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Development of Lab Scale Algae Production-Harvesting Integrated System (APHIS) for Future Sustainable Energy

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ABSTRACT

Nowadays, the shortage of fossil fuel is the main problems to the worlds. The emission of come from the transport that used fossil fuel such as diesel is gradually concern in order to replace the fossil fuel with renewable energy such as biofuels. This is why a renewed interest has risen in recent years towards producing biodiesel from microalgae. This renewable energy is expected to offer new prospects fuel supply sources. This kind of renewable energy such as biodiesel from microalgae can be replaced for transportation fossil fuels in future for sustainable energy. Therefore the motivation of this paper was to developed algae production harvesting integrated system in one closed loop system. The axiomatic design concept as design matrix was involved in this development. The drawing for design was used AutoCAD and SketchUp Software. As we found that conceptual design 2 is the most reliable and best suited to the requirement and objective of this study compare to design conceptual 1. In future, this model of APHIS can be used to study the analysis performance of this system.

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INTRODUCTION

The world has been confronted recent decades with energy crisis, associated with irreversible depletion of traditional sources of fossil fuel, as a major form of energy is indeed unsustainable, further to accumulation of greenhouse gases in the atmosphere that bring about global warming. With the urgent need to reduce carbon emissions, and the dwindling reserves of crude oil, liquid fuels derived from plant material is also known as biofuels appear to be an attractive source of energy. Compared with other form of renewable energy like wind, tidal and solar, biofuels allow energy to be chemically stored, and also be used in existing engines and transportation infrastructures after blending to various degrees with petroleum diesel (Singh & Gu, 2010). This biodiesel is in essence a set of monakyl esters of long-chain fatty acids and at present is derived chiefly from the acylglycerols of plant oils. Besides renewable, biodiesel is also non-toxic and biodegradable (Meher, Vidya, & Naik, 2006). Presently many options are being studied and implanted in practice, with different degrees of success, and in different phases of study and implementation. Example includes solar energy, thermal, biofuels and carbon sequestration, among others (Dewulf & Langenhove, 2006).

Every technology has its own advantages and also disadvantages. It is depends on what functions it used. As stated by European Union (EU) the transportation and energy sectors are the major anthropogenic sources, responsible in for more than 20% and 60% of greenhouse gas (GHG) emissions, respectively [European Environmental Agency, 2004]. Therefore the best alternative for transportation fuels is to use biofuels. Such as diesel, the best alternative is biodesel. As we know that the main alternative to diesel fuel in EU is biodiesel, representing 82% of total biofuels production and is still growing in Europe, Brazil, and United States (Emad A. Shalaby, 2011).

A study shown that the overwhelming rates of fuel consumption at present may cause the world fossil fuel reserves will be depleted in less than 50 year (Roldofi, 2008). The large scale use of fossil fuels for transport, promote increases the greenhouses gases emission and imperative to develop abatement methods and adopt policies to minimize the impacts of global warming (Brennan & Owende, 2010).

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Therefore nowadays its show an increased interest in developing second generation biofuels produced from non-food feedstock such as microalgae, which potentially offer greatest opportunities in the longer term as stated by Emad A. Shalaby, (2011).

Emad, 2011 also reviewed that one alternative to oil crops is the algae because they contain lipids suitable for esterification or transesterification. Among many types of algae, microalgae seem to be promising because:

1. They have high growth rates; e.g., doubling in 24 hours (Rittmann, 2008).
2. Their lipid content could be adjusted through changing growth medium composition (Naik *et al*., 2006).
3. They could be harvested more than once in a year (Schenk *et al*., 2008).
4. Salty or waste water could be used (Schenk *et al*., 2008).
5. Atmospheric carbon dioxide is the carbon source for growth of microalgae (Schenk *et al*., 2008).
6. Biodiesel from algal lipid is non-toxic and highly biodegradable (Schenk *et al*., 2008).
7. Microalgae produce 15–300 times more oil for biodiesel production than traditional crops on an area basis (Chisti, 2007)

With this motivation, the study was developed to aim the lab scale size for algae production harvesting integrated system or called as APHIS in one closed loop system. The setup of this lab scale was developed and improves the design to get the better and final design. This paper also reviews the current status of microalgae cultivation, harvesting and processing.

Methodology:

This study was conducted in Fluids Lab, Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS). The development of algae production harvesting integrated system (APHIS) in lab scale are referring to the capacity or size of production of this APHIS. Therefore for this study, the volume used for harvesting is less than 10 gallon (approximately 37.85 litres) for lab scale study. As the volume used for harvesting is less than 37.85 litres, the design also need to be within the constraint. For this study the microalgae were considered to be used in the APHIS.

