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Hydrogen Production by Hybrid photovoltaic Thermal System

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Abstract

Hydrogen fuel is a good alternative to fossil fuels. It can be produced using a clean energy without contaminated emissions. This work is concerned with experimental study on hydrogen production via solar energy. Hybrid photovoltaic thermal system (PV/T) is used to convert solar radiation to electrical and thermal energy. The electrical energy is used to analyze water into hydrogen and oxygen by using alkaline water electrolyzer with stainless steel electrodes. The absorbed thermal energy is used to heat circulating water inside the copper serpentine pipe fixed on the back surface of the PV panel. A perforated pipe connected on the upper edge of PV panel is used to spray a thin layer of water on the PV panel surface for auxiliary cooling and improve the generated electrical power. The hydrogen production system is tested at different temperature of electrolysis water (40, 45, 50, 55, 60)˚C. The experimental results show that the PV module electrical efficiency is improved by (14.31)%. while the power generated was enhanced by (3.94 to 15.40)%. The maximum hydrogen production rate is 153.3 ml/min, the efficiency of the system is 20.88% and the total amount of hydrogen produced in one day is 220.752 liter.

Keywords: photovoltaic thermal panel, electrolyzer, hydrogen.

1. Introduction

Solar energy presents the prime source of energy for life on earth [1]. Photovoltaic (PV) is the most direct way to convert solar radiation into electricity [2]. Usually, most of the losses that associated with photovoltaic conversion of sunlight to electricity are wasted in the form of internal heat inside the cell, to prevent these losses, thermal photovoltaic system is used. The heat is removed from the panel and used to heat water used in domestic applications[3]. The solar hydrogen production system by alkaline water electrolysis with different input conditions of voltages and currents has been studied experimentally, Increasing the temperature and electrolyte concentration led to net increase of volume flow, current intensity and efficiency [4]. Generating hydrogen fuel through water electrolysis using a small (PV) photovoltaic panel has been investigated, the costs of concentrator photovoltaic to generate hydrogen is (3.63$/kg) and it is cheaper than other systems namely gas reformation(1.15$/kg)[5]. Using the emitted heat from the PV/T system improves the overall system energy efficiencies from 15% to 50% and using fuel cell heat also increases the energy efficiency while the exergy efficiency goes from 2.8% to 19.8%. Utilizing emitted water improves the energy and exergy efficiency by 0.02% and 0.1%, respectively. Fuel cell produces 80 liter of drinking water after using 80m^3 of hydrogen[6].

2. Theoretical Model

There are many mathematical models in the literature to describe photovoltaic cells, from simple to more complex models. Some of them is used two-diode model and other used one-diode model [7]. In present work one-diode model is used. The current–voltage (I–V) characteristic of a photovoltaic module can be described with a single diode in Eq.(1) [8].

$$I = I_L - I_o\left[\exp\left(\frac{V+IR_s}{N_s n_I V_t}\right)-1\right]-\frac{V+IR_s}{R_{sh}} \quad \dots (1)$$

V_t is depending on the cell temperature, which is defined as

$$V_t = \frac{kT_c}{q} \quad \dots (2)$$

2.1 Four - Parameter Model

The four parameters model adopted in this work is based on IL, I_o, R_s, a, [9]. Assume R_{sh} as infinite and neglecting in the third term in Eq.(1)

$$I = I_L - I_o\left[\exp\left(\frac{V+IR_s}{mV_t}\right)-1\right] \quad \dots (3)$$

Where m is the product of $N_s n_I$.To evaluate the power generated by PV module, the simple relationship used

$$P = IV \quad \dots (4)$$

Introducing Eq.(3) into Eq. (4), the power would be

$$P = IV = \left\{I_L - I_o\left[\exp\left(\frac{V+IR_s}{mV_t}\right)-1\right]\right\} V \quad \dots (5)$$

R_s is assumed to be independent of both temperature and solar radiation so that $R_s = R_{s,ref}$ $R_{s,ref}$ it is calculated as :

$$R_{s,ref} = \frac{a_{ref}\ln\left(1-\frac{I_{mp,ref}}{I_{L,ref}}\right)-V_{mp,ref}+V_{OC,ref}}{I_{mp,ref}} \quad \dots (6)$$

a_{ref} is calculated by:

$$a_{ref} = \frac{\mu_{V,oc} T_{c,ref} - V_{oc,ref} + E_q N_s}{\frac{T_{c,ref}\ \mu_{I,sc}}{I_{L,ref}} - 3} \quad \dots (7)$$

The electrical efficiency of the module at maximum-power point can be calculated as

$$\eta = \frac{P}{G \times A} \times 100 \quad \dots (8)$$

The current produced by incident light is computed by :

$$I_L = \left(\frac{G}{G_{ref}}\right)\left[I_{L,ref} + \mu_{I,sc}\left(T_c - T_{c,ref}\right)\right] \quad \dots (9)$$

The reverse saturation current of p-n diodes is computed by :

$$I_o = I_{o,ref}\left(\frac{T_c}{T_{c,ref}}\right)^3 \exp\left[\left(\frac{E_q N_s}{a}\right)\left(1 - \frac{T_{c,ref}}{T_c}\right)\right] \dots (10)$$

$I_{o,ref}$ is calculate by

$$I_{o,ref} = \frac{I_{L,ref}}{\exp\left(\frac{V_{oc,ref}}{a_{ref}}\right) - 1} \quad \dots (11)$$

a is calculated as

$$a = a_{ref}\frac{T_c}{T_{c,ref}} \quad \dots (12)$$

2.2 Mathematical Analysis of Hydrogen Generation Cell

The core of an electrolysis unit is an electrochemical cell, which is filled with pure water and has two electrodes connected with an external power supply. The following equations represents the cathode, anode and the total reaction existed for electrolysis of water, [10].

