Hydrogen Production by Water Electrolysis Via Photovoltaic Panel

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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. Photovoltaic module is used to convert solar radiation to electrical energy. The electrical energy is used for electrolysis of water into hydrogen and oxygen by using alkaline water electrolyzer with stainless steel electrodes. A MATLAB computer program is developed to solve a four-parameter-model and predict the characteristics of PV module under Baghdad climate conditions. The hydrogen production system is tested at different NaOH mass concentration of (50,100, 200, 300) gram. 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.

Key words : photovoltaic module, four parameter model, electrolyzer, hydrogen.

أنتاج الهيدروجين بواسطه التحليل الكهربائي للماء عن طريق اللوح الكهروضوئي

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خلاصه

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. يستخدم اللوح الكهروضوئي لتحويل الإشعاع الشمسي الى طاقه كهربائيه.يتم استخدام الطاقه الكهربائيه لتحليل الماء الى هيدروجين واوكسجين باستخدام المحلل القلوي مع أقطاب فولاذيه مقاوم للصدأ.تم تطويربرنامج ماتلاب لحل نموذج الاربع متغيرات والتبوء بخصائص اللوح الكهروضوئي في ظل الظروف المناخيه للعراق. يتم اختبار نظام إنتاج الهيدروجين في تراكيز مختلفه لهيدروكسيد الصوديوم(50، 100، 200، 300)غرام. أقصى إنتاج للهيدروجين هو(153.3) مل/دقيقه. كفاءه المنظومه هي (20.88)% وإجمالي كميه الهيدروجين المنتجه في يوم واحدهي (220.752لتر).

الكلمات الرئيسيه : اللوح الكهروضوئي، نموذج الاربع متغيرات ، المحلل الكهربائي ، هيدروجين.

1. INTODUCTION

Solar energy presents the prime source of energy for life on earth, **Sharma**, **et al.**, **2009**. Photovoltaic (PV) is the most direct way to convert solar radiation into electricity, **Pamplona**, **2008**. Hydrogen gas is a good alternative to fossil flues, when considering environmentally friendly hydrogen production, the obvious choice for the input energy is renewable energy, mainly solar energy, **Dincer**, **and Joshi**, **2013**. Increasing the temperature of water and electrolyte concentration led to net increase of volume flow of hydrogen gas and efficiency of the electrolyzer, **Chennouf**, **et al.**, **2012**. Different electrodes(aluminum, stainless steel, graphite) used in hydrogen production using photovoltaic cell, the highest accumulative hydrogen gas was obtained with aluminum electrodes and the lowest was with graphite electrodes, **kargi**, **2011**. Increase the electrical efficiency of the PV-electrolysis system by matching the maximum power output and voltage of the photovoltaic to the operating voltage of a proton exchange membrane (PEM) electrolyzer by using DC-DC convertor connected to the PV power circuit (battery system) studied by, **Gibson**, **and Kelly**, **2010**. The objectives of this work are to evaluate theoretically and experimentally the photo-hydro characteristics of solar hydrogen generator under outdoor test for Iraq climate conditions. Mono-crystalline PV panel of 50 W is used to generate hydrogen with stainless steel electrodes used to electrolysis of water.

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, **Eicker**, **2003**. 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 such as **Fanny**, **et al.**, **2002.**

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

where I is current of the module (A), I_L is the light-generated current (A), I_o is the reverse saturation current of the p–n diodes (A), V is the voltage of the module (v), R_s is the series resistance of the cells (Ω), R_{sh} is the shunt resistance of the cells (Ω), N_s is the number of cells in series, n_I is the diode ideality factor, V_t is the thermal voltage (V) depending on the cell temperature, which is defined as

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

where k is Boltzman's constant $=1.381*10^{-23}$ J/K, T_c is the cell temperature (K), q is electron charge = $1.602*10^{-19}$ Coulomb.

2.1 Four - Parameter Model

The four parameters model adopted in this work is based on I_L, I_o, R_s, a, as given in the work of **Kou**, **et al.**, **1998**.Where a is curve fitting parameter for the four-parameter model. Assume R_{sh} as infinite so the third term in Eq.(1) yields:

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

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

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

where P is power of the module (W), V is voltage of the module (V). Introducing Eq.(3) into Eq. (4), the power would be

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

where R_s is series resistance, the series resistance is assumed to be independent of both temperature and solar radiation so that $R_s = R_{s,ref}$ and $R_{s,ref}$ is series resistance at reference condition (Ω) , and it is calculated as :

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

where

a_{ref} is curve-fitting parameter for the four-parameter model at reference condition. It is calculated by:

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

$I_{mp,ref}$ is current at maximum-power point at reference condition (A), $I_{L,ref}$ is light-generated current at reference condition = $I_{sc,ref}$ (A), $V_{mp,ref}$ is voltage at maximum-power point at reference condition (V), $V_{OC,ref}$ is open-circuit voltage at reference condition (V), $\mu_{V,oc}$ is temperature coefficient of open-circuit voltage (V/K), $T_{c,ref}$ is cell temperature at reference condition = 298 (K), E_q is energy-band gap = 1.124(eV) for mono crystalline silicon photovoltaic module, $\mu_{I,sc}$ is temperature coefficient of short-circuit current (A/K). The electrical efficiency of the module at maximum-power point can be calculated as

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

where G is incident solar radiation at reference condition (W/m^2), A is module area (m^2). The current produced by incident light is computed by :

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

where G_{ref} is solar irradiance at reference condition = 1000 (W/m^2).The reverse saturation current of p-n diodes is computed by :

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

where $I_{o,ref}$ is diode reverse saturation-current at reference condition (A), calculate by

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

a is calculated as

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

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, **Neagu**, **et al.**, **2000**.

