DESIGN, CONSTRUCTION AND COMMISSIONING OF PHOTOBIOREACTOR FOR PRODUCTION OF MICROALGAE FOR BIODIESEL

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"I hereby declare that I have read this project report and in my opinion this project report is sufficient in terms of scope and quality for the award of the bachelor degree of Chemical Engineering (Biotechnology)"

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A project report submitted in partial fulfillment of the requirements for the award of the Bachelor degree of Chemical Engineering (Biotechnology)

Faculty of Chemical and Natural Resources Engineering
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"I hereby declare that this thesis entitled "Design, Construction and Commissioning of photobioreactor for production of microalgae for biodiesel" is the result of my own research except as cited references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree".

Signature : .....
Name : NUR ATTEYA BINTI AIDILFITRI
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Special Dedication to:

My mom, Puan Fatimah Binti Ahmad,
My dad, Encik Haji Aidil Fitri Bin Haji Othman,
My family members,
My fellow lecturers,
My friends and
My fellow colleagues.

For all your care, support and belief in me.

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ABSTRACT

Oil can potentially be produced by microalgae which then can be converted into biodiesel. The objective of this research is to design, construct and commission a solar receiver which is the part of the photobioreactor which will enable the operator to monitor and control mixing and the level of dissolved CO_2 in the medium and as well expose it to sunlight for the microalgae to undergo photosynthesis. The construction consist of two stages namely the first stage on the construction of the vertical airlift photobioreactor which will provide the flow, and the second stage on the construction of the horizontal solar receiver photobioreactor which will enable the microalgae to tap on the sunlight for photosynthesis. The work in this thesis only focused on the second stage. For the second stage, the most important objective is that the flow is turbulent. We can manipulate it by varying the flow rate of air sparged through the airlift bioreactor. There were three steps that have been done to complete this research which is the design, construction and commissioning processes. The design of photobioreactor has been used to construct the solar receiver and the support structure of the solar receiver. For the commissioning process, black dye has been used to determine the pattern of the flow in the solar receiver. Initially, the pressure of the sparging air used is 4, 8, 12, 16 and 20 psi respectively. For the 4 psi, the flow of the dye is slow and it dispersed in the water too slowly. For the pressure 8 and 12 psi, both the flow is moderate. For the 8 psi, the dye dispersed slowly while for the 12 psi the dye dispersed quickly. At 16 psi, the flow was fast and the dye dispersed immediately. At 20 psi, it took the shortest time to complete the cycle but there was overflow in the degassing zone. Thus, the best pressure that can be used to complete the cycle with the shortest time is at 16 psi which is equal to 110.32 kPa and the flow is turbulent. All the research objectives have been achieved.

ABSTRAK

Mikroalga berpotensi untuk menghasilkan minyak dan boleh ditukar menjadi biodiesel. Tujuan kajian ini dijalankan adalah untuk merancang, membina dan menguji penerima suria yang merupakan sebahagian daripada fotobioreaktor yang akan membolehkan operator untuk memantau dan mengawal pencampuran dan tahap CO_2 terlarut dalam media dan juga membenarkan sinar matahari menembusi reactor untuk mikroalga menjalani fotosintesis. Pembinaan terdiri dari dua tahap iaitu tahap pertama pada pembangunan penaik udara menegak akan memberikan aliran, dan tahap kedua pada pembangunan fotobioreaktor penerima horizontal suria yang akan membolehkan mikroalga untuk menerima sinar matahari untuk fotosintesis. Kajian dalam tesis ini tertumpu pada tahap kedua. Untuk tahap kedua, tujuan yang paling penting adalah menghasilkan aliran yang.bergelora. Kita dapat memanipulasinya dengan memvariasikan kelajuan aliran udara melalui bioreaktor penaik udara. Ada tiga langkah yang telah dilakukan untuk menyelesaikan kajian ini iaitu rekaan, pembinaan dan proses menguji. Design fotobioreaktor telah digunakan untuk membina penerima suria dan struktur sokongan untuk penerima suria. Untuk proses komisioning, pewarna hitam telah digunakan untuk menentukan pola aliran dalam penerima suria. Awalnya, tekanan udara Sparging digunakan adalah 4, 8, 12, 16 dan 20 psi masing-masing. Untuk 4 psi, aliran pewarna lambat dan terdispersi dalam air terlalu lambat.Waktu yang diperlukan untuk menyelesaikan kitaran itu ialah 474 saat. Untuk tekanan 8, 12, 16 dan 20 psi, masa yang diambil ialah 210, 165, 140 dan 119 saat. Dengan demikian, tekanan terbaik yang boleh digunakan untuk melengkapkan kitaran dengan waktu terpendek ialah 16 psi yang sama dengan 110,32 kPa Dengan ini, semua tujuan kajian telah dicapai.

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LIST OF SYMBOLS/ABBREVIATION

A_r	Cross sectional area of riser,	m^2
A_d	Cross sectional area of downcomer,	m^2
C_f	Fanning friction factor	
g	Gravitational acceleration,	$m\ s^{-1}$
h_r	Height of riser,	m
K_B	Frictional loss coefficient for the bottom zone of the airlift	
K_T	Frictional loss coefficient for the top of the airlift	
L_{eq}	Equivalent length of solar loop,	m
PBR	Photobioreactor	
U_L	Superficial liquid velocity in the tube,	$m\ s^{-1}$
ε_r	Gas holdup in the riser	
ε_d	Gas holdup in the downcomer	
μ_L	Viscosity of the culture broth,	$kg\ m^{-1}.s^{-1}$
ρ	Density of the fluid,	$kg\ m^{-3}$
∅	Solar tube diameter,	m

CHAPTER 1

INTRODUCTION

1.1 Research Background

Biofuels from microalgae have a great potential to meet future challenges of carbon dioxide neutral energy supply and storage. The climate change and shortage of resources call for a substantial change of global power supply from fossil to regenerative energy sources. For electricity generation, powerful techniques such as wind, photovoltaic or geothermal energy exist already today. However, currently, electricity accounts only for a minor fraction of the global energy demand. Two thirds of the world's final energy consumption is covered by oil, coal and gas (IEA 2009)

Microalgae are one of the groups of photosynthetic, heterotrophic organisms which have an extraordinary potential for cultivation as energy crops. They can be cultivated under difficult agro climatic conditions and are able to produce a wide range of commercially interesting by products such as fats, oils, sugars and functional bioactive compounds. As a group, they are of particular interest in the development of future renewable energy scenarios. Certain microalgae are effective in the production of hydrogen and oxygen through the process of bio-photolysis while others naturally manufacture hydrocarbon which are suitable for direct use as high energy liquid fuels.