Cathode $2H_2O + 2e^- \rightarrow 2OH + H_2$ … (13)

Anode $2OH^- \rightarrow H_2O + 2e^- + \frac{1}{2}O_2$ … (14)

Total $2H_2O \rightarrow H_2 + \frac{1}{2}O_2 + H_2O$ … (15)

The hydrogen flow rate, can be evaluated as [11]:

$$Q = \eta_F \frac{I_{ely}}{nF} \times 3600 \times 0.224136 \times 1000 \quad \dots (16)$$

η_F expresses how much current is converted in the desired reaction and it is the ratio of the experimental volume of hydrogen and the theoretical volume of hydrogen, [12]

$$\eta_F = \frac{V_{H_2\ experimental}}{V_{H_2\ theroritical}} \times 100 \quad \dots (17)$$

$V_{H_2\ experimental}$ can be obtained from the experimental data, $V_{H_2\ theroritical}$ can be calculate from this Eq.

$$V_{H_2\ theroritical} = \frac{I \times t \times v_m}{n\ F} \quad \dots (18)$$

The total efficiency of the electrolyze is found from Eq.(19), [12].

$$\eta = \frac{H_{H_2} \times V_{H_2\ experimental}}{U \times I \times t} \times 100 \quad \dots (19)$$

3. Experimental Setup

The experimental system consists of mono-crystalline photovoltaic module was south oriented at 45 ° with the horizontal. A serpentine copper pipe of (12.7 mm) diameter and 10 meter length is fitted on the back surface of the PV module to cool it by circulating water to remove the heat from the solar panel and protect it from excess heating as well as provide the electrolyzer with hot water to study the effect of inlet water temperature on the performance on hydrogen production. Water pump is used to circulate water from storage tank to serpentine pipe and return again to storage tank with (30 l/m) maximum flow rate. Perforated plastic pipe (770 mm length, 15 mm diameter, 9 holes, diameter of each holes is 2 mm) is connected on the upper edge of solar module to distribute a thin water layers on a front face of solar module to reduce its temperature and therefore increase the generated power. Submersible pump (8W) with 1000 l/h maximum flow rate is used to circulate water to the perforated pipe. The hydrogen production system consist of two stainless steel plate electrodes (140×80×1) mm connect to 9Ah/12V sealed type lead-acid battery to provide the electricity needed to start water electrolysis and the battery connected to PV panel through solar charge controller type (HBSC201) 12/24V 20A.The two electrodes inserted inside two plastic graduated cylinders of 260 mm length and 90 mm diameter to collect hydrogen gas, the cylinders upside down immersed in a basin filled with water, one of electrodes is connected to the positive pole of battery to work as an anode and the other is connected to the negative pole of battery to make it as a cathode. The Schematic diagram of the experimental set-up shown in **Fig.1**

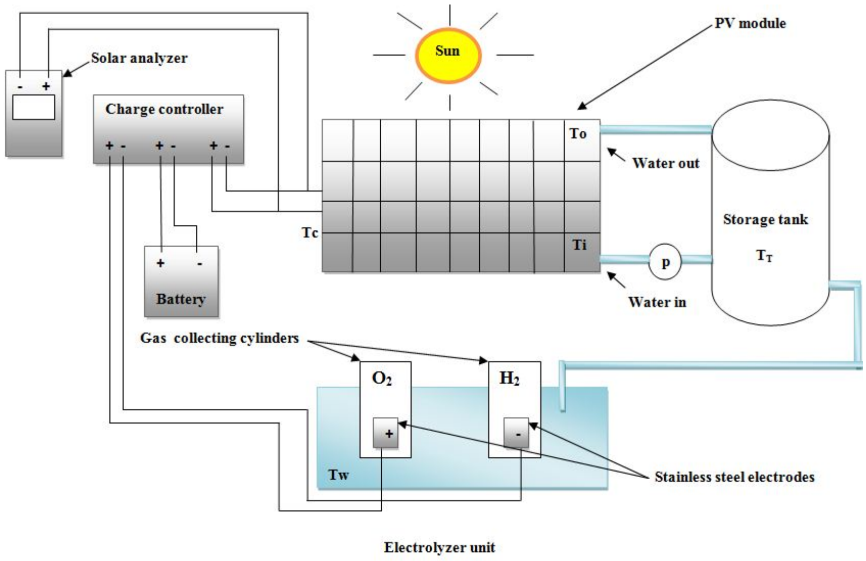


Figure 1: Schematic diagram of the experimental set-up with thermocouples locations.

PROVA 200 solar module analyzer is used to present (I-V) and (P-V) curves for solar module, calculate the maximum solar power (P_{max}), identify the maximum voltage (V_{max}), maximum current (I_{max}), voltage at open circuit (V_{open}), current at short circuit (I_{short}) and predict the electrical efficiency. Solar power meter type TES (1333R) is used to measure the solar irradiation in W/m², it has four digit display with 0.1W/m² resolution. A digital thermometer type (TPM-10) probe, LCD display, temperature range -50˚C to +70˚C, accuracy of ±1˚C and of resolution of 0.1 located on the back side of the module to measure its temperature (Tc), The temperature inside the storage tank (T_T), inlet and outlet water temperature of the serpentine tube (Ti, To), temperature of the basin water used in electrolysis (Tw) as well as the ambient temperature (Ta).

