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Generation of Solar Hydrogen Gas Energy from Water Splitting Process as an Alternative to Fossil Fuel

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ABSTRACT

Hydrogen is a promising fuel, can be obtained from different sources of raw materials, including water. Water is a renewable, abundant and sustainable source, which can produce high hydrogen purity via electrolysis. The aim of this study is to produce clean hydrogen energy gas and breathable oxygen gas from water splitting process as an alternative to fossil fuels in a newly developed photo-electrochemical electrolyzer. The photo-electrochemical electrolyzer is of dimension 24 cm by 42 cm by 28 cm, designed and fabricated with 10-plate stainless-steel electrode. The electrolyzer was connected upwardly to gas storage container, dc compressor and a gas cylinder. The designed electrolyzer was further connected to a 12 V 9 Ah battery and two-100W solar panels.

A mixture of 8 L of water and 160 g of NaOH was charged into the electrolyzer after which electrolysis process commenced. The process was left for 5 days. Within these time, hydrogen and oxygen gases were produced simultaneously and collected by upward method. The produced gases were compressed by high pressured gas cylinders respectively. Voltage and current supplied by solar panels to the electrolyzer were monitored. The maximum and minimum voltage and current reading ranged from 2.11 – 13.57 V and 1.05 -7.53 A respectively.

This study revealed that high voltage and near constant amperage readings will produce more hydrogen gas than low voltage readings. The weight of hydrogen produced after 5 days of observations was 1.84 kg. This study established that hydrogen can be produced abundantly through the new fabricated photo-electrolyzer and replace fossil fuels to create a clean and green global environment.

1. INTRODUCTION

With the continuous worldwide increase in population and standards of living, meeting the ever-increasing global energy demand in an affordable, clean, reliable, and sustainable manner has become one of the most challenging tasks of the twenty-first century (Acar and Dincer, 2017). Due to the repercussion of fossil fuels' restricted supply and extraction around the world (leading to an increase in price), fossil fuels cannot to keep pace with the growing energy needs. In conjunction with financial matters, greenhouse gas discharges as a consequence of fossil fuel consumption, and their influence on climate change, have been causing significant worries to global community (Acar and Dincer, 2017).).

During the twentieth and the beginning of the twenty-first century, the world's energy consumption has increased steadily due to the global rise in population and standards of living (Dincer & Acar, 2014). World's total primary energy supply (TPES) was 12,717 MTOE (millions of tonnes of oil equivalent) in 2010, about 80% of this amount came from fossil fuels. In the same year, the amount of worldwide electricity generation was 21,431 TWh while 70% of this amount was generated by using fossil fuels. The worldwide CO_2 emissions were 30,326 Mt in 2010 (Demirbas, 2002). This amount was mainly as a result of using fossil fuels. This enormous increase in worldwide CO_2 emission has contributed greatly to global warming and other numerous air pollutants which are among the

most important issues that threaten the health and peaceful existence of mankind. The reoccurrence of these issues in the past century has been a major concern and no concrete solution has been introduced in order to curb their ill-effects on the planet earth.

Transport and industrial sectors are major contributors to environmental degradation through various toxic emissions as a result of increase fossil fuel consumption (Muhibbudin et al., 2020). Safety considerations should be enforced to search for alternative clean energy sources to power transport and industrial sector worldwide. Many different approaches are under experimental investigations or being utilized in this regard, however hydrogen gas energy remain undauntedly the best option among fuels with no or little carbon footprint (25; 9)

Hydrogen gas energy remains one of the most attractive renewable-energy as an alternative to fossil fuel. The idea of using hydrogen as an energy carrier was strengthened noticeably after the global energy crisis of 1974. Hydrogen is chemical energy carrier with energy density of 140 MJ kg-1 and no secondary contaminants generated during its oxidation (reference). The outstanding features and properties of hydrogen such as its lightweight, exclusive abundance and environmentally benign oxidation product, make it an ideal synthetic energy and very promising energy carrier, although it is not naturally available as a ready to use substance (23).

Hydrogen can be produced from varieties of feedstock including fossil and renewable resources. Several process technologies such as chemical, biological, electrolytic, photolytic and thermo-chemical can be used for hydrogen production. Common hydrogen production methods include steam methane reforming, gasification of coal and other hydrocarbons, electrolysis of water, hydrogen from biomass, and hydrogen from nuclear energy (Muhibbudin et al, 2020: Sharma and Ghoshal, 2015).

