Study on the dynamic performance of SOEC under the joint input of varying electric energy and thermal energy in PV/T system

Z. Fu
College of Energy and Mechanical Engineering, SUEP, Shanghai, China
S. Pei
College of Energy and Mechanical Engineering, SUEP, Shanghai, China
Y. Li
College of Energy and Mechanical Engineering, SUEP, Shanghai, China
J. Li
School of Mechanical Engineering & Hydrogen Energy Research Centre, BIPT, Beijing, China
Q. Zhu
College of Energy and Mechanical Engineering, SUEP, Shanghai, China

Introduction

With the large amount of fossil energy extraction and combustion, a huge amount of greenhouse gases is produced, causing serious damage to the ecological environment. Thus, the construction of renewable energy is being promoted all over the world [1-2]. However, since the highly intermittent characteristic of renewable energy restricts its direct utilization, fluctuating energy needs to be converted into stable energy by means of energy storage technologies [3]. Electrochemical devices are an alternative option as they can provide a reversible pathway between electricity and fuel, with solid oxide electrolytic cell (SOEC) receiving much attention [4].

Most of the studies have focused on transient changes in voltage or current [5-6], and the effect of simultaneous changes in inlet temperature and voltage on the transient performance of SOECs has rarely been investigated. And the photovoltaic-thermal (PV/T) system can provide both electrical and thermal energy to SOEC. Therefore, it is more helpful to explore the transient performance of SOEC under the simultaneous change of voltage and temperature for hydrogen production by SOEC coupled with PV/T system.

This study establishes a two-dimensional, multi-physics field model of SOEC dynamics and validates it with experimental I-V curves. The effects of different cathode mass flow rates and other operating conditions on the SOEC performance are investigated under the SOEC-coupled PVT system.

Modeling

A dynamic 2D axisymmetric model of a tubular SOEC is established. The 2D multiscale model of the SOEC unit includes fuel/air channels, composite cathode, electrolyte, and composite anode. The thicknesses of the cathode, anode, and electrolyte are 310 μm, 30 μm, and 15 μm, respectively. Where the electrolysis principle of SOEC is shown in Fig. 1, where steam flows in from the cathode channel, and when an external voltage is applied to the SOEC, O^{2-} is transported from the cathode side to the anode side to produce oxygen at the anode.

In order to ensure the comparability of the simulation results with the experimental results, the geometry and operating conditions of the model and the experiment [7] are kept consistent. Fig. 2 shows the validation curves of the simulation and experiment [7], and the model simulation results are basically in agreement with the experimental results, with a maximum deviation of only 3.44%.

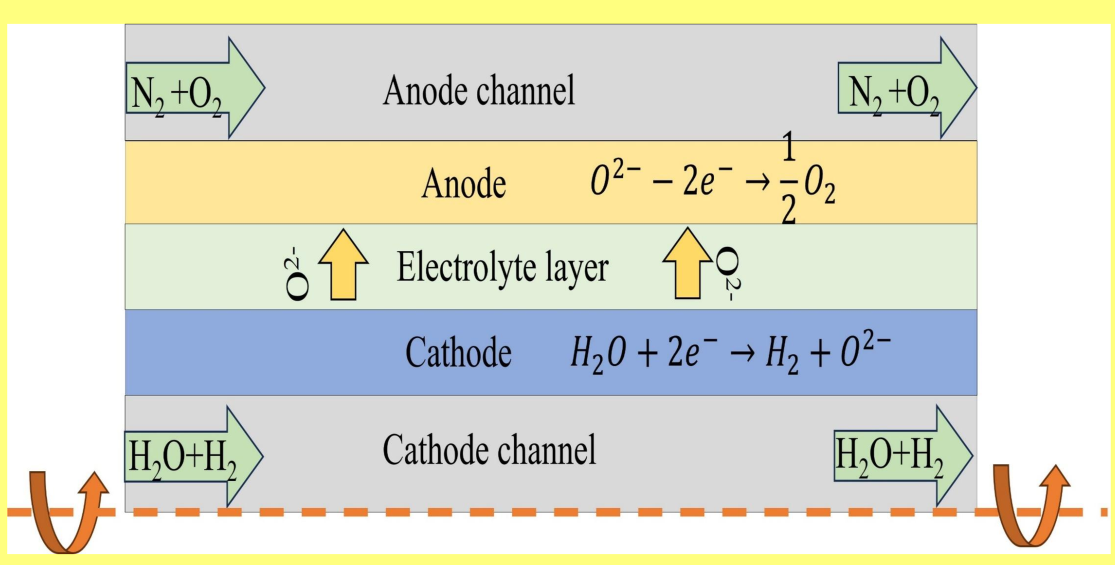

Fig. 1. 2D rotating geometry model.

