

Short communication

Feasibility study of a simple unitized regenerative fuel cell

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Abstract

Conventional fuel cells use hydrogen and oxygen as the fuel and oxidant, respectively. Hydrogen and oxygen can be produced through electrolysis of water in an electrochemical cell. A simple unitized regenerative fuel cell (URFC), by combining an electrolyzer and a fuel cell, is constructed to check the feasibility of such a device. In the first cycle, hydrogen and oxygen gases are generated from water containing NaHCO_3 when a given dc voltage is applied across Ni–Co/stainless steel electrodes. A solar photovoltaic cell is also used to provide the power. The generated gases are trapped between their respective electrodes and nylon mesh. In the second cycle, the hydrogen and oxygen gases are used in the same electrochemical cell (fuel cell) to produce electricity under a specific load. The current density and voltage are measured by varying different parameters, e.g., time of electrolysis, magnitude of voltage applied, and electrolyte concentration. An open-circuit voltage (OCV) of 1.3 V is obtained from two regenerative fuel cells in series with a total active electrode area of 300 cm^2 . A current density of about 0.5 mA cm^{-2} is generated using 0.5N NaHCO_3 when 4.5 V is applied for 25 min. A maximum power of 36.5 mW is obtained at 0.21 mA cm^{-2} .

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1. Introduction

Fuel cell technology is gaining popularity as an efficient and emission-free means to generate power. The principle of the fuel cell has been understood for almost 150 years [1–4]. The operation is similar to that of a battery except that one or both of the reactants are not permanently contained in the electrochemical cell but are fed from an external source when power is desired. The electrode materials of the fuel cells are inert and they are not consumed during the cell reaction but have catalytic properties, which enhances the electrooxidation and the electroreduction of the fuel and oxidant, respectively. One of the major factors that have influenced the development of fuel cells, in recent times, have been the increasing concern over the environmental consequences of burning fossil fuels in transportation applications. Although there has been considerable development of fuel cells for power generation, the single most important factor holding back their commercialization is cost.

An electrolyzer operates in a reverse manner to that of fuel cell, i.e., it utilizes water as the feed and electrical energy to produce hydrogen and oxygen [5]. In a regenerative fuel cell (RFC), hydrogen produced by the electrolyzer is stored and supplied to a fuel cell that in turn generates electricity [6,7]. An unitized regenerative fuel cell (URFC) works in the electrolyzer mode first and the hydrogen produced is stored and supplied to the same system when desired that then operates the fuel cell mode. Thus, a URFC is a simpler and more compact system than a RFC and it uses only one electrochemical cell [7]. Both RFCs and URFCs require greater energy input for a fixed output compared with advanced rechargeable batteries. Lehman et al. [8] studied the production of hydrogen by means of a photovoltaic source and then used the gas in a proton-exchange membrane fuel cell. The performance, safety, and maintenance issues of the regenerative system were reported. An electrolyzer efficiency of 76.7%, a photovoltaic efficiency of 8.1%, and a hydrogen production efficiency of 6.2% were obtained from testing the system for more than 3900 h. Baldwin et al. [9] also suggested the same concept of hydrogen generation from solar energy and its potential use in extraterrestrial applications. Since, the efficiency of solar cells is low and a large panel area is required for high power density employing a solar cell for the

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production of hydrogen and the subsequent use of this gas in a fuel cell can result in higher efficiency. Fuel cells are compact in nature and can produce high power density due to the high conversion of fuel and oxidant by oxidation and reduction reactions and the high surface area of the electrodes. Kirk et al. [10] employed a nickel–cobalt (Ni–Co) amorphous alloy as an electrocatalyst for alkaline water electrolysis and found that it is less active than the crystalline form for the hydrogen evolution reaction. In this study, a very simple URFC is designed, in which the evolved gases are trapped in the anode and cathode chambers. Thus, the need for a separate gas-storage chamber is avoided and the configuration of the URFC is different from that used by other investigators [6,7]. A Ni–Co/stainless steel (SS) electro-catalyst is used for both the anode and the cathode of the fuel cell in an alkaline electrolyte medium whereas, electrodes reverse their role for hydrogen generation in electrolyzer mode. The effect of different parameters (e.g., time of electrolysis, applied voltage, and electrolyte concentration) on the current and the voltage generated in the fuel cell is studied in detail.

