A Proof-of-Concept Demonstration of the Integrated Methanol Reforming – Desalination Fuel Cell System: The Effect of CO_2 and CO on the Cell Performance

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1. Introduction

The desalination fuel cell (DFC) is an nascent technology that simultaneously generates electricity and desalted water through hydrogen-oxygen redox reactions. Methanol reforming (MR) is a well-established method for H_2 generation; but also produces CO_2 and CO as byproducts. Although the adverse effects of CO on proton exchange membrane fuel cells (PEMFCs) are well-known, the impact of CO presence in DFC is unclear. Our research introduces an untested integrated MR-DFC system, aiming to explore its performance limitations, specifically focusing on CO and CO2 effects from the MR effluent directly supplied to the DFC's inlet

2. Methods

The DFC is identical to the cell used by salman et al. [1], operated in pH mode; the anolyte was 0.5 M NaOH and the catholyte was 0.5 M $HClO_4$. For MR the feed volumetric water-to-methanol ratio was 2:1 fed at 0.1 ml/min to the evaporator and Ar feed flow rate was 6.8 ml/min as a carrier gas to the tube furnace. The detailed integrated DFC-MR system is presented in Fig. 1. Various tests were conducted to assess the MR-DFC system's performance. We measured the open circuit voltage (OCV) and limiting current using the MR outlet as feed. Additionally, we evaluated the ohmic region and observed the performance dependency on extracted current. Finally, a stability test compared anode Pt catalyst poisoning when using pure H2 inlet.

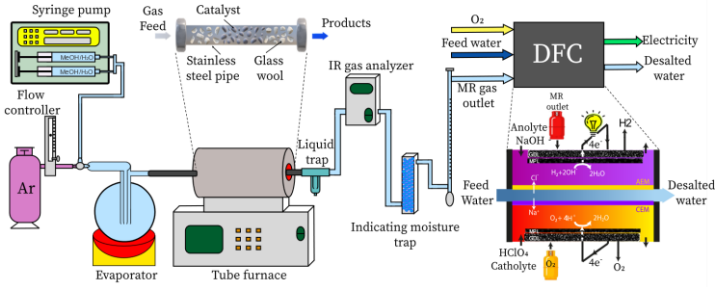

Figure 1. Schematic illustration of the MR-DFC system.

3. Results and discussion

Fig. 2 shows H_2 flow rate, selectivity, and conversion of the MR system. The experiment shown in Fig. 2a was initiated at 400 °C with decreasing temperature in steps of 25 °C, with step duration of 1 h to reach the steady state. The H_2 flow rate was on average 60 sccm above 325 °C and dropped gradually as the operating temperature was decreased. This behavior is expected as methanol reforming is endothermic reaction. The obtained H_2 flow rates correspond to the conversion range of 27-100%, with the methanol conversion. Selectivity to CO_2 generation, was on average 97±0.05% in the entire temperature range. Methanol reformer performance was then investigated in steady-state operation for over 5 h at 400 °C. Fig. 2a presents the H_2 flow rate, selectivity, and conversion in steps of 30 minutes, at each step three measurements were taken to account for flow deviations. In this experiment, the selectivity was 95% for all measurements, while conversion and H_2 flow rates recorded on average at 75% and 45 sccm, respectively. The MR product stream contained 14.3% CO2 and 13100 ppm of CO, as measured by the IR analyzer. The MR working temperature of 400 °C was selected for further experiments, due to stability and sufficient H_2 supply for DFC operation.