Figure 3 shows the variation of voltage and inlet temperature with time. At 0-30 min, the voltage and temperature rise every 5 min with a rise duration of 5 min, and at 30-60 min, the voltage and temperature decrease every 5 min for a duration of 5 min. The magnitude of change in voltage and temperature is 0.1 and 20, respectively, within 5 min of change.

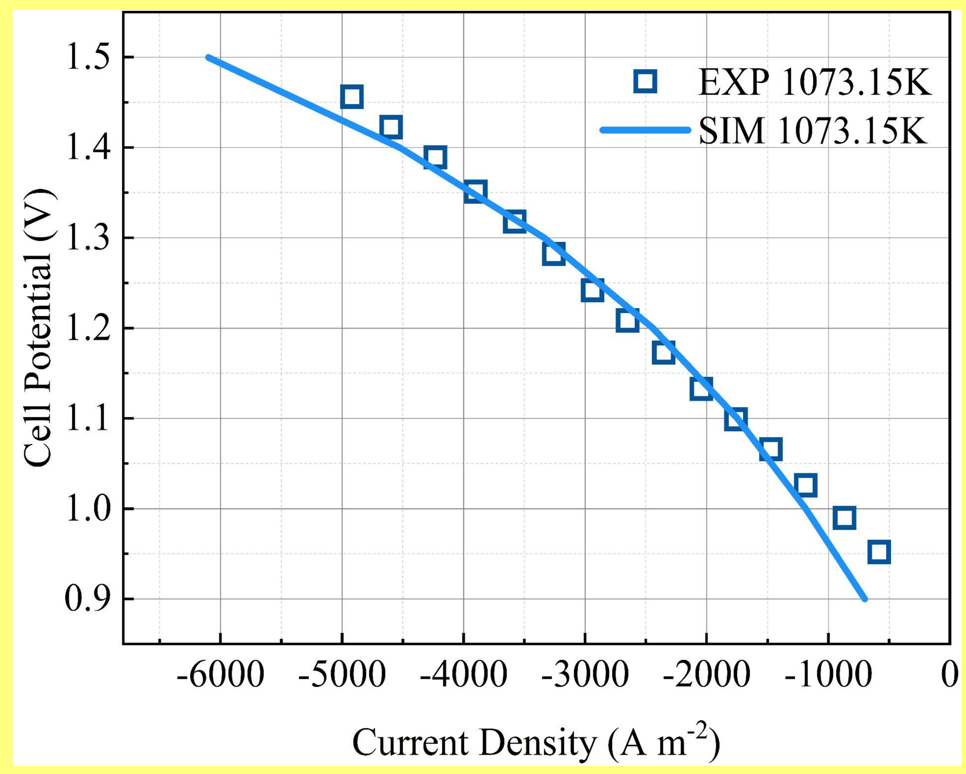

Fig. 2. Model validation with experimental results from Ref [7].

