technical and non-technical backgrounds to operate.

Mass Flow Sensor

The mass flow sensor was designed last year to measure the flow through the photobioreactor. The mass flow is determined using equation 1 below. The general idea is that if a known heat is applied to the system, with a known specific heat and temperature change, the mass flow can be calculated. This semester, this sensor will be calibrated and improved.

$$\dot{Q} = \dot{m}\, C_{P} \Delta T \qquad (1)$$

Another alternative way to measure the mass flow rate is currently being examined by the design team. It uses ultrasound waves to send a signal into the flow. When the signal is returned, the frequency will be shifted because of the Doppler Effect. The amount of shift depends on the speed of the flow. This, combined with the concentration of the fluid, would allow us to calculate the mass flow.

Concentration Sensor

The concentration sensor was developed by last year's senior design team. It works by emitting light through the photobioreactor piping via light-emitting-diodes (LED's). The light, as it travels through the pipe and algae-water, hits a Light Dependent Resistor (LDR) on the other side. By observation under a microscope, the actual concentration of algae can be determined. This value, used with the resistance measured from the sensor, allows us to calibrate the sensor to an accurate reading of algae concentration. This year, the team will work on improving the functionality and accuracy of this sensor. The possible improvements are listed below.

- The accuracy of the sensor can be improved by adding another photo resistor on the Wheatstone bridge to double the sensitivity. The Wheatstone bridge converts the variation on resistance of the sensor into voltage.
- Another possibility is to replace the photo-resistor sensor with a photo-transistor sensor (IR-Sensor) which can read a more narrowed range of frequencies, leading to less noise interference in the sensor's readings.

Automatic Addition/Extraction Units

Every photobioreactor system currently existing at UFPR or FSU operates on a batch system. A batch system requires a photobioreactor to be shut down while algae are extracted, pipes are cleaned, and new nutrients or algae are added to the unit. This type of operation reduces the potential productivity of the entire system. The development and implementation of automatic media-addition and algae-extraction units, in combination with the use of the concentration and mass flow sensors, would allow the Photobioreactor to operate continuously – i.e. without periodic shutdowns for extraction/addition – while ideally keeping the algae at a constant exponential growth rate. Thus, these units would greatly increase a photobioreactor's potential output rate of biomass. Similar systems often used in chemical processes include a "chemostat" and "turbidostat". These systems will be studied and used as base technologies for understanding the requirements of the desired units. The performance specifications for the addition/extraction units are listed below:

- The pressure of the fluid being added to the photobioreactor must exceed the pressure of the fluid inside the photobioreactor at the point of addition (in order to create an inward flow).
- The pressure of the fluid being extracted from the photobioreactor must exceed the pressure of the fluid, or lack thereof, outside of the photobioreactor at the point of extraction (in order to create an outward flow).
- The units must be attachable and detachable in a non-permanent fashion to any photobioreactor system existing at UFPR or FSU.
- The units must be able to automatically determine the proper amounts of algae-extraction and media-addition that are needed to maintain a constant concentration of algae inside the photobioreactor.

- The units must include liquid storage areas where either the algae or media solution can be temporarily held if the customer desires or if dependent processes require intermediary storage (such as the use of a non-continuous flocculator).
- In the case of intermediary storage, the extracted algae must be agitated sufficiently to reduce sedimentation or sticking to storage tank walls.
- The pressure of the fluid being added to the photobioreactor must not harm the cells.
- The extraction unit must not cause cavitation in the system.
- The size of both units should be such that the units are easily moveable and only require a single person to operate under manual conditions.
- The cost of the units must be minimal and within the budget of the project.
- The units should require minimal maintenance and as little expertise as possible to operate.

Sensor Test Unit Performance Specifications

A small testing unit will be built to model a system similar to the photobioreactor. Currently, in order to test and calibrate the sensors, the group must wait up to two months for enough algae to grow to fill the photobioreactor. Once the test unit is built, the group will be able to start testing and calibrating immediately. A few performance specifications are listed below. Construction of this test unit will take approximately two weeks. Designs have been presented and are currently under review.

- The test unit must model and simulate all conditions similar to the photobioreactor.
- The test sections should be interchangeable, allowing different sensors and materials to be attached.
- The mass flow sensor, concentration sensor, and addition/extraction units should be able to be attached to the test unit.
- The unit should have a pump to establish a constant flow.

8.0 Decision Matrix for Algae Extraction/Addition Units

Decision Matrix Criteria

1. Low-Cost

-The group's budget is only $1500 with the new units only able to use part of these funds because of other project objectives. Also, the idea of developing these technologies is to make them as low-cost as possible so that eventually a commercial product can be sold at a reasonable price with high rate of return. Low-cost is one of the most important criteria of the project.

2. Weather-Proof

-The photobioreactor uses the sun's energy to grow fats for fuel production, therefore it needs to rest outside and be able to withstand normal environmental conditions such as rain, wind, humidity, etc. Thus, all supporting equipment that will be used to maintain a continuously operating photobioreactor will also need to withstand the same environmental conditions. This is not one of the most important criteria because in many cases it would not be difficult to manually place the sensors on and remove them from the photobioreactor daily. In fact, the sensors will probably be checked daily, anyway, to ensure they are in proper working condition and in some cases to gather data. It is a very important criterion, however, in terms of reducing manual labor via automation.

