Design and Development of an Automated Continuous Harvesting System for Microalgae Photobioreactors

Team Number: Group 9, FIPSE: UFPR - FSU Senior Design

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Authors: Kaelyn Badura[α], Ben Bazyler[β], Courtnie Garko[β], Yuri Lopes[β], Tomas Solano[α]

α – Department of Mechanical Engineering, UFPR – Universidade Federal do Paraná

β – Department of Mechanical Engineering, FSU – Florida State University

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Abstract

The Group 9 Senior design team has been organized and members have chosen roles, responsibilities, and have collaborated to develop a code of conduct. The engineering design process has begun and background research has been performed. Information has been gathered and consolidated on topics ranging from the current state of photobioreactors and microalgae cultivation to flocculation methods, biomass applications, and clarifier design. The scope of the project for Group 9 has been defined through a need statement and goal statement. This senior design project will focus on the design of an automated and continuous harvesting system for microalgae, a novel endeavor, as there is currently no existing way to harvest microalgae continuously. A list of objectives was created in order to establish criteria and tangible benchmarks for quantifying progress and success. Some main objectives include that the system must be automated, continuous, sustainable, adaptive, and scalable. Design constraints have also been identified and are related to budget, available resources, and process product generation. A methodology for how this design problem will be solved in order to fulfill the specified need has been outlined and a schedule of how tasks relevant to the described methodology will take place throughout the semester. This needs assessment will serve as a vital foundation and infrastructure as team 9 commences moving into the design concept generation phase.

1 Introduction

Currently 80% of the world's energy demand is fulfilled by fossil fuels[3]. Recent studies indicate that fossil fuels are being consumed at a rate 105 times higher than they are being produced in nature[1]. This demand for energy will quickly supercede the world's supply of fossil fuels and will inevitable lead to an energy source transition. It is therefore prudent and desirable to begin to invest in, research, and development other more sustainable avenues for viable energy production. One high potential alternative is microalgae photobioreactors. These photobioreactors cultivate microalgae utilizing the autotrophic characteristics of the algae and then produce solid biomass, clarify the medium the algae is grown in, remediate emissions, and can produce hydrogen and other biogases[1]. This process possesses the capability of being autonomous, sustainable, environmentally friendly, and produces biomass which can be used as a feedstock, fertilizer, coloring agent, chemical production, and a material source with which to generate biodiesel.

Within the photobioreactors, the microalgae cultivation and growth is governed by a time dependent curve which dictates the microalgae lifecycle. On this curve there is a point where the growth rate of the algae culture is a maximum. In order to optimize the cultivation and harvesting of microalgae, it is possible to maintain algae growth at this peak point in its life cycle. A specialized harvesting system could then continuously collect the microalgae. A continuous supply of cultivated microalgae requires a continuous way of separating the biomass from the medium and extracting said biomass. This is usually done through flocculation which is a process which separates the algae from its aqueous medium. Traditionally, flocculation is performed by using a centrifuge or by a adding a chemical flocculant and waiting for the flocculated algae to settle. Additionally, there are methods which rely wholly on non-chemical bio flocculation.

The objective of this project is to design and construct a fully automated microalgae growth and harvesting plant. Additionally, the developed harvesting system should allow the novel capacity to accommodate all three harvest regimes including: batch, semi-continuous, and continuous collection. This is achieved using the primary components of a smart control system that can decide when to start harvesting, stop harvesting, and to add growth medium etc., and a developed biomass separator and extractor. This separator and extractor will be designed in such a way that allows the biomass to be extracted from the medium and the medium to be recycled back for further use. This will be a sustainable fully autonomous system with high potential for environmental recyclability and as an energy source generator.

2 Project Definition

2.1 Background research

"Technology for producing and using biodiesel has been known for more than 50 years"[2] Research in potential biodiesels such as soybeans, animal fats, and vegetable oils have opened a large field of study into alternative natural fuel sources and mass production of these renewable resources[2]. For many years, FSU-FAMU College of Engineering has partnered with UFPR, an engineering company in Brazil that focuses on the growth and production of microalgae, a product that can be used as an alternative fuel source. Recently, research in both facilities has been done to try and optimize the growth of algae in an attempt to discover the most efficient environment and process of cultivating the biomass. Previous FSU- FAMU Senior Design groups along with the help of Dr. Juan Ordonez have spent many hours researching the most effective levels of CO_2, the proper angle of flasks set for maximum algal growth, peak points in growth, time required in the photobioreactor and many smaller aspects that contribute to efficient biomass production. Both small and large scale harvesting plants have been designed and are currently in use to cultivate microalgae around the world. All previous research and microalgae system developments have been partially or non-autonomous until now and no groups have attempted to design an automated system that will increase production time and lessen the need for human interference to keep the biomass production running.