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, **El-shenawy**, **et al.**, **2012**:

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

where I_{ely} is the measured current of electrolyzer (A), η_F is Faraday efficiency, it 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, **Papagiannakis**, **2005**.

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

where $V_{H_2\ experimental}$ is the experimental volume of hydrogen can be obtained from the experimental data, $V_{H_2\ theroritical}$ is the theoretical volume of hydrogen can be calculate as:

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

where I is the current (A), t is the time measured during the experiment (second), v_m is the molar volume of hydrogen = 24 at 20˚C (l/mol), The total efficiency of the electrolyzer is found from Eq.(19), **Papagiannakis**, **2005**.

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

where H_{H_2} is the calorific value of hydrogen = 11920 kJ/m^3 at 20˚C, U is voltage (Volt).

2.3 Computer Algorithm for Determine PV Model Parameters

Matlab 2014 is used to compute the four-parameter model and establishing (I-V) and (P-V) characteristic curves. The steps of computer algorithm are shown in **Fig.1**.

3. EXPERIMENTAL SETUP

The experimental setup shown in **Fig. 2** consists of mono-crystalline photovoltaic module was south oriented at 45 ^{o} with the horizontal. Each experiment was carried out from 09:00 AM to 16:00 PM for clear days and for Baghdad climate conditions. Electrical characteristics data of the solar module at reference

condition are as follows: short circuit current = 3.1A, open circuit voltage = 22V, current at maximum power point = 2.9A, voltage at maximum power point = 17.5V, power at maximum power point = 50W, with 36 cells. 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 is shown in **Fig.3**. PROVA 200 solar module analyzer shown in **Fig.4** 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) shown in **Fig. 5** 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) and the temperature of the basin water used in electrolysis (Tw) as well as the ambient temperature (Ta). An electronic balance unit type (TE214S) of 400 g capacity, 0.1mg readability ,seven digit , 3second response time (average), allowable ambient operating temperature 5 ˚C to 40 ˚C, is used to measure the mass of NaOH.

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

$$P = P_{atm} - \rho g h \quad (20)$$

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) respectively. 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 the power supply (battery or solar module) the electrolysis of water will begin .Insert thermometer in water basin 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. Change the NaOH concentration (100,200,300) gram and repeat the previous steps for each concentration. The results of theoretical and experimental studies were presented in Tables 1- 6.

4. RESULTS AND DISCUSSION

The discussions of photovoltaic module used for hydrogen generation are presented. The hydrogen production system and the effects of NaOH concentration on hydrogen production are discussed also. **Fig. 6** shows the characteristics curve for PV panel on 11th of October 2015. The current and power increase gradually from sunrise to reach their maximum value (2.73 A, 38.49 W) 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 at 16:00 p.m (close to sunset) at which solar radiation was 150 W/m^2 . The short circuit current (I_{sc}) increases with solar radiation from (2.46 A) at 09:00 a.m to its maximum value (3.36 A) at 10:00 a.m and decreases gradually with solar radiation to its lowest value (0.33 A) (close to sunset). The open circuit voltage (V_{oc}) also increases with solar radiation but it is affected by temperature of cell. (V_{oc}) decreases when the temperature of cell increases and reach its maximum value at 15:00 p.m when solar radiation reaches

500 W/m^2 and solar cell reaches 39.8˚C. **Fig. 7** shows theoretical calculated characteristics curve of PV panel on 11th October 2015, the power and current increase gradually from sunrise to reach their maximum value (52.33 W, 3.6 A) at 11:00 a.m and decreases after that to reach lowest value (7.06 W, 0.46 A) at 16:00 p.m. **Fig. 8** shows a compassion between experimental and theoretical work in electrical efficiency with time, the theoretical efficiency is better than experimental by (26.43%). **Fig. 9** shows the maximum power with time, the power in theoretical is better than experimental by (26.44%). This difference between theoretical work and experimental work is due to weather conditions that effect on PV panel and due to the accuracy of devices used in the measurement. Four concentration of NaOH have been tested to exhibit its effect on hydrogen production . The concentrations adopted are (50,100,200,300) gram in 10 kg of water or mass concentration of (0.5,1,2,3 %) respectively. **Fig. 10** shows accumulative volume and pressure with accumulative time for 50 gram of NaOH (0.5%) percentage mass concentration and inlet water temperature of 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%). **Fig. 11** shows the same trend in accumulation behavior for NaOH concentration mass of (100 gram , 1% by mass). The time required to accumulate (1000 ml) was (1200 s) while that for concentration mass of (50 gram) was (2160 s) i.e. there is a saving in accumulation time equals to (960 s). **Fig. 12** represents the accumulative hydrogen volume generated for NaOH concentration mass of (200 gram, 2% by mass). It illustrates a time saving of (420 s) compared with concentration mass of 100 gram. **Fig. 13** shows accumulative volume and pressure with accumulative time at (300 gram, 3% by mass) the time saving was by (390 s) compared with 200 gram. **Fig. 14** shows the accumulative time with accumulative volume at different concentration of NaOH. An obvious improvement is reported, the time required to collect 1000 ml of hydrogen was 2160 seconds at 100 gram but at 300 gram the time decrease to 390 seconds. The inlet water temperature is higher than the ambient temperature this due to the interaction between water and sodium hydroxide, the reaction is exothermic.

4.1 Comparison with Previous Results

To verify the results obtained from the present work, a comparison was made with the results achieved by previous studies. **Fig.15** shows the comparison in characteristics curve for PV panel between present study and ,**Chennouf**, **et al.**, **2012** for the same PV panel specifications, the present work shows improvement in current by (21.8 %) and in power by (20.9%). **Fig. 16** shows a comparison in time required to collect 1000 ml of hydrogen between present work and ,**Kargi**, **2011** under the same type and different (shape,size) of electrodes and different type of electrolyte. The improvement in accumulative time in present work is (99.77)%.

