A study on design improvement for tank photobioreactor

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Abstract. This study aims to design an improved photobioreactor from the current conventional approached in cultivating microalgae in lab scale using conical flask and glass tanks. In order to design a photobioreactor, thus the study required to investigate parameters that important affecting the cultivation process of the microalgae. The study also applied several techniques and knowledge of product design during the designing process for the photobioreactor. It is also important to consider the present product to be used for the industrial scale in future, therefore the techniques for product design must be applied. The techniques used are such as data collection of customer needs, concept generation, concept screening, concept selection and others knowledge also have been used. Finally, the developed photobioreactor was validated by cultivating 4 litre of *Chlorella sp.* within 10 days in MLA medium at pH 10. The highest cell concentration achieved at 0.33 g/l after 4 days of cultivation.

1. Introduction

Microalgae are the longest living autotrophic taxon in this world, and they are tissue-less organisms, simple multicellular organisms that can reproduce sexually or asexually [1]. Microalgae can be used to produce the biofuels because they synthesize three main biochemical compounds which are carbohydrates, proteins and lipids in large amount [1]. Those biochemical compounds are the main compounds to produce biofuels. Algae is more suitable than other plants in cultivating to produce biofuels because they produce large amount of those three compounds, and it is possible for them to produce 10 to 100 times of more oil compared to those oil plants [1]. Since algae are so important for the production of biofuels, it should be cultivated and can be handled easily to fulfil the demand for the renewable energy because of rapid population growth in future. Algae can be cultivated in two types of systems which is open system such as pond or lake and closed system which is known as photobioreactor [1-4].

Photobioreactor can be described as an enclosed, illuminated culture vessel designed for controlled biomass production [1]. The photobioreactor are usually made of glass, poly vinyl chloride (PVC), low-density polyethylene (LDPE) or other materials that are transparent [2]. Photobioreactor are usually used for the cultivation of microalgae because it is a closed system, so the environment or condition inside the photobioreactor can be easily controlled by the scientists. Besides, photobioreactor also prevent the system from contaminants which will destroy the growth of microalgae in the system. Other than that, the photobioreactor also provides the advantages over the open system where photobioreactor can

achieve higher productivity per unit area, allow to save water and chemical agents, and photobioreactor is suitable for outdoor or indoor installation [1]. However, there are many parameters that will affect the performance of the photobioreactor such as light, mixing, temperature, and mass transfer. Besides, the photobioreactor that available now is not preferable for the mass production of algae due to many factors such as cost, design and especially the productivity that affected by the design of the photobioreactor and also due to lack of deep understanding in the parameters mentioned as well as deeper understanding of efficient reactor design [5]. Therefore, this study is to design the tank photobioreactor that can help to improve the productivity of biomass production.

Microalgae are photoautotrophs and can use light as their only energy source for the synthesis of biomass and metabolites in photoautotrophic conditions. Therefore, light is one of the most critical parameters for the cultivation of microalgae, thus the design of photobioreactor needs to consider the light intensity for the optimal condition because the growth rate for different species of microalgae will affected by different light intensity. There is a research have been done shows that microalgae were able to perform photosynthesis at a higher efficiency under the low light conditions. The reason microalgae were not able to achieve high photosynthetic efficiency under high light intensity because microalgae need to dissipate part of the absorbed light energy as heat instead of biochemical energy [6]. Although the research shows that low light intensity is better for the cultivation of microalgae, but the optimal light intensity for microalgae is varies significantly among different algal species.

Besides, the light emitted will also emit the heat to the photobioreactor at the same time. Some researchers have done the research on the relationships between light exposure and broth temperature. The study shows that the reactor wall and shading factor where both related to direct and reflected solar irradiation are the major influence on the broth temperature. From the research, the researchers conclude that the best way to maintain temperature range is limiting the irradiance reaching the reactor [7].

On the other hand, the light exposure not only affects the temperature for microalgae, it also involves the photoperiods of microalgae. Photoperiods are the periods of the microalgae exposed to the light and it can be classified into three main groups which are long-term, frequency and short photoperiods. Long-term photoperiods encompass periods of hours, frequency photoperiods are number of cycles per day while short photoperiods are cover light/dark cycles in seconds or milliseconds. The results of the research show that *Scenedesmus obliquus* species of microalgae was able to store enough energy for the cell growth for continuous periods up to 2 hours in the dark without affecting the photosynthetic rate. Therefore, the application of knowledge of photoperiods in cultivation of microalgae can reduce the energy demand by microalgae during photosynthetic process. Thus, it is a very effective strategy in reducing costs for biomass production in condition the problem of only natural photoperiods available in real cultivation systems are overcame [8].