Production Cultivation Microalgae:

There are many ways of production or cultivation for algae or microalgae. The cultivations can be in open pond, closed pond, vertical-column photobioreactors and tubular photobioreactor. As stated by Oilgae, 2007, the increase in pH of the cultures would also lead to frequent re-carbonation of the cultures, which would consequently increase the cost of algal production. Therefore, in this study closed system is considered.

Harvesting Microalgae:

In harvesting microalgae, there are also many ways to harvest such as chemical method, mechanical method. In this study we are focusing in mechanical method in developing the APHIS.

System Design:

The designing process of the system will be using the AutoCAD software and also SketchUp software. Before that, a few conceptual designs were discuss in terms of its design parameters and function requirements. The design also includes all the parameters involve in the system with the exact dimension of each part for the ease of fabrication. In the design process the parameters that need to be concern of are the flow rate, density, pressure and the power of the pump.

Fabrication:

The fabrication process is the continuity of the designing parts, in fabrication there are certain thing that needs to be stress on is material selection. For this project, the material selection should be suitable with the system so that it will function well as the system is operating. In fabrication also the dimension of each parts of the system need to be precise so that it will not lead to the systemic error. The fabrication also was done in Fluids Lab Faculty of Engineering, UNIMAS.

RESULTS AND DISCUSSIONS

The Effective way of Production Cultivation Microalgae:

Table 1 shows the findings for prospects and limitations of comparison for cultivation microalgae in open and closed pond. Table 2, shows the findings for prospect and limitation for vertical-Column and tubular photobioreactors.

Table 1: Prospect and Limitations for open and closed pond.

Open Pond	Closed Pond
Prospects • low production costs • low operating costs • large quantity of algae cultivated Limitations • Bad weather can stunt algae growth • Contamination from strains of bacteria or other outside organisms • Temperature of water hard to maintain • uneven light intensity and distribution within the pond	Prospects • allows more species to be grown • if heated it can produce year round • simplest of all the growing techniques Limitation • cost more than the open ponds

Table 2: Prospect and Limitations for Vertical-Column and Tubular.

Vertical-Column Photobioreactors	Tubular Photobioreactors
Prospects • High mass transfer • good mixing with low shear stress • low energy consumption • high potentials for scalability • easy to sterilize • readily tempered • good for immobilization of algae • reduced photo inhibition • photo-oxidation Limitations • Small illumination surface area • their construction require sophisticated materials • shear stress to algal cultures • decrease of illumination surface area upon scale-up	Prospects • Large illumination surface area • suitable for outdoor cultures • fairly good biomass productivities • relatively cheap Limitations • Gradients of pH • dissolved oxygen and CO2 along the tubes • fouling • some degree of wall growth • requires large land space

Therefore, from the result, production system for this study was using the concept of photobioreactor that will integrate with the harvesting system.

The Effective way of Harvesting Microalgae:

For harvesting part, the findings result were shows in Table 3 below.

Table 3: Prospect and Limitations for flocculation, filtration and centrifugation.

Flocculation	Filtration	Centrifugation
Prospect • Microalgae separate completely with water before harvesting Limitations • additional chemicals are difficult to remove from the separated algae • inefficient uneconomic for commercial use • cost to remove these chemicals may be too expensive	Prospect • collect microalgae or cells of very low density Limitations • limited to small volumes • leads to the eventual clogging	Prospect • useful on a commercial and industrial scale Limitations • sensitive algal cells may be damaged • too expensive for personal use,

Therefore, Algae Production and Harvesting Integrated System (APHIS) is a system that combines production and harvesting in one system. This system consists of the most effective way in production and harvesting algae. In APHIS, the system is constructed based on the previous study of the method of producing and harvesting algae. In this system, there are four major part that is important to ensure that the system working. The first part is cultivation part which consists of cultivation tank and mechanism that important to cultivate the microalgae such as nutrients, CO_2 gas and light. This mechanism is important for photosynthesis. The second part is harvesting part which consists of the new way of harvest the microalgae. The harvesting process will be using ultrafiltration membrane. The first water filter is used to filter the microalgae and the second water filter is used as the indicator to show that the microalgae are fully harvested in the first water filter. The third part is water tank. The use of water tank is to storage the water that has been separated from the microalgae. This water is then pumped up again into the cultivation tank. From this process we can know that the whole system is a closed loop system. This system is named as integrated system because it is a hybrid system which is consists if cultivation and harvesting part.

Conceptual Design for APHIS:

In this study we have done 2 conceptual designs in order to achieve the objectives of this development. Figure 1 shows the axiomatic design for conceptual design APHIS.

