MANUFACTURING AND ASSESSMENT OF A UNIT FOR PRODUCING HYDROGEN GAS FROM WATER

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ABSTRACT

The main objectives of this research were to design a small unit for the production of hydrogen gas from water, to rationalize the use of energy needed for the separation of hydrogen. Also determine the water quality for hydrogen production, and test the optimal geometry for producing higher levels of hydrogen gas. The experimental results of hydrogen cells production unit are presented. It is used for electrical analysis of three types of water (tap - acidic - saline). The results obtained showed that the highest production of hydrogen energy was observed with 15 cells number was 5.12 kWh at working time 60 min, distance between cells 0.5 mm, cell temperature 46.7°C and water temperature 56.1°C in the presence of saline water. At same time the lowest hydrogen energy observed with number of cells 15 cells number was 1.788 kWh, working time 15 min, distance between cells 1.5 mm, cell temperature was 30.6°C and water temperature was 29.9°C in the presence of tap water. Total energy was increased by 186.52%, increasing number of cells and lack of distance between cells.

INTRODUCTION

Hydrogen gas is pure, high quality fuel, environmentally friendly and can be used to operate engines to achieve various agricultural operations, generate electricity, using simple energy of electricity as a source from water analysis. hydrogen and oxygen can be produced from water using electricity with an electrolyzed. **Walt et al. (1994)** Stated that the installation and operation of a 12 cell Hydrogen Wind Inc. 1000 Watt electrolyzed. This electrolyzed can produce 170 liters/hour (6 cubic feet/hour) of hydrogen and 85 liters/hour (3 cubic feet/hour) of oxygen (at standard temperature and pressure).

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Hailed et al. (2001) declared that the fuel cell generally consists of two electrodes, the anode and the cathode, separated by an electrolyte. Fuel cells high temperature based on molten carbonate (MCFC) or solid oxide (SOFC) technology operate at sufficiently high temperatures to run directly on methane. This is sometimes called "internal reforming." Thus, MCFC and SOFC systems do not need a pure or relatively pure hydrogen stream as do proton exchange membrane (PEM) and phosphoric acid (PAFC) systems, but can run directly on natural gas or biogas or landfill gas. **Andre at el. (2001)** searched every fuel can liberate a fixed amount of energy when it reacts completely with oxygen to form water. This energy content is measured experimentally and is quantified by a fuel's higher heating value (HHV= 141.86 MJ/kg) and lower heating value (LHV = 119.93 MJ/kg). The difference between the HHV and the LHV is the "heat of vaporization" and represents the amount of energy required to vaporize a liquid fuel into a gaseous fuel, as well as the energy used to convert water to steam**. Trygve et al. (2006)** stated the total energy that is needed for water electrolysis is increasing slightly with temperature, while the required electrical energy decreases. A high-temperature electrolysis process might, therefore, be preferable when high-temperature heat is available as waste heat from other processes. **Kaveh et al. (2012)** The main reason was stated to be the shrinking effect of pressure on the gas bubbles which cause the comic voltage drop and power dissipation to reduce. Moreover, high pressure electrolysis has less power demand for the phase of product compression. They conducted their experiments were conducted in a typical three compartment electrolyte with a varying temperature between 25°C and 90°C. Cell current density was kept at 1 am cm^{-2} with an electrolyte of either a 34% wt or 25% wt KOH solution in distilled water. **Romdhane (2013)** According to the type of used electrolyte (tap water, margin, gas, liquor, waste water from cooking, puckered olive, urine, vinegar of pink, municipal waste water and finally milk, water), there is variation of the hydrogen flow rate produced by supplying the electrolytes in electrical current by the photovoltaic module as the energetic efficiency does not change often in the same direction as the produced hydrogen flow. This voltage is not the operating voltage of fuel cell have shown us. Our first task is to show why the initial theoretical voltages are different. By applying alone we can see that the EMF of the fuel cell is directly dependent on the desired operational temperature, this is the case because we have seen in the last chapter that volume is directly dependent on temperature. **Jyothi1 and Reddy (2014)** enabled such systems can be designed to produce additional purified hydrogen as a byproduct (e.g. for use as a vehicle fuel), by feeding additional fuel and then purifying the hydrogen-rich “anode tail gas” from the fuel cell into purified hydrogen. **(Ogden 2014)** Hydrogen production via electrolysis of water seems to be the most viable method. A small unit to produce hydrogen gas from stainless steel was designed with a number of cells (9, 11, 13, 15 cells), cell distance (1.5, 1.0, 0.5 mm), duration of unit operation (15, 30, 45, 60 min) and Type of water (Tap water, Acidic water and Saline water (sea water in particular)). The water temperature and temperature of the cell were measured to show the extent of their effect and the effect of the study factors on the quantity of produced gas (l/h) and the quantity of energy produced and consumed (kWh).The main objectives of this work to design a small hydrogen gas production unit to produce hydrogen gas from different water type and evaluation of the process of producing hydrogen gas.

