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MAXIMIZE HYDROGEN GAS PRODUCTION FROM A SMALL UNIT USING ACIDIC AND SALINE WATER

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Abstract

The Main objectives for this work design a small hydrogen gas production unit and maximize hydrogen gas from water. A small unit was designed from stainless steel 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 (Acidic water and Saline water (sea water in particular)). The experimental results of hydrogen cells production unit are presented. It is used for electrical analysis of two types of water (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 (2.606 kWh), working time (15 min), distance between cells (1.5 mm), cell temperature was (35.5°C) and water temperature was (31.2°C) in the presence of acidic water. Total energy was increased by 96.47%, increasing number of cells and lack of distance between cells.

Key words: *hydrogen gas, fuel cells, consumed energy, produced energy, cell temperature, evaluate*

INTRODUCTION

Hydrogen is one of the most promising renewable fuels because it can generate from resources like biomass and water. Hydrogen gas energy carrier is growing fast with the development of fuel cells and its application such as the fuel cell, and hydrogen usage as transportation fuel in the form of a compressed gas.

Used Electrolysis of saline water (sea water in particular) is examined as feedstock for the production of hydrogen by electrolysis. Hydrogen could be produced from abundant sources of sea water along with solar energy, for countries where fresh water is scarce. However, due consideration is not given to the availability and quality of raw materials used in the production of hydrogen; this is water. In normal operating conditions, the electrolysis cell behaves to produce H_2 / Cl_2 instead of H_2 / O_2. The experimental results of the electrolysis of a wide range of saline water (0.5 - 7.0% TDS) are presented and explanations are given for two key characteristics of cell operation are the rate of hydrogen production and chlorine evaluation [5].

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 [12].

Enabled such systems can be designed to produced additional purified hydrogen as a by product by feeding additional fuel and then purifying the hydrogen-rich “anode tail gas” from the fuel cell into purified hydrogen [5].

The hydrogen supply options include 'hydrogen production via electrolysis process using renewable and carbon dioxide-free electricity sources such as solar, wind or wave powered electrolysis, gasification of coal, petroleum coke and biomass with carbon dioxide capture and storage technology, the splitting of water by thermo chemical means such as high temperature nuclear and solar heat [10].

Hydrogen gas can be electrochemically produced in microbial reverse-electrodialysis electrolysis cells (MRECs) using current derived from organic matter and salinity-gradient energy such as river water and seawater solutions. Here, it is shown that ammonium bicarbonate salts, which can be regenerated using low-temperature waste heat, can also produce sufficient voltage for hydrogen gas generation in an MREC. The maximum hydrogen production rate was 1.6 m^3 $H_2/m^3 \cdot d$, with a hydrogen yield of 3.4 mol H_2/mol acetate at a salinity ratio of infinite. Energy recovery was 10% based on total energy applied with an energy efficiency of 22% based on the consumed energy in the reactor. The cathode over potential was dependent on the catholyte (sodium bicarbonate) concentration, but not the salinity ratio, indicating high catholyte conductivity was essential for maximizing hydrogen production rates [8].

Studied was proposed to develop a new method for hydrogen production in significant amounts. Furthermore, it was an innovative method for hydrogen production. In fact, SO_2 was fed into a PEM electrolyzed stack. The dissolved SO_2 was oxidized at the anode which led to the production of sulphuric acid; whereas, hydrogen (H_2) was produced at the cathode. This new method was able to treat 3.7 t/day of SO_2 in order to produce 0.116 t/day of hydrogen and recover 5.6 t/day of 35 wt.% H_2SO_4. Results showed that the studied procedure was more economical in terms of energy consumption than the Westinghouse hybrid process. Hence, 67% of the energy needed for the decomposition step. After the presentation of the principles of the new process design, each part of the process was sized. The calculations showed that the number of electrolyzes could be calculated using the same formula used for the number of electrolyzes for water [6].

Hydrogen was produced by electrolysis of formalic acid solutions. The effect of Formic acid and NaOH concentrations on the voltage was studied. The voltage was found to be related to the actual formic acid concentration. When the actual formic acid concentration is higher than 0.8×10^{-9} m, the initial electrical voltage can be low to 0.30 volts, which is much lower than the open circuit voltage in the proton exchange membrane fuel cell. Specifically in 1.0 M Sodium Hydroxide and 4.0 HCO, the constant voltage value increases from 0.62 to 0.70 V with a current density increase of 1.0 to 6.0 mA / cm^2. In 3.0 m HCO and 2.5 M Sodium Hydroxide, the hydrogen production rate is 53 μm / h under 8.0 mA / cm^2 [2].