2. Experimental

2.1. Materials

A SS/Ni–Co plate of size 15 cm × 10 cm served as the electrode, and NaHCO₃ as the electrolyte. Distilled water was used in all the experiment.

2.2. Set-up

A schematic diagram of the experimental set-up is shown in Fig. 1. It consists of two cells (glass troughs) that each contain NaHCO₃ solution as an electrolyte. A pair of Ni–Co/SS electrodes act as the cathode and the anode. A transformer was connected to the electrode terminals to provide an external source of dc power for the electrolysis of water. Nylon

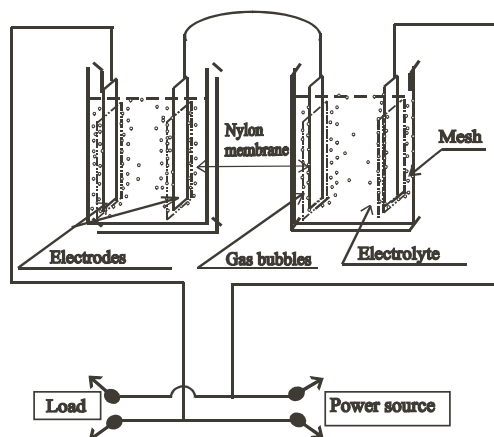
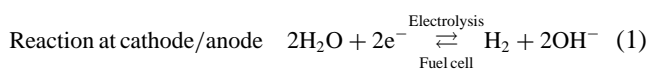


Fig. 1. Schematic diagram of unitized regenerative fuel cell.

mesh was used to trap hydrogen and oxygen gas bubbles around the respective electrodes.

2.3. Method

A solar photovoltaic cell was also used to supply power for water electrolysis. The current and voltage generated by the reverse chemical reactions at the electrodes in the presence of an electrode-catalyst were measured using a multi-meter (Sanwa, PC5000). The hydrogen and oxygen gas generated as a result of electrolysis work as the reactants (fuel) for the fuel cell in the same system when the power supply is disconnected. In the presence of electrode-catalysts and an alkaline medium, the following chemical reactions take place [2,5]:



3. Results and discussion

3.1. Effect of electrolyte concentration

The current density increases with increase in NaHCO₃ concentration and time of electrolysis as shown in Fig. 2. On the other hand, the open-circuit voltage (OCV) remains approximately constant (1.3 V) for different NaHCO₃ concentrations, see Fig. 3. With increase in NaHCO₃ concentration, the ionic conductivity of the medium increases, which results in a higher production of hydrogen and hydroxyl ions. Thus, large number of electrons are generated from the anode, as shown by the reactions given by Eqs. (1) and (2). This, in turn, results in an increase in current density.

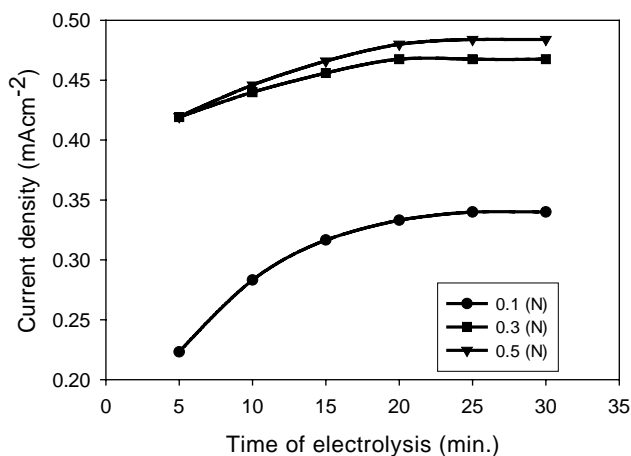


Fig. 2. Current density vs. electrolysis time (3 V dc) at different NaHCO₃ concentrations.