3.1 Water Displacement Method

This method is used to measure the volume of hydrogen generated. The gas collecting cylinders are filled with water and located upside down in the basin. When the electrolysis of water begins and hydrogen with oxygen released, the gas displaces the water inside the cylinder down and takes his place and the displacement of water continues until the cylinder is filled with gas.

3.2 Data Analysis Processing

The electrical efficiency of the solar module is calculated using Eq.(8). The efficiency of hydrogen production system is calculated using Eq.(19). The gas pressure is evaluated as

$$P=P_{atm}-\rho gh \quad \dots (20)$$

where P_{atm} is the atmospheric pressure, ρ is density of the liquid kg/m^3, g is acceleration due to gravity = 9.8 m/s^2, h is the difference between the water level inside cylinder and the water level outside cylinder.

3.3 Experimental Procedure

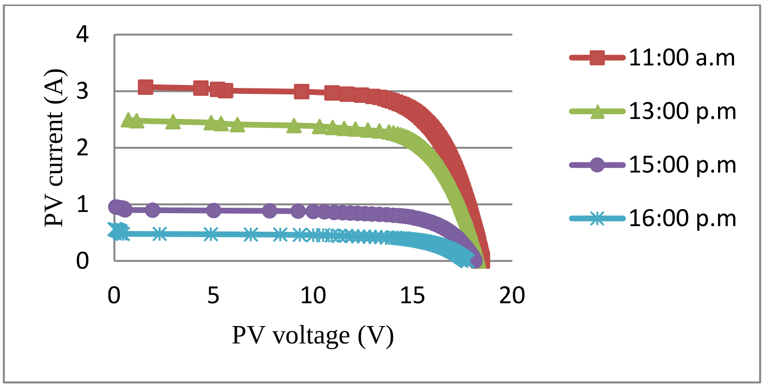
Connect the solar module analyzer to solar module and use solar power meter to measure the solar radiation and input the value in analyzer and connect the solar module analyzer to the laptop and click auto scan button to measure open circuit voltage, short circuit current, maximum power, maximum voltage, maximum current and efficiency for each hour. Use the digital thermometer to measure the hourly temperatures for module and ambient (Tc, Ta) and water inlet (Ti), water outlet (To) temperatures for cooling pipe, as well as the tank temperature (T_T). Fill the storage tank with water and Pumping water to serpentine pipe (cooling pipe). Admit a thin layer of water to flow on the front face of solar module until the temperature of module reach a steady state condition (approximately 10 minutes) after pumping water by auxiliary pump then the pump is turned off. Fill the basin with 10 liters of water and dissolve 50 gram of NaOH into the basin water. Fill the cylinders with water and upside down in the basin. Insert the electrodes into the cylinders. Connect the two electrode to power supply (battery or solar module) the electrolysis of water will begin .Insert thermometer in basin water to measure the Tw. Measure the total gas produced by using water displacement method .Record the time required to collect 100 ml of hydrogen and repeat this for (200,300,400,500,600,700,800,900,1000) ml. Fix the concentration of NaOH at 50 gram and change the temperature of water (40,45,50,55,60)˚C and repeat the previous steps for each temperature.

4. Results and Discussion

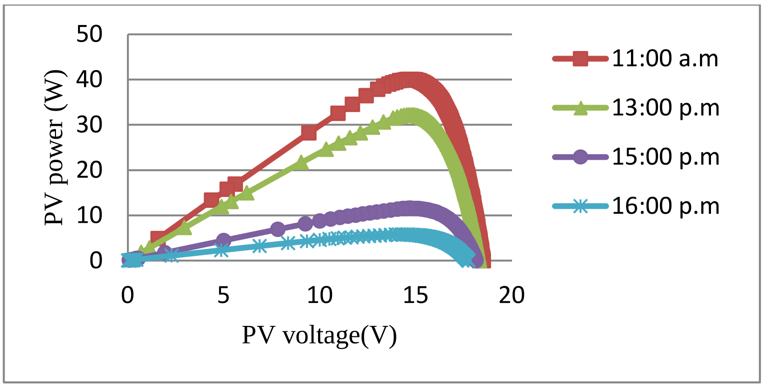
The discussion of photovoltaic module used for hydrogen generation are presented. The hydrogen production system and the effects of temperature of water on hydrogen production are discussed also.

4.1 With Cooling (Case I)

In this case the pump of the main loop is powered on. **Fig. 2** shows the characteristics curve for PV panel on 10th of October 2015, the current and power increases gradually from sunrise to reach their maximum value (2.72 A,40.03W) at 11:00 a.m because the solar radiation reach the largest value of 1160 W/m^2 and decreases after that, they reach lowest value (0.40 A, 5.77 W) at 16:00 p.m (close to sunset) at which solar radiation was 190 W/m^2. The short circuit current (Isc) increases with solar radiation from (2.21 A) at 09:00 a.m to its maximum value (2.72 A) at 11:00 a.m and decreases gradually with solar radiation to its lowest value (0.40 A) (close to sunset). The open circuit voltage (Voc) also increases with solar radiation but it is affected by temperature of cell. (Voc) decreases when the temperature of cell increases and reaches its maximum value at 09:00 a.m when solar radiation reaches 910 W/m^2 and solar cell reaches 47.8˚C. Data of photovoltaic panel with cooling (case I) on 10th of October 2015 shown in **table1.**



(a)



(b)

Figure 2: Characteristics of PV panel on 10th of October 2015case I (a) I-V curve (b) P-V curve.

