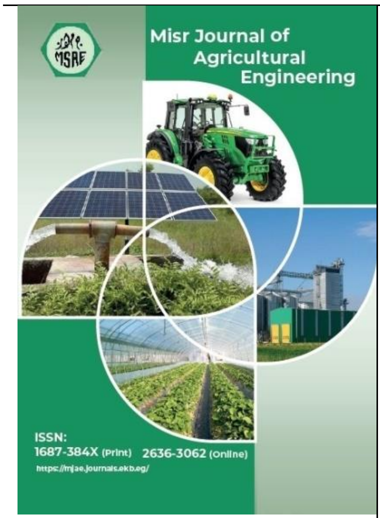
MISR JOURNAL OF AGRICULTURAL ENGINEERING
https://mjae.journals.ekb.eg/
ISSN-Print: 1687-384X
ISSN-Online: 2636-3062
Misr J. Ag. Eng., 41 (4): 359 – 374
DOI: 10.21608/mjae.2024.310379.1143

ELECTROLYSIS OF SALT WATER AND ITS EFFECT ON THE PRODUCTION OF GREEN HYDROGEN

Kassem A.S. [1] , A. E. Eissa[2] , Abdalla Zaineldin [1],
S. G. Hemeda[3] and Abdelaziz I. Omara[1]

[1] Prof. of Ag. and Biosystem Eng. Dept., Fac. of Ag, Alex. U., Egypt.
[2] Assistant Lect., Fac. of Ag. Saba Basha, Alex. U., Egypt.
[3] Researcher, Ag. Eng. Res. Inst., Ag. Res. Centre, Egypt.
* E-mail: ameraeissa@alexu.edu.eg



Keywords:
Hydrogen; Electrolyzer; Electrolysis; Fuel cell; Power consumption.

ABSTRACT

In recent decades, efforts have been intensified to find new fuels to replace fossil fuels. Among these fuels, hydrogen has drawn much attention for its advantages, particularly in terms of availability and cleanliness. It can be made using a variety of raw materials. (For example, biomass and water) and consuming a lot of resources, especially the electrolysis of water and the reformulation of natural gas. However, electrolysis of water combined with Greenhouse gas emissions can be reduced and hydrogen produced most cleanly using renewable energy sources. In addition, Fuel cells powered by hydrogen can be utilized to generate electrical and thermal energy. This work was carried out at the testing and research station for tractors and agricultural machinery in Alexandria Governorate. The purpose of this work was to test the influence of some factors on hydrogen production from the electrolysis process to identify ideal conditions for the electrode interaction area and the space between the electrodes, which is represented by the gasket thickness and the water used, which resulted in the highest production and the least energy consumption. From the results, we noted that the best production of hydrogen gas is 242.68 liters per hour when using a reaction surface area of 300 cm 2 with a 2 mm distance between the reaction slices and sea water as an electrolyte.

1. INTRODUCTION

Green hydrogen is considered one of the most important renewable energy sources (RES) green energy such as solar energy, wind energy, geothermal energy, and biomass, in addition to exploring for newer fuel sources (such biogas and hydrogen). to replace fossil products (like petroleum natural gas coal, and petroleum oil). **(Boulmrharj, Khaidar et al., 2020)** The world's power consumption is rapidly growing. Given the circumstances of the Russian-Ukrainian war and how it exacerbated the global economic and energy crises, the necessity of green energy and alternative sources of fossil fuels is amplified. As a result, Egypt benefits greatly from renewable energy sources, particularly wind and solar energy, where yearly solar radiation varies, green energy and alternative fossil fuel sources are becoming increasingly important. As a result, Egypt is a country rich in renewable energy resources, especially wind and solar energy., where annual solar radiation ranges from (2000-3200) kWh/m2 from north to south, and the state has allocated approximately 7,650 thousand square kilometres of land for the implementation of energy projects. Renewables will absorb around 35 GW of wind power and 55 GW of solar power, with the goal of increasing renewables' share of energy generating capacity to 50% by 2030 **(Colbertaldo et al., 2019)**. To offset rising electricity use. This will minimise their reliance on fossil fuels, which is now approximately 90% **(Sahbani et al. 2016)**. The Benban Solar Power Complex is Egypt's most impressive renewable energy investment, ranking among the world's largest solar power complexes. The Benban Solar Energy Complex produces almost 90% of the power produced by the High Dam, since it has 32 solar plants with a capacity of 1,465 megawatts, investments of up to two billion dollars, and several renewable energy sources. Among the most notable of these new projects are a photovoltaic plant in Hurghada with a capacity of 20 MW, built in collaboration with the Japan International Cooperation Agency (JICA), a photovoltaic plant in Zafarana with a capacity of 50 MW, built in collaboration with the German Bank Development, and a photovoltaic power plant in Kom Ombo with a capacity of 50 MW, built in collaboration with the Arab Fund for Development. Other solar power projects are also being undertaken by the private sector, including the 200 MW PV plant project at Kom Ombo, Aswan, under ASWA Power's Build Own Operate (BOO) scheme, and the 200 MW PV plant project, under the scheme Build, Own, and Operate (BOO) system of Al Nowais, Emirati. The goal of these plants was to send power to the EU region, the Middle East, and North Africa via a transnational electrical distribution network that might include high-voltage direct current (HVDC) transmission lines **(Samus et al. 2013)**. Yet since renewable energy is unpredictable and intermittent, it is necessary to develop efficient storage technologies to store excess energy, which is then used in times when production isn't occurring. Currently available energy storage options include batteries, superconductors, hydrogen, biogas, molten salt, and hydrogen. **(Ould Amrouche et al., 2016)**. The storage of electricity in the form of hydrogen has generated tremendous attention over the past decades because of its many benefits, including efficiency and cleanliness. Because hydrogen has a low density under ambient circumstances, increasing its density, which means decreasing its volume, is critical for storage. Depending on the use, storage capacity, temperature, and pressure, it can be stored in one of three states: compressed in high-pressure gas cylinders, liquid, or solid in metallic and non-metallic hydrate containers **(Ball & Wietschel, 2009)**. Hydrogen is abundant in nature. However, most of this element is coupled with other atoms, such as water. Therefore, the creation of hydrogen is needed. It may be created utilising a variety of resources, including water, biomass, and fossil fuels. mostly water electrolysis and natural gas reformulation **(Boulmrharj, El Ibrahimi et al., 2020)**. Petroleum and other petroleum products (coal, natural gas, and crude oil, for examples) create slightly more than 96% of the world's total hydrogen, with water electrolysis accounting for around 4%. However, water electrolysis, the most environmentally friendly method of creating hydrogen while reducing greenhouse gas emissions is to combine it with renewable energy alternatives. **(Dutta, 2014)**. This is owing to its several advantages, including cleanliness, water availability, and high-quality hydrogen production **(Mohammadi & Mehrpooya, 2018)**. Solid oxide, alkaline, and proton exchange membrane (PEM) electrolyzers are among the various types of electrolyzers. **(Shiva Kumar & Himabindu, 2019)**. So, it can be classified depending on enclosed system to two main types (a dry cell electrolyzer and electrolyzer for wet cells). An electrolyzer that is fully enclosed is called a dry cell electrolyzer. **(El-Oleimy et al, (2017)** studied a dry cell electrolyzer type. A wet cell electrolyzer which can be two metal plates in a bowl of water. The difference between these species, as shown in their electrolytes and operating temperatures, has been discussed in **(Rashid et al., 2015)**. Hydrogen produced and retained by fuel cells, which are applicable to hybrid power and heat systems (such as reciprocating engines, small turbines, rotary engines, fuel cells), can be used to generate electricity, thermal power, and water from the exothermic reaction between hydrogen and oxygen **(Peighambardoust et al., 2010)**. These systems operate more efficiently than traditional power cycles. Fuel cells are commonly utilised in automobiles and structures because to their modularity, increased efficiency (about 85-90%), cleanliness, and low noise level. Furthermore, the operating temperature, electrolyte, and fuel utilised are the most significant parameters considered when classifying fuel cells. The writers of **(Dodds et al., 2015)** discussed the various types of fuel cells as well as their properties. A proton exchange membrane (PEM) fuel cell, for example, is better suited for micro cogeneration applications because to its several benefits, a low temperature, less corrosion, fast start-up and load following, and high power density **(Hamelin et al., 2001)**. This study aims Developing an electrolytic water analyzer, studying the effect of some influences on the flow of generating hydrogen and the water analysis procedure, and clarifying the factors under study that give the highest production rate.

