FABRICATION OF A SIMPLE BUBBLE COLUMN CO_2 CAPTURE UNIT UTILIZING MICROALGAE

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ABSTRACT

This paper focuses on the fabrication of a vertical column CO_2 bioreactor and the experimentation of microalgae. On the manufacturing aspect of the project, the base design was modelled on Solidworks and assigned a material. The model was then loaded onto a finite element analysis (FEA) software to determine various engineering stresses and strains to confirm the specimen's strength. Once the simulation had completed, the model was ready for 3-D printing. The species of microalgae to be used in this study was Chlorella Vulgaris. The medium solution was prepared by mixing many types of salts suitable for this type of algae. Experimental trials of algae growth were conducted mainly to see whether the algae would indeed grow more rapidly using the developed medium. After failure in early trials, some experiments were conducted to determine which concentration of stock solution would be the most ideal for the algae to grow in. These early experiments proved the major impacts of the concentration of the medium on the rate of growth of the algae. The knowledge gained in these experiments will be instrumental during the next stages of this project.

KEYWORDS

Microalgae, CO_2 Capture, Vertical Column Bioreactor, Fabrication, Carbon Capture, Chlorella Vulgaris

1. INTRODUCTION

This paper is a continuation of the previous paper which reported the research conducted in the field of CO_2 capture. Many of the following points that will be mentioned in this introduction were researched in-depth previously in a paper titled "Feasibility and Design of a Bubble Column CO_2 Capture Unit Utilizing Microalgae" [1].

Increasing levels of carbon dioxide emissions are driving global climate change, one of the primary threats to economic and ecological sustainability. While there are many sources of carbon dioxide, fossil fuel-based power plants are among the worst CO_2 polluters. Once released into the atmosphere, it is extremely difficult to trap and remove the CO_2. However, technologies that remove or capture carbon at its source (called carbon capture systems, CCSs) prevent the release of CO_2 into the air and may be more effective solutions to carbon dioxide pollution and global climate change. In particular, newer CCSs use photosynthetic microalgae to consume carbon dioxide pollutants and release oxygen. Then the microalgae may be harvested for biofuels and other products. One challenge with microalgae CCSs is that the conditions for algal growth

are not yet optimized to handle real-world combustion gasses (which include CO_2 and noxious gasses) and this may affect the efficiency of the microalgae CCS.

Photobioreactors utilize the natural ability of living organisms through the process of photosynthesis to absorb CO_2. Scientists have experimented using different types of algae finding that free-floating microalgae are well suited for the task of CO_2 sequestration.

Algae have many promising potential uses [2]. The algal end product produced through this CCS could be used in many other applications such as: food supplements and animal feeds [3], bio-plastics and pigments [4], fertilizers, or biofuels [5]. One of the most interesting and potentially profitable is that of using the naturally occurring lipids contained within the algae cells to produce biofuels. Algae are a new and upcoming player for use as an alternative to conventional crops in use for producing biofuels. As the world begins to move towards alternative biofuels, one must consider the effects this will have on economies, social life, and the environment. One must also take into consideration the ethical aspect of using algae over other method of producing energy. The economic effects of using algal-biomass has truly yet to be understood. The small amount that is currently being produced is so small compared to traditional petroleum sources of diesel and even compared to other sources of biodiesel such as those produced using soybeans or vegetable oil. Currently biodiesel produced from algae has little to no effect on the economy, but as humanity pushes to more alternative fuel sources, one can expect algae to come to the forefront of the biofuel community. This is one of the uses that may make this method of CO_2 sequestration economically possible. Other uses such as fertilizers, food additives, and supplements are also possible. One more use is the successful treatment of various types of water waste, as algae can remove pollutants such as carcinogenic chemicals from waste water [2].

Environmental benefits of using algal-biomass for alternative fuel production will be substantial. Looking at producing ethanol from corn, one can find that for every mega joule of energy 81 to 85 kilograms of carbon dioxide is produced. For soybean that value drops to 49 kilograms per mega joule of energy produced [6]. Comparatively, algae when used to produce biodiesel, remove 183 kilograms of carbon dioxide for every mega joule of energy produced [6].

Photobioreactors of many shapes and sizes can be fixed or placed in nearly any location with direct sun exposure. Along the sides of overpasses near busy streets or in the middle of populated areas taking the place of other water features or statues. These living pieces of architecture and art seem to becoming commonplace in many designers imagination, one can expect these dreams to find their way to reality in the near future. Recent examples, such as the “Freeway Algae Garden” in Switzerland, show just how easy it is to install a photobioreactor in any location [7].

