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# Hydrogen Production using a Bench Type Electrolyzer

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***Abstract***

*This work is intended to design an Electrolyzer to produce 100 L/day of hydrogen at 1atm and 30oC. The Electrolyzer designed by Solid-works program, then manufactured in local shops as bench type work. The Electrolyzer is powered by photovoltaic solar panels to create electrical energy. The Electrolyzer passes this electric current through 4M KOH solution, causing the molecules of water to separate into hydrogen and oxygen gases. From the outcome of the result, the optimum value of electrical power to get higher percent of efficiency is 65 W.*

***Keywords:*** *Hydrogen; Production; Electrolyzer; Electrolyte;Efficiency.*

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## I. INTRODUCTION:

Petroleum is one of the main resources in the world and widely used in many critical applications such as power generation, transportation and many industrial applications. However, it is a problem to dependence on petroleum because it's polluting and non-renewable source [1-4].

The hydrogen production by solar energy is a clean and renewable source, our work is one of the common methods and promising techniques in the production of hydrogen by clean energy, it is a design bench type of electrolysis to separate water molecules into hydrogen and oxygen. This work utilizes photovoltaic (PV) cells to create electrical energy. The Electrolyzer designs are operated using water premixed with a caustic electrolyte, most often potassium hydroxide to be alkaline electrolysis[1,12].

Clean energy comes from natural resources and the most important thing about this energy that it's renewable. It exist in the nature in different forms, it can come from the sun rays or wind. Also, it can derive from ocean surface waves, tides and rain. These are some examples of the clean energy and some of these example was use long time ago even before evolution of science such as the wind. However, there is an important resource for clean energy which is hydrogen and its importance such like the sun and the wind. Clean energy replaces conventional fuels in different areas like: motor fuels, electricity generation and some industrial application [1, 6-9].

At the end of 2004, global capacity grew in the use of renewable energy in many applications until it reached around 10-60%. The growth rate accelerated in 2009; especially wind power, which saw a growth rate more than the rest of renewable energies acceleration. Also there are increased in Solar PV even reached 60% in the end of 2011.Finally, in 2010, the renewable power constituted around third of the power generation in the world**[2, 8-13].**

Fuel Cell is an electrochemical device which produces electricity from a fuel source (hydrogen, $H_2$) and oxidant (oxygen, $O_2$) by electrolytic process. In presence of an electrolyte, introduced hydrogen and oxygen in the cell, they will react and produce output product which can be store. As we know, water is the result of combining $H_2$ and $O_2$. However, the electrolytic process can be a continuous process if the flow of resources are maintained and electricity will formed as a result of this process[5-12].

Fuel cell consists of three main parts which are; cathode, anode and electrolyte. In the presence of these three parts, two chemical reactions occur. At the anode, the electrolyte which is a catalyst, e.g. potassium hydroxide will be present which used to oxidize the hydrogen fuel. So the hydrogen gas will turn to electrons and ions. The ions will transfer through the electrolyte to the cathode and they will combined and react with the oxidant to produce water. Nickel is used as cathode catalyst which allows passing the electrons through it to produce electricity. So, in the fuel cell the load is the formed electricity and the water is the byproduct.

However, 0.7 volt is the normal produce of a fuel cell at full load; the fuel cells can combined in series to get the desired voltage. On the other hand, connect it in parallel to get the desired current[4, 7-13].

The reverse of the fuel cell reaction called water electrolysis. The fuel cells which use PEM and solid oxide technology can work also as a water electrolysis cell which depends directly to the direction of the electrical current. So, the equations of both water electrolysis and the fuel cell are basically reverse to each other. This work is intended to design an Electrolyzer to produce 100 L/day of hydrogen at 1atm and $30^oC$.

## II. MATERIAL AND METHOD

### 2.1 Electrolyzer Type:

The alkaline electrolytic methodsplitting water into its two simple components of $H_2$ and $O_2$. Electrolysis implicates passing an electric current over electrolyte. The current pass in the electrolysis device through the cathode (a negatively charged electrode), passes through the electrolyte, and leaves through an anode (a positively charged electrode). Hydrogen is evolved and collected at the cathode and oxygen is generated and collected at anode. he alkaline electrolytic solution consisting potassium hydroxide (KOH) and dematerialized water ($H_2O$)[2,24].