Electrolysis of water is the decomposition of water into oxygen and hydrogen gas due to the passage of an electric current. This technique can be used to make hydrogen gas and breathable oxygen gas or commix the two gases into oxyhydrogen (HHO) (Felseghi, 2015; Appleby and Foulkes, 1989). It is also called water splitting process. It ideally requires a minimum potential difference of 1.23 volts to split water.

The splitting of a water molecule by means of electrolysis has been studied for a long time. Water is subjected to a direct current in order to force its molecules to decompose. The occurring half-reactions at the electrodes are given by equations (1) and (2).

Reduction at Cathode: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ …… (1)

Oxidation at Anode: $2OH^- \rightarrow {}^1/_2\, O_2 + H_2O + 2e^-$ … … … … … … … … … … … … … ….(2)

Water is naturally occurring, readily available the most promising source for hydrogen production. This is due to its abundance, low cost, and easy access on earth. Consequently, a great deal of effort has been devoted to generating hydrogen from water through sustainable, energy-efficient, and cost-effective processes that have the potential to attain industrial scales.

Electrolysis of water requires energy in the form of overpotential to overcome various activation barriers. The electrolysis of water is a slow process. This is due to the limited self-ionization of water (Hoogers, 2003). Water has an electrical conductivity of about one-millionth that of seawater. Water is a poor conductor of electricity. The efficiency of water electrolysis can be increased through the addition of an electrolyte (such as a salt, an acid or a base) and the use of electrocatalysts.

Water electrolysis could be used for hydrogen production at any place around the globe. The only requirements are available electricity and water. This goal can be achieved if the required electricity is obtained from an emission-free method such as wind, solar, geothermal systems, ocean wave and any other renewable green sources (Mazloomi and Gomes, 2012). With regard to water electrolysis, this method is capable of producing absolutely sustainable and clean hydrogen.

The aim of this research work is to produce clean and carbon-free hydrogen gas energy and breathable oxygen gas from water splitting photo process as an alternative to fossil fuels. The need to carry out this study is necessitated by the benefits of the application and utilization of hydrogen gas energy. Coupled with this, solar hydrogen is a versatile energy carrier that can be used as a liquid fuel and converted to electricity (via reaction in a fuel-cell). Solar hydrogen can be produced anywhere that water and sunlight are available, enabling distributed energy generation and reducing the dependence on countries with fossil fuel without any side effect on human health and the environment

2. METHODOLOGY

2.1 Sample Preparation

A beaker was used to measure 8 litres of water and poured into the fabricated electrolyzer, after which the 160 g of NaOH was measur ed and dissolved with water. Both were thoroughly mixed to prepared 0.5M concentration.

2.2 Electrolyzer Fabrication

A container with a volume capacity of 25 liters was used for the fabrication of the photo-electrolyzer . A 10 plate stainless-steel (electr olytic cells) perforated and coupled together to form anode and cathode electrode in 5 plate cells respectively. The dimension of each plate is 16cm by 4.5 cm. The distance in-betweens the plate is 0.5 cm. Two stainless steel arrays were needed to function as the cathod

e electrode and the anode electrode separated 20 cm in the chambers of the container. Negative (-) side for the production of hydrogen gas (cathode) gaining electrons while the positive side (+) is for oxygen gas (anode) losing electrons. A hose each was connected to th e lid of the container to transport the products (i.e., hydrogen and oxygen) from each cell to a storage unit.

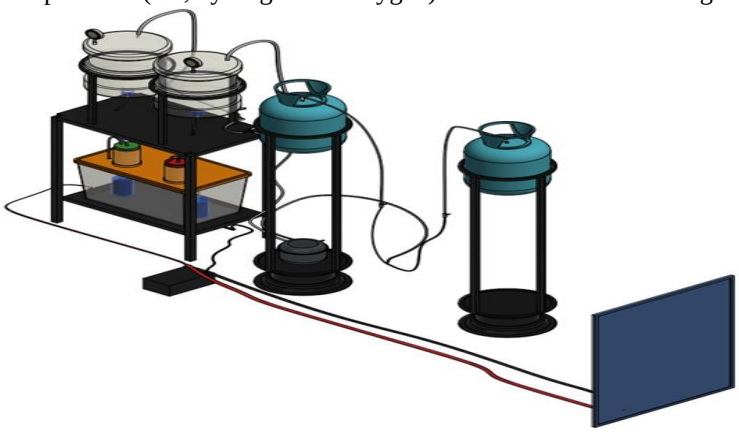
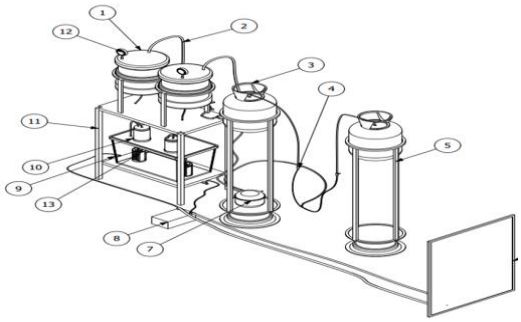
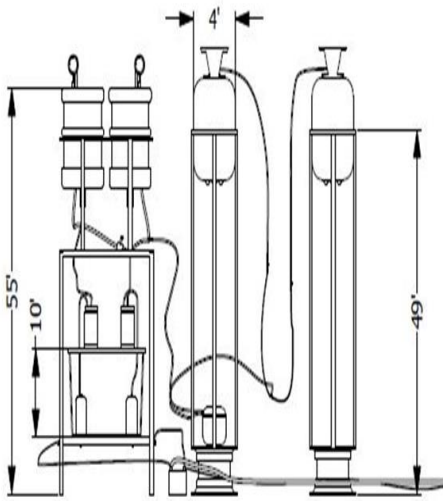


