Feasibility Studies of Vortex Flow Impact On the Proliferation of Algae in Hydrogen Production for Fuel Cell Applications

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Abstract. The instability of crude oil price in global market as well as the sensitivity towards green energy increases, more research works being carried out to find alternative energy replacing the depleting of fossil fuels. Photobiological hydrogen production system using algae is one of the promising alternative energy source. However, the yield of hydrogen utilizing the current photobioreactor (PBR) is still low for commercial application due to restricted light penetration into the deeper regions of the reactor. Therefore, this paper studies the feasibility of vortex flow impact utilizing magnetic stirring in hydrogen production for fuel cell applications. For comparison of results, a magnetic stirrer is placed under a PBR of algae to stir the algae to obtain an even distribution of sunlight to the algae while the controlled PBR of algae kept in static. The produced hydrogen level was measured using hydrogen sensor circuit and the data collected were communicated to laptop using Arduino Uno. The results showed more cell counts and hydrogen produced in the PBR under the influence of magnetic stirring compared to static PBR by an average of 8 percent in 4 days.

1. Introduction

There are many green energy initiatives taking place all over the globe in reducing the carbon dioxide footprints. Solar energy, wind energy, tidal wave energy is among some of the famous energy being researched and implemented. Yet, the dependencies of these energy to nature especially with ever changing climate impose challenges to the effort in fully implementing and replacing the crude oil energy. Another alternative energy that promises a better reliable solution would be harnessing the energy from hydrogen.

Photobiological Hydrogen Production system using algae seems to be a promising method in harnessing clean and reliable energy [1, 2]. In tropical countries such as in Malaysia, algae are vastly found and this resource could be used to produce clean energy continuously as Malaysia is blessed with sunlight all year long [3]. The algae’s nature being environmentally friendly, by absorbing the carbon dioxide and produces hydrogen as a by-product which then can be converted to electricity through fuel cell made this technology even promising to be explored further. In terms of algae resources, it can be harvested in the ponds, and the fast growing algae needs sunlight, water as well as carbon dioxide as its basic needs to multiply within hours, thus produces sufficient amount of hydrogen for electricity production which can act as an alternative to the current...
diminishing crude oil source [4 -7]. The produced hydrogen from algae then acts as a fuel for the fuel cell to convert hydrogen to electricity. Fuel cell is known as an electrochemical device that can operate to convert the chemical energy from fuel into electric current, which is act as static converter and produce water as by product.

Fuel cell technology is capable to produce energy for rural area which is off-grid or highly in cost for wiring and distribution of electricity is required, then it is enable to substitute fossil fuel for this system [8]. The fuel cell technology growing by years due to its high efficiencies, low noise and pollutant output, with its potential to develop the power generation industry with a shift from centrally located generating stations and long-distance transmission lines to dispersed power generation at load sites and also have the capability to replace internal-combustion engine that primarily depend on fossil fuel with the invention of electric vehicle (EV). Table 1 summarizes the comparison of various generation system with fuel cell being the best in terms of efficiency.

Fuel cells produce electricity and heat through out electrochemical reaction that slightly reversed electrolysis reaction. This reaction happens between the oxygen and hydrogen to form the water. Although, various types and designs of fuel cell available, yet the working principles of fuel cell remains the same. The main differences between the fuel cells are the type of chemical for electrolyte. Eq. (1) shows the electrochemical reaction of a fuel cell [8].

\[
2\text{H}_2 (g) + \text{O}_2 (g) \rightarrow 2\text{H}_2\text{O} + \text{energy (electricity + heat)} \quad (1)
\]

However, in the commercial and industry application, the yield of hydrogen gas (H2) from any of the processes is still very low and the result is not promising enough for companies to invest more in this system [10,11]. The hydrogen level is low mainly due to the restriction of light penetration into the deeper regions of the photobioreactor. Consequently, only the outer regions of the photobioreactor produces efficient amount of hydrogen.

