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Effect of alkaline water level and electrode surface area on the hydrogen production rate as renewable energy source using electrolysis system

Mohamed H.Abdelgwad, Adel H.Bahnasawy and Elsayed G.Khater
Agricultural and Biosystems Engineering Dept., Faculty of Agriculture, Benha University, Egypt
E-mail: alsayed.khater@fagr.bu.edu.eg

Abstract

This work focuses on the possibility of using electrolysis system in hydrogen production from water at different levels of alkaline and electrode surface area. Five levels of alkaline water (0, 2, 6, 10 and 14%wt KOH) were used, three Surface area of the electrodes namely (200,300 and 400 cm^2) and three number of stainless steel in unit (9, 11 and 13) slice were also investigated. The obtained results finding indicated that, the produced energy of water increases with decreasing the numbers of stainless steel and increasing operating time. It also refers that, the produced energy of water increases with increasing potassium hydroxide concentration until it reached the peak with 10%wt KOH potassium hydroxide concentration and then decreased. The highest value of the produced energy from water (448.73 kW h) was found with the 10%wt KOH potassium hydroxide concentration after 150 min for 300 cm^2 of surface area of the electrodes. On the other hand, the lowest value of the accumulated produced energy of water (51.45 kW h) was results with the 0%wt KOH potassium hydroxide concentration after 210 min for 400 cm^2 of surface area of the electrodes. The highest value of the operating time required to analyze one liter of water (240 min) was found with the 0%wt KOH potassium hydroxide concentration for 200 cm^2 of the surface area of the electrodes. While, the lowest value of the operating time required analyzing one liter of water to produce hydrogen (120 min) was found with the 10%wt KOH potassium hydroxide concentration for 400 cm^2 of the surface area of the electrodes.

Keywords: Hydrogen, Electrolysis, Renewable energy, Operating time, Potassium hydroxide.

1. Introduction

Global energy demand increased dramatically due to the accelerated population growth **[5]** Now day, the utilization of worldwide energy has significantly increased due to a growth and industrial intervention. Energy is necessary for the global economy and social modernization and at present, approximately 65% of the worldwide energy requirement has been used by nonrenewable sources such as fossil fuels **[14]**.

hydrogen could be used as a source of energy in transportation and operating chemical. In Egypt, the increase of population made a high demand of energy especially the renewable energy such as hydrogen energy **[1].** The renewable energy sources (RESs) because an urgent goal in Egypt to reach the sustainable development. Using renewable energy sources (RESs) still in Egypt facing stability problems due to the interaction between the different system of producing RES **[7].**

Around 90% of the gasses in the universe is hydrogen, which makes it very important elements in energy where, it contains the value per weight unit compared to other fuels **[18].**

Rising standard of human living and increasing population accelerate the global energy consumption in renewable energy sources especially, hydrogen while is helping in solve pollution as a clean source of energy as solar and wind sources **[11].** Hydrogen is produced from water by electrolysis system, which made it environmental friendly and it has high potential because its high value of energy (142 kJ /g) **[15]** Production of hydrogen using renewable energy sources such as wind provides a good method of energy storing and gas-power phenomena **[6]** Also, hydrogen could be produced from other renewable sources such as biomass derivatives reformation or electrolysis of water **[8].**

The accelerated needs of energy required searching for various sources of energy generation **[16]** Besides, the tradition source of energy such as fossil fuel harms the environment and to overcome the challenge of change in climate **[3].**

The demand for a sustainable energy supply is obvious because depletion of fossil energy resources, environmental pollution and climate change and increasing dependency on fossil fuels. Fossil fuel combustion or reformation causes environmental impacts, which force the scientists to search for other alternatives for tradition fuels. Low carbon emission is considered when lake for new fuel alternatives in both mobile and stationing implementations **[13].** Hydrogen is one of the clean energy sources that the world technology based on it, because it is source, affordable, produced domestically and used in all sectors. It plays important roles in the future as energy **[4].**

Therefore, this work aimed to enhance the rate of hydrogen production from water by electrolysis through changing the level of KOH in water, number of stainless steel in unit slice and the surface area of the electrodes.

2. Materials and Methods:

This work is conducted at the Agricultural and Bio-Systems Engineering Department, Collage of Agriculture, Moshtohor, Benha University, Egypt. During the period of May to September, 2024.

2.1. Materials

2.1.1. Description of the hydrogen production unit:

Figures (1 and 2) show the hydrogen production unit. It has an external cover, and cells (stainless steels) separated by interval of Gasket rubber flex, the unit is gathered with nails and has two openings for water entry and exit. The ingress of water between the positive and negative cells is separated into two hydrogen atom and oxygen atom. Hydrogen gas comes out of the top slot of the lid high water tank. Acrylic cover dimension 300 × 300 mm was used to cover and link the whole unit. The unit is provided by 5 L polyethylene water cylinder (φ16 cm diameter and 32 cm height) and a hose of 1 cm diameter was connected to the water tank upper opening through a small tube. There are three openings in the tank, one for delivering water to the cell, the other for collecting hydrogen from the cell, and the third for clearing hydrogen gas and collecting it in a reflex tube in a container filled with water and exposed to the atmosphere.

The unit was providing by energy using power supply of electricity to operate the hydrogen gas production unit. It used to convert from AC to DC. The outlet power of power supply is 12 Volts and 10 Amps. Kutcher flexible Gaskets rectangular in shape were used for its guardian compression ratio. They were used to isolate the positive cells from the negative cells and prevent water leakage of the gas output. Local manufactured gaskets are available in various areas of 200, 300, and 400 cm^2.

The gasket has dimensions of 21× 21 cm. Hoses that made from plastic were used to connect between the opening of hydrogen produced and water tank. Check value was fixed on it to control the flow. Bolts and nuts were used to bind the components of unit cell to assure the power transferring through it.