Furthermore, technical improvements in algae-based biofuel production have been magnified in recent years [9]. The artificial cultivation system known as photobioreactor also is the most effective technology for cultivation of microalgae, in terms of high production volume because of the improved cultured environmental conditions. However, the economic feasibility is still questionable due to the high operating cost, which makes generic engineering cultivation method a potential innovation, but the environment feasibility of this method is under heavy criticism [10]. Thus, this study aims to develop a prototype for a lab scale algae cultivation tank with better control of light emission and air flow. *Chlorella sp.* species was used to validate the ability of the prototype developed.

2. Methodology

2.1 Design and Simulation

Observation is required so that further understanding is achieved instead of by using imagination on the existing products for identifying customer needs. The customer in this study is defined as the end user of photobioreactor. Besides, the observation of existing products also exposed the working principles of photobioreactors which is important in the design stage. Besides, an interview with customer is carried out to understand and investigate the customer needs for this study. The questionnaire from interview with customer is developed based on the existing products.

The list of needs according to customer has been created for generating product specifications. Second, list of metrics is also been created to list out all the specifications that required for the design of a photobioreactor. Then, a needs-metrics matrix was created according to the list of metrics to determine

the functionality of each specifications and the necessity of considering that specifications during the design of the photobioreactor.

In concept generation stage, the concept of product is generated. During the generation of concept for product, the details of concept have been searched externally to have an exposure of the design available through literature review. Then, the concept also has been searched internally which means this stage will use the personal knowledge and creativity to generate a lot of solution concept. Screening process is performed in concept selection stage by using the concept screening matrix to screen the concept into two most promising concepts from the large amount concept generated in previous stage. Then, the last two concepts undergone the concept scoring matrix in order to select the most promising concept and the concept will be selected for further development.

For conceptual design stage, the final conceptual design of the laboratory scale for the concept of photobioreactor has been created by using the SolidWorks software. SolidWorks software also has been used to do the analysis for the assembly, interferences, clearance, 2D drawing, and exploded view of the model. Besides, the performance of the design such as simulation also been studied and performed using the SolidWorks software.

2.2 Fabrication

After the simulation is performed by using SolidWorks software, the fabrication process is carried out according to the conceptual design in software. Several tools have been used in this fabrication process such as the plastic cutter to cut the Perspex used for the design, chloroform liquid which used to glue the Perspex together and others. However, since some of the parts and components are available in them market, therefore procurement process is taken instead of fabrication process. The product which is photobioreactor is fabricated and assembled according to the conceptual design. However, only the main body of the photobioreactor is fabricated meanwhile other components or parts are bought and obtained from market and recycled from industrial wastes.

2.3 Validating stage with Chlorella sp.

The developed cultivation vessel was tested using *Chlorella sp*. The cultivation was done using MLA medium (modified algae) growth medium at pH 10. The whole photobioreactor was sterilised under UV light inside the laminar flow for 20 minutes. The vessel filled with 90% of medium mixed 10% of starting culture with a total volume of 4 litre. The air flow rate was 2.654×10^{6} m^3. The light intensity used was 2266 lux provided by LED light. Triplicate sample were collected at 24 hr interval for 10 days. The biomass concentration was then determined by measuring optical density at 680nm using spectrophotometer.

3 Results and discussion

3.1 Design and Simulation

SolidWorks software has been used to do the analysis for the assembly, interferences, clearance, 2d drawing, and exploded view of the model. Besides, the performance of the design such as simulation also been studied and performed using the SolidWorks software. There are total 24 parts in this design. However, 19 out of 24 parts are standard which able to obtain from the market. Therefore, the dimension and shape of 19 parts are modelled according to the real dimension (Figure 1)