MATERIAL AND METHODS

This research work was carried out at Gemmeiza Agricultural Research Station, Department of Agricultural Engineering and Agricultural Research Center in Giza, to investigate the possibility of manufacture a small unit to producing hydrogen gas from water.

Study parameters

Four different study parameters were investigated including water type, space between cells and working time.

* Water type (Tap - Acidic - Saline (sea water in particular)).
* Distance between cells (0.5 - 1.0 - 1.5 mm).
* Number of cells were used (9 - 11 - 13 - 15 cells); the highest efficiency was number of cells (15 cells).
* Working time (15 - 30 - 45 - 60 - 75 - 90 - 105 - 120 - 135 - 150 min).

The hydrogen production unit

The production unit of hydrogen gas consisted of a group stainless sheets of negative and positive poles. Between each two successive stainless steel sheets. Gasket **"Aspects"** was uses to avoid leakage of both water and hydrogen gas. Gaskets were also used to control the distance between cells. Acrylic covers of 30 cm * 35 cm were used to cover and link the whole unit.

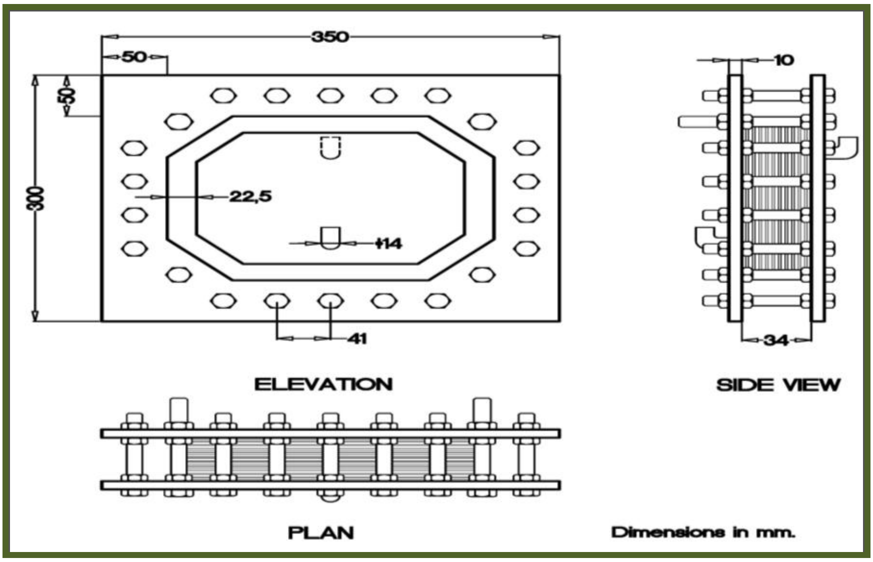


Figure (1): The hydrogen gas production unit, plan, elevation and side view.

Measurement of current intensity and voltage.