Fig. 3 shows the temperature of the storage tank (T_T)with time on 10th of October 2015, (T_T) increases gradually each hour until 14:00 p.m, it reaches 59.9 ˚C till 15:00 p.m then decreases to 59.2 ˚C at 16:00 a.m ,this decreasing is due to The decrease in cell temperature from 43.8˚C to 37.8 ˚C. The decreasing of cell temperature happened because the ambient temperature decreasing from 34.6˚C to 33.8˚C.

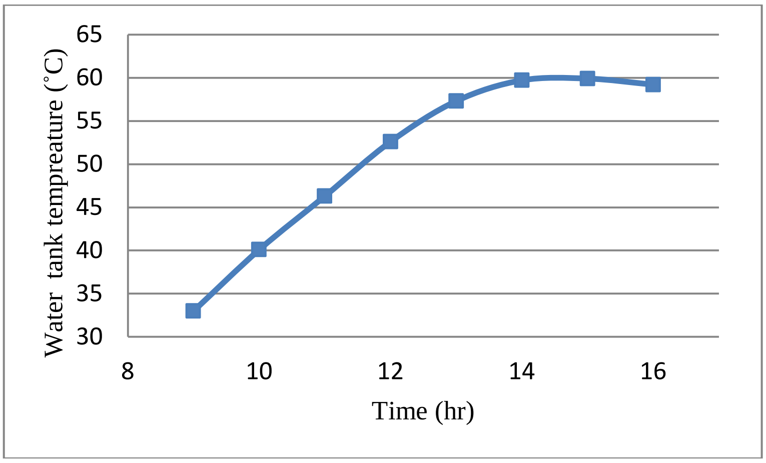
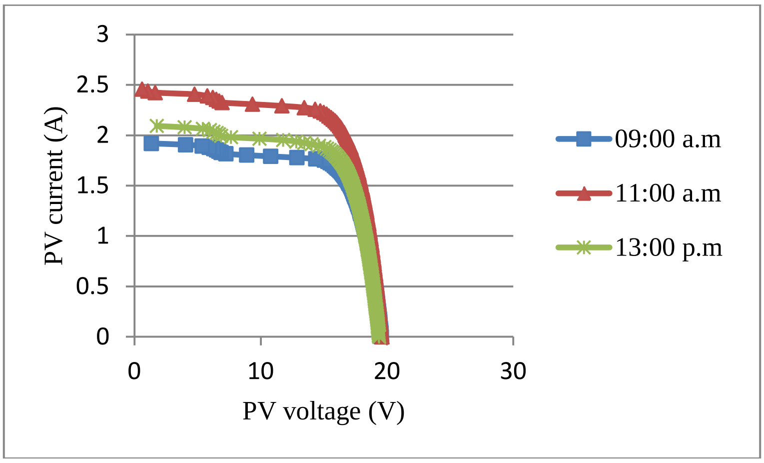


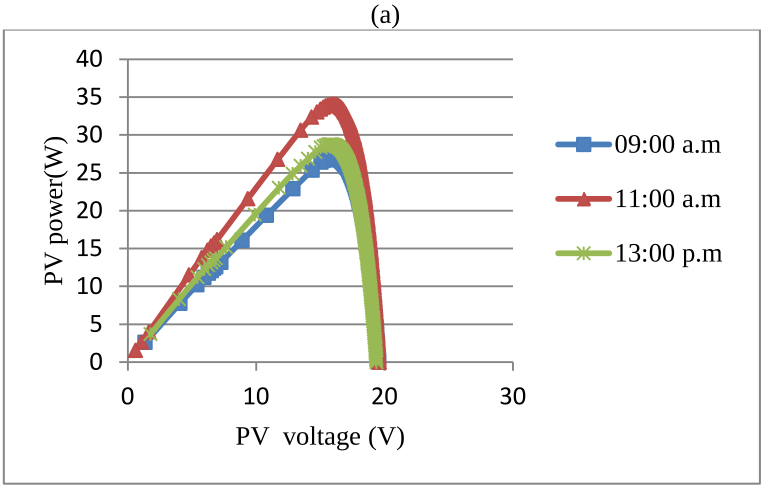
Figure 3: Temperature of the storage tank with time on 10th of October 2015.

4.2 With Auxiliary Cooling System (Case II)

In this case a continuous water circulation is adopted in the main loop with intermittent operation (about 10 minutes each hour) of submersible pump to feed water to the perforated pipe for drop cooling with 300 ml/min flow rate. **Fig. 4** shows the characteristics curve for PV panel on 29th of August 2015, current and power reach their maximum value at 11:00 a.m (2.12 A, 34.05W) and minimum value of (1.68A , 26.94 W) at 09:00 a.m. Data of photovoltaic panel auxiliary cooling (case II) on 29th of August 2015 shown in **table 2**.



(a)



(b)

Figure 4: Characteristics of PV panel on 29th of August 2015 case II (a) I-V curve (b) P-V curve.

Table 1: Data of photovoltaic panel with cooling on 10th of October 2015.

