

Effects of Geometry of Electrodes and Pulsating DC Input on Water Splitting for Production of Hydrogen

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Abstract- Electrolytic production of hydrogen from water is gradually gaining its importance among the other conventional processes of hydrogen production in the context of renewable energy source utilization and environmentally clean technology. Worldwide research is being carried out to make the process cost effective. Apart from the different material of construction of electrodes, the geometry is also playing an important role in developing an energy efficient process for electrolytic production of hydrogen. However, no information is available in the literature on this aspect. The aim of this paper is to study the effect of geometry of electrodes on energy efficiency of water electrolysis and rate of hydrogen production. The experimental results using cylindrical electrodes showed the enhancement of the power efficiency of water electrolysis and the rate of production of hydrogen by 30% and 25%, respectively compared to the data obtained using plate type electrodes. Also, the power efficiency of the water electrolyzer was found to improve by 34% using pulsating DC instead of constant DC input.

Keywords- Hydrogen; power efficiency; electrode geometry; pulsating DC input.

1. Introduction

Hydrogen is recognized as the environmentally benign fuel for future which can be produced from renewable sources. It is easy to transport and store, having highest gravimetric energy density of all known fuels. In any electrolytic cell, electrodes are the main physical part of the system [1]. Out of two types of electrode, active electrodes get involved in the redox reaction by accumulating or consuming materials of electrodes. Electrode made of copper is commonly used as active electrode. Inert electrodes just use its surface for neutralization of ions to take place. Platinum, carbon and stainless steel are frequently used as inert electrodes [2].

Geometry of the electrodes is also an important parameter of electrolytic cell. However, no information is available in the literature on this aspect. Since it is always recommended to have internal resistance as low as possible in order to keep energy consumption sufficiently small, the common practice is to utilize the maximum available surface of the electrodes and the minimum pitch of the electrodes [3]. In an attempt to afford high surface area of electrodes, experiments were carried out by different researchers using

different flat surfaces of the plates with different widths or by using sheets or strips with larger areas. Large surface area can be achieved by use of sintered structures, finned bodies, screens, sand blistering, perforated plates or flat plates with electrochemically-roughened surfaces.

The surface of the electrode remains inert so long the gas bubbles remain attached with it. The electrical resistance of the electrolytic cell increases with increase in volume fraction of gas bubbles, resulting the decrease in efficiency of water electrolysis [4].

The projected area on the faces of electrodes can be changed by changing geometry of electrodes keeping surface area same. As the production of hydrogen depends on movement of ions in the electrolytic solution, the shape of electrodes may be a parameter to improve the efficiency of electrolysis. The current intensity can be increased by increasing the applied voltage as the current intensity is directly proportional to the applied voltage for constant resistance [5]. As lowering the applied voltage reduces the overpotential thus decreasing the power efficiency, it is necessary to maximize the current intensity at minimum overpotential. In view of the stated fact, the aim of this work is to study the effect of electrode geometry on power

efficiency defined as the product of current efficiency and voltage efficiency as well as on the production capacity of hydrogen.

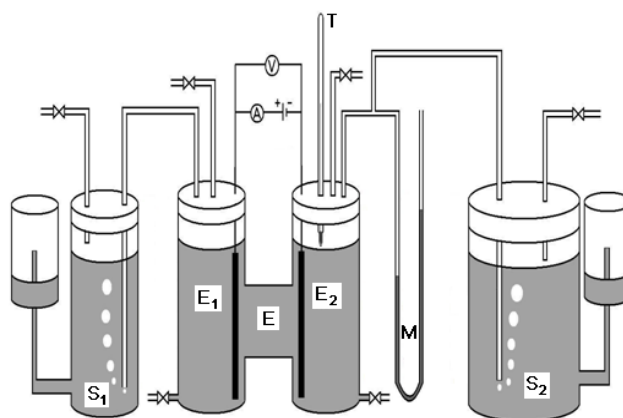
PWM, Pulse Width Modulation, is a new technique used to deliver an intermediate amount of power. In addition to its extensive use in telecommunication, it can be used for power delivery and voltage regulation. A PWM sends signal in pulses. The width of each pulse determines the amount of transmitted power, and this technology can be used in brown gas generators. By using PWM, it is possible to maintain a gas production plant with exceptional characteristics of high efficiency and a wide range of hydrogen production rate [6]. In the present investigation, manipulation of DC supply for the production of hydrogen using a PWM with variable frequency was also studied to find its effect on the power efficiency of the electrolyzer.