Figure 1: photo-electrochemical electrolyzer fabricated

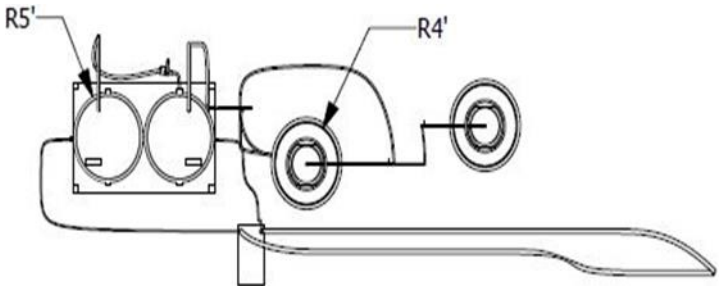


PARTS LIST	
ITEM	PART NAME
1	DISPENSER
2	HOSE
3	GAS CYLINDER
4	VALVE
5	GAS CYLINDER STAND
6	SOLAR PANEL
7	COMPRESSOR
8	DC BATTERY
9	ELECTROLYZER CONTAINER
10	CONTAINER(SMALL)
11	FRAME
12	PRESSURE METER
13	ELECTROLYTES

Side view of photo-electrolyzer



Front view of photo-electrolyzer



Plane view of photo-electrolyzer

Figure 2: photo-electrochemical electrolyzer design



Plate 1: Design Electrolyzer

2.3 Solar panel connection

After fabrication of electrolyzer, the solar panel was connected and sited in an area where optimum sun rays (intensity) can be obtaine d. The panels were connected with solar controller which was used in regulating the amount of voltage and current to be supplied into battery (12V 9 Ah) and electrolyzer. The positive terminal (+) from the battery was connected to one of the terminals of the electrolyz er which make Anode while negative terminal from the battery (-) was connected to the other terminal of the electrolyzer which is cath ode. The photo-electrochemical system was allowed to run twenty four hours nonstop for five days.

2.4 Electrolysis Process

Electrolysis process commenced with the passage of regulated voltage and current from the solar panel to the electrolyzer after the mi xture of water and NaOH in the electrolyzer. Sodium hydroxide acted as a substance to increase the conductivity of water. Bubbles of hydrogen and oxygen evolved in a separated chamber within the electrolyzer which indicates an effective electrolysis process (i.e., em ission of gas from the electrodes). The process was left to run independently for a period of five days nonstop while collecting the gase s emitted from both chambers through the hose at the lid simultaneously by upward method.

2.5 Sample Storage

The hydrogen gas generated from the electrolyzer was transported from upward collection process through an elastic transparent hose into a gas compressor at 350 bars. The compressed the hydrogen gas before storing into a gas cylinder. Also, the breathable oxygen w as transported in the same pattern into an empty gas cylinder and can be sent to hospitals or laboratories for use. The gas cylinder cont aining hydrogen gas was weighed and hydrogen produced was measured to be 1.84kg

2.7 Tests for Hydrogen

After the experiment was conducted for 5 days, a splinter test was conducted to confirm the presence of hydrogen. A splint (lighter) is lit and held near the opening of the hose. The release valve was opened to let out the hydrogen gas trapped in the container A 'squeaky pop' sound was experienced which led to an explosion and damage of the container for the collection of hydrogen gas.

3. RESULTS AND DISCUSSION

3.1 Observed frequency of hydrogen bubbles evolved (production) with corresponding voltage and ampere readings for five days of water electrolysis.