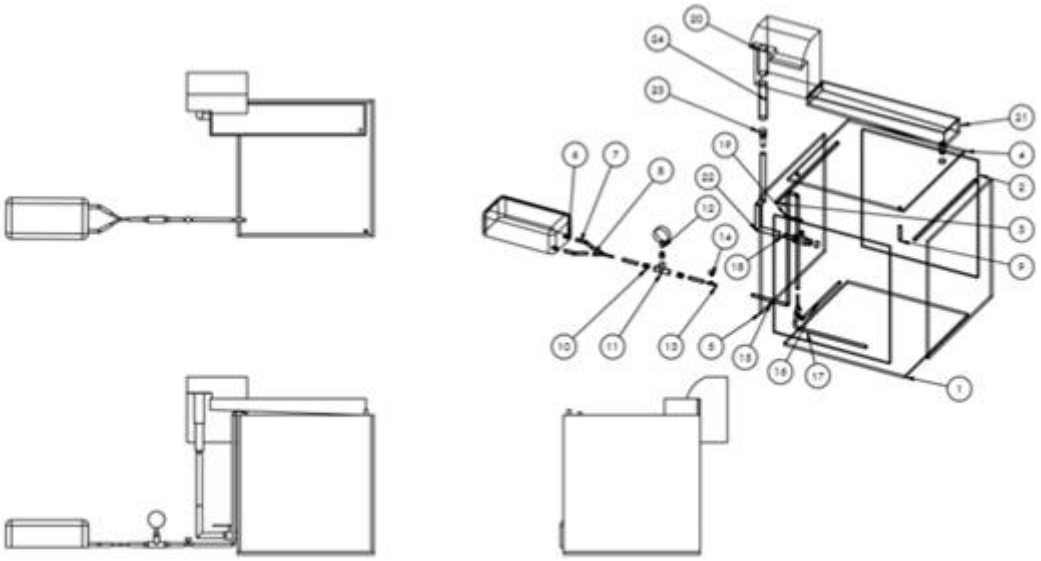
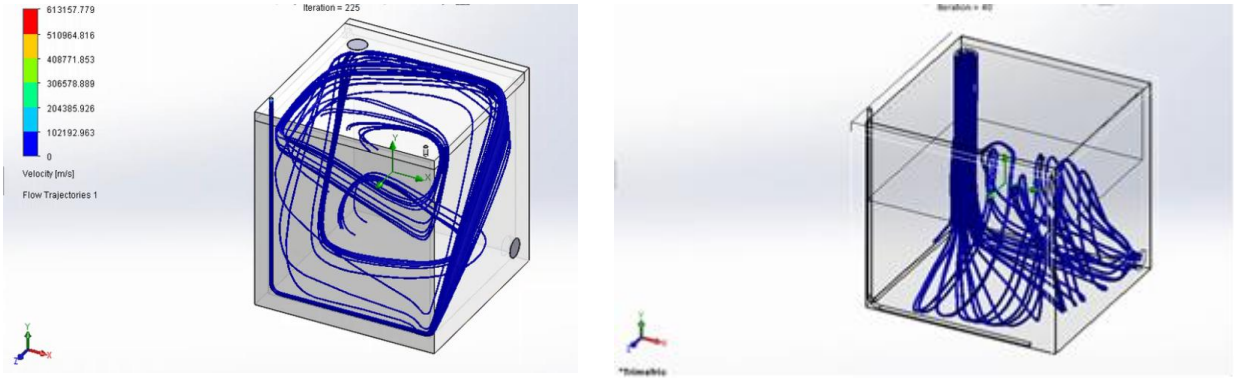


Figure 1 Drawing for final conceptual design for the tank and equipments.

During this process, the simulation of the performance of the photobioreactor is done by using some advanced simulation techniques in SolidWorks software. The simulation performed is only in the main body instead of the whole design. This is because the most important is the simulation inside the main body to show the flow inside the main body. Besides, there are two simulation that are performed for the design which one is for the air flow while another one is the water flow inside the main body (Figure 2).



(a) (b)

Figure 2: The simulation for (a) air (b) water inside the main tank of photobioreactor

3.2 Fabrication

The material used to fabricate the main body and cover is Poly (methyl methacrylate) or more known as Perspex with 5mm thickness. Perspex is selected as the fabrication material for the product because it is transparent, and it is an important feature for cultivation of microalgae since the product need to allow light to penetrate into the main body. The 5mm thickness of Perspex sheet is used to ensure the main body is able to withstand the pressure when there is water inside and also the pressure cause by the cultivation of microalgae. After the fabrication of the main body and the procurement of components, the photobioreactor is assembled and tested the functionality as shown in Figure 3.

