Jurnal
Teknologi

Full Paper

HYDROGEN PRODUCTION BY INFRARED LASER ELECTROLYSIS ON NACL SOLUTION

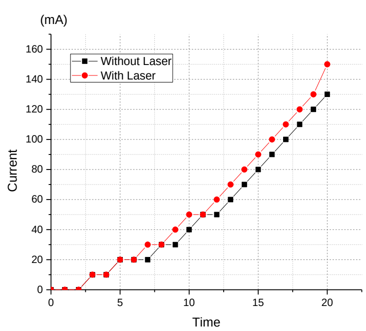
N. E. Khamsan*, Ganesan Krishnan, N. Bidin

Laser Center, Ibnu Sina Institute for Scientific and Industrial Research, (ISI-SIR), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

Article history
Received
10 October 2014
Received in revised form
10 December 2014
Accepted
13 January 2015

*Corresponding author
nur.ezaan@gmail.com

Graphical abstract



Abstract

A method referred as Hydrogen Production by Infrared assisted Electrolysis (HyPIR) is presented in this work. Two graphite electrodes are immersed in electrolytic cell containing 0.517 g of NaCl and 7 ml of ethanol C_2H_5OH solution which act as supplements for a partial oxidation reaction. Erbium YAG laser with wavelength of 2.94 µm and 57.6 mJ energy per pulse at a pulse rate of 4 Hz is illuminated directly on the electrolytic solution. The irradiating light facilitates the dissociation of water by stretching the inter-atomic hydrogen-oxygen bonds in the electrolytic solutions and directly increase the rate of hydrogen yields.

Keywords: Hydrogen production; Er:YAG; electrolysis; NaCl

Abstrak

Satu kaedah yang disebut sebagai Penghasilan Hidrogen oleh Inframerah Elektrolisis terbantu (HyPIR) dibentangkan dalam kajian ini. Dua elektrod grafit direndam dalam sel elektrolisis yang mengandungi 0.517 g NaCl dan 7 ml larutan etanol C_2H_5OH yang bertindak sebagai tambahan untuk tindak balas pengoksidaan separa. Erbium YAG laser dengan panjang gelombang 2.94 µm dan 57.6 mJ tenaga per denyut pada kadar nadi 4 Hz diterangi secara langsung pada larutan elektrolisis. Lampu penyinaran memudahkan penceraian air dengan meregangkan ikatan hidrogen-oksigen antara atom dalam larutan elektrolisis dan secara langsung meningkatkan kadar penghasilan hidrogen.

Kata kunci: Penghasilan hidrogen; Er: YAG; elektrolisis; NaCl

1.0 INTRODUCTION

Hydrogen production technology is considered as one of the most important topic studied by the scientific community due to its potential application in sustainable energy system [1]. Basically, hydrogen can be considered as chemical energy carrier which is proven to be utilized in carbon-free energy consumption process [2, 3]. Due to this special characteristic offers by hydrogen, the world is looking into possibility of a future transition to a total hydrogen-based economy.

To date, mass production of hydrogen is employed from different method including electrolysis [4], steam reforming of fossil fuels [5, 6] and coal gasification [7]. Among all these methods, electrolysis technique holds great potential in sustainable hydrogen energy supply while the other techniques still facing the old existing problem of non-renewable and also imposed a major drawback towards environmental system due to pollution [8-10].

Majority of research works on hydrogen production by electrolysis are mainly focused on enhancement of the process efficiency. There are several factors that influence the hydrogen production rate including the electrolyte quality, surrounding temperature, pressure, size, and alignment of electrode and many more [11, 12]. To the best of our knowledge, less attention has been given on the effect of external field radiation on the electrolyte solution towards the hydrogen production rate.

In this work, enhancement of hydrogen production was demonstrated via electrolysis of NaCl solution with the direct irradiation of infrared laser on the electrolyte solution. Relation between hydrogen production rate and external field provided by the laser beam is examined while the other factors are kept at constant value.

2.0 EXPERIMENTAL SET-UP

A schematic diagram of the experimental setup is shown in Figure 1. Two electrodes of graphite rods were immersed in 250 ml of distilled water. About 0.517 g of NaCl and 7 ml of ethanol C_2H_5OH are used as supplements for a partial oxidation reaction. These supplements were added into the water to make an electrolytic solution. Only small amounts of ethanol are needed in order to prevent flaming and combustion that may occur with the partial oxidation reaction. The experiment was conducted at ambient temperature under normal atmospheric pressure.