Hours	P_{max} (W)	I_{max} (A)	V_{max} (V)	V_{open} (V)	I_{short} (A)	Ta (C)	Tc (C)	T_T (C)	T_o (C)	Ti (C)	G (w/m^2)	η (%)
09:00	33.16	2.21	14.98	18.74	2.47	32.9	47.8	33.0	33.2	32.9	910	8.43
10:00	38.08	2.55	14.88	18.70	2.88	34.2	51.2	40.1	40.3	40.0	1070	8.23
11:00	40.03	2.72	14.71	18.54	3.09	34.2	51.2	46.3	46.3	46.1	1160	7.98
12:00	37.89	2.58	14.65	18.41	2.93	35.2	53.8	52.6	52.6	52.2	1130	7.76
13:00	32.17	2.19	14.67	18.33	2.51	35.4	54.4	57.3	57.2	57.0	910	8.18
14:00	27.45	1.81	14.16	18.60	2.10	34.9	46.9	59.7	59.4	59.3	780	8.14
15:00	11.5	0.78	14.76	18.16	0.96	34.6	43.8	59.9	59.7	59.6	360	7.39
16:00	5.77	0.40	14.27	17.80	0.56	33.8	37.8	59.2	58.8	58.8	190	7.04

Table 2.: Data of photovoltaic panel case II on 29th of August 2015.

Hours	P_{max} (W)	I_{max} (A)	V_{max} (V)	V_{open} (V)	I_{short} (A)	Ta (C)	Tc (C)	T_T (C)	T_o (C)	Ti (C)	G (w/m^2)	η (%)
09:10	26.94	1.68	15.96	19.59	1.93	38.1	40.3	34.9	35.3	35.1	650	9.59
10:10	33.34	2.06	16.20	19.82	2.38	41.1	47.2	43.9	44.6	44.2	790	9.79
11:10	34.05	2.12	16.01	19.63	2.47	44.5	48.5	52.3	52.8	52.3	890	8.85
12:10	33.22	2.11	15.70	19.37	2.44	45.2	50.3	59.4	59.8	59.4	950	8.09
13:10	28.75	1.81	15.87	19.40	2.10	45.2	45.5	64.7	64.9	64.7	790	8.42

Fig. 5 shows a comparison in cell temperature with time between case I and case II, the cell temperature in case II is less than case I by (14.64 to 29.45 %).

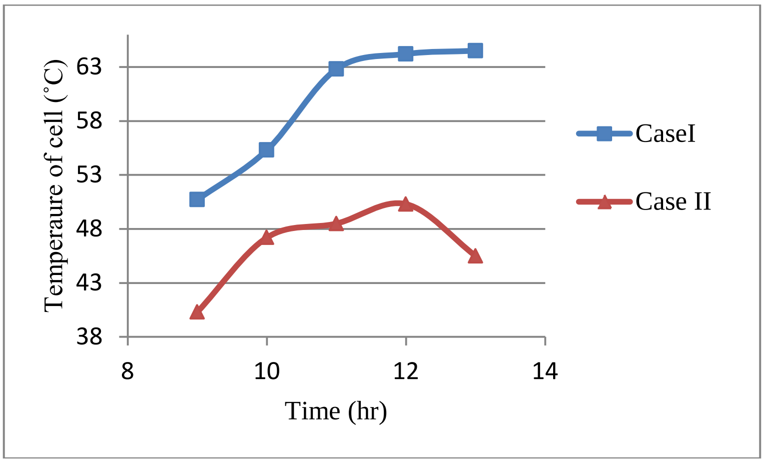


Figure 5: Comparison in temperature of cell with time between case I and case II.

Fig. 6 shows a comparison in electrical efficiency with time between case I and case II the improvement in case II is (13.68 to 14.38)% , because the auxiliary cooling in case II decreases the temperature of cell by spraying water on the front side of PV panel and this decreasing leads to increase in electrical efficiency.

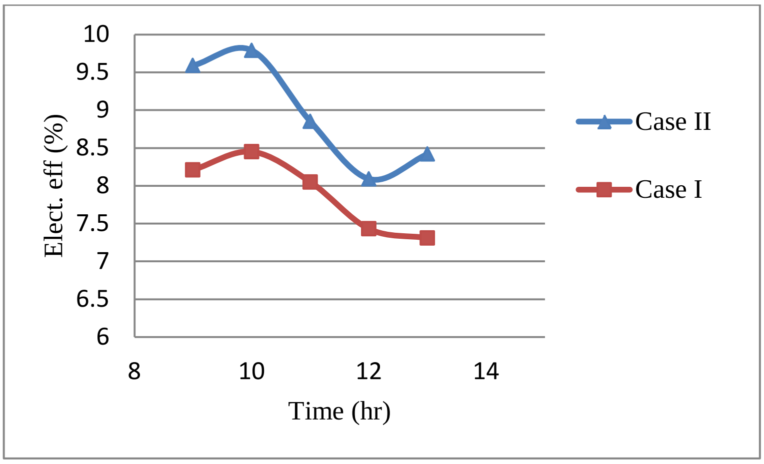


Figure 6: Comparison in electrical efficiency with time between case I and case II.

4.3 The Effect of Temperature of Water

The effect of water inlet temperature to the electrolyzer is studied experimentally to indicate its effect on hydrogen production. The range of inlet water temperature adopted in this work was 40˚C to 60 ˚C with 5˚C step rise with 50 gram of NaOH (0.5%) percentage mass concentration. with accumulative time at 40˚C inlet water

Fig. 7 shows accumulative volume and pressure with accumulative time at 40˚C, this figure reports a linear increase of accumulative volume accompanied by a slight increase of gas pressure (which agrees with gas law PV=mRT) since the accumulated mass is increased by (0.2%). Data of hydrogen production system for NaOH=50 gram, Tw =40 ˚C and 38˚C ambient temperature shown in **table 3**.