MY-61 Digital Multimeter/Volt/Amp/Diode/Ohm/Capacitance tester Transistor VEJ56 T18 0.5 was used for measuring current intensity and voltage.

- Principles of electrolysis

The principle chemical equations are shown in reaction 1, where the electrochemical flow is shown for acidic and alkaline environments. This work involves the alkaline reaction pathway.

$$\text{Net Reaction:} \quad H_2O \rightarrow H_2 + \frac{1}{2} O_2 \qquad (1)$$

Acidic Reaction	Alkaline Electrolysis
Anode: $H_2O \rightarrow \frac{1}{2}O_2 + 2H^+ + 2e^-$	$2OH^- \rightarrow \frac{1}{2}O_2 + H_2O + 2e^-$
Cathode: $2H^+ + 2e^- \rightarrow H_2$	$2H_2O + 2e^- \rightarrow H_2 + 2OH$

- Fuel Cell Efficiency

Fuel cell efficiency is commonly taken to mean the actual efficiency of the electrochemical reaction. This efficiency can be derived as follows.

The amount of energy released when hydrogen and oxygen combine to form water according to the reaction $H_2 + ½O \rightarrow H_2O$ is quantified as the "enthalpy of reaction" (ΔH°). This value is measured experimentally and depends on whether the water is formed as a gas or a liquid. For fuel cells, the water forms as a gas and the enthalpy of reaction is known to be:

$$\Delta H^{o} = -230 \frac{BTU}{mole_{water}} = -242 \frac{KJ}{mole_{water}} \quad (2)$$

$$mole_{water} = 6.023 * 10^{23} \text{ molecules of water} \quad (3)$$

This value of the enthalpy of reaction is only strictly correct at 25ºC and 1 atmosphere.

Gibbs free energy" (ΔG°) for gaseous water at 25°C and 1 atmosphere this is known to be: The negative sign denotes that the energy is released during the reaction, and not absorbed. Gibbs free energy can be determined from the following equation.

$$\Delta G_{gas} = -217 \frac{BTU}{mole_{water}} = -229 \frac{KJ}{mole_{water}} \quad (4)$$

The voltage of each cell (**ε_{cell}**) is related to the Gibbs free energy according to the equation:

$$\mathcal{E}_{cell} = -\frac{\Delta G^{o}}{n\,\mathcal{F}} \quad (5)$$

Where:

n = Number of electrons involved in the reaction. This is most conveniently Expressed as "mole of electrons" (or mole e^-) where each mole e^- is equal to $6.023x10^{23}$ electrons. From the anode and cathode reactions ($H_2 \rightarrow 2H^+ 2e^-$ and $½ O_2 + 2e^- + 2H^+ \rightarrow H_2O$**)** two electrons are involved in the formation of each water molecule. Thus n = 2 mole e^- for every 1$mole_{water}$ formed.

$\mathcal{F}$ = Faraday's constant. Equal to 96.500 coulombs/mole e^- Coulombs are Aunt of electric charge.

Substituting values into the equation (using imperial units):

$$\mathcal{E}_{cell} = -\frac{-217\,BTU}{mole_{water}} x \frac{1055.7\ J}{BTU} x \frac{mole_{water}}{2\,mole\ e^-} x \frac{mole\ e^-}{96.500\ coul} = \frac{1.187\ J}{coul} = 1.187\ V \quad (6)$$

Similarly, using metric units:

$$\mathcal{E}_{cell} = -\frac{-229\,BTU}{mole_{water}} x \frac{1000\ J}{KJ} x \frac{mole_{water}}{2\ mole\ e^-} x \frac{mole\ e^-}{96.500\ coul} = \frac{1.187\ J}{coul} = 1.187\ V \qquad (7)$$

Thus each cell can generate a maximum theoretical voltage of 1.187V (at 25ºC and 1 atmosphere). The fuel cell efficiency is therefore simply the proportion of the actual voltage the cell produces with respect to this theoretical maximum:

$$Efficiency_{cell} = \frac{V_{Acuall}}{\mathcal{E}_{cell}} \cong \frac{V_{Acuall}}{1.2\ V} \qquad (8)$$

For a real fuel cell, typical voltages are between 0.5 and 0.6V at normal operating loads and can reach 1.1V at open circuit conditions.