The objective of this work was to test the effect of some factors on the production of hydrogen from the electrolysis process to determine the optimal conditions for the interaction area of the electrode and the distance between the electrodes, which is represented by the gasket thickness and the water used which gives the highest production and the least consumed energy.

2. MATERIALS AND METHODS

2.1. Materials:

2.1.1. The Analyzing unit:

The electrolysis method has been selected as the way to produce hydrogen (H_2) for many energy applications due to its effectiveness. Electrolyzer for hydrogen production is classified into two main types dry and wet electrolyzer. In this work, we used the wet electrolyzer.

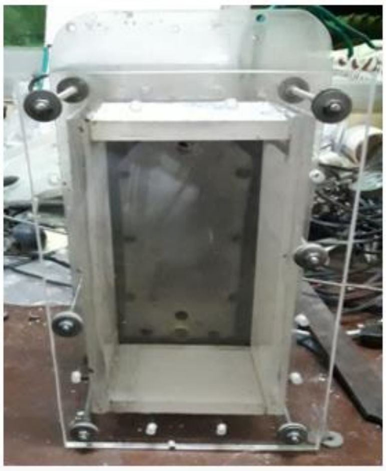


Fig. (1): The manufactured wet type electrolyzer.

2.1.1.1. Wet cell electrolyzer type:

The wet electrolyzer like a dry electrolyzer unit in the case of design, but it is encircled by an outer box as shown in Fig.1 that permits the electrolyzer unit to be submerged in water. Which increases the efficiency of the electrolyzer.

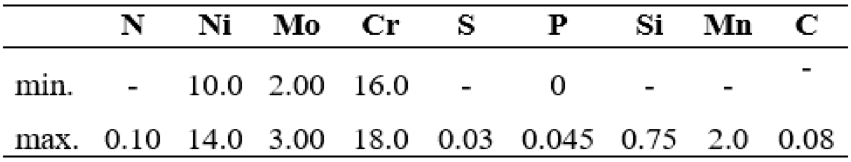
A dry cell electrolyzer type **(El-Oliemy et al., 2017)** was as illustrated in figure (2) and comprised a few plates (neutral, positive, negative, and end plates) sandwiched between wires, pipes, a DC power source, a bubbler, a flashback arrester, rubber seals, fasteners, etc. Rubber seals separate the plates to avoid the leakage of water.

Fig. (2) Components of a Dry Cell (El-Oleimy et al. 2017)

2.1.1.2. The wet salty water electrolyzer unit:

The wet cell electrolyzer for salt One common technology for water electrolysis is water. It is composed of 10 parallel cells. Each slice measures 10 x 20 cm and is 0.9 mm thick and is made of 316 stainless steels (stainless steel grade specifications are shown in Table 1, insulated by rubber gaskets. The cells are immersed in an acrylic box, assembled using 10 stainless screws and polystyrene insulation tubes. A pair of nozzles supply water and exit hydrogen from the electrolyzer.

Table 1: specifications of the stainless-steel grade:



	N	Ni	Mo	Cr	S	P	Si	Mn	C
min.	-	10.0	2.00	16.0	-	0	-	-	-
max.	0.10	14.0	3.00	18.0	0.03	0.045	0.75	2.0	0.08

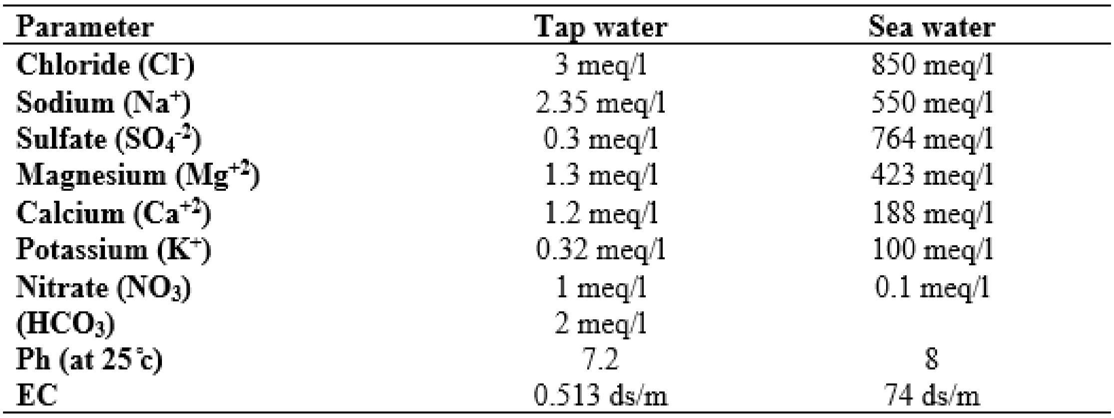
2.1.1.3. Sea water:

To reduce the cost of hydrogen produced by water electrolysis, it is necessary to reduce the capital cost and increase the energy efficiency of the cell. This can be achieved through the appropriate selection of electrodes and the use of a cheap and abundant electrolyte, such as sea water, due to its abundance, whether it is sea water or desert land well water that is not suitable for direct use due to its increased salinity, and these are the places in which this study was conducted. The use of solar energy in the electrolysis of this water is of particular importance to the study areas due to the increasing resources in these areas.

Hydrogen production from seawater electrolysis also has the advantage of producing chlorine instead of oxygen at the anode, which can be used to disinfect water for desalination plants.

Table 2 shows the chemical analysis of sea water and tap water shows the chemical analysis of sea water and tap water that was analyzed in the soil and Chemistry Laboratory, Faculty of Agriculture, saba basha, Alexandria University.

Table 2: Chemical analysis of sea water tap water.



