

Proposal of original hydrogen carrier system using $\text{NO}_x\text{-HNO}_3\text{-NH}_3$ conversion

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Abstract

Hydrogen carrier system is desired for use of the excess power of renewable energy such as solar power. A typical hydrogen carrier system has been proposed, which is consist of the hydrogen production by electrolysis of water using excess solar power, the ammonia generation using hydrogen and nitrogen, and the hydrogen generation from ammonia using catalysis decomposition. However, the comprehensive energy efficiency of the hydrogen carrier system is not clear^{1,2}. In this paper, simple hydrogen carrier system that is consisting the solar power panels, an electrolysis of water, the hydrogen storage metal alloy, and the proton exchange membrane fuel cell was examined to investigate the comprehensive energy efficiency. The performance of the system was 11.8 % efficiency. To improve the energy efficiency, an innovative hydrogen storage, carrier, and utilization system was proposed.

1. Introduction

Hydrogen is a clean energy because its use does not produce any toxic gases that cause environmental problems. However, the use of hydrogen has a large energy loss due to transportation and physical storage. Ammonia is a hydrogen storage material that may solve several problems related to hydrogen transportation and storage. Therefore, a hydrogen energy carrier and storage system using ammonia has been proposed. For example, a system consisting of the hydrogen production by electrolysis of water using excess solar power, the ammonia generation using hydrogen and nitrogen, and the hydrogen generation from ammonia using catalysis decomposition, is recognized as a hydrogen storage, carrier, and utilization system. In the solar power generation site, the efficient ammonia synthesis at a low temperature and an atmospheric pressure are desired to storage hydrogen generated by excess solar power.

Many extensive researches have reported on each system such as energy efficiency of solar panel, hydrogen production, and fuel cells, however, they are scarce information about energy efficiency of the hydrogen energy carrier system. Therefore, the experimental apparatus consist of solar panel, the PEM electrolyzer, and the PEM fuel cell was built. The energy efficiency of each conversion step and system overall were examined.

2. Experimental

A schematic diagram of power generation using PEMFC with solar power system is shown in Fig. 1. A solar panel, which area size was 8.96 m^2 , was installed facing north direction and tilted vertically at 20° . Its maximum power generation was 1500 W. The Proton Exchange Membrane (PEM) electrolyzer (FC-R&D Co., Ltd.) has four cells with maximum hydrogen generation of 60 L/h. The type of the fuel cell was PEMFC with 48 cells and maximum power generation of 1000 W. The generation by solar panel, the

power consumption by PEM electrolyzer, the hydrogen generation by PEM electrolyzer, the hydrogen consumption by PEMFC and the power generation by PEMFC were measured.