5. CONCULSION

The present work investigates the hydrogen production using solar photovoltaic panel. The conclusion is that the power of PV panel increases by the increase of solar radiation. The short circuit current (Isc) and open circuit voltage (Voc) increases gradually with increases solar radiation. Increase the mass concentration of NaOH decreases the time required to collect 1000 ml and therefore increases the hydrogen production rate.

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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, eV.

F = Faraday's constant, C/mol.

G = solar irradiance, W/m^2.

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

H_{H2} = calorific value of hydrogen, kJ/m^3.

I = current of the module, 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, 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, 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, K.

V = voltage of the module, V.

V_{H2} = volume of hydrogen, L.

V_m = molar volume of hydrogen, l/mol.

$V_{mp,ref}$ = voltage at maximum-power point at reference condition, V.

$V_{OC,ref}$ = open-circuit voltage at reference condition, V.

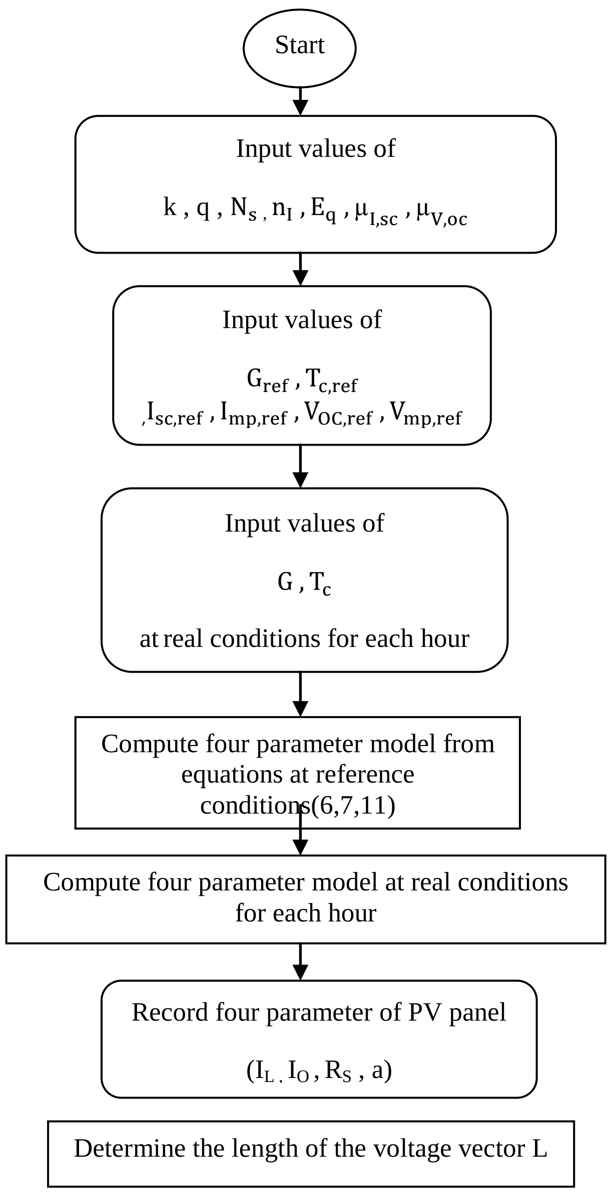
V_t = thermal voltage, V.

η= efficiency of the module at maximum-power point, dimensionless.

η_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.



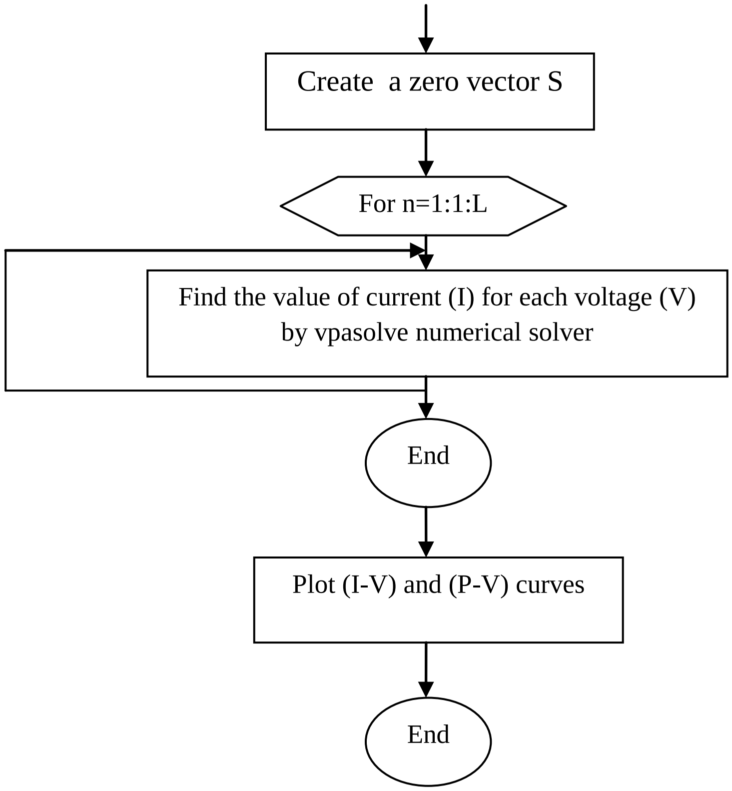


Figure 1. Flowchart of computer algorithm for PV panel.