Parameter	Tap water	Sea water
Chloride (Cl^-)	3 meq/l	850 meq/l
Sodium (Na^+)	2.35 meq/l	550 meq/l
Sulfate (SO_4^{-2})	0.3 meq/l	764 meq/l
Magnesium (Mg^{+2})	1.3 meq/l	423 meq/l
Calcium (Ca^{+2})	1.2 meq/l	188 meq/l
Potassium (K^+)	0.32 meq/l	100 meq/l
Nitrate (NO_3)	1 meq/l	0.1 meq/l
(HCO_3)	2 meq/l	
Ph (at $25^{\circ}c$)	7.2	8
EC	0.513 ds/m	74 ds/m

2.1.1.4. Hydrogen collected tank:

A hydrogen tank is a container that may hold hydrogen in either a liquid or gaseous state, as shown in Figure (3). They may also be referred to as cylinders, cans, or cartridges of hydrogen. The long history of innovation in the design and production of hydrogen tanks can be attributed to the need for the container to meet distinct physical criteria based on temperature and pressure during storage. Hydrogen fuel tanks are used in a wide range of applications that generate or use hydrogen, including electrolyzer systems, rockets, space travel, and fuel cells. A hydrogen system storage typically includes a hydrogen fuel tank.

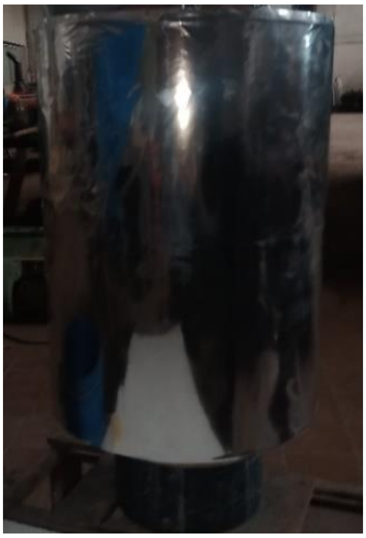


Fig. (3): Hydrogen cylinder tank.

Hydrogen cylinder tank specification:

- The Composite Overwrapped Pressure Vessel (COPV) H2 Max 29L hydrogen liquid has superior fast-filling capabilities.
- Perfect for harsh environments and cryogenic applications
- A working pressure of 3.5 bar for the custom cylinder.

2.1.2. Laboratory equipment:

During the experimental work, several measurements were executed using different measuring devices.

2.1.2.1. Digital multimeter:

This meter is one of a series of handheld professional measuring instruments. It has the following capability of performing functions: large screen digital.

- AC Voltage (V): from 200mV to 700V
- The DC voltage (V) ranges from 200mV to 1000V.AC Current (A): 20mA, 200mA, 20A
- Direct. Current (A): 200uA, 2, 20, 200mA and 20A

2.1.2.2. Multi-function Power monitor:

The 100A LCD on the huge screen Power, current, voltage, frequency, power factor, and power consumption can all be displayed simultaneously by a digital voltage, watt, current, power frequency, ammeter, and voltage. Features of the AC current transformer equipped:

- The huge screen can display power, current, voltage, frequency, power factor, and power consumption simultaneously.
- Completely brand new and of the highest quality.
- Capable of measuring maximum current of 20/100A and voltage range of AC 110V-250V

2.1.2.3. DIGITEN 3/8" hydrogen Gas Flow Meter Counter:

- DIGITEN 3/8" hydrogen Gas Flow Meter Counter Model GFS803 has these specifications:
- Gear 3/8" flow sensor for hose.
- Power requirement: 3-12VDC.
- Flow range: 1-30L/min.
- Accuracy: ±0.5%.
- Output signal: pulse singal,2.5mL/P.
- The appropriate pulse Signal is produced by the hall-effect sensor. Utilizable with Raspberry pi.

2.2. Methods:

2.2.1. Mathematical of a wet electrolyzer:

Sea water electrolysis for hydrogen production is the simplest promising technology especially for this study because large capacities of dual-purpose desalination plants are operating.

Hence the electricity needed for H_2 production from the sea is available and the product chlorine from electrolysis can be useful for disinfection of potable water. Furthermore, solar energy can also be utilized in sea water electrolysis either directly by photoelectrochemical techniques or indirectly by photovoltaic cells as will -be discussed later in this work.

The basic electrolysis reaction is **(Shen et al., 2011)**.

$$H_2O + Electricity = H_2 + \frac{1}{2} O_2 \qquad (1)$$

2.2.2. Theoretical calculations of wet electrolyzer hydrogen production:

Water electrolysis's hydrogen generation model is thought of as a DC load. The rate at which hydrogen is produced increases with increasing input current. The rate of electron transfer at the electrodes is correlated with the electrical current in the external circuit, as per Faraday's law, and this has an impact on hydrogen production.

To ascertain the overall rate of hydrogen production in the electrolyser, which is made up of many parallel cell connections, the **(Koundi & EL FADIL, 2019)** equation for operation is stated below.

$$V_{ez\,H2} \quad = \quad \frac{n_c\, R\, a\;\, I_{ez}\;\, T}{z\quad P\quad F} * 3600 * 1000 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Hydrogen production rate (L/h) can be determined
nc = the number of electrolytic slices in parallel
I ez = the electrolyzer current (0.2 A/cm^2).
a = the area of electrolytic slices (cm^2).
F = the Faraday constant, (96485.33 C mol^{-1} coulombs per mole)
R = the constant of gas Amount (8.3144 m3·pa·K^{-1}·mol^{-1})
T = operating temperature of the electrolyzer (298.15 K)
z = the electron count, which is two for hydrogen and four for oxygen.
P = pressure of electrolyzer (101325 pa)

3.3.4. Estimating the rate of hydrogen production from the electrolyzer:

Under laboratory circumstances, the water displacement metering device Figure (٤) was used to volumetrically measure the hydrogen generation rate (l/h) by cumulated hydrogen per replication

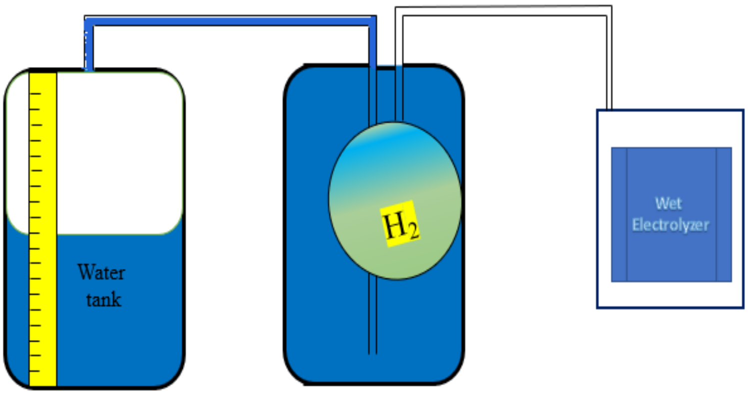


Fig. (4): The water displacement system.

3.3.5. Experimental wet Electrolyzer Power Consumption:

Two multi-meter devices are connected as shown in figure (5), one in series to measure the intensity of the current and the other in parallel to measure the voltage, to calculate the amount of energy used in the electricity used for the experiments.

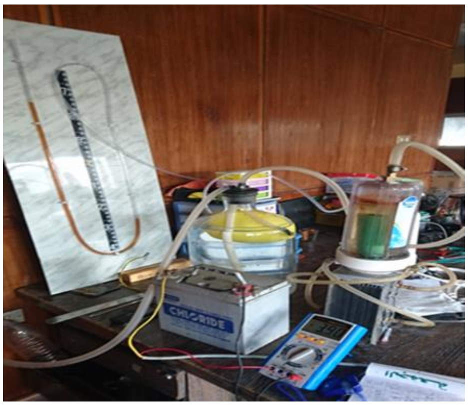


Fig. (5): Estimation of experimental wet electrolyzer power consumption.

