Design and development of centred-light photobioreactor for microalgae cultivation system

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Abstract. The cultivation of microalgae within a controlled condition allows the production of biomass with lower contamination and suitable for high value pharmaceutical products. The controlled environment for microalgae growing can be accomplished by utilizing photobioreactor as a platform for introducing the basic needs needed by microalgae to grow effectively. However, due to some problems of high cost, low illumination and complicated cultivation systems which referring to available photobioreactors had contributed to low biomass production. This study deals with designing a new lab scale photobioreactor for overcoming the problems contributed by the available photobioreactors. During the developing process of the photobioreactor, the user needs are identified, and the most suitable concept based on the user needs was generated. The concept was then fabricated to prototype and its performance was validated. A centred-light photobioreactor was successfully developed for lab scale usage and being tested by cultivating *Chlorella vulgaris* species. A maximum of 0.281 g/L cell concentration was achieved using white light source during cultivation of *Chlorella vulgaris*.

1. Introduction

Microalgae can be grown in the two types of systems which are either open systems, such as raceway ponds or closed systems, such as photobioreactors [1]. A closed equipment which utilizing closed system is called as photobioreactor is useful for providing a controlled environment which able for enabling the high productivity of microalgae [2]. There are various commercial applications for microalgae nowadays which are enhancing the nutritional value of animal feed and human food, helping in aquaculture and improving cosmetics production [3]. In an open system, the growing of microalgae is highly potential to be exposed to contamination. These conditions occurred because the environment for microalgae growing cannot be controlled as in closed systems.

Recently, various types of photobioreactors have been designed and developed for production of algae. Photobioreactors can be placed indoor or outdoor. Indoor photobioreactor usually having lab scale size which is smaller than outdoor photobioreactor and suitable to be used by researches.

Outdoor photobioreactors are suitable for large scale production of microalgae and mostly used by industries. There are few standard designs of photobioreactors that can be used as a foundation for further improvisations which are categorized as flat plate reactors, annular reactors and tubular reactors [2,4]. Annular reactor usually acts as bubble column which the inner cylinder is empty to increase the surface to volume (S/V) ratio and to avoid any dark parts [4]. Among these reactors, tubular reactors which having transparent tubes are more preferable and commonly used in photobioreactors design. There are big numbers of closed photobioreactors designed are made by using tubular reactor [4]. In designing the tubular reactors, the choice of the tube diameter is becoming an important decision for getting the optimal design of the photobioreactors. The choice of tube diameter affects the surface to S/V ratio which resulting the light uptake of the culture [5].

There are quite a number of lab scale photobioreactors that have been in the market but most of the available photobioreactors are having a high cost, low illumination surface area and complicated algae harvesting systems. Photobioreactor systems allow for better control of the algae culture environment but the systems tend to be more expensive than the raceway ponds [6]. Chun-Yen et al. [7], argue that although many efforts have been made to develop an efficient and cost-effective of photobioreactor, however, the high cost of installing and operating artificial light sources in conventional photobioreactors with artificial illumination systems remains a major problem. Mass production of microalgae oil faces a number of technical problems that render the current development of the algae industry economically unfit [7]. In addition, it is also necessary but very difficult, to develop cost-effective technologies that would permit efficient biomass harvesting and oil extraction [7]. Thus, these limitations in available photobioreactors must be eliminated to exploit the potential in algae industries.

The study consists of designing a lab scale photobioreactor that is simple and reliable to overcome the limitations of high cost, low illumination surface area and complicated algae drainage system in available photobioreactors for microalgae growing. The photobioreactor should have minimum parts as to reduce the cost. Moreover, the photobioreactor should allow high penetration of light to cultivation medium as to increase the illumination. In order to allow the high productivity of algae, sufficient amount of CO_2 and light supplied should also be considered in designing the new photobioreactor.

2. Methodology

2.1 Design of cultivation system

A lab scale of photobioreactor which suitable to be used for microalgae is developed based on demands from a user in an Alpha Institution. The demands from customer then being translated to the desired specifications for the lab scale photobioreactor. From the specifications, several concepts are generated and the best concept was chosen to develop as a final product. Computer Aided Design, CAD model or 3D model for the chosen concept was then created by using SolidWorks software. The model was produced in order to give more understanding about concept. The chosen concept which has problems was modified for improvements and the CAD model for the concept which has been improved was then created. Moreover, the prototype of developed photobioreactor consisted of several parts, some parts are fabricated with some parts are standard. Once the prototype is completed, the performance for the photobioreactor was studied. The flowchart for this study is shown in Figure 1.