3- Efficiency of the unit for producing hydrogen gas

It was calculated according **Mario et al. (2007)** Equation:-

$$\left(p + \frac{n^2 a}{V^2}\right)(V - nb) = nRT \qquad (9)$$

Where: **V** = Size (m^3)

n = Number of moles.

T = Temperature (°C) **p** = Pressure (P_a) **R** = Constant.

a = Coefficient approximation to the impact of reform pressure.

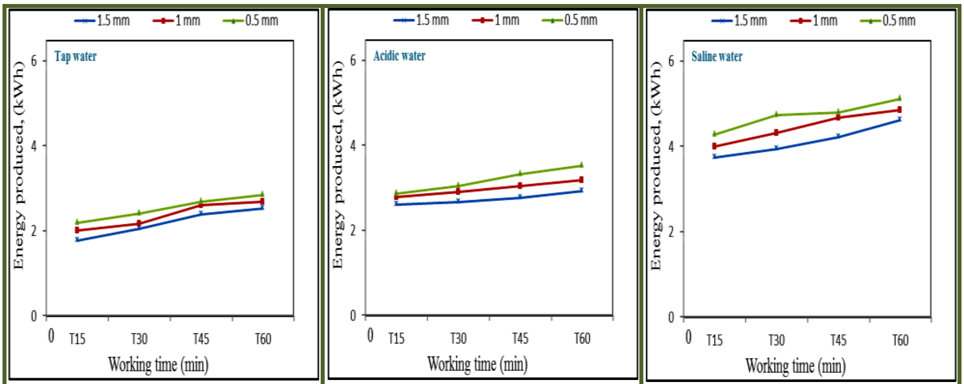
b = Coefficient approximation to reform the effect size.

RESULTS AND DISCUSSIONS

The unit production of hydrogen gas test, data has been collected to get the best set of operating standards under study analysis. The results of this current work discussed under the following headings:

1- Effect of distance between cells and working time on produced energy.

The results showed in Figure (2) that the production of energy after continuous working time 15 min, distance between cells 1.5 mm at number of cells 15 cells with saline water was highest than tap water by 110.46%, and with acidic water by 44.40%. While the production of energy after continuous working time 60 min, distance between cells 0.5 mm at number of cells 15 cells with saline water was highest than tap water by 79.50% and with acidic water by 44.84%. This is evident from hydrogen gas production unit using tap water and working time (15 to 60 min). The lowest energy of hydrogen gas was (1.788, 2.055, 2.396, 2.454 kWh) with distance between cells 1.5 mm at number of 15 cells. While the highest hydrogen gas capacity was (2.185, 2.409, 2.688, 2.854 kWh) continuous working time (15 to 60 min) with distance between cells 0.5 mm at number of 15 cells. While the hydrogen gas production unit using acidic water had the lowest



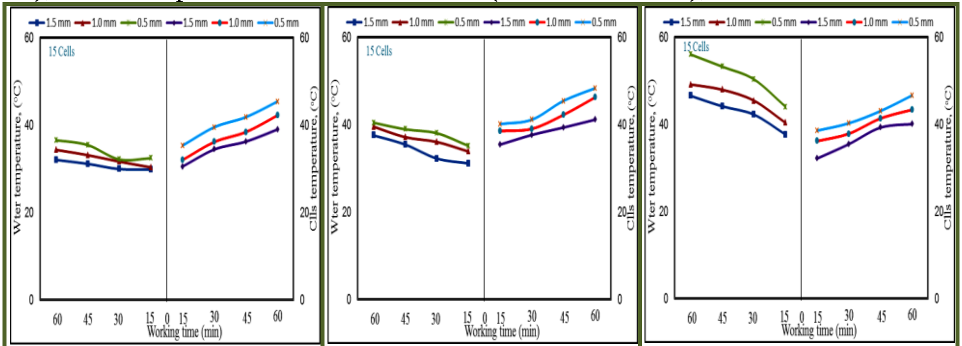
15 Cells | 15 cells | 15 cells

Figure (2): Effect of working time and distance between cells on produced energy (kWh) with three types of water.