The hydrogen and oxygen yields are collected by using different test tubes. The test tubes are initially filled with water and positioned over a negative and positive electrodes respectively. Hydrogen are generated on the negative terminal. The water level inside the test tube act as an indicator for the hydrogen volume measurement. The hydrogen gas volume was measured for every 60 second during the electrolysis process where a DC voltage was applied between those two electrodes. For comparison purposes, two different measurements were recorded simultaneously. The first set of data was obtained through a conventional electrolysis process while the other set of data was obtained with the present of Erbium YAG laser illuminated directly on the electrolytic solution as shown in Figure 1.

A graphite cylinder with diameter of 3 mm is chosen to be the electrodes because carbon does not dissolve in water under the influence of an electron current and carbon also is electrically neutral. A rectangular molybdenum foil with dimension of 2 x 1 cm^2 is used as a sacrificed agent to protect the cathode electrode from a slow decay. The molybdenum foil is cut into a rectangular shape to expose as much metallic area as possible to the electrolytic solution. Erbium-YAG laser with a wavelength of 2.94 μm was selected for this experiment. The laser provided a beam of light with 57.6 mJ energy per pulse at a pulse rate of 4Hz. Copper wires are used to connect both electrodes to a DC power supply. A steady voltage from DC power supply provides enough current to cause the decomposition of water. In this experiment the voltage was varies from 0 to 20 V accordingly.

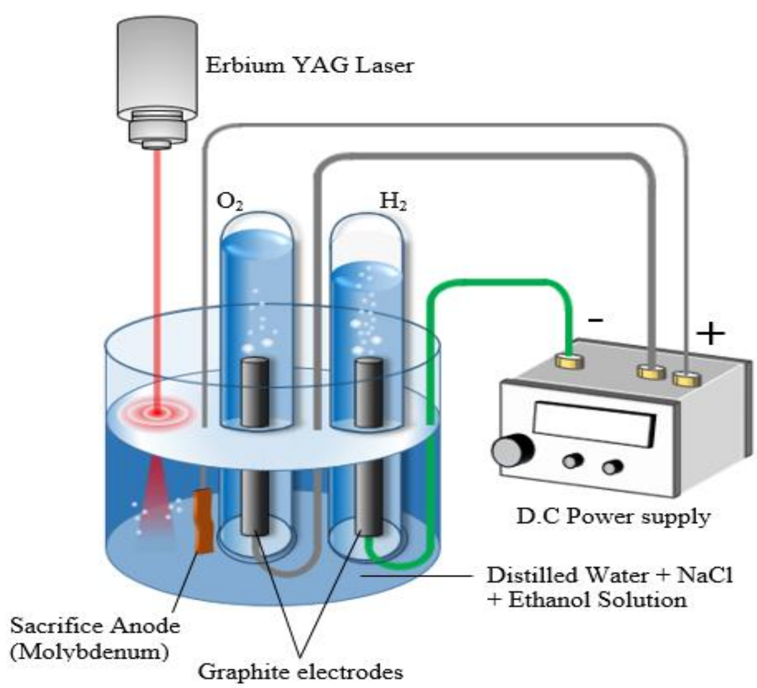


Figure 1 Schematic diagram of experimental set-up

3.0 RESULTS AND DISCUSSION

Two different electrolysis systems are designed in which one system is having Erbium-YAG laser irradiated on its electrolytic solution. Input voltage of the DC power supply is varied from 0 to 20 V. Hydrogen and oxygen gases produced at cathode and anode terminals are observed and recorded for both systems. These reactions occurred according to relations:

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad (1)$$

$$H_2O \rightarrow 2H^+ + (1/2)\, O_2 + 2e^- \quad (2)$$

For convenience of analysis, volume of hydrogen yields are plotted against the applied DC voltage as presented in Figure 2. Result shows that the amount of hydrogen yields increase with the increment of applied DC voltage for both systems with or without the influence of Erbium-YAG laser. It is shown that volume of hydrogen gas produced is exponentially proportional with respect to the applied DC voltage. However, the production of hydrogen was quiet better when laser was used as an irradiating external source. Towards the end of the experiment, a prominent increased of hydrogen production is clearly noticed for the system with the influence of Erbium-YAG laser. For further analysis, hydrogen production rates are calculated and plotted against the applied voltage for both systems. Hydrogen production occurred more quickly in higher voltage experiments than in lower voltage experiments, possibly due to the raise of temperature after the absorption of IR.