The result of the Electrolyzer Power Consumption was calculated by multiplying the measured current and the measured voltage in the following equation to determine the amount of energy consumed **(Esposito, 2023)**.

Electrolyzer Power Consumption (W) = V × I…………………………………..… ….……..(3)

2.3. Experimental conditions:

The following diagram shows the factors under study affecting hydrogen production. Water type, interaction area and gasket thickness.

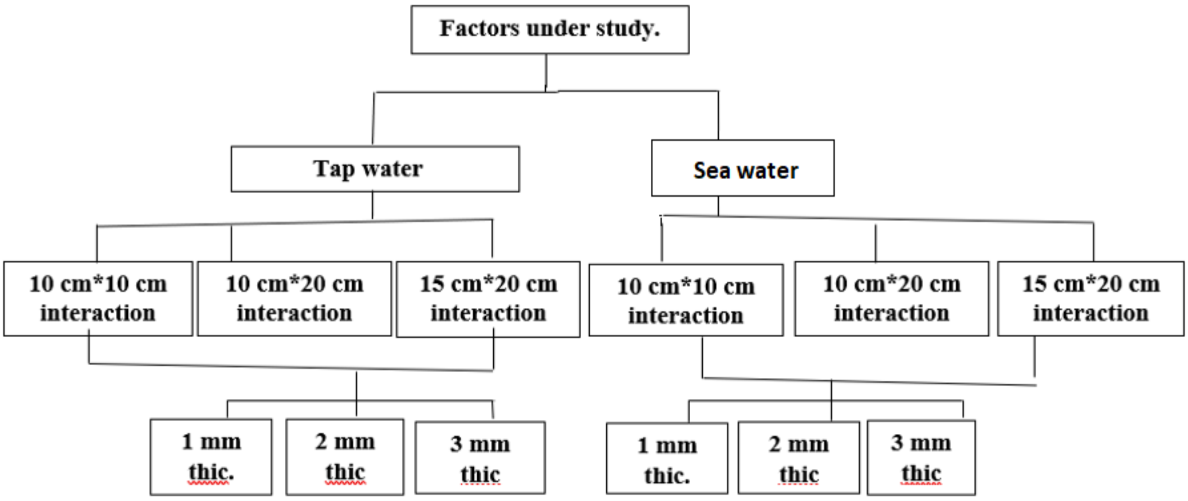


Fig: (6): Schematic diagram for factors under study.

3. RESULTS AND DISCUSSION

Electrolyzer experiments to evaluate the electrolyzer performance unit and its ability to produce hydrogen gas in one hour were conducted. The optimal set of operating standards for the research analysis has been obtained by gathering data from the electrolyser units. Nonetheless, the following headings have been used to discuss the findings of this current work:

3.1. Effect of water types on hydrogen production rat:

Indicated in Tables (3, 4, and 5) and figures (7 and 8) the effect of water used in the different study treatments on hydrogen production.

In the case of using tap water as a electrolyte between the reaction slices, the data showed that the least hydrogen production was 4.73 liters/hour when using one cell of the electrolyzer and the distance between the reaction plates was 1 mm and the reaction surface area was 10×10 cm, while it was 54.22 liters/hour in the case of using 10 cells, and a distance between the reaction plates was 1 mm, and the reaction surface area was 10×10 cm, while the highest hydrogen production was 179.96 liters/hour in the case of using 10 cells, and a distance between the reaction plates was 2 mm, and the reaction surface area was 15×20 cm.

While, In the case of using sea water as a electrolyte between the reaction slices, the data showed that the least hydrogen production was 7.38 liters/hour when using one cell of the electrolyzer and the distance between the reaction plates was 1 mm and the reaction surface area was 10×10 cm, while it was 68.72 liters/hour in the case of using 10 cells, and a distance between the reaction plates 1 mm, and the reaction surface area was 10×10 cm, while the highest hydrogen production was 242.68 liters/hour in the case of using 10 cells, and a distance between the reaction plates was 2 mm, and the reaction surface area was 15×20 cm. From the previous results, we note that

1- the hydrogen production rate is increasing with increase the interaction surface area.

2- the use of saltwater gives a greater production of hydrogen gas, and this is due to the dissolved salts, that increase electrical conductivity and increased efficiency of the electrolysis process.

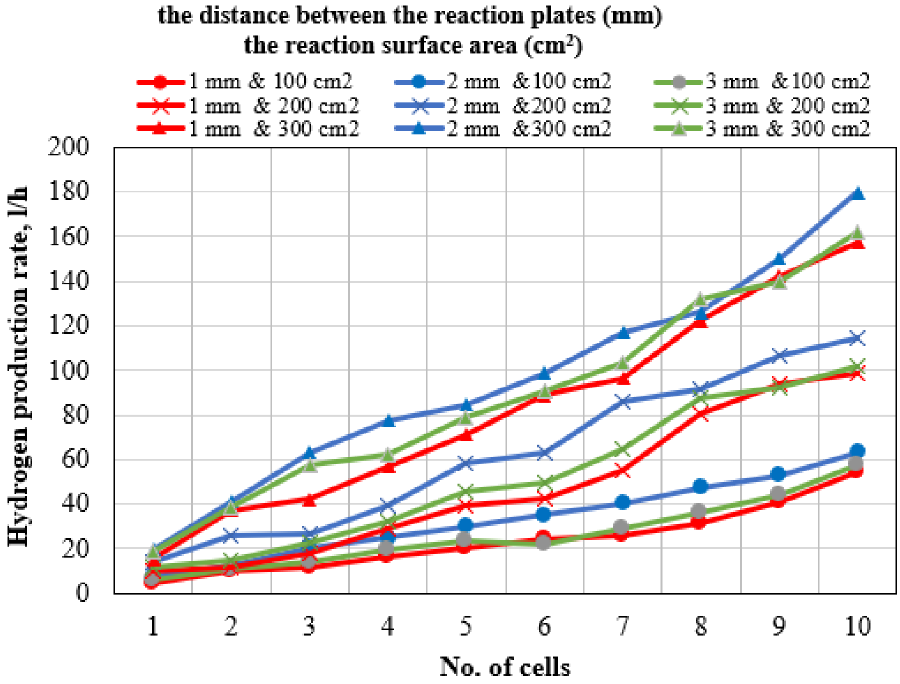


Fig. (7): Hydrogen production rate under different treatments of study with tap water electrolyte.