A photobioreactor is a bioreactor which incorporates some types of light source to provide photonic energy input into the reactor. Photobioreactor also has been used widely in culturing microalgae. An open pond also could be seen as photobioreactor but mostly the term photobioreactor only refers to closed system. System closed to the environment having no direct exchange of gases and contaminants with the environment. In this research, we will study the effect of airlift system height and the mixing of microalgae.

In an optimal system where no other factors limit, the light availability determines the rate of photosynthesis and productivity. However, excessive light can be harmful and is known to produce a photo inhibitory response (Bannister, 1979; Aiba, 1982).We will also need to design an effective CO2 sparger so that we can monitor and study the optimum carbon dioxide supply for microalgae's growth. The effect of this study will help to make an upscale design of photobioreactors that will save amount of space of lands or ponds.

1.2 Problem Statement

Nowadays, there are many water pollution occurred in Malaysia. Poor sewage treatment has been blamed as being one of the causes of corals slowly dying in the sea off the east coast of peninsular Malaysia, as algae was found to have smothered some reef, indicating nutrient pollution. Thus, to overcome the problem, photobioreactor was designed to produce the optimum growth of the microalgae itself. For the optimum growth of the microalgae several parameter has to be manipulated, that is:

a) Pressure of air sparged from the air compressor.
b) Turbulent flow in the solar receiver part to mix the microalgae.

1.3 Research Objectives

The objectives of the research are to:

a) Design and construct the photobioreactor for the production of microalgae
b) Commissioning and testing the photobioreactor by manipulating the pressure of air sparged through the airlift sytem to create the turbulent flow.

1.4 Scope of Research

The scope of the research is to achieve the research objectives. The construction and commissioning process of the photobioreactor have been done in Engineering Workshop FKKSA UMP. For this research, the scopes of study are:

a) Photobioreactor design
b) Manipulated variable
    i) Mixing
    ii) Pressure of air sparged.
c) Relationship between the PBR design and manipulated variable.

CHAPTER 2

LITERATURE REVIEW

2.1 Photobioreactor Design

2.1.1 Tubular Solar Receiver

Tubular photobioreactors that circulate the culture by using an airlift device are especially attractive for several reasons: circulation is achieved without moving parts and this provides a robust culture system with a reduced potential for contamination (Chisti,1989); the cell damage associated with mechanical pumping is avoided (Chisti,1999;Vandanjon et al.,1999); and the airlift device combines the function of a pump and a gas exchanger that removes the oxygen produced by photosynthesis (Camacho Rubio et al.,1999). Continuous removal of oxygen is essential, as excessive dissolved oxygen in the broth inhibits photosynthesis.

Unlike open raceways, photobioreactors permit essentially single-species culture of microalgae for prolonged durations. Photobioreactors have been successfully used for producing large quantities of microalgal biomass (Molina Grima et al., 1999; Tredici, 1999; Pulz, 2001; Carvalho et al., 2006). A tubular photobioreactor consists of straight transparent tubes that are usually made of plastic or glass. This tubular array, or the solar collector,is where the sunlight is captured The solar collector tubes are generally 0.1m or less in diameter. Tube diameter is limited because light does not penetrate too deeply in the dense culture broth that is necessary for ensuring a high biomass productivity of

the photobioreactor. The solar collector is oriented to maximize sunlight capture (Molina Grima et al., 1999; Sánchez Mirón et al., 1999). In addition, the design must ensure that the flow in the solar tube is turbulent (i.e. the minimum Reynolds number should exceed 3000) so that the cells do not stagnate in the dark interior of the tube. At the same time, the dimensions of the fluid microeddies should always exceed those of the algal cells. So that turbulence associated damage is prevented.

For maximizing the biomass productivity, the irradiance on the surface of the solar tubes must be maximized. This external surface irradiance depends mainly on the solar irradiance, which is a function of the location and the weather conditions (Incropera and Thomas, 1978). For a given location and weather, the geometric arrangement of the solar receiver tubes also determines the irradiance on the surface of the tubes and so does the albedo effect (irradiance enhancement because of reflectance) of the surrounding. The geometric distribution of the tube over a given land surface controls the extent of mutual shading.

To know the flow is turbulent or not, there is the equation which is the equation to calculate the Reynolds number, Re. The Reynolds number, Re can be calculated as follows:

$$Re = \frac{\rho U_L \phi}{\mu_L}. \tag{1}$$

Where U_L is the velocity of the liquid in the tubes, ρ is the fluid's density, $\emptyset$ is the diameter of the tube and the $\mu_L$is the viscosity of the fluid.