2. Experimental

2.1. Set-up

The experimentation was carried out in the set-up shown in Fig. 1. It consists of two compartments (ID and height of each compartment were 8 cm and 28 cm, respectively) in the electrolyzer of total capacity of 3 liter were connected by a narrow rectangular conduit of size (15 cm × 4.5 cm × 4 cm). The electrodes were made-up of carbon. Graphite was chosen as electrode material because of its relatively inert property in alkaline solution compared to metals and also for its porous structure [2]. Porous structure helps graphite to adsorb hydrogen [7]. Flat plate type (20.5 cm × 5 cm × 0.5 cm) or cylindrical rod type (diameter = 3.30 cm & length = 20.5 cm) electrodes having same length (20.5 cm) and surface area (230.5 cm²) were used. The distance between the two electrodes was kept constant at a value of 5.5 cm. AC power supply was connected to a bridge rectifier through a step down transformer (500 VA, Input: 0 - 220/ 230 V AC, Output: 0 - 24 V AC). The electrodes were connected with bridge rectifier (AC to DC converter). The range of DC output was varied from 0 to 24 V. A variac was used to vary the applied voltage. Ammeter (0 - 20 A DC) and voltmeter (0 - 50 V DC) were connected respectively in series and parallel to the electrolyzer to measure current and voltage applied to the system. The gases obtained from the anode and the cathode limbs were collected separately in gas storage tanks S1 and S2 respectively, by downward displacement of water. Oxygen evolved from anode limb was collected in storage tank S1, although hydrogen evolved from cathode limb was collected in storage tank S2. The volume of hydrogen produced was twice the amount of oxygen produced. So, to get same displacement in water level of both the tanks the cross sectional area of storage tank S2 is chosen nearly double of the cross sectional area of storage tank S1. The inner diameter of storage tank S1 and S2 are 16.5 cm and 22.5 cm, respectively. The left arm of U-tube manometer was connected to the top of the cathode limb to measure the gauge pressure of produced hydrogen gas. The right arm of the manometer was opened to atmosphere. Absolute pressure of produced hydrogen gas was calculated by adding atmospheric pressure to the gauge pressure.

A PWM (range of frequency: 0-100 kHz, operating voltage: 0-15 V DC and maximum current output: 5 A DC) was connected with a constant DC source of 12.65 V battery to supply a pulsating DC voltage to the electrolyzer. A multi-meter was used across the PWM to measure the frequency of the supply.



A: Ammeter, E: Electrolytic cell, E1: Anode, E2: Cathode, M: Manometer, S1: Oxygen storage tank, S2: Hydrogen storage tank, T: Thermometer, V: Voltmeter.

Fig. 1. Experimental set-up

2.2. Procedure

Electrolytic solutions were prepared at different concentration of KOH varying from 0.25 to 1.0% (w/v) of volume 2.5 liter. The electrolytic cell was then filled by electrolytic solution. To balance pressure of the system the storage tanks were filled with water up to the same level in both the tanks. Bubbles were removed from the electrolytic cell. Afterward all the openings were sealed and the experimentation was started. The supplied voltage was maintained at a fixed value for an experiment (5 V, 7.5 V, 10 V and 15 V). Levels of storage tanks, manometer and electrolytic cell, volume of water displaced from the storage tanks, temperature and current used were noted down up to 60 minutes with the time interval of 10 minutes [8]. The experimentation was carried out for the two types of electrodes.

Experiments were carried out with 0.14025% (w/v) aq. KOH to study the effect of PWM on rate of production of hydrogen and power efficiency of electrolysis. The power efficiency was calculated as

$$\text{Power efficiency} = \frac{\text{Theoretical power require}}{\text{Actual power used}}$$

$$= \text{Current efficiency} \times \text{Voltage efficiency} \quad (1)$$

$$\text{Current efficiency} = \frac{\text{Theoretical current require}}{\text{Actual current used}} \quad (2)$$

$$\text{Voltage efficiency} = \frac{\text{Theoretical voltage require}}{\text{Actual voltage used}} \quad (3)$$

3. Results and Discussion

The experiments were carried out covering the stated system variables. The data have been presented in Table 1 for the electrolysis of water using plate and cylindrical rod types of electrodes with aqueous solution of KOH [0.25% (w/v)] in order to compare the data of power efficiency vs. applied voltage for the electrodes. The experimental results using cylindrical electrodes showed the enhancement of the power efficiency of water electrolysis by about 30%. Similar observation with different magnitudes was found as shown in Fig. 2 while the experiments were carried out using three other concentrations of KOH. The Figure further shows that the power efficiency decreases with increase in applied voltage indicating the maximum efficiency at the lowest concentration of KOH, i.e. 0.25% within the limits of the present investigation. Figure 3 shows the comparison of rate of production of hydrogen with applied voltage for plate and cylindrical electrodes in 1.0% (w/v) aqueous KOH solution. It has been revealed from the Figure that the rate of production of hydrogen by 25% (approx.) can be achieved using cylindrical electrodes. The experimental data using other three concentrations of KOH shows the similar trend. Increased power efficiency and rate of production of hydrogen might be due to the fact that, for plate electrode fraction of ions collide and then bounce back to the opposite direction because of the shape of this electrode, but for cylindrical electrode ions move forward to the back side of the electrode rather bounced back to the opposite direction because of its geometrical shape [9]. Another plausible reason is the uniform charge density on the surface of cylindrical electrode improves the utilization of input power, in contrary the charge density is concentrated on the sharp edges of rectangular electrode and diluted on plate surface.

