THE EFFECTS OF THE VARIATION OF THE ELECTRODE AND ELECTROLYTE MATERIALS ON WATER HYDROLYSIS FOR HYDROGEN PRODUCTION

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ABSTRACT

Water electrolysis is a simple and easy way to produce hydrogen though there are some major challenges about energy consumption, production and maintenance cost, and durability. This study presents an experimental analysis of hydrogen production by water electrolysis using different electrodes and electrolyte to find an effective way of hydrogen production. The purpose of this research work is to identify the best electrode and electrolyte materials for hydrogen production along with some effective operating parameters. Experiments were performed on a water electrolysis cell with three electrode materials (stainless steel, carbon steel (iron), galvanized zinc) and three electrolyte materials (Potassium hydroxide (KOH), Sodium hydroxide (**NaOH**), Sodium bicarbonate ($NaHCO_3$)) alternatively. Throughout the experiments, different composition of electrodes, different composition of electrolytes, and ampere were investigated on volume of hydrogen production. Results showed that various factors have the influence on the performance of water electrolysis. Indeed, this study revealed that the hydrogen gas production efficiency of carbon steel-based electrode is the highest (146%) compared with other electrodes over the range of operating parameters tested. Among these three electrode, carbon steel can be the best selection for the maximum hydrogen production compared to other electrodes under the present experimental conditions.

Keywords: *Hydrogen, Water electrolysis, Electrode, Electrolytes,*

1. INTRODUCTION

The Paris Agreement, which was agreed at COP 21 in 2015, aims to cut carbon emissions by 10% by 2030 for both developed and developing countries. Because of its lower carbon footprint, the conversion from fossil fuels to biofuels has been hastened as part of this endeavor [1]. Sustainable and renewable energy can supply present and anticipated world's energy needs, and it is becoming increasingly unavoidable due to public environmental concerns and fossil fuel depletion [2]. Biofuels, on the other hand, are not yet cost and efficiency competitive with natural gas, coal and oil. Several issues must be solved in order to commercialize biofuels, including the high total cost of biomass consumption, poor efficiency of the transformation process into fuels, and inadequate reactivity of biomass raw resources [3] [4]. However, direct energy use and integration into the current power system is extremely difficult. It is critical to revolutionize the way it is used, and converting it into storable hydrogen energy is one viable option [5].

Hydrogen is energy that could use by vehicles to replace gasoline which made from fossil fuel. Previously, the aerospace industry used hydrogen as a rocket fuel because of hydrogen characteristic which high energy density on a mass basis, high flame speed and wide flammability range [6]. Nonetheless, 90% of the globe's hydrogen is currently produced through the reprocessing of fossil fuels, which requires a lot of energy and produces a lot of CO_2 [7] [8]. Traditionally, hydrogen was produced from fossil fuel process such as steam methane reforming, gasification of coal and by-product of gasoline oil. Though, all of those processes emit carbon dioxide and carbon monoxide which contribute to global warming. Studies on emission in the transportation sector from the year 2012 to 2017 shown carbon dioxide emission from the transportation sector were the highest compare to another sector [9]. There is also hydrogen production from renewable and sustainable energy resources such as water electrolysis, biomass, biological hydrogen, biomass pyrolysis, biomass gasification, wind energy, solar energy and etcetera [10].

On earth, there are about 70% of water. Water is a combination of two molecules which is hydrogen and oxygen. Both of the molecules could be split by using a simple process which electrolysis. Electrolysis of water is the process of splitting water molecules to form hydrogen and oxygen gas. Hydrogen produces on a cathode or negative plate, while oxygen will produce on an anode or positive plate [11]. When the current flow in water, hydroxide ion $(OH)^-$ and hydrogen ion (H^+) are attracted to anode and cathode. The electrolysis reaction for the hydrogen production is given below [12]:

$$H_2O \rightarrow H_2 + {}^1/_2\, O_2 \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$where\ \Delta E^0 = E^0_{H_2O/_{H_2}} - E^0_{OH^-/O_2} = -1.23\ V$$