When cultivating algae, a number of factors need to be considered: water, mineral medium, light, and available CO_2. The closed system provides a controlled environment allowing for high productivity and was selected for this project against open systems.

There are four main types of photobioreactors (PBRs), flat panel, tubular, internally illuminated, and vertical column [8]. Of the four main types of PBR, the vertical column PBR was selected for study in this project. Under the vertical column class of photobioreactors, there are four subclasses, bubble column, split-column airlift, internal loop airlift, and external loop airlift. Of the four subtypes mentioned, the bubble column was chosen based on the following criteria: Power efficiency, volume capability, cost to build, ease of construction, ease of maintenance, and efficiency of CO_2 removal [8]. Using a decision matrix and the criteria mentioned, the vertical column configuration was selected over the other three types of PBRs [1].

The species of microalgae to be used in this study was determined to be Chlorella Vulgaris. The options were Spirulina and Chlorella Vulgaris. The selection was made based on cost of acquisition, acquisition difficulties, medium needs, growth rate, life span, lighting requirements, PH requirements, and potential environmental impact. The characteristics of the system, such as light and medium requirements, were based on the need of Chlorella Vulgaris. The growth medium needs of Chlorella Vulgaris are simpler to meet and maintain when compared to other species of algae. It also provides a high growth rate when supplied with enough light at the proper wavelengths.

2. REACTOR DESIGN

It was decided that the main structure of the photobioreactor would be composed of ABS plastic. The base was 3D printed allowing for superior customization and leaving holes for the inlet air and drainage channels for easy emptying of the PBR. This system was designed with the ability to be used for the small scale testing.

2.1. Detailed Design of the Photobioreactor

The design proposed for the PBR is a variation of the bubble column design. Figure 1 illustrates the proposed design and the layout of the photobioreactor.

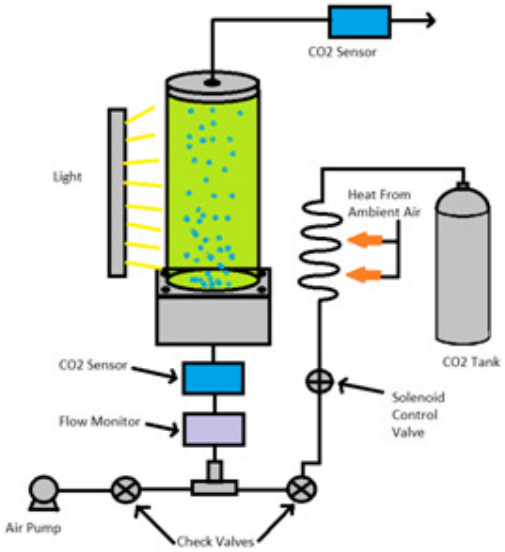

Figure 1: The schematic diagram of the experimental setup [1]

The bubble column itself is made up of an ABS plastic base, a clear acrylic cylinder, and a closed ABS plastic top that restricts the outlet flow to a CO_2 sensor. As illustrated in Figure 1, CO_2 leaves a compressed tank and flows through the length of tubing allowing for the CO_2 to increase in temperature. This ambient temperature CO_2 flows into a flow control valve through a check valve. Once through the check valve, the CO_2 flows through a flow monitor to measure the flow rate and then through a sensor to measure the input CO_2 content to the photobioreactor. From the sensor, the input is forced through diffusers to create the bubbling effect that can be seen illustrated in Figure 1.

2.2. Finite Element Analysis (FEA) of the PBR Base

A finite element analysis of the base of the PBR was conducted to determine the maximum force that can be applied to the bolts being used to hold the base together. The testing was to help prevent yielding of the base and bringing the design closer to the application in an industrial environment. The FEA was performed using SolidWorks software to determine the stresses and strains on the base of the photobioreactor. The analysis showed that the stresses caused by the bolts that hold the base together and the water within the column is well below the maximum stress that the base design can withstand.

3. FABRICATION PROCESS

3D printing was the means for manufacturing the PBR base and cap. The listed steps to follow cover the main points that were used to ensure the quality of the product:

- Identifying needs and requirements
- Conceptual design
- SolidWorks models of sketches
- Detailed SolidWorks drawings
- Finite element analysis
- Correcting the design to allow for a factor of safety
- 3D printing of the PBR base and cap
- Tubing for inlet air as well as the drain valve
- Securing two perpendicular light stands and fastening the LED light strips
- Lastly, bolting the PBR together and to the wooden base

These points represent steps that were followed throughout this project. Some of the problems encountered during the manufacturing process are covered later.