3. Low-Maintenance

-It would not be worthwhile to invest time and effort into automating a system, only to need just as much manual labor and/or receive the same profit as compared to the previous system. This is an important criteria, however it also takes into account that with more automation usually comes at least a little bit more maintenance. For the current decision matrix, maintenance is not as important, however it will have more affect on the specific equipment selections and control system developments.

4. Moderate-to-Low Noise

-Because the photobioreactor will be located outside, the noise consideration is not as big of a problem compared to a device located inside. However, it would still be desirable to have a quiet system to reduce noise pollution for future commercial applications. Also, it will be relatively easy to attenuate undesirable sound levels with enclosures since the devices being considered do not produce large amounts of noise in the first place.

5. Adaptable to all Photobioreactors (PBR's)

-This is probably the most important criterion listed. It is essential that all of the newly developed systems can be adapted to all existing photobioreactor systems at FSU and UFPR. It is uncertain at this point in the research which type of photobioreactor would have the best productivity at commercial scale. In addition, there may be a need for all types of existing photobioreactors based on individual project requirements or constraints. Thus, it is best to make sure all new systems are robust enough to be able to function properly on all existing photobioreactor systems.

6. Physically Accessible

-Physical accessibility was ranked as relatively important because at this stage in the research, it is uncertain how much this initial design will change or how much maintenance will be required. Since this is the first design of these new units, it will be very important to easily access them for these reasons.

7. Flexible Location

-For the sake of having a robust technology, it would be convenient to be able to locate the new units anywhere on the photobioreactor. This would increase adaptability to existing and future photobioreactors while also allowing the customer to change locations if the initial installation was not effective. This is not a very important criterion, especially when compared to the importance of at least providing a working unit, no matter where it is located.

8. Able to be Automated

-This condition is almost one of the most important conditions, however it was given a slightly lower weight due to the fact that if all of the components in the system are not able to be automated (i.e. some valves), the continuous system would still be able to function without requiring a lot of manual effort. For example, if a control valve is used to control media flow into the system, the valve could be set manually because the media addition will most likely be continuous and the valve will not need to be moved again for a long time.

9. Able to Control Flow

-Even though automating the valves is not necessarily required, although it is highly important, being able to control the flow is essentially the solution to having a continuous system. Thus, this criterion carries a maximum weight in the decision evaluation.

10. Able to Operate Continuously or Pulsed

-This criterion appears to be part of the flow-control criterion and in fact, it has much to do with flow control. However, it encompasses a very important characteristic in flow control that is best to address individually, as well. Because it is uncertain at this point how the photobioreactor system will be affected by "constant" media input and algae extraction in regards to its response time and sensitivity to such frequent system changes, it is very important to ensure that the flow system is able to operate truly continuously, as well as in pulsed cycles. For example, if media is added and algae are extracted simultaneously and continuously, there is a chance that the photobioreactor's response time is slower than a single cycle of water within the photobioreactor. The flow rate of the water in the photobioreactor is somewhat controllable, however the rate of media addition and algae extraction is independent of the photobioreactor's flow rate – it is dependent on the volume of fluid and the concentration of algae. Thus, capability to perform both continuous and pulsed media addition and algae extraction is important.

11. Simple/Easy-to-Use

-This criterion is very important for future versions of the technology and is important at this stage for the sake of creating a working prototype. However, having a working prototype is much more important than that prototype being simple or ensuring that anyone can use it once installed.

12. Benign to Media/Algae

-This criterion received a selection weighting slightly under most important because although future operations may require that algae enter the extraction unit unharmed, the current project is assuming that algae will be processed soon after it is harvested and thus does not need to be preserved alive. It is still crucial, however, that the media and algae are not affected in a way that diminishes the production rate of the system.

Decision Matrix

Evaluation Criteria		Media Addition Unit		Algae Extraction Unit		
Criteria	Weight	Gravity Feed	Pump	Controlled Valve / Check Valve	Overflow	Pump
Low-cost	9	3	5	7	7	5
Weatherproof	7	7	7	7	7	7
Low-maintenance	5	3	5	7	7	5
Moderate-to-cow noise	3	5	5	7	7	5
Adaptabie to all PBR's	9	7	7	7	5	7
Physically accessible	7	3	7	7	5	7
Flexible location	3	5	7	7	1	7
Able to be automated	7	7	7	7	7	5
Able to control flow	9	5	5	5	5	7
Able to operate continuously or pulsed	9	7	5	7	7	5
Simple/Easy-to-Use	5	5	5	7	7	5
Benign to media/algae	7	7	7	7	7	5
Weighted Totals	560	436	480	542	492	470

Figure 3 Decision Matrix of Media Addition Unit and Algae Extraction Unit methods considering various weighted criteria.

