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Improving the gas productivity of the alkaline electrolyzer through the circulation technique

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Abstract

This research aims to study and improve the efficiency of a KOH electrolyzer through the gas productivity of the electrolyzer with different the circulation technique. In this work, the conceptual design of an electrolyzer falls into 2 categories; without pumping and with pumping. Direct current electricity at 5 different levels of 10, 15, 20, 25 and 30 A are charged into the system and the gas flow rate generated from the electrolyzer is subsequently monitored. The results show that at 30 A the gas generated from the circulation with pumping and the circulation without pumping are 2.31 litre/min and 1.76 litre/min, respectively. It is also found that the energy consumed by both techniques is the same; however, the circulation with pumping design shows the better gas productivity than that of the circulation without pumping design.

Keywords : Alkaline water electrolysis, Electrolyzer, Energy consumption, Gas production rate

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1. Introduction

Nowadays, the energy used is very volatile and price sensitive in the marketplace [1, 2]. The reliance on fossil energy alone may result in instability of energy. Hydrogen as an alternative energy can offset fossil energy like solar, wind, hydraulic and wave [3, 4]. Hydrogen can be produced by various processes [1, 3]. The simplest process in the manufacture is theelectrolysis process which water splitting has gained importance lately because of its production with neither adverse environmental impact nor fossil fuel requirement. Electrolysis process is a separation of substances from solution by electricity. The electrochemical reactions for alkaline water electrolysis are shown in Eqs.R1 and R2 [1, 5].

At anode: $2OH^- \rightarrow 1/2O_2 + H_2O + 2e^-$ R1

At cathode: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ R2

Net: $H_2O \rightarrow H_2 + 1/2O_2$ R3

The direct current maintains the electron flow from the negative terminal of the direct current source to the positive terminal at which the electrons are consumed by water to form hydrogen gas and hydroxyl ions. The hydroxyl ions transfer through the electrolyte solution to the anode, at which the hydroxyl ions give away electrons and these electrons return to the positive terminal of the direct current source, producing oxygen gas. Therefore, hydrogen is produced at the cathode and oxygen is produced at the anode and the overall reaction of the alkaline water electrolysis is shown in Eq.R3. The electrolysis process is not widely renowned due to the high cost of energy consumption and efficiency of process [6]. Therefore, an alkaline water electrolyzer is developed in this work due to its low cost and uncomplicated technology. The alkaline water electrolyzer consists of electrodes (anode and cathode), an electrolyte solution, a power supply and a container [1, 7 and 8]. Ohmic resistance is a type of electrical resistance, which can cause a voltage loss according to Ohm's law. The electrolyzer resistance varies with wire and connector resistance, electrodes resistance (anode and cathode), bubble resistance (hydrogen and oxygen bubble) and electrolyte ions resistance. Hydrogen and oxygen gas bubble are formed on electrode surface. The gas bubble covering the electrode surface is assumed as an additional electrical resistance to the system. Therefore, the bubble phenomenon is relevant to parameters such as bubble rise, the space between electrodes and pressure [9-11]. Literature has been devoted to the development of correlation of gas bubble on the electrical resistance of the electrolyte in which Eq. 1 can be used to determine the bubble resistance [1, 12 and 13].

$$R_{bubble,j} = \frac{x_j}{A\rho_{B,j}} \qquad (1)$$

The resistance of ionic solution and bubbles can be modeled as a function of time, diameter of bubble, pressure and temperature. ρ_B from Eq. 1 can be related to the electrical conductivity of the electrolyte when bubbles are neglected. According to the Bruggeman equation, ρ_B can be expressed in Eq. 2.

$$\frac{\rho_B}{\rho_0} = (1-\alpha)^{\frac{3}{2}} \qquad (2)$$

where, $R_{bubble,j}$ is resistance of the electrolyte of species j, ρ_0 is electrical conductivity, ρ_B is mixture conductivity, x_j is distance between electrodes of species i, A is area and α is void fraction. The characteristic physical properties of electrical conductivities of pure, distilled, municipal, river and industrial water liquids. It was found that a change in physical properties of the solution would have an effect on the electrical conductivity [12]. The gas bubbles in the electrolyte solution, in the terminal electrodes and within the electrolyzer can cause the resistance of the electrolyte solution which can be changed during the time of gas production.