2.2. Methods:

2.2.1. Principles of electrolysis:

Equations from 1 to 5 show the electrochemical flow of water electrolysis as follows **[17].**

Water Electrolysis

Net Reaction: H2O = H2 + 1/2 O2 (1)

-Acidic Reaction

Anode: $H_2O \rightarrow 1/2O_2 + 2H^+ + 2e^-$ (2)

Cathode: $2H^+ + 2e^- \rightarrow H_{2\ (gas)}$ (3)

-Alkaline Electrolysis

$2OH^- \rightarrow 1/2O_2 + H_2O + 2e^-$ (4)

$2H_2O + 2e^- \rightarrow H_{2\ (gas)} + 2OH^-$ (5)

Electrochemical pathway for acidic and saline electrolysis is to understand the principles of electrolysis, Perhaps the most basic experiments is the use of two pencils sharpened at both ends with the top being connected to a battery and the bottoms inserted into alkaline water. Illustration the concept is showing many bubbles appearing at the negative pencil and half that many appearing at the positive the reactions are:

Positive: 2OH- → 1/2O2 + H2O + 2e (6)

Negative: 2H2O + 2e → H2 + 2OH- (7)

2.2.2. Treatments:

The treatments include: five potassium hydroxide concentrations in tap water (0, 2, 6, 10 and 14%wt KOH), three different surface areas of the electrodes (200, 300 and 400 cm^2) and three numbers of stainless steel (9, 11 and 13 slices).

2.2.3. Measurements:

The power requirements were determined by clampmeter to measure the line current (I) and the potential difference value (V)

$$P = \frac{Current\ (I) \times Potential\ (V) \times cos\ \theta}{1000} \tag{8}$$

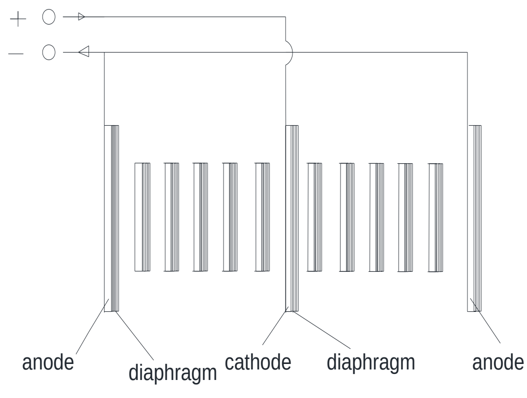

Fig. (1): The experimental schematic diagram of electrical conduction for unit.

Fig.(2): Photographic of the materials used for the hydrogen production unit.

Where:
P is the required power, kW
I is the line current, Amperes.
V is the potential difference, Voltage.
Cos θ is the power factor, equal 0.8.
Hydrogen produced was collected in a scaled flask and recorded each 10 min.
The unit efficiency was determined as follows according to **[11]**:

$$\eta = \frac{NH_2 \times HHV}{E} \times 100 \quad (9)$$

Where:
η is the efficiency of unit, %.
NH_2 is the rate of hydrogen production, kg h^{-1}.
HHV is the hydrogen high heating value, 39.40 kWh / kg.
E is the electric energy inputs, kW.
The hydrogen volume is determined as follows according to **[11]**:

$$VH_2 \text{ ideal} = \frac{I \times VM \times t}{2 \times F} \times 100 \quad (10)$$

Where:
I is the current (in Amps) passes through the cell during a period, t
VM is the molar volume of ideal gas under standard conditions, 298.15 K and 1 atm
F is Faraday's number, 96 485 C/mol
Hydrogen volume is determined from the following equation according to **[10].**

$$VH_2 \text{ real} = (VH_2 \text{ measured}) \frac{T \text{ standard}}{T \text{ measured}} \quad (11)$$

Where:
VH_2 measured is the hydrogen volume
T standard is reference temperature, K
T measured temperature, K**.**

3. Results and Discussion

3.1. Accumulated produce energy of water

Figure (3a, b and c) shows the accumulated produced energy of water at different potassium hydroxide concentrations (0, 2, 6, 10 and 14%wt KOH) and at different numbers of stainless steel (9, 11 and 13 slices) with 200 cm^2 of surface area of the electrodes. The produced energy of water increases with increasing the numbers of stainless steel and operating time. Results indicate also that the produced energy increases with increasing potassium hydroxide concentration until it reached the peak with 10%wt KOH potassium hydroxide concentration and then decreased. It could be seen that the produced energy of water increased from 12 to 326, 13 to 331, 16 to 373 and 14 to 321 kW h, when the operating time increased from 10 to 210, 10 to 190, 10 to 160 and 10 to 180 min for 2, 6, 10 and 14%wt KOH potassium hydroxide concentration, respectively. The produced energy of water increased from 2 to 58 kW h as the operating time increased from 10 to 240 min for control (0%wt KOH). The highest value of the accumulated produced energy of water (373 kW h) was obtained with the 10%wt KOH potassium hydroxide concentration after 160 min. While, the lowest value of the accumulated produced energy of water (58 kW h) was found with the 0%wt KOH potassium hydroxide concentration (control) after 240 min for 200 cm^2 of surface area of the electrodes. These results are in agreement previous findings by **[12].**

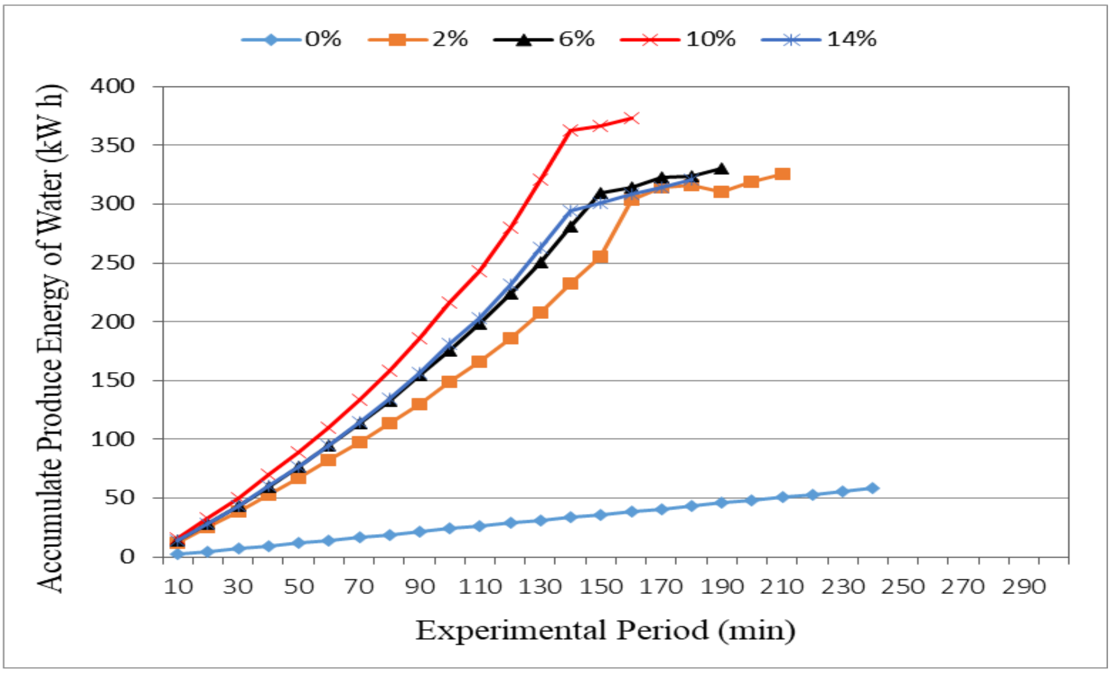

Fig. (3a): The accumulated produced energy of water at different potassium hydroxide concentrations at nine numbers of stainless steel with 200 cm^2 of surface area of the electrodes.

For eleven numbers of stainless steel, the result showed that, the produced energy increased from 9.97 to 284.78, 11.61 to 310.07, 13.53 to 343.89 and 12.14 to 307.83 kW h, when the operating time increased from 10 to 240, 10 to 200, 10 to 170 and 10 to 200 min for 2, 6, 10 and 14%wt KOH potassium hydroxide concentration, respectively, compared to increase from 2.28 to 61.84 kW h produced an increase of the time from 10 to 260 min for control (0%wt KOH). The highest value of the produced energy (343.89 kW h) was found with the 10%wt KOH potassium hydroxide concentration after 170 min. While, the lowest value of the produced energy (61.84 kW h) was resulted with the 0%wt KOH potassium hydroxide concentration (control) after 260 min for 200 cm^2 of surface area of the electrodes.

For thirteen numbers of stainless steel, the produced energy increased from 8.67 to 264.32, 9.61 to 278.01, 10.84 to 281.49 and 9.79 to 260.08 kW h, when the operating time increased from 10 to 280, 10 to 250, 10 to 220 and 10 to 240 min for 2, 6, 10 and 14%wt KOH potassium hydroxide concentration, respectively. The increase of operating time from 10 to 300 min produced an increase of accumulated produced energy the 10%wt KOH potassium hydroxide concentration after 220 min. While, the lowest value of the produced energy (69.11 kW h) was found with the 0%wt KOH of water from 2.21 to 69.11 kW h. The highest value of

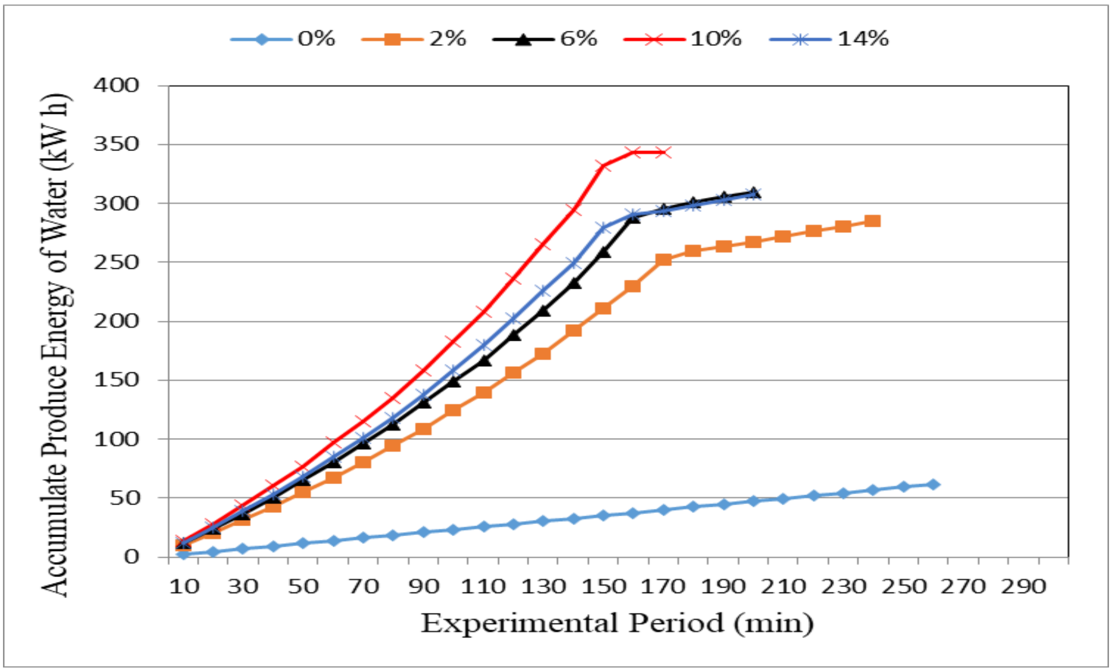

Fig. (3b): The accumulated produced energy of water at different potassium hydroxide concentrations at eleven numbers of stainless steel with 200 cm^2 of surface area of the electrodes.

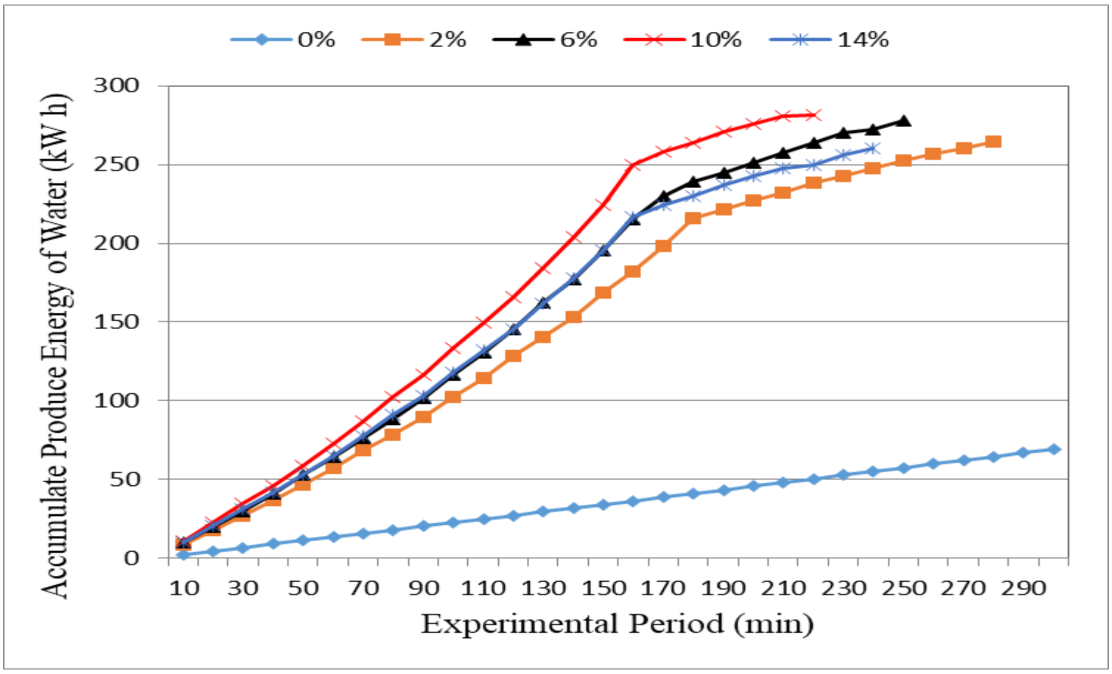

Fig. (3c): The accumulated produced energy of water at different potassium hydroxide concentrations at thirteen numbers of stainless steel with 200 cm^2 of surface area of the electrodes.

the produced energy (281.49 kW h) was resulted with potassium hydroxide concentration (control) after 300 min for 200 cm^2 of surface area of the electrodes.

The results showed that, the produced energy decreases with increasing the numbers of stainless steel. It could be seen that, the produced energy was decreased from 326.00 to 264.32, 331.00 to 278.01, 373.00 to 281.49 and 321.00 to 260.08 kW h, when the number of stainless steel increased from 9 to 13 for 2, 6, 10 and 14%wt KOH potassium hydroxide concentration, respectively. These results are inagreement previous findings by **[9].**

Figure (4a, b and c) shows the accumulated produced energy of water at different potassium hydroxide concentrations (0, 2, 6, 10 and 14%wt KOH) and at numbers of stainless steel (9, 11 and 13 slices) with 300 cm^2 of surface area of the electrodes. Results showed that the produced energy increases with an increase in the numbers of stainless steel and operating time. The produced energy increases with increasing potassium hydroxide concentration until it reached the peak with 10%wt KOH potassium hydroxide concentration and then decreased. It could be seen that the produced energy increased from 18.00 to 382.70, 19.67 to 429.57, 25.29 to 448.73 and 21.03 to 368.45 kW h, as the time increased from 10 to 200, 10 to 180, 10 to 150 and 10 to 170 min, respectively for 2, 6, 10 and 14%wt KOH potassium hydroxide concentration compared to increase from 2.38 to 57.47 kW h when the operating time increased from 10 to 230 min for control (0%wt KOH). The results indicate that, the highest value of the accumulated produced energy (448.73 kW h) was resulted with the 10%wt KOH potassium hydroxide concentration after 150 min. While, the lowest value of the accumulated produced energy of water (57.47 kW h) was obtained with the 0%wt KOH potassium hydroxide concentration (control) after 230 min for 300 cm^2 of surface area of the electrodes.

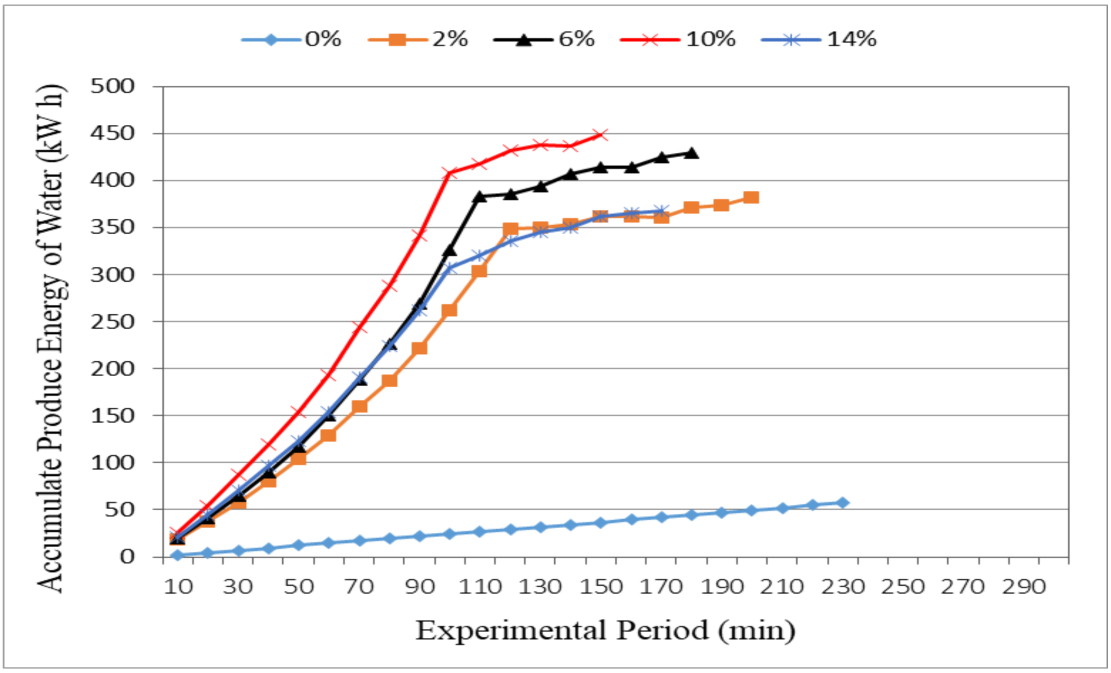

Fig. (4a): The accumulated produced energy of water at different potassium hydroxide concentrations and at nine numbers of stainless steel with 300 cm^2 of surface area of the electrodes.

For eleven numbers of stainless steel, the result indicate that, the produced energy increased from 15.62 to 396.00, 15.50 to 403.56, 21.03 to 405.71 and 17.70 to 354.00 kW h, as the time increased from 10 to 220, 10 to 190, 10 to 170 and 10 to 200 min for 2, 6, 10 and 14%wt KOH potassium hydroxide concentration, respectively, compared to increase from 2.30 to 58.19 kW h when the operating time increased from 10 to 240 min for control (0%wt KOH). The highest value of the produced energy (405.71 kW h) was obtained with the 10%wt KOH potassium hydroxide concentration after 170 min. While, the lowest value of the produced energy (48.19 kW h) was resulted with the 0%wt KOH potassium hydroxide concentration (control) after 240 min for 300 cm^2 of surface area of the electrodes.

For thirteen numbers of stainless steel, the result indicated that, the produced energy increased from 10.95 to 285.31, 12.42 to 291.29, 14.35 to 342.58 and 12.49 to 309.19 kW h, as the time increased from 10 to 270, 10 to 240, 10 to 200 and 10 to 230 min for 2, 6, 10 and 14%wt KOH potassium hydroxide concentration, respectively, compared to increase from 2.25 to 66.67 kW h as the time increased from 10 to 280 min for control (0%wt KOH). The highest value of the produced energy (342.58 kW h) was resulted with the 10%wt KOH potassium hydroxide concentration after 200 min. While, the lowest value of the produced energy (66.67 kW h) was obtained with the 0%wt KOH potassium hydroxide concentration (control) after 280 min for 300 cm^2 of surface area of the electrodes.

The results showed that, the produced energy decreased with increasing the numbers of stainless steel. It could be seen that, the produced energy was

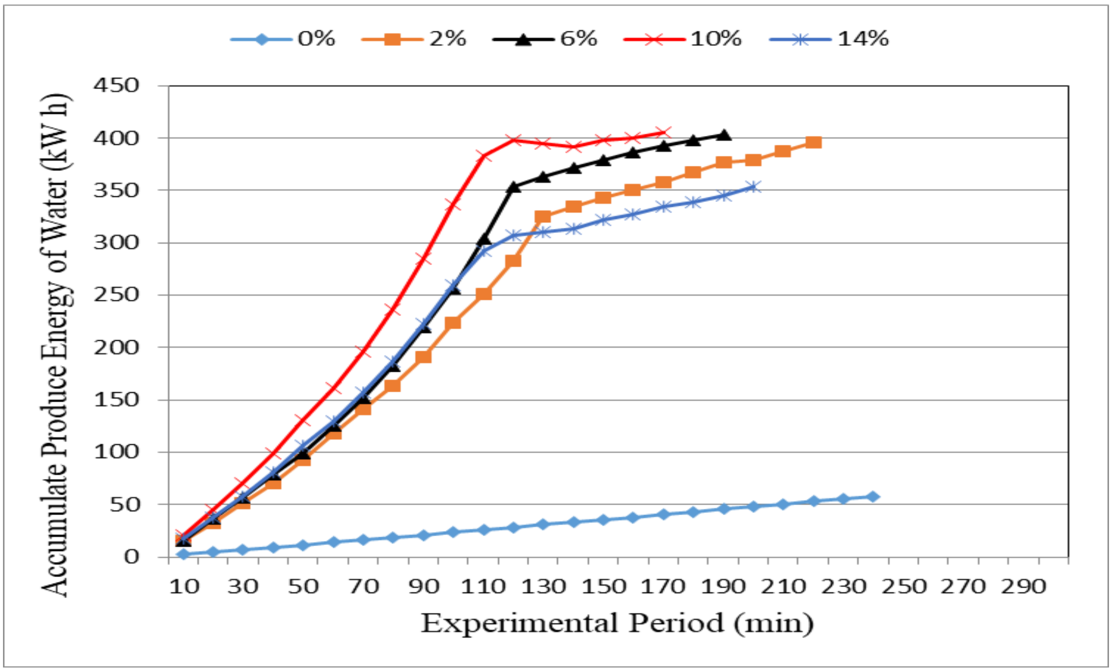

Fig. (4b): The accumulated produced energy of water at different potassium hydroxide concentrations at eleven numbers of stainless steel with 300 cm^2 of surface area of the electrodes.

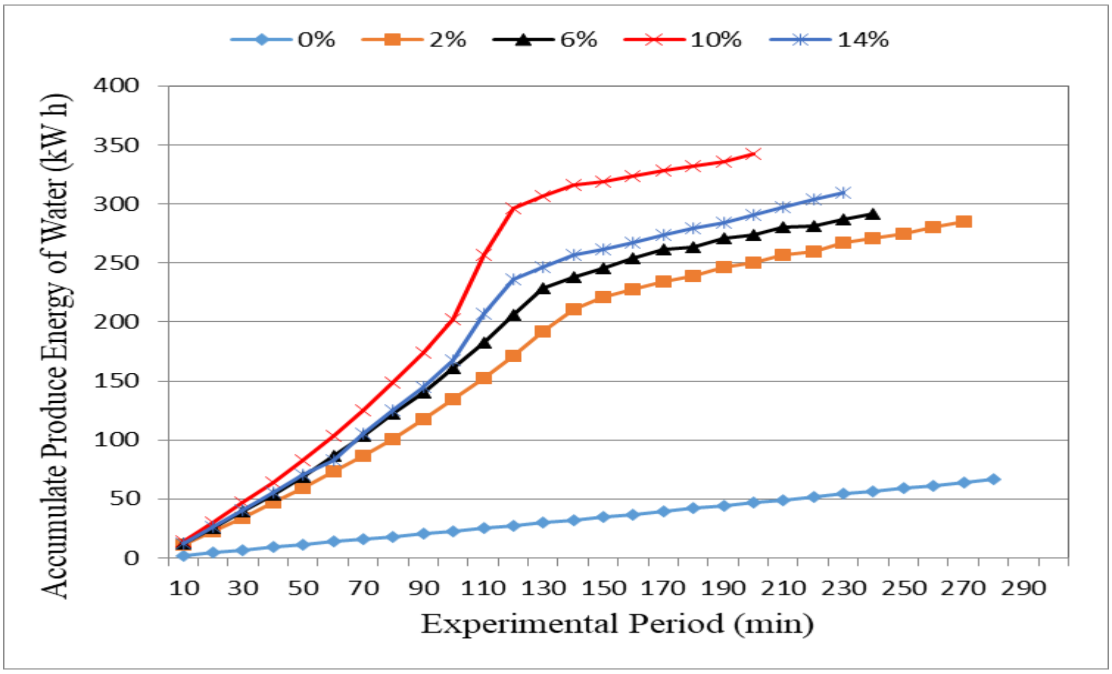

Fig. (4c): The accumulated produced energy of water at different potassium hydroxide concentrations and at thirteen numbers of stainless steel with 300 cm^2 of surface area of the electrodes.

decreased from 382.70 to 285.31, 429.57 to 291.29, 448.73 to 342.58 and 368.45 to 309.19 kW h, when the number of stainless steel increased from 9 to 13 for 2, 6, 10 and 14%wt KOH potassium hydroxide concentration, respectively.

Figure (5a, b and c) shows the produced energy at different potassium hydroxide concentrations (0, 2, 6, 10 and 14%wt KOH) and at numbers of stainless steel (9, 11 and 13 slices) with 400 cm^2 of surface area of the electrodes. The results indicated that the produced energy increases with increasing the numbers of stainless steel and operating time. The results also indicated that, the accumulated produced energy increases with increasing potassium hydroxide concentration until it reached the peak with 10%wt KOH potassium hydroxide concentration and then decreased. It could be seen that the produced energy increased from 22.60 to 354.00, 27.95 to 379.29 38.62 to 439.45 and 29.10 to 388.26 kW h, as the time increased from 10 to 180, 10 to 150, 10 to 120 and 10 to 170 min for 2, 6, 10 and 14%wt KOH potassium hydroxide concentration, respectively, compared to increase from 2.39 to 51.45 kW h as the time increased from 10 to 210 min for control (0%wt KOH). The highest value of the produced energy (439.45 kW h) was resulted with the 10%wt KOH potassium hydroxide concentration after 120 min. Meanwhile, the lowest value of the produced energy (51.44 kW h) was resulted with the 0%wt KOH potassium hydroxide concentration (control) after 210 min for 400 cm^2 of surface area of the electrodes.

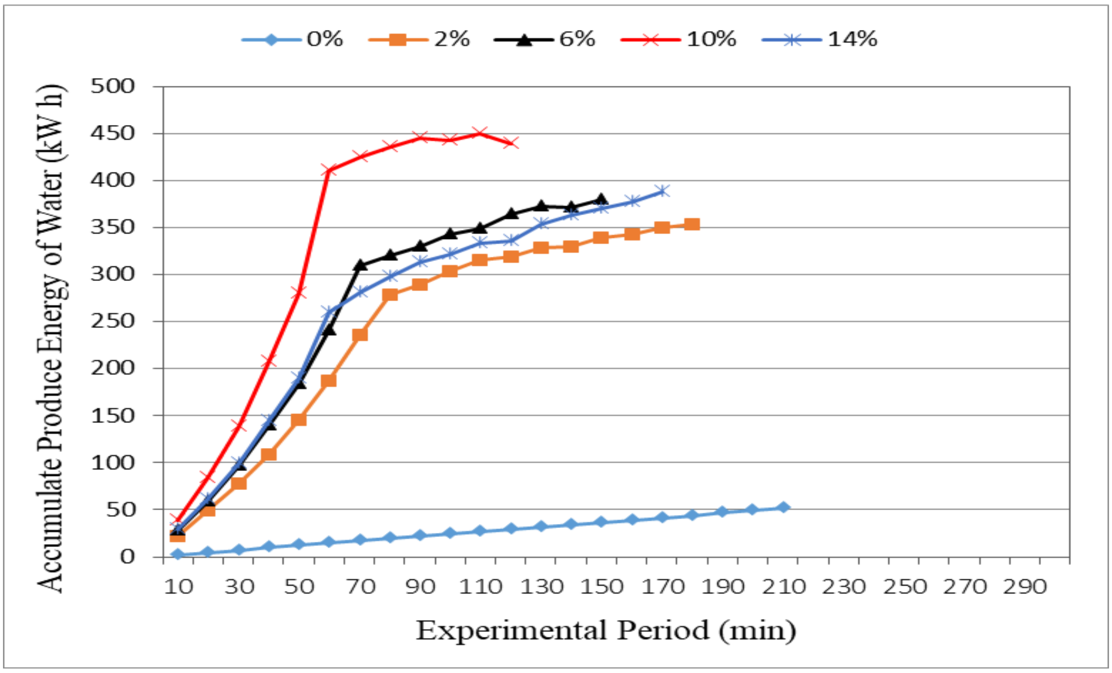

Fig. (5a): The accumulated produced energy of water at different potassium hydroxide concentrations and at nine numbers of stainless steel with 400 cm^2 of surface area of the electrodes.

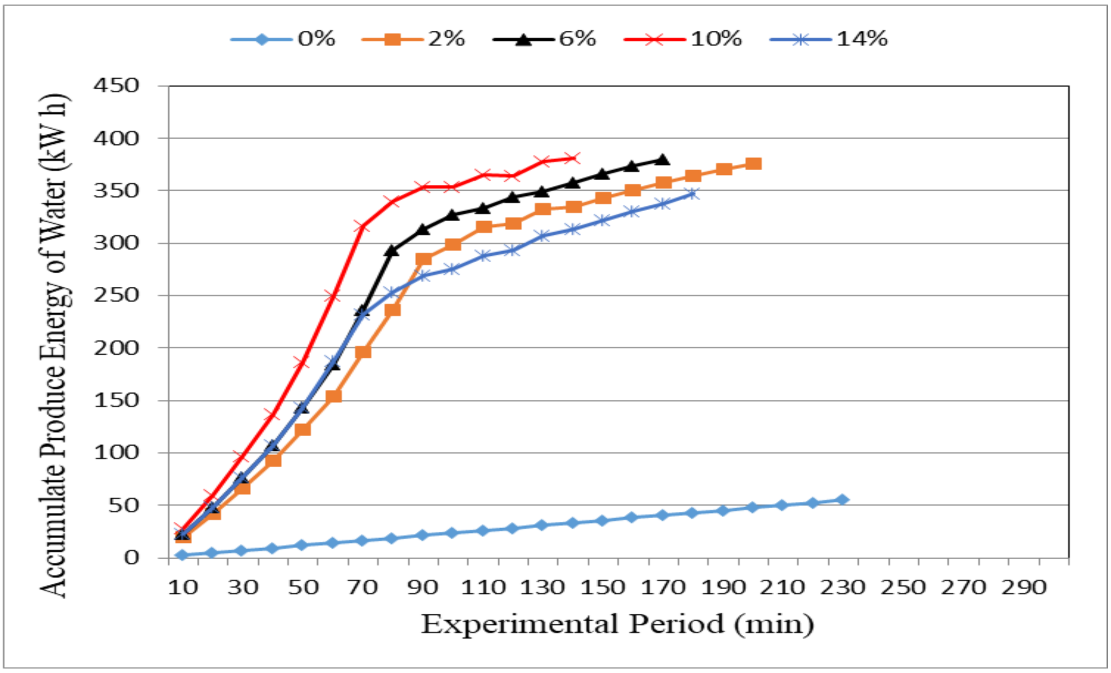

Fig. (5b): The accumulated produced energy of water at different potassium hydroxide concentrations and at eleven numbers of stainless steel with 400 cm^2 of surface area of the electrodes.

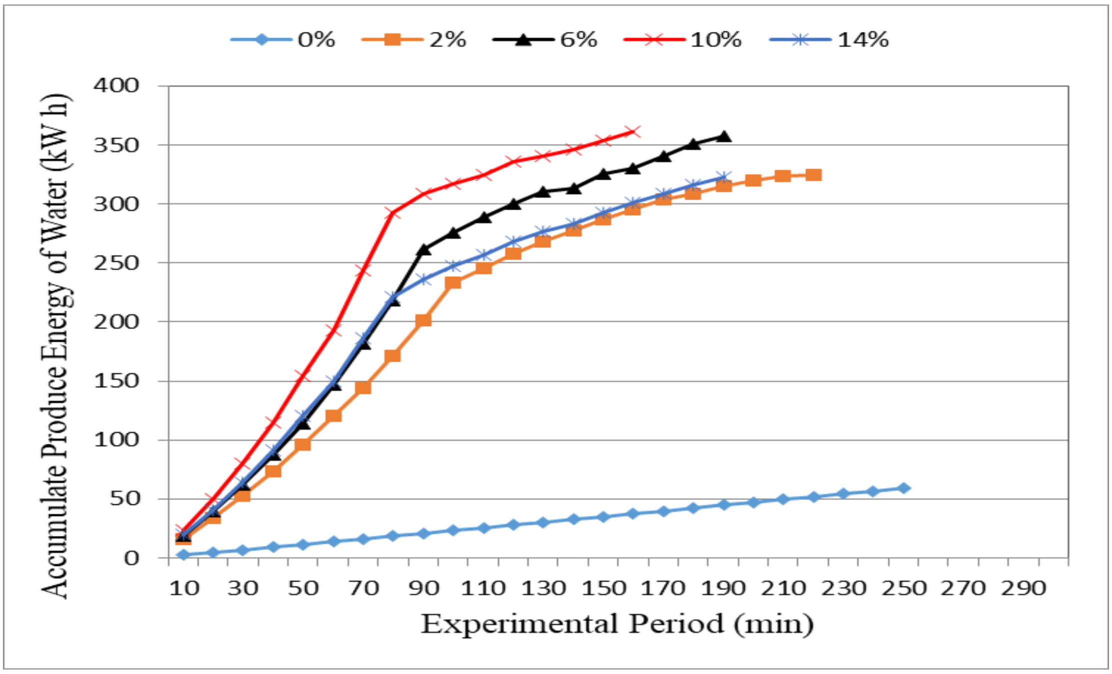

Fig. (5c): The accumulated produced energy of water at different potassium hydroxide concentrations at thirteen numbers of stainless steel with 400 cm^2 of surface area of the electrodes.

For eleven numbers of stainless steel, the result indicated that, the produced energy increased from 20.04 to 375.93, 22.60 to 380.08, 28.32 to 381.23 and 23.09 to 347.56 kW h, as the time increased from 10 to 200, 10 to 170, 10 to 140 and 10 to 180 min for 2, 6, 10 and 14%wt KOH potassium hydroxide concentration, respectively, compared to increase from 2.34 to 55.33 kW h as the time increased from 10 to 230 min for control (0%wt KOH). The highest value of the produced energy (381.23 kW h) was resulted with the 10%wt KOH potassium hydroxide concentration after 140 min. While, the lowest value of the produced energy (55.33 kW h) was obtained with the 0%wt KOH potassium hydroxide concentration (control) after 230 min for 400 cm^2 of surface area of the electrodes.

For thirteen numbers of stainless steel, the results indicated that, the produced energy increased from 16.21 to 324.50, 19.14 to 357.13, 23.60 to 361.53 and 19.49 to 322.85 kW h, as the time increased from 10 to 220, 10 to 190, 10 to 160 and 10 to 190 min for 2, 6, 10 and 14%wt KOH potassium hydroxide concentration, respectively, compared to increase from 2.30 to 58.87 kW h as the time increased from 10 to 250 min for control (0%wt KOH). The highest value of the produced energy (361.53 kW h) was resulted with the 10%wt KOH potassium hydroxide concentration after 160 min. While, the lowest value of the produced energy (58.87 kW h) was obtained with the 0%wt KOH potassium hydroxide concentration (control) after 250 min for 400 cm^2 of surface area of the electrodes.

The results showed that, the produced energy decreases with increasing the numbers of stainless steel. It could be seen that, the produced energy was decreased from 354.00 to 324.50, 379.29 to 357.13, 439.45 to 361.53 and 388.26 to 322.85 kW h, when the number of stainless steel increased from 9 to 13 for 2, 6, 10 and 14%wt KOH potassium hydroxide concentration, respectively.

Table 1. The Operating time of hydrogen production unit.

3.2. Operating time of hydrogen production unit:

Data in table (1) shows the operating time required to analyze one liter of water to produce hydrogen at different potassium hydroxide concentrations (0, 2, 6, 10 and 14%wt KOH), at numbers of stainless steel (9, 11 and 13 slices) and different surface areas of the electrodes 200, 300 and 400 cm^2). Results indicated that the operating time required to analyze one liter of water to produce hydrogen decreases with increasing the surface area of electrodes. The results also indicate that, the operating time required to analyze one liter of water to produce hydrogen decreases with increasing potassium hydroxide concentration until it reached the peak with 10%wt KOH potassium hydroxide concentration and then increased during the test. It could be seen that, the operating time required to analyze one liter of water to produce hydrogen decreased from 240 to 210. 210 to 180, 190 to 150, 160 to 120 and 180 to 170 min, when the surface area of the electrodes increased from 200 to 400 cm^2 for 0, 2, 6, 10 and 14 %wt KOH, respectively. The highest value of the operating time required to analyze one liter of water to produce hydrogen (240 min) was obtained with the 0%wt KOH potassium hydroxide concentration for 200 cm^2 of the surface area of the electrodes. While, the lowest value of the operating time required analyzing one liter of water to produce hydrogen (120 min) was resulted with the 10%wt KOH potassium hydroxide concentration for 400 cm^2 of the surface area of the electrodes.

Potassium Hydroxide Concentration, %wt KOH	**Surface area of electrodes, cm^2**		
	200	**300**	**400**
		Operating time, min	
0 (**without KOH)**	240	230	210
2	210	200	180
6	190	180	150
10	160	150	120
14	180	170	170

4. Conclusion

This work was carried out to study the possibility of using electrolysis system in hydrogen production from water at different levels of alkaline and electrode surface area. The treatments under study were five types of water (0, 2, 6, 10 and 14%wt KOH) were used, three surface area of the electrodes namely (200,300 and 400 cm^2) and three number of stainless steel in unit (9, 11 and 13) slice. The obtained results can be summarized as follows:

- The produced energy was decreased from 326.00 to 264.32, 331.00 to 278.01, 373.00 to 281.49 and 321.00 to 260.08 kW h, when the number of stainless steel increased from 9 to 13 for 2, 6, 10 and 14%wt KOH potassium hydroxide concentration for 200 cm^2 surface area of the electrodes, respectively.
- The produced energy was decreased from 382.70 to 285.31, 429.57 to 291.29, 448.73 to 342.58 and 368.45 to 309.19 kW h, when the number of stainless steel increased from 9 to 13 for 2, 6, 10 and 14%wt KOH potassium hydroxide concentration for 300 cm^2 surface area of the electrodes, respectively.
- The accumulated produced energy of water was decreased from 354.00 to 324.50, 379.29 to 357.13, 439.45 to 361.53 and 388.26 to 322.85 kW h, when the number of stainless steel increased from 9 to 13 for 2, 6, 10 and 14%wt KOH potassium hydroxide concentration for 300 cm^2 surface area of the electrodes, respectively.
- The highest value of the operating time required to analyze one liter of water to produce hydrogen (240 min) was found with the 0%wt KOH potassium hydroxide concentration for 200 cm^2 of - the surface area of the electrodes. While, the lowest value of the operating time required analyzing one liter of water to produce hydrogen (120 min) was found with the 10%wt KOH potassium hydroxide concentration for 400 cm^2 of the surface area of the electrodes.

References

[1] Abdin, Z., A. Zafaranloo, A. Rafiee, W. Merida, W. Lipinski and K.R. Khalilpour (2019). Hydrogen as an energy vector. Renew. Sustain. Energy Rev., 120: 109620. https://doi.org/ 10.1016/j.rser.2019.109620

[2] Abdin, Z., A. Zafaranloo, A. Rafiee, W. Merida, W. Lipinski, K.R. Khalilpour (2020). Hydrogen as an energy vector. Renewable and Sustainable Energy Reviews, 120: 109620.

[3] Alaswad, A., A. Baroutaji, H. Achour, J. Carton, A. Al Makky and A.G. Olabi (2016). Developments in fuel cell technologies in the transport sector. Int. J. Hydrogen Energy, 41 (37): 1-10.

[4] Arzu, C.A. and T. Ethem (2021). A new analysis of two phase flow on hydrogen production from water electrolysis. International Journal of Hydrogen Energy 24(11):6986-6995, https://doi.org/10.1016/j.ijhydene.2021.03.180

[5] Burton, N.A., R.V. Padilla, A. Rose and H. Habibullah. (2021). Increasing the efficiency of hydrogen production from solar powered water electrolysis. Renewable and Sustainable Energy Reviews, 135: 110255.

[6] Daniel, N., M. Delpisheh, S. Ramakrishnan and M. Mamlouk (2024). Review of next generation hydrogen production from offshore wind using water electrolysis. Journal of Power Sources, 592: 233904. https://doi.org/10.1016/j.jpowsour.2023.233904.

[7] Hussein, A., M. Karar and M.M.F. Darwish (2022). Comprehensive Review on Renewable Energy Sources in Egypt-Current Status, Grid Codes and Future Vision, IEEE ACCESS.10.1109/ACCESS.2022.3140385

[8] Jose, L.C., M. Natalia and D.S. Cordeiro (2024). Renewable hydrogen production from biomass derivatives or water on trimetallic based catalysts. Renewable and Sustainable Energy Reviews 189 (2024) 113909. https://doi.org/10.1016/j.rser.2023.113909

[9] Kassem, A.S., A.E. Eissa, A. Zaineldin, S.G. Hemeda and A.I. Omara (2024). Electrolysis of salt water and its effect on the production of

green hydrogen. Misr J. Ag. Eng., 41 (4): 359 – 374.

[10] Okonkwo, P.C., E. Barhoumi, I.B. Mansir, W. Emori and H. Bhowmik (2022). Effect of electrode material on the hydrogen production using a low-cost home-made alkaline electrolyzer. Vacuum, 198: 110878.https://doi.org/10.1016/j.vacuum.2022.11087.

[11] Okonkwo, P.C., H. Bhowmik, I.B. Mansir, M.A.A. Marhoon and N.F.A. Sfarini (2021). Effect of electrode spacing on hydrogen production using a home-made alkaline electrolyzer, Materials Letters (2021), doi: https://doi.org/10.1016/j.matlet.2021.130841

[12] Rashid, M., M.K.Al Mesfer, H.Naseem and M. Danish (2015). Hydrogen production by waterelectrolysis: a review of alkaline water electrolysis, PEM water electrolysis and high temperature water electrolysis. International Journal of Engineering and Advanced Technology, 4(3): 80 - 94.

[13] Romagnoli, F., D. Blumberga and I. Pilicka (2011). Life cycle assessment of biohydrogen production in photosynthetic processes. International Journal of Hydrogen Energy, 36, 7866-7871.

[14] Shams, A. , F. Khan, Y. Zhang and A. Djire (2021). Recent development in electrocatalysts for hydrogen production through water electrolysis. International journal of hydrogen energy, 46: 32284 – 32317.

[15] Tan, Y., H. Yang, J. Cheng, J. Hu, Tian G, Yu X.(2022). Preparation of hydrogen from metals and water without CO2 emissions. Int.J. Hydrogen Energy, 47: 38134 38154. https://doi.org/10.1016/ j.ijhydene.2022.09.002.

[16] USDOE (2009). Hydrogen Production – Overview of Technology Options. Freedom Car and Fuel Partnership Project EERE, DOE.

[17] Veziroğlu, T.N.S. and ahin S. (2008). hydrogen energy system,”. Energy Convers. Manag.,49(7):1820-1831.

[18] Zainul Abdin , Ali Zafaranloo , Ahmad Rafiee d , Walter Merida b , Wojciech Lipinski , Kaveh R. Khalilpour .(2020). Hydrogen as an energy vector. Renewable and Sustainable Energy Reviews 120 (2020) 109620.