Electrolysis of water is one of the most effective methods for generating hydrogen because it employs renewable H_2O and delivers solely pure oxygen as a by-product. Furthermore, the electrolysis method uses DC power from renewable energy sources such as solar, wind, and biofuel. However, because to cost constraints, only 4% of hydrogen can be generated by electrolysis of water at the moment [12] [14]. Water electrolysis has a number of advantages, including high cell efficiency and a higher rate of hydrogen generation with high purity, which makes it a better candidate for transformation to electrical energy using moderate temperature fuel cells [15]. The water molecule is the reactant in the electrochemical reaction, and under the effect of electrical energy, it is split into hydrogen (H_2) and oxygen (O_2). Water electrolysis is divided into four categories based on the electrolyte, working conditions, and ionic agents (OH^-, H^+, O^{2-}) used, although the operational principles are the same in each case. The four types of electrolysis processes are (1) Alkaline water electrolysis (AWE), (2) Solid oxide electrolysis (SOE), (3) Microbial electrolysis cells (MEC), and (4) PEM water electrolysis [16].

Alkaline water electrolysis is the most popular technology for industrial hydrogen generation up to the megawatt range. In AWE, two molecules of alkaline solution are required to produce one molecule of hydrogen and two hydroxyl ions. The created H_2 leaves the cathode surface to recombine in a gaseous state, and the hydroxyl ions (OH) pass through the porous diaphragm to the anode under the pressure of the electrical system between electrode and electrolyte. Then, hydroxyl ions produce oxygen and water [17]. At the electrode's surface, the O_2 recombines and hydrogen departs. Alkaline electrolysis uses alkaline solution ($KOH, NaOH$) as the electrolyte and runs at lower temperatures, such as 30–80 °C, and the electrolyte concentration is 20–30% [18]. Alkaline water electrolysis has evolved into a mature technology; yet, there are still some areas of the technique that can be developed, such as the cost of hydrogen production and alkaline medium stability. Alkaline water electrolysis has an inherent low-cost feature because it can use a quasicatalyst and a permeable divider. Alkaline water electrolysers, on the other hand, are challenging to shut down/start up, and their performance can't be ramped up rapidly since the pressures on the anode and cathode sides of the cell must always be equalised to avoid gas bridging through the porous cell separator [19]. As a result, using renewable energy's inconsistent and fluctuating power for traditional alkaline water electrolysis is extremely problematic. New electrolyser systems are required to avoid product gases from mixing over a variety of current densities and efficiently leverage the low-cost characteristic of alkaline water electrolysis to make renewable energy conversion more feasible and economically viable.

In this experiment, the electrode is selected based on the cheapest and availability such as stainless steel, carbon steel and galvanized zinc which can produce hydrogen efficiently. The performance of these electrodes in alkaline water electrolysis will be investigated changing several parameters such as types of electrodes, type of electrolytes and applied current in electrodes. It is expected that carbon steel electrode will exhibit highest efficiency among all these three electrodes. This study will help to find an economical way to produce fuel that is environmental friendly.

2. METHODOLOGY

Potassium hydroxide (KOH), Sodium hydroxide ($NaOH$), Sodium bicarbonate ($NaHCO_3$) were purchased from Fischer Scientific, USA. Stainless steel, carbon steel (iron) and galvanized zinc were supplied by Merck, USA. All the chemicals were analytical reagent with percentage of grade purity as stated and used as received.

There are several factors taken in order to run the experiment which is the electrode type, the electrolyte type and the current flow. All of those factors will be analyzed in this section to achieve optimize state.Firstly, set up single cell of stainless-steel electrode. Prepare 0.25M of potassium hydroxide with deionized water as electrolyte. Allow current flow at 0.3 Ampere (A) and wait until hydrogen and oxygen come out from flexible hose. Filled up graduating cylinder with tap water and turn it upside down in water basin. Then, trap hydrogen and oxygen gas with graduating cylinder and set timer for one minute. After one-minute record amount of hydrogen and oxygen were trap in graduating cylinder. Then, current flow was change to 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 A and repeated the above mentioned procedure. After that, the experiment was repeated changing the electrolyte materials such as sodium hydroxide and baking soda.