Further research done by engineers such as Yusuf Chisti[2], Sina Salim, and many others has helped to contribute to knowledge on cultivation, flocculation, harvesting microalgae, photobioreactor engineering, and the potential uses of microalgal biomass. Their published works including "*Biodiesel from Microalgae"*[2], "*Flocculation as a low-cost method for harvesting microalgae for bulk biomass production"*[4], and other similar papers have helped to better the understanding of the entire process and the future economical improvements that can be made by using microalgae biomass in place of diesel fuels.

Right now, there are few gaps in the actual production of biomass from microalgae. Growth has been optimized and extensive research has been done on the separate parts of the process such as flocculation, coagulation, clarification, and extraction. The next step of this research is to design an effective system to automate this process.

2.2 Need Statement

As a result of waning fossil fuel resources it is desirable to have access to a sustainable alternative energy source. Microalgae photobioreactors are viable options for simple and sustainable energy source production. The operation of these bioreactors has the potential for automation and produces environmentally friendly biomass and biogas which have many widespread applications, as aforementioned. The current state of microalgae photobioreactors is very dependent on consistent maintenance and check-ups to keep the algae growing. In addition, there are no viable methods for automated harvesting of the microalgae. This is unsatisfactory because it limits the scope of utilizing microalgae as a large scale biofuel source. UFPR in conjunction with FSU are sponsoring the Senior Design team to develop a continuous harvesting system which requires minimal intervention as a solution to the harvesting problem.

Need Statement: **" There is no existing way to harvest microalgae continuously."**

2.3 Goal Statement & Objectives

The goal statement specified within a project outlines the general aims of the project. For Group 9, the FIPSE: FSU – UFPR Senior design team, the goal statement is given below.

Goal Statement: "**Design of an automated and continuous harvesting system for microalgae**"

Objectives are tangible milestones against which to gauge progress and quantify success in fulfilling the outlined goal. The relevant objectives for the design of an automated and continuous harvesting system for microalgae are defined below.

Objectives:

- Biomass production process must be fully automated.
  - From cultivation through collection and flocculation to separation.
- System must have ability to separate produced biomass and clarified water.
- Must work for batch, semicontinuous, and continuous collection.
- Must incorporate continuous flocculation and sedimentation.
- Must be sustainable, both in construction and in process.
  - Minimized energy and resource consumption.
- System must be scalable and will show functionality at both lab and pilot scales.
- Harvesting system will work with different species of algae.

2.4 Constraints

These are requirements potential designs must meet in order to be fully considered as a legitimate and appropriated design.

Constraints

- The developed system must work with FSU's current skeleton photobioreactor infrastructure.
- The total cost may not exceed $1,500.
- The clarified medium must be recyclable.
- The produced biomass must remain usable.
- The entire system's flow rate will be dictated by the growth rate of the utilized microalgae. The growth rate of each algae is different and therefore the system must be able to adapt.

2.5 Methodology

The design of an automated microalgae cultivation and separation system consists of 3 major components. These are the control for the automation of the system, the control is composed of the microcontroller, source code, and actuators. The other two parts are the flocculation system and the separator/clarifier tank.

The design process of these systems starts with literature review. Reading and compiling an ample library of relevant research that will aid or guide us through the design of these systems. The literature agglomeration will also include papers that will give us insight to what the problems in the industry are that limit these systems. The literature will teach us about the microalgae cultivation, something necessary to have as background knowledge in order to proceed. Once this material is well understood, a review on flocculation along with design of clarifiers will enable our creative process to begin.