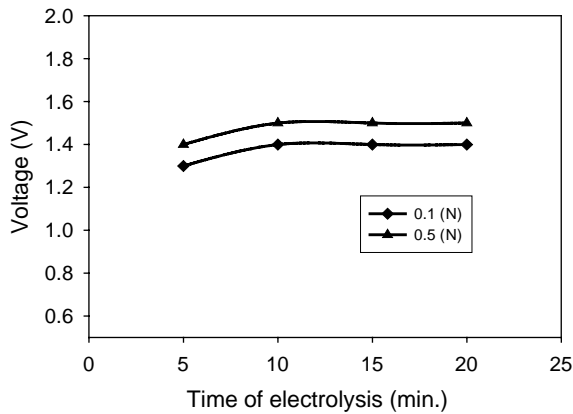


Fig. 3. Open-circuit cell voltage vs. electrolysis time (4.5 V dc) at different NaHCO_3 concentration.

Nevertheless, a steady value of 0.48 mA cm^{-2} is reached at 0.5N NaHCO_3 when electrolysis is conducted with a 3 V dc supply for 25 min. This may be due to saturation of the electrodes with hydrogen and oxygen gases.

3.2. Effect of applied voltage

The current density increases with increase in applied voltage for a given time of electrolysis, see Fig. 4. The amounts of hydrogen and oxygen produced are also increased, which leads to an increase in fuel concentration. Consequently, current density increases with increase in fuel and oxidant concentrations. When the electrodes become saturated with hydrogen and oxygen gases, a steady-state value of the current density is obtained.

3.3. Decay of voltage and current

The decrease in current density and open-circuit voltage with time after 25 min of electrolysis at 4.5 V are shown in Fig. 5(a) and (b), respectively. Note that after disconnecting the dc power supply, the electrolysis is stopped and the cell

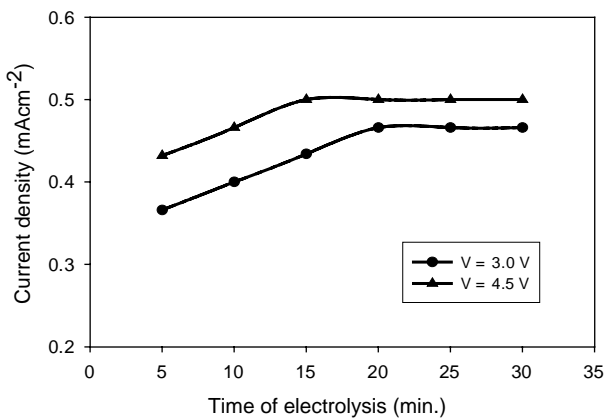
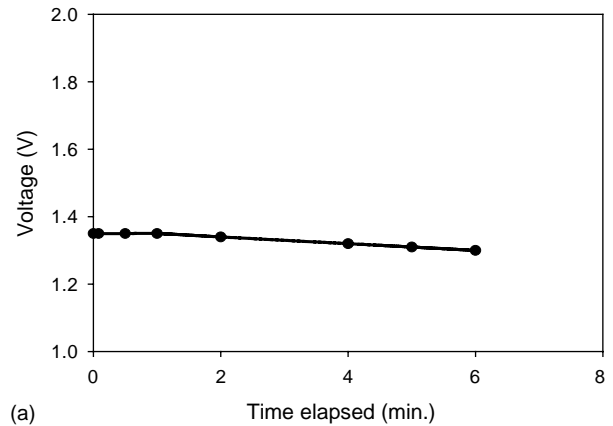
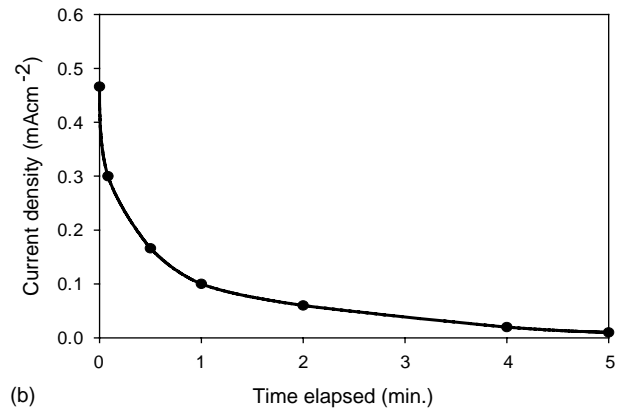