The liquid flow in the solar receiver is driven by the airlift pump. For water- like fluid such as the microalgal broth, the induced flow velocity depends mainly on the geometric configuration of the circulation loop and the differences in gas hold up in the riser and the downcomer zones of the airlift column. This relationship has been established (Chisti, 1989) to be:

$$U_L = \sqrt{\frac{2g(\varepsilon_r - \varepsilon_d)h_r}{K_T/(1-\varepsilon_r)^2 + K_B(A_r/A_d)^2 1/(1-\varepsilon_d)^2}}, \tag{2}$$

where the K_T and K_B are the frictional loss coefficient for the top and the bottom connecting sections respectively of the airlift loop. Eq (2) is based on principles of energy conservation and it has been repeatedly validated for a broad range of scales and configurations of airlift devices (Chisti, 1989). In eq (2) h_r is the height of the riser section, A_r and A_d are the cross-sectional areas of the riser and downcomer, ε_r is the gas holdup in the riser and ε_d is the holdup in the downcomer. Generally, K_T is much smaller than K_B, hence K_T can be neglected. (Chisti, 1989). This is particularly true of the loop configuration used for photobioreactor. Because of the bottom section of the loop is simply continuous pipe(the solar receiver), the frictional loss coefficient K_B can be approximated as

$$K_B = 4C_f \frac{L_{eq}}{\phi}, \tag{3}$$

where C_f the fanning factor established with Blasius equation (eq 4) and L_{eq} is the equivalent length of the loop. The latter is the straight tube length L plus additional length that provides the same pressure drop as the bends and valves in the loop combined.

$$C_f = 0.0791\ Re^{-0.25} \tag{4}$$

In addition, the photobioreactor geometry must maximize capture of sunlight while minimizing the land surface occupied (Molina et al., 2001). Effects of tube length, flow velocity, the airlift column height, and the geometric configuration of the solar receiver on various performance parameters have been discussed. Figure 2.1 shows the example of microalgae photobioreactor that consists of airlift and its solar collector.

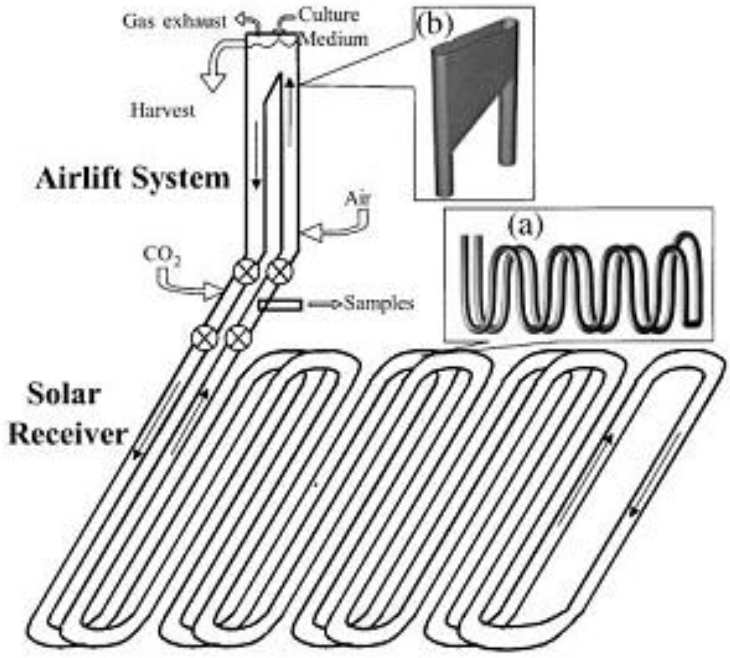

Figure 2.1: Example of photobioreactor

Photobioreactor tubes operated with high-density culture for attaining high productivity inevitably contain a photo limited central dark zone and a relatively better lit peripheral zone (Molina Grima et al., 1999, 2001). Light intensity in the photo limited zone is lower than the saturation light level.

2.1.2 Airlift system

In an airlift driven tubular photobioreactor, the recirculation velocity of the culture and oxygen removal characteristics are closely linked. The culture performance is critically dependent on attaining an optimal design that provides the requisite flow and gas exchange. The airlift column circulates the culture through the solar collector tubing where most of the photosynthesis occurs. The oxygen produced by photosynthesis accumulates in the broth until the fluid returns to the airlift zone where the accumulated oxygen is stripped by air. A gas–liquid separator in the upper part of the airlift column prevents gas bubbles from recirculating into the solar collector. The solar loop is designed to efficiently collect the solar radiation, minimize resistance to flow, and occupy minimal area to reduce the demand for land. In addition, the diameter of the solar tubing is selected so that the volume of the dark zone (i.e. one with light intensity below saturation) is kept to a minimum. Also, the interchange of fluid between the light and the dark zones in the solar loop must be sufficiently rapid that element of fluid does not reside continuously in the dark zone for long (Ogbanna and Tanaka, 1997).

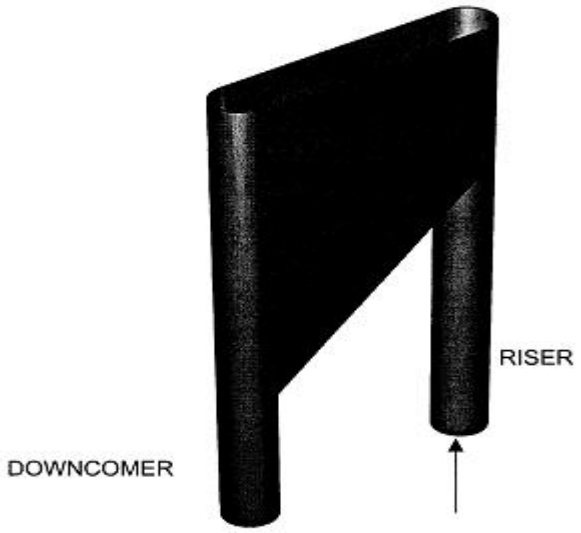

Figure 2.2: The gas liquid separator

The head zone of the airlift column (Figure 2.2) was designed for almost complete separation of the gas from the liquid, before the broth recirculated into the solar collector. Complete disengagement of gas meant that the driving force for liquid circulation was the maximum attainable for any aeration rate in the airlift riser. To achieve effective separation of gas and liquid, the distance between the entrance and the exit of the degasser should be such that the smallest bubbles have a sufficient time to disengage before the fluid enters the down comer (Chisti and Moo-Young, 1993).