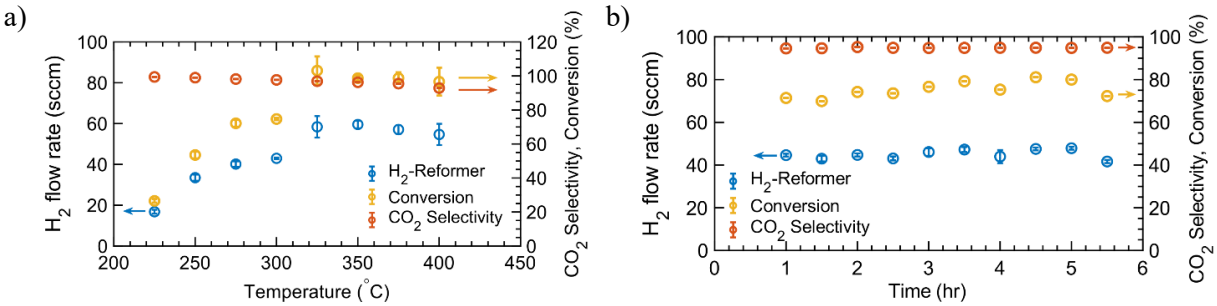

Figure 2. a) H_2 flow rate, selectivity, and conversion rate comparison of methanol reformer operated at various temperatures. Error bars represent standard deviation between 3 measurements. b) Reformer performance for 5 h test duration at 400 °C.

The experiment in Figure 3, the open voltage circuit (OCV) obtained for the pure H_2 inlet was 1.71 V, a value lower than the theoretical calculation derived from the Nernst equation (2.02 V). The observed activation region extends until 1.3 mA/cm², followed by Ohmic region, and eventually reaching the mass transport region at a limiting current of 18 mA/cm². Feeding a mixture of H_2 and CO_2, the OCV decreased to 1.55 V. Similar polarization behavior was observed with an activation region extending until 1.3 mA/cm², as seen with pure H_2. Previous studies have indicated that higher CO_2 concentration in the H_2 feed can diminish the performance of PEMFC [2]. Introducing the MR outlet stream into the anode gas inlet resulted in an OCV of 1.33 V, reaching a lower limiting current of around 15 mA/cm2. Voltage measurements in this experiment exhibited fluctuations, particularly at low current densities, which became more pronounced close to the limiting current density, a phenomenon also documented in other studies and attributed to the uneven distribution of reactants across the catalyst surface area [3].

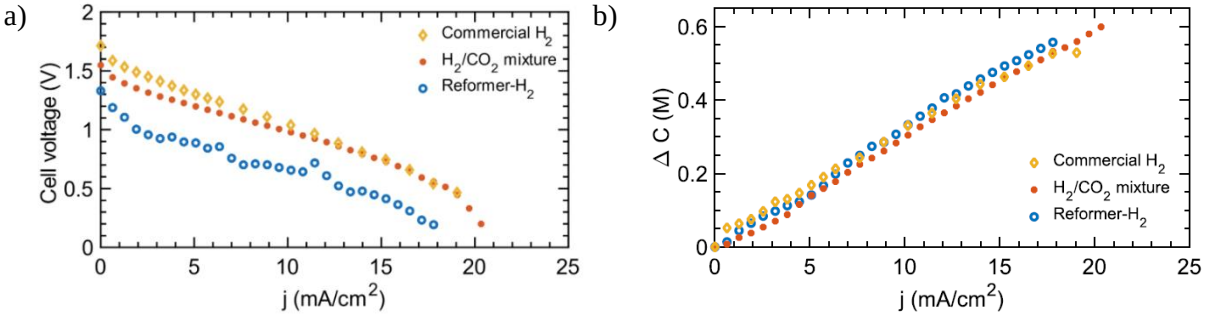

Figure 3. a) Measured polarization curve vs. extracted current density, and (b) Measured desalination extent vs. extracted current density for different anode side gas inlet: pure H_2, H_2/CO_2 mixture, and MR outlet stream.

4. Conclusions

Our study introduces the first integration of a desalination fuel cell with methanol reforming for continuous H_2 supply to the DFC's anode. We evaluated the system performance compared to H_2 + CO_2 and pure H_2 feeds. Pt catalyst poisoning from CO in the reformer gas stream led to decreased DFC performance, confirmed by electrochemical characterization. Thus, effective catalysts, reactor configurations, and operating conditions are crucial to minimize CO generation for the integrated DFC-MR system's application.

References

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Keywords

Methanol reformer; Desalination fuel cell; CO tolerance; hydrogen oxidation.