# ELECTRICITY GENERATION BY PEMFC BASED ON RHODOPSEUDOMONAS SP.

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**Abstract—** Proton exchange membrane fuel cell (PEMFC) needs pure hydrogen gas to generate direct current electricity. PEMFC gives zero pollution emission unlike combustion power generation technology using fossil fuels. Biological hydrogen (BioH2) production processes by purple nonsulfur photosynthetic bacteria (PNSB) is an alternative to generate hydrogen gas with several benefits such as environmental friendly, economical and sustainable especially when bacteria obtained from natural resources were growth. At present, many efforts on yields and efficient processes of photosynthetic bacteria have been intensively studied worldwide. Little study is interested on electricity production by fuel cell supplied BioH2. In this work, the electricity generation estimation for a PEMFC supplied by hydrogen produced by Rhodopseudomonas sp. was reported and the mathematic equations were presented using numerical method. Voltage, current and power of PEMFC data were obtained according to resistance loads. Power estimation is useful for small PEMFC study and application of biological hydrogen produced by purple nonsulfur bacteria in future work.

**Index Terms—** Fuel Cell, PEMFC, Biological hydrogen, Hydrogen, Electricity, Technology.

## I. INTRODUCTION

Electricity is the most importance form of energy in the modern world for every life. Most of Fossil fuel sources are commonly used for electrical power generation by centralized power plants and contribute to huge amount of greenhouse gas emissions. Instead of coal, oil, and natural gas burning processes, hydrogen from biological processes are less expensive, renewable, and sustainable using natural microorganisms. Hydrogen as gas or liquid fuels can be applied to fuel cell to generate electricity. Fuel cell is in commercial state and it is the zero emission electrochemical device which convert fuels to electricity with supplied hydrogen and oxygen. Fuel cell technology is in commercial stage and the available size in market ranges from a few wattage to several MWs. PEMFC requires hydrogen and oxygen as fuel to operate at room temperature and given water vapor as the only by product. Several methods have been developed to generate hydrogen such water electrolysis, chemical processes, or biological processes. Hydrogen productions by biological processes using purple nonsulfur bacteria (PNSB) are the emerging clean and sustainable development and many research projects on hydrogen productivity ability show good performances. Several bacteria strains were studied of hydrogen production conditions [1]. T. Assawamongkholsiri studied the photofermentation and lipid accumulation of Rhodobacter sp. KKU-PS1. The maximum hydrogen production rate by Rhodobacter sp. KKU-PS1 was 13.2 mL H2/h [2]. A. N. Khusnutdinova and P. Phankhamla found new tolerant strains of purple nonsurfur bacteria for hydrogen production [3, 4]. Matthew R. Melnicki, et al., investigated the hydrogen production and growth rate of the purple photosynthetic bacteria Rhodospirillum rubrum UR2 and Rhodopseudomonas palustris CGA009 [5]. J. Miyake worked on the simulation of the daily sunlight irradiation pattern on photosynthetic bacterium Rhodobacter sphaeroides RV for photohydrogen production. Only 1% light energy conversion efficiency was reported [6]. Robert L. Uffen focused on the bacteriochlorophyll and carotenoids synthesized by cells grown anaerobically under dark and light conditions of purple nonsulfur photosynthetic bacteria. It was found that the ultrastructure of the photosynthetic apparatus in cells grown anaerobically in the dark is similar to in the light [7]. N. Y. Yusuf reviewed the hydrogen production issues concerning biological pathway and fuel cell. The purification system is essential to purify biohydrogen to 99.99% to prevent negative impact on fuel cell performance and durability [8]. There is no report on mathematic model of power and voltage characteristics of fuel cell with biohydrogen based on changing resistive load. In this paper the power and voltage characteristics of a small PEMFC supplied with biohydrogen produced by Rhodopseudomonas pentothenatexigens is presented. The mathematic equations were developed from the experimental data by the least squares method to estimate the electricity in the form of power output. As the power output is related nonlinear with voltage and load values. The knowledge derived from this study is a very useful tool for choosing desired fuel cell power or voltage operation point or the maximum power point. For other fuel cell types and bacteria strains different power estimations should be considered.

## II. BACKGROUND

### A. PEMFC

PEMFC is an electrochemical device that converts

hydrogen gas and oxygen gas to DC electricity. The output current and voltage at a certain load depends on several factors such as type of mediator, surface area the gas entrance, gas concentration, etc. The only byproduct of PEMFC is heated water.