Furthermore, there is still no appropriate bioreactor design for the hydrogen production [12-17]. The industry applies various methods such as open pond method, photobioreactor method but divided into a few more designs. There is no specific design because every design has its own advantages and disadvantages in terms of costs or space requirements [12]. Researchers and engineers are still working out on the best design balancing the both advantage and disadvantages in the design factors.

Therefore, this paper proposes the development of a wireless magnetic stirring system that allows the cultured algae to orbit evenly and receive adequate amount of uniform sunlight concentration to increase the growth rate of algae and determine the effectiveness of the system by comparing two identical tubes of cultured algae except one being static and another being controlled by the magnetic stirrer system. By using the developed magnetic stirring system, this paper also investigates the feasibility of vortex flow impact utilizing magnetic stirring on the proliferation of algae in hydrogen production for fuel cell applications.

2. Methodology

2.1. Photobiological Reactor
The developed system of photobiological reactor is mainly consist of a magnetic stirrer as well as a hydrogen sensor and detector. Details as described in the following subsection.

2.1.1 Magnetic Stirrer

The work begins by preparing a magnetic stirrer which connects the power source to a power bank. The power source rated at 5V produces 600 rpm inside the jar. Two magnets of opposite poles were placed at the center of the fan to stir the cultured algae while the magnetic stirrer bar is placed inside the PBR.

2.1.2 Hydrogen Sensor and Detector

The hydrogen sensor module prepared by coding the Arduino microcontroller, which being utilized to measure the hydrogen in parts per million (ppm). A hydrogen harvesting jar was built by attaching the MQ-8 Hydrogen H2 Sensor Module (Fig. 1) hydrogen sensor just below the cover and the Arduino Uno R3 (Fig. 2) on the top. Then, all the holes of the cover were sealed with hot glue to ensure the most precise reading of hydrogen. This sensitive hydrogen sensor module which can measure from 10 to 1000 ppm is responsible to detect the hydrogen produced by the algae in the hydrogen jar. Arduino Uno R3 is the microcontroller programmed to be used as a medium of interaction by receiving input from the hydrogen sensor module and sending output to the laptop for data recording purposes. The coding commands the Arduino to display the hydrogen reading in ppm every second. The produced amount of hydrogen gas value only taken once the readings from the hydrogen sensor found to be in stable condition as a part of the calibration process.

Fig.1 MQ-8 Hydrogen H2 Sensor Module.

Fig.2 Arduino Uno R3.
2.2 Algae Culture, Cell Proliferation, And Hydrogen Gas Production

The culture of algae begins by preparing algae in two different PBR by having 10% Bold’s Basal Medium to provide nutrition for its growth. Two species of algae used known as chlorella vulgaris which has high amount of chlorophyll and Chlamydomonas sp. which produces hydrogen from anaerobic process. The growth of algae in anaerobic process were carried out by sealing the PBR. When the algae in the shortage of air environment, algae will automatically produces hydrogen as a by-product. Later on, the algae in the PBR were placed under fluorescent light for four days. The algae stirring of 600 rpm were made constant by making sure continuous electrical supply were given by powering it with alternate power banks.

After four days of growth, the tube’s seal were opened to allow the produced hydrogen being collected at the hydrogen harvesting jar. As the photobioreactor sealed for four days and there were additional hydrogen gas produced, an opening causes air pressure. Thus, the hydrogen gas in the PBR flows to the hydrogen harvesting jar due to the air pressure. The hydrogen collecting process took 30 minutes and the readings were shown simultaneously in the Arduino software. Furthermore, cell counting process were carried out by having 1 ml of the cultured algae to be displayed under the microscope for the process to take place. The cell counting process crucial as to further support the data analysis on the impact of the vortex flow utilizing magnetic stirrer on the increase of the proliferation of the algae. The general experimental flow is as shown in Figure 3.