energy capacity of (2.606, 2.667, 2.767, 2.491 kWh) continuous working time (15 to 60 min), with distance between cells 1.5 mm at number of cells 15 cells. While the highest hydrogen energy was (2.881, 3.058, 3.332, 3.537 kWh) continuous working time (15 to 60 min) with distance between cells 0.5 mm at number of 15 cells. While the unit of production of hydrogen gas using saline water was the lowest energy for hydrogen gas (3.763, 3.951, 4.217, 4.624 kWh) continuous working time (15 to 60 min) with distance between cells 1.5 mm at number of 15 cells. While the highest energy for hydrogen gas (4.286, 4.758, 4.791, 5.123 kWh) continuous working time (15 to 60 min) with distance between cells 0.5 mm at number of 15 cells. This is due to the presence of the negative anion (OH^-) and the positive cations group (C^+) found in saline water, which increases the reaction speed in acidic water and tap water.

2- The relationship between working time and distance between cells and their effect on water and cell temperature.

The results shown in Figure (3) the comparison between effect of distance between cells and working time on cells temperature and water temperature and its effect on produced energy. It was found that in hydrogen gas production unit of tap water, the lowest of distance between cells from (1.5 to 0.5 mm) with number of 15 cells at increase in working time from (15 to 60 min), water temperature increased from (29.9 to 36.6 °C), cells temperature increased from (30.6 to 45.5 °C),



Tap water | Acidic water | Saline water

Figure (3): Effect of working time and distance between cells on water and cell temperature

increasing the total produced energy of hydrogen gas from (1.788 to 2.854 kWh). While using acidic water, the lowest distance between cells (1.5 to 0.5 mm), number of 15 cells at increase in working time (15 to 60 min), water temperature increased from (31.2 to 40.5°C), cells temperature increased from (35.5 to 48.4°C), increasing the total produced energy of hydrogen gas from (2.606 to 3.537 kWh). By using saline water, with a lowest distance between cells (1.5 to 0.5 mm) with number of 15 cells and an increase in working time (15 to 60 min), water temperature increased from (37.7 to 56.1°C) and cells temperature from (32.2 to 46.7°C) Increases the total produced energy of hydrogen gas from (3.763 to 5.123 kWh). From the above it is clear that, cells temperature of acidic water was greater than cells temperature of saline water, while acidic water temperature was lowest than saline water temperature. This is due to the fact that acidic reaction is quick and chilly, so the cell absorbs more temperature than in the case of saline water. While saline water is neutral (strong alkaline and strong acidic), water absorption is highest than acidic temperature.

3- Influence of water type consumed and produced hydrogen.

Indicated in Figure (4) the impact of water used in the different types of study in consumed energy and produced energy.

Produced Energy, for the three studid types of water were the averages of results achieved for produced energy when the average distance between cells (0.5, 1.0, 1.5 mm), number of cells (9, 11, 13, 15 cells) and working time (15, 30, 45, 60 min) as the following:

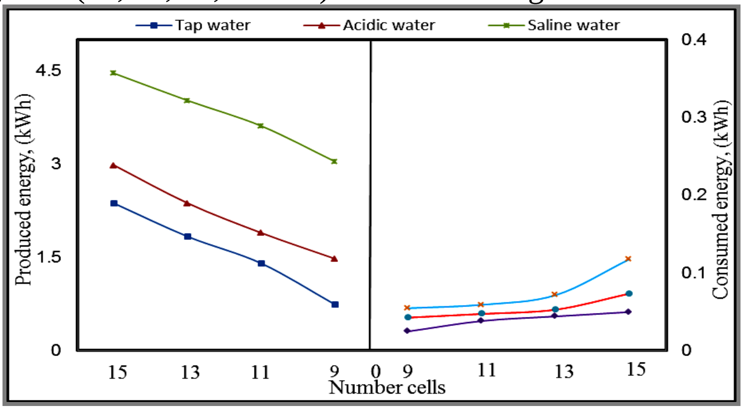
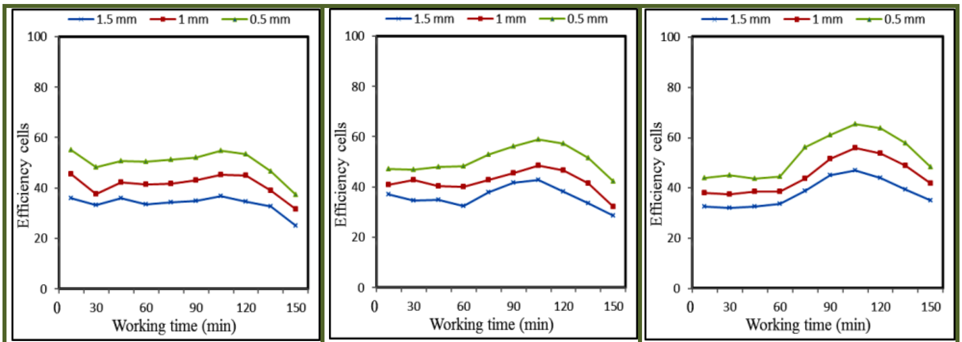


Figure (4): Effect of water types, working time, number of cells and distance cells on produced and consumed energy (kWh).

Tap water, the average minimum value signed for produced energy 0.741 kWh was obtained when the average distance between cells 1.5 mm, number of 9 cells and working time 60 min. Whereas, the highest value for produced energy 2.367 kWh was obtained at number of 15 cells, working time 60 min and the average distance between cells 1.5 mm. **Acidic water,** the average minimum value signed for produced energy 1.478 kWh was obtained when the average distance between cells 1.5 mm, number of 9 cells and working time 60 min. Whereas, the highest value of produced energy 2.979 kWh was obtained at number of 15 cells, working time 60 min and the average distance between cells 1.5 mm. **Saline water,** the average minimum value signed for produced energy 3.040 kWh was obtained when the average distance between cells 1.5 mm, number of 9 cells and working time 60 min. Whereas, the highest value of produced energy 4.458 kWh was obtained at number of 15 cells, working time 60 min and the average distance between cells 1.5 mm. Thus, it is clear from the previous measurements of the difference between the average consumed energy (input) and produced energy (output) that the minimum difference was energy 2.342 kWh for tap water, 2.936 kWh for acidic water and 4.403 kWh for the saline water. Therefore, The best operating and produced energy was obtained from due to the highest value of differences between the consumed and produced energy.

4- Efficiency of hydrogen gas production unit and effect of distance between cells,working time (η°)

Figure (5) During test period, working time (15 to 120 min), distance between cells (1.5 to 0.5 mm) and three types of water (tap - acidic - saline) was the efficiency of cells as follows; In presence of tap water lowest efficiency (25.12%), working time 150 min and distance between cells 1.5 mm. The highest efficiency of cells (54.76%), working time 105 min and distance between cells 0.5 mm.



Tap water | Acidic water | Saline water

Figure (5): Effect of water types, working time and distance between cells on efficiency cells.