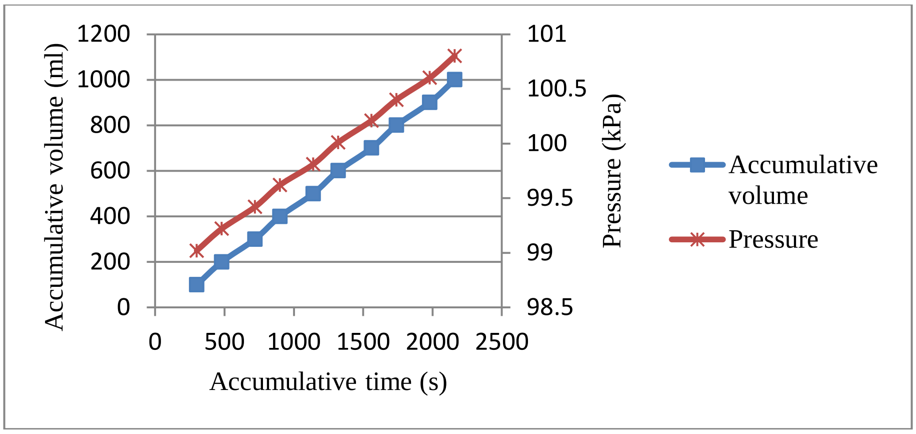


Figure 7: Accumulative volume and pressure with accumulative time for 50 gram NaOH concentration, 40 ˚C inlet water temperature and 38˚C ambient temperature.

Table 3: Data of hydrogen production system for NaOH=50 gram, Tw =40 ˚C and 38˚C ambient temperature.

No.	Accumulative time (s)	Height difference (mm)	Accumulative volume (ml)	Pressure (kPa)
1	300	200	100	99.02
2	480	180	200	99.22
3	720	160	300	99.42
4	900	140	400	99.62
5	1140	120	500	99.81
6	1320	100	600	100.01
7	1560	80	700	100.21
8	1740	60	800	100.40
9	1980	40	900	100.60
10	2160	20	1000	100.80

Fig. 8 shows accumulative volume and pressure with accumulative time at 45˚C, the time required to collect 1000 ml is decreased by 120 minutes compared with that of temperature (40˚C). Data of hydrogen production system for NaOH=50 gram, Tw =45◦C and 42˚C ambient temperature shown in **table 4**.

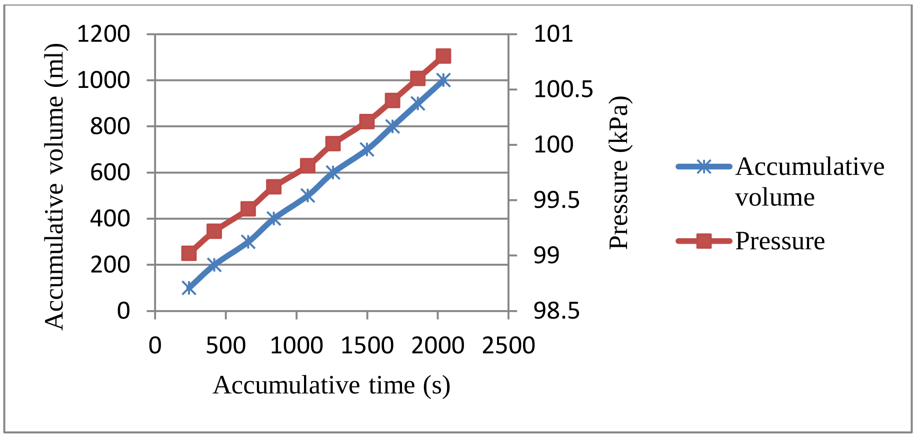


Figure 8: Accumulative volume and pressure with accumulative time for 50 gram NaOH concentration, 45 ˚C inlet water temperature and 42˚C ambient temperature.

Table 4: Data of hydrogen production system for NaOH=50 gram, Tw =45˚ C and 42˚C ambient temperature.

No.	Accumulative time (s)	Height difference (mm)	Accumulative volume (ml)	Pressure (kPa)
1	240	200	100	99.02
2	420	180	200	99.22
3	660	160	300	99.42
4	840	140	400	99.62
5	1080	120	500	99.81
6	1260	100	600	100.01
7	1500	80	700	100.21
8	1680	60	800	100.40
9	1860	40	900	100.60
10	2040	20	1000	100.80

Fig. 9 shows accumulative volume and pressure with accumulative time at 50 ˚C, the time is decreased by 90 minutes relative to temperature (45˚C) and 210 min to that required for40˚C.

Data of hydrogen production system for NaOH=50 gram, Tw =50◦ C and 43˚C ambient temperature shown in **table 5.**

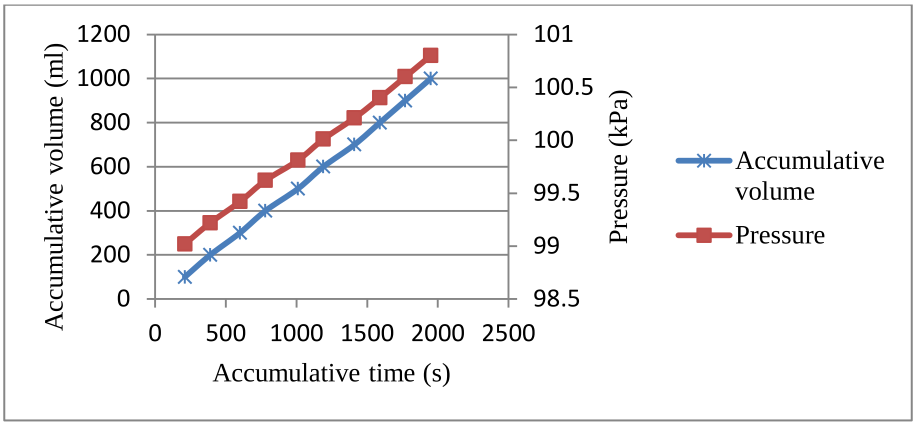


Figure 9: Accumulative volume and pressure with accumulative time for 50 gram NaOH concentration, 50˚C inlet water temperature and 43˚C ambient temperature.