Fig. 4. Current density vs. electrolysis time at different voltages and 0.5N NaHCO_3 .



(a) Voltage vs. time elapsed for 0.5 N NaHCO_3 and after 25 min of electrolysis with a 4.5 V power supply.



(b) Current density vs. time elapsed for 0.5 N NaHCO_3 and after 25 min of electrolysis at 4.5 V power supply.

starts working as fuel cell with a limited supply of hydrogen and oxygen at the respective electrodes. Thus, the current density and the open-circuit voltage decrease with depletion of hydrogen and oxygen gases. It should be noted that the initial current is very high and that it attains a steady value instantly. This is perhaps because the electrode–electrolyte interface act as capacitor initially when the electrochemical cell changes from the electrolyzer to the fuel cell mode [11]. The current and corresponding voltage due to capacitor action is not included in the data presented here.

The current–voltage curve for the fuel cell at two different electrolyte concentrations, 0.1 and 0.3N NaHCO_3 , is shown in Fig. 6. The maximum power of 36.5 mW is obtained at 0.21 mA cm^{-2} . Similar results were obtained when a solar photovoltaic cell was used for the power supply during water electrolysis. Although the current–voltage curve for electrolysis (in electrolyzer mode) is not presented, 0.7 mA cm^{-2} is typically measured at 3 V.

The simple unitized regenerative fuel cell devised in the present study shows promise as a low-wattage, back-up, power supply. A solar photovoltaic cell can be used for electrolysis in tandem with the unitized regenerative fuel cell. A battery of unitized regenerative fuel cells can be used in cyclic fashion, where a number of cells would be in elec-

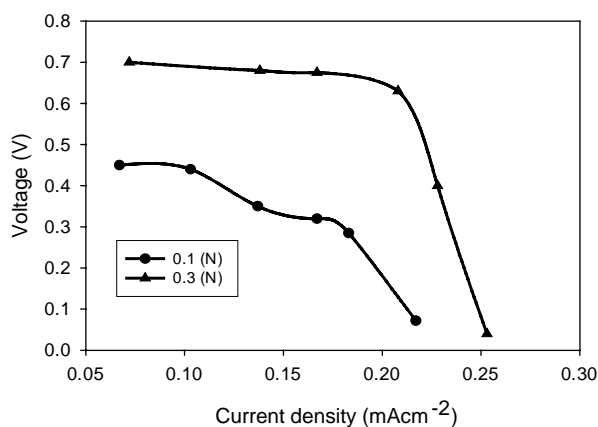


Fig. 6. Polarization curve of fuel cell after 15 min of electrolysis.

trolizer mode for gas generation and another set would work as fuel cells for electricity generation.

4. Conclusion

A simple unitized regenerative fuel cell has been demonstrated. It has a maximum open-circuit voltage of 1.3 V and a current density of 0.5 mA cm^{-2} . The current density and cell voltage increase with increase in electrolyte (NaHCO_3) concentration, time of electrolysis, and magnitude of the voltage applied. A constant current density of 0.5 mA cm^{-2} is reached after 25 min of electrolysis at 4.5 V and at NaHCO_3 concentration of 0.5 N. A steady value of 1.3 V is generated within the range of NaHCO_3 concentration used and the dc

voltage applied. The maximum power obtained is 36.5 mW at current density of 0.21 mA cm^{-2} .

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