In the presence of lowest efficiency acidic water (28.72%), working time 150 min and distance between cells 1.5 mm. The highest efficiency of cells (58.96%), workin time 105 min and distance between cells 0.5 mm. In the presence of lowest efficiency saline water (31.91%), working time 30 min and distance between cells 1.5 mm. The highest efficiency of cells (65.37%), working time 105 min and distance between cells 0.5 mm. In presence of lowest efficiency tap water (25.12%), working time 150 min at distance between cells 1.5 mm. The highest efficiency of cells (65.37%), working time 105 min and distance between cells 0.5 mm at saline water**.** This is because presence of an electrochemical reaction breaks down bonds of its reactors to produced new bonds in resulting materials and to synthesize new materials that are different in their chemical and physical properties. Which results in their deposition on surface of cells, reducing their efficiency by increasing working time.

CONCLUSIONS

The highest produced of hydrogen gas was observed with number of cells 15 cells in the presence of saline water, distance between cells 0.5 mm, working time 60 min, cell temperature 46.7°C water temperature increased to 56.1°C by 5.123 kWh. While the lowest produced of hydrogen gas energy was with number of cells 15 cells in used of tap water, distance between cells was 1.5 mm, working time 15 min), cell temperature was 30.6°C water temperature increased to 29.9°C by 1.788 kWh. Thus the increase with saline water was by (186.52%) the energy produced in the presence of tap water. In the presence of lowest efficiency tap water (25.12%), working time 150 min and distance between cells 1.5 mm. The highest efficiency of cells (65.37%), working time 105 min and distance between cells 0.5 mm at saline water**.**

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الملخص العربى

تصنيع وتقييم وحدة لإنتاج غاز الهيدروجين من المياه

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تم إجراء التجربة بوحدة بحوث الهندسة الزراعية - المحطة البحثية بالجميزة - مركز البحوث الزراعية بالجيزة. وكان الهدف من هذا البحث تصميم نموذج لانتاج الهيدروجين وكذلك تحديد أنسب عدد للخلايا المستخدمة، وانسب مسافة بين الخلايا وزمن تشغيل متغير للوحدة . وكذلك دراسة العوامل التى تؤثرعلى إنتاج طاقة الهيدروجين من استخدام مياه (حمضية – مالحة - ماء صنبور) واختبار عدد الخلايا المناسبة (٩ - ١١ - ١٣ - ١٥ الخلايا) تحت ساعات تشغيل مختلفة (١٥ - ٣٠ - ٤٥ - ٦٠ دقيقة). ؛

وأظهرت النتائج التي تم الحصول عليها أن أعلى إنتاج طاقة هيدروجين لوحظ مع عدد ١٥ خلية ٥,١٢٣ كيلوواط ساعة، وقت تشغيل الوحدة ٦٠ دقيقة، مسافة بين الخلايا ٠,٥ مم، درجة حرارة الخلية ٤٦,٧ درجة مئوية ودرجة حرارة المياه ٥٦,١ درجة مئوية في وجود (ماء ملحي) ماء البحر. وفي الوقت نفسه كان أدنى طاقة هيدروجين لوحظ مع عدد 15 خلية ١,٧٨٨ كيلوواط ساعة، وقت تشغيل الوحدة ١٥ دقيقة، مسافة بين الخلايا ١,٥ مم، درجة حرارة الخلية ٣٠,٦ درجة مئوية ودرجة حرارة المياه ٢٩,٩ درجة مئوية في وجود ماء الصنبور. تم زيادة الطاقة الكلية بنسبة (١٨٦,٥٢ %) من خلال زيادة زمن التشغيل وقلة المسافة بين الخلايا. أظهرت النتائج أيضا، أن أقل كفاءة لوحدة انتاج غاز الهيدروجين (٢٥,١٢ %) مع ماء الصنبور، مسافة بين الخلايا ١,٥ مم، وقت تشغيل ١٥٠ دقيقة وعدد الخلايا ١٥ خلية. أما أعلي كفاءة لوحدة انتاج غاز الهيدروجين(٦٥,٣٧ %) مع ماء ملحي، مسافة بين الخلايا ٠,٥ مم، وقت تشغيل ١٠٥ دقيقة وعدد الخلايا ١٥ خلية.

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