Table 5: Data of hydrogen production system for NaOH=50 gram, Tw =50°C and 43˚C ambient temperature.

No.	Accumulative time (s)	Height difference (mm)	Accumulative volume (ml)	Pressure (kPa)
1	200	200	100	99.02
2	385	180	200	99.22
3	575	160	300	99.42
4	755	140	400	99.62
5	975	120	500	99.81
6	1155	100	600	100.01
7	1365	80	700	100.21
8	1535	60	800	100.40
9	1710	40	900	100.60
10	1890	20	1000	100.80

Fig. 10 shows accumulative volume and pressure with accumulative time at 55˚C, the time is decreased by 60 minutes relative to temperature (50˚C). Data of hydrogen production system for NaOH=50 gram, Tw =55 ˚C and 45˚C ambient temperature shown in **table 6**

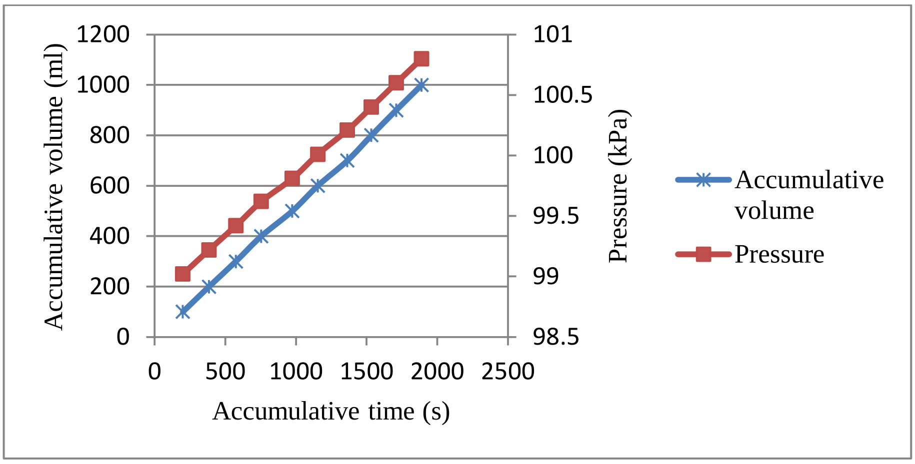


Figure 10: Accumulative volume and pressure with accumulative time for 50 gram NaOH concentration, 55 ˚ C inlet water temperature and 45˚C ambient temperature.

Table 6: Data of hydrogen production system for NaOH=50 gram, Tw =55 ˚C and 45˚C ambient temperature.

No.	Accumulative time (s)	Height difference (mm)	Accumulative volume (ml)	Pressure (kPa)
1	210	200	100	99.02
2	390	180	200	99.22
3	600	160	300	99.42
4	780	140	400	99.62
5	1010	120	500	99.81
6	1190	100	600	100.01
7	1410	80	700	100.21
8	1590	60	800	100.40
9	1770	40	900	100.60
10	1950	20	1000	100.80

Fig. 11 shows accumulative volume and pressure with accumulative time at 60˚C, the time is decreased by 30 minutes relative to temperature (55˚C).The time required to collect 1000 ml of hydrogen is decreased with the increase of water temperature. Data of hydrogen production system for NaOH=50 gram, Tw =60 ˚C and 45˚C ambient temperature shown in **table 7**.

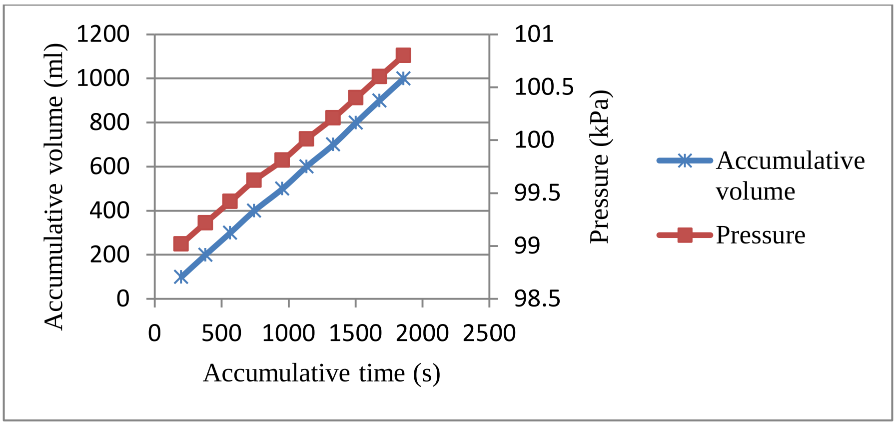


Figure 11: Accumulative volume and pressure with accumulative time for 50 gram NaOH concentration, 60 ˚ C inlet water temperature and 45˚C ambient temperature.

Table 7: Data of hydrogen production system for NaOH=50 gram, Tw =60 ˚C and 45˚C ambient temperature.