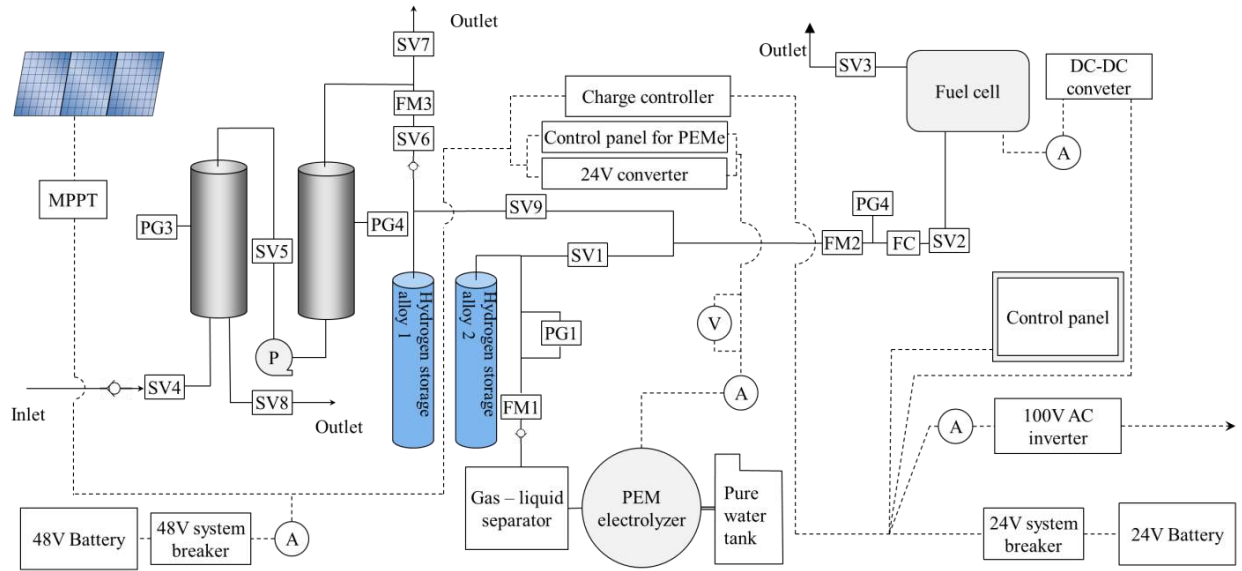


Fig. 1 Experimental setup of power generation using PEMFC with solar power system

SV: solenoid valve PG: pressure gauge FM: flow meter FC: flow controller

3. Result & Discussion

3.1 Solar panel

In the studied system, the energy was harvested from solar radiation, and the power generated by the solar panel was stored in a battery. The amount of power generated in this step was expressed by measuring the energy stored in the battery.

The measurement of power generation by photovoltaic was conducted for one month in July 2016 and the averaged result is shown in Fig. 2. The power generated by the solar panel was stored in a battery. The measurement of power generation was done by measuring the energy stored in the battery.

The daily average is found to be 1408 Wh. The information on the amount of energy transferred by solar radiation was obtained from Japan Meteorological Agency Website³. The energy efficiency of photovoltaic (η_{photo}) is defined as

$$\eta_p = \frac{E_{photo}}{E_{solar}} \times 100 \% \quad (1)$$

where E_p is power generation by solar panel, E_{solar} is the energy carried by solar radiation. The calculation result of η_{photo} was found to be 13.9 %.

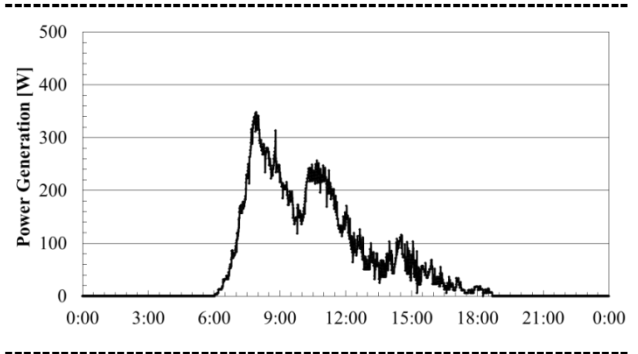


Fig. 2 Experimental result of photovoltaic.

3.2 PEM electrolyzer

PEM electrolyzer was used to produce hydrogen as the energy carrier by splitting water using the energy generated from solar panel. Fig. 3 shows the hydrogen generation and power consumption by PEM electrolyzer. The energy efficiency of PEM electrolyzer (η_{PEM}) is defined as

$$\eta_{PEM} = \frac{\Delta_c H_{H_2}^\circ \times V_{PEM}}{E_{PEM}} \times 100 \% \quad (2)^4$$

where $\Delta_c H_{H_2}^\circ$ is the standard enthalpy change of combustion of hydrogen of H_2^5 , V_{PEM} is the volume of hydrogen produced, E_{PEM} is the energy consumption of PEM electrolyzer. The calculation result of η_{PEM} was found to be 58.2 %.

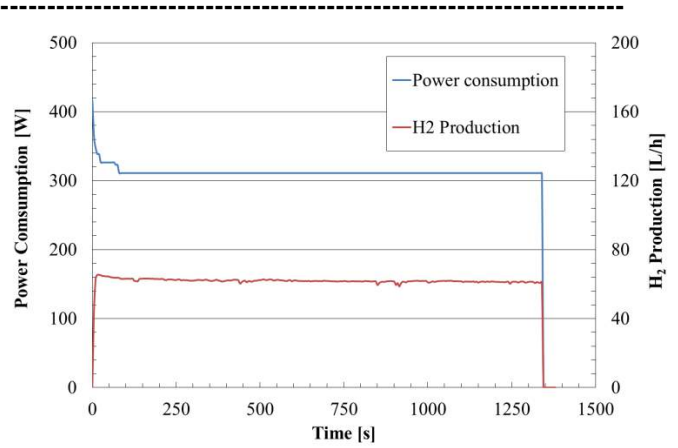


Fig. 3 Experimental result of PEM electrolyzer.