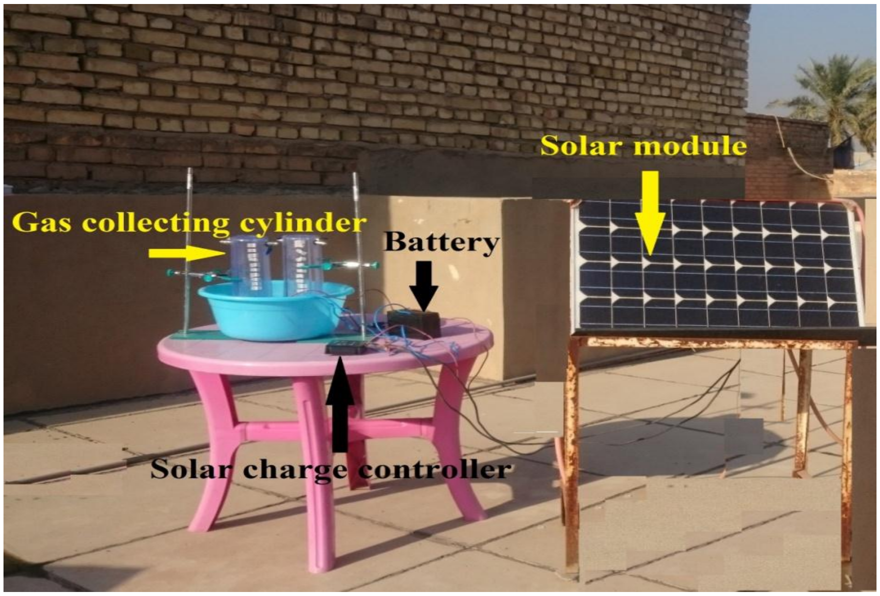


Figure 2. Experimental setup.

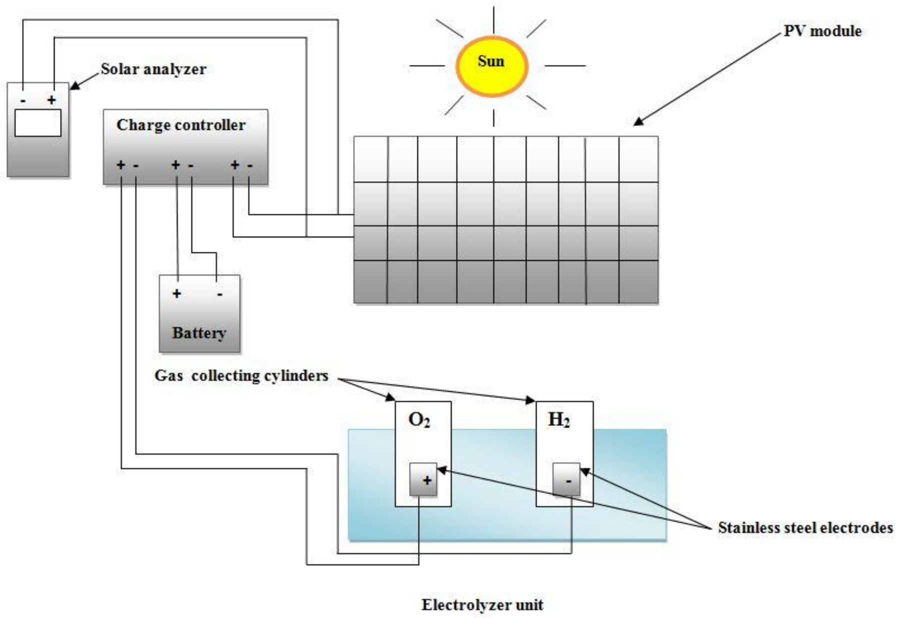


Figure 3. Schematic diagram of the experimental setup.

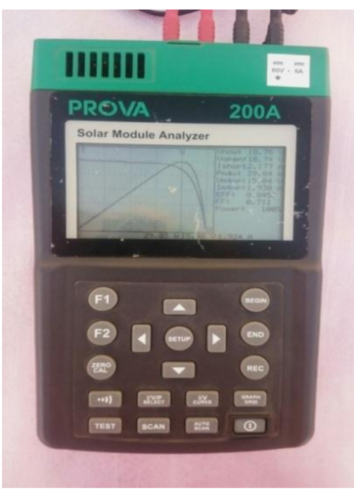
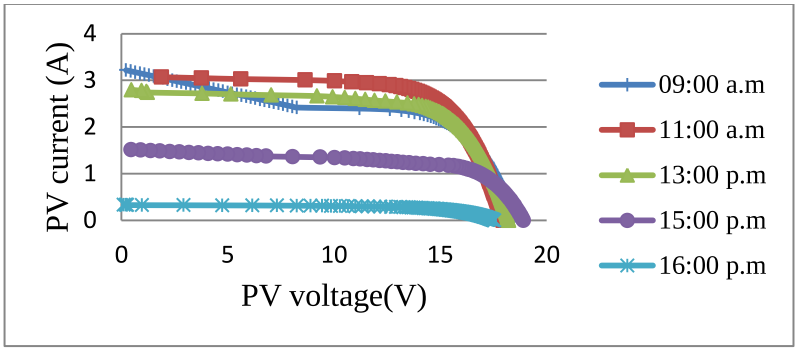
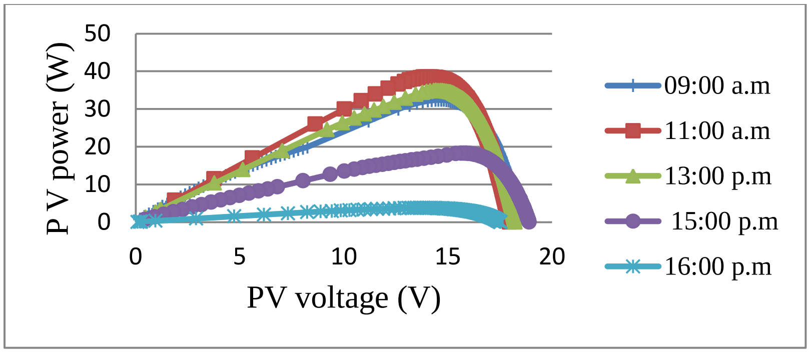


Figure 4. The PROVA 200 solar panel analyzer.