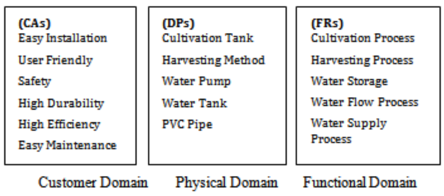

Fig. 1: Axiomatic Design for APHIS.

Design Matrix

In the Axiomatic Design, all conceptual designs process only focuses on mapping between functional domains (FRs) and physical domain (DPs). This mapping process is represented by the design equation (1).

$$FR = [A]\ DP \quad \ldots. \qquad (1)$$

The good design matrix for conceptual designs may be stated Figure 2 below;

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \\ FR4 \\ FR5 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 & X \\ 0 & X & 0 & 0 & 0 \\ 0 & 0 & X & 0 & 0 \\ 0 & 0 & 0 & X & 0 \\ 0 & 0 & 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \\ DP4 \\ DP5 \end{Bmatrix}$$

Fig. 2: Good Design Matrix.

Product Architecture:

Product architecture is the arrangement of the physical elements of a product to carry out its required APHIS functions. The project general process are specify in block diagram in Figure 3 below.

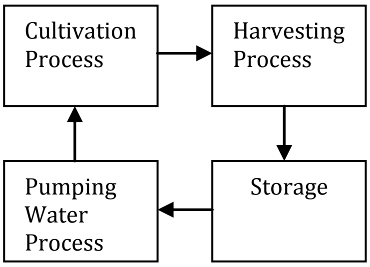

Fig. 3: Block diagram of Desired APHIS.

In order to achieved the desired function of APHIS. The conceptual designs were need to follow all the required function and methods.

Figure 4 shows conceptual design 1 and Figure 5 shows the conceptual design 2. In these results we do comparison of the functions and physical domains to suit the design requirement. Figure 6 and Figure 7 shows the design matrix for conceptual design 1 and 2 respectively.

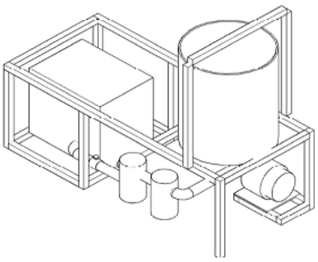

Fig. 4: Conceptual Design 1.

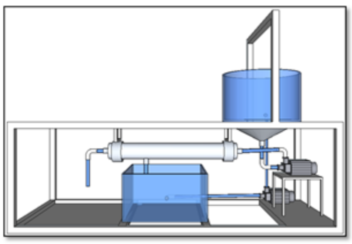

Fig. 5: Conceptual Design 2.

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \\ FR4 \\ FR5 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 & 0 \\ 0 & X & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & X & 0 \\ 0 & 0 & 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \\ DP4 \\ DP5 \end{Bmatrix}$$

Fig. 6: Design Matrix Conceptual Design 1.

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \\ FR4 \\ FR5 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 & X \\ 0 & X & 0 & 0 & 0 \\ 0 & 0 & X & 0 & 0 \\ 0 & 0 & 0 & X & 0 \\ 0 & 0 & 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \\ DP4 \\ DP5 \end{Bmatrix}$$

Fig. 7: Design Matrix Conceptual Design 2.

Therefore, from the axiomatic design that has been done we found that the most effective, reliable and suit the design requirement to the objective of lab scale APHIS was conceptual design 2.

After the selected design chooses, then the fabrication was undertaking. Therefore the fabrication was conducted by referring to the conceptual design 2. The final product of this APHIS was done in Fluids Lab Faculty of Engineering, UNIMAS. Figure 8 shows the final product of APHIS.

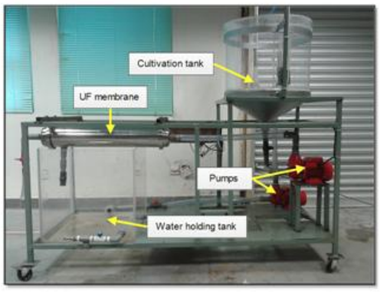

Fig. 8: Final Product of APHIS.

Conclusions and recommendations:

In conclusion, this study was successful to develop the production of microalgae using photobiorector concept that integrated with the mechanical harvesting method. The method of cultivating microalgae such as raceway pond and photobioreactors and harvesting methods either chemical or mechanical such as flocculation, filtration and centrifugation also has been studied. In this study, the axiomatic design was method used to choose the best design before fabrication. The fabrication of lab scale APHIS was accomplished suit to the design requirement. The testing of APHIS also has been done. The result of production and harvesting microalgae using lab scale APHIS to promote renewable energy of biodiesel also has been done. The result will be publishing in next paper.

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