The involved reaction on anode side and cathode side are written respectively as,

$$2H_2 \rightarrow 4H^+ + 4e^- \quad (1)$$

$$O_2 + 4e^- + 4H^+ \rightarrow H_2O \quad (2)$$

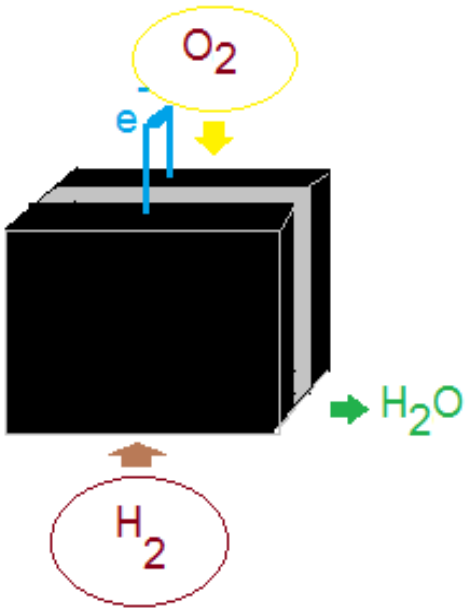



**Fig.1.Construction of a PEMFC**

A small PEMFC, Horizon PEM Reversible FC FCSU-023 Model, was selected. Its specification has rated voltage and current of 0.6 V and 360 mA. A unit of PEMFC was connected to bioH2 .Power of PEMFC at any operating condition can be calculated by eq.(3).

$$P_i = V_i * I_i \quad (3)$$

Where Vi and Ii are output voltage and current at point i.

Thus the rated power output of the PEMFC is 0.21 W (210 mW), the surface area is 6.76 cm2 (2.6 cm x 2.6 cm).

## B. Hydrogen Production by PNSB

Rhodopseudomonas pentothenatexigens, new thermotolerant purple nonsulfur bacteria found by Phakhamla et. al. at Khon Kaen University, Thailand were selected due to the high H2 production ability [1]. The isolations of Rhodopseudomonas sp. were incubated anaerobically under LED light source at room temperature (26-29 °C) in laboratory. The Omerod medium was composed mainly of glutamic acid 9g L-1 as nitrogen source and malic acid 8g L-1 as carbon source. The evolved gas was collected from a bubble trapped bottle then supplied to fuel cell to generate electricity.



**Fig.2. Hydrogen production by the proposed PNSB**

## C. Mathematical Model

A numerical method, Least squares method is a simple and accurate procedure to determine the best curve fitting line [9]. The mathematic equation of the best line (y) or the estimation line can be simply written as;

$$y = a_0x^0 + a_1x^1 + .. + a_mx^m \quad (4)$$

Where

a0, a1,.., am are the coefficients in the sequence of 0,1,..,m

x is the data set

For the best fitting curve line (y), the estimation line must have minimum error (Err) for all coefficients ($a_0$ to $a_m$).

$$E = \sum_{n=1}^{N}(y_n - y)^2 \quad (5)$$

All coefficients can be determined by Eq.(6) and they must minimize value of Err.

$$\frac{\partial E}{\partial a_0} = 0$$

$$\frac{\partial E}{\partial a_1} = 0 \quad (6)$$

(3)

$$\frac{\partial E}{\partial a_m} = 0$$

Then the equations obtained can be written as;

$$\left.\begin{aligned} a_0\left(\sum_{n=1}^{N}1\right) + a_1\left(\sum_{n=1}^{N}x_n\right) + .. + a_m\left(\sum_{n=1}^{N}x_n^m\right) &= \sum_{n=1}^{N}y_n \\ a_0\left(\sum_{n=1}^{N}x_n\right) + a_1\left(\sum_{n=1}^{N}x_n^2\right) + .. + a_m\left(\sum_{n=1}^{N}x_n^{m+1}\right) &= \sum_{n=1}^{N}x_n y_n \\ \downarrow \qquad\qquad\qquad\qquad\qquad\qquad \downarrow & \\ a_0\left(\sum_{n=1}^{N}x_n^m\right) + a_1\left(\sum_{n=1}^{N}x_n^{m+1}\right) + .. + a_m\left(\sum_{n=1}^{N}x_n^{m+m}\right) &= \sum_{n=1}^{N}x_n^{m-1}y_n \end{aligned}\right\} \quad (7)$$

Denote matrix form as [A], [X],[B] in eq.(8).