Supporting Information

The following includes general notes about some of the design components and reasoning behind some of the evaluation results of all of the systems:

- A scale of 1-9 was used for the weighting system and a scale of 1-7 was used to evaluate each design option. This was simply based on a consensus that the weighting should range between 1-10 but that the ranking of each design option was relative to the other and so a pre-set number system was not necessary. Thus designs were initially evaluated free of a number system and then reduced to the 1-7 system.
- Weatherproofed micro-controllers will be used no matter what mechanical method of addition and extraction is used. These electronics will be the hardest components to ensure endurance to environmental conditions and thus weatherproofing the mechanical systems was considered to be comparatively simple and relatively the same across all design options.
- Achieving automatic operation was considered equally "easy" across each system. No system will require the use of any type of device that is completely foreign to another system - i.e. each system will be using simple and low-cost pipes, valves, and/or pumps that will be controlled by the same type of micro-controller and control algorithms.
- Each design option is almost equally suited to safely handle media and algae, with the exception of a pump extraction system simply because of the nature of algae destruction inside pumps.
- All of the automated systems will be controlled via micro-controllers to ensure proper addition and extraction flow, pump operation, and safety precautions. The control designs will take place during the detailed design of the selected physical system designs, however it is expected that all controls will revolve around the operation of valves, pumps, and possibly some sensors.

Automatic check valves work on the concept of a cracking pressure, which is the maximum pressure the valve can withstand while remaining closed. If the cracking pressure is exceeded, the valve will be forced open and fluid will pass through until the cracking pressure is again reached and the valve closes. As an example, consider a 1.5 meter high tank filled with water to the 1.0 meter mark and a check valve at the bottom set to a cracking pressure equal to the pressure of water 1 meter below the surface. At this point, the check valve is closed because its cracking pressure exactly matches the pressure of water pushing on it. Now pour a bucket of water into the tank. The water level will rise and the depth of the water in the tank will increase, thereby increasing the pressure at the bottom of the tank and exceeding the cracking pressure of the valve. This will open the valve until the water level returns to 1.0 meters and the cracking pressure again matches the pressure at the bottom of the tank.

9.0 Media Addition Unit Design Options

Design Selection

The decision matrix showed a higher score for the pump-feed system, 480, compared to the gravity-feed system, 436, out of a total possible weighted 560 points. The group agrees with the results of the decision matrix and will choose the pump-feed system as the primary design option, however the gravity-feed system will remain a viable option since it is so similar to the pump-feed design and may also be prototyped and tested, as well, if there is sufficient time.

1. Gravity Feed Media Addition

Possible main components

- Two media storage containers
- Pump
- Control valve or automatic check valve
- Micro-controller

Possible Configurations

The gravity-fed media addition system is characterized by a media storage reservoir whose water level always exceeds, in height, the level of water inside the photobioreactor. In terms of valves and controls, this method would either utilize a valve controlled by a micro-controller, a simple check valve, or a flush system to control flow into the system. Two possible configurations are described below and are noted as configurations 1a and 1b in figure X:

a) A small container of media solution located at the top of the photobioreactor that is fed media via a pump from a second reservoir at ground level.
b) A container of media solution that is taller than the photobioreactor and fed media via a pump from a second reservoir at ground level next to the first.

Advantages/Disadvantages

The main advantage of this addition method over other options is that the pump does not need to be running while media is being added. As long as enough media solution exists the in storage container, it can flow into the photobioreactor system. Another benefit is that media addition could be easily operated under both continuous and pulsed conditions because the flow can be controlled with a valve, independent of the pump. In terms of operation, all components would be fairly simple can be easily controlled with micro-controllers. Operating on a continuous or a pulse feed method would be relatively simple because this would only be dependent on the controlled valve. Also, this feed method could be easily adapted to all of the existing photobioreactor systems.

One disadvantage is that this type of system would be relatively expensive compared to other options. Normally a gravity-feed system would be cheaper and not require a pump, but because the photobioreactor height is greater than the pressure head from the building's plumbing, a pump is still required to set up the gravity-based system. There would, however, be some very small energy savings from pump's reduced operation time or from operating the pump at times of lower electricity price, such as at night. Maintenance for this method would also most likely be greater because more components are involved. In addition, accessibility to system components using this method would be difficult because many would be located high off the ground or at the top of the photobioreactor.

2. Pump Feed Media Addition

Possible main components

- Media storage container
- Pump
- Control valve or automatic check valve
- Micro-controller

Possible Configurations

The pump-feed addition system is characterized by media input via pump operation. The valves and controls of this system would be the same as the previous, but without the possibility of a flush system. A basic configuration could include a storage reservoir at ground level that holds the media solution, a pump which sends the media to the photobioreactor, and a number of automatic check valves or valves controlled by the micro-controller to facilitate flow into the photobioreactor. An outline of this method is shown as configuration 2 in figure 4.

Advantages/Disadvantages

In this system, media could only be input while the pump is operating because there is no other source of pressure, such as in the gravity based system. This could potentially lead to higher maintenance or higher electricity costs. Also, pulsed operation with the pump would require control of a pump and connected valves instead of just a single valve as in the gravity based system, along with potential maintenance issues from high repetition of on/off pump cycles.