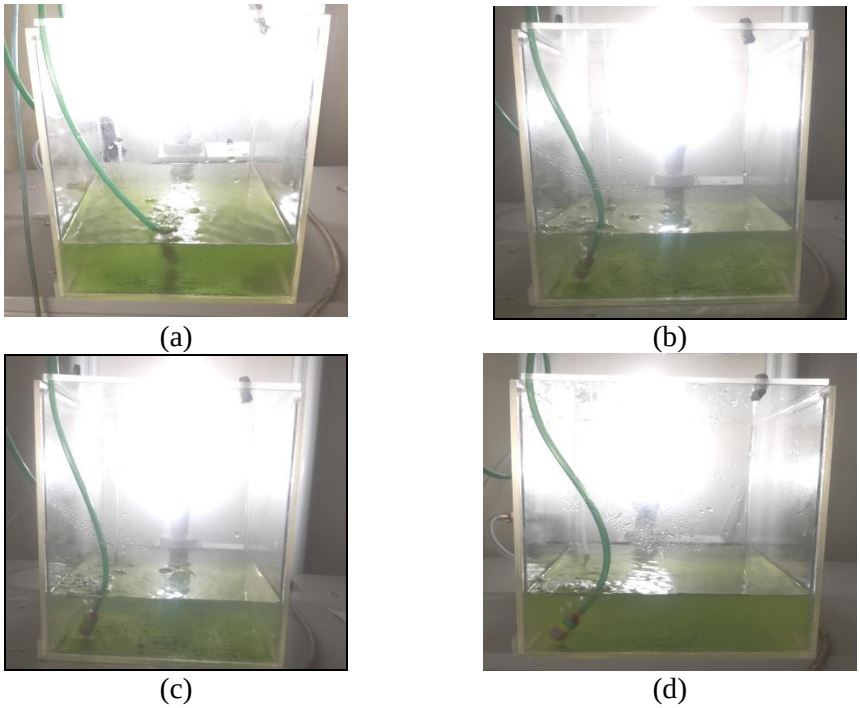


Figure 3: Cultivation of *Chlorella sp.* (a)3rd day (b) 4th day (c) 6th day (d) 9th day

3.3. Experimental analysis

In Figure 4, the growth of *Chlorella sp.* increases only until 5th day and it shows drastic decrease on 6th day. But the growth slightly increase from 7th to 10th day. Besides flocs were noticed starting from the third day in the photobioreactor. This maybe due to an excess of nutrients particularly phosphorus and nitrogen and higher concentrations of these nutrients in water cause increased growth of microalgae in the early stage of cultivation. Thus, from the it can be observed that the concentration increases rapidly from day 0 to day 1. But, the growth microalgae started to decrease from 5th day. The nutrients inside the photobioreactor is depleted as it was consumed by the rapid growing cells. At higher cell concentrations, the light intensity must be passable to penetrate through the culture. However the light intensity used for the experiment is not sufficient for the algae growth. But, too high light intensity may result in photo-inhibition and overheating environment. Thus, optimum light intensity study is required for better cell growth.

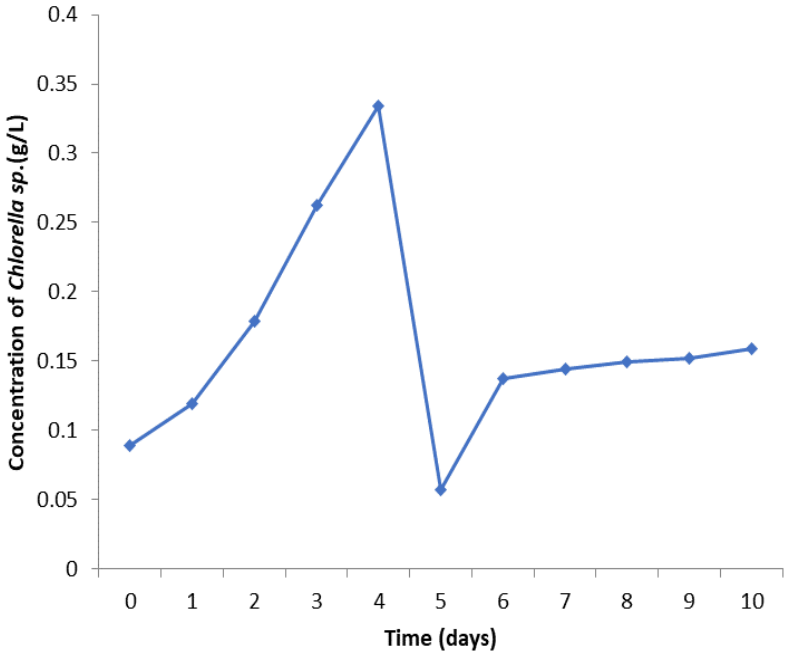


Figure 4 Concentration of *Chlorella sp.* vs time.

3.4 Comparison new photobioreactor with existing photobioreactor

According to the observation and interview session, the existing photobioreactor is only using a simple conical flask to perform the cultivation of microalgae. The existing approach was not easy to adjust light intensity because the lighting system used is a normal fluorescent bulb without a controller. Besides, the air flow rate entering the vessel is not able to accurately adjust because the vessel was not equipped with any meter or sensor to detect the air flow rate.

Therefore, the design photobioreactor provide more advantages and functions over the existing approach. The photobioreactor equipped with the pressure gauge and air flow controller to provide accurate control for air flow rates. Besides, the new photobioreactor also equipped with the lighting system that has adjustable light intensity function. The lighting system allows the changing or adjusting of light intensity with a simple switch.

4 Conclusion

The present study has been done in order to improve the design of existing photobioreactor in order to have the controllability of certain parameters (light and air/water flowrate) and improve the efficiency of photobioreactor. The new photobioreactor designed has the adjustable light intensity which is important for cultivating different species of microalgae. In addition, the photobioreactor also equipped with the accurate controllable air flow rate which allows the concentration of air/gas injected into the medium of microalgae is adjustable in order to produce optimal productivity.

5 Acknowledgement

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