Figure 5. Solar power meter

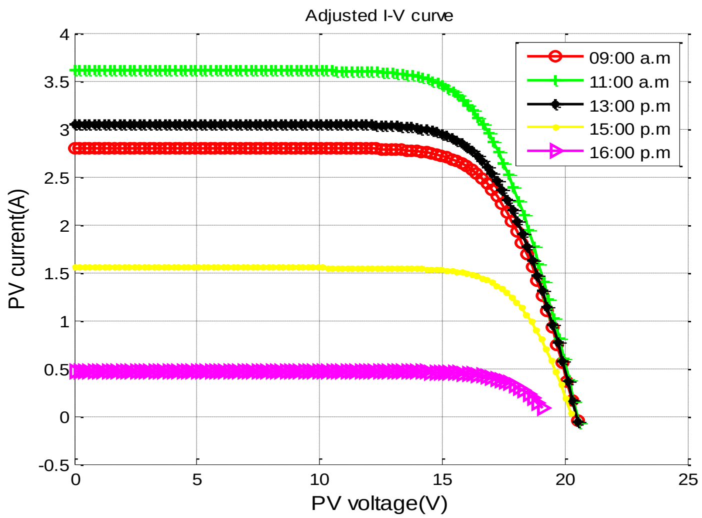


(a)



(b)

Figure 6. Characteristics curve of PV panel on 11th of October 2015 case I (a) I-V curve (b) P-V curve.



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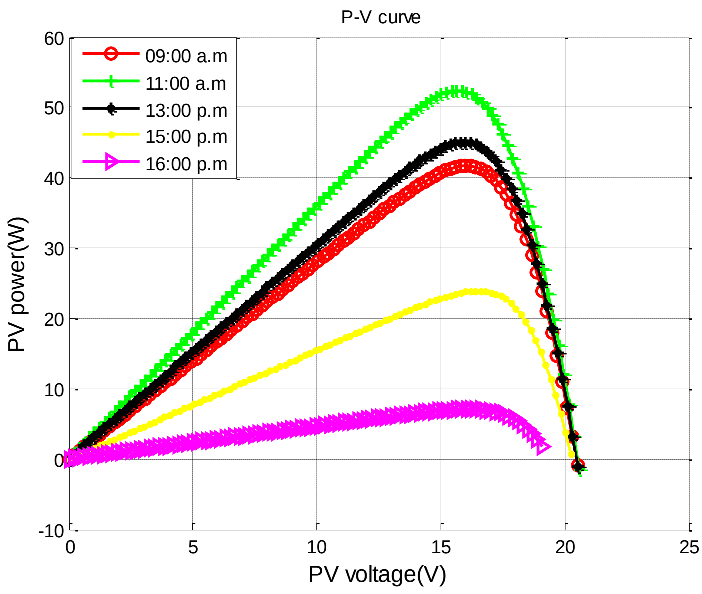


(b)

Figure 7. Theoretical characteristics of PV panel on 11th of October 2015 (a) I-V curve (b) P-V curve.

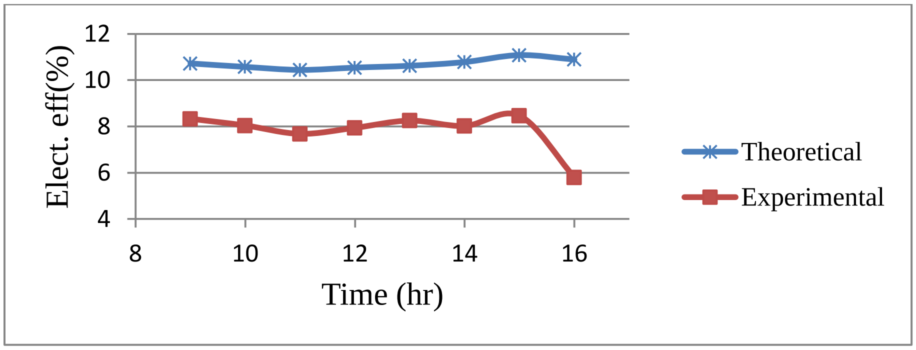


Figure 8. Electrical efficiency with time on 11th of October 2015.

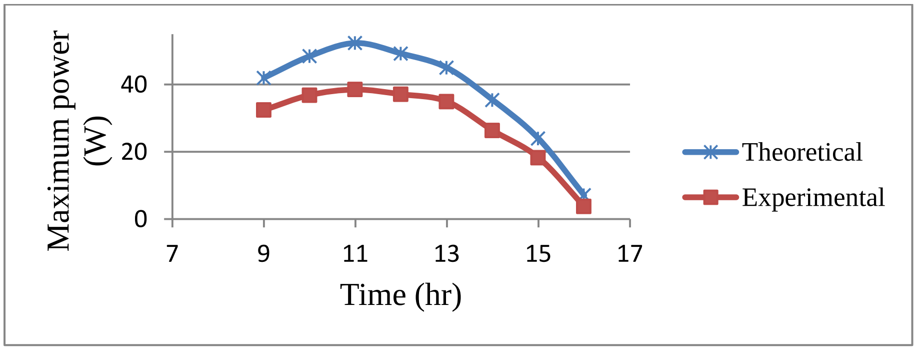


Figure 9. Maximum power with time on 11th of October 2015.