Following the literature review a lab scale prototype design of the systems will commence. This will include breaking down the systems into the major or important components. Once the components have been identified, research on how the components operate how these can be substituted or omitted completely if possible, will be conducted. Taking advantage of the five group members each member of the team will present his or her own unique ideas and designs for each component. Once the designs have been completed, according to schedule (Table 1 and Figure 1), the decision on which will design will be used will be finalized. This decision will be reached with the aid of a morphological method of design decision and a pugh matrix. This tools will help us narrow our decisions to two top designs, from which in a democratic vote one will be chosen after an in depth discussion on them. A house of quality will help us during the design process by showing the importance of each requirement and characteristic going into the design (Figure 2).

Due to the nature of the project; i.e the group, as well as the equipment is split between two countries; different tasks or stages of the project will be completed by each part of the team. The team as a whole will take part in the design process for the prototype the first semester. Once the design has been finalized, a lab scale prototype will be built in order to prove its viability and allow for testing to later be optimized. The building of this prototype will be done in Brazil by the two group members located there. While the building of the prototype is underway the Tallahassee group members will start setting up micro algae cultivation equipment and cultivating microalgae to then run a trial inoculation of a mini photobioreactor. The mini photobioreactor will be used to scale up the designs next semester (Spring 2016).

Starting the 2016 Spring semester, the entire team will be in Tallahassee and the scaling up, optimization, and final system will be completed.

2.6 Schedule

Table 1. Table of tasks shown on Gantt chart for the first half of the project design.

Task	Start	Duration	End	Responsible Part
i. Problem Definition/Needs Statement	**8/14/2015**	**7**	**8/21/2015**	**UFPR**
I. Background/Literature Review	**8/14/2015**	**37**	**9/20/2015**	**BOTH**
II. Prototype Design	**9/14/2015**	**26**	**10/10/2015**	**BOTH**
1. Concept Generation/Selection	9/14/2015	14	9/28/2015	BOTH
2. Paramers/Constraints	9/21/2015	7	9/28/2015	UFPR
3. Dimensionizing	9/29/2015	8	10/7/2015	BOTH
4. CAD Drafting	9/29/2015	13	10/12/2015	FSU
5. Finalize Design	10/6/2015	6	10/12/2015	BOTH
III. Set-up Culture Equipment	**9/21/2015**	**56**	**11/15/2015**	**FSU**
1. Parts Aquisition	9/21/2015	19	10/9/2015	FSU
2. Hardware Set-up	10/10/2015	6	10/16/2015	FSU
3. Growing Trial Period	10/17/2015	29	11/15/2015	FSU
IV. Prototype Build	**10/10/2015**	**41**	**11/20/2015**	**UFPR**
1.Material Aquisition	10/10/2015	9	10/19/2015	UFPR
2. Floculator Build	10/20/2015	13	11/2/2015	UFPR
3. Clarifier Build	11/1/2015	19	11/20/2015	UFPR
V. Prototype Testing	**11/15/2015**	**15**	**11/30/2015**	**UFPR**
1. Build Quality Check	11/15/2015	2	11/17/2015	UFPR
2. Water Run	11/17/2015	3	11/20/2015	UFPR
3. Algae Run	11/20/2015	10	11/30/2015	UFPR
VI. Culture Equipment Testing	**11/15/2015**	**27**	**12/12/2015**	**FSU**
1. Algal Growth/Cultivation	11/15/2015	15	11/30/2015	FSU
2. Trial Innoculation	12/1/2015	12	12/12/2015	FSU