No.	Accumulative time (s)	Height difference (mm)	Accumulative volume (ml)	Pressure (kPa)
1	200	200	100	99.02
2	380	180	200	99.22
3	565	160	300	99.42
4	745	140	400	99.62
5	955	120	500	99.81
6	1135	100	600	100.01
7	1335	80	700	100.21
8	1505	60	800	100.40
9	1680	40	900	100.60
10	1860	20	1000	100.80

5. Conclusion

The present work investigates the hydrogen production by using hybrid photovoltaic thermal system. According to the previous discussion of the obtained results the conclusion is the power of PV panel increases by the increase of solar radiation, when solar radiation increases from 190 to 1160 W/m^2 the power increases by 85%. The short circuit current (Isc) increases by increase solar radiation and temperature of cell, when temperature of cell increases from 37.8 to 51.2 ˚C the(Isc) increases by 81%. Open circuit voltage(Voc) increases by increase solar radiation and decreases by increase temperature of cell, when temperature of cell decreases from 47.8 to 37.8 the (Voc) increases by 5%. Temperature of water in the storage tank increases by 46% when temperature of cell increases from 40.3 to 45.5˚C. Adding the auxiliary cooling system decreases the temperature of cell by 29.45% and increases the power of PV panel by 15.40%. Increase the temperature of the electrolysis water from 40 to 60 ˚C decreases the time required to collect 1000 ml of hydrogen by 13.8% and therefore increases the hydrogen production rate.

Nomenclature

a= curve-fitting parameter for the four-parameter model, dimensionless.

a_{ref} = curve-fitting parameter for the four-parameter model at reference condition, dimensionless.

A = module area, m^2.

Eq = energy-band gap= 1.124 (eV) for mono crystalline silicon.

F = faraday's constant, C/mol.

G = solar irradiance, W/m^2.

G_{ref} = solar irradiance at reference condition= 1000 (W/m^2).

H_{H2} = calorific value of hydrogen= 11920 kJ/m^3 at 20˚C.

I = current of the module, A.
I_{ely} = current of electrolyzer, (A).
$I_{L,ref}$ = light-generated current at reference condition, A.
I_{mp} = current at maximum-power point, A.
$I_{mp,ref}$ = current at maximum-power point at reference condition, A.
I_o = diode reverse saturation-current, A.
$I_{o,ref}$ = diode reverse saturation-current at reference condition, A.
$I_{sc,ref}$ = short-circuit current at reference condition, A.
K = boltzmann's constant =$1.381*10^{-23}$ J/K.
n= number of electrons that are exchanged in order to release one particle at the electrode, dimensionless.
n_I = diode ideality factor, dimensionless.
N_S = number of cells in series in one module, dimensionless.
P = power of the module, W.
Q = hydrogen flow rate, 1/h.
q = electron charge= $1.602*10^{-19}$ Coulomb.
R_S = series resistance, Ω.
$R_{S,ref}$ = series resistance at reference condition, Ω.
R_{sh} = shunt resistance, Ω.
t = time, s.
T_C = cell temperature, K.
$T_{C,ref}$ = cell temperature at reference condition= 298 (K).
U= voltage of electrolyzer, (V).
V = voltage of the module, V.
V_{H2} = volume of hydrogen, L.
V_m = molar volume of hydrogen= 24 at 20˚C (l/mol).
$V_{mp,ref}$ = voltage at maximum-power point at reference condition, V.
$V_{OC,ref}$ = open-circuit voltage at reference condition, V.
V_t = thermal voltage, V.
Ƞ= efficiency of the module at maximum-power point, dimensionless.
$Ƞ_{F}$ = faraday efficiency, dimensionless.
$\mu_{I,sc}$ = temperature coefficient of short-circuit current, A/K.
$\mu_{V,oc}$ = temperature coefficient of open-circuit voltage, V/K.

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أنتاج الهيدروجين بواسطه النظام الهجين الكهروضوئي الحراري

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الخلاصة :

وقود الهيدروجين هو بديل جيد للوقود الأحفوري. يمكن إنتاجه باستخدام الطاقه النظيفه دون انبعاثات ملوثه. هذا العمل يهتم بدراسه عمليه لإنتاج الهيدروجين عن طريق الطاقه الشمسيه. أستخدم النظام الهجين (الكهروضوئي/ الحراري) لتحويل الإشعاع الشمسي الى طاقه كهربائيه وحراريه. تستخدم الطاقه الكهربائيه لتحليل الماء الى هيدروجين و أوكسجين باستخدام المحلل القلوي مع أقطاب فولاذيه مقاومه للصدأ. تستخدم الطاقه الحراريه الممتصه لتسخين الماء الذي يدور في الأنبوب النحاسي الملتوي المثبت على السطح الخلفي من اللوح الشمسي. أنبوب مثقب يربط على الحافه العلويه للوح الشمسي يستخدم لرش طبقه خفيفه من الماء على سطح اللوح الكهروضوئي للتبريد وتحسين الطاقه الكهربائيه المتولده . يتم اختبار نظام إنتاج الهيدروجين لدرجات مختلفه لماء التحليل الكهربائي(40، 45، 50، 55،60) درجه مئويه. النتائج العمليه اظهرت تحسن في الطاقه الكهربائيه للوح الشمسي بنسبه (14.31)%. في حين تعزيز القدره المتولده بنسبه (15.40-3.94)%. اقصى إنتاج للهيدروجين هو(153.3) مل لكل دقيقه. كفاءه المنظومه هي (20.88)% وإجمالي كميه الهيدروجين المنتجه في يوم واحد هي (752. 220) لتر.

كلمات رئيسيه: لوح كهروضوئي حراري،محلل كهربائي، هيدروجين.