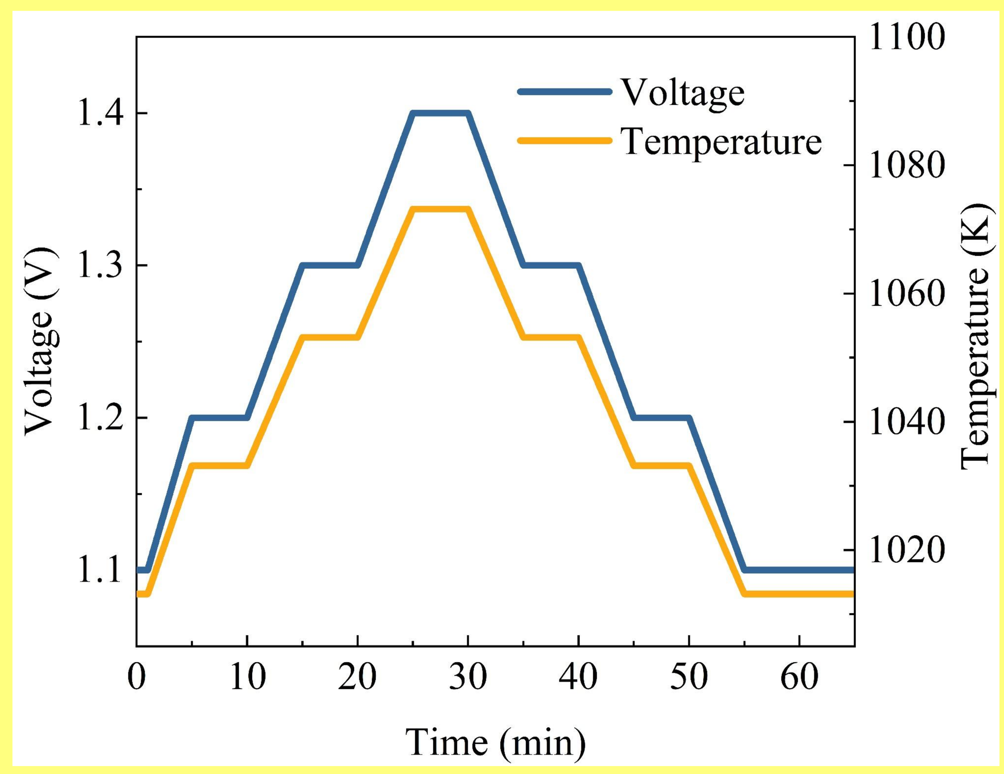

Fig. 3. The variation curve of import temperature and voltage for SOEC.

Results

Figure 4 shows the average temperature variation of SOEC, at 0-15 min, the increase in cathode mass flow rate increases the average temperature of SOEC, however, at 15 min-30 min, the increase in cathode mass flow rate decreases the average temperature of SOEC. At 0-15 min, when the SOEC is in a heat-absorbing state, the hotter gas is able to bring more heat downstream as the cathode mass flow rises, causing the average temperature of the SOEC to rise. At 15min-30min, when the SOEC is in an exothermic state, the cooler gas is able to carry away more heat downstream as the cathode mass flow rises, causing the average temperature of the SOEC to drop. Fig. 5 shows the variation of the maximum temperature gradient at the SOEC cathode. the maximum cathode temperature gradient for SOEC is highest at 30.5 min. The maximum temperature gradient is 25.66 K/cm, 21.17 K/cm, 18.04 K/cm and 16.50 K/cm for 50 ml/min, 100 ml/min, 150 ml/min and 200 ml/min respectively, and the maximum temperature gradient for 200 ml/min is reduced by 35.7% compared to 50 ml/min. Therefore, an increase in cathode mass flow rate helps to reduce the temperature gradient of SOEC during the dynamic process, and the higher the cathode mass flow rate, the smaller the fluctuation of the temperature gradient when the temperature and voltage are varied.

