



13th IEA Heat Pump Conference
April 26-29, 2021 Jeju, Korea

Analysis of the operating characteristics of electrochemical hydrogen compressors through parametric study

Min soo Kim^a, Min sung Kim^a, Min kyu Jung^a, Jung chul Kim^b, Dong kyu Kim^{a,*}

^aChung-Ang University, 84 Heukseok-ro, Seoul, 06974, Korea

^bKorea Institute of Machinery&Materials, 156 Gajeongbuk-ro, Daejeon, 34103, Korea

Abstract

As the supply of hydrogen energy increases, the need for development of hydrogen storage technology is emerging. In the case of the existing mechanical hydrogen compressor, there are many problems such as low compression efficiency and high power consumption, huge volume and noise due to parts of the driving part, and high maintenance cost due to corrosion. As an alternative to this, an electrochemical hydrogen compressor that compresses hydrogen using an electrochemical reaction has been proposed. In this study, an analysis of the operating characteristics of an electrochemical hydrogen compressor was performed through a parametric study in consideration of the factors affecting the compression of the electrochemical hydrogen compressor. First, the performance change of the compressor due to the change of activation loss and resistance loss according to the change of current density was measured. Second, the performance change of the compressor due to the difference in potential energy according to the temperature change was measured. Finally, the performance change of the compressor due to the difference of inlet pressure was measured. Through this study, it is possible to understand the optimum driving conditions and efficiency of the electrochemical compressor. This study will serve as a guideline for introducing electrochemical compressors into the industry.

Keywords: Electrochemical compressor; Hydrogen; Polymer electrolyte membrane; Parametric study.

1. Introduction

Currently, the world is striving to realize an eco-friendly future globally [1]. They are striving to change the existing fossil fuel society to a hydrogen society and to use hydrogen as an energy source. In order to realize such a hydrogen society, a hydrogen compressor technology that compresses produced hydrogen and compresses transported hydrogen, stores it in a charging station is very important.

Existing hydrogen compressors are mostly mechanical, such as reciprocating piston and diaphragm. For example, the hydrogen compressor currently used in the Korean hydrogen charging station uses a diaphragm type compressor. In the case of a mechanical compressor, a large number of drives (cylinders) are required, and for this reason, the need for maintenance is large and noise and vibration are severe, so the life of the entire system is low. In addition, there is a risk of hydrogen contamination in the case of compressors using lubricating oil. An electrochemical compressor can be proposed as a way to overcome this [2].

In the case of an electrochemical compressor, the hydrogen purification and compression mechanism are unified, so the loss is small [3]. In addition, since there are no continuously moving parts such as pistons, energy consumption and maintenance costs are low, and there is no noise [4]. The study of the principle of electrochemical compressors was experimentally studied by S.A Grigoriev [5]. It is shown that a cell voltage of only 350 mV is required to obtain a current density of 1 A/cm². The polarization curve through modeling of the electrochemical compressor is shown in N.V Dale [6]. To account for real time losses the efficiency of electrochemical compressor is assumed to be 70% for current density of 0.7 A/cm². Studies on the performance of electrochemical compressors have been carried out, but mechanism analysis for the influencing factors has not been performed. It is necessary to grasp the mechanism of electrochemical compressors through parametric

* Corresponding author. Tel.: +82-02-820-5192.

E-mail address: dkyukim@cau.ac.kr.

studies of electrochemical compressors. In this research, a parameter study on an electrochemical compressor was carried out. An analysis of the performance of an electrochemical compressor according to current density, temperature and inlet pressure was performed.

2. Methodology

2.1. Principle of electrochemical compressor

Figure 1 shows the principle of electrochemical compressor. Hydrogen is oxidized to H^+ ions at the anode due to the potential difference. And it is reduced to hydrogen at the cathode after passing through the polymer electrolyte membrane. Hydrogen produced by proton reduction in an enclosed cathode space is compressed and discharged at high pressure. Table 1 describes the reactions that take place inside the electrochemical compressor.