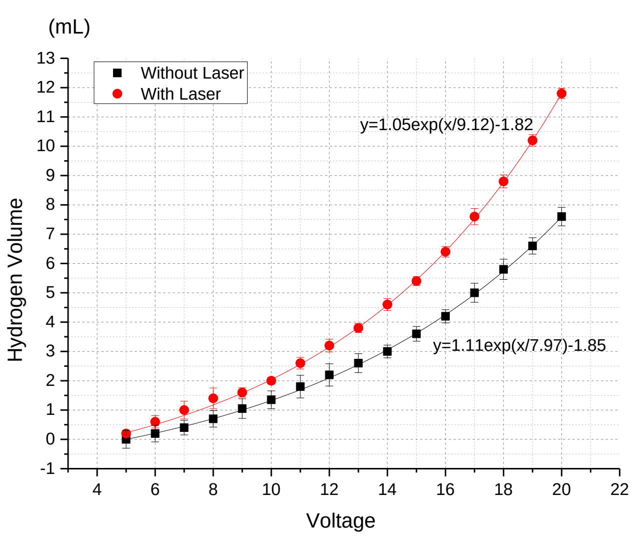


Figure 2 Average hydrogen production with respect to DC voltage

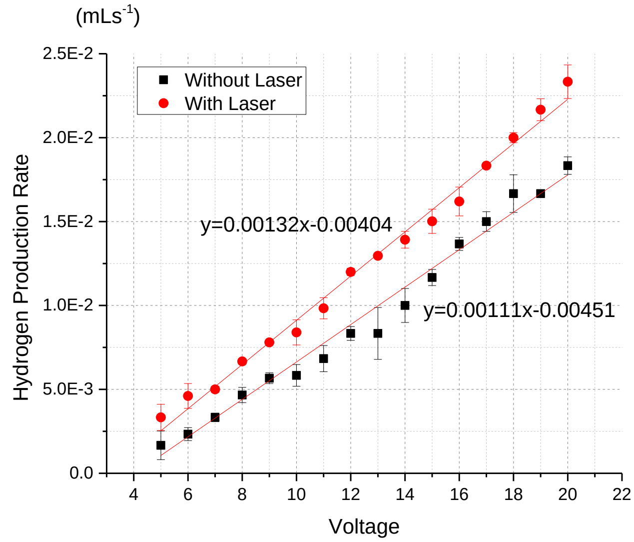


Figure 3 Hydrogen production rate with respect to DC voltage

The hydrogen production rate with respect to DC voltage are shown in Figure 3. The experimental result shows that the hydrogen production rate exhibit linear dependency on the DC voltage applied through the electrodes. The lowest production rate are recorded around 0.0183 mLs^{-1} corresponding to the electrolysis system without applied laser beam. As clearly shown from the figure, electrolysis system with laser beam illuminated on the electrolytic solution possess significantly higher hydrogen production rate as compare to the system without the illumination of laser. Analytical analysis shows that the red line are having greater slope calculated around 0.00132 $mLs^{-1}V^{-1}$. Basically, performance of the systems are determined from the efficiency of the hydrogen production process. Efficiency, η is calculated as the ratio between the amounts of hydrogen collected experimentally and the amount of hydrogen produced theoretically, which is calculated based on the consumed charge during experiment. The relations are given as:

$$\eta\% = \frac{V_{H_2}^R}{V_{H_2}^T} \times 100 \quad (3)$$

Where $V_{H_2}^R$ is the volume of hydrogen measured directly from electrolysis with the infrared laser beam, and $V_{H_2}^T$ is the volume of hydrogen theoretically calculated from the charge value which is given by:

$$V_{H_2}^T = (Q/2F)(RT/P) \quad (4)$$

From the equation above, Q is defined as consumed charge where Q=It. I is the induced current measured directly from the experiment and t is time. The term F is known as Faradays constant and the value is 96485 $Cmol^{-1}$. R is the molar gas constant, P is the pressure and T is the temperature reading in Kelvin.