![Diagram](image)

**Fig.3** The general flow of the experiments.

3. Results

3.1 Photobiological Reactor

Fig. 4 shows the whole set up of a magnetic stirrer photobiological reactor for the experiment. The photobiological reactor consists of a wireless magnetic stirrer, alge culture bottle, hydrogen harvesting jar, hydrogen sensor, and the microcontroller used as a medium of interaction by receiving input from the hydrogen sensor module and sending output to the Arduino software in the laptop for data recording.

![Image](image)

**Fig.4** The wireless magnetic stirring photobiological reactor for algae culture that has been developed.
3.2 Cell Proliferation

Chlorella Vulgaris and Chlamydomonas sp were the algae used and cultured under two separate photobioreactor with one under the influence of magnetic stirrer and the other one under static condition. The two types of algae were cultured for four days before results were recorded in terms of cell count. The Chlorella Vulgaris under the influence of magnetic stirring has an average of 197.25 number of cells and under the static condition the amount of cell in an average of 177.25 as shown in Fig. 5, while for the Chlamydomonas sp under the influence of magnetic stirring has an average of 39.25 number of cells and an average of 37.1 number of cells under the static condition as shown in Fig. 6. These results indicate the increase of algae proliferation of about 11.3% for Chlorella Vulgaris and 5.8% of Chlamydomonas sp respectively.

The average hydrogen level in the photobioreactor under the magnetic stirrer system is found to be higher than the average hydrogen level in the static photobioreactor system by 7.8% as shown in Fig. 7. This is due to the presence of magnetic stirrer which enables an even exposure of sunlight to the algae whereas the algae in the static photobioreactor were not exposed to even amount of sunlight to grow.
Fig. 7. The hydrogen gas production in the system. (A) Stirred condition and, (B) Static condition.

4. Discussions

In 1939, Hans Gaffron observed that the algae he was studying, Chlamydomonas reinhardtii would sometimes switch from the production of oxygen to the production of hydrogen [16]. He never knew the factor of this change and for many years until in the late 1990s, Professor Anastasios Melis discovered that if the algae culture medium lacked of Sulphur, the algae then switches from the production of oxygen to the production of hydrogen. He found out that the enzyme responsible for this reaction hydrogenized but it lost this function in the presence of oxygen [16, 25]. In short, Chlamydomonas reinhardtii found to be a good strain for the production of hydrogen [1, 17]. Thus, this paper only proposes specific algae to be harvested as a future renewable energy for the world as not all algae would be able to produce hydrogen during the anaerobic process.

The current design of photobioreactor’s disadvantage found to be the restrictions of the sun light penetrations which causes only the outer regions of algae produces hydrogen for the usage of fuel cell. In order to overcome this challenge, the experiment conducted proposing the utilization of magnetic stirrer which would induce in the vortex flow clearly proves an increase not only on the algae cell count but also in the hydrogen production. This is due to the vortex flow which enables cultured algae to orbit evenly and receive adequate amount of sunlight in order to increase the growth rate and the performance of algae. Furthermore, Halasz et al. has reported that magnetic stirrer developed vortex flow that can maintain the stability, produce “anticentrifugal” force acts, and spread dye very quickly [19].

In this study, the proliferation of Chlorella Vulgaris and Chlamydomonas sp under the influence of vortex flow of magnetic stirrer were 11.3% and 5.8% higher than the static condition, respectively. The average hydrogen level in the photobioreactor under the magnetic stirrer system was also 7.8% higher than the average hydrogen level in the static photobioreactor system. This result suggested that by enhancing the flow of culture medium may also enhance the proliferation and hydrogen production of algae [19,26]. These results are in line with our previous finding where the performance of cell was enhanced by enhancing the perfusion of culture medium [20]. Based on the conducted literature review, it’s also showed that the magnetic field produced from a static magnet can also affect the cell proliferation and enhance the performance of the cell [21].