The airlift device fulfills two needs: the circulation of the fluid through the solar loop and stripping of oxygen from the broth. The volume of the broth in the airlift device needs to be small compared to the volume in the solar loop so that the cells spend as much time as possible in the relatively better illuminated loop. In this work, the riser and down comer tubes of the airlift device were vertical extensions of the ends of the solar loop. The volume in the gas liquid separator was minimized by reducing the spacing between the parallel walls to the width of the riser (or the down comer) tube (Fig.2.2).

An efficient large scale PBR has yet to be developed [Ogbanna and Tanaka, 1997]. This has left commercial production of algae to open ponds. Open ponds do not provide conditions necessary for high density algal biomass production because of diurnal and annual variation in light intensity and temperature. Chen (1996) states that enclosed PBRs have the following advantages over open pond production.

1. Better control of algal culture
2. Large surface-to-volume ratio
3. Better control of gas transfer
4. Reduction in evaporation of growth medium
5. More uniform temperature
6. Better protection from outside contamination
7. Higher algal cell densities are possible.

2.2 Requirement for microalgae growth

2.2.1 Light source and Carbon dioxide

Availability and intensity of light are the major factors controlling productivity of photosynthetic cultures (Lee and Low, 1992; Pulz and Scheinben-bogen, 1998). Photosynthesis is a process comprising two steps, light reactions that only occur when the cells are illuminated, and carbon fixation reactions, also known as dark reactions, that occur both in the presence and absence of light. Thus in the first step the cells transform light energy into chemical energy, which is stored in high-energy compounds for later use in the carbon-fixation reactions (Iverson, 2006). The use of these photosynthetic pathways in environmental engineering processes requires the use of solar energy so as to develop clean technology processes (Essam et al., 2007). Thus the cells use the light energy by way of exergonic reactions, producing energy that is used in the synthesis of compounds as from carbon dioxide fixation by way of endergonic reactions (Horton et al., 1994).

In photosynthetic cultures, the amount of light energy received and stored by the cells has a direct relationship with the carbon fixation capacity, consequently determining the productivity in biomass and cell growth rate. In nature, light energy is available in a discontinuous way, since the light varies from day to night. Such considerations are relevant in carbon sequestration processes in photobioreactors, since the viability of these systems requires the use of solar energy for photosynthesis.

Carbon dioxide is the usual carbon source for photosynthetic culture of microalgae. Carbon dioxide is typically supplied by continuous or intermittent injection of the gas at the beginning of a tubular solar receiver. As the carbon is consumed, oxygen is ultimately produced by photolysis of water. The generated oxygen is released into the culture fluid. The fluid in a tubular solar receiver in plug flow; hence, the concentration of carbon dioxide reflected in the culture pH changes (Livansky and Bartos, 1986) along the tube and so does the concentration of oxygen (Weissman et al., 1988).

2.3 Comparison of photobioreactor and raceways

There is the comparison between photobioreactor and the raceways. The table 2.1 below shows that the comparison of both of it.

Table 2.1: Comparison of photobioreactor and raceways methods

Comparison of photobioreactor and raceway production methods

Variable	Photobioreactor facility	Raceway ponds
Annual biomass production (kg)	100,000	100,000
Volumetric productivity (kg m^{-3} d^{-1})	1.535	0.117
Areal productivity (kg m^{-2} d^{-1})	0.048[a] 0.072[c]	0.035[b]
Biomass concentration in broth (kg m^{-3})	4.00	0.14
Dilution rate (d^{-1})	0.384	0.250
Area needed (m^2)	5681	7828
Oil yield (m^3 ha^{-1})	136.9[d] 58.7[e]	99.4[d] 42.6[e]
Annual CO_2 consumption (kg)	183,333	183,333
System geometry	132 parallel tubes/unit; 80 m long tubes; 0.06 m tube diameter	978 m^2/pond; 12 m wide, 82 m long, 0.30 m deep
Number of units	6	8

[a] Based on facility area.
[b] Based on actual pond area.
[c] Based on projected area of photobioreactor tubes.
[d] Based on 70% by wt oil in biomass.
[e] Based on 30% by wt oil in biomass.

This comparison is for an annual production level of 100t of biomass in both cases. Both production methods consume an identical amount of carbon dioxide (Table 2.1), if losses to atmosphere are disregarded. The production methods in Table 2.1 are compared for optimal combinations of biomass productivity and concentration that have been actually achieved in large-scale photobioreactors and raceways. Photobioreactors provide much greater oil yield per hectare compared with raceway ponds (Table 2.1). This is because the volumetric biomass productivity of photo-bioreactors is more than 13 fold greater in comparison with raceway ponds (Table 2.1).

Both raceway and photobioreactor production methods are technically feasible. Production facilities using photobioreactors and raceway units of dimensions similar to those in (Table 2.1) have indeed been used extensively in commercial operations (Terry and Raymond, 1985; Molina Grima, 1999; Molina Grima et al.,1999; Tredici,1999; Pulz,2001; Lorenz and Cysewski,2003; Spolaore et al.,2006).

Recovery of microalgal biomass from the broth is necessary for extracting the oil. Biomass is easily recovered from the broth by filtration, centrifugation, and other means (Molina Grima et al., 2003). Cost of biomass recovery can be significant. Biomass recovery from photobioreactor cultured broth costs only a fraction of the recovery cost for broth produced in raceways. This is because the typical biomass concentration that is produced in photobioreactors is nearly 30 times the biomass concentration that is generally obtained in raceways (Table 2.1). Thus, in comparison with raceway broth, much smaller volume of the photobioreactor broth needs to be processed to obtain a given quantity of biomass.

2.4 Potential of microalgal biodiesel

Table 2.2: Comparison of some sources of biodiesel

Comparison of some sources of biodiesel

Crop	Oil yield (L/ha)	Land area needed (M ha)[a]	Percent of existing US cropping area[a]
Corn	172	1540	846
Soybean	446	594	326
Canola	1190	223	122
Jatropha	1892	140	77
Coconut	2689	99	54
Oil palm	5950	45	24
Microalgae[b]	136,900	2	1.1
Microalgae[c]	58,700	4.5	2.5

[a] For meeting 50% of all transport fuel needs of the United States.
[b] 70% oil (by wt) in biomass.
[c] 30% oil (by wt) in biomass.