Otherwise, one important advantage of this system over the first is that all devices could be located close to the ground where maintenance, monitoring, and troubleshooting would be significantly easier. Another advantage is that there would be less components overall compared to the gravity feed system and therefore less maintenance is expected. Finally, this system is adaptable to all existing photobioreactors and is more easily moveable on each one since the pump can supply the needed pressure at any height on the photobioreactor.

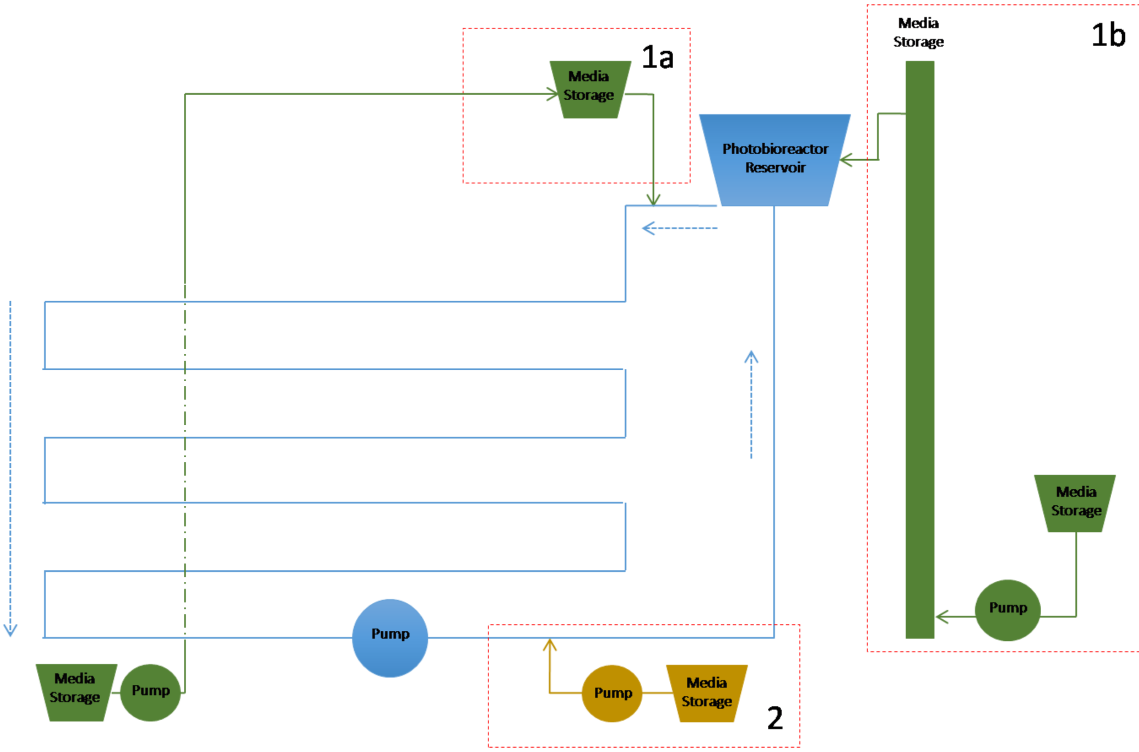


Figure 3 Outline of media addition method configurations including: 1a) Gravity Feed Media Addition (config 1), 1b) Gravity Feed Media Addition (config 2), 2) Pump Feed Media Addition. In this figure, extraction methods are shown as connected to a large pump-operated photobioreactor system.

10.0 <u>Algae Extraction Unit Design Options</u>

Design Selection

The decision matrix showed the highest score of 542 for the Automatic/Control Valve Algae Extraction method, the second highest score of 492 for the Overflow Algae Extraction method, and the lowest score of 470 for the Pump-Operated Algae Extraction method. The total possible score for the options was 560. The group agrees with the results of the decision matrix and will choose to move into detailed design of the Automatic/Control Valve Algae Extraction method. The group will also, however, begin a detailed design for the other two methods as the photobioreactor system is extremely complex and requires detailed analysis of operation conditions to fully determine the requirements of a particular extraction method.

1. <u>Automatic/Control Valve Algae Extraction (Gravity Fed)</u>

Possible main components

- Algae storage container
- Control valve or automatic check valve
- Micro-controller

Possible Configurations
This extraction method is characterized by a very simple gravity fed algae extraction. No pumps are needed since the algae would be extracted from the photobioreactor at a location of pressure greater than atmospheric and flow would be controlled either by an automatic check valve or by a micro-controller controlled valve. One of the simplest configurations would include the algae storage tank at ground level connected via piping to the photobioreactor. A visual example of this concept is shown as configuration 1 in figure 4.