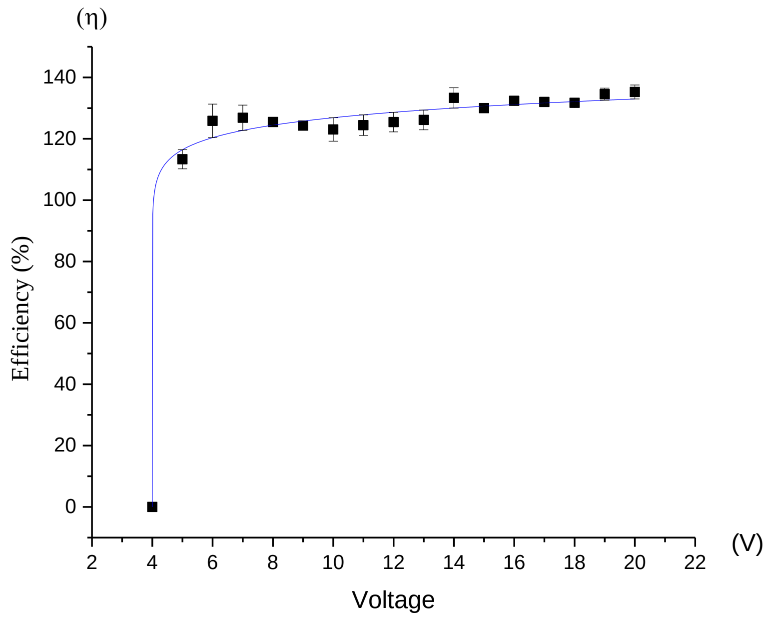


Figure 4 Efficiency of hydrogen production with respect to DC voltage

3.2 Object Highlighting

Figure 4 represents the efficiency of hydrogen production process with respect to applied DC voltage. It is observed that the process efficiency increases rapidly to 113% when the voltage is increased to 5V as the hydrogen gas starts to accumulate on cathode electrode around this point. Hydrogen production efficiency continues to increase as magnitude of the applied voltage increases and it reach maximum value of approximately 135% at corresponding voltage of 20 V. Thus, it is found that the efficiency of this system is greater than the normal Faradic efficiency. This phenomenon occurs due to the present of external IR laser irradiation during the electrolysis process.

Table 3.1 Vibrational modes of water

Vibrational Mode	Wavelengths (μ)
Bending	6.270
Symmetric stretch	2.734
Asymmetric stretch	2.662

In this experiment, a collimated and coherent beam of Erbium-YAG laser with a wavelength of 2.94 μm is selected as the external IR laser source. This specific type of laser offers a unique characteristic where the photon energy at this wavelength is readily absorbed in water. As references, wavelengths of the vibrational modes of water molecules are shown in Table 3.1. Basically, thermal motion and collision between molecules and phonons cause the band of wavelength that can be affected by the laser beam to broaden. In this experiment, introduction of the laser beam into the electrolyte solutions excites the vibrational modes of the interacting water molecules. This phenomenon directly leads to the stretching of the hydrogen-oxygen bond between the water molecules itself. This excitation of the vibrational modes of water can also appear as a heating effect on the electrolyte solutions since the average motion of the water molecules increased. The crucial different is, a conventional heat source for examples solar heater and oven will distribute the energy separately across three different modes including vibration, translation and rotation of the molecules. Contrary, vibrational modes excitation from the laser beam is more efficient because the photon energy is used to increase the specific vibrational mode of the H-O bond within the molecules and thus enhance the hydrogen production process.

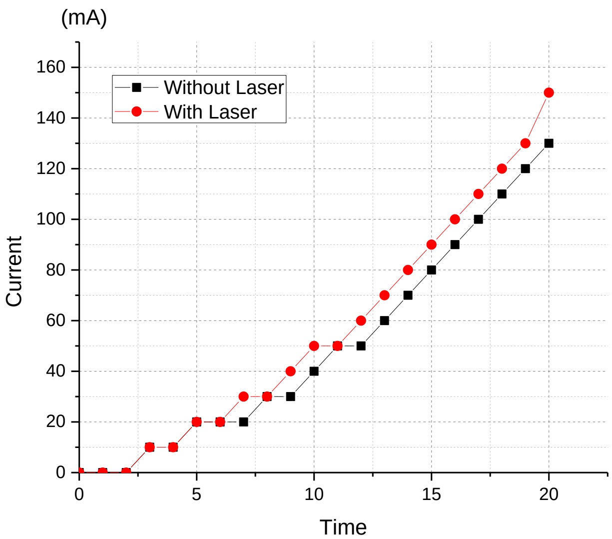


Figure 5 Current reading against time (min)

The present of the laser beam also induces an additional electric fields which is indicated by the increase of current flow within the electrolyte solutions. Figure 5 shows the current reading plotted against time for both experiment with and without the illumination of Erbium: YAG laser. After 20 minutes, highest magnitudes of current are recorded at 150 and 130 mA corresponding to the system with and without laser irradiation respectively. Presumably, this additional field improves the conductivity as well as mobility of the charges in the water electrolysis process and thus, increasing the rate of hydrogen production effectively.