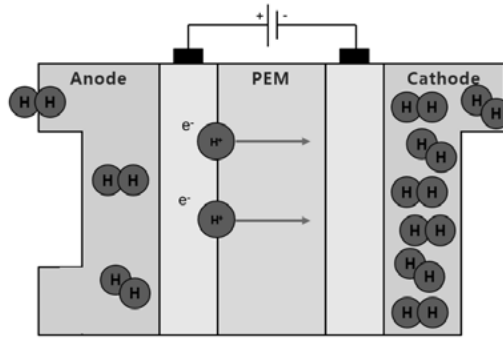


Fig. 1. Principle of electrochemical compressor

Table 1. Reactions in electrochemical compressor

Location	Expression
Anode	$H_2 \rightarrow 2H^+ + 2e^-$
Cathode	$2H^+ + 2e^- \rightarrow H_2$

The theoretical cell voltage of an electrochemical compressor is determined by the Nernst equation (1) [7].

$$E = \frac{RT}{2F} \ln\left(\frac{P_c}{P_a}\right) \quad (1)$$

Here, R is the gas constant, T is the temperature of the cell, F is the Faraday constant, and P_a and P_c are the hydrogen partial pressures at the anode and cathode, respectively. For the total cell voltage, the resistance loss η_{ohm} and the activation loss η_{act} are included and are described as follows (2) [7].

$$V_{cell} = E + \eta_{ohm} + \eta_{act} \quad (2)$$

2.2. Experimental setup

The experiment was conducted with a single cell, and it was evaluated by mounting it on a test station. Hydrogen was controlled at a constant flow rate through mass flow controller (MFC, Bronkhorst), humidified through bubbler (CNL), and supplied to the electrochemical compressor. The gas temperature was controlled using a line heater and a temperature controller (HX9, Hanyoungnux), and the gas temperature and pressure of the electrochemical compressor inlet and outlet were measured. The performance of the fuel cell was measured through power supply (EX20-240, ODA). The schematic of the electrochemical compressor experiment was shown in Figure 2.

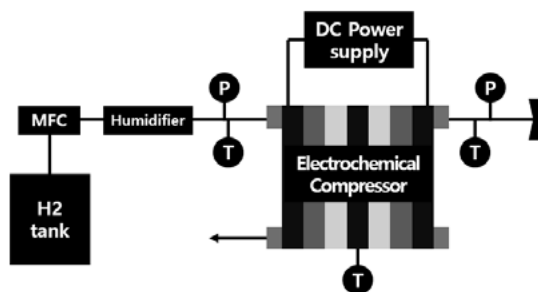


Fig. 2. Schematic of electrochemical compressor system

3. Result

3.1. Effect on current density on electrochemical compressor

Figure 3 shows the voltage change according to the pressure ratio on different current density. In order to reach the target pressure within a short time, it must be driven with a high current density. However, the voltage is lower at the same pressure when driven at a low current density. This means that the Nernst efficiency is high when driving with a low current density. This is because the ohmic loss and activation loss increase in proportion to the current. The total power consumption from 1 bar to 5.4 bar is 0.00632 Wh on 1 A/cm², 0.005 Wh on 0.7 A/cm², and 0.00359 Wh on 0.3 A/cm². When driving with a low current density, the total power consumption up to the target pressure can be reduced.

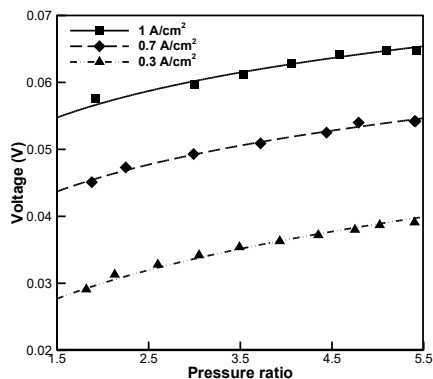


Fig. 3. Voltage change according to the pressure ratio on different current density

3.2. Performance analysis according to operating temperature

Figure 4 shows the voltage change according to the pressure ratio at different operating temperature. There is little difference in compression depending on temperature. However, when driven at a low temperature, the electrode potential of the battery is low, so the Nernst efficiency is high. The total power consumption from compression ratio 1.5 to compression ratio 5 is 0.00339 Wh at 70 °C, 0.00330 Wh at 60 °C, and 0.00318 Wh at 50 °C. When operating at low temperatures, the total power consumption up to the target pressure can be reduced.