Advantages/Disadvantages
The greatest advantage of this extraction method is its simplicity and potential to be low-cost. It uses almost the fewest number of components possible for an extraction system with only one component, the valve, possibly in need of control. If a variable cracking pressure automatic check valve is used, then this method could essentially run automatically without any electrically controlled components. Also, as long as the surface level of liquid-algae in the extraction tank is located below the surface level of water in the photobioreactor, gravity will ensure that the flow direction is into the extraction tank. This method is indifferent to the addition method, i.e. continuous or pulsed, as it is only dependent on a change in volume within the photobioreactor, thus it can be easily used with a continuous or pulsed media addition. It is also easily accessible because it can be located at ground level, as well as adaptable to any of the photobioreactor systems since they all have a vertical configuration and therefore will have increasing pressures with water depth.

The disadvantages of this system could be imprecise extraction due to sensitivity limitations of check valves or controlled valves, however this disadvantage is common to all extraction method options. Another disadvantage is that if a different volume inside the photobioreactor is desired and a check valve is used, the cracking pressure would have to be manually reset.

2. <u>Overflow Algae Extraction</u>

Possible main components

- Algae storage container

Possible Configurations
This is by far the simplest option of algae extraction. As long as the photobioreactor system operates with a consistent maximum water level height, which is easily achievable for most of the current systems, an overflow method would only require an extraction container and a connection pipe. An example outline is shown as configuration 2 in figure 5.

Advantages/Disadvantages
The greatest advantage of this system, much like the previous option, is its simplicity and low-cost. It requires the fewest number of components, the least operational control, and would be expected to require the least amount of maintenance. Like the previous option, this method is also indifferent to mode of media addition, i.e. continuous or pulsed, as it is only dependent on the change in water level inside the photobioreactor. It is also inherently automatic and without need for an electronic control system or regulation valves.

Unfortunately, there exist some significant disadvantages of this method that make it undesirable in meeting the needs of the project. The main disadvantages are the inadaptability, immobility, and lack of flow control of the setup. The overflow pipe would always be fixed at a certain height of the photobioreactor, however the level of water in the photobioreactor changes based on the rate of air input into the system for gas exchange. This would lead to a decrease in total volume of the system. Increasing the rate of air input would not be a major problem because the overflow valve would simply collect more algae initially, followed by a change in the dilution rate based on information from the concentration sensor, and finally the addition extraction process would stabilize again. However, if the air rate was decreased and the water level in the photobioreactor thus dropped, the new water level could be located well below the overflow level. In this case, the level of water would continue to rise with media addition without any algae extraction and a separate control algorithm could be needed to determine the required dilution rate during this period.

3. <u>Pump-Operated Algae Extraction</u>

Possible main components

- Algae storage container
- Pump
- Control valve or automatic check valve
- Micro-controller

Possible Configurations

This method of algae extraction is characterized by flow control via a pump and control valves. Control valves would be used to open or close the path to the extraction container and the pump would be simultaneously activated to regulate flow at the desired rate or to extract the desired volume. The basic configuration is demonstrated as configuration 3 in figure 5 and is marked by algae extraction via a pump through a valve connected to the photobioreactor into a pipe that connects to an extraction container.

Advantages/Disadvantages

This method is most useful for it's potential controllability. By using a pump, a more exact amount of algae can be removed from the photobioreactor, eliminating the need for additional sensors or uncertainties in amount of fluid extracted that may arise from gravity-based extraction. It is also very adaptable to all existing photobioreactors, as well accessible and mobile in regards to its possible location on each photobioreactor.

There are many more disadvantages to this system than advantages, primarily that the cost may be significantly higher compared to other methods, the complexity and operational requirements of the system increases, and that it increases the chance that extracted algae will be killed in the process of extraction. Some pump technologies would be more ideal than others, such as peristaltic pumps. However, though a peristaltic pump would allow for greater flow control and solve the issue of impacting algae growth, the expense for most of the possible devices is outside the budget of this project.