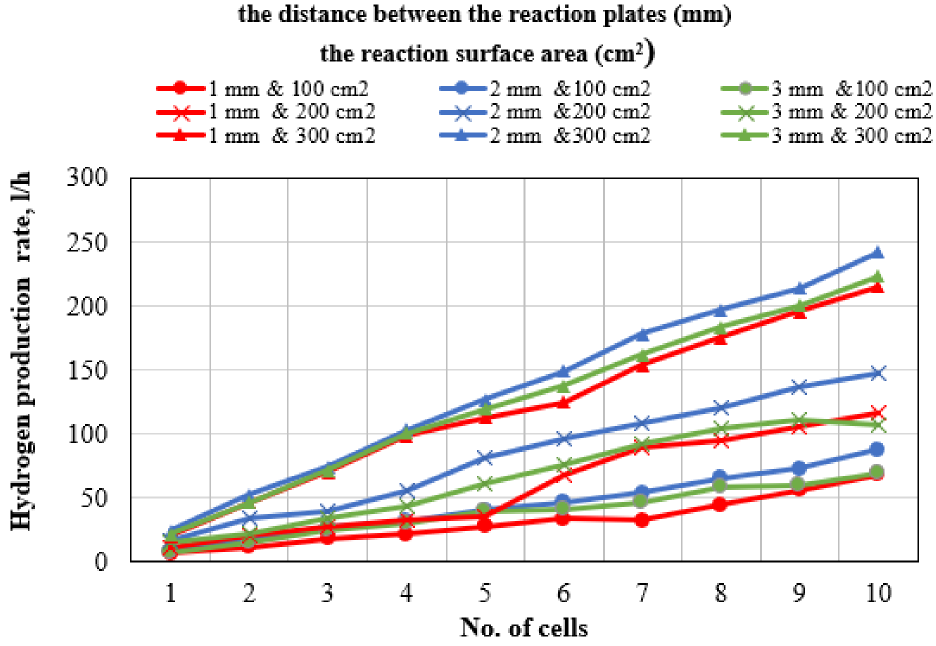


Fig. (8): Hydrogen production rate under different treatments of study with sea water electrolyte.

3.2. Effect of the gasket thickness (mm) on hydrogen production:

In the case of using the slice's reaction area (10x10 cm), the lowest hydrogen production was 54.22 l/h for a 1 mm distance between the cells and tap water, while the highest hydrogen production was 87.76 l/h for a 2 mm distance between the cells and sea water.

In the case of using the reaction area (10×20 cm) for slides, case the lowest hydrogen production was 99.04 l/h for a 1 mm distance between the cells and tap water, while the highest hydrogen production was 147.57 l/h for a 2 mm distance between the cells and sea water.

In the case of using the reaction area (15×20 cm) for slides the lowest hydrogen production was 157.23 l/h for a 1 mm distance between the cells and tap water, while the highest hydrogen production was 242.68 l/h for a 2 mm distance between the cells and sea water.

3.3. Effect of the reaction surface area of slices on hydrogen production:

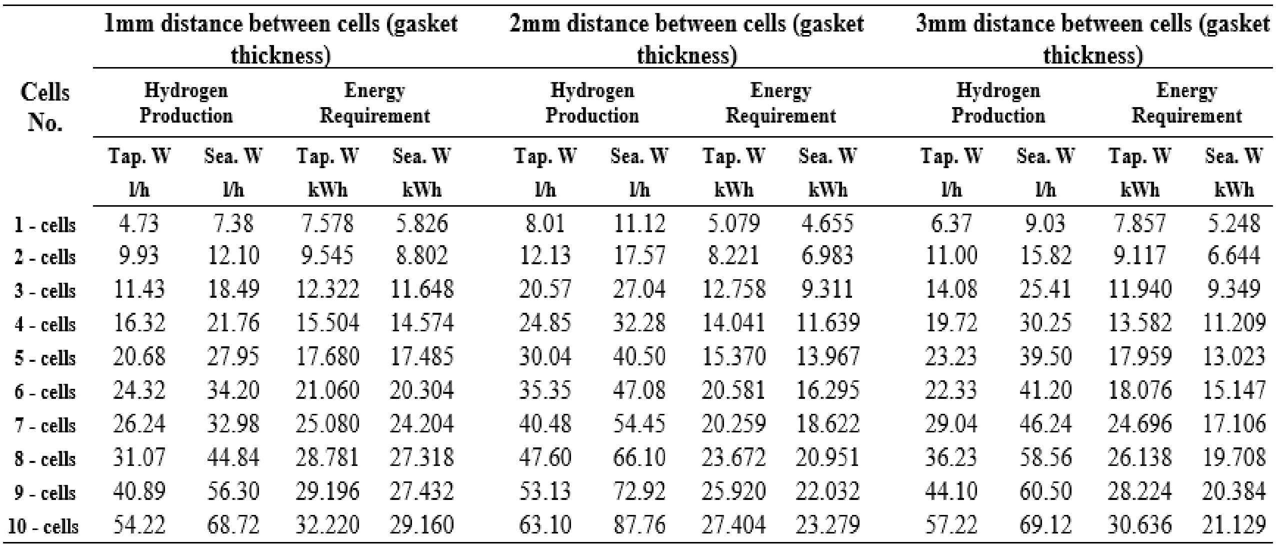
In the case of using the distance (1 mm) between the slices, the lowest hydrogen production was 99.04 l/h with 100 cm^2 the reaction surface area and tap water, while the highest hydrogen production was 215.94 l/h with 300 cm^2 the reaction surface area and sea water.

In the case of using the distance (2 mm) between the slices the lowest hydrogen production was 114.73 l/h with 100 cm^2 the reaction surface area and tap water, while the highest hydrogen production was 242.68 l/h with 300 cm^2 the reaction surface area and sea water.

In the case of using the distance (3 mm) between the slices, lowest hydrogen production was 57.22 l/h with 100 cm^2 the reaction surface area and tap water, while the highest hydrogen production was 223.72 l/h with 300 cm^2 the reaction surface area and sea water.

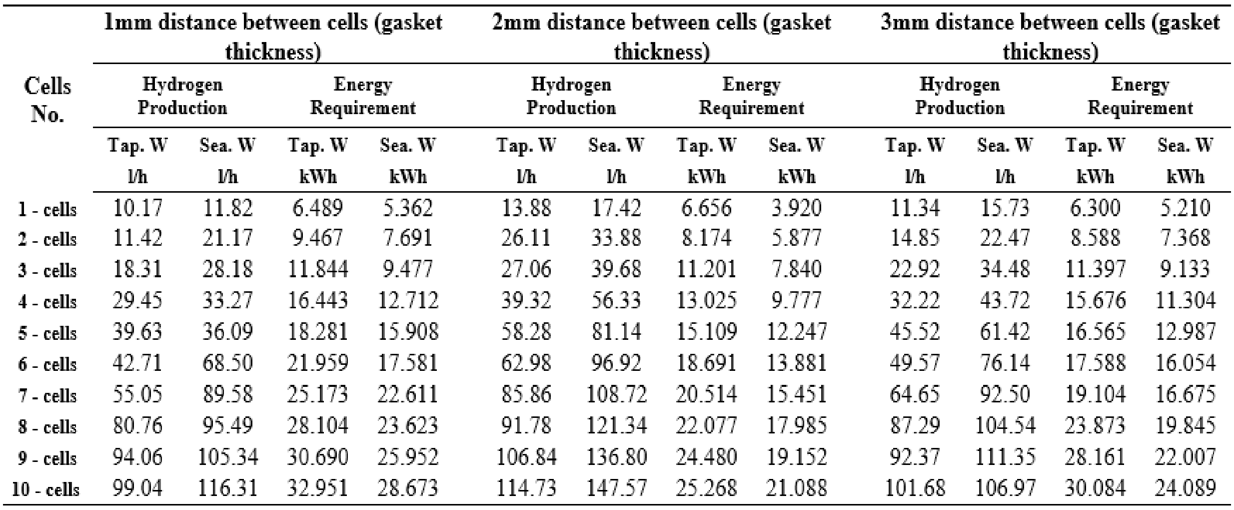
According to the data for the evaluation of the electrolyzer unit's performance in this part, experiments revealed that the best production of hydrogen gas is 242.68 liters per hour when using the reaction surface area of 300 cm square with a distance between the reaction slices 2 mm and the use of sea water such as an electrolyte.

