Testing and characterization of a 5 kW SOE stack: full load, partial load and hot-standby mode analysis

F. Panaccione*, E. Crespi , M. Bolognese, L. Prattico, M. Testi
* corresponding author: fpanaccione@fbk.eu
Fondazione Bruno Kessler, Via Sommarive, 18, 38123 Povo (TN), Italy
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Abstract

Introduction: The purpose of the study is to characterize a 5 kW SOE stack, to analyse its performance when operated in different working conditions, mainly full load, partial load and hot standby mode. The stack characterization is required to implement similar SOE stacks in relevant environment, as planned in the PROMETO project, where 25 kW pilot systems will be designed and tested. The systems will be powered by PV electricity and heat from a concentrated solar power plant and will produce hydrogen to be injected into the natural gas grid or for ammonia generation.

Objectives: The objectives of this work are:

1. To characterize the 5 kW SOE stack when producing hydrogen at full load and at partial operation, under different operating conditions.
2. To identify the optimal conditions to operate the stack in hot-standby mode, keeping the stack warm without producing hydrogen while preserving the stack's health. Hot-standby operation mode is required for example during the night, when renewable electricity from the sun is not available for green hydrogen production.

Material and methods: The stack characterization is performed through an experimental campaign, which has been carried out at FBK facilities using a dedicated test bench. The stack is tested at different voltages (ranging from the OCV value, ~63V, and 100 V), operating temperature (i.e., varying the temperature setpoint of the reactants heaters and of the stack heater between 680°C and 760°C), steam flowrate entering the stack (ranging from 360 g/h and 1900 g/h), and hydrogen concentration in the steam entering the stack.

Results: The experimental campaign has allowed to identify the stack current (proportional to hydrogen production) in many different conditions. Additionally, the stack has been characterized in terms of Area Specific Resistance (ASR) [1] [2] and concentration overvoltage at high current density [3]. For example, Figure 1 shows that, fixed the operating temperature and steam flowrate, to increase the hydrogen production a drop in the theoretical stack efficiency (i.e., the ratio between thermoneutral voltage and stack voltage, Vth/V [4]) is required, moving from the endothermic to the exothermic region). Performances are positively affected by an increase in temperature or steam flowrate. Performance obtained at thermoneutral voltage (Figure 2) are of main importance for the definition of the control of the produced hydrogen flowrate. According to the experimental results, two different control strategies are identified, both keeping the stack at constant voltage and differing for the way in which the hydrogen generation is controlled: i) varying the steam flowrate supplied to the stack while working at maximum steam utilization and constant temperature, ii) varying the stack temperature while the steam flowrate is controlled to have a low steam utilization.

The hot-standby tests have allowed to analyse the decay of the stack performance over time in three different operating conditions:

a) Hydrogen-enriched forming gas (20% H2 and 80% N2) flowing in the negative electrode. Air flows in the positive electrode. No power is applied to the stack.
b) Hydrogen-enriched steam (20% H2 and 80% steam) flowing in the negative electrode. Air flows in the positive electrode. No power is applied to the stack.
c) No flow in the negative electrode. Air flowing in positive electrode side. Application of constant voltage (1 V per cell) to the stack.

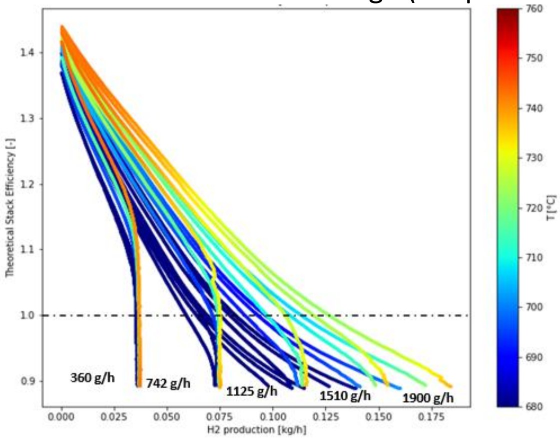

Figure 1 - Theoretical stack efficiency vs hydrogen production.

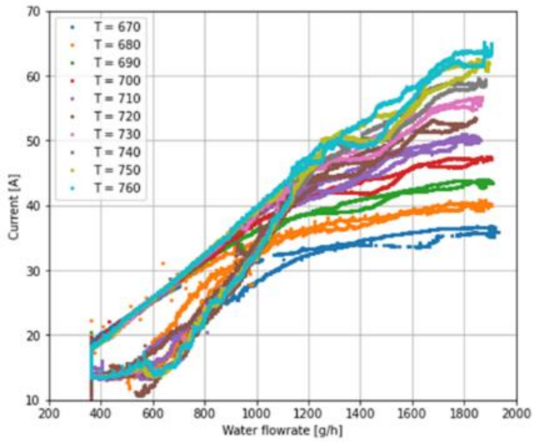

Figure 2 – Current values measured for different steam flow rates and set point temperatures.

For each standby mode, the performance of the stack after 200 hours has been compared to the initial value (health check). While standby mode a) and b) showed negligible performance variation, standby mode c) shows a relevant performance drop, possibly cause by the oxidation of the electrode for a reverse flow of air in the negative electrode.

Conclusions: In conclusion, this work includes an innovative analysis of a 5 kW SOE stack, which is tested not only at nominal full load operation, but also at partial load and in hot standby mode. The identification of the stack performance in different operating conditions has allowed to define a control for the hydrogen production as well as to identify the best conditions to keep the system hot when hydrogen is not produced.

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