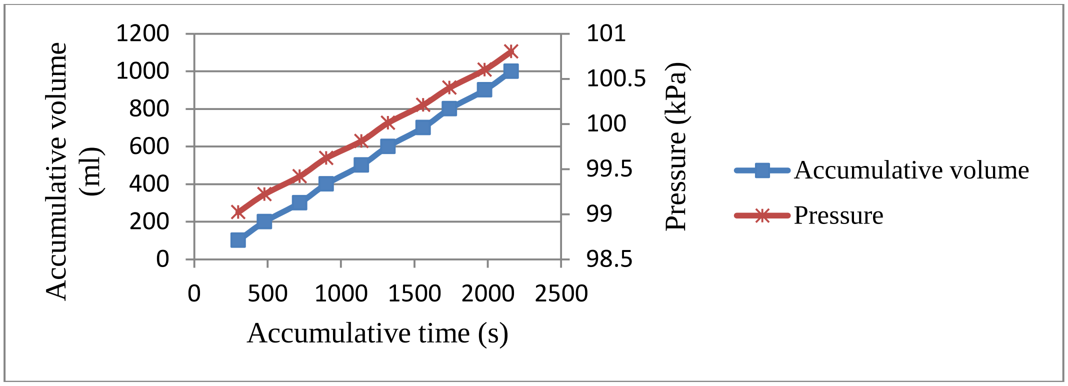


Figure 10. Accumulative volume and pressure with accumulative time for 50 gram NaOH concentration , 40 ˚C inlet water temperature and 38˚C ambient temperature.

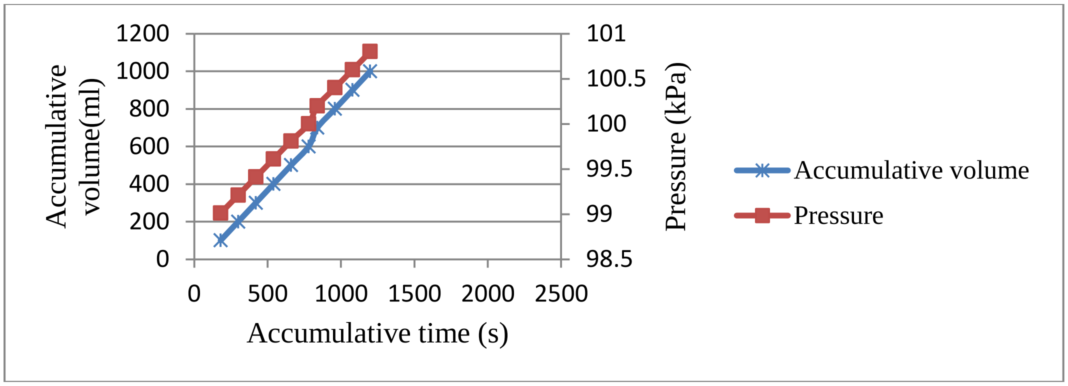


Figure 11. Accumulative volume and pressure with accumulative time for 100 gram NaOH concentration , 40 ˚C inlet water temperature and 38˚C ambient temperature.

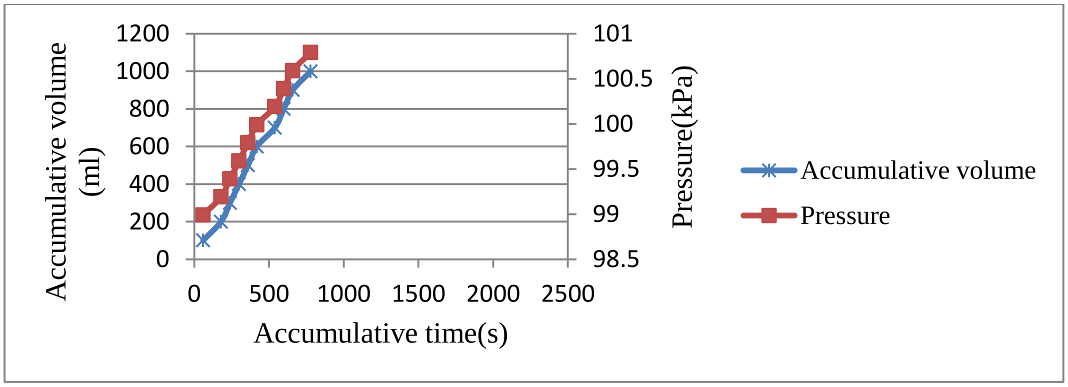


Figure 12. Accumulative volume and pressure with accumulative time for 200 gram NaOH concentration , 40˚C inlet water temperature and 38˚C ambient temperature.

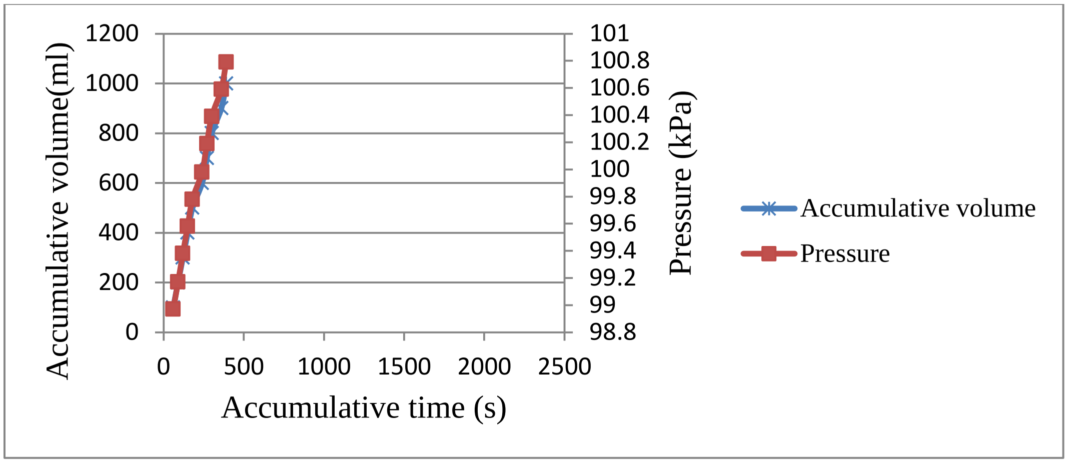


Figure 13. Accumulative volume and pressure with accumulative time for 300 gram NaOH concentration, 40 ˚C inlet water temperature and 38˚C ambient temperature.