Found that, electrodes were added with carbon loads in order to control the grain size and with this, the current density for hydrogen evolution in alkaline media. A carbon 1.59 % weight present produced a 3.4 nm grain size and the lowest over potential for the HER at polarization current density 0.12 A/cm^2. In a layer by layer preparation of Ni-Fe-C electrodes on Cu. [13].

Measured slope it was found that nickel Raney added with PTFE increased its electro active area in 102 - 103 times compared to the geometric area. Using Ti, Cr and Fe as additives stable electrochemical performance was seen at 60°C. Changing growth conditions during electro deposition process showed an effect on catalytic properties of nickel alloys, in particular Ni-W, which grown under super gravity conditions [7].

Reported that, electrolysis of both synthetic sea water and Arabian Gulf water were carried out using a simple Hoffman electrolysis apparatus simulated composition of sea water was chosen to cover the range all the way from brackish (say 4,000 ppm) to MSF desalination rejects (say 60,000 ppm). Electrolysis took place under the conditions of: 6 - 20 V, 25 - 126 mA/cm^2 and up to 1000 coulombs of electricity. For the solutions investigated, it was found that the hydrogen production rate was dependent upon the applied current density alone. The quantity of hydrogen produced on a platinum electrode of area l.5835 cm^2 is 85 ml h-1 for 120 mA cm^{-2} current density. Similarly, the rate of hydrogen production increases chemically (follows Ohm's law) with the increase in voltage for natural and synthetic seawater.

However, the rate of increase at low values of voltage, say 6 - 8 V, is rather slow, since the production rate is dependent on the current density. At higher voltages (l0 V and above), the initial conductivity is no longer affecting the current density and the solution behaves like a resistance, with lower resistance at high TDS; hence, the increase in salinity level gives a proportional increase in the hydrogen productivity [4].

Produced hydrogen can be used either directly as a fuel or as a reducing agent in chemical processes. Water splitting can be realized both at low temperatures (typically below 100 °C) and at high temperatures (steam water electrolysis at 500, 1000 °C), while different ionic agents can be electrochemically transferred during the electrolysis process (OH, H^+, O_2). Singular requirements apply in each of the electrolysis technologies (alkaline, polymer electrolyte membrane and solid oxide electrolysis) for ensuring high electro catalytic activity and long-term stability. The aim of the present article is to provide a brief overview on the effect of the nature and structure of the catalyst electrode materials on the electrolyser's performance. Past findings in the development of efficient anode and cathode materials appropriate for large-scale water electrolysis are presented [11.]

There are five major types of fuel cells being known or used in the market. They all have the same basic design as mentioned above, but with different chemicals used as the electrolyte. These fuel cells are: Alkaline Fuel Cell (AFC), Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC), Solid Oxide Fuel Cell (SOFC) and Proton Exchange Membrane Fuel Cell (PEMFC). All the above fuel cells require fairly pure hydrogen fuel to run. However, large amount of hydrogen gas is difficult to transport and store. Therefore, a reformer is normally equipped inside these fuel cells to generate hydrogen gas from liquid fuels such as gasoline or methanol [3, 9].

From these options, hydrogen production via electrolysis of water seems to be the most viable method. The Main objectives for this work design a small hydrogen gas production unit and maximize hydrogen gas from water.

MATERIALS 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 during summer (2016). Four different study parameters were investigated including water type, space between cells, working time and number of cells.

-Water type (Tap - Acidic - Saline)
-Distance between cells (0.5- 1.0 - 1.5 mm).
-Numbers of cells were used (9-11-13-15 cells)
-Working time (15 - 30 - 45 - 60 min).

The water temperature and temperature cell were measured also produced gas (l/h) and the quantity of energy produced and consumed (kWh).

The hydrogen production unit

The production unit of hydrogen gas consisted of a group stainless sheets of negative and positive poles.