2.2 Fabrication of cultivation system

The materials needed for fabricating parts in cultivation system are prepared as in Table 1. The process for fabrication is begun by making holes. Holes as markers with diameter of 5 mm are made on the lids and tanks of cultivation followed by the holes with respective required diameters (12.5 mm, 13 mm, 16.5 mm, 15 mm and 21 mm) by using bench drilling machine with rotation of 340 rev/min. The lids, transparent pipes, ball valves, tank nipples, clippers, rubber washers,

nozzles and tank connectors are then assembled to the cultivation tanks. There are 3 units of cultivation tanks and each tank contains 1 unit lid, 2 units (260 mm length, 22 mm outer diameter and 19 mm inner diameter) transparent pipes, 1 unit ball valve, 1 unit tank nipple, 2 units clippers, 6 units rubber washers, 1 unit nozzle and 2 units tank connectors. Sealing tape is used if there is any leakage to the tanks.

For the upper base, the fabrication processes are begun by cutting the 15 mm width × 15 mm height square mild steel tube to the lengths of 180 mm (2 units), 405 mm (2 units) and 150 mm (4 units) by using hacksaw. Angles of 45^{o} are made at the one ends of the 150 mm length (4 units) and both ends of 80 mm length (2 units) of the square mild steel tube by using hacksaw. A mild steel plate with the dimension of 37 mm width × 3 mm thickness is cut by using shear cutter machine to 575 mm length (3 units). Then, the mild steel plates are bent to the shape of oblong. Another 2 units of mild steel plate with the dimension of 175 mm length × 17 mm width × 1.2 mm thickness are prepared by using shear cutter machine and 2 holes with diameter of 6 mm are made on the plates by using bench drilling machine. The oblong shapes, plates and the prepared square mild steel tubes are assembled together by using metal inert gases, MIG welding to form a part called upper base. In order to remove the excessive weld material formed on the parts, hand grinder is used.

Table 1 Materials needed for fabricating photobioreactor system.

Parts	Materials and descriptions
Lids (3 units)	• Made from polypropylene plastic • Diameter for holes: - 12.5 mm (1 hole) - 21 mm (2 holes) - 16.5 mm (1 hole)
Cultivation tanks (3 units)	• Made from polypropylene plastic • Diameter for holes: - 15 mm (2 holes) - 13 mm (1 hole) • Standard parts used: - 22 mm outer diameter and 19 mm inner diameter of transparent pipes (6 units of 260 mm length) - Ball valves (3 units) - Tank nipples (3 units) - Clippers (6 units) - Rubber washes (9 units) - Nozzles (3 units) - Tank connectors (6 units) - Sealing tapes
Upper base (1 unit)	• 15 mm width × 15 mm height of square mild steel tube - 180 mm length (2 units) - 405 mm length (2 units) - 150 mm length (4 units) • 37 mm width × 3 mm thickness of mild steel plate - 575 mm length (3 units) • 17 mm width × 1.2 mm thickness - 175 mm length (2 units)