After receiving the salts for the media, it was realized that the amount of salts received was not enough to sustain the system at its current volume. Due to this discovery, it was decided that a smaller acrylic tube would be purchased to decrease the volume. With this decision, many changes needed to be made to the design of the PBR, primarily the size of the base. The size change of the base resulted in less material and less cost.

4. ALGAE CULTIVATION

Algae cultivation is comprised of two primary methods: open, taking advantage of freshwater pond resources and closed, utilizing photobioreactors. The project is working with a closed system and for this reason constraints are:

- Adequate mixing between both the algae and the nutrients
- Adequate gas mass transfer into the medium
- Low energy input to the reactor
- Inexpensive manufacturability

The closed system PBR offers better gas mass transfer control due to the higher vertical distance that provide a longer period of time for the gaseous CO_2 to dissolve. The reactor is protected from any external contaminations due to the reactors' closed nature. The algae grown in a PBR has the highest quality which means the algae will be consuming more CO_2, producing more oxygen, and

able to be kept homogeneous species of algae. The algae to be grown will have special parameters that must be taken into account in both the medium selection and provided environment.

4.1. Medium

The impacts the nutrients have on the algae is immense for both the growth rate and the concentration. Microalgae is known to grow more abundantly in eutrophication fluids, which leads to frequent algal blooms. The optimized conditions for higher biomass production of selected strain was 4% CO_2 [9].

During the preparation process, the medium was in the aqueous solution from a single stock which pertains all the needed chemicals. The stock solution of each chemical should be prepared separately using distilled water. Figure 2 shows the preparation setup.

Figure 2: Medium preparation process

Microalgae are known to grow more abundantly in nutrient-rich waters leading to algal blooms. Utilizing the Bolds Basal medium mix, the needed mass for each salt was mixed. Initially we didn't follow the correct order of the salts which led leaving some precipitants in the solution. Figure 3 shows the reaction mentioned after the first trial. The team addressed this problem using H_2SO_4.

Figure 3: The solution after first trial

4.2. Algae Growth

A total number of 8 drips of algae were administered into the stock solution and was then capped on the top with an air hose. The solution was then left to grow for a duration of two weeks without any managed lighting. Figure 4 shows the results.

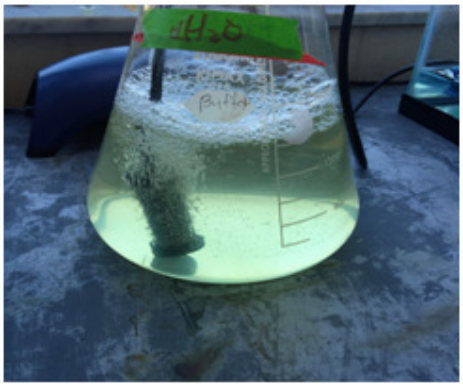

Figure 4: Preliminary Algae growth

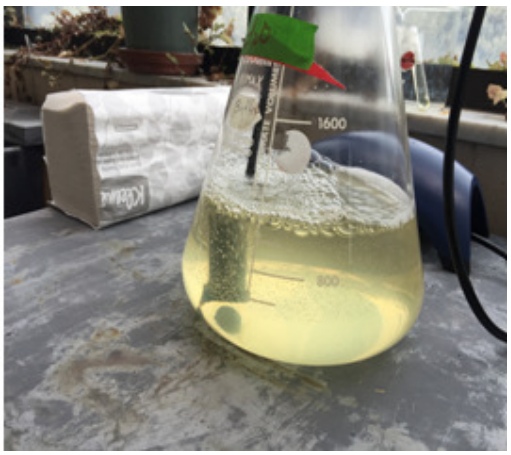

Figure 5: Result of preliminary growth

A fortnight later, Figure 5 was what was encountered. The solution had evaporated a whole 600 mL, a sample of the solution was taken to be looked under a microscope. The result of the first trial was the depletion of algae cells due to problem with the high concentration of the salts and lighting.

After the appropriate acids, salts, and lights were obtained, another stock solution was prepared using a 2-L flask with 1600 mL of the stock solution. The 200 mL of solution then was poured into four flasks, each flask comprised of different percentages of water to stock solution concentration. The percentages were: 10%, 20%, 50% and 75%. The reason behind this experiment was to determine which of these percentages were the most efficient for the algae growth. The flasks were moved to a sterile laboratory for inoculation. A total number of 8 drips were administered into each of the beakers and were all sealed with air-pumps and left for growth for a period of five days under the presence of LED lighting where 12 hours was with and a further 12 was without lighting. Figure 6 below shows the results of the respective growth after the given time period.