4.0 CONCLUSION

The experimental result of irradiating the electrolytic solution during electrolysis revealed that, the presence of Erbium-YAG laser was highly efficient in production of hydrogen when compared to electrolysis using the same electrolytic solution without irradiation. Laser with a wavelength near the specific vibration mode of the electrolytic fluid causes an increase in the production of hydrogen, when compared to water electrolysis alone. The vibrational modes stretch the inter-atomic bonds of hydrogen in the electrolytic solution.

Acknowledgement

We would like to thank the Laser Center, Ibnu Sina Institute for Scientific and Industrial Research (ISI-SIR), Universiti Teknologi Malaysia (UTM) for providing research facilities.

References

[1] Dincer, I. and G. F. Naterer. 2014. Overview of hydrogen production research in the Clean Energy Research Laboratory (CERL) at UOIT. *International Journal of Hydrogen Energy*. 39(35): 20592-20613.

[2] Guoqiang Zhan, Daping Li, Yong Tao, Xiaoyu Zhu, Lixia Zhang, Yujian Wang, Xiaohong He. 2014. Ammonia as Carbon-free Substrate for Hydrogen Production in Bioelectrochemical Systems. *International Journal of Hydrogen Energy*. 39(23): 11854-11859

[3] Acar, C. and I. Dincer. 2014. Comparative Assessment of Hydrogen Production Methods From Renewable And Non-Renewable Sources. *International Journal of Hydrogen Energy*. 39(1): 1-12.

[4] Kelly, N. A. 2014. Hydrogen Production by Water Electrolysis, in Advances in Hydrogen Production, Storage and Distribution, A. Basile and A. Iulianelli, Editors. Woodhead Publishing. 159-185.

[5] Masao Hori, Kazuaki Matsui, Masanori Tashimo, Isamu Yasuda. 2005. Synergistic Hydrogen Production by Nuclear-heated Steam Reforming of Fossil Fuels. *Progress in Nuclear Energy*. 47(1-4): 519-526.

[6] Stefan Martin, Gerard Kraaij, Torsten Ascher, Penelope Baltzopoulou, George Karagiannakis, David Wails, Antje Wörner. 2015. Direct Steam Reforming of Diesel and Diesel–biodiesel Blends for Distributed Hydrogen Generation. *International Journal of Hydrogen Energy*. 40(1): 75-84.

[7] Yujie Xu, Guiyan Zang, Haisheng Chen, Binlin Dou, Chunqing Tan. 2012. Co-production System of Hydrogen and Electricity Based on Coal Partial Gasification With CO_2 Capture. *International Journal of Hydrogen Energy*. 37(16): 11805-11814.

[8] Bockris, J. O. M. 2002. The Origin of Ideas on a Hydrogen Economy and Its Solution to the Decay of the Environment. *International Journal of Hydrogen Energy*. 27(7-8): 731-740.

[9] Das, D. and T.N. Veziroğlu. 2001. Hydrogen Production by Biological Processes: A Survey of Literature. *International Journal of Hydrogen Energy*. 26(1): 13-28.

[10] Caliskan, H., I. Dincer, and A. Hepbasli. 2013. Exergoeconomic and Environmental Impact Analyses of a Renewable Energy Based Hydrogen Production System. *International Journal of Hydrogen Energy*. 38(14): 6104-6111.

[11] Mazloomi, S. K. and N. Sulaiman. 2012. Influencing Factors of Water Electrolysis Electrical Efficiency. *Renewable and Sustainable Energy Reviews*. 16(6): 4257-4263.

[12] Muzhong Shen, Nick Bennett, Yulong Ding, Keith Scott. 2011. A Concise Model for Evaluating Water Electrolysis. *International Journal of Hydrogen Energy*. 36(22): 14335-14341.