Table (3). The effect of water used at different gasket thickness on hydrogen production at 10 x 10 cm reaction surface:



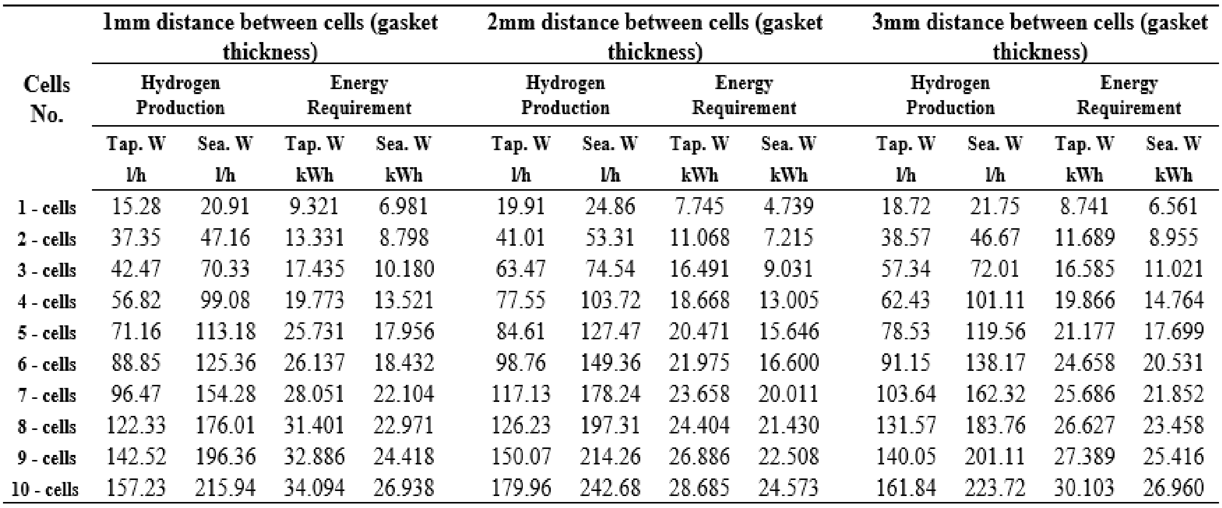
Cells No.	1mm distance between cells (gasket thickness)				2mm distance between cells (gasket thickness)				3mm distance between cells (gasket thickness)			
	Hydrogen Production		Energy Requirement		Hydrogen Production		Energy Requirement		Hydrogen Production		Energy Requirement	
	Tap. W l/h	Sea. W l/h	Tap. W kWh	Sea. W kWh	Tap. W l/h	Sea. W l/h	Tap. W kWh	Sea. W kWh	Tap. W l/h	Sea. W l/h	Tap. W kWh	Sea. W kWh
1 - cells	4.73	7.38	7.578	5.826	8.01	11.12	5.079	4.655	6.37	9.03	7.857	5.248
2 - cells	9.93	12.10	9.545	8.802	12.13	17.57	8.221	6.983	11.00	15.82	9.117	6.644
3 - cells	11.43	18.49	12.322	11.648	20.57	27.04	12.758	9.311	14.08	25.41	11.940	9.349
4 - cells	16.32	21.76	15.504	14.574	24.85	32.28	14.041	11.639	19.72	30.25	13.582	11.209
5 - cells	20.68	27.95	17.680	17.485	30.04	40.50	15.370	13.967	23.23	39.50	17.959	13.023
6 - cells	24.32	34.20	21.060	20.304	35.35	47.08	20.581	16.295	22.33	41.20	18.076	15.147
7 - cells	26.24	32.98	25.080	24.204	40.48	54.45	20.259	18.622	29.04	46.24	24.696	17.106
8 - cells	31.07	44.84	28.781	27.318	47.60	66.10	23.672	20.951	36.23	58.56	26.138	19.708
9 - cells	40.89	56.30	29.196	27.432	53.13	72.92	25.920	22.032	44.10	60.50	28.224	20.384
10 - cells	54.22	68.72	32.220	29.160	63.10	87.76	27.404	23.279	57.22	69.12	30.636	21.129

Table (4). The effect of water used at different gasket thickness on hydrogen production at 10 x 20 cm reaction surface:



Cells No.	1mm distance between cells (gasket thickness)				2mm distance between cells (gasket thickness)				3mm distance between cells (gasket thickness)			
	Hydrogen Production		Energy Requirement		Hydrogen Production		Energy Requirement		Hydrogen Production		Energy Requirement	
	Tap. W l/h	Sea. W l/h	Tap. W kWh	Sea. W kWh	Tap. W l/h	Sea. W l/h	Tap. W kWh	Sea. W kWh	Tap. W l/h	Sea. W l/h	Tap. W kWh	Sea. W kWh
1 - cells	10.17	11.82	6.489	5.362	13.88	17.42	6.656	3.920	11.34	15.73	6.300	5.210
2 - cells	11.42	21.17	9.467	7.691	26.11	33.88	8.174	5.877	14.85	22.47	8.588	7.368
3 - cells	18.31	28.18	11.844	9.477	27.06	39.68	11.201	7.840	22.92	34.48	11.397	9.133
4 - cells	29.45	33.27	16.443	12.712	39.32	56.33	13.025	9.777	32.22	43.72	15.676	11.304
5 - cells	39.63	36.09	18.281	15.908	58.28	81.14	15.109	12.247	45.52	61.42	16.565	12.987
6 - cells	42.71	68.50	21.959	17.581	62.98	96.92	18.691	13.881	49.57	76.14	17.588	16.054
7 - cells	55.05	89.58	25.173	22.611	85.86	108.72	20.514	15.451	64.65	92.50	19.104	16.675
8 - cells	80.76	95.49	28.104	23.623	91.78	121.34	22.077	17.985	87.29	104.54	23.873	19.845
9 - cells	94.06	105.34	30.690	25.952	106.84	136.80	24.480	19.152	92.37	111.35	28.161	22.007
10 - cells	99.04	116.31	32.951	28.673	114.73	147.57	25.268	21.088	101.68	106.97	30.084	24.089

Table (5). The effect of water used at different gasket thickness on hydrogen production at 15 x 20 cm reaction surface:



Cells No.	1mm distance between cells (gasket thickness)				2mm distance between cells (gasket thickness)				3mm distance between cells (gasket thickness)			
	Hydrogen Production		Energy Requirement		Hydrogen Production		Energy Requirement		Hydrogen Production		Energy Requirement	
	Tap. W l/h	Sea. W l/h	Tap. W kWh	Sea. W kWh	Tap. W l/h	Sea. W l/h	Tap. W kWh	Sea. W kWh	Tap. W l/h	Sea. W l/h	Tap. W kWh	Sea. W kWh
1 - cells	15.28	20.91	9.321	6.981	19.91	24.86	7.745	4.739	18.72	21.75	8.741	6.561
2 - cells	37.35	47.16	13.331	8.798	41.01	53.31	11.068	7.215	38.57	46.67	11.689	8.955
3 - cells	42.47	70.33	17.435	10.180	63.47	74.54	16.491	9.031	57.34	72.01	16.585	11.021
4 - cells	56.82	99.08	19.773	13.521	77.55	103.72	18.668	13.005	62.43	101.11	19.866	14.764
5 - cells	71.16	113.18	25.731	17.956	84.61	127.47	20.471	15.646	78.53	119.56	21.177	17.699
6 - cells	88.85	125.36	26.137	18.432	98.76	149.36	21.975	16.600	91.15	138.17	24.658	20.531
7 - cells	96.47	154.28	28.051	22.104	117.13	178.24	23.658	20.011	103.64	162.32	25.686	21.852
8 - cells	122.33	176.01	31.401	22.971	126.23	197.31	24.404	21.430	131.57	183.76	26.627	23.458
9 - cells	142.52	196.36	32.886	24.418	150.07	214.26	26.886	22.508	140.05	201.11	27.389	25.416
10 - cells	157.23	215.94	34.094	26.938	179.96	242.68	28.685	24.573	161.84	223.72	30.103	26.960

3.4.1. Power consumption:

The optimal set of operating standards for the research analysis has been obtained by gathering data from the electrolyzer units. Nonetheless, the following headings have been used to discuss the findings of this current work.

3.4.2. Effect of water types on power consumption:

Indicated in Tables (3, 4, and 5) explains the effect of water used in the different study treatments on power consumption.

In the case of using tap water as a electrolyte between the reaction slices, the measured data showed that the least power consumption was 5.079 kWh when using one cell of the electrolyzer and the distance between the reaction plates was 2 mm and the reaction surface area was 10×10 cm, while it was 25.268 kWh in the case of using 10 cells, and a distance between the reaction plates was 2 mm, and the reaction surface area was 10×20 cm, while the highest power consumption was 34.094 kWh in the case of using 10 cells, and a distance between the reaction plates was 1 mm, and the reaction surface area was 15×20 cm.

While, In the case of using sea water as a electrolyte between the reaction slices, the measured data showed that the least power consumption was 3.920 kWh when using one cell of the electrolyzer and the distance between the reaction plates was 2 mm and the reaction surface area was 10×20 cm, while it was 21.088 kWh in the case of using 10 cells, and a distance between the reaction plates 2 mm, and the reaction surface area was 10×20 cm, while the highest power consumption was 29.160 kWh in the case of using 10 cells, and a distance between the reaction plates was 1 mm, and the reaction surface area was 10×10 cm..

3.4.3. Effect of the gasket thickness (mm) on power consumption:

In the case of using the reaction slides area (10×10 cm), the lowest power consumption was 21.129 kWh for a 3 mm distance between the cells and sea water, while the highest power consumption was 32.22 kWh for a 1 mm distance between the cells and tap water.

In the case of using the reaction area (10×20 cm) for slides, the lowest power consumption was 21.088 kWh for a 2 mm distance between the cells and sea water, while the highest power consumption was 32.951 kWh for a 1 mm distance between the cells and tap water.

In the case of using the reaction area (15×20 cm) for slides, the lowest power consumption was 24.573 kWh for a 2 mm distance between the cells and sea water, while the highest power consumption was 34.094 kWh for a 1 mm distance between the cells and tap water.

3.4.4. Effect of the reaction surface size of slices on power consumption:

In the case of using the distance (1 mm) between the slices, the lowest power consumption was 26.938 kWh with 300 cm^2 the reaction surface area and sea water, while the highest power consumption was 34.094 kWh with 300 cm^2 the reaction surface area and tap water.

In the case of using the distance (2 mm) between the slices, the lowest power consumption was 21.088 kWh with 200 cm2 the reaction surface area and sea water, while the highest power consumption was 28.685 kWh with 200 cm^2 the reaction surface area and tap water.

In the case of using the distance (3 mm) between the slices, the lowest power consumption was 21.129 kWh with 100 cm^2 the reaction surface area and sea water, while the highest power consumption was 30.636 kWh with 100 cm^2 the reaction surface area and tap water.

According to the data for the evaluation of how well this section's electrolyzer unit performed, experiments revealed that the best lowest power consumption is 21.088 kWh when using the reaction surface area of 200 cm square with a distance between the reaction slices 2 mm and the use of sea water such as an electrolyte.

4. CONCLUSION

Laboratory experiments were conducted to evaluate the performance of electrolysis of saline water and production of green hydrogen used as the most important alternative and clean renewable energy sources at the Renewable Energy Research Laboratory, Morning Tractor Research and Testing Station, Agricultural Engineering Research Institute, Agricultural Research Center. This study aims to develop a water electrolyzer to reach the highest rate of hydrogen production through water electrolysis using an electrolyzer under various factors such as the type of water used, the interaction surface area of the electrolyzer slices, and the thickness between the slices. According to the data for the evaluation of the performance of the electrolyzer unit, experiments revealed that the best production of hydrogen gas is 242.68 liters per hour when using the reaction surface area of 300 cm^2 with a distance between the reaction slices 2 mm and the use of sea water such as an electrolyte.

According to the data for the evaluation of the how well this section's electrolyzer unit performed, experiments revealed that the best lowest power consumption is 21.088 kWh when using the reaction surface area of 200 cm square with a distance between the reaction slices 2 mm and the use of sea water such as an electrolyte.

REFERENCES

Abdullah, A. G., Fahruddin, A. r., Ichsani, D., Taufany, F., & Nandiyanto, A. B. D. (2018). Improving PEM fuel cell performance using in-line triangular baffles in triple serpentine flow field. *MATEC Web of Conferences*, *197*. https://doi.org/10.1051/matecconf/201819708010

Ball, M., & Wietschel, M. (2009). The hydrogen economy: opportunities and challenges.

Boulmrharj, S., El Ibrahimi, M., Louardi, A., Aarich, N., Bennouna, A., Bakhouya, M., Raoufi, M., Monkade, M., Zehaf, M., & Khaidar, M. (2020). Modeling and Performance Analysis of a Grid-connected Polycrystalline Silicon Photovoltaic System under the Maritime Climate of El Jadida in Morocco. *International Journal of Renewable Energy Research (IJRER)*.

Boulmrharj, S., Khaidar, M., Siniti, M., Bakhouya, M., & Zine-dine, K. (2020). Towards performance assessment of fuel cell integration into buildings. *Energy Reports*, *6*, 288-293. https://doi.org/https://doi.org/10.1016/j.egyr.2019.08.058

Colbertaldo, P., Agustin, S. B., Campanari, S., & Brouwer, J. (2019). Impact of hydrogen energy storage on California electric power system: Towards 100% renewable electricity. *International Journal of Hydrogen Energy*, *44*(19), 9558-9576. https://doi.org/https://doi.org/10.1016/j.ijhydene.2018.11.062

Dodds, P. E., Staffell, I., Hawkes, A. D., Li, F., Grünewald, P., McDowall, W., & Ekins, P. (2015). Hydrogen and fuel cell technologies for heating: A review. *International Journal of Hydrogen Energy*, *40*(5), 2065-2083. https://doi.org/https://doi.org/10.1016/j.ijhydene.2014.11.059

Dutta, S. (2014). A review on production, storage of hydrogen and its utilization as an energy resource. *Journal of Industrial and Engineering Chemistry*, *20*(4), 1148-1156. https://doi.org/https://doi.org/10.1016/j.jiec.2013.07.037

El-Oliemy, R. M., El-Metwalli, A. M. H., Darwish, M. R., & Hemeda, S. G. (2017). Utilization of hydrogen generated by using ultrasonic techniuqe as a new source of energy for operating a small engine. *Misr Journal of Agricultural Engineering*, *34*(4), 2073-2082.