3.3 PEM fuel cell

The PEM fuel cell is used to generate energy for consumption by oxidizing hydrogen gas. Fig. 4 shows the power generation and hydrogen consumption by PEM fuel cell. The energy efficiency of PEM fuel cell (η_{PEMFC}) is defined as

$$\eta_{PEMFC} = \frac{E_{PEMFC}}{\Delta_c H_{H_2}^\circ \times V_{PEMFC}} \times 100 \% \quad (3)^6$$

where E_{PEMFC} is power consumption by PEM fuel cell, V_{PEMFC} is the volume of hydrogen consumed by the PEMFC. The calculation result of η_{PEMFC} was found to be 70.1 %.

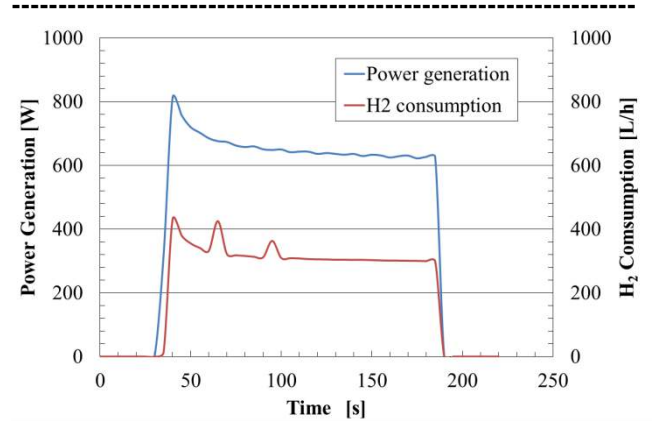


Fig. 4 Experimental result of PEM fuel cell.

3.4 System performance

The overall energy flow through the system is summarized in Table 1.

The solar panel was exposed to solar radiations which carried energy of 235 MJ and generated 18.94 MJ. PEM electrolyzer consumed 9.72 MJ and produced 566 L hydrogen. PEMFC consumed 546 L hydrogen and generated 846 Wh electricity. The external power supply output was only 320 Wh because part of the electric power generated by PEMFC was consumed for controlling the system. 320 Wh is 6.1 % of the energy generated by solar panel. However, if PEM electrolyzer consumed all electricity generated by solar panel and PEMFC consumed all hydrogen produced by PEM electrolyzer, the external power supply output was 622Wh. 622 Wh is 11.8 % of the energy generated by solar panel.

Table 1 Energy flow through the system

	Energy flow	Energy flow in MJ *	Efficiency per step	Overall efficiency
Solar radiation to solar panel	235MJ solar radiation	-	-	-
Photovoltaic	5260 Wh generated (2702 Wh would be used)**	18.94	13.9%	100%
PEM electrolyzer	566 L hydrogen produced (546 L would be used)***	7.22	58.2%	86.6%
PEM Fuel cell	846 Wh generated	3.05	70.1%	66.0%
External power supply	320 Wh	1.15	-	56.0%

* the amount of energy flow expressed in MJ for convenience.

** only 2702 Wh was used to produced H₂ by PEM electrolyzer and the rest was stored in the battery.

*** only 546 L was used to generate electricity by PEMFC and the rest was stored in the H₂ storage alloy

4. Conclusion

A comprehensive power generation system using hydrogen as an energy carrier was assembled and its performance was studied. The solar panel generates electricity with energy efficiency of 13.9 %. The daily average of power generation is 1408 Wh in July. PEM electrolyzer produces hydrogen with energy efficiency of 58.2 %. PEM fuel cell generates electricity with energy efficiency of 70.1 %. Overall, the system can supply energy from solar panel using hydrogen as energy carrier with 6.1 % efficiency. However, the maximum potential of the system is 11.8 % efficiency.

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