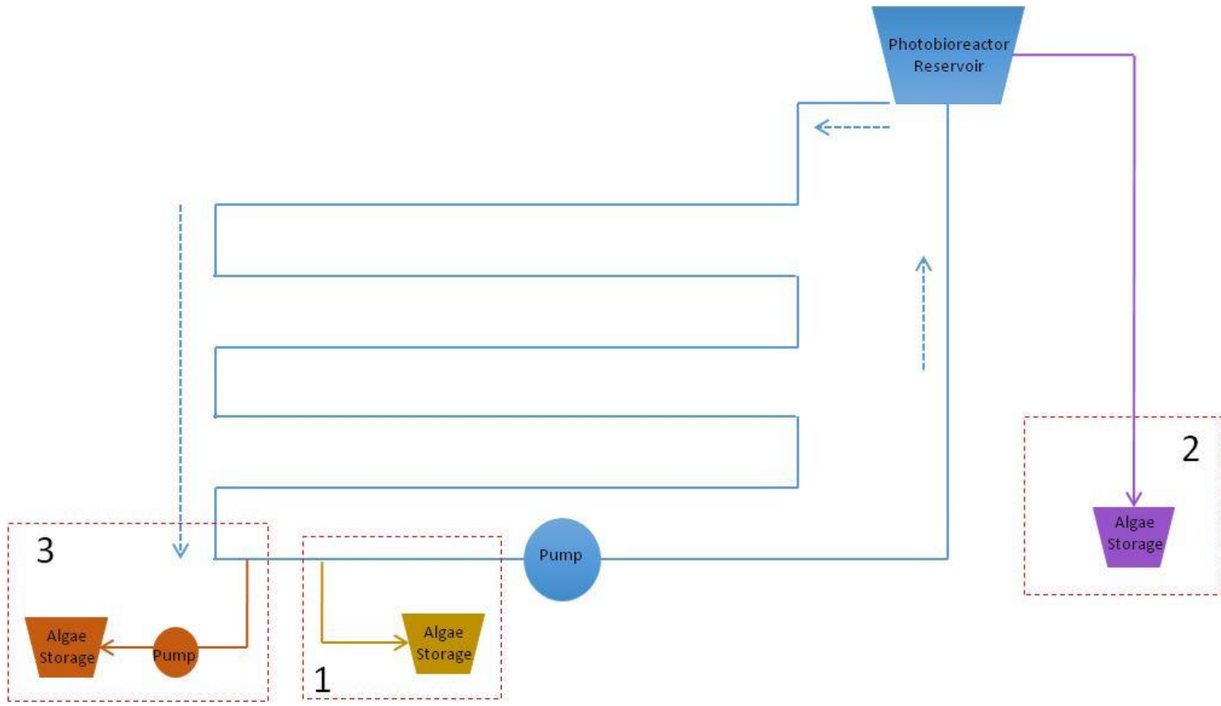


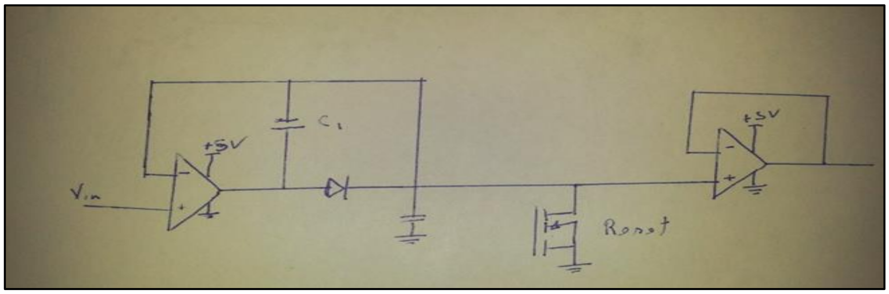
Figure 4 Outline of algae extraction method configurations including: 1) Automatic/Control Valve Algae Extraction, 2) Overflow Algae Extraction, 3) Pump-Operated Algae Extraction. In this figure, extraction methods are shown as connected to a large pump-operated photobioreactor system.

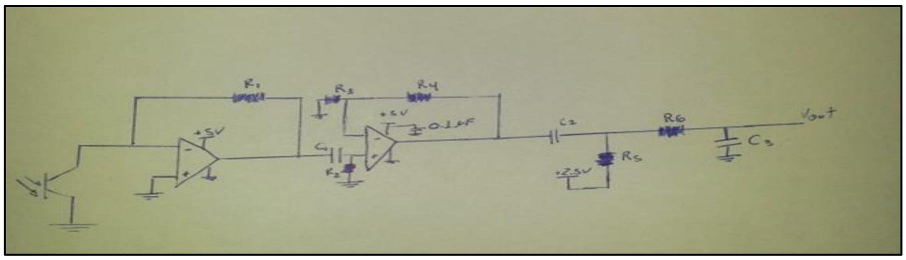
11.0 Concentration and Mass Flow Sensor Design Options

The following section will describe the design improvement concepts of the mass flow and concentration sensors. Because these are improvements and not designs from scratch, we have not presented multiple design improvement concepts.

Concentration Sensor Design Improvements

Diego Soler, is the lead sensor engineer on the FSU/FAMU engineering team. He has presented a couple ideas that will lead to the improvement of the concentration sensor. First, an Infrared (IR) LED will replace the original LED. This IR LED will emit light through the pipe at a different wavelength for the receiver to read as a voltage. This light is less sensitive and is not as affected by incoming sunlight. Second, Peak detection will be added to the sensor because the values should not change during one measuring process. The two improved circuits are seen below in the figure.





Mass Flow Sensor Design Improvements

The original mass flow sensor design uses a metal pipe because the heating output on the sensor will melt the PVC pipe. The main problem with this design is that the sensor is no longer mobile and has to stay in one place on the Photobioreactor. Our team has come up with an idea to eliminate the metal pipe. To do this we have decided to try to implement an ultra-sonic sensor into the mass flow sensor. This sensor will send an ultrasonic wave into the bioreactor which will be reflected by the algae. This reflection by the algae on the flow will result in a shifted frequency. The sensor then receives the frequency and converts this shift to a velocity. This is achieved by the Doppler Effect. The ultrasonic sensor has a patent therefore we cannot get an invention disclosure using this design improvement. We will report this to our sponsor and see if he wants to proceed. Below is a photo of the ultrasonic sensor we are going to use. We purchased it for only $4.91 on amazon.

Figure 5 shows the ultrasonic sensor used in the improvement of our mass flow sensor.