Table 1 to 5 summarize the peak number of bubbles obtained at the cathode (hydrogen gas) from the fabricated photo-electrolyzer, containing the mixture of NaOH and water in the morning (700 hr – 1000 hr), afternoon (1200 hr – 1500 hr) and at evening (1800 hr – 2100 hr) from Day 1 to Day 5. Readings of corresponding ampere and voltage were taken from multi-meter connected to the electrolyzer at peak number of bubbles of hydrogen gas. The varying number of bubbles of hydrogen release, amperes and voltages depend on intensity of the sun.

Table 1: Peak number of bubbles at the cathode, voltage and ampere on Day 1

Time of Day	Voltage (V)	Ampere (A)	No. of bubbles
Morning (700 hr – 1000 hr)	11.98	6.98	6
Afternoon (1200 hr – 1500 hr)	12.65	7.63	10
Evening (1800 hr – 2100 hr)	5.57	2.86	4

Table 2: Peak number of bubbles at the cathode, voltage and ampere on Day 2

Time of Day	Voltage (V)	Ampere (A)	No. of bubbles
Morning (700 hr – 1000 hr)	11.29	4.33	5
Afternoon (1200 hr – 1500 hr)	11.17	4.39	6
Evening (1800 hr – 2100 hr)	4.91	2.83	4

Table 3: Peak number of bubbles at the cathode, voltage and ampere on Day 3

Time of Day	Voltage (V)	Ampere (A)	No. of bubbles
Morning (700 hr – 1000 hr)	10.60	4.73	5
Afternoon (1200 hr – 1500 hr)	13.5	7.42	11
Evening (1800 hr – 2100 hr)	3.73	1.79	3

Table 4: Peak number of bubbles at the cathode, voltage and ampere on Day 4

Time of Day	Voltage (V)	Ampere (A)	No. of bubbles
Morning (700 hr – 1000 hr)	11.80	5.95	5
Afternoon (1200 hr – 1500 hr)	12.80	7.56	9
Evening (1800 hr – 2100 hr)	4.89	2.92	3

Table 5: Peak number of bubbles at the cathode, voltage and ampere on Day 5

Time of Day	Voltage (V)	Ampere (A)	No. of bubbles
Morning (700 hr – 1000 hr)	11.93	5.77	5
Afternoon (1200 hr – 1500 hr)	15.21	7.27	9
Evening (1800 hr – 2100 hr)	5.52	3.07	3

3.2 Effect of voltage and ampere on hydrogen production

The influence of voltage applied on the hydrogen production was studied, over five (5) days. During the production, the reaction conditions were: 8L H_2O, 160g NaOH solution with varying voltage and ampere input reading from the solar panels. The durations to produce a volume of hydrogen (time for the appearance of one bubble of hydrogen gas) at different voltages during the production are recorded.

The tables 1 to 5 indicate that voltage applied at the terminals of electrodes has a great impact as hydrogen evolves at the cathode. At a near-constant current, when the voltage increases the amount of bubbles experiences (hydrogen gas produced) also increases. The migrations of electrons would make reduction-oxidation reaction thereby in cathode water was reduced to hydrogen ion H+ and in anode OH will be oxidized to be oxygen. (15)

Cathode: $4H_2O + 4e^- \rightarrow 2H_2 + 4OH^-$---------- (3)

Anode: $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$---------- (4).

From the result obtained, it was remarked that the current seems to be constant with increasing voltage leading to an increase in hydrogen production. However, at a voltage of 13.57V, the highest production of hydrogen was recorded (highest number of bubbles) after which subsequent voltage reading resulted in a decrease in hydrogen production. Therefore, the peak voltage for maximum production of hydrogen for the experiment was recorded to be 13.57V.

4.0 CONCLUSION

A newly fabricated photo-electrochemical electrolyzer was designed from locally sourced materials to produce hydrogen gas and oxygen gas simultaneously in a separate chamber. NaOH was used to improve the conductivity of water to allow photo-electrolytic process possible. NaOH concentration and sun intensity have effect on hydrogen production. The electrolytic process shows that increase in voltage supply with relatively constants current resulted to the increase in hydrogen gas production. The weight of hydrogen gas produced was 1.84 kg. Maximum hydrogen gas was produced as the voltage increases when current (ampere) seems to be constant. With this new photo-electrochemical electrolyzer, hydrogen gas energy and oxygen will be made available, cheap and utilize by everyone leading to clean global environment. The new photo-electrochemical electrolyzer will lead to abundant hydrogen gas stations with further research and investment.

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