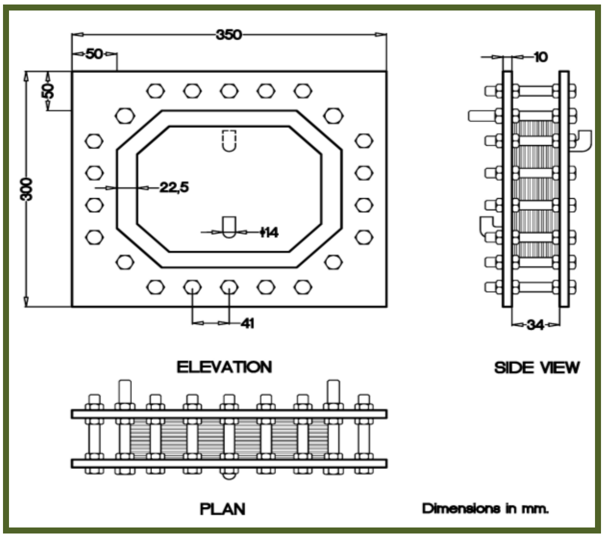

Fig.1.The assembly of fuel cells, plan, elevation and side view of the hydrogen gas production unit.
Source: Own design.

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 25 cm * 35 cm were used to cover and link the whole unit.

Measurement of current intensity

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

1. 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.

Net Reaction: $H_2O \rightarrow H_2 + ½ O_2$ .... (1)

Acidic Reaction

Anode: $H_2O \rightarrow ½O_2 + 2H^+ + 2e^-$

Cathode: $2H^+ + 2e^- \rightarrow H_2$

Alkaline Electrolysis

$2OH^- \rightarrow ½O_2 + H_2O + 2e^-$

$2H_2O + 2e^- \rightarrow H_2 + 2OH$

2. 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:

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

....(2)

$mole_{water} = 6.023*10^{23}$ *molecules of water* ....(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.

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

....(4)

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

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

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):

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

....(6)

Similarly, using metric units:

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

....(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:

$$Efficiency_{cell} = \frac{V_{Acuall}}{\mathcal{E}_{cell}} \cong \frac{V_{Acuall}}{1.2\,V} \quad \text{.......(8)}$$

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:-

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

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

Experiments and laboratory tests to evaluate the performance of the proposed design unit and its ability to produce hydrogen gas in varying amounts in different periods of time were conducted. The unit production of hydrogen gas test, data has been collected to get the best set of operating standards under study analysis. However, Can the results of this current work discussed under the following headings:

1.Influence of water type on produced hydrogen.

Indicated in Figure (2) the impact of water used in the different types of study in hydrogen produces.

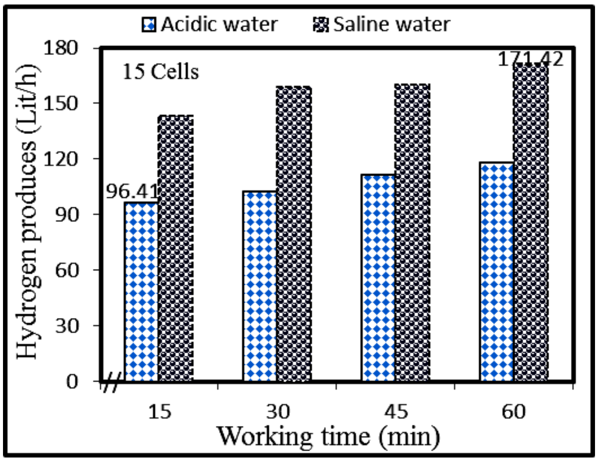

Fig.2. Effect of water types and working time on produce hydrogen.
Source: Own design based on the obtained results.

Thus, the previous measurements show that the lowest output hydrogen was 96.41 L/h for acidic water and 143.41 L/h for saline water with 15 cell counts, 0.5 mm cell distance, 15 min working time, the hydrogen produced with saline water was 48.75% higher than acidic water. The highest output capacity was 118.37 L/h of acidic water and 171.42 L/h of saline water with 15 cell counts, distance between cells 0.5 mm, running time of 60 min, thus the hydrogen produced with water saline increased by 44.81% for acidic water.

2.Effect of water used on the difference consumed and produced energy.

Effect of different types of water used on consumed and produced energy as shown in Figure (3).

Power gen, for the case of two types of water when distance between cells (0.5 mm), number of cells (15 cells) and working time (15, 30, 45, 60 min) were changed. The results slow that: **Acidic water,** The lowest value of the power gen was obtained. The difference was 2.8649 kWh with distance between 0.5 mm cells, number of 15 cells and working time 15 min. While the highest value of power gen was 3.4638 kWh with number of 15 cells, working time 60 min. and distance between cells was 0.5 mm.