### 2.2 The Electrolyte (Potassium hydroxide)

Potassium hydroxide (KOH) is an ionic compound, also is a good conductor of electricity because it is totally ionized in solution. However, there is other electrolytes can be used such as Sulfuric acid and Sodium hydroxide. Sulfuric acid is more corrosive and because of that, we did not use it as electrolyte. In addition, sodium hydroxide can be used but when we compare it with potassium hydroxide we found that, sodium hydroxide is less conductive than potassium hydroxide. Finally, KOH is the best choice for alkaline electrolyzes. We used (Eq. 2.1) to find the desired weight of 4M of KOH in1L of dematerialized water, where needs 1795.52 g of KOH in 8 L (Electrolyzer Capacity) of dematerialized water.

$m = C*V*M_W$[1.1]

### 2.3 Materials for the Electrolyzer (Acrylic)

Poly(methyl methacrylate), it also knowns by different names, Acrylic or by the trade name which is Pexiglas, it comes in sheet form. The acrylic sheet can easily joind by using a glue which called superglue with heat or by the chloroform which ia an organic compund. However, acrylic has many properties, its resestance to most chemicals is high, so it does not affect or react by alkalies or acids solutions. Also, it is transparent thermoplastic, strong, good impact strength, and lightweight material. Its density is less than half of the glass density which equat to $1.17 - 1.20\ \frac{g}{cm^3}$. [3].Finally, Acrylic is the best choice to build an Electrolyzer body .

### 2.4 Materials for the Electrodes (Monel 400)

Monel is consider as nickel alloy, it is composed of multiple materials but primary of nickel (up to 67%) and specific amounts of copper, iron, manganese, carbon, and silicon which make it stronger than pure nickel. The most important property of Monel is, its resistance to many corrosive, acidic and alkaline environments especially the corrosion of seawater. In addition, it is resistant to brine and pitting in chloride and caustic alkaline solutions[3]. Where design each one with following dimension (200 mm x 56 mm). In addition, a hole (3.50∅) was drilled in each electrode to holding the electrodes in the cover of the Electrolyzer.

### 2.5Design of the Electrolyzer:

The design of Electrolyzer is shown in Fig.1. below.

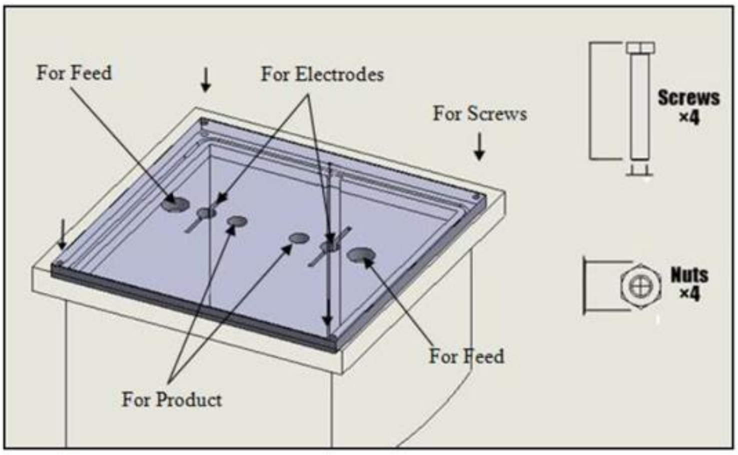



*Fig 1,a: Shows and describe the top section holes*

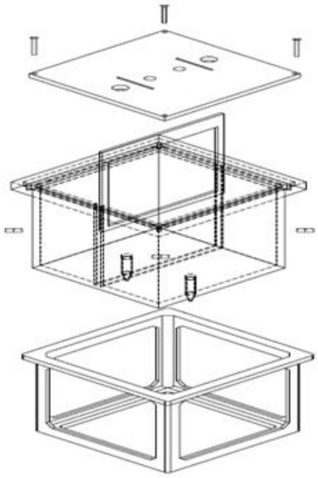
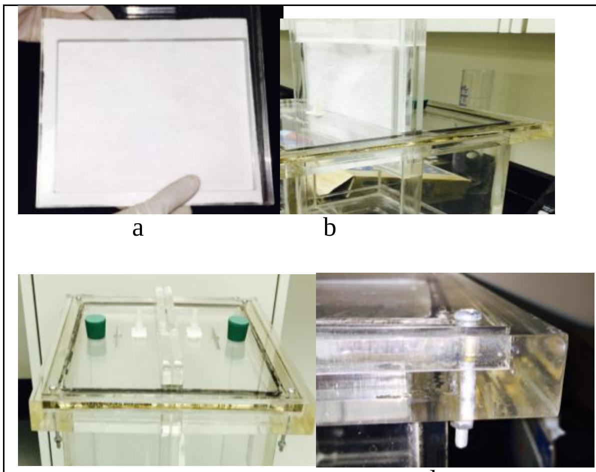