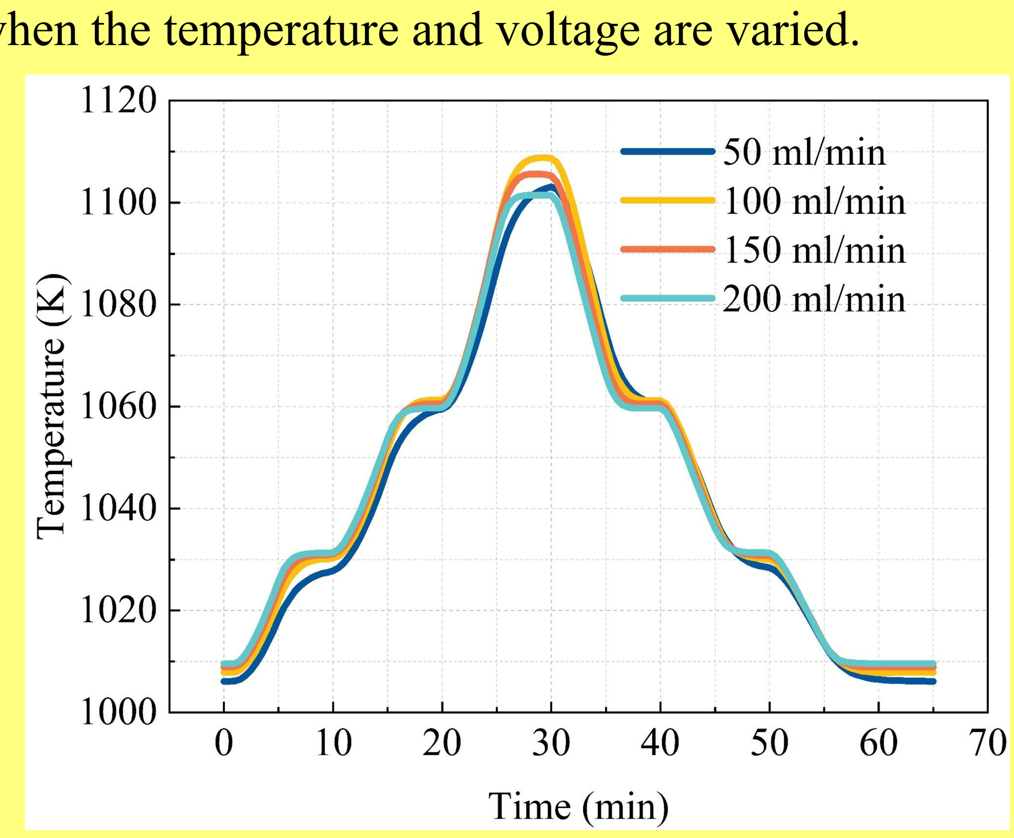

Fig. 4. Change in average temperature.

Fuel starvation processes constitute critical operating conditions as they cause severe degradation effects in the microstructure of metal-ceramic electrodes. Fig. 6 shows the minimum steam mass fraction in the SOEC cathode. The minimum steam mass fraction in the cathode in 100 ml/min and 200 ml/min has been maintained above 0.1 during the variation of temperature and voltage. However, when the cathode mass flow rate is 50 ml/min, the minimum steam mass fraction in the cathode stays below 0.1 at 26.5-31 min, which can lead to fuel starvation. Therefore, to avoid SOEC degradation, the cathode mass flow rate should be kept above 50 ml/min.