In order to improve the efficiency of the electrolysis process, factors affecting the process must be aware of. Factor affecting the efficiency of electrolysis is the resistance that occurs in electrolyte including the ionic and bubble resistance as aforementioned. The improvement or the change in physical properties of the solution would have an effect on the electrical conductivity. The objective of work is to improve the electrolyte conductivity by means of circulation by pumping the electrolyte solution and to study the amount of gas generated. The effect of circulation with pumping and circulation without pumping on the gas production will be investigated and the results will be subsequently discussed.

2. Experimental apparatus and method

The water electrolysis of KOH solution is conducted under atmospheric pressure using alloy steel as electrodes. Each side of electrode is 400 mm^2. The concentration of electrolyte is 10 %wt and 95% purity. Parameters varied are current, without pumping and with pumping as shown in Table 1. The diagram of the experimental apparatus is shown in Fig.1. The liquid container (250 mm long x 150 mm wide x 250 mm high) is made of polymethyl methacrylate, in which the electrodes are completely immersed with a certain space.

AC power supply is connected to a bridge rectifier through a step down transformer (5.3 KVA, input: 220/230 V AC). The electrodes are connected with AC to DC converter. Regulated DC power supply working in the range of 10-160 A is used and the current is adjusted in the range of 10-30 A. Voltmeter (V) and ammeter (A) are connected in parallel and series respectively to the electrolyzer to measure voltage and current applied to electrolytic process. The gases obtained from the cathode and the anode is collected separately in gas tube and the volume of gas produced is measured with GAS Mass Flow Meter and re-checked by water displacement. Temperature, voltage and current are recorded by the NI-USB6218 (DAQ).

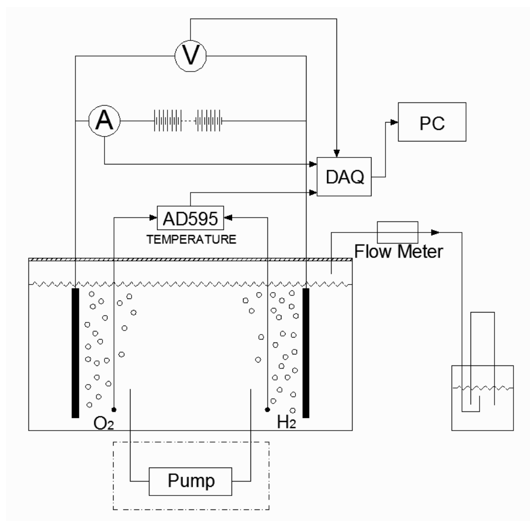

Figure 1 Diagram of experimental apparatus

In this study, current and electrolyzer are considered as input data and the gas production rate as an output (Y). The levels adopted for factors are summarized in Table 1. There is also a study the effect of electrolyte circulation by pumping. However, the study did not focus on the amount of oxygen existing in the electrolyte solution.

Table 1 Parameters of Experimental

Factor	Number of Level	Value of Level
current	5	10, 15, 20,25, 30 (A)
circulation technique	2	the circulation without pumping and the circulation with pumping
Pressure		Atmospheric
Electrodes	Material	alloy steel
Electrolyte	KOH	10% wt 95% purity