*Fig1.b, Final Assembly of the electrolizer*

**2.6 Assembly of the Electrolyzer**

The procedures of installation the Electrolyzer parts as follow as shown in fig. :

- The membrane (Polypropylene felt) is placed between the two parts of the membrane holder, and putting the membrane holder inside the Electrolyzer, this shown in Fig.2 a, b.
- The cover is put on the Electrolyzer, and then the cover was closed by 4 screws to fix it and to prevent any leakage Fig.2 c, d.

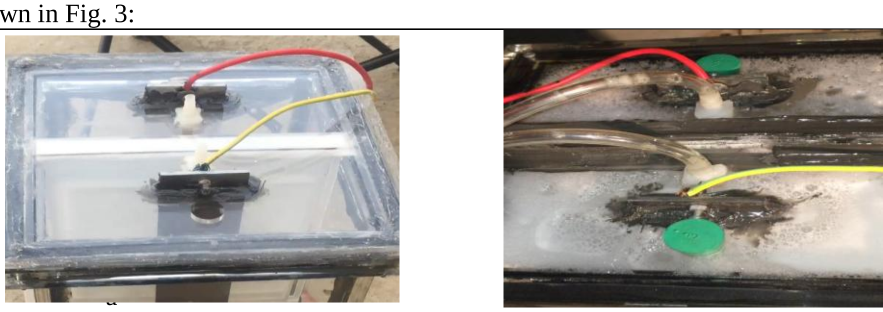


a b

c d

*Fig. 2, : a, membrane in the membrane holder,b: the membrane holder inside the electrolyzer ,c: the cover of the electrolyzer with the membrane holder, d:: fixing the cover by the screws*

- Before filling the Electrolyzer by the solution, the two electrodes (Monel_400) is fixed in the allotted slots, as shown in Fig. 3:



a b

*Fig. 3: a, the electrodes placed in the slots and connected to the cables,b:final assembly of the electrolyzer.*

- After filling the Electrolyzer by the solution, the two feeding holesis closed by using the rubber stoppers. Also, the tubes was connected to the two holes that responsible of collecting Hydrogen and Oxygen products.