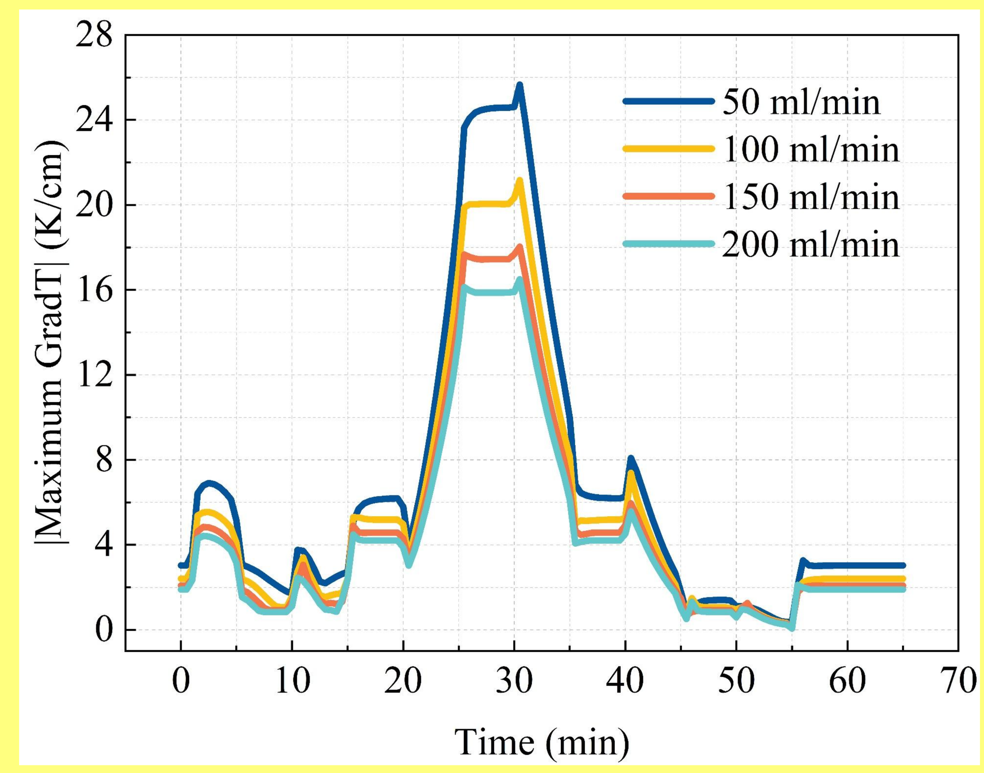

Fig. 5. Maximum temperature gradient at the cathode.

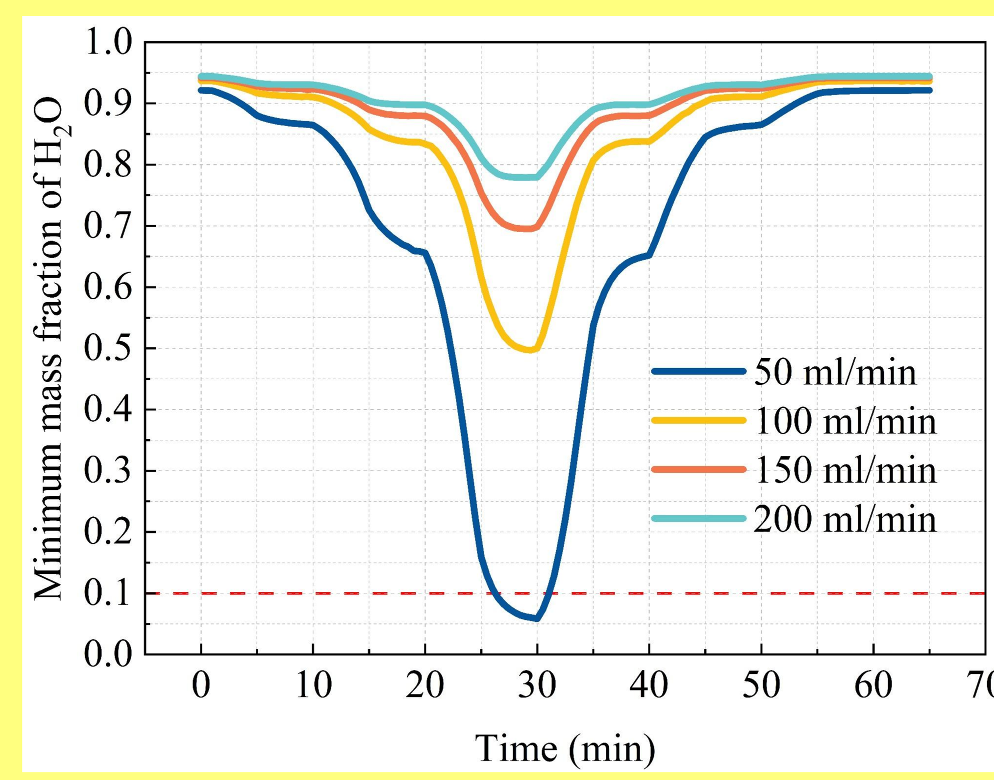

Fig. 6. Minimum mass fraction of steam.

Conclusions

The main conclusions drawn from this study are:

- The increase in cathode mass flow rate helped to reduce the temperature gradient of SOEC during the dynamic process, where 200 ml/min reduced the maximum temperature gradient by 35.7 % compared to 50 ml/min.
- The higher cathode mass flow rate results in lower temperature gradient fluctuations during temperature and voltage changes, which contributes to the safe operation of the SOEC.
- The cathode mass flow rate should be kept above 50 ml/min to avoid fuel starvation in SOEC.

References

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