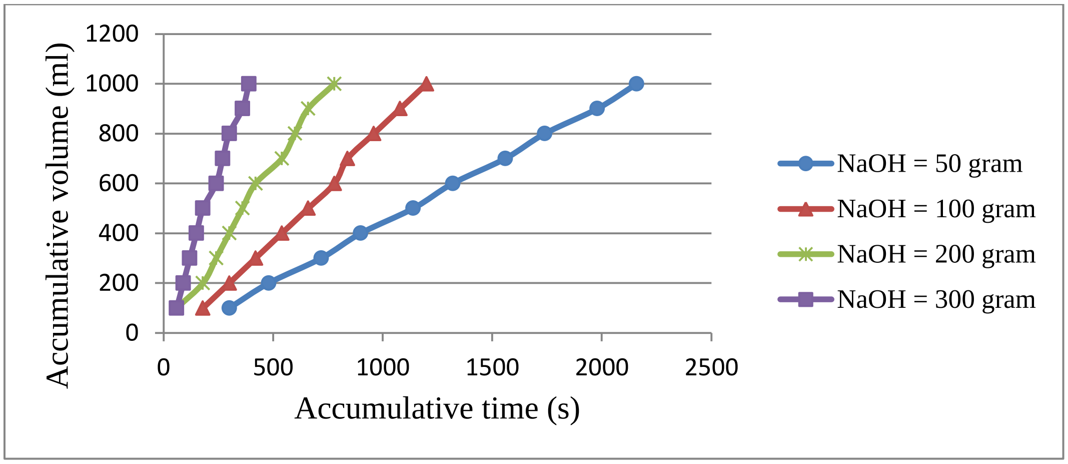


Figure 14. Accumulative volume with accumulative time at different concentration of NaOH.

Table 1. Theoretical data of photovoltaic panel at reference and real working conditions on 11th of October 2015.

Hours	**a (--)**	**I_L (A)**	**R_S (Ω)**	**I_o (A)**	**V_{OC} (A)**	**P_{max} (W)**	**η (%)**
Ref.	1.01	3.10	0.58	$1.29*10^{-9}$	22.00	50.00	11.57
09:00	1.09	2.79	0.58	$2.16*10^{-8}$	20.51	41.69	10.72
10:00	1.10	3.29	0.58	$2.73*10^{-8}$	20.59	48.41	10.57
11:00	1.11	3.60	0.58	$3.40*10^{-8}$	20.58	52.33	10.44
12:00	1.10	3.35	0.58	$2.85*10^{-8}$	20.59	49.21	10.54
13:00	1.10	3.04	0.58	$2.56*10^{-8}$	20.52	44.99	10.62
14:00	1.09	2.36	0.58	$2.02*10^{-8}$	20.33	35.40	10.78
15:00	1.06	1.55	0.58	$9.00*10^{-9}$	20.23	23.95	11.08
16:00	1.05	0.46	0.58	$4.69*10^{-9}$	19.07	7.06	10.89

Table 2. Experimental data of photovoltaic panel on 11th of October2015.

Hours	P_{max} (W)	I_{max} (A)	V_{max} (V)	V_{open} (V)	I_{short} (A)	Ta (C)	Tc (C)	G (W/m^2)	η (%)
09:00	32.40	2.21	14.61	18.46	2.46	31.4	47.5	900	8.33
10:00	35.85	2.59	14.18	18.14	3.36	33.0	49.7	1060	8.04
11:00	38.49	2.73	14.05	17.99	3.08	34.2	51.8	1160	7.68
12:00	37.09	2.61	14.21	18.02	2.96	34.9	50.1	1080	7.94
13:00	34.95	2.42	14.43	18.25	2.81	35.1	49.1	980	8.25
14:00	26.35	1.79	14.64	18.29	2.09	34.9	46.9	760	8.02
15:00	18.28	1.15	15.77	18.93	1.52	34.2	39.8	500	8.46
16:00	3.76	0.27	13.64	17.56	0.33	33.6	34.5	150	5.80

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

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

ambient temperature.

Table 4. Data of hydrogen production system for NaOH=100 gram, Tw =40°C and 38˚C ambient temperature.

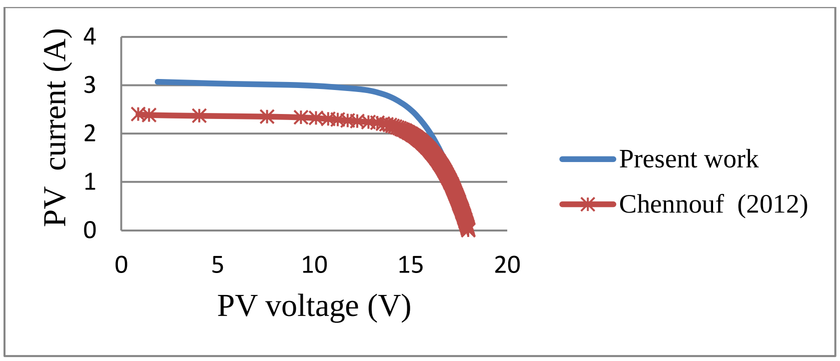
No.	Accumulative time(s)	Height difference (mm)	Accumulative volume(ml)	Pressure (kPa)
1	180	200	100	99.01
2	300	180	200	99.21
3	420	160	300	99.41
4	540	140	400	99.61
5	660	120	500	99.81
6	780	100	600	100
7	840	80	700	100.20
8	960	60	800	100.40
9	1080	40	900	100.60
10	1200	20	1000	100.80

Table 5. Data of hydrogen production system for NaOH=200 gram, Tw =40°C and 38˚C ambient temperature.