12.0 Photobioreactor Test Unit Design Concepts

The mini-bioreactor test unit is needed so we do not have to wait and fill the entire bioreactor to calibrate and test the sensors. This test unit will only need one gallon of algae; this is twelve times less than the original bioreactor. This means we can start testing about two months before we fill the larger bioreactor. The cost of the test unit will be dependent on the price of the steel flanges, which will be talked about later in the report. A good estimate is around

$160 dollars. In the following subsection, we will talk about how we are going to connect the different sections of the test unit, what material for the mass flow sensor we will use, and the current design for the test unit.

Easy Connect and Disconnect

We wanted each section of our test unit to be removable. The current bioreactor from last year has all permanent attachments. This makes it very hard to clean the bioreactor and remove the sensor sections. Our team decided to build flanges for each section of the mini bioreactor test unit. By using a flange we will be able to easily connect and disconnect each section of the test unit. The cost increases but the overall maintenance of the bioreactor will decrease. An O-ring will be inserted to prevent leaks. A drawing of our flange is seen to the right. Markus Dillman works in the machine shop and will be able to create these flanges. If we like how they operate in the test unit, we will implement them into the actual Photobioreactor.

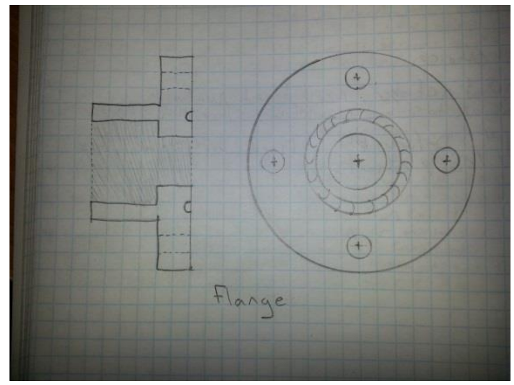
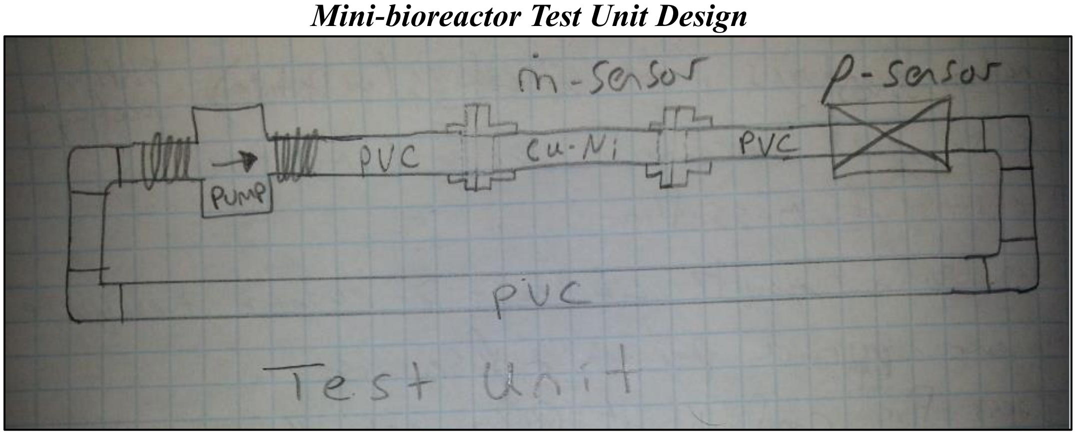


Figure 6 shows the flanges that are to me manufactured for the Test Unit.

Material Selection for Mass Flow Sensor in Test Unit

For the mass flow sensor to work, we need to expose the algae to high temperatures as described previously. In order to minimize the exposure of high temperature to the algae a more efficient method of transferring the heat input to the algae is required. Currently a plain carbon galvanized steel pipe is used as the interface between the algae and heating pads. A material with a higher thermal conductivity will benefit the system by reducing the total time for the pipe to reach steady state operational temperature also reducing the cool down time to reach steady state ambient temperature. The requirements of this material are that is must be corrosion resistant, have a high thermal conductivity, and be rigid. We have narrowed the materials down to two possibilities: aluminum 6061 or a copper-nickel allow. If cost is a major constraint, aluminum will be chosen.

Mini-bioreactor Test Unit Design



13.0 Procurement

Most of parts for this project will be purchased from McMaster-Carr. These parts include materials for the mini-bioreactor test unit and additional parts for the actual Photobioreactor. All the material for the sensors will be purchased online for the best price.