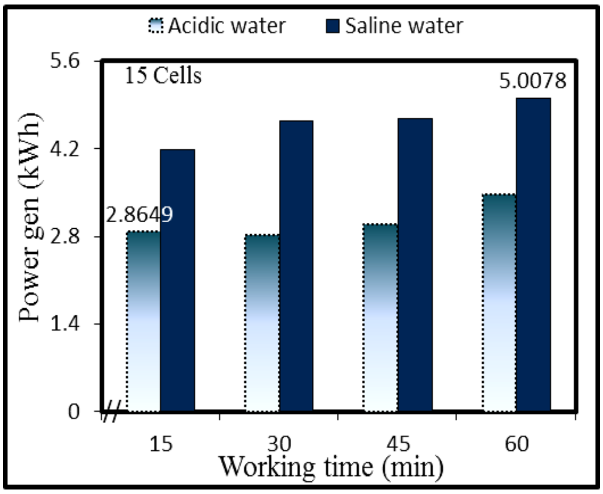

Fig. 3. Effect of water types and working time on power gen.
Source: Own design based on the obtained results.

Saline water. The lowest value of the power gen was obtained. The difference was 4.1883 kWh with distance between 0.5 mm cells, number of 15 cells and working time 15 min. While the highest value of power gen was 5.0078 kWh with number of 15 cells, working time 60 min. and distance between cells was 0.5 mm. As shown above, the net energy between produced and consumed energy increases with saline water in acidic water by 44.57%. This is due to the increase in cations in saline water that accelerate the separation of hydrogen from them in acidic water.

3. Effect of number of cells and water types on produce hydrogen.

Figure (4) shown the effect of number of cells

(9, 11, 13, 15 cells) and different types of water used on produced hydrogen. The results obtained from the average hydrogen produced with number of cells (9, 11, 13, 15 cells) in the presence of two types of water, distance between cells (0.5 mm) and working time (60 min).

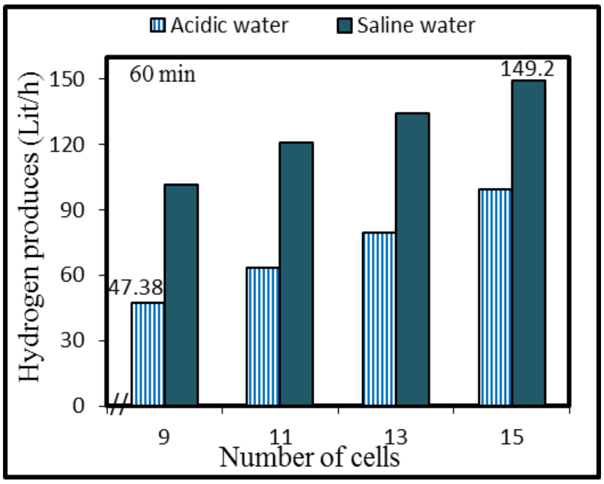

Fig. 4. Effect of water types and number of cells on produces hydrogen.
Source: Own design based on the obtained results.

Results with acidic water, the lowest average obtained value of produced hydrogen 47.38 L/h with distance between cells 0.5 mm, number of 9 cell and working time 60 min. While the average highest value of produced hydrogen 99.49 L/h with number of 15 cells, working time 60 min. and distance between cells 0.5 mm. Results with saline water, the lowest average obtained value of produced hydrogen 101.87 L/h with distance between cells 0.5 mm, number of 9 cell and working time 60 min. While the average highest value of produced hydrogen 149.2 L/h with number of 15 cells, working time 60 min. and distance between cells 0.5 mm. From the above, the increase in number of cells increases produced hydrogen as a result of increasing the exposed surface and separation of hydrogen from water. It increases with 15 cells and saline water by 214.90% from 9 cells and acidic water.

4.Effect of distance between cells and number of cells on producing hydrogen.

Indicated in Figure (5) shown the effect of distance between cells (1.5, 1.0, 0.5 mm) and different types of water used on produced hydrogen. The results obtained from the average hydrogen produced with distance between cells (1.5, 1.0, 0.5 mm) in the presence of tow types of water, number of cell (15 cells) and working time (60 min). Results with acidic water, the lowest average obtained value of produced hydrogen 91.86 L/h with distance between cells 1.5 mm, number of 15 cells and working time 60 min. While the average highest value of produced hydrogen 107.15 L/h with number of 15 cells, working time 60 min. and distance between cells 0.5 mm.