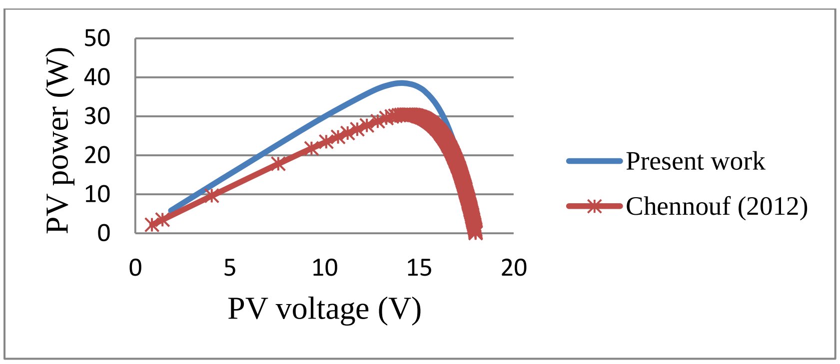
No.	Accumulative time(s)	Height difference (mm)	Accumulative volume(ml)	Pressure (kPa)
1	60	200	100	98.99
2	180	180	200	99.19
3	240	160	300	99.39
4	300	140	400	99.59
5	360	120	500	99.79
6	420	100	600	99.99
7	540	80	700	100.19
8	600	60	800	100.39
9	660	40	900	100.59
10	780	20	1000	100.79

Table 6. Data of hydrogen production system for NaOH=300 gram ,Tw =40°C and 38°C ambient temperature.

No.	Accumulative time(s)	Height difference (mm)	Accumulative volume(ml)	Pressure (kPa)
1	60	200	100	98.97
2	90	180	200	99.17
3	120	160	300	99.38
4	150	140	400	99.58
5	180	120	500	99.78
6	240	100	600	99.98
7	270	80	700	100.19
8	300	60	800	100.39
9	360	40	900	100.59
10	390	20	1000	100.79

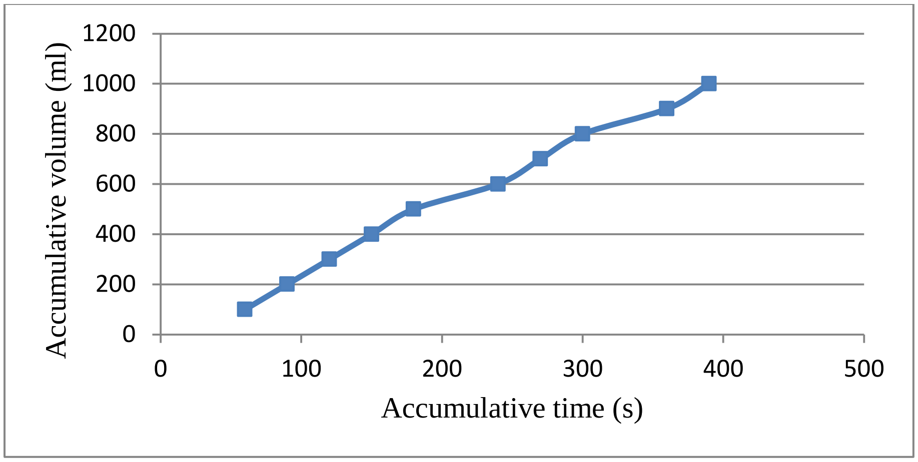


(a)

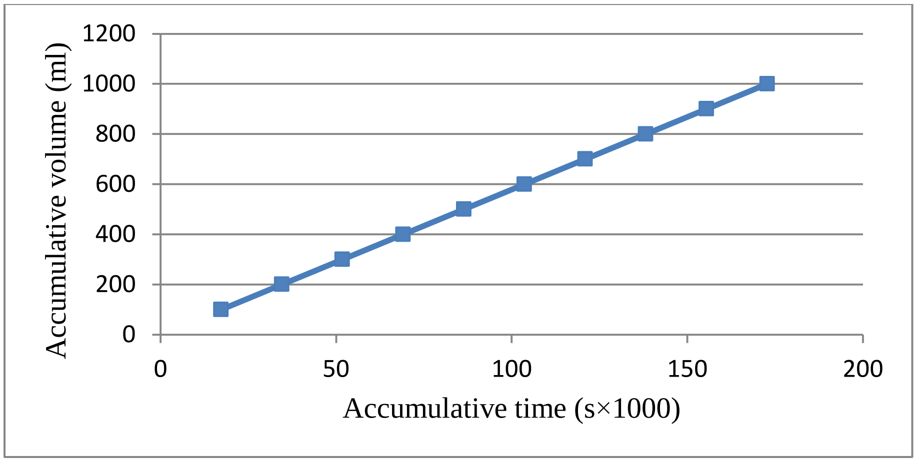


(b)

Figure 15. Comparison with previous results (a) (I-V) curve (b) (P-V) curve.



(a)



(b)

Figure 16. Accumulative time with accumulative volume (a) present work (b) **Kargi, 2011.**