14.0 Future Work

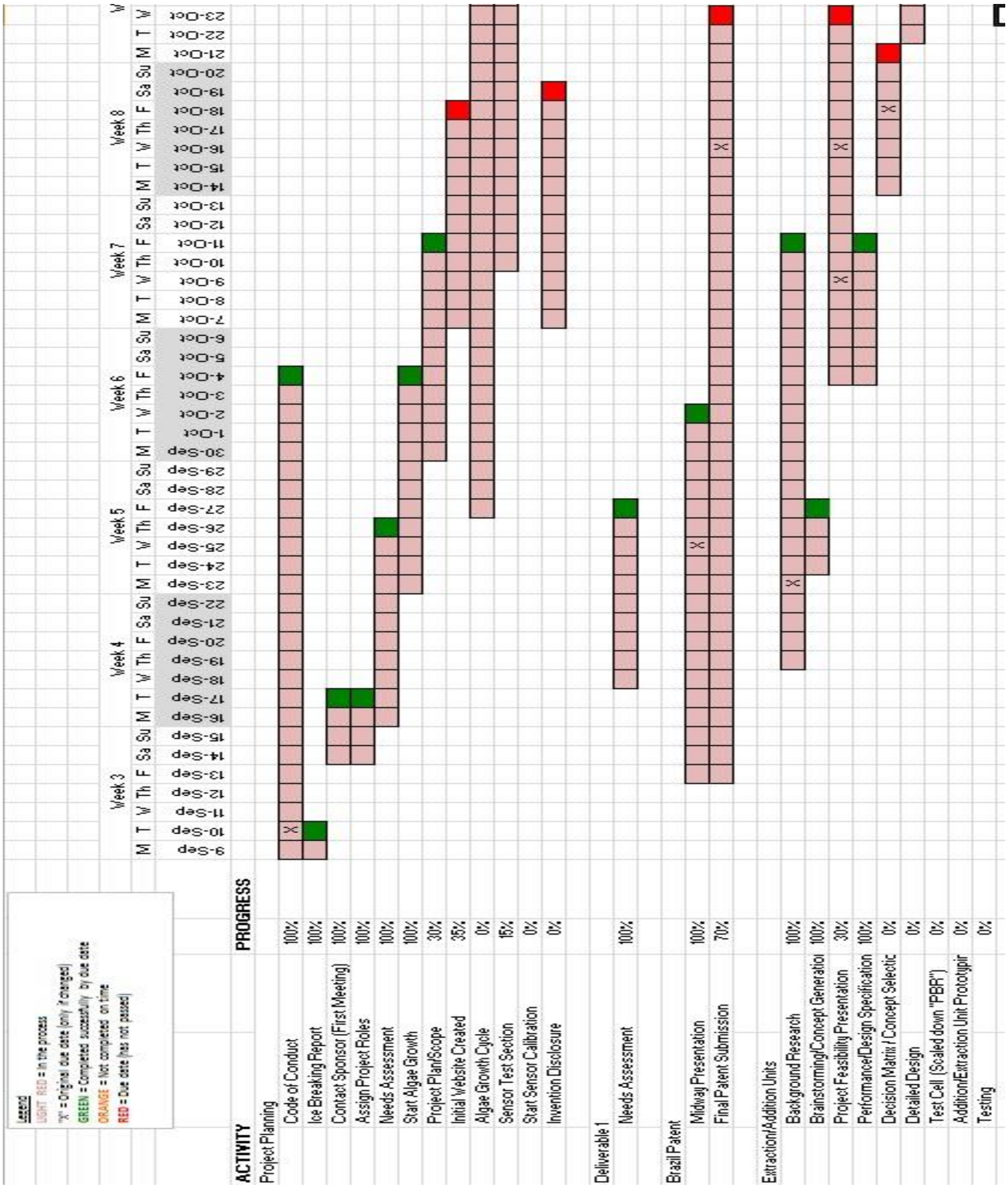
Now that most of the plans for the test unit have been finalized, we are going to order the parts from McMaster-Carr and start to machine the flanges. When the parts are shipped, it should only take a week to assemble the test unit. Once that is done, the improvements to the sensors will be made and we will start the calibration process.

15.0 References

1) Chisti, Yusuf. *Bio Diesel from Microalgae*. N.p.: Biotechnology Advances, n.d. Print.

2) Ordonez, Juan C., and Jose Vargas. "Senior Design Proposal, 2013-2014." FSU and UFPR, n.d. Web. 26 Sept. 2013.

Gantt Chart


Legend
LIGHT RED = In the process
"X" = Original due date (only if changed)
GREEN = Completed successfully by due date
ORANGE = Not completed on time
RED = Due date (has not passed)
ACTIVITY
PROGRESS
Week 3
Week 4
Week 5
Week 6
Week 7
Week 8
Project Planning
Code of Conduct 100%
Ice Breaking Report 100%
Contact Sponsor (First Meeting) 100%
Assign Project Roles 100%
Needs Assessment 100%
Start Algae Growth 100%
Project Plan/Scope 30%
Initial Website Created 35%
Algae Growth Cycle 0%
Sensor Test Section 15%
Start Sensor Calibration 0%
Invention Disclosure 0%
Deliverable 1
Needs Assessment 100%
Brazil Patent
Midway Presentation 100%
Final Patent Submission 70%
Extraction/Addition Units
Background Research 100%
Brainstorming/Concept Generation 100%
Project Feasibility Presentation 30%
Performance/Design Specification 100%
Decision Matrix / Concept Selection 0%
Detailed Design 0%
Test Cell (Scaled down "PBR") 0%
Addition/Extraction Unit Prototyping 0%
Testing 0%