Figure 6: 2nd trial algal growth

From the figure above, the beaker on the far right showed the best results and grew more efficiently as compared to the other three. The percentage of this particular solution was 20%. Therefore, once all the parameters were taken into account, including the LED lighting, it was deduced that the 20% was the best and most efficient solution.

Precautions must be taken at all times when preparing the inoculum. When removing the algae from its shipping containers, any microbial contamination should be prevented. This involved the use of sterile equipment such as a sterilized wire loop for removing the algae.

Upon inoculation of the growth vessels with Chlorella Vulgaris, one would need to ensure that the specimen and its' medium are placed in a well air-conditioned sterilized room. It is advised that this process be preceded with a host of at least two individuals to set up the procedure. Equipment such as a wire loop, beaker of the medium and a Bunsen burner are needed for the inoculation.

When working with non-native algae or any organism not native to the areas in which one is working in, disposal of unneeded algae must be carefully taken into account. Chlorella Vulgaris simply needs to be exposed to low levels of chlorine, such as those found in common tap water to be killed. To further ensure that the environment isn't exposed, one could add a small amount of household bleach to ensure no algae survives.

The duration of light exposure is an important criterion to be taken into account when it comes to the implementation phase of the project. In the vertical tubular bioreactor, the light source would come from an indoor light, thus enabling the team to adjust and monitor the light intensity as it is supplied to the column. The photoperiods have a significant impact on the growth rate of the algae. It should be noted however that excessive light exposure to the column could lead to a decline in cell growth.

5. METHOD OF EXPERIMENTATION

The experimentation method for this project was very critical because it determined whether or not the PBR was successful. The sensors implemented in the design measured the amount of input and output CO_2 from the system at the scheduled time intervals [10].

For the experimental phase of this project, the bill of material consisted of some key items that were either manufactured via 3D printing or purchased. These items consisted of a CO_2 tank, a

solenoid valve, check vales, air pump, flow monitor, two CO_2 sensors, 30 inch high-output LED lights, two part 3D printed base, 3D printed cap, 5.25 inch diameter 30 inches tall acrylic tube, and a custom made microalgae solution suitable for the experiment. A detailed map of the assembly is provided Figure 1.

One of the most important aspects of the experimentation phase was the data collection and analysis. LabQuest 2 was used to read the CO_2 level entering and leaving the PBR. Ultimately, the change in the CO_2 level calculated in percentage can determine the efficiency of the reactor. The readings for temperature and CO_2 concentration were taken every 2 hours and the readings for PH and algae biomass density were taken once a day.

The team concluded that measuring the dry weight of a particular volume of liquid drawn off from the center of the reactor would be the most accurate method for measuring the biomass within the reactor.

6. DISCUSSION AND CONCLUSION

The goals of this project consisted of finalizing the design of the PBR base and cap, and performing a detailed FEA analysis on the base, assuring that no part will be affected by the stresses applied on it by the bolts. Lastly, the objective was to conduct the experimentations using the microalgae Chlorella to produce results allowing the group to confirm that this photobioreactor is a viable means of capturing and sequestrating CO_2.

The team was able to finalize the design and via FEA demonstrated that the design is sound. The parts to be manufactured were 3D printed, all other parts were donated or purchased with the funding attained. While all of the parts were acquired, the waterproofing the PBR base proved to be exceptionally challenging which caused significant delay in the manufacturing of the column and thus the experimentations.

The medium solution was produced by mixing many types of salts, including di-potassium hydrogen orthophosphate, potassium di-hydrogen orthophosphate, magnesium sulfate heptahydrate, sodium nitrate, calcium chloride dehydrate, sodium chloride, zinc sulfate heptahydrate, manganous chloride tetrahydrate, etc. This solution was used for preliminary growth of algae. These early experiments demonstrated the importance of lighting conditions and the concentration of the medium in the rate of growth of the algae. The sensors purchased and were tested to determine the accuracy and efficiency of the devices.

Overall while the group was not able to meet all of the goals previously mentioned, the experience and the knowledge gained will be extremely valuable and instrumental during the next stages of this project.

ACKNOWLEDGEMENTS

The authors would like to think the Biology and Chemistry departments at West Virginia University Institute of Technology (WVUIT) for their supports. Also an extended thanks is owed to the project sponsors, William Adarkwah, WVUIT SGA, and Lonmin Platinum for their financial supports.

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