However, further investigation is necessary for detail clarification. Besides, the magnetic stirrer prevents the bacteria from interfering the algae’s proliferation. Holmstrom et al. reported that the bacteria such as members of genus Cytophaga and Pseudoaltermonas strains have been found to inhibit the growth of phytoplankton by producing bioactive compounds, growth inhibitors and exopolymers such as polysaccharides [22]. The results have indicated positive findings for the future development of the study where there is an increase of hydrogen production due to the vortex flow of the magnetic stirrer as it causes a more evenly saturated solution for the absorption of sunlight and able to prevent the disturbance of the growth of algae from bacteria.

The increase of hydrogen production through the proposed method, opens up various possibility of fuel cell applications in various industries especially in power generation and transportation industry. The most famous
fuel cell in need of pure hydrogen as its fuel known as Proton Exchange Membrane Fuel Cell (PEMFC). Utilizing the proposed method, pure hydrogen can be supplied for PEMFC which largely used in micro-grid or de-centralized power system. PEMFC mainly focus on small scale distribution power system which is 50-250kW for decentralized used or below 10 kW for household. Early design considered fuel cells for residential power supply, in which the waste heat of fuel cells can also be utilized for household usage in which this significantly increases the overall efficiency [23].

The recent advancement in research and development in vehicle industries have given birth to electric vehicles such as Tesla Cars. Fuel cells technology in transportation industries gaining popularity by days and having an adequate hydrogen supplies would be necessary in order for the industry to introduce electric vehicles or even the power generation for house-holds far from grid. Certainly, the proposed method of vortex flow using magnetic stirrer would be an advantage for these industries in securing the right amount of hydrogen for common people usage when these technologies introduced replacing the conventional fossil fuel.

This is due to the suitability of PEMFC in the fuel cell electric vehicle system. Commonly, PEMFC stack is used as power source for fuel cell electric vehicle (FCEV) due to its low operating temperature (about 80 °C), high power and current density, compactness, light weight, quick start up system and fast output power adjustment [23]. Another criteria in choosing power supply for vehicles would be to have high power density and rapid start up. PEMFC can be much more superior to internal combustion engine in many aspect except the initial cost issue [23,27]. The usual capacity of PEMFC found to be around 20 kW to 250kW, which indeed can be considered as power range for transportation that includes normal car, utility vehicle and buses.

The ASEAN countries also embarking on green technology initiatives whereby Fuel Cell is one of the green technology being ventured. In Cambodia, on 24th and 25th July 2012, the GSMA Green Power for Mobile Programme hosted another successful South East Asia Regional Working Group in Phnom Penh, Cambodia co-hosted by Hello (Axiata Group). This program talk about green power for mobile application that involved fuel cell technology [24]. While, Singapore is known as the top ten countries with the highest levels of private investment in fuel cells. The country is looking forward to be regional center for fuel cell technology especially in The Fuel Cell (FC) centric Flying Wing Unmanned Aerial Vehicle (UAV) [24].

As a results of many fuel cell applications, would certainly need the support of continuous supply of hydrogen in order to have a reliable energy source. The proposed method of vortex flow using magnetic stirrer at the lab scale looks feasible and promising in the increase of hydrogen production by the algae. Certainly, more extensive research need to be carried out in a larger scale to increase the efficiency of PBR in producing the hydrogen fuel for fuel cell applications.

5. Conclusion

The results obtained show that it’s feasible through vortex flow impact utilizing magnetic stirrer yields more algae cell counts and hydrogen production which can be extended for fuel cell applications. Since, with the introduction of magnetic stirrer provides an even distribution of light to each of the alga cell and inhibit bacteria growth, it’s possible to utilize the same method in the PBR to produce hydrogen continuously to power up fuel cell for electricity generations and other various applications. This method would certainly secures the future of fuel cell technology and support the fuel cell in the green energy initiatives. The proposed method can be extended in a larger scale for future research works.

6. Acknowledgement

This research is fully supported by RAGS grant, RAGS/1/2015/TK03/UPNM/03/1. The authors fully acknowledged Ministry of Higher Education (MOHE) and National Defence University of Malaysia for the approved fund which makes this important research viable and effective.

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