Esposito, L. (2023). Renewable energy consumption and per capita income: An empirical analysis in Finland. Renewable Energy, 209, 558-568.

Grimes, C. A., Varghese, O. K., & Ranjan, S. (2008). *Light, water, hydrogen: the solar generation of hydrogen by water photoelectrolysis* (Vol. 546). Springer.

Hamelin, J., Agbossou, K., Laperrière, A., Laurencelle, F., & Bose, T. K. (2001). Dynamic behavior of a PEM fuel cell stack for stationary applications. *International Journal of Hydrogen Energy*, *26*(6), 625-629. https://doi.org/https://doi.org/10.1016/S0360-3199(00)00121-X

Koundi, M., & EL FADIL, H. (2019). Mathematical modeling of PEM electrolyzer and design of a voltage controller by the SMPWM approach. 2019 international conference on power generation systems and renewable energy technologies (PGSRET),

Mohammadi, A., & Mehrpooya, M. (2018). A comprehensive review on coupling different types of electrolyzer to renewable energy sources. *Energy*, *158*, 632-655. https://doi.org/https://doi.org/10.1016/j.energy.2018.06.073

Ould Amrouche, S., Rekioua, D., Rekioua, T., & Bacha, S. (2016). Overview of energy storage in renewable energy systems. *International Journal of Hydrogen Energy*, *41*(45), 20914-20927. https://doi.org/https://doi.org/10.1016/j.ijhydene.2016.06.243

Peighambardoust, S. J., Rowshanzamir, S., & Amjadi, M. (2010). Review of the proton exchange membranes for fuel cell applications. *International Journal of Hydrogen Energy*, *35*(17), 9349-9384. https://doi.org/https://doi.org/10.1016/j.ijhydene.2010.05.017

Rashid, M., Al Mesfer, M. K., Naseem, H., & Danish, M. (2015). Hydrogen production by water electrolysis: a review of alkaline water electrolysis, PEM water electrolysis and high temperature water electrolysis. *International Journal of Engineering and Advanced Technology*.

Sahbani, S., Mahmoudi, H., Hasnaoui, A., & Kchikach, M. (2016). Development Prospect of Smart Grid in Morocco. *Procedia Computer Science*, *83*, 1313-1320. https://doi.org/https://doi.org/10.1016/j.procs.2016.04.274

Samus, T., Lang, B., & Rohn, H. (2013). Assessing the natural resource use and the resource efficiency potential of the Desertec concept. *Solar Energy*, *87*, 176-183. https://doi.org/https://doi.org/10.1016/j.solener.2012.10.011

Shen, M., Bennett, N., Ding, Y., & Scott, K. (2011). A concise model for evaluating water electrolysis. International Journal of Hydrogen Energy, 36(22), 14335-14341. https://doi.org/https://doi.org/10.1016/j.ijhydene.2010.12.029

Shiva Kumar, S., & Himabindu, V. (2019). Hydrogen production by PEM water electrolysis – A review. *Materials Science for Energy Technologies*, *2*(3), 442-454. https://doi.org/https://doi.org/10.1016/j.mset.2019.03.002

Zou, J.-J., Zhang, Y.-P., & Liu, C.-J. (2007). Hydrogen production from dimethyl ether using corona discharge plasma. *Journal of Power Sources*, *163*(2), 653-657. https://doi.org/10.1016/j.jpowsour.2006.02.078

التحليل الكهربائي للمياه المالحة وتأثيره على إنتاج الهيدروجين الأخضر

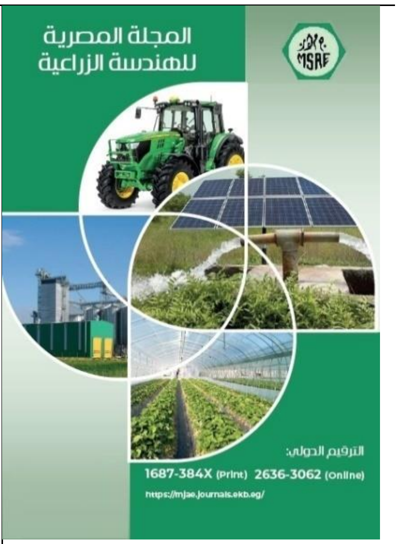
أ.د. عبد الوهاب شلبي قاسم[١]، م.م. أميرة عيسى علي عيسى[٢]، أ.د. عبد الله مسعد زين الدين[١]،
د. سامي جمعة حميدة[٣] و أ.د. عبد العزيز إبراهيم عمارة[١]

[١] أستاذ - قسم الهندسة الزراعية - كلية الزراعة - جامعة الإسكندرية - مصر.
[٢] مدرس مساعد - كلية الزراعة سابا باشا - جامعة الإسكندرية - مصر.
[٣] باحث - معهد بحوث الهندسة الزراعية – وزارة الزراعة - مصر.

الملخص العربي

أجريت التجارب المعملية لتقييم أداء تحليل الكهربي للمياه المالحة وإنتاج الهيدروجين الأخضر المستخدم كأهم مصادر الطاقة المتجددة البديلة و النظيفة في معمل بحوث الطاقة المتجددة، محطة أبحاث واختبارات الجرارات الصباحية، معهد بحوث الهندسة الزراعية، مركز البحوث الزراعية و هذه الدراسة تهدف الى تطوير محلل المياه الكهربي للوصول إلى أعلى معدل انتاج من الهيدروجين عن طريق التحليل الكهربي للمياه باستخدام الإليكتروليزر تحت العوامل المختلفة من نوع المياه المستخدمة و مساحة سطح التفاعل لشرائح الإليكتروليزر و السمك بين الشرائح. ووفقا لبيانات تقييم أداء وحدة التحليل الكهربي أظهرت التجارب أن أفضل إنتاج لغاز الهيدروجين هو٢٤٢,٦٨ لترا في الساعة عند استخدام مساحة سطح التفاعل ٣٠٠سم^{٢} مع وجود مسافة بين شرائح التفاعل ٢ مم واستخدام مياه البحر.

وعند دراسة الطاقة المستهلكة في انتاج الهيدروجين تحت الظروف المختلفة تشير البيانات إلى تقييم أداء وحدة التحليل الكهربائي أن أقل استهلاك للطاقة هو٢١,٠٨٨ كيلو وات ساعة عند استخدام مساحة سطح التفاعل٢٠٠ سم٢ مع مسافة بين شرائح التفاعل ٢ مم واستخدام مياه البحر.



الكلمات المفتاحية:
إنتاج الهيدروجين؛ المحلل الكهربائي الرطب؛ تفاعل التحليل الكهربائي؛ خلية الوقود؛ استهلاك الطاقة.