In view of Table 2.2, microalgae appear to be the only source of biodiesel that has the potential to completely displace fossil diesel. Unlike other oil crops, microalgae grow extremely rapidly and many are exceedingly rich in oil. Microalgae commonly double their biomass within 24h. Biomass doubling times during exponential growth are commonly as short as 3.5h. Oil content in microalgae can exceed 80% by weight of dry biomass (Metting, 1996; Spolaore et al., 2006).

Microalgae with high oil productivities are desired for producing biodiesel. Depending on species, microalgae produce many different kinds of lipids, hydrocarbons and other complex oils (Banerjee et al., 2002; Metzger and Largeau, 2005; Guschina and Harwood, 2006). Not all algal oils are satisfactory for making biodiesel, but suitable oils occur commonly. Using microalgae to produce biodiesel will not compromise production of food, fodder and other products derived from crops.

Potentially, instead of microalgae, oil producing heterotrophic microorganisms (Ratledge, 1993; Ratledge and Wynn, 2002) grown on a natural organic carbon source such as sugar, can be used to make biodiesel; however, heterotrophic production is not as efficient as using photosynthetic microalgae. This is because the renewable organic carbon sources required for growing heterotrophic microorganisms are produced ultimately by photosynthesis, usually in crop plants.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this research, the photobioreactor had two parts which are airlift system and solar receiver. For airlift system, it has been done by another student (Syafiq, 2010). Thus, in this section, the steps to fabricate the solar receiver are explained.This section had been divided into three categories that is the design, construction and lastly the commissioning process.

3.2 Design of solar receiver

For the design of solar receiver which is a part of photobioreactor, the materials that have been used were polyvinylchloride (PVC) plastic, comprising of transparent and non-transparent (grey) PVC. Fittings have also been used to connect the series of pipe with diameters of 10 cm and 6cm. Besides that, the dimension of the solar receiver was determined.

3.3 Construction of solar receiver

The construction process involved cutting and welding of metal and PVC material. Training was provided before the construction was started. The work was done under the supervision with the use of suitable personal protective equipment such as goggle, gloves mask and ear protection. The process was divided into two phases, the construction of support structure and the construction of the solar receiver.

For the construction of support structure, it was built by using hollow carbon steel. The construction involved cutting and welding the steel. This support structure functions as the base for the solar receiver. After that, the construction of solar receiver was continued.

3.4 Combining the solar receiver with the airlift system

When all the construction was done, the solar receiver was combined with the airlift system. The combination of the two parts was called as the photobioreactor.

3.5 Testing and commissioning the photobioreactor

In the testing process, there were two tests. The first testing was done to make sure whether the photobioreactor had any leaking or not. For this test, the photobioreactor was fully filled with water and the outlet valve was closed. Then, observation was made and the places that had a leaking were marked. The second testing was to make sure the flow in the photobioreactor was turbulent. To test the flow, the black dye was used. Then, the air compressor was connected to the airlift part which is to control the flow rate of the air sparged.

Before the testing was started, the photobioreactor was fully filled with water. The inlet of air and outlet valve of photobioreactore was closed. Then, the syringe filled with 10 ml black dye was used to inject the dye into the photobioreactor through the carbon dioxide probe orifice. The air compressor was set up and the pressure was set as 4 psi for the first trial. The valve of air inlet was opened. The time for the black dye to complete a cycle in the PBR was taken. The flow pattern and dispersion of black dye was observed. The water was drained from the photobioreactor after the black dye had completely dispersed and the water was completely black in color. The commissioning process is repeated for pressure of 8, 12, 16and 20 psi.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this section, the results of the research was.reported and followed by the discussion of the results.

4.2 Results and Discussion

Here, the results of the research were divided into 3 parts which were photobioreactor design focus on solar receiver, the construction of solar receiver, and combining and testing the photobioreactor.

4.2.1 Photobioreactor Design (Solar Receiver)

For this part, the dimensions of the solar receiver were determined. The maximum surface area was used as the objective to design the solar receiver in order to get the optimum growth of microalgae. The final design of the solar receiver was showed in the figure 4.1.