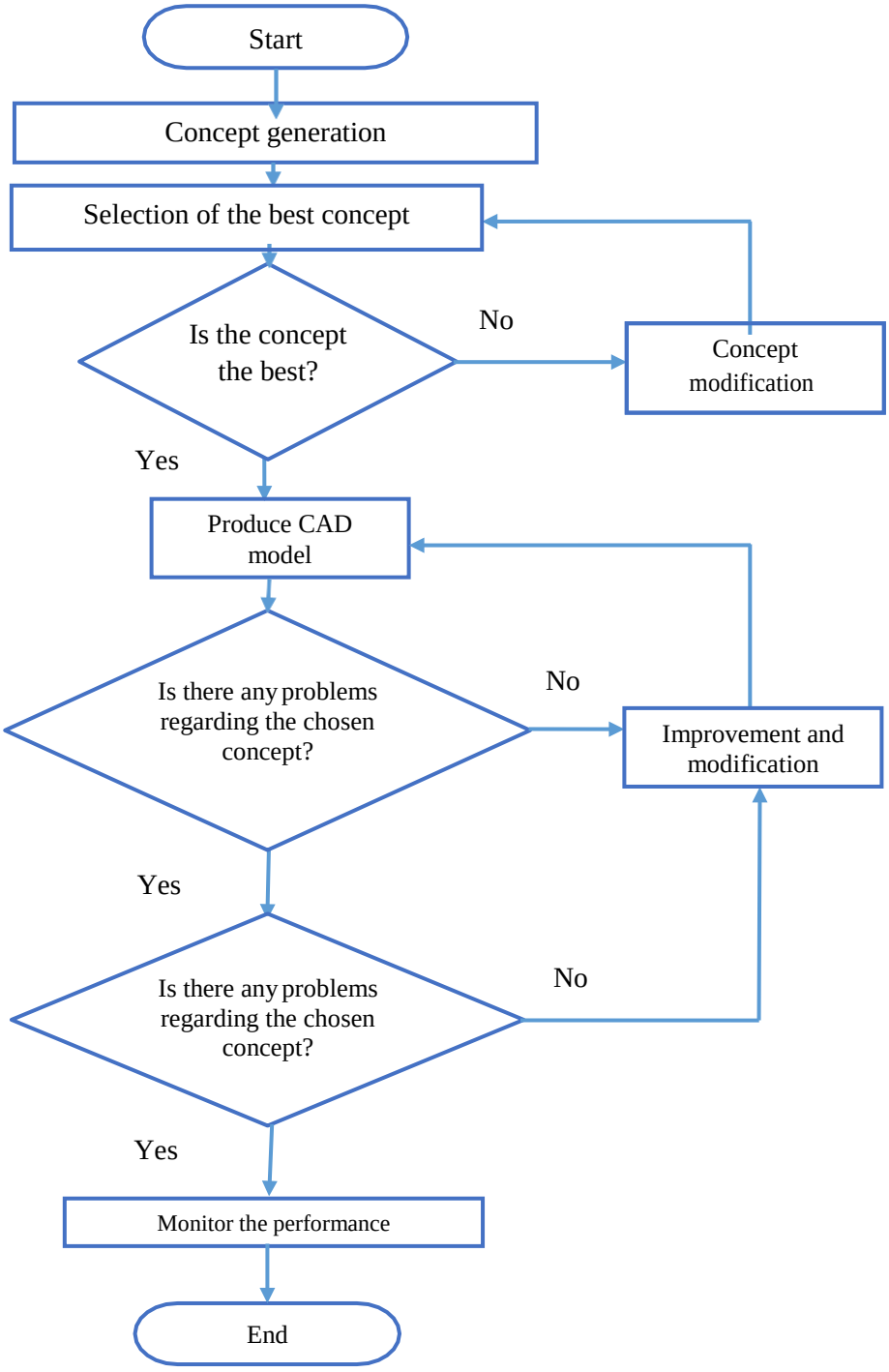


Figure 1 Flowchart for developing a new lab scale of photobioreactor.

2.3 Performance monitoring stage or testing

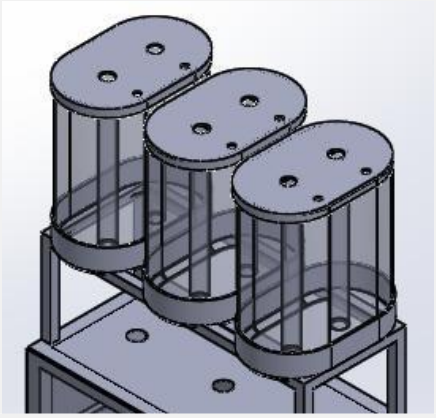
The performance of developed prototype for the centred-light photobioreactor was investigated using *Chlorella vulgaris*. The cultivation of *Chlorella vulgaris* was done using MLA medium (modified algae) growth medium [8] at pH 10.5. The vessel filled with 3.6 litre of medium mixed 400ml of microalgae (starting culture) was added to start the process. Two type of light source was used; white color and red color light were set to 3000 lux. Triplicate sample were collected at 24hour interval for 12 days. The biomass concentration was then determined by measuring optical density at 680nm using spectrophotometer.