The complete set-up is shown in Fig.**4**below**:**

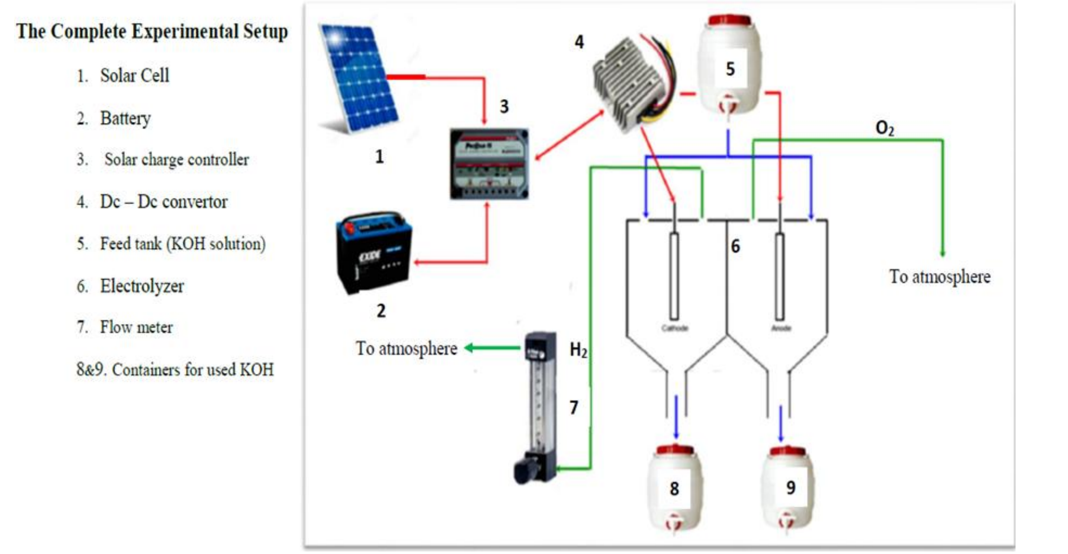



**Fig4: The complete experimental set-up**

## III. RESULTS:

### 3.1 Theoretical Calculation

*Input power supply to produce 100 L/day by (Eq2.1):*

*Power=Current×Voltage*[2.1]

$20\times4=80\ W= 80\ (J)/s=288\ KJ/hr$

***Amount of water to produce 100 liters of $H_2$:***

As its known, 8 liter of water =8000 Grams water, the amount of moles in 8 liters of water:

(8000 g)/( 18 g⁄mol )=444.444 mole of H_2 O

From Ideal Gas Low at 1 atm, 30 $^oC$, 1 mole of $H_2$ yields:

$$V= (n\ R\ T)/P = ((1*\ 0.08205*\ 303)/1)) =24.86\ L. \qquad [3.1]$$

By multiply the answer of (Eq. 3.1) .The 8 liters of water yields:

444.444 mole*24.86 (L/(1 mole)) = 11049.39 liters of hydrogen

Now, amount of water to produce 100 liters of $H_2$:

8 liters of H2O× (100 liters of H_2)/11049.39=0.0724 liters of H_2 O

**Amount of energy & time requires producing 100 liters of $H_2$:**

The electrolysis requires a minimum Gibbsfree energy of 237.13 kJ (Incropera book) of electrical energy input to dissociate each mole.

For 8 liters of water:

237.13 KJ/( mol) * 444.444 mol = 105391 KJ

### 3.2 Experimental Calculation

Now, the amount of energy requires for 0.0724 L of water is:

105391 KJ×(0.0724 liters of H_2 O )/(8 liters of H_2 O) = 953.79 KJ

To calculate the time requires for producing 100 L of H2, the amount of energy calculated is divided by input power:

953.79 KJ×hr/(288 KJ) =3.312 hr

Based onthe theoretical calculations, we need 3 hours and 19 minutes to produce 100 liters of $H_2$ at constant power supply (100 W).The $H_2$ flow rates, number of mole per hour and the mass flow rate in different runs at 1 atm 30$^oC$ wereshown in Table1.

**Table 1:** Different runs to measure the hydrogen flow:

| Current (A) | Volt (V) | Power (W) | Time (S) | $H_2$ Flow (L/hr) | No# mol/hr | Mass Flow (g/hr) |
|---|---|---|---|---|---|---|
| 16.8 | 3.8 | 63.84 | 3.00 | 15.60 | 0.627514 | 1.255028 |
| 17 | | 64.60 | 3.00 | 15.60 | 0.627514 | 1.255028 |
| 17 | | 64.60 | 2.98 | 15.70 | 0.631726 | 1.263451 |
| 18 | | 68.40 | 2.96 | 15.81 | 0.635994 | 1.271988 |

### 3.2.1 Electrolyzer Efficiency (ɳ):

The Electrolyzer Efficiency is calculated depend on that,one mole of water requires 282.1 kJ of energy. Then the hydrogen energy (KJ/hr) is:
282.1 KJ/mol* (NO# mol)/hr [4.1]
Electrolyzer (ɳ)=(Energy Out)/(Electrical Energy IN) [5.1]
Fig. 5shows that the efficiency of the system is decreased while increasing the power.