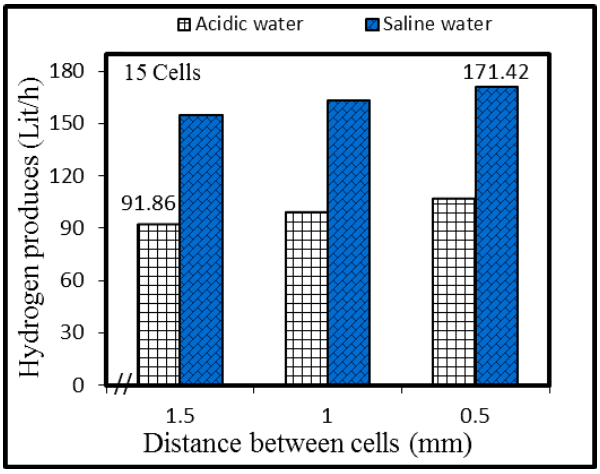

Fig. 5. Effect of distance between cells and number of cells on producing hydrogen.
Source: Own design based on the obtained results.

Results with saline water, the lowest average obtained value of produced hydrogen 154.72 L/h with distance between cells 1.5 mm, number of 15 cell and working time 60 min.
While the average highest value of produced hydrogen 171.42 L/h with number of 15 cells, working time 60 min. and distance between cells 0.5 mm. As shown above, the lack of distance between cells increases the hydrogen produced by the lack of water between cells increases the speed of analysis separation of hydrogen from water. The analysis increases with 0.5 mm in the presence of saline water by 86.61% than 1.5 mm in the presence of acidic water.

5. Efficiency of hydrogen gas production unit and effect of distance between cells,working time (η^{o})

Figure (6) Efficiency of hydrogen gas production unit the efficiency of fuel cells is usually taken to mean actual efficiency of electrochemical reaction. This value is measured experimentally and depends on whether water is formed as gas or liquid. For fuel cells, water is formed as gas. Thus, total efficiency is ratio of produced energy (output) transferred to water and leaving hydrogen cells to consumed energy (input) hydrogen gas energy.

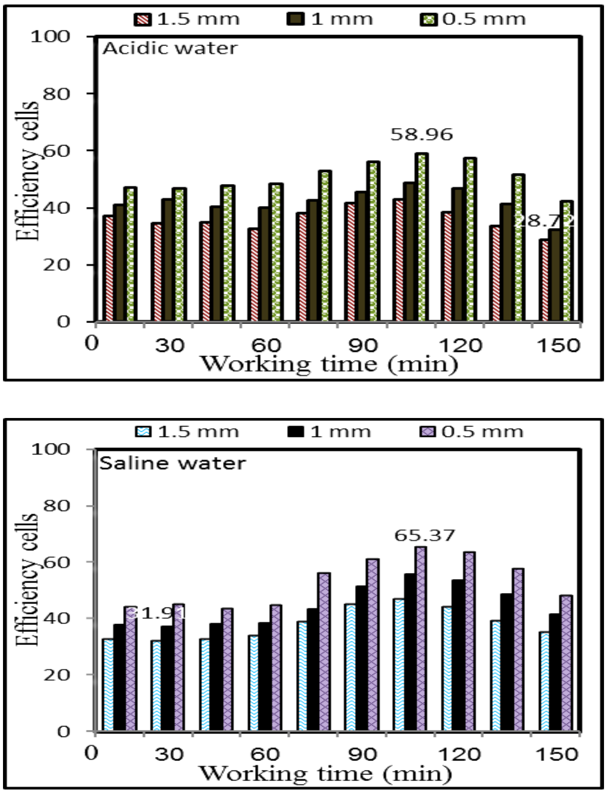

Fig. 6. Effect of water types, working time and distance between cells on efficiency cells.
Source: Own design based on the obtained results.

During test period, working time (15 to 120 min), distance between cells (1.5 to 0.5 mm) and two types of water (acidic - saline) was the efficiency of cells as follows; 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%), working 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 acidic water (28.72%), working time 150 min at distance between cells 1.5 mm. Efficiency of cells the highest (65.37%) at working time 105 min and distance between cells 0.5 mm with saline water. This is because presence of an electrochemical reaction breaks down bonds of its reactors to produce new bonds in resulting materials and to synthesize new materials that are different in their chemical and physical properties. This 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 acidic water, distance between cells was 1.5 mm, working time 15 min, cell temperature was 35.5°C water temperature increased to 31.2°C by (2.606 kWh).

Thus the increase with saline water was by 96.58% the energy produced in the presence of acidic water.

In the presence of lowest efficiency acidic water (28.72%), working time 150 min and distance between cells 1.5 mm.

Efficiency of cells the highest (65.37%) at working time 105 min and distance between cells 0.5 mm with saline water.

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