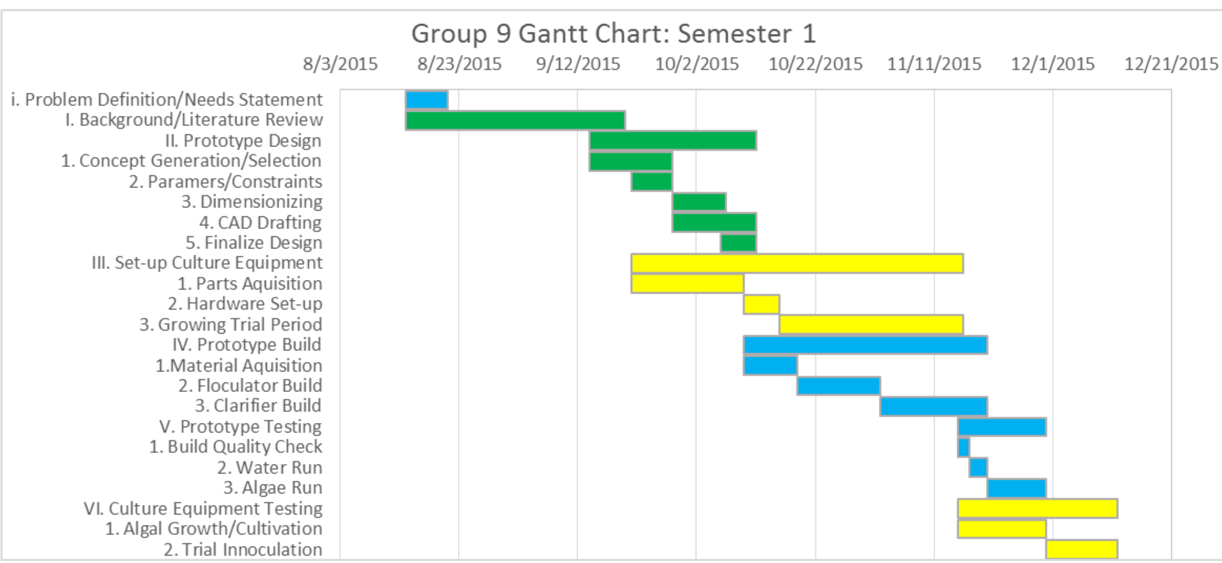
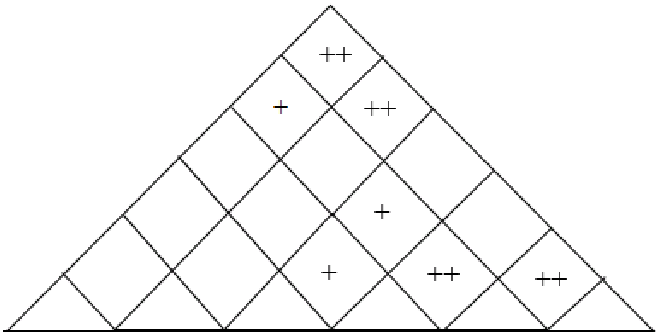


Figure 1. Gantt chart outlining schedule of tasks for the first semester of project design.



			Engineering Characteristics							
		Importance	Amount of biomass	Resistance to corrosion	Cost of Energy	Micro-Controller Timing	Biomass extraction efficiency	Design of Clarifier	Customer Total	Percentage
Customer Requirements	Fully automated	5			1	9		3	65	22.90%
	Separate biomass	5	1			3	9	1	70	24.60%
	Works with different cycles	3	3			1			12	4.20%
	Continuous Flocculation + Sedimentation	5				9			45	15.80%
	Sustainable	3		9	9				54	19.00%
	Scalable	2	3					9	24	8.50%
	Works with different algae	2	1				3	3	14	4.90%
		Total	22	27	32	108	51	44		
		Percentage	7.70%	9.50%	11.30%	38.00%	18.00%	15.50%		

Figure 2. House of Quality showing the importance of each customer requirement and engineering characteristic

3 Conclusion

Microalgae is a promising source of biofuel that could replace fossil fuels in the future. Currently, microalgae growth and harvesting is a difficult process that is mostly done in small scale operations. Though the whole process is already operational, the desire for this project is to make the process fully autonomous instead of having human interaction from one stage to the next. UFPR and FSU are sponsoring Group 9 to develop an autonomous harvesting system that can grow, separate and extract the biomass. The extracted biomass will be stored and converted into biodiesel in the future. Along with the extraction of the biomass, the filtered water will also be recycled and used indefinitely in this autonomous process. Future work should include the plans and specifications for the system prototype.

4 References

[1] G. Satyanarayana, A. B. Mariano, and J. V. C. Vargas. 2011. A review on microalgae, a versatile source for sustainable energy and materials. *International Journal of Energy Research* 35: 291–311. Accessed: 09/24/2015

[2] Yusuf, Christie. 2007. Biodiesel from Microalgae. *Biotechnology Advances* 25: 294 - 306. Accessed 09/24/2015

[3] Zechen Wu, Yi Zhu, Weiya Huang, Chengwu Zhang, Tao Li, Yuanming Zhang, and Aifen Li. 2012. Evaluation of flocculation induced by pH increase for harvesting microalgae and reuse of flocculated medium. *Biosource Technology* 110: 496 - 502. Accessed: 09/24/2015