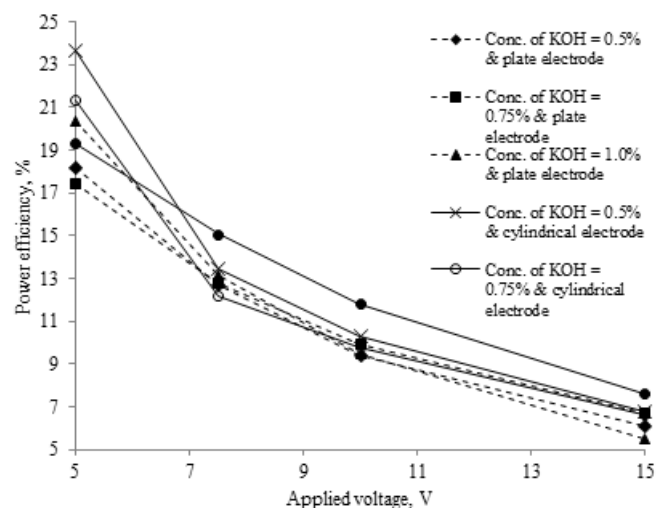


Fig. 2. Power efficiency vs. applied voltage for plate and cylindrical electrodes using three different concentrations of KOH

Table 1. Comparison on power efficiency for different types of electrodes using 0.25% aq. solution of KOH

Applied voltage (V)	Power efficiency, %	
	Plate type electrodes	Cylindrical rod type electrodes
5	22.01	23.65
7.5	12.67	13.47
10	9.09	11.25
15	5.97	7.19

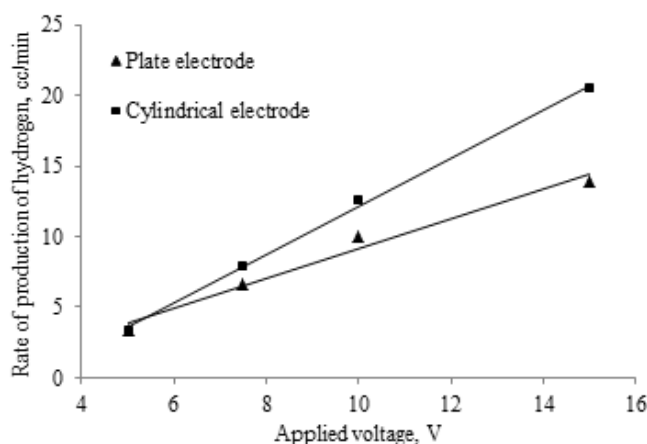


Fig. 3. Production rate of hydrogen vs. applied voltage for different types of electrodes using 1.0% aq. solution of KOH

Table 2. Effect of pulsating DC input to the electrolyzer with variable frequency

Input voltage (V)	Input current (A)	Frequency (kHz)	Production rate (cm ³ /min)	Surface area of cathode (cm ²)	Power efficiency (%)
12.65	2	No pulse, continuous DC	15.020	59.6	9.60
12.65	2	2.25	14.200	59.6	9.07
12.65	2	3.70	18.190	59.6	11.63
12.65	2	3.90	17.170	59.6	10.97
12.65	2	17.20	18.360	59.6	11.73
12.65	2	17.35	18.970	59.6	12.12
12.65	2	47.00	10.400	59.6	6.65
12.65	2	60.00	20.133	59.6	12.87
12.65	2	69.50	12.900	59.6	8.24
12.65	2	89.73	18.580	59.6	11.88

As the efficiency of water splitting depends on the breaking of H-O bond, the efforts to exceed or achieve bond energy might improve the water splitting efficiency [10]. In this context the attempt to manipulate input DC supply to the electrolyzer surprisingly shows considerable improvement by 34% (approx.) in hydrogen production as well as in power efficiency. Table 2 indicates that maximum production was achieved at a particular frequency of 60 kHz. These experimental results reveal an additional significant feature

of water splitting by electrolysis that the pulsating DC input destabilizes the H-O bond at a particular frequency and facilitated water splitting. This might be due to electrical polarization process. Placement of a pulse-voltage potential using a pulse width modulator inhibits or prevents electron flow from within the Voltage Intensifier Circuit causes the water molecule to separate into its component parts momentarily and pulling away orbital electrons from the water molecule.

4. Conclusion

Among all the approaches to increase the production rate of hydrogen by electrolysis of water, cylindrical geometry of electrodes and pulsating DC supply at a specific frequency i.e. 60 kHz appear promising. Apart from the selection of suitable electrode material to increase power efficiency, the geometry namely cylindrical electrode also improves power efficiency than rectangular electrode. Efforts to manipulate the continuous DC power input into pulsating DC supply to electrolyzer also increase production rate of hydrogen via water splitting. Further research is now necessary to develop this laboratory study into a practical reality.

Acknowledgements

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