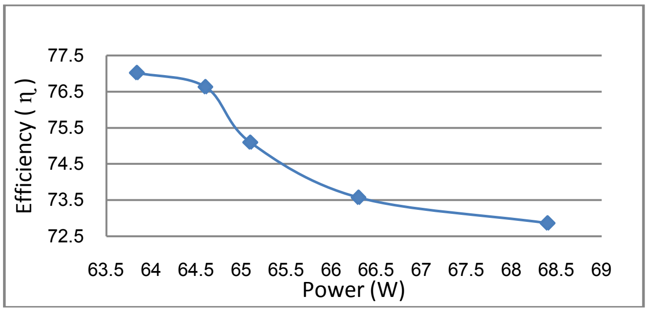


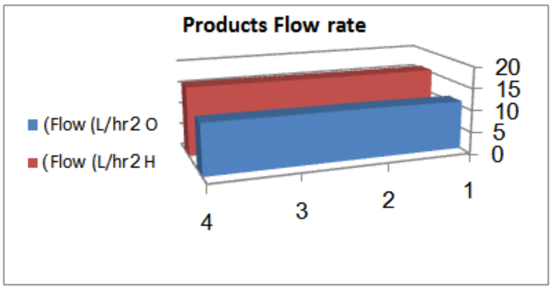

**Fig. 5:** the efficiency of the system with power

### 3.2.2 Products Ratio

*The study seeks to establish the current density and power density. Increasing the current density is factors for increase the activation energy and the rate of bubble growth on electrode surface. Where the electrode properties, concentration of electrolyte and temperature is other factors cannot be ignored [8].Table 2 presentd Hydrogen and Oxygen ration in in different runs at 1 atm 30°C while Table 3 shown Current and Power Densities.Fig. 6,a demonstrated the H2 and O2 flow ratewhile Fig. 6,b shown the relation between the power and H2:O2 ratio.*

**Table 2**: Hydrogen and Oxygen ration in in different runs at 1 atm 30°C.

| Power (W) | Time (s) | H2 Flow (L/hr) | O2 Flow (L/hr) | Ratio H2:O2 |
|---|---|---|---|---|
| 63.84 | 3 | 15.60 | 11.14 | 1.40 |
| 64.6 | 3 | 15.60 | 11.46 | 1.36 |
| 64.6 | 2.98 | 15.70 | 11.52 | 1.36 |
| 68.4 | 2.96 | 15.81 | 11.64 | 1.36 |



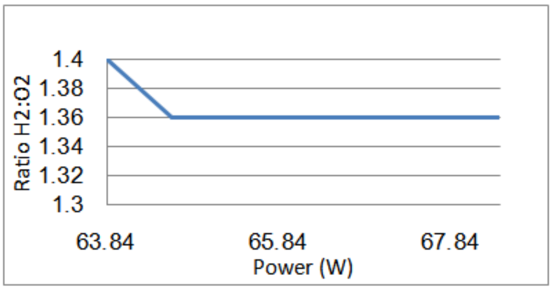




*Fig 6,a: illustrated the H2 and O2 flow rateFig 6,b: illustrated the relation between the power and H2:O2 ratio.*

The electrical efficiencywere calculated as follow:
1.24/Volt*100%[6.1]
Current Density=I⁄(Reactive Area)[7.1]
Power Density=P⁄(Reactive Area)[8.1]

***Table 3 :*** *Current & Power Densities*

| Electrical Efficiency, η (%) | Current Density (A/mm^2) | Power Density (W/mm^2) |
|---|---|---|
| 32.63 | 0.000814585 | 0.003095423 |
| 32.63 | 0.000824282 | 0.003132273 |
| 32.63 | 0.000824282 | 0.003132273 |
| 32.63 | 0.00087277 | 0.003316524 |

Based on average value taken from the above tables, we took the average flow rate of hydrogen is 15.68 L/hr from (Table 2). Also, the Energy of hydrogen &Electrolyzer Efficiency are 49.42 J/s and 75.16% respectively. Also, from the results it's obvious that, when increasing the power, the efficiency of the Electrolyzer will decrease, because it will heat the cell and it leads to consumption of energy in the form of heat. Also the relation between the efficiency and power is inverse relation, as shown in (Fig 5). Summary of the experimental results of this workis shown in Table 4.

***Table 4: Summary of the experimental results of this work .***

| Power (W) | Time (S) | H2 Flow (L/hr) | H2 Energy (J/s) | Efficiency (η) %: |
|---|---|---|---|---|
| 65.36 | 3 | 15.68 | 49.42 | 75.16 |

## IV. CONCLUSION

The design enabled successful build a bench type Electrolyzer to produce hydrogen gas by utilizing solar energy. The total efficiency of the Electrolyzer was 75.16%, with flow rate around 15.68 liter of $H_2$ per hour at optimum value of power supply (65.36 W), where the efficiency of the electrical system is 82%.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