



ORIGINAL ARTICLE

Photoelectrochemical Process of Producing Hydrogen Gas Energy from Brewery Wastewater

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Abstract

The major portion of the energy needs of the world are obtained from fossil fuels. However, the future of fossil fuel is beclouded with environmental threats and degradation, which has caused an adverse effect on human health. Therefore, seeking a non-polluting alternative energy source has become important and necessary. Hydrogen gas energy constitutes low-cost energy without any negative impact on the environment and human health. Furthermore, Hydrogen gas energy can replace fossil fuels based on its physical and chemical properties. This research aims to produce hydrogen gas via a photo-electrochemical process unit using brewery wastewater. The specific objective is to design and fabricate a new electrolyzer to produce hydrogen gas from brewery wastewater. A new fabricated photo-electrochemical electrolyzer of dimension 24 cm x 42 cm x 28 cm was designed with a 10-plate stainless-steel electrode. The electrolyzer was connected upwardly to a gas storage container, dc compressor, and a gas cylinder. The electrolyzer was connected to a 12 Volt 9 Amps battery, two-100W solar panels. A mixture of 8 liters of brewery wastewater and 160 grams of NaOH was charged into the electrolyzer, after which the electrolysis process commenced. The process was left for 5 days. Within these times, hydrogen and carbon dioxide gases were produced simultaneously and collected by the upward method. The produced gases were compressed by high pressured gas cylinders respectively using a compressor of 350 bars. Voltage and current supplied by solar panels to the electrolyzer were monitored. The maximum and minimum voltage and current readings were ranged between 3.63 V – 13.60 V and 1.83 A -7.81A, respectively. This result revealed that high voltage and near-constant amperage readings would produce more hydrogen gas than low voltage readings. The weight of hydrogen produced after 5 days of observations was 2.01kg. This study demonstrated that hydrogen gas energy could be produced from locally made non-polluting devices, turning brewery wastewater into a useful form of energy and creating a carbon-free environment.

Keywords: Energy Sustainability, Photo-Electrolytic Process, Brewery Wastewater, Hydrogen Generation, Carbon Neutrality

Introduction

Fossil fuels are being consumed and exhausted worldwide. Moreover, fossil fuels are responsible for climate change, such as CO₂, SO₂, NO_x (NO and NO₂), and fine particulate matters (IEA, 2010). More specifically, fossil fuel accounted for a significant amount of carbon dioxide (CO₂) emissions and exposed the earth to global warming and unpredictable weather patterns (Adeniran et al., 2019). Therefore, seeking a non-polluting alternative energy source has become so important. However, all these generations of alternative energy sources require high capital costs and are limited. Therefore, many researchers are concerned with going for low-cost energy generation without any negative impact on the environment and human health. Then, the production of hydrogen gas energy is an attractive and ultimate alternative to fossil fuels as it can be produced both from renewable sources and non-renewable sources. Hydrogen can then be utilized in vehicular transportation, powered engines, and distributed electricity generation through fuel cells (Nanaki and Koroneos, 2017).

The increasing trend in the global energy need is expected to continue in the future. As a result, growth in energy generation capacity will be needed and required. Therefore, finding more secure, clean, and diversified energy sources could be a successful strategy to reduce and eliminate greenhouse gas emissions and meet the energy needs of the world. Compared to other alternatives, hydrogen has a large number of advantages; therefore, it could be used to reduce various forms of atmospheric (organic and inorganic) emissions, which include volatile organic compound, polycyclic aromatic hydrocarbon, CO, CO₂, SO₂, O₃, NO_x, Heavy metals, and fine particulate matter. In addition, pollutants produced from the combustion of fossil fuels cause even more health problems due to the urbanization and industrialization of the world population (Sethia and Sayari, 2016).