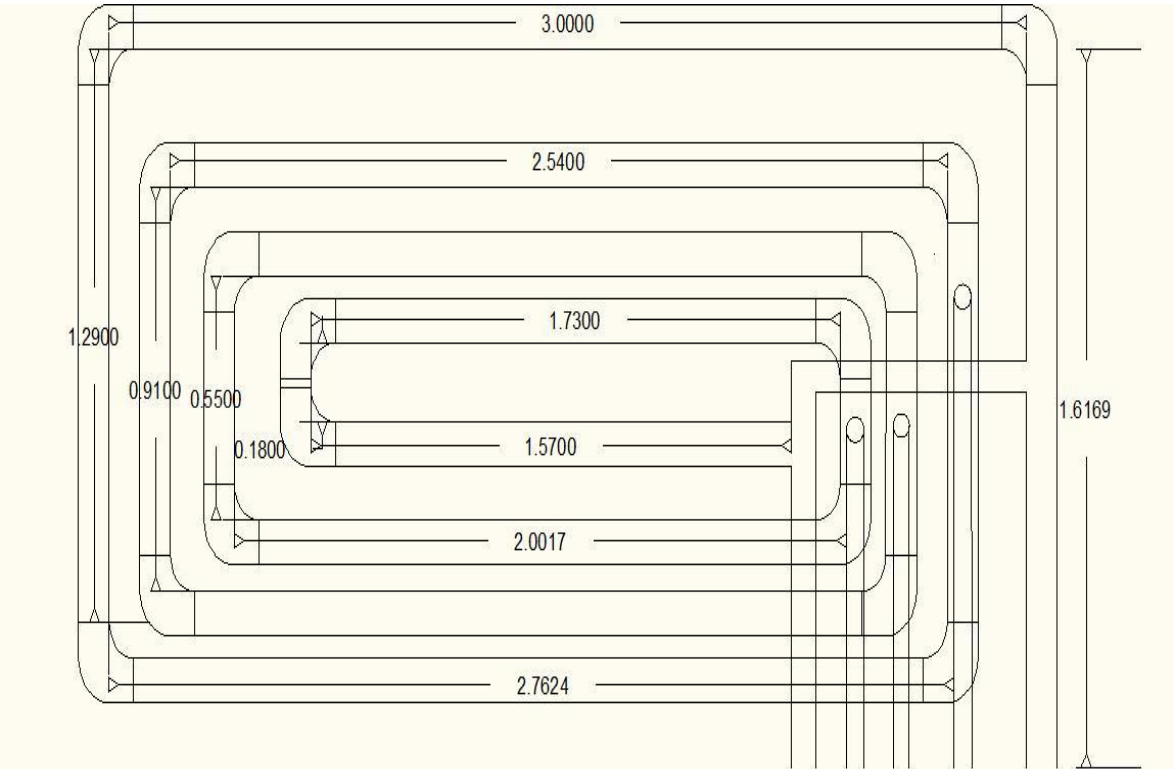

Figure 4.1: Schematic Diagram of Solar Receiver

Figure 4.1 showed that the solar receiver of PBR. It was designed by using Autocad 2007 software. The scale of the design was in meters. This design was used to construct the actual solar receiver. It also would be combined with the airlift system where the airlift system acts as the driver for the solar receiver. The airlift system will be used to create a flow in the photobioreactor (PBR). The flow was driven by the bubble from the air sparged in the riser column. The pressure in the riser should be higher than the solar receiver part, so that the air bubbles are capable to move the fluid in the PBR.

The solar receiver was designed to be functioning as the place for the optimum growth of microalgae. By using the transparent tubes material to construct the solar receiver where the diameter is 0.1m, it would allow sunlight to penetrate through the transparent tubes. Thus, the microalgae would get the light source to do the photosynthesis process. Not only the light source, the carbon dioxide source also would be supply for microalgae to do the complete photosynthesis process.

4.2.2 Construction of Solar Receiver

For the construction process, it took 3 months to complete the solar receiver. The construction process of the solar receiver was done by the help of Mr. Hairul Hisham Bin Ismail (PJP) from FKKSA and Mr Ding Gong Tao a postgraduate student of FKKSA. It consists of two major structures which were the solar receiver and the support of solar receiver. For the solar receiver, it was fabricated by using the polyvinyl chloride (PVC) both transparent and non-transparent. The non transparent was used as fitting of the transparent tubes while for the transparent PVC was used to capture the sunlight At the solar receiver, there was also the probe part for the measurement of carbon dioxide supply which was one of the sources for microalgae did its photosynthesis process.

Besides that, the other reason why the transparent PVC was used in the construction of the solar receiver is because the pattern of the flow could be easily observed whether it was laminar or turbulence flow. For the support of the receiver, it was built by using hollow carbon steel. It was done after the solar receiver was completed. The figures of the process of making the solar receiver were shown in Appendix A.

4.2.3 Combining and testing the photobioreactor

After the construction process was done, the combining process was followed. In the combination process, the airlift system and the solar receiver were combined. When the two parts were combined, it called the photobioreactor. The process of combination were shown in Appendix.A

The testing process has been done on the photobiorector. There were two tests. The first test to be done is to make sure whether the photobioreactor was leaking or not. When the first test was conducted, leaks were observed. Then, to solve the leaks, the glue of the PVC was used. The process was shown in Appendix B.

After the leaks were solved, the second test was carried out. For the second test, water and black dye were also to be used. Before the tests have been completed calculation theory was calculated. In this theoretical calculation, the Reynolds number was calculated. Besides that, the head loss value also has been calculated to make sure the velocity in the PBR was fast enough to create the turbulent flow in the PBR. The calculation of the Reynolds number and also the head loss was shown in the Appendix B. Based on the calculation, the Re value showed that the flow in the solar receiver was the turbulent flow. For the calculation of the velocity of the liquid, it could not be solved because of there was no value of the gas holdup in riser. Thus, to solve that problem there was the recommendation that the rotameter should be put at the PBR.

Then the result of the theoretical calculation was proven by doing the testing process. The time taken fo the dye to complete a cycle in PBR has been measured and the dispersion of the dye in the water has been observed. The results of the testing was tabulated in the table 4.1 and plotted in figure 4.2 and also recorded by video that was attached in CD.

Table 4.1: Results of testing process

pressure (psi)	observation		
	time complete the cycle (s)	**flow**	**Dye dispersion**
0	-	no	-do not move and slowly immersed
4	474	slow	-black dye was dispersed too slow
8	210	moderate	-black dye was dispersed slowly
12	165	moderate	-dispersed quickly
16	140	fast	-dispersed immediately
20	119	more fast	-overflow in degassing unit