[A][X] = [B] (8)

Where Where

$$[X] = \begin{bmatrix} a_0 \\ \vdots \\ a_m \end{bmatrix}$$

Solve the linear algebra problem for the coefficients.

$[X] = [A^{-1}] [B]$ (9)

## III. RESULTS AND DISCUSSION

### 3.1. Biohydrogen production by PNSB

PNSB were growth under anaerobic condition under artificial light. Evolved gas was collected and then supplied to small PEMFC at anode and oxygen was provided at cathode as shown in Fig.3. oxygen was generated by electrolyzer from water. Each of hydrogen and oxygen volume of 30 mL was noted at the beginning of the experiment.

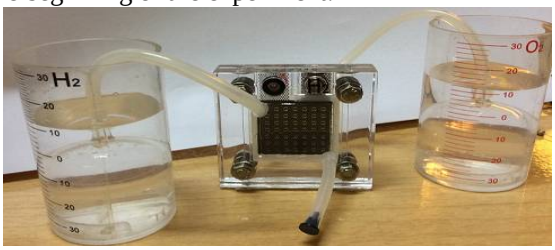



**Fig.3. PEMFC Experiment set-up**

The resistive load was placed at the positive and negative sides of PEMFC and the output voltage and current ($V_{FC}$, $I_{FC}$) data were recorded according to resistive load. Then power output was calculated.

### 3.2. Mathematic Model

The approximated lines by least squares method were determined for the data set (FC output power and voltage pairs) for two and three coefficients as shown in Fig.4. The resistive load was placed at the positive and negative sides of PEMFC and the output voltage and current (VFC, IFC) data were recorded according to resistive load. Then power output was calculated.

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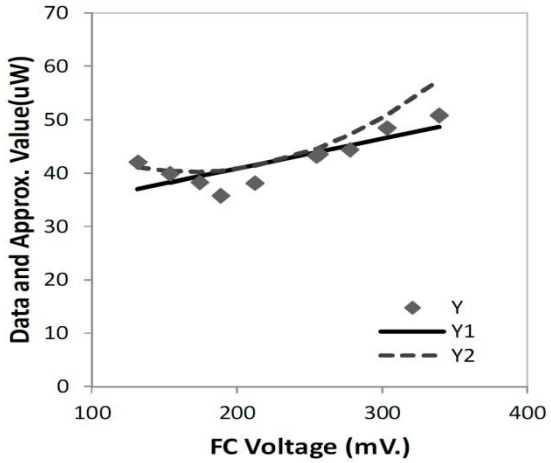



**Fig.4. The power-voltage approximation lines**

Fig.4 shows the plot of the measurement data and the approximated lines. $y_1$ and $y_2$ are power point corresponding to voltage at any point(x). The power estimation straight line or first order equation ($y_1 = a_0 + a_1.x$ ) and the curve line or second degree equation ( $y_2 = a_0 + a_1.x + a_2.x^2$ ) are less than 0.98% RMSE. The power estimation has high accuracy to fit the data set. The mathematic equation with coefficients of both lines can be presented as;

$y_1 = 29.7022 + (0.0558*x)$

$y_2 = 57.5839 – (0.2040*x) + (0.0006*x^2)$

It was also observed that the output power of fuel cell fed with bioH2 increases when the voltage is increased (low resistive value). Although the voltage and power as high as 339mV and 50.9 µW was generated at high resistive load (2000 ohm in this study) however the efficiency of the fuel cell fed with bioH2 is very low (less than 1%).With resistive load between 400 and 1000 ohm the power is 75% of the power generated at 2000 ohm resistive load. This finding suggested that power varied with voltage due to resistive load for small PEMFC based bioH2 produced by Rhodopseudomonas sp. Other purple nonsulfur bacteria gives result in different characteristics of PEMFC, especially power generation at different resistive loads.

## CONCLUSION

In this paper, the electricity generation estimation for a PEMFC supplied by biological hydrogen produced by purple nonsulfur bacteria, Rhodopseudomonas sp., was reported. The least squares method was implemented to find the mathematic equations presented power and voltage relationship. Power of small PEMFC depends on resistive loads. Load selection play significant role of power generation by PEMFC. The proposed power estimation using least square s method provide useful for small PEMFC study and application supplied with biological hydrogen in future work.

## ACKNOWLEDGMENT

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