Hydrogen is the lightest, simplest, and most plentiful of all chemical elements in the universe. However, it occurs only in combination with other elements, primarily with oxygen in the water and with carbon, nitrogen, and fossil fuels. Therefore, hydrogen is not a primary source of energy (Acar and Dincer, 2017). However, it becomes an attractive energy carrier when split from these other elements using an energy source. In addition, hydrogen is very clean in terms of zero emissions at the point of use. It's combined with oxygen to generate electricity without carbon emission. The only by-product is water and heat in the fuel cells (Groneworld, 2019).

The economic advantage the world stands to gain from hydrogen is the elimination of pollutions caused by fossil fuels. Thus, when hydrogen is used to generate electricity and transportation, it is a completely clean technology with no environmental threats or dangers (Abe et al., 2019). Since fossil fuel are exhausting, coupled with its political, economic, and environmental turbulence. Therefore, there is a need to find sustainable and readily available sources. There are significant efforts that have been put into finding the cost-effective hydrogen production method (Celik and Yildiz, 2017). Brewery wastewater has been an alternative to the growing hydrogen gas energy production techniques as a future fuel. The brewing industry is water-intensive and consequently produces huge volumes of wastewater. Brewery wastewater can produce hydrogen instead of constituting waste in the environment. To secure a sustainable hydrogen gas production and supply, a renewable source for hydrogen production must be developed, such as a photo-electrolyzer and available raw materials like brewery wastewater. Thus, this research aims to produce hydrogen gas via a developed photoelectrochemical process unit using brewery wastewater.

The need to carry out this study is necessitated by the potentials of hydrogen gas energy, considered a clean energy carrier and a future energy source, and turning brewery wastewater into useful form energy. The unique properties of hydrogen give it an edge over any other renewable source of energy. Furthermore, hydrogen produced from brewery wastewater via designed photo-electrolyzer will decentralized hydrogen gas energy.

Materials and Methods

Sample Preparation

Brewery wastewater was obtained from a local brewery industry. First, 8 liters of brewery wastewater were measured with a beaker and poured into the fabricated electrolyzer, after which the 160 g of NaOH (sodium hydroxide) was measured and dissolved with water. Finally, both were thoroughly mixed to prepare 0.5M concentration.

Electrolyzer Fabrication

A two-chamber container with a volume capacity of 25 liters was used for the fabrication of the electrolyzer. Ten stainless-steel plates (electrolytic cells) were perforated and coupled to form anode and cathode electrodes in 5 plate cells each, respectively. The dimension of each plate is 16cm by 4.5 cm. The distance in-between the plate was 0.5cm. Two stainless steel arrays were needed to function as the cathode electrode, and the anode electrode separated 20cm in the chambers of the container.

The negative (-) side is for the production of hydrogen gas (cathode) gaining electrons, while the positive side (+) is for carbon dioxide and oxygen gases (anode) losing electrons. A hose was connected to the lid of the container to transport the products (i.e., hydrogen and carbon dioxide/ oxygen) from each cell to a storage unit through a 350-bar compressor. It was assembled and shown in the following Figures 1, 2, 3 and 4.