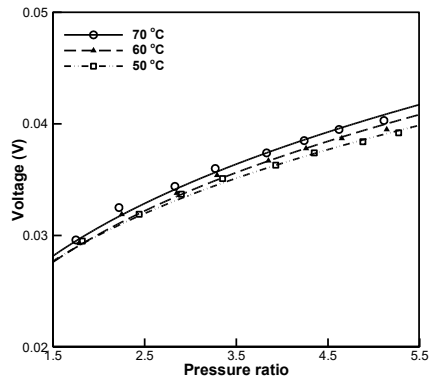


Fig. 4. Voltage change according to the pressure ratio at different operating temperature

3.3. Effect of inlet pressure on electrochemical compressor

Figure 5 shows the voltage change according to the pressure ratio on different inlet pressure. The higher the inlet pressure of the electrochemical compressor, the lower the compression ratio increase rate. This is because the number of H_2 passing from the anode to the cathode is determined according to the current density. Since the same amount of H_2 goes over, the lower the inlet pressure, the higher the increase rate of the compression ratio. The lower the inlet pressure, the lower the voltage at the same pressure ratio, so the Nernst efficiency is better.

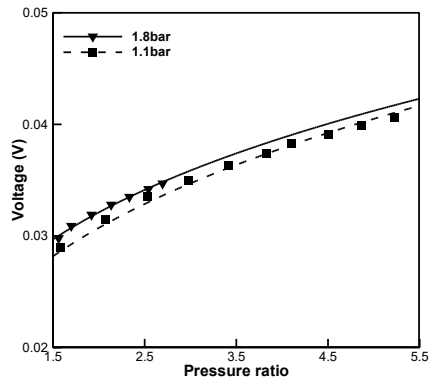


Fig. 5. Voltage change according to the pressure ratio on different inlet pressure

4. Conclusion

In this study, the performance of the electrochemical hydrogen compressor was analyzed through parametric studies that affect the compression of the electrochemical hydrogen compressor. For electrochemical compressors, the Nernst efficiency is good when operating at low current density, low temperature and low inlet pressure. This study will serve as a guideline for applying to industry by replacing the existing mechanical compressor with an electrochemical compressor.

Acknowledgements

This work was supported by Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government (MOTIE) (NO. 20192050100060, Chemisorption heat pump system using electrochemical compressor); this work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea (No. 20206810100030); and this work was supported by the National Fire Agency and the Korea Institute of Energy Technology Evaluation and Planning (KETEP) (No. 20008021).

References

- [1] Kim MS, Song JH, Kim DK. Development of optimal conditioning method to improve economic efficiency of polymer electrolyte membrane (PEM) fuel cells. *Energies* 2020;13. <https://doi.org/10.3390/en13112831>.
- [2] Sdanghi G, Dillet J, Didierjean S, Fierro V, Sdanghi G, Dillet J, et al. Operating heterogeneities in a PEM Electrochemical Hydrogen Compressor To cite this version : HAL Id : hal-02186747 2019.
- [3] Rhandi M, Trégaro M, Druart F, Deseure J, Chatenet M. Electrochemical hydrogen compression and purification versus competing technologies: Part I. Pros and cons. *Chinese J Catal* 2020;41:756–69. [https://doi.org/10.1016/S1872-2067\(19\)63404-2](https://doi.org/10.1016/S1872-2067(19)63404-2).
- [4] Mackenzie BS, Bloomfield DP. Electrochemical hydrogen compressor. DOE Grant DE-FG02-05ER84220 to Analytic Power Corp. Final Report. 2006.
- [5] Grigoriev SA, Shtatniy IG, Millet P, Porembsky VI, Fateev VN. Description and characterization of an electrochemical hydrogen compressor/concentrator based on solid polymer electrolyte technology. *Int J Hydrogen Energy* 2011;36:4148–55. <https://doi.org/10.1016/j.ijhydene.2010.07.012>.
- [6] Dale N V, Mann MD, Salehfar H, Dhirde AM, Han T. Modeling and analysis of electrochemical hydrogen compression 2008.
- [7] Bampaou M, Panopoulos KD, Papadopoulos AI, Seferlis P, Voutetakis S. An electrochemical hydrogen compression model. *Chem Eng Trans* 2018;70:1213–8. <https://doi.org/10.3303/CET1870203>.