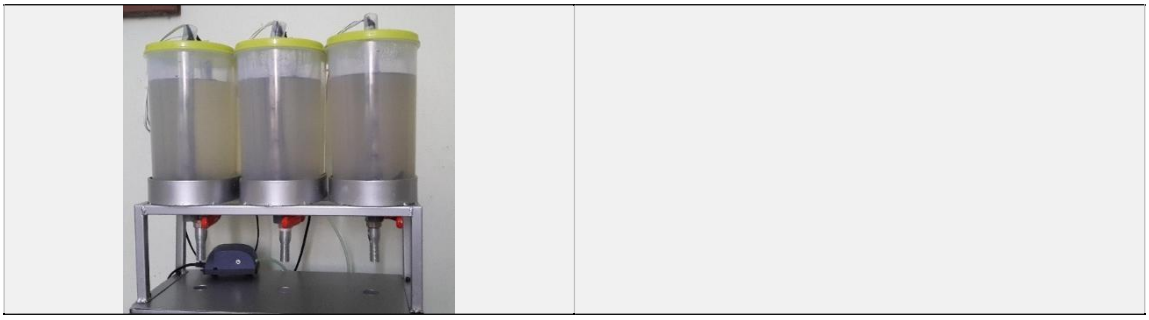
3. Results and discussion

3.1 Prototype of lab scale photobioreactor

Table 2 shows the final concept which has been chosen to develop the prototype. It provides more advantages if compared to conventional method using shake flask or 5.0 litre mineral bottle setup. A 13500 ml photobioreactor (each tank has volume of 4500 ml) consists of cultivation system (Table 2) is developed and fabricated. The overall dimension of the photobioreactor is 440 mm length × 230 mm width × 740 mm height. The parts in cultivation system are attached by screws to parts in drainage port and they can be removed for convenience. Light-emitting diodes (LED) lights are standard parts which have red colour of lights. The air pump is also one of the standard parts used which has flow rate of 3000 ml/min. Only one air pump is used in the photobioreactor and all the tanks need to share. Thus, each tank will have 1000 ml/min. The illumination system that used centre-lighting was integrated within the system to have a wider range of light emission in the reactor (0- 2000 lux) and can be easily change with different type of colours (red and white). Vo et al (2019) stated illumination patterns and different source of light can be attractive solutions to increase biomass yield in photobioreactor design [9].

Table 2: Cultivation system.

Cultivation system	Function
 The final concept that has been chosen to develop to prototype.	The function for cultivation system is to be a vessel for growing microalgae. The basic needs required by microalgae are introduced in this system. **Problems solved:** • Advantages 1: One of the main advantages is to prevent from water blockage at the cultivation tanks since ball valves and nozzles are used to transfer water and microalgae from cultivation tanks via drainage port. • Advantages 2: Another main advantage is that the working volume is higher compared to previous concepts and thus allows for high productivity of algae. • Advantages 3: The tanks are separated to each tank and has a working volume of 4500 ml. It is because to avoid contamination. If one of the tanks has been contaminated, it will not affect another tank. Thus, operating cost can be reduced.



3.2 Cultivation of Chlorella vulgaris in prototype photobioreactor

The effect of white light and red light were tested on the microalgae growth. Figure 2 shows the effect of microalgae growth using different light colors on *Chlorella vulgaris*. The white light gave higher cell concentration, 0.281 g/L compared to red light cultivation, 0.197 g/L which is 1.42 times higher. However, according to previous study by Rai and co-workers (2015) red light give higher cell concentration if compared to white light [10]. The result might vary due to different type of light source (LEDs) and positioning of the light source. Too much light can damage the microalgae or inhibit the growth.

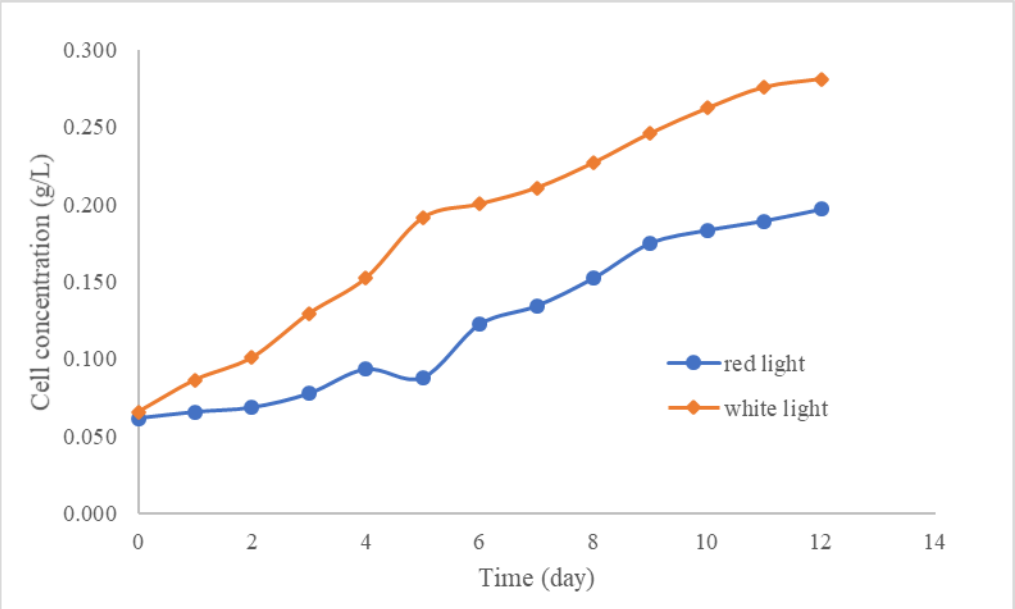


Figure 2: *Chlorella vulgaris* growth in prototype photobioreactor using 2 different light sources.

4. Conclusion

The development of new design of photobioreactor has been successfully executed especially for the cultivation system. Even the designed photobioreactor is not fully overcome the problems faced by the end user such as in-situ sterilization and fully automated controller, but it still provides the user with easy drainage port, better light illumination and bigger operating volume for higher productivity with minimum space required. The photobioreactor also shows a growth of *Chlorella vulgaris* cultivation in 12 days.

5. References

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6. Acknowledgements

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