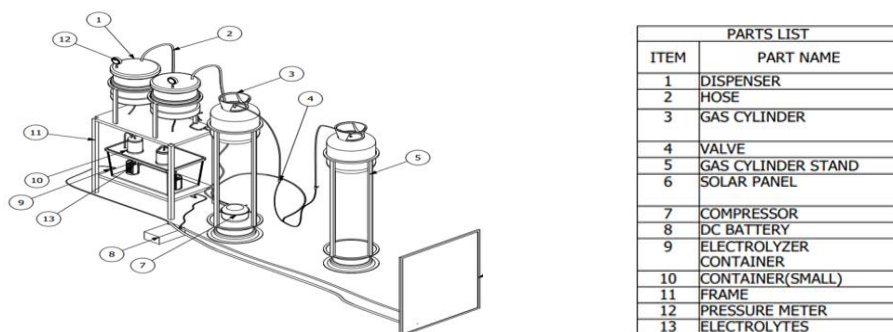


Figure 1. Side view of designed photo-electrolyzer

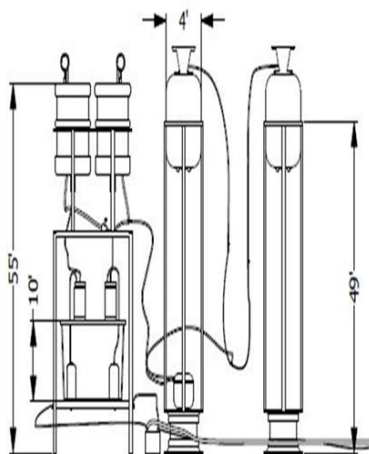


Figure 2. Plane view of designed photo-electrolyzer

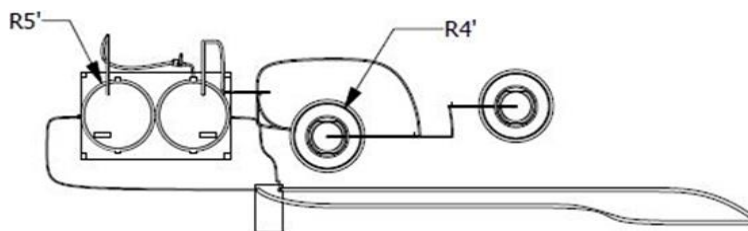


Figure 3. Top view of designed photo-electrolyzer



Figure 4. Design Electrolyzer

Solar panel connection

After fabrication of the electrolyzer, the solar panel was connected and sited in an area where optimum sun rays (intensity) could be obtained. The panels were connected to a solar controller, which was used to regulate the voltage and current to be supplied into a 12V 9ah battery and electrolyzer. The positive terminal (+) from the battery was connected to one of the terminals of electrolyzers that make anode. In contrast the negative terminal from the battery (-) was connected to the other terminal of the electrolyzer, which is the cathode. The photo-electrochemical system was allowed to run twenty-four hours nonstop for five days.

Electrolysis Process

The electrolysis process commenced with the passage of regulated voltage and current from the solar panel to the electrolyzer after the mixture of brewery wastewater and NaOH in the electrolyzer. Sodium hydroxide acted as a substance to increase the conductivity of brewery wastewater. Bubbles of Hydrogen and carbon dioxide evolved in a separated chamber within the electrolyzer, which indicates an effective electrolysis process (i.e., emission of gas from the electrodes). The process was left to run independently for five days nonstop while collecting the gases emitted from both chambers through the hose at the lid simultaneously by the upward method.

Sample Storage

The hydrogen gas generated from the electrolyzer was transported from the upward collection process through a transparent elastic hose into a gas compressor at 350 bars. They compressed the hydrogen gas before storing it in a gas cylinder. Also, the carbon dioxide was transported in the same pattern into an empty gas cylinder. It can be sent to fire extinguisher manufacturers, carbonated drink industries for use. The gas cylinder containing hydrogen gas was weighed, and the hydrogen produced was measured to be 2.01kg.

Results and Discussion

Observed highest frequency of bubbles evolved (hydrogen production) with corresponding voltage and ampere readings for five days of water electrolysis. Table 1 to Table 5 summarizes the peak number of bubbles obtained at the cathode (hydrogen gas) from the fabricated photo-electrolyzer, containing the mixture of NaOH and brewery wastewater in the morning (700hrs – 1000hrs), afternoon (1200hrs – 1500hrs), and at evening (1800hrs - 2100hrs) from Day 1 to Day 5. Corresponding ampere and voltage reading were taken from multi-meter connected to the electrolyzer at observed number of hydrogen gas bubbles. The varying number of bubbles of hydrogen release, amperes, and voltages depend on the intensity of the sun.

Table 1. Day 1

Time of Day	Voltage (V)	Ampere (A)	No. of bubbles
Morning (7:00h – 10:00h)	10.62	5.81	7
Afternoon (12:00h – 1500h)	13.35	7.81	11
Evening (18:00h – 21:00h)	5.33	2.92	4

Table 2. Day 2

Time of Day	Voltage (V)	Ampere (A)	No. of bubbles
Morning (7:00h – 10:00h)	11.83	6.51	6
Afternoon (12:00h – 1500h)	12.93	4.39	11
Evening (18:00h – 21:00h)	4.78	2.52	4

Table 3. Day 3

Time of Day	Voltage (V)	Ampere (A)	No. of bubbles
Morning (7:00h – 10:00h)	10.77	5.83	6
Afternoon (12:00h – 1500h)	13.75	7.63	12
Evening (18:00h – 21:00h)	3.63	1.83	4

Table 4. Day 4

Time of Day	Voltage (V)	Ampere (A)	No. of bubbles
Morning (7:00h – 10:00h)	11.31	6.43	6
Afternoon (12:00h – 1500h)	13.50	7.56	12
Evening (18:00h – 21:00h)	4.73	2.61	4

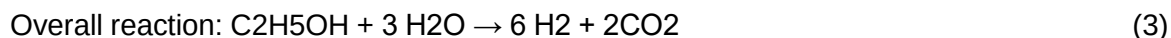
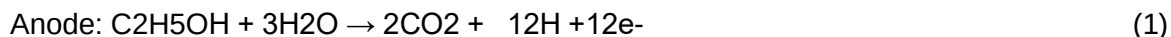
Table 5. Day 5

Time of Day	Voltage (V)	Ampere (A)	No. of bubbles
Morning (7:00h – 10:00h)	12.02	6.98	9
Afternoon (12:00h – 1500h)	12.84	7.45	12
Evening (18:00h – 21:00h)	5.69	2.98	5

Effect of voltage and ampere on hydrogen production

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

The results indicate that voltage applied at the terminals of electrodes has a great influence as hydrogen evolves as the cathode (Fatima et al.2017). At a near-constant current, the amount of bubbles experienced (hydrogen gas produced) increases when the voltage increases. The migrations of electrons would make a reduction-oxidation reaction. In the cathode, brewery wastewater was reduced to hydrogen ion H^+ while in anode, OH^- was oxidized to CO_2 as shown in equations (1) to (3).



Using a photoelectrochemical electrolyzer led to the electrochemical decomposition of brewery wastewater into hydrogen gas. From the result obtained, it was observed that when the current seems to be constant with increasing voltage leads to an increase in hydrogen production. However, at a voltage of 13.60 V, the highest hydrogen production was recorded (highest number of bubbles). A subsequent voltage reading resulted in a decrease in hydrogen production. Therefore; the peak voltage for maximum hydrogen production for the experiment was recorded to be 13.60 V.

Conclusion

A two-chamber photoelectrochemical electrolyzer was fabricated and designed from locally sourced materials to simultaneously produce hydrogen gas and carbon dioxide in a separate chamber of the electrolyzer, collected by the upward method. NaOH was used to improve the conductivity of brewery wastewater to allow the photo-electrolytic process possible. Time and NaOH concentration has effect on hydrogen gas production. The electrolytic process shows that increases in voltage supply with the relatively constant current increase hydrogen gas production. The weight of hydrogen gas produced was 2.01 kg. Maximum hydrogen gas was produced as the voltage increased when the current (ampere) seemed to be constant.

Electrocatalysts will improve the high rate of clean hydrogen gas by the photo-electrochemical process of brewery wastewater in this built photoelectrolyzer. With this fabricated photo-electrochemical electrolyzer, hydrogen gas energy production can be carried out in a decentralized location, making hydrogen readily available and utilized by everyone in any part of

the world, leading to a carbon-free world. This research is limited to using the available local resources for the brewery wastewater electrolytic process. The voltage and current were solely dependent on the intensity of the sun which cannot be controlled. In addition, Anode and cathode electrode (materials) was limited to the available cheap stainless steel electrodes.

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