3. Results and discussion

In the tests, an electrolyzer cell was designed and tested at temperature between 40 °c and 70 °c and at atmospheric pressure. The experimental results of the factors affecting the gas production rate are shown in Figs. 2 and 3. The difference between the gas production rate of circulation without pumping and the gas production rate of circulation with pumping are shown in Fig.2. As can be seen, the gas production rates vary from 0.86 litre/min at 10 A to 1.76 litre/min at 30 A when the electrolyzer is used by circulation without pumping, while the gas production rates are much higher in case of circulation with pumping, varying from 0.92 litre/min at 10 A to 2.31 litre/min at 30 A. In fact, the difference of gas production rate is caused by the conductivity of electrolyte solution. In case of circulation without pumping, the conductivity was not consistent since the gas bubble occurs at the electrode surface. As a result, the electrical resistance of the electrolyte solution is higher and the conductivity of the electrolyte is decreased. In case of circulation with pumping, the bubble is dispersed throughout the electrolyte in which the bubbles layer thickness on the electrode surface is decreased, so the conductivity of the electrolyte is increased significantly especially at higher current.

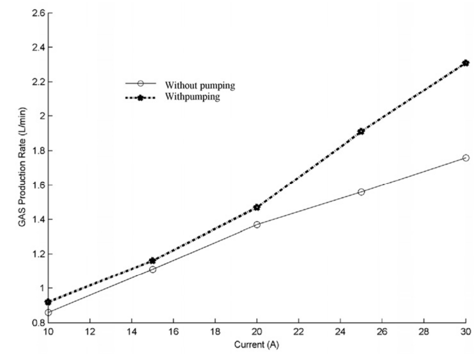

Figure 2 Current - gas production rate comparison of various circulation techniques

Fig. 3 also shows the gas production rate as different power consumption of the electrolyzer operating with the circulation without pumping and the circulation with pumping. It can be noted that the gas production rate range from 0.92 litre/min at 106 watt (10 A) to 2.32 litre/min at 520 watt (30 A) of circulation with pumping and, in case of circulation without pumping, the gas production rate ranges from 0.86 litre/min at 112 watt (10 A) to 1.76 litre/min at 408 watt (30 A). These results express that, at the same power, the circulation with pumping produces gas volume higher than that of the circulation without pumping.

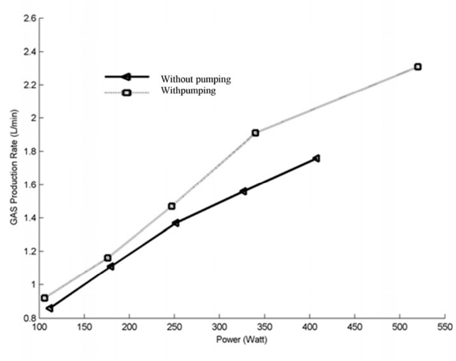

Figure 3 Power consumption - gas production rate comparison of various circulation techniques

From Figs.2 and 3, the gas production rate is proportion to the amount of the current (electrons) applied. In addition, when the current is increased, the gas production rate of circulation without pumping is lower than the gas production rate of circulation with pumping because the accumulation of gas bubble is occurred on the electrode surface and, therefore, blocks the flow of electrical current. Sarkar et al. [14] reported that gas produced at the electrode and dissolved directly into the liquid would diffuse in to the rising bubble. Therefore, the bubbles layer could cause a change in conductivity than those larger ones.

4. Conclusions

In this paper, the electrolyzer performance was tested using terminal current measurements involving current of up to 30 A, while different the circulation techniques are compared to improve the efficiency of the electrolysis process. Gas bubble is formed and covers the electrode surface which is assumed as an additional electrical resistance to the system, leading to the low efficiency of the electrolysis process. The physical properties of the electrolyte related conductivity such as bubble layer at electrodes surface can be reduced by improving mass transport which is consisted in the electrical conductivity of the electrolyte. The results show that at 30 A the gas generated from the circulation with pumping and the circulation without pumping are 2.31 litre/min and 1.76 litre/min, respectively. Therefore, in the development and improvement of electrolyzers, it is important to understand the behavior of these factors in order to minimize the bubble effect which holds a key to the electrolyzer efficiency improvement.

5. Acknowledgements

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