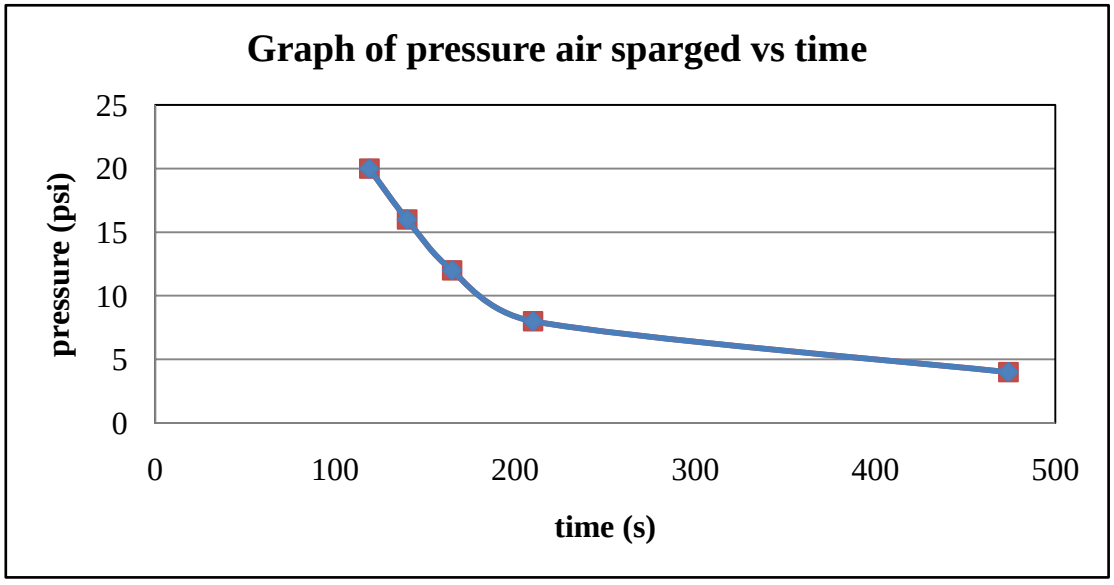

Figure 4.2: Graph of pressure air sparged versus time

From the observation and graph above, the high pressure that used to sparged the air is 20 psi while the lower pressure is 4 psi. It followed by 8, 12, 16 and 20 psi respectively. For the 4 psi, the flow of the dye is slow and it dispersed in the water too slowly. The time taken to complete the cycle was 474 second. For the pressure 8 and 12 psi, both the flow is moderate. The times taken to complete a cycle are 210 sec and 165 sec respectively. For the 8 psi, the dye dispersed slowly while for the 12 psi the dye dispersed quickly. At 16 psi, the time taken was 140 sec, the flow was fast and the dye dispersed immediately in water. At 20 psi, it took the shortest time to complete the cycle but it was overflow in the degassing zone.

Thus, the optimum pressure that needed to complete the cycle with the shortest time is at 16 psi which is equal to 110.32 kPa and all the flow is turbulent flow. Based on the observation, it can be assumed that the mixing in the PBR is optimum at 16 psi. The mixing part is very important to make sure all the microalgae in the PBR get enough sources especially sunlight and carbon dioxide.

Turbulent in the tube causes rapid cycling of the fluid between the light and dark zones. The frequency of light dark cycling depends on several factors, including the intensity of turbulence, concentration of cells, optical properties of the culture, the diameter of the tube, and the external irradiance level (Molina Grima et al., 2000, 2001). Under conditions of sufficient and excess external irradiance, light–dark cycling of above a certain frequency can increase biomass productivity relative to the case when the same quantity of light is supplied continuously over the same total exposure time (Philliphs and Myers, 1953; Terry, 1986; Grobbelaar, 1994; Nedbal et al., 1996; Grobbelaar et al., 1996; Camacho Rubio et al., 2003).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The objective of this research has been achieved. The solar receiver has been designed, constructed and commissioned successfully. The optimum pressure for air to be sparged is up to 16 psi. When the pressure is increase, the time taken is decrease. But, too much pressure will cause overflow in the degassing zone. The turbulence flow in the solar receiver was created. It is expected that, the pressure will be higher when the real broth of microalgae is used because the density of microalgae broth is higher than water.

5.2 Recommendations

To optimize the performance of the microalgae photobioreactors, there were several recommendations have to be done and thus maximize the growth of the microalgae photobioreactor:

i. Use standard scale pressure meter for precise reading

ii. Install flowmeter for more precise reading. For example:

a. Orifice meter

b. Rotameter

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APPENDIX A

MATERIALS AND METHODOLOGY

A.1 MATERIALS

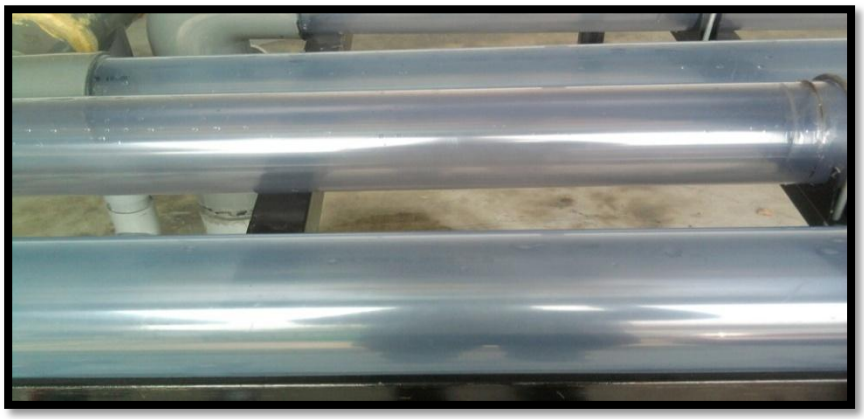

Figure A.1: Transparent tubes

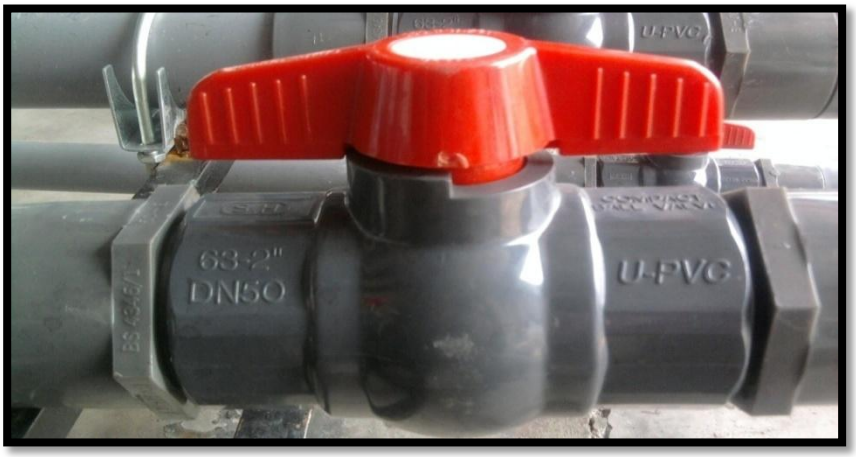

Figure A.2: Ball Valve

Figure A.3: 90^{o} Elbow

Figure A.4: Reducing Coupling

Figure A.5: Tee fitting

A.2 Personal Protective Equipment

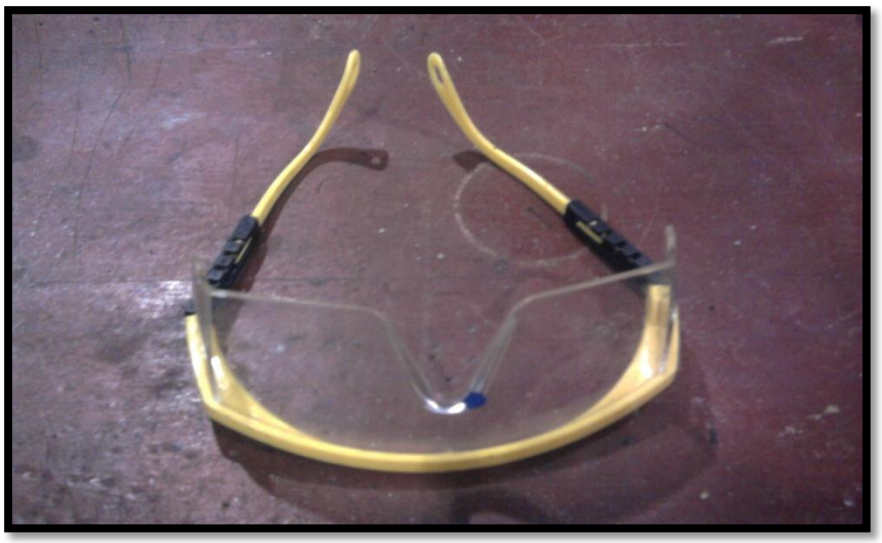

Figure A.6: Goggle

Figure A 7: Ear Protection

Figure A.8: Hand Glove

Figure A.9: Mask

A.3 Construction Process

Figure A.10: Cut off machine

Figure A.11: Cut off machine for steel

Figure A.12: Front view of solar receiver

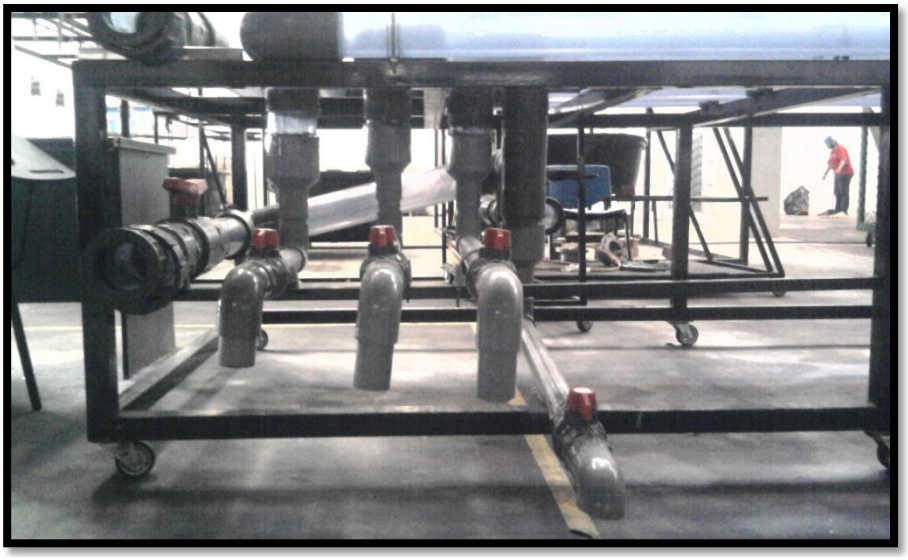

Figure A.13: Side view of solar receiver

Figure A.14: Top view of solar receiver

A.4 Combining Process

Figure A.15: Combine section with airlift system at solar receiver

Figure A.16: Combine section at airlift system

Figure A.17: A complete photobioreactor

A.5 Testing and commissioning process

Figure A.18: First Testing

Figure A.19: Checked the leaking

Figure A.20: Air Probe

Figure A.21: Air Compressor

Figure A.22: Injected the dye

Figure A.23: Carbon Dioxide Probe

Figure A.24: Drain system

APPENDIX B

RESULT AND DISCUSSION

B.1 Theory Calculation

The volume flow rate is 0.00524 m^3/s. From the volume flow rate value, the velocity can be determined by using cross sectional area which the area is 0.1 m in diameter. From the calculation the velocity value is 6.672 m/s. Then, by using velocity value, the Reynolds Number can be determined by using Eq 1:

$$Re = \frac{\rho U_L \phi}{\mu_L}.$$ = 6.6451 X 10^5 > 4000

The Re value showed that the flow is turbulent.

The head loss equation is shown as below:

$H_L = f\ (L/D)\ (V^2/2g) + K_L(V^2/2g)$

By using the equation of the head loss, the value that calculated is equal to 169.96 m. Then, this value has been used in the Eq (3) to get the K_B value. After that, the Eq (2) has been used to calculate the velocity of the liquid.

B.2 Results of the testing process

Figure B.1: The leaks at the photobioreactor

Figure B.2: The mark place of leaks

Figure B.3: The part of leak with glu

Figure B.4: 3 ton metal epoxy.

Figure B.5: PVC Solvent Cement

Figure B.6: Fiberglass Repair Kit

Table 4.1: Results of testing process

pressure (psi)	observation		
	time complete the cycle (s)	**flow**	**Dye dispersion**
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20	119	more fast	-overflow in degassing unit