Secondly, galvanized zinc electrode was combined with 0.25M of potassium hydroxide electrolyte in a cell for hydrogen production. Current flow of 0.3A was applied in the cell to split water into hydrogen and oxygen. A 1L cylinder was filled with water and turned it upside down in water basin. Produced hydrogen and oxygen gas were trapped in graduating cylinders. There was a timer which is set for one minute. The amount of hydrogen and oxygen trapped in graduating cylinder was recorded in every minutes. Then, current flow was change to 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 A and repeated the above mentioned procedure. After that, the experiment was repeated changing the electrolyte materials such as sodium hydroxide and baking soda.

Lastly, carbon steel electrode was taken in the cell with 0.25M of potassium hydroxide electrolyte for hydrogen production. Current flow of 0.3A was applied in the cell to carry out water electrolysis reaction. A 1L cylinder was filled with water and turned it upside down in water basin. Produced hydrogen and oxygen gas were trapped in graduating cylinders, and a timer was set for one minute. The amount of hydrogen and oxygen trapped in graduating cylinder was recorded in every minutes. Then, current flow was change to 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 A and repeated the above mentioned procedure. After that, the experiment was repeated by taking sodium hydroxide electrolyte and baking soda electrolyte. The hydrogen production efficiency can be expressed as the following equation [20]:

$$\eta = \frac{N_{H_{2.out}} HHV}{E + Q_{cell}\left(1 + \frac{T_0}{T_S}\right) + Q_{H_2O}(1 + \frac{T_0}{T_S})} \dots\dots\dots\dots\dots\dots (2)$$

Here, $N_{H_{2.out}}$ is the outlet flow rate of H_2, HHV is the higher heating value of H_2 (39.4 kWh per kg), E is the electric energy input, Q_{H_2O} is the thermal energy input to the second heat exchanger for further heating up H_2O, T_0 and T_S are the temperatures of the environment and external heat source, respectively. Not only the key distinction between electric and thermal energy are recognized in this definition of efficiency, but the efficiency is also directly linked to environmental temperatures, sources of heat, and electrochemical cells.

3. RESULTS AND DISCUSSION

Figure 1 shows the hydrogen production efficiency of the electrodes in the $NaOH$ electrolyte at various applied current in the electrodes. It can be seen that the efficiency of electrodes fluctuated with the changes of applied current. Stainless steel-based electrodes showed efficiency of 92.25, 110.56, 103.37, 90.5, 102.14, 94.07, 99.3 and 85.79% at applied current of 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 A, respectively. Again, galvanized zinc electrode exhibited the hydrogen production efficiency of 109.15, 107.24, 97.49, 115.32, 107.51, 114.09, 103.62 and 112.56% in the $NaOH$ electrolyte at applied current of 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 A, respectively. In carbon steel electrodes, the efficiency was 113.48, 109.43, 115.94, 118.21, 109.43, 117.8, 119.16 and 115.94% in 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 A, respectively. Maximum efficiency was found in carbon steel-based electrode at 0.9 A in $NaOH$ electrolyte. It was also found that carbon steel electrode in $NaOH$ electrolyte provided a more stable efficiency at different current compared to stainless steel and galvanized zinc electrodes.

Figure 2 represents the efficiency versus current curves of the electrodes in the KOH electrolyte. Stainless steel electrodes provided efficiency of 120.78, 121.46, 125.75, 104.79, 101.8, 97.17, 95.01 and 104.28% at applied current of 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 A, respectively. Galvanized zinc electrode showed efficiency of 122.01, 109.25, 111.05, 125.02, 122.16, 137.04, 121.81 and 125.54% in applied current of 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0 A, respectively. The efficiency found in carbon steel electrode were 127.97, 123.28, 146.7, 128.92, 129.31, 118.37, 127.97, 130.27% in 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 A, respectively. carbon steel electrode showed maximum efficiency of 146.7% in KOH electrode when 0.5 A current was applied. Figure 2 also indicate that the efficiency of the hydrogen production was not very fluctuating like stainless steel and galvanized zinc electrodes.

In this experiment, baking soda was used as electrolyte with stainless steel, galvanized zinc and carbon steel electrodes separately. The hydrogen production efficiency of the electrodes is plotted against current in Figure 3. The efficiency of stainless steel electrode was recorded 85.11, 88.63, 84.66, 55.58, 85.74, 98.71, 82.69 and 96.53% in 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 A, respectively. similarly, efficiency for galvanized zinc was measured 67.56, 48.6, 38.64, 58.5, 76.35, 62.87, 100.9 and 77.48% in 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 A, respectively. In carbon steel electrodes, the efficiency was 92.4, 83.13, 92.25, 90.35, 95.43, 102.67, 89.34 and 99.1% in 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 A, respectively. From figure 3, it was found that carbon steel electrode exhibited maximum efficiency of 102.67% in 0.8A of applied current. Figure 4 shows the comparison of the efficiency of the electrodes at $NaOH$ electrolyte, KOH electrolyte and baking soda electrolyte. It was found that carbon steel electrode showed the highest hydrogen production efficiency in KOH-based electrolyte. From the above analysis, it can be concluded that carbon steel electrode and KOH electrolyte are best combination in terms of the hydrogen production efficiency compared to other electrodes and electrolytes analyzed in this study.

The efficiency of water electrolysis process is largely dependent on the electrode materials. To reduce the electrolysis's operation and maintenance expenses, the electrode materials must be resilient in highly corrosive alkaline conditions. Carbon steel materials have higher corrosion resistance by alkalis and higher electrolytic activity than stainless steel and galvanized zinc [21]. For these reasons, carbon steel electrode showed the greater hydrogen production efficiency than stainless steel electrode and galvanized zinc electrode.

The electrolyte efficiency also depends on the electrolyte materials used in the cell. The highest hydrogen production efficiency in the KOH electrolyte may happen for the greater overpotential of property of KOH electrolyte. Sodium-based electrolytes exhibit lower overpotential compare to the potassium-based electrolytes [22]. For this reason, the hydrogen production efficiency of electrodes is higher in the KOH electrolyte compared to $NaOH$ electrolyte and $NaHCO_3$ electrolyte.

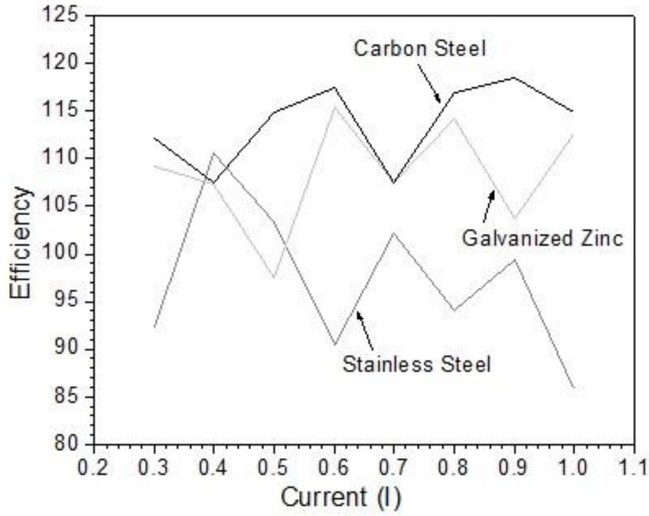

Figure 1: The hydrogen production efficiency of the electrodes is plotted against current in $NaOH$ electrolyte.

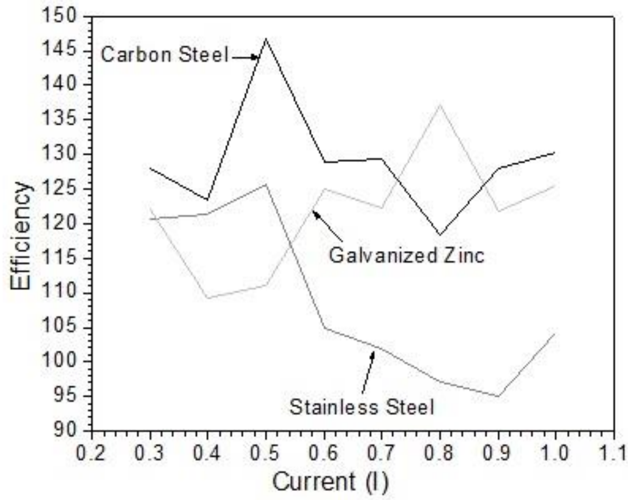

Figure 2: The hydrogen production efficiency of the electrodes is plotted against current in KOH electrolyte.

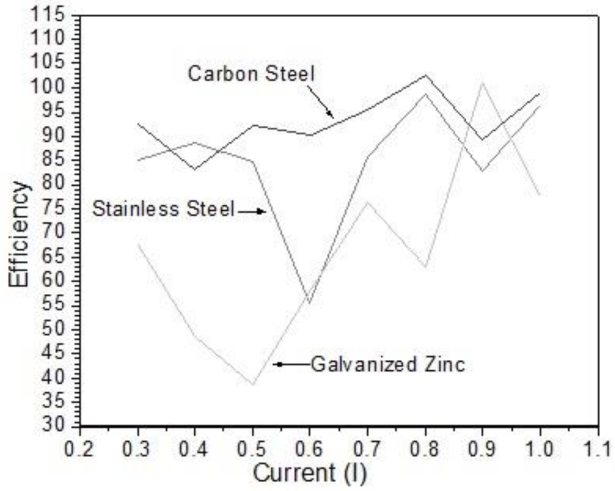

Figure 3: The hydrogen production efficiency of the electrodes is plotted against current in $NaHCO_3$ electrolyte.

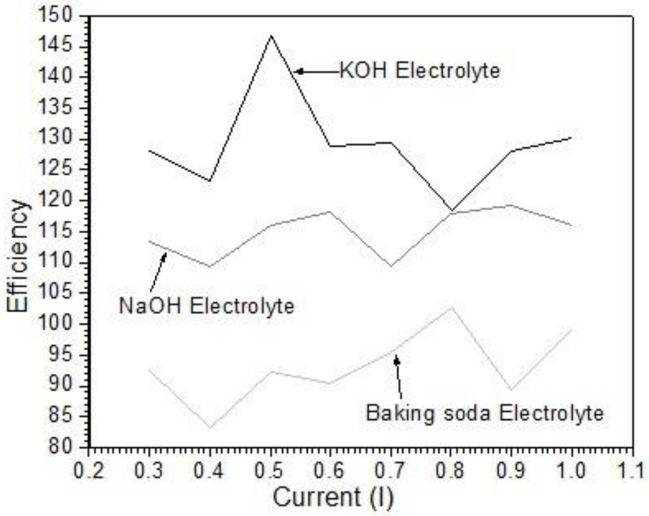

Figure 4: Comparison of the hydrogen production of efficiency of carbon steel electrode in different alkyl electrolyte.

4.0 CONCLUSION

This study have successfully examined three different electrode materials including stainless steel, galvanized zinc and carbon steel for alkaline water electrolysis under three different alkyne such as KOH, $NaOH$, $NAHCO_3$. In this experiment, every electrode was kept in the 0.25M KOH, $NaOH$ and $NAHCO_3$ electrolyte solution separately. Then, the best combination of an electrode and an electrolyte in a cell was identified from three electrodes and three electrolytes. An electrochemical cell consists of carbon steel electrode and KOH electrolyte performed the operation of splitting water into hydrogen and oxygen better than other electrodes and electrolytes used in this research. The hydrogen production efficiency in carbon steel/KOH cell was found maximum, and the value was 146%. The optimum condition generated gas can minimize energy consumption and combustion gas